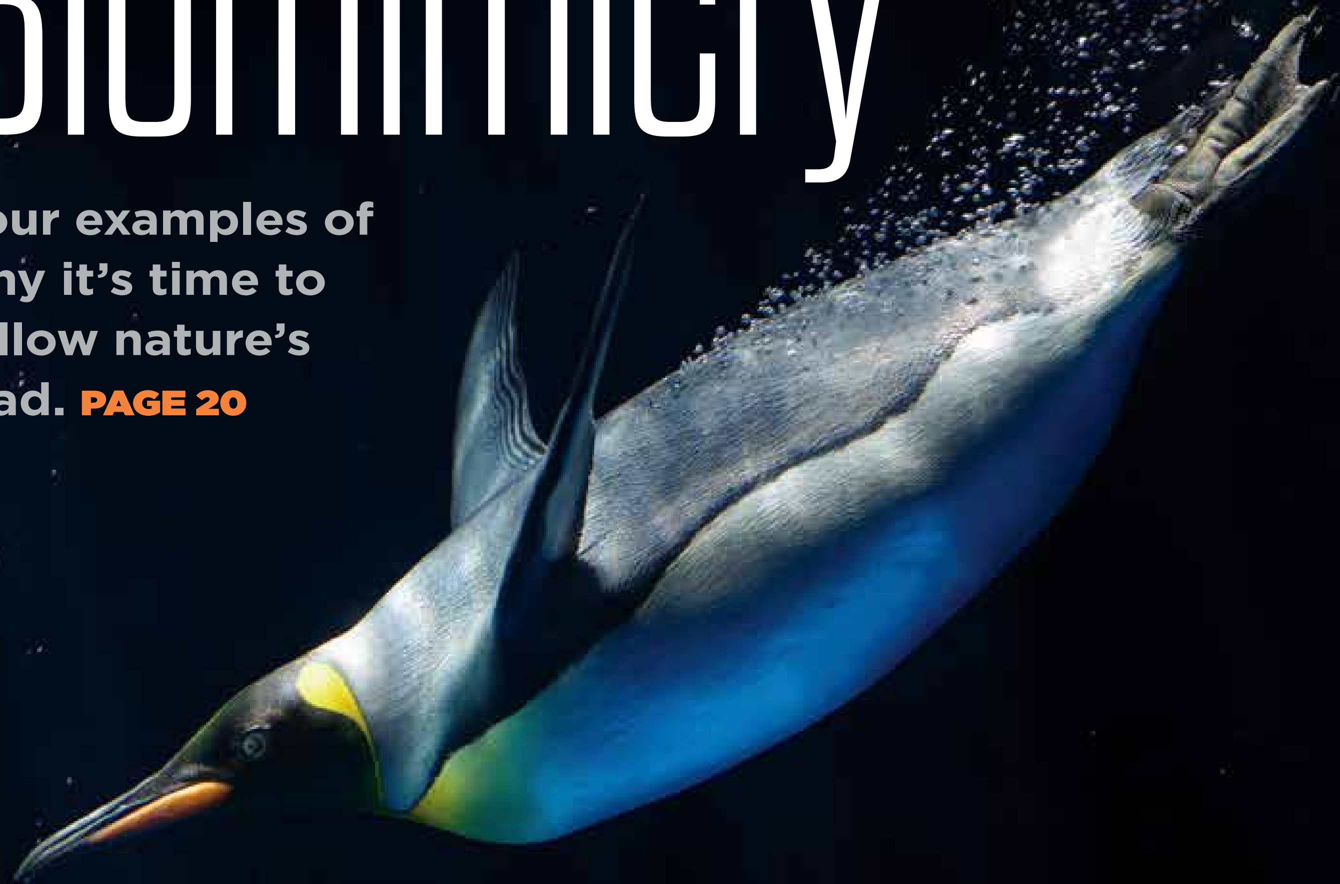
AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

Biomimicry

Four examples of why it's time to follow nature's lead. PAGE 20



FEBRUARY-MARCH 2021 | A publication of the American Institute of Aeronautics and Astronautics | aerospaceamerica.aiaa.org

AIAA
SHAPING THE FUTURE OF AEROSPACE

On the cover: Text to come. Description of cover here.

Image credit: Credit text

AEROSPACE
★ ★ ★ AMERICA ★ ★ ★

FEBRUARY/MARCH 2021, VOL. 59, NO. 2

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
Moriba Jah, Robert van der Linden, Jan Tegler, Debra Werner, Frank H. Winter

Basil Hassan **AIAA PRESIDENT**
Daniel L. Dumbacher **PUBLISHER**
Katie Taplett **DEPUTY PUBLISHER**

ADVERTISING
advertising@aiaa.org

ART DIRECTION AND DESIGN
THOR Design Studio | thor.design

MANUFACTURING AND DISTRIBUTION
Association Vision | associationvision.com

LETTERS
letters@aerospaceamerica.org

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

IN THIS ISSUE

Keith Button

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

PAGES 16

Cat Hofacker

As our staff reporter, Cat covers news for our website and regularly contributes to the magazine.

PAGES 9, 10

Moriba Jah

Before becoming an associate professor at the University of Texas at Austin, Moriba helped navigate the Mars Odyssey spacecraft and the Mars Reconnaissance Orbiter from NASA's Jet Propulsion Lab and worked on space situational awareness issues with the U.S. Air Force Research Laboratory.

PAGE 64

Jan Tegler

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

PAGE 20

Debra Werner

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

PAGE 32

DEPARTMENTS


CALL FOR PAPERS
PROPULSION ENERGY FORUM
9–11 AUGUST 2021 | DENVER, CO
The AIAA Propulsion and Energy Forum is the world's only event that showcases both aeronautics and space propulsion as well as energy technologies at a single venue.
AIAA is soliciting papers for the 2021 forum in the following technical disciplines:
Additive Manufacturing for Propulsion Systems
Advanced Integrated Intelligent Propulsion Controls
Advanced Mechanical Components
Advanced Propulsion Concepts
Advanced Vehicle Systems
Aerospace Power Systems
AIAA/IEEE Electric Aircraft Technologies Symposium (11–13 August 2021)
Electric Propulsion
Energetic Components and Systems
Energy Conversion Technology
Energy-Efficient and Renewable Energy Technologies
Fuel and Power Generation Technology
Gas Turbine Engines
High-Speed Air-Breathing Propulsion
Hybrid Rockets
Inlets, Nozzles, and Propulsion Systems Integration
Liquid Propulsion
Nuclear and Future Flight Propulsion
Pressure Gain Combustion
Propellants and Combustion
Propulsion Education
Small Satellites
Solid Rockets
Thermal Management Technology
Unmanned Aircraft Systems (UAS): Propulsion, Energy, and Applications
ABSTRACTS ARE DUE 11 FEBRUARY 2021, 2000 HRS EST
aiaa.org/propulsionenergy/cfp
AIAA
SHAPING THE FUTURE OF AEROSPACE

Passion + Curiosity x Diversity = Career Success

During the 2021 AIAA SciTech Forum, a panel of women aviation and aerospace trailblazers imparted sage advice to attendees about pursuing passion with perseverance and staying curious. The panel was part of the special programming on the national holiday honoring Dr. Martin Luther King Jr.* These extremely impressive trailblazers spoke directly to what AIAA stands for – igniting and celebrating ingenuity and collaboration, and their importance to our way of life. Our purpose is to fuel AIAA members' imaginations and support their ambitions. The end result, though, is not merely supporting imaginative and ambitious members – it is to ensure members' dreams and achievements combine to advance humanity.

Pursuing Passion With Perseverance

In my early days I watched Alan Shepherd, John Glenn, and the first astronauts push the limits of the known world. My passion to travel to the stars fueled my life's work. Recognizing I was probably too tall to be an astronaut, I realized there was an important role to play on the teams who design, build, and operate the rockets and spacecraft that would carry human travelers to Earth orbit, the moon, and beyond. This passion has led to a wonderful career journey.

Challenges – like the Apollo 1 fire and the *Challenger* and *Columbia* disasters – are part of exploring the unknown. It was passion and perseverance that carried us through the challenges. Everyone redoubled their efforts to discover the causes of failures, fix the problems, and get back to landing on the moon, exploring the solar system, and building the International Space Station. The keys to moving forward in the face of adversity were passion, perseverance, and being incessantly curious.

Staying Curious

As a Professor of Practice, I implored students to stay curious, to always keep learning, and to continue asking questions, especially "why?". These are essential traits for success in aerospace. AIAA is here to help students at all points in their careers continue to learn about the latest technologies, methods, and programs, and to better understand the external environment that drives the aerospace and defense industry.

AIAA aims to deliver essential educational opportunities from experts on today's most relevant subjects, designed to help you meet today and tomorrow's challenges. With the pandemic restrictions, we have found ourselves teaching and learning in new ways. In 2020, AIAA converted its premier forums to fully online events, reaching more than 20,000 individuals with live and on-demand opportunities. We will continue with the online forum components as we add back in-person events as soon as it is safe to do so.

Over 500 people took advantage of 13 AIAA continuing education course offerings in 2020. Looking ahead at spring 2021, we have scheduled 11 online courses to meet the growing need. You can browse the online learning catalog and register for courses directly at **learning.aiaa.org**. The courses offer invaluable knowledge and practical solutions that you can put to immediate use in your career, without having to go back to school for a grade or degree. Create your own momentum as you pursue lifelong learning. Remember, "Education is not the learning of facts, but the training of minds to think," according to the great physicist Albert Einstein.

Accelerating Change

Staying curious also means pursuing diverse thoughts and perspectives, which is essential when tackling tough problems. Across AIAA, we have the opportunity and responsibility to put more focus on embracing diversity of thought across the aerospace and defense industry. AIAA is addressing this need in education and career development. Fueling the entire educational pipeline – from sparking interest in the young, to staying current in one's early career, to tracking advances happening more rapidly than ever as a professional – is key to our collective future. We must intentionally promote diversity, equity, and inclusion in our educational institutions and continuing through our respective career journeys across the industry.

Accelerating this amount of change may seem daunting. Anthropologist Margaret Mead once said, "Never doubt that a small group of thoughtful, committed, citizens can change the world. Indeed, it is the only thing that ever has." AIAA members in our regions, sections, and branches are exactly the groups that can make this shift. They can reach into underserved and economically disadvantaged neighborhoods where they live and work to promote STEM programs and invite bright future students and young professionals to join them. It's vital for us to push harder and change faster as we see the future challenges for our society. Now is the time for all of us to cause "good trouble," as the late Rep. John Lewis would say, in taking actions that promote diversity today and also lays the foundation for an inclusive future.

Achieving Career Success

Engineering is a great teacher in understanding a problem or situation, understanding the constraints, and determining the validity of information to arrive at information-based conclusions and results. Our engineering education instills the fundamentals and points us to a future. We must continue to stay curious through our career journeys, seek out diversity of thought and perspective, and persevere with passion. AIAA is your "go to" resource to help you succeed. ★

Dan Dumbacher
Executive Director, AIAA

*You can view the "Tribute to Service: Community, Country, and Humanity" presented by AIAA and NSBE Aerospace Special Interest Group at **aiaa.org/scitech** to hear the panel discussion that inspired this message.

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

Right Stuff for the Wright brothers

Q. A consultant has the power to take the Wright brothers forward or backward in time to gather tips for their Wright Flyer. The travel agent, a history buff, suggests Isaac Newton, England, 1687, or Daniel Bernoulli, Russia, 1738. The consultant says, “No, take us to Langley, Virginia, 1941, Bob Gilruth.” The agent looks puzzled: “You mean the space guy?” What doesn’t the agent know?

Draft a response of no more than 250 words and email it by noon Eastern March 15 to aeropuzzler@aiaa.org for a chance to have it published in the April issue.

FROM THE JANUARY ISSUE

DESIGNING FOR TITAN RETURN VELOCITY: We asked you what’s wrong with a junior engineer’s plan to design a small nose radius for a reentry body that will return hydrocarbons from Saturn’s moon Titan.

WINNER: A sharp-nosed reentry vehicle will experience less drag than a blunt body due to the fact that the shockwave is oblique rather than detached, however it is this same phenomenon (the oblique shock) which dooms a sharp-nosed design. Peak heating occurs near the shock front, and the detached shock characteristic of a blunt body thus keeps the area of peak heating displaced from the surface of the reentry vehicle. The sharp-nosed body’s oblique shock, on the other hand, brings the area of peak heating right to the leading edge surface of the reentry vehicle. This intense heat flux will cause ablation of the leading edge until the reentry vehicle “naturally” assumes the shape of a blunt body.

Joseph Kusko
Kusko is a junior studying aerospace engineering at Texas A&M in College Station. jwkusko@gmail.com

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

Battling those other emissions: nitrogen oxide

BY CAT HOFACKER | catherineh@aiaa.org

Researchers at MIT have drawn up the blueprint for a refrigerator-sized ceramic cylinder that, if it works as proposed on tomorrow's passenger aircraft, would all but eliminate their emissions of nitrogen oxide, a pollutant from aviation and other sources that aggravates asthma and damages the atmosphere.

Researchers were inspired by a type of catalytic converter on diesel trucks, in which engine exhaust mixes with an ammonia solution and passes through a honeycombed sheet of ceramic, often an aluminum and silicon compound called zeolite. It's chemically treated with iron or copper salts that catalyze a reaction among the hydrogen and nitrogen in the ammonia and the nitrogen oxides in the combustion gases. The reaction turns the oxides into water vapor and less dangerous nitrogen gas.

The researchers describe their proposed aviation version of such a catalytic converter in the January issue of the journal Energy & Environmental Science. Instead of passing exhaust through a honeycomb structure, they would pass the exhaust through a 2.2-meter-long cylinder formed by rolling up a sheet of zeolite that's been folded to create pleats. Researchers call this device a catalyst, and its cylindric shape makes it easier to fit aboard an aircraft while providing "a lot of surface area through which to pass the flow" of exhaust, explains Steven Barrett, lead author of the paper.

But because the exhaust must now pass through a catalyst, thrust would be reduced slightly. So Barrett says the concept would be best suited for one of today's hybrid-electric conceptual designs that move the engines to the aircraft's belly and supplement thrust with small electrically driven propellers on the wings. In the preliminary configuration outlined in the paper, generators positioned behind each of the two jet engines would create electricity that is routed via cables to the electric motors that drive the propellers.

A valve near the engine or engines would spray an ammonia solution into the exhaust stream, catalyzing the conversion of the nitrogen oxides into nitrogen gas and water vapor, which would travel down the aircraft's tailpipe and be expelled into the atmosphere.

"The key downside of this setup" is if it were installed on a hybrid-electric aircraft roughly the size of a Boeing 737, "you probably end up increasing fuel burn by about half a percent compared to what it otherwise would have been," Barrett says. That's due to the weight of the tank to hold the ammonia solution.

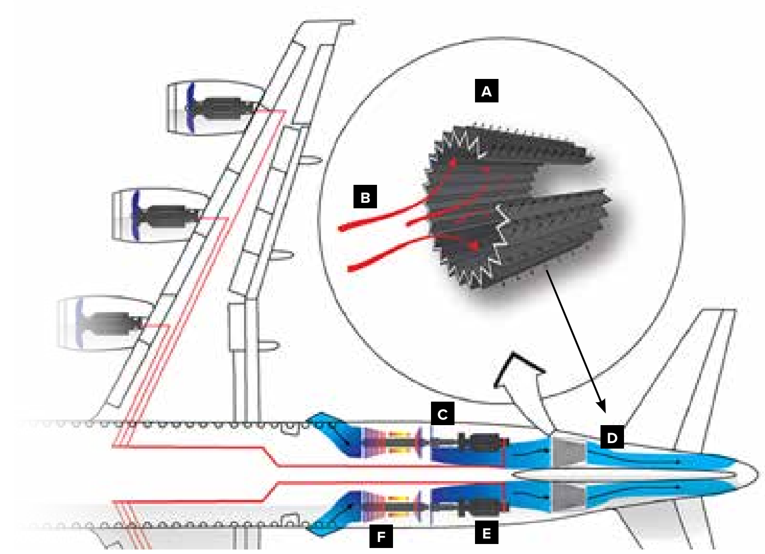
But he believes this tradeoff would be worth it. While some aircraft concepts will seek to reduce or eliminate carbon dioxide emissions, "there are other emissions that we also need to zero out for a long-term sustainable aviation sector," Barrett says. "We need a solution that both addresses climate change and addresses the air pollution issue."

The researchers are refining the design of their proposed plane. ★

Scrubbing out nitrogen oxide emissions

An aviation version of a catalytic converter would reduce emissions that harm lung tissue.

- A Flow-through catalyst
- B Gas turbine exhaust
- C Power turbine
- D Treated exhaust
- E Electric generator
- F Small-core gas turbine



MIT researchers have crafted an early design for a hybrid-electric aircraft that would route exhaust from the aircraft's gas turbine engines through ceramic cylinders where nitrogen oxides would be converted to nitrogen gas and water vapor.

Drawing by Prakash Prashanth, MIT Laboratory for Aviation and the Environment

Urban air mobility master

A year ago, Pamela Cohn took on a task she calls "building a startup inside of a giant behemoth." As chief operating officer of Hyundai's UAM Division, Cohen directs the division's internal operations and interactions with real estate developers, infrastructure planners and others whose decisions will impact the company's plans for selling and operating air taxis to ferry passengers and goods locally. I spoke with her by video call to her home office in Virginia about the decisions ahead. Here's our conversation, compressed and lightly edited.

— Cat Hofacker

PAMELA COHN

POSITIONS: Inaugural chief operating officer since of the UAM Division of Hyundai Motor Group of Seoul and Washington, D.C., since January 2020; in that role is also in charge of the division's U.S.-based operations; founder and managing partner of Ascension Global, a Washington, D.C., aviation consultancy, 2018-2020; engagement manager at consulting firm McKinsey and Co., 2014-2018.

NOTABLE: While at McKinsey and Co., founded the firm's Unmanned Aircraft Systems Hub to advise clients on topics related to UAS technology, including market trends. In 2018, created the Ascension Global consulting firm, which acquired clients including NASA and the Transportation Research Board, a division of the National Academy of Sciences, Engineering and Medicine.

AGE: Declined to say

RESIDES: Arlington, Virginia

EDUCATION: Bachelor of Arts in social sciences, economics and politics, University of Durham in England, 2012; Master of Arts in war studies, King's College London, 2014.

More online aerospace america. aiaa.org

Q: What makes an aviation consultant decide to work for a car company's urban air mobility venture?

A: I'd been working in the UAM and the UAS industry for most of my career, and this was just such a great opportunity to kind of go and put all of the thinking and all of the consulting into practice and say, "OK, let's take all of that stuff that we know about the vehicle, about the aerospace community and let's work with this incredible company that really wants to make a difference and bring it to life."

Q: With all the legacy and startup aerospace companies trying to enter the UAM market, what does Hyundai bring to the table?

A: Automotive has a really unique advantage because when you look at the scale of what we need to produce today and the affordability level that we're hoping to produce, that is something that has been unattainable for the aerospace industry. Even getting an extra one or two tails out the door every month is excruciatingly painful for most aviation players, both because of supply chain and manufacturing concerns and the way that it's structured for QA/QC, quality assurance and quality control. Automotive can crack that code on affordability and high-scale production. Hyundai can actually bring that production level in line with the highest quality standards to get an affordable product to market in the right volumes. The other thing that's really unique about automotive is that they're very customer centric because they actually are a business-to-consumer company most of the time. A lot of the aerospace players are in the business-to-business space, and the way that they think about customers and the customer journey is a little bit removed from the actual customer experience. Companies in the car industry and particularly Hyundai are used to thinking about the individual customer journey and thinking about those very tactical pain points and how you can design around them, both in terms of products and services to meet it.

Q: So how does having a customer-first perspective affect the design of an air taxi?

A: Outside of actually building the vehicle, there's that whole ecosystem of everything else that needs to happen from owning the vehicles, to financing the vehicles, to managing the fleet operations, to the flight service providers. In certain markets, we might simply build a vehicle and we'll be selling them off to a lesser or to an operator, and so that'll be a B2B experience. In other markets we might decide that we actually want to be the flight service provider, so there would be a much more B2C journey. We are taking that B2B component out of it when we think about how we design our vehicle. We're really focusing on the customer journey and saying, "OK, even if we're selling to another business in some cases, as opposed to directly at customers, whether they're going to get on our vehicle or not is going to happen at the customer level." And it's a little bit different for UAM than for traditional aerospace where there's not a lot of differentiation between different airlines and planes. The airplane design really doesn't drive a customer's decision about which airplane they decide to book in order to go on a vacation. For UAM, there are so many competing technologies and so many competing modes of mobility that it does matter to really get into that individual decision-making.

"The physical infrastructure is kind of the make-or-break aspect of a UAM market. It's just a fancy flying science project if you don't have a place to actually land and take off and a robust enough network of those places to service the community's needs."

Q: What are the pain points for future UAM passengers that these aircraft designs must eliminate?

A: For us, user design and human-centered design goes beyond simply noise and how jittery the aircraft is and goes into how we make this inviting and exciting and a safe and comfortable part of your everyday experience. The big ones that we talk about are noise and making sure that this is a pleasant experience when you're on the aircraft or when the aircraft is flying over your home or your business, or a park or a school. Those are going to be important parts of that user experience, that pain point. The second big one that we focus on is that seamless mobility journey. You shouldn't have to think through multiple different types of mobility of how you get from point A to point B; it should just be a very seamless experience. You say, "OK, I'm at home. I need to get to work," or "I'm at home. I need to get to school," and you open up an app or whichever way we are booking travel in eight to 10 years. It's probably going to be an intermodal journey, and I shouldn't have to think about that intermodal component. I should just book it and then it should go and take me the way that I need to go, whether it's an e-scooter and then a car, whether it's a car and then a UAM vehicle, or a combination of everything above. Those are really important parts of the user experience, but I think one of the more nuanced ones is the way the vehicle looks and feels, which actually has a big role to play. There are so many products where images and lines can evoke different types of emotions and can make something an inviting experience or can make something a little bit of an anxiety-producing experience. Especially when we think about the aviation industry: People like us who work in the industry love aviation, so getting on a plane is really exciting and we love airports. But for the average consumer, getting on a plane can kind of feel scary. So thinking through what are those components of design, whether it's in the shape of the vehicle and fuselage, whether it's in the interface that we have inside of the vehicle and the way that they interact with the outside world or they interact with the pilot, all of those things can make this a really pleasant or very anxiety producing experience.

Q: One very recent pain point is the social distancing prompted by the coronavirus pandemic. Given that many of these UAM operations rely on a ridesharing model, do Hyundai and other manufacturers need to rethink that design?

A: I'm very hopeful that by the time we begin passenger flights in 2028, this is over, otherwise I'm going to be very sad. But we're also being really cognizant that the pandemic might change the dynamic, that the huge push toward ridesharing may alter because of what happened with the pandemic. So when we think about the way that we design our cabin, are there ways to do separation if it's necessary? Are there ways that we can design as to have that comfort level if there's another pandemic so that we can easily retrofit our taxis or make it part of our design if necessary? We're not jumping too far in that direction right now, just because there is such a long timeline, and we think that these trends are going to really shift and shape over the coming years before they're really set. But it is something that we consider, and it's on our radar as we go through the design process.

Q: What have you learned about the pros and cons of different features that will be required in passenger air taxis versus cargo aircraft?

A: One lesson learned is that the needs of one city are incredibly different from the needs of another. You have the hypothesis walking in that, "Oh, that would make sense when you think about infrastructure networks," because the flow of people and the topography of the city can vary so dramatically. Of course, infrastructure networks will look different and the need for different mobility services will look different. So that was one that wasn't super surprising, but definitely reaffirms a lot of our work so far. The other thing is people have different reactions to different types of technologies, what they are or are not comfortable with, if they come from different cultures. One of the big differences that I think everyone talks about all the time is autonomy. There is a very big age bias when you look at the data: Younger people are more comfortable with autonomous vehicles. They feel a lot more comfortable with the concept of ever going on one or seeing one inside of their environment, whereas older communities are a little bit more skeptical because they're not digital natives. Those kinds of trends — whether they're based on age, whether they're based on where you've been or your exposure to different technologies in that societ — they actually vary dramatically, even inside what you would consider a pretty homogenous group. During my consulting days we were doing a public acceptance study on drones and cargo. Inside of the United States, from state to state and city to city, there were dramatically different concerns about having UAS flying overhead. In more rural communities, a lot of it was about the impact on wildlife: What would the noise impact be? Whether it was their personal cats and dogs or the actual livestock that they were raising, how would that affect the breeding and the health and safety of those animals? In cities, it was a lot more about digital pollution and audio pollution and very practical questions about where aircraft would land. And the way that you address that, both in terms of how you address the communities but also how you might design some of the vehicles and services, is going to vary dramatically between the different areas.

Q: How do the vertiports or landing pads where people could be picked up or dropped off factor into the design of this new form of transportation?

A: The physical infrastructure is kind of the make-or-break aspect of a UAM market. It's just a fancy flying science project if you don't have a place to actually land and take off and a robust enough network of those places to service the community's needs. A landing pad shouldn't just be a landing pad. It should be something that people can get excited about. It should look different from different city to city. New York City is a lot more challenging than somewhere like Dallas or Houston, where it's a little bit more spread out. That to me is one of the best places where we can bring the community together and have that be a really unique feature that adds to the city, as opposed to just taking up space inside of the city to support the UAM flights. The user experience journey inside of the vertiport or skyport — or whatever we ended up calling them — that's really critical because when you think about your journey through an airport, the airport plays a really big role in your entire journey in any form of aviation. If we're able to make it a really inviting experience when you go to one of these, it's going to impact the overall feeling people have and the overall sense of security and excitement for this new form of transportation.

Q: Another make-or-break element for UAM could be the transition from piloted flights to autonomous operations. What will it take for that handover to occur?

A: We do want to eventually get to autonomous operations because we believe that that's actually going to make UAM flights safer and more efficient. Those two things are very important for our customers

▲ **This design** of a four-passenger air taxi, which Hyundai unveiled at the 2020 Consumer Electronics Show in Las Vegas, is one of the configurations the company is weighing for its future fleet of electric takeoff and landing aircraft.

Hyundai Motor Group

and for what we view as our role inside of the industry, but we're not going to do it before the regulation is in place, before we have the conviction in the safety of these systems. And honestly, until the public is ready. There's a very real chance that we as an industry will get conviction around the safety of the technology and the regulators get that conviction, but the public isn't ready. That's something that we take very seriously. Obviously, we would like to make autonomous flights capable as soon as possible, but at the same time we are not going to force it on the public. If they need an extra five, 10 years of having a pilot in the seat, then they get an extra five, 10 years of having a pilot in the seat.

Q: How would you measure the passenger experience during test flights of any air taxi designs?

A: We're not talking publicly right now about our test flight schedule, but one thing that we are going to start doing, hopefully in the next couple of years, is augmented reality and virtual reality to test consumer reactions. We won't be putting the public on this aircraft until it's certified, and we're going to need those insights before we get certified. So in order to get people's reaction to these taxis, we're looking into different tools through VR and AR. At the 2020 Consumer Electronics Show, we had a very early-stage version of this — not quite as robust as it needs to be — where the seats moved and you had the goggles on. That's the first stage of what we want to do, but eventually we're going to do AR and VR testing in a replica, in a mockup of our air taxis, but they won't be flying because we want to ensure safety as our absolute first priority.

Q: If that 2028 entry-to-service date holds, Hyundai might not be the first UAM on the market. Is there a concern that by not being first out of the gate you might miss some of the early passengers?

A: We don't necessarily think the first to market is going to be the market leader. There's a couple of big reasons why we chose 2028 instead of an earlier date; one of the big things is we just don't think the market will be ready until 2028 or so. The time it's going to take to build the infrastructure networks and to design them in a purposeful manner that meets the needs of communities, that's really long. Infrastructure lead times and planning and development through state and local authorities and departments of

"One thing that we are going to start doing, hopefully in the next couple of years, is augmented reality and virtual reality to test consumer reactions. We won't be putting the public on this aircraft until it's certified, and we're going to need those insights before we get certified."

transportation, it takes a very long time, as it should because these are very important decisions that are being made that will change the landscape of a community. We don't think that the infrastructure is necessarily going to be there in time, so what we're really focusing on is making sure that we get the right design for our vehicles and all of our services and products, that we get the right user feedback and that the public is ready to get on these and the infrastructure is ready. The confluence date of that is around 2028 to 2030, so that's why we're hoping to get into the market in 2028 and be one of the market leaders as the market matures and becomes robust throughout the 2030s.

Q: You've established that infrastructure will probably look different from city to city. In suburban and rural areas where these landing pads might be farther apart, how might that infrastructure look different?

A: Actually, suburban and rural areas are great for infrastructure because they have some space available. It makes it a lot easier to make these hubs and these vertiports and to actually do a really interesting, exciting consumer-centered design for them because you have the space and you have the ability and it's actually a lot less expensive to be able to develop out there. In terms of distance, will we ever have longer missions because there are further destinations? I do think so. When you look at not necessarily the Gen. 1 vehicles, but Gen. 2 and

Gen. 3 vehicles, air mobility is going to be important. That will require, most likely, different vehicle designs. We believe the battery propulsion will be sufficient for the initial types of routes that we're going to be doing in cities and suburban areas. They're going to be something like 20- to 30-minute hops, but the aircraft will be capable of going farther than that.

Q: The infrastructure you're describing sounds too big for one company to create, so who needs to get on board to build all these landing pads or ground stations?

A: It's going to take an actual village to make this happen. We will need partnerships with state and local governments so that we can have a really clear connection with their planning and make sure that we are thinking about not just what routes are profitable, but the community goals in terms of access and opportunity and equity. We are going to make profitable networks of air taxis in the sky, but ones that actually meet community needs beyond simply having a profitable transportation business. Individual communities have different pain points that often we don't see when we look at the macro level of the city, and so when you look at those communities, you have to ask, "Where is it really, really hard for you to get to right now?" Then you can actually design where the infrastructure will best be placed to suit what they need on a day-to-day basis and what their journey looks like. Partnerships also will be needed with real estate developers and financiers. In more densely populated cities, for example, a lot of this is going to have to go on top of existing infrastructure, and that means working with real estate owners and having them see UAMs as an amenity that people inside of their buildings are going to want. The other big partnerships, of course, will be with other mobility service providers to make sure that we're designing the infrastructure not just for the UAM vehicles and for the Hyundai vehicles, but also for other mobility service providers that are going to be there.

Q: In the distant future, do you think the UAM market could ever resemble the automotive market: dozens of companies offering lots of similar models?

A: At least for the foreseeable future, it's going to be a much smaller number of options. These aren't going to be personally owned aircraft, so the individual touch of "I definitely want leather inside of my interior," or "I want blue leather inside of my interior and a red exterior," will be less important as we learn toward more of that ridesharing economy. I don't think air taxis are ever going to replace cars. I think that they're going to be a complementary system. Cities and suburban areas are becoming more and more congested, and over the next 20, 30 years that problem's only going to get significantly worse. The answer to it isn't just air and it isn't just ground, and it isn't just micromobility. It's a combination of all of these things. ★

▲ **In this illustration,** a Hyundai air taxi (right) approaches a landing port in the middle of a city. These ground stations where passengers board and disembark will be "the make-or-break aspect of a UAM market," Cohn predicts.

Hyundai Motor Group

Eye on laser fusion

Components made by laser powder bed fusion sometimes come off the printer with tiny voids trapped in the metal as it hardens. Researchers are on their way to fully learning the causes of these voids. Keith Button spoke to the researcher whose imaging technique has been key to the progress so far on unraveling the mystery.

BY KEITH BUTTON | buttonkeith@gmail.com

"The industry holy grail really is that you can print these parts with the manufacturing dimensional data and get a good part every time, no matter what machine you do it on, no matter what location you do it at, no matter what batch of powder you put in."

—Chip Blankenship,
University of Virginia

As promising as laser powder bed fusion has been in aerospace manufacturing, the technique has a downside. Bubbles of gas in molten material can leave voids, called "pores," hidden inside the walls of metal parts. This kind of defect is annoying for noncritical parts such as air-conditioning brackets, but unacceptable for critical parts, such as components of engines, because they can lead to cracking. Critical parts made by this technique must be painstakingly inspected and recycled if defective, an outcome that is expensive.

The mystery of how and why pores form is beginning to lift, largely because of a microscopic imaging technique applied by Tao Sun, a professor at the University of Virginia, and his team. As it turns out, when a laser beam zips over a thin layer of metallic powder, a molten pool of metal about the width a human hair forms for just an instant, but that's long enough for the bubbles of gas to form in it. Some of the bubbles disappear, but others leave pores when the material hardens.

The team has more to learn about pore formation but results so far suggest that engineers might soon be able to predict pores and adjust their processes to avoid them, lending even more potential to this increasingly popular method of 3D printing, also known as additive manufacturing.

At the moment, with some exceptions, manufacturers hesitate to make intricate, critical parts by laser fusion, despite a long list of benefits. Newly designed parts could be made from high-strength alloys for installation in airplanes and space vehicles without the need to set up and program tools to machine away metal. In many cases, shifting to the additive method could shave six months from the time it takes to manufacture the first batch of a new part.

One of those who has made the shift for a critical part is GE Aviation. At its plant in Auburn, Alabama, the company makes fuel nozzle tips for its LEAP turbofan engines with a laser fusion technique developed by GE Additive, the corporation's 3D-manufacturing arm. Each tip is a complex part with passages for fuel and air that otherwise would require making 20 separate pieces from castings and formed sheet metal and then brazing them together. The 6-centimeter-tall fuel nozzle tip can require up to 3,000 layers of material.

GE, like other manufacturers, relies on extensive inspection processes to root out any defective nozzle tips. The company is confident in it safety, but Sun's team believes it can help manufacturers with cost effectiveness.

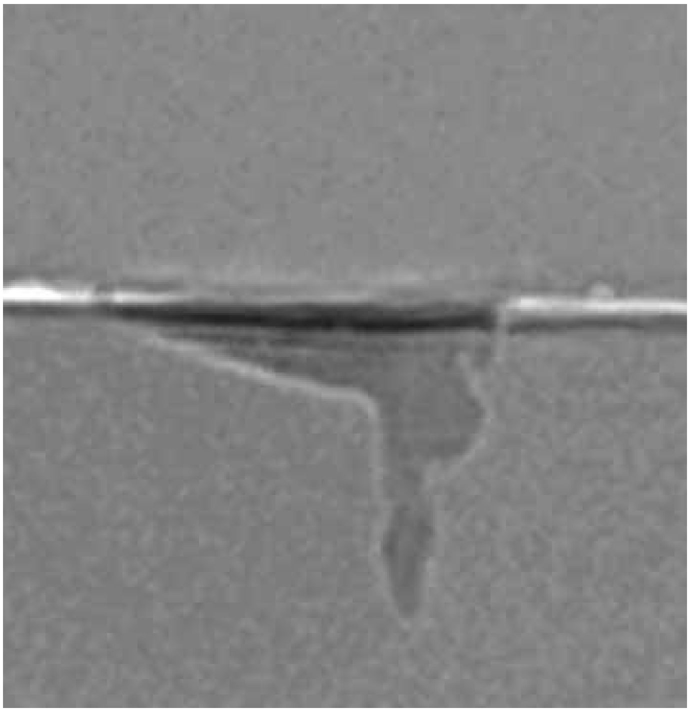
"The industry holy grail really is that you can print these parts with the manufacturing dimensional data and get a good part every time, no matter what machine you do it on, no matter what location you do it at, no matter what batch of powder you put in," says Chip Blankenship, a University of Virginia professor and former vice president of GE's commercial engines group who is not affiliated with Sun's team. "We haven't achieved these goals yet, so the industry is not 100% comfortable with the process, but we're getting there."

An inside view

To find out how bubbles form, Sun and his team had to look below the surface of the molten metal as the laser passed by and take images of bubbles. Some of those can harden into pores ranging in diameter from a few microns to 200 microns. They also had to record the images quickly, because the laser moves across the powder bed surface at 1 meter per second, which means the laser's weld time at one spot is only a few milliseconds at most.

The solution for viewing the molten metal was a high-speed X-ray imaging technique invented about 15 years ago. Sun had applied that technique and improved it for research he started nine years ago for his previous employer, Argonne National Laboratory outside of Chicago. The imaging technique requires high-energy X-ray beams that are generated at only four locations in the world, one of them being Argonne's Advanced Photon Source, or APS.

Researchers set up their testing about 37 meters downstream from the X-ray source, with a series of shutters made of lead and water-cooled copper blocks to interrupt the 2-by-2-millimeter-wide X-ray beam as they recorded their images.



▲ Researchers are creating and examining images of vapor trenches formed in microscopic molten pools of metal created during laser powder bed fusion. This image, created with a high-energy X-ray beam, shows a vapor trench, also known as a keyhole, about 200 microns deep, created as a laser moved from left to right over a layer of metallic powder.
University of Virginia

▶ GE Aviation makes fuel nozzle tips for LEAP engines with laser powder bed fusion.
GE Aviation

One issue was that they didn't have enough room for a complete laser fusion device. They needed a diminutive version that could be lined up with the X-ray beam and microscope. While at Argonne, Sun and his post-doc researcher at the time, Cang Zhao, now a professor at Tsinghua University in Beijing, invented a simulated laser fusion printer to generate the conditions created by commercial laser fusion. The compact setup could be mounted on a table and precisely positioned for high-speed X-ray imaging. Sun and Zhao were the first to apply high-speed X-ray imaging to view laser fusion printing, Sun says. In 2019, when Sun joined the University of Virginia, he and his research team — currently one post-doc and two graduate students — began running a version of this simulated printer in the X-ray setup and analyzing the pore defects they saw.

The keyhole is key

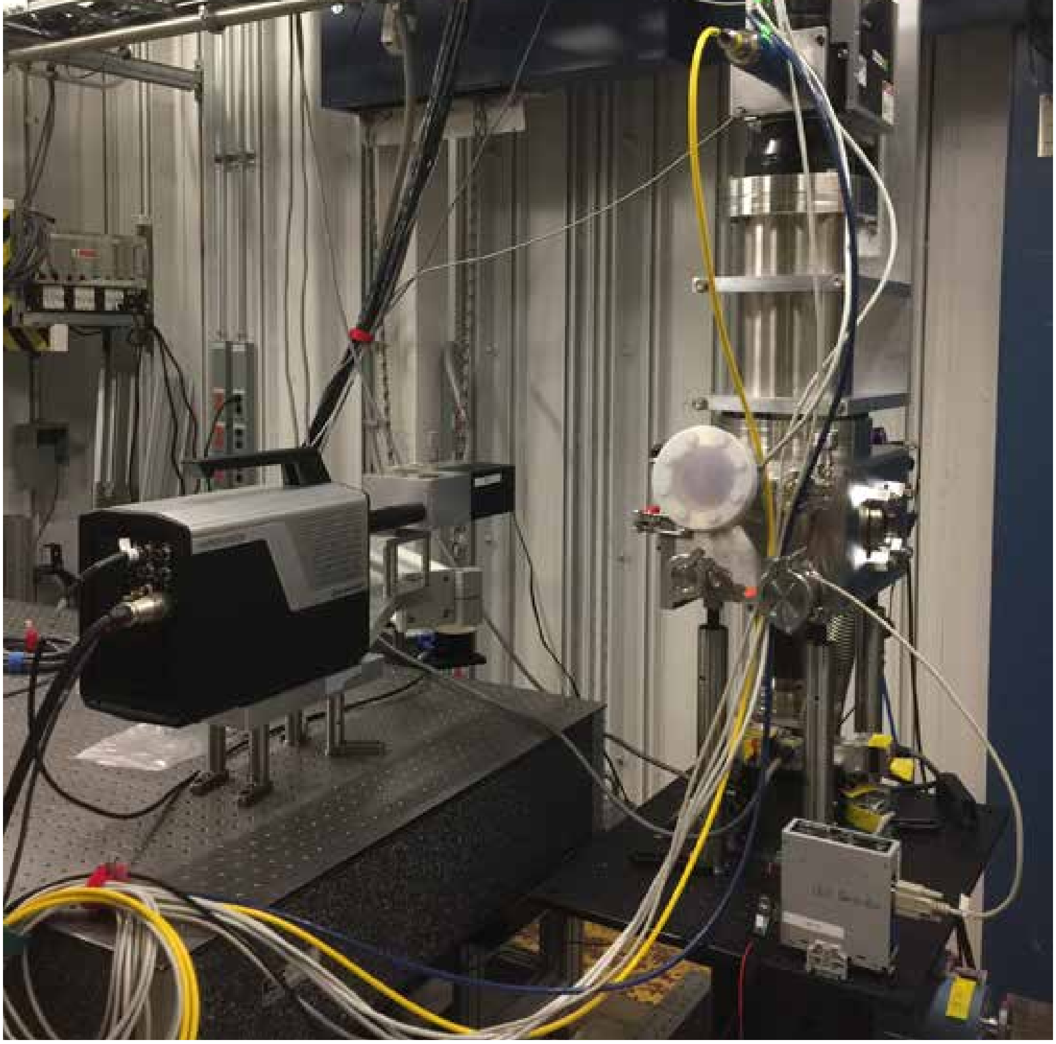
As for the origin of the bubbles, they can be caused by moisture in the metallic powder or even hollow powder particles. But the hardest source to control is a trench that sometimes forms in the molten pool. Each trench, known as a keyhole, forms when the laser vaporizes the metal. Sun and his team found that if the keyhole becomes narrow and deep, and if its walls fluctuate too much, the walls are likely to pinch together, creating a bubble at the deepest point. If the bubble doesn't reattach to the keyhole or pop to the surface of the molten pool, it will become trapped in the metal as it solidifies and become a pore.

The researchers also discovered a force in the molten pool that jostled bubbles away from the keyhole, even when thermal currents should have been causing the bubbles to escape back to the keyhole. They determined that acoustic waves account for the force, but they don't agree yet on what is causing the waves, Sun says. One explanation could be that two high-velocity liquids push together to cause waves. Or explosive boiling sometimes caused by the laser in the molten pool could cause acoustic waves.

If researchers can determine what causes the acoustic waves, the source of the waves could be eliminated so more bubbles could escape the molten pool. In the next stages of the pore research, Sun says the researchers will probably incorporate acoustic sensors into their tests to try to pinpoint what's causing the waves.

The researchers also found that bad keyholes — those that are narrow and deep with fluctuating walls that create bubbles — are predictable. By graphing the various combinations of laser power and scanning speeds that did and did not create the defects, they mapped out a clear boundary between the laser settings that reliably led to many bubbles and those that eliminated them.

Sun has so far focused most of his research on a titanium-aluminum-vanadium alloy (titanium 64), one of the most common alloys in the aerospace industry, with additional work on other aluminum alloys, stainless steel and a high-temperature nickel-chromium alloy (nickel 718) found in turbine engines. He also hopes to learn why other defects form in parts, such as cracks.



▲ University of Virginia researchers captured the laser powder bed fusion process in action with this setup at Argonne National Laboratory near Chicago. Image frames were generated at a rate of a million per second by projecting an X-ray beam from Argonne's synchrotron electron accelerator through a polymer window on the right side of the stainless steel chamber at the base of the cylinder in the image. The beam passed over a simplified laser fusion device behind the circular viewing port, and out another polymer window and to the small black box at left. There, the X-ray was converted to visible light and directed to the camera, the large box with the handle on top.

University of Virginia

Next steps

Sun is continuing research with high-speed X-ray imaging by pairing the technique with visible-light cameras and infrared cameras taking images of the surface during laser fusion printing. He wants to find out whether the surface images coincide with interior events that lead to pore formation, as depicted by the X-ray images. If they do, then researchers and eventually manufacturers could rely on only the visible-light and infrared cameras to pick up on conditions that lead to pore defects during a laser fusion print. For the manufacturers, the technique might enable them to adjust their printer or at least stop a printing that is creating defects.

Sun is working with professors in the area of machine learning and artificial intelligence to see if computers could be enlisted to examine the images, perhaps with technology similar to facial recognition algorithms. Right now, researchers must analyze hundreds of thousands of image frames for just one data point. In one day of beam time, the researchers collect millions of images. That means a post-doc student has to sit for months, or even years, viewing the slow-motion X-ray movies created by the research to extract all the useful information from just one day of testing at the high-energy X-ray site.

For now, human observation is the best way to examine the images because humans can apply a knowledge of physics to pick up subtleties that the computer can't, yet, Sun says. The computers don't know what to look for.

"We certainly put a lot of effort into trying to develop algorithms to recognize all the structure features with the computer. It's not easy, but I think that's the future," Sun says. ★

Bio-inspired

With their ability to manipulate their surroundings, morph, bend and change color, our planet's creatures and plants outperform our sophisticated flying machines in some respects. Though long intrigued by this reality, aircraft engineers have yet to fully plumb biology for design inspiration. This is set to change, and Jan Tegler shows us how.

BY JAN TEGLER | wingsorb@aol.com

British engineer and inventor Frederick Lanchester spent his afternoons during an 1892 voyage to the United States watching herring gulls gliding on rising air, their wings barely moving but curling up at the ends to help them stay aloft. Further studies of the birds led to his 1897 patent for an aerial machine that never flew but would have had "capping planes" rising from its wing tips to capture the airflow off the end of each tip and add lift.

It took until the 1970s and a spike in oil prices for something resembling Lanchester's concept to be incorporated into commercial airliners and other planes. Today we know them as winglets, the near-vertical wing extensions that improve aircraft fuel efficiency and range.

Now, however, "we're on the verge of a big acceleration" in bio-inspired design in aerospace, predicts Thomas Koonce, who manages the Revolutionary Technology Portfolio of Lockheed Martin Skunk Works in California. Why does he think so? Because of the advent of artificial intelligence and deep machine learning, he says.

Here are four biologically inspired innovations that are part of that acceleration:

Learning from Hercules beetles

Lockheed Martin Skunk Works has taken note of the amazing ability of the hand-sized Hercules beetles of tropical Central and South America to automatically darken or lighten to match the daily shifting hue of the surrounding rainforest whose colors look deeper in humid conditions than drier ones.

The secret to this camouflaging lies in each beetle's multilayered forewings that fold up to form the beetle's hard outer layer. A translucent, spongy yellow layer is sandwiched between a transparent outer layer and a black base layer. In dry conditions, pores in the yellow layer hold only air, and ambient light reflects yellow from this layer's structure. As humidity rises, the pores fill with water, and now the black layer becomes visible.

Researchers at Skunk Works think something like this tactic could improve manufacturing of composite aircraft parts. They want to create "attritable sensors that could alert technicians to when a complex structure is at the right level of humidity to move on to the next step of the manufacturing process," says Thomas Koonce who manages the Skunk Works' Revolutionary Technology Portfolio.

If the humidity is too high, the part could cure with weak areas or blisters, forcing it to be scrapped. "Color change sensors would be a fast, inexpensive, reliable way of determining whether or not the conditions are correct for manufacturing," Koonce says. Instead of attaching electronic sensors and then interpreting the data, technicians could simply look at a color change sticker that would signal whether a part is ready for the next step. "It's a low-cost, low-manpower solution," he says.

Skunk Works is famous for its pioneering work on radar stealth, so could the company have in mind visual stealth? Koonce says only that the technology would be applicable "to a wide variety of vehicles including aircraft and spacecraft" but it's at a low stage of readiness and there's no specific non-manufacturing application for it "that Lockheed Martin can share at this time."

A modified Gulfstream III was the test bed for Adaptive Compliant Trailing Edge research carried out by NASA and the U.S. Air Force Research Laboratory.
NASA

Morphing surfaces edge toward "mainstream"

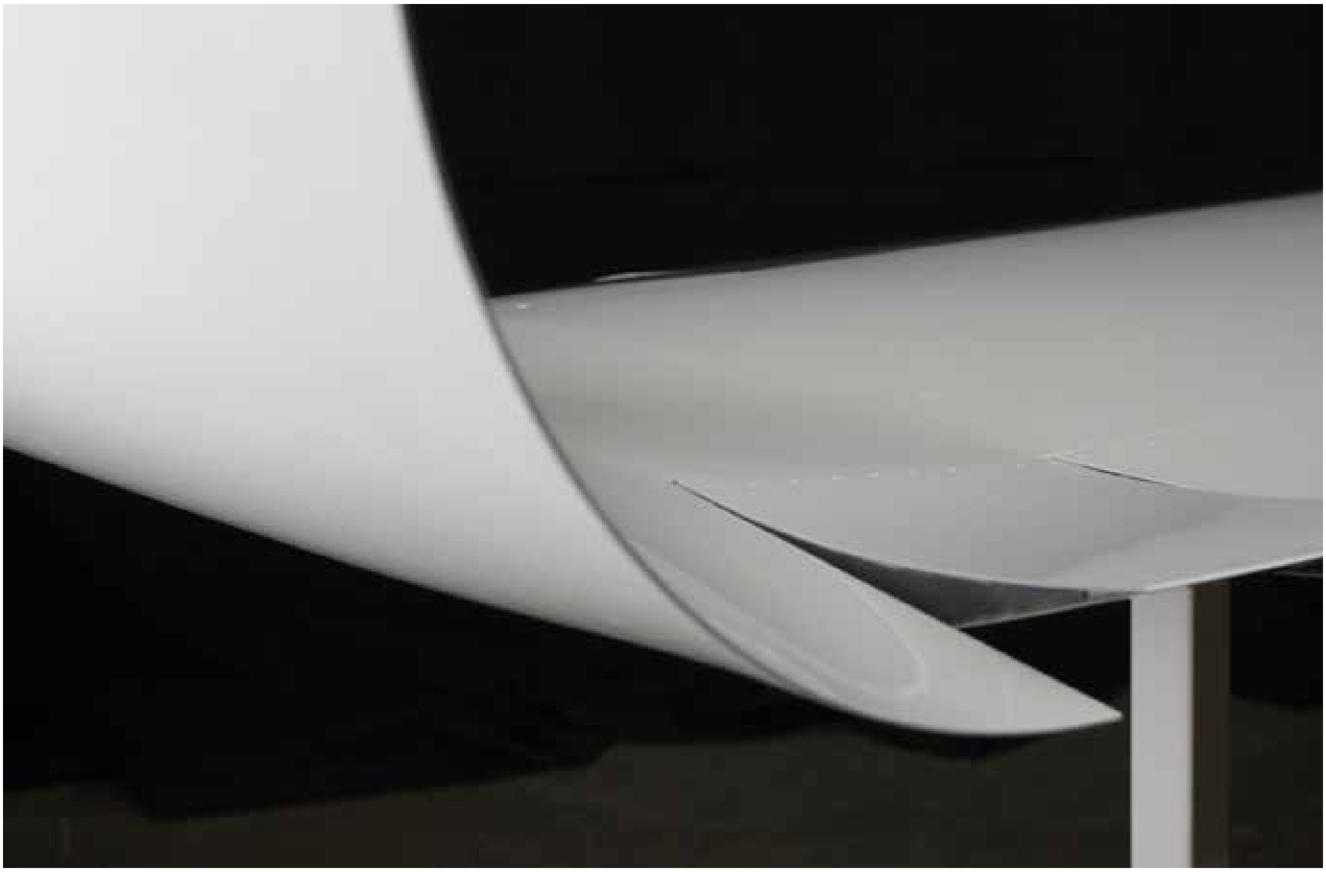
Pondering one of nature's most common wonders some years ago, Sridhar Kota, a professor of mechanical engineering at the University of Michigan, had an epiphany. "Most anything that people have designed in engineering is strong but also stiff," he recalls thinking. "Things in nature are strong and flexible, like tree branches. Why can't we design things to be strong and flexible?"

So began a 20-year effort by Kota and colleagues to develop aircraft flight test control surfaces that would bend and twist, potentially replacing traditional stiff control surfaces articulated by hinges that induce drag and harm fuel economy.

Kota founded FlexSys Inc. in 2000 to develop these "morphing" control surfaces whose shape would be changed by adjusting the positions of aluminum or, in some versions, composite beams beneath the surface. The boldest test yet will come if the U.S. Air Force moves forward with plans to test the technology on the wings of a KC-135 refueling tanker under a $5 million program called ALACS, short for Active Load Alleviation Control Surface.

An earlier version of the morphing technology performed "beautifully" as a replacement for the standard flaps on a NASA Gulfstream III jet between 2014 and 2017, Kota says. The morphing flaps improved fuel efficiency by an estimated 3% to 4%.

That said, their direct fuel efficiency contribution



▲ **FlexFoil demo load deployed**
Sridhar Kota

is not the biggest reason the Air Force wants to try the morphing surfaces on KC-135s. The Air Force has long wanted to add winglets to its fuel-thirsty tankers to generate additional lift and improve fuel efficiency. That hasn't been possible due to the aerodynamic forces that the winglets would impart onto the wings when the aircraft climbs, descends or banks. Tantalizingly, NASA proved this potential benefit when it fitted a KC-135 with them and flew it in 1979 and 1980, demonstrating an increase in range of up to 7% during cruise, when maneuver loading is not a worry.

Enter the FlexSys technology. Plans call for equipping each wing of a KC-135 with what Kota calls a "load alleviation surface" measuring 140 centimeters outboard of each wing's aileron. Internally, electric motors would move aluminum beams to bend the surface upward, counteracting the maneuver loading. The latest design is much like the flaps tested on the Gulfstream III except that on the KC-135, electric motors would extend or retract arms to curl the load alleviation control surfaces up or down, whereas on the Gulfstream III that was accomplished with hydraulic cylinders. Also, the beams in the Gulfstream III flaps were composite, not aluminum. As with the Gulfstream III, the beams would be geometrically arranged to evenly distribute loading, keeping strain low across the structure, preserving its ability to withstand aerodynamic load.

On any aircraft, the surfaces can "act as one continuous surface," Kota says, eliminating drag from seams or hinges. Flexible, articulating transition surfaces that unfold like hand fans keep the fixed parts of the wing connected to the shape morphing control surface.

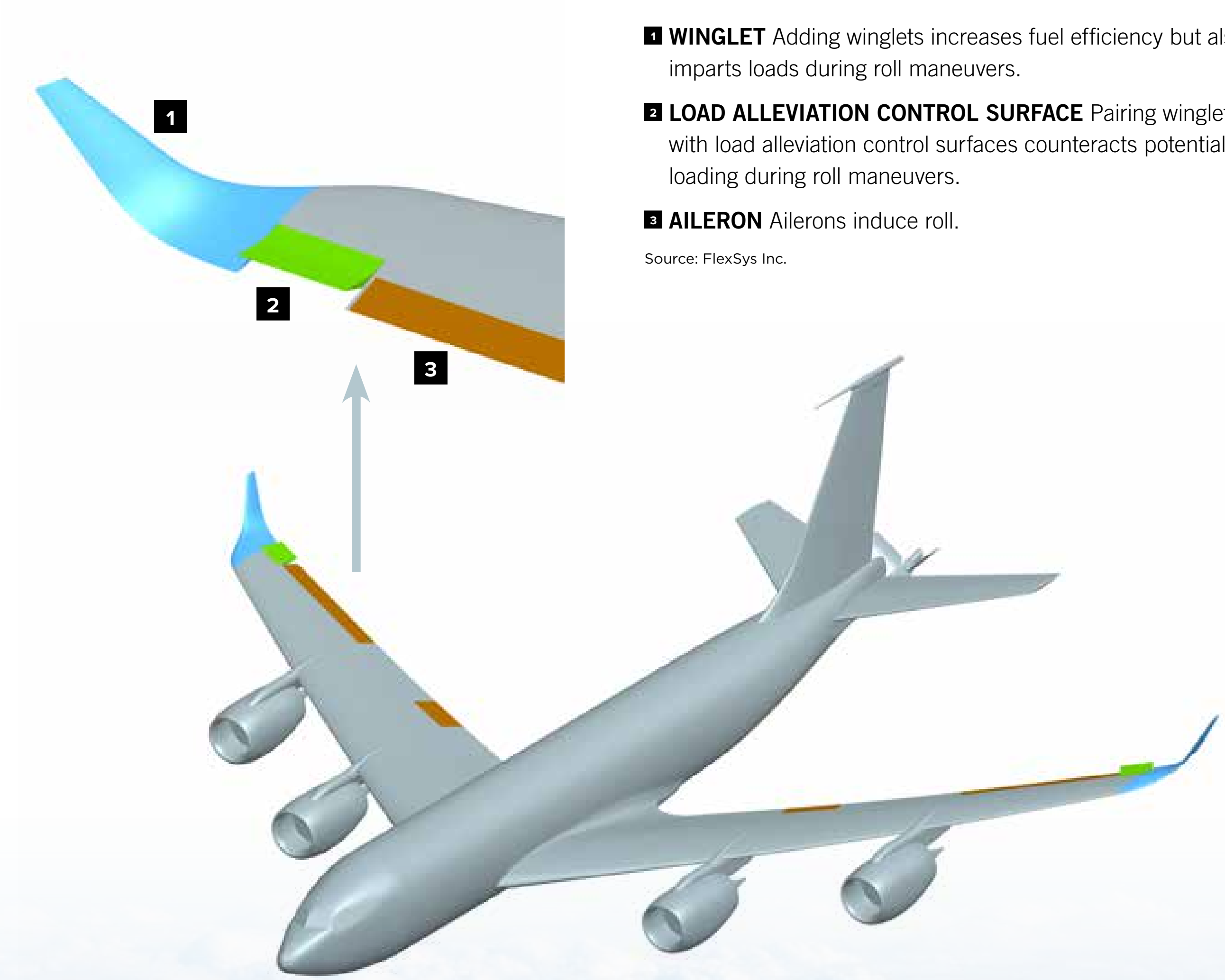
He calls the concept distributed compliance, and although tree branches inspired the idea, he likes to compare it to the mechanics of a bow and arrow. "You pull back on the bow string and bend the entire bow or beam," Kota explains. "That's what the structure of our morphing control surfaces is like."

As for the KC-135 flights, engineers have so far completed a design-data gathering phase and a ground test phase. If funding is approved, a KC-135R from the Utah Air National Guard's 151st Air Refueling Wing would be modified for a series of test flights in 2022 to assess the load alleviation control surface and winglet combination. Modeling shows a 5.5% gain in fuel efficiency that could increase range and flight time, Kota says.

The KC-135 effort "represents a first step in getting flight crews comfortable with the idea of flying with morphing control surfaces, a first foray into making morphing mainstream."

Improving KC-135 fuel efficiency

Adding winglets would improve fuel efficiency of the U.S. Air Force's refueling tankers, if only someone could address the accompanying wing loading. FlexSys Inc. hopes to flight test a possible solution under the Active Load Alleviation Control Surface program.



1 WINGLET Adding winglets increases fuel efficiency but also imparts loads during roll maneuvers.

2 LOAD ALLEVIATION CONTROL SURFACE Pairing winglets with load alleviation control surfaces counteracts potential loading during roll maneuvers.

3 AILERON Ailerons induce roll.

Source: FlexSys Inc.

KC-135 AT A GLANCE

WEIGHT FULL: 146,285 kilograms

WEIGHT EMPTY: 44,630 kilograms

TANK CAPACITY: 90,719 liters

Taming sonic booms with a little help from penguins

On land, emperor penguins walk with a wobbling gait, occasionally falling down and scooting comically on their bellies over Antarctic ice and snow. But in the water, each "performs like a champion," says Isaiah Blankson, a senior technologist at NASA's Glenn Research Center in Ohio. They dive, turn and climb with graceful agility, catching prey and dodging predators.

Blankson first learned how emperor penguins swim so acrobatically during his studies of drag reduction in 1968. The knowledge stuck with him while working on NASA's ongoing Low Boom Flight Demonstration program aimed at diminishing sonic booms with aerodynamic shaping.

When he left the program in 2018, Blankson began research on an alternative approach to boom reduction. Instead of shaping an aircraft to delay the formation of supersonic shock waves that pile up on an aircraft's nose and tail section, he wants to heat the air in front of supersonic aircraft, breaking it down until it becomes less dense. This should prevent strong shock waves from forming and resulting in sonic booms.

Believe it or not, this idea was loosely inspired by the strategy emperor penguins evolved to swim so effortlessly. When an emperor penguin dives into icy water, thousands of tiny air bubbles trapped in its feathery coat are released. The bubbles combine with the water, creating a bubbly air-water mixture that encases the penguins' body, "effectively breaking down the water flowing around the penguins' bodies into a less-dense, lower-drag medium," Blankson says.

He wants to create less-dense, lower-drag air for a plane to fly through by a concept he calls "forward energy deposition." The difference is that brief bursts of laser light are fired at target areas well ahead of a supersonic aircraft instead of the local release of air bubbles immediately around the penguins' bodies. Here's how it would work.

A laser mounted on the nose of a supersonic aircraft would fire arrays of light beams in patterns focused at a range between 61 to 91 meters in front of an aircraft flying at supersonic speed. The beams of light would heat atoms in the air at those focal points by thousands of degrees, forming channels of plasma that would be less dense than air. "The result is that the local flow behaves as if it is subsonic instead of supersonic and that means much, much reduced drag," Blankson explains.

Firing bursts of lasers at millisecond rates would create a nearly unbroken streak of plasma whose length would depend on the power of the laser, Blankson explains. That would weaken shock waves

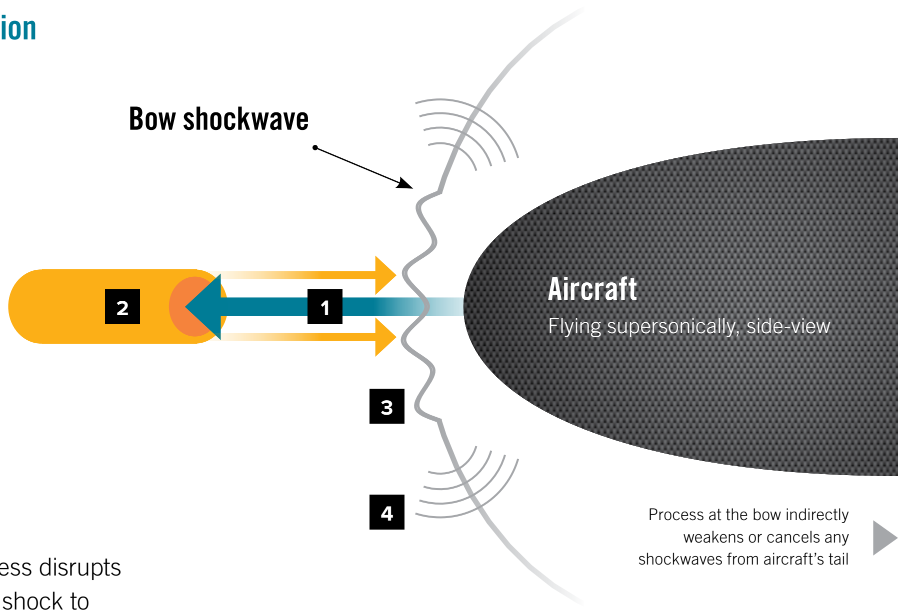
Weakening or preventing sonic booms with lasers

NASA researchers think that by projecting rapid pulses of laser in front of a supersonic plane they can cancel or weaken the shock waves on the plane and soften or eliminate any sonic boom that might be heard on the ground. More research lies ahead to scale up the concept and make it practical.

Visualizing forward energy deposition

Time span: 1/100 of a millisecond

1. Aircraft fires a pulse of laser.
2. Focusing the laser beam causes the air to ionize into a plasma filament, and this generates a blast wave.
3. The plasma ions and the blast wave interact with the blow shockwave, weakening the bow shock.
4. Secondary waves from the interaction in step 3 further weaken or eliminate the blow shock wave.



NOTE: Rapidly repeating the above process disrupts the conditions that would cause the bow shock to reconstitute itself, thereby softening or elimnating any sonic boom that might be heard on the ground.

Source: NASA's Glenn Research Center

forming on the aircraft and prevent them from re-forming, ultimately reducing the shock signature or boom heard on the ground.

The concept is still at "the exploratory stage," Blankson says. So far, he has created plasmas by firing a laser beam from the side of a supersonic wind tunnel in front of a long cylinder mounted in the tunnel. "We create a spot of plasma that hangs in the air and you are almost tempted to touch it with your finger."

Challenges to overcome include determining the optimal geometric pattern for laser pulses, and timing the pulses to prevent shock waves from re-forming. Also crucial would be scaling lasers with low system mass and weight and the right amount of power for use on a real airplane. Blankson is also investigating supplementary energy sources to produce and intensify plasmas and prolong their effects on shock waves.

Plans for testing forward energy deposition outside the lab ultimately include flying a scaled-up laser. That would be done on NASA's F-15B at Armstrong Research Center in California, Blankson says.

"The F-15 has tremendous amounts of electrical power that can be used for this type of experiment and we're doing joint research with Armstrong Research Center that will eventually lead to a laser that can be tested in flight on the F-15."

When an emperor penguin dives into icy water, thousands of tiny air bubbles trapped in its feathery coat are released. The bubbles combine with the water, creating a bubbly air-water mixture that encases the penguins' body, "effectively breaking down the water flowing around the penguins' bodies into a less-dense, lower-drag medium." — Isaiah Blankson, NASA

Harbor seal whiskers inspire turbine blades

Vikram Shyam, a researcher in the turbomachinery and heat transfer branch at NASA's Glenn Research Center in Ohio, is designing low-drag turbine blades inspired by the whiskers of harbor seals. His research is part of NASA's Advanced Air Transport Technology Project, an effort to develop revolutionary energy efficiency for fixed-wing aircraft.

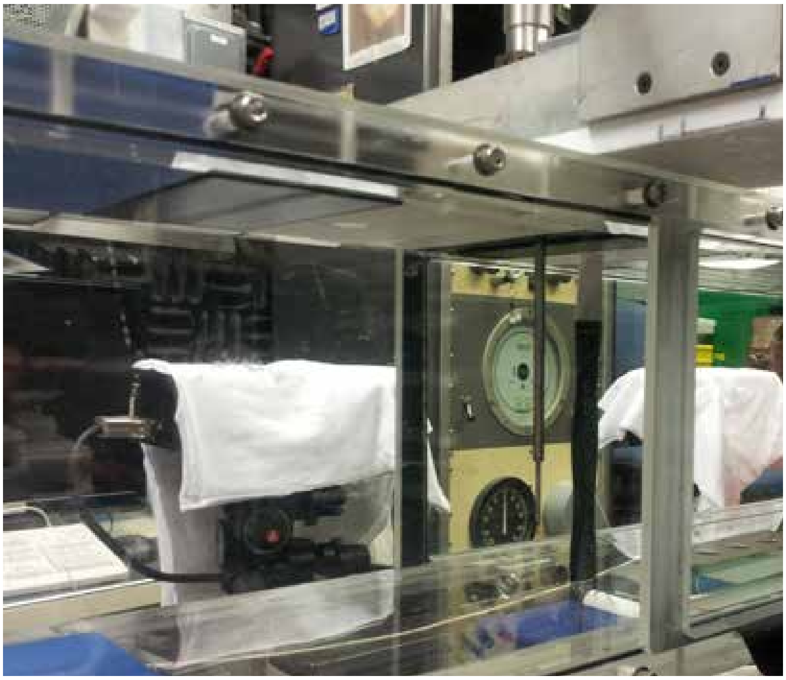
Harbor seal whiskers loosely resemble ripe bean pods. They have bulges and their edges are wavy. This way, the whiskers "produce much smaller wakes and significantly lower turbulence and drag than smooth whiskers," Shyam says. This keeps the whiskers relatively still while the animal swims, so the whiskers can pick up the small vibrations and wakes crayfish create in murky Arctic waters.

Shyam's small team of researchers began mapping the parameters of harbor seal whiskers eight years ago and created enlarged 3D plastic models for testing in Glenn's low-speed wind tunnel with the goal of developing turbine blades that would draw air into the turbine stage of future hybrid-electric jet engines with less drag than those today, a change that could dramatically improve fuel efficiency and lower emissions.

The wind tunnel tests confirmed that, just as in the water, the whiskers' bulges and zig-zagging edges help keep the flow attached to their surfaces. The peaks, valleys and waviness create low-pressure paths for airflow to follow along the whisker shape, Shyam says, keeping the flow "from separating and creating drag."

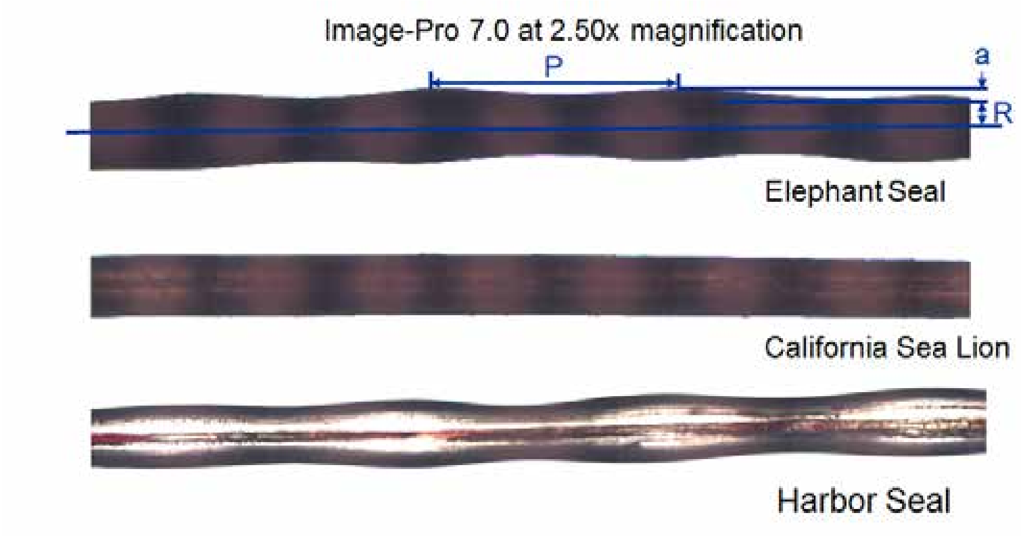
Turbine blades with similar bulges and zigzags at their leading and trailing edges could also reduce drag, enabling them to spin with less energy. That would be beneficial for hybrid-electric jet engines that pair a conventional turbine jet engine with a fan driven by an electric motor. In this configuration, the jet engine provides thrust but also transfers power to the electric motor to spin the fan and create additional thrust. Delivering power to the electric motor requires the engine to operate over a wide range of power settings, causing its turbine blades to spin at faster and slower speeds than blades in a conventional jet engine that operates over a smaller rpm range.

Think of each blade as an airfoil or wing. Like a wing, turbine blades are shaped to function best at specific angles relative to onrushing air. Spinning the blades faster or slower than the rpm range they are shaped for can change the angle at which each blade meets the air by enough to cause airflow to separate from them. Separated airflow produces less thrust for a given amount of fuel than smooth air and limits the range of power settings a jet engine



A 3D-printed seal whisker blade is mounted for testing in a low-speed tunnel. The blade made of thermoplastic polymer and 30 times the size of a normal whisker is the vertical black item to the right of the gauges in the background.
Vikram Shyam

A wavy blade design based on a harbor seal whisker was tested among reference blades in a transonic wind tunnel at NASA's Glenn Research Center. Test blades are geometrically larger than real turbine blades to better characterize the flow physics.
Vikram Shyam



An optical microscopic comparison of the whiskers of three types of seals. P is the pitch, or distance between peaks. "R" and "a" indicate major axis length.
Vikram Shyam

can operate at.

Comparing models of smooth turbine blades to blades with bulges and wavy edges, Shyam's team found that the bio-inspired shape can reduce drag, enabling turbine blades to operate efficiently at a wide range of speeds, potentially improving thrust output and decreasing fuel consumption.

But the shape for the whisker-inspired turbine blades will require fine-tuning, Shyam notes, explaining that unlike a harbor seal whisker, which has bulges over its entire surface, turbine blades must have bulges on one side only.

That's because the blades must have a low-pressure side like the top side of a wing and a high-pressure side like the bottom of a wing to produce lift as the mixture of air and combustion exhaust rushes over the blades. This "lift is what makes the blades spin to generate power," Shyam explains. "One of the changes we made was ensuring that the lift side of the blades did not carry those undulations."

Modeling of turbine blades with bulges and zigzags at their trailing edges has also shown that "the waviness can reduce noise compared to smooth baseline blades because the shape produces less turbulence," Shyam says.

Shyam's team is now focused on translating its results into a 3D harbor seal whisker-inspired design for testing in simulated environments as close to realistic as possible over the next five years.

Could harbor seal-inspired blades become a reality by the end of the decade? Shyam says it's possible. "The end result might not look like the seal whisker but will be three-dimensional and it will include the waviness." ★

AEROSPACE SYSTEMS

Electrochemical Energy Systems for Electrified Aircraft Propulsion: Batteries and Fuel Cell Systems
STARTS 5 MAY

Foundations of Model-Based Systems Engineering (MBSE)
STARTS 7 MAY

Fundamentals of Data and Information Fusion for Aerospace Systems
STARTS 7 APRIL

Missile Aerodynamics, Propulsion, and Guidance
STARTS 14 APRIL

FOUNDATIONAL KNOWLEDGE

Technical Writing Essentials for Engineers
STARTS 24 MARCH

Fundamentals of Python Programming with Libraries for Aerospace Engineers
STARTS 13 APRIL

SPACE

Design of Space Launch Vehicles
STARTS 6 APRIL

Fundamentals of Classical Astrodynamics and Applications
STARTS 4 MARCH

Understanding Space: An Introduction to Astronautics and Space Systems Engineering
STARTS 6 APRIL

TESTING

Design of Experiments: Improved Experimental Methods in Aerospace Testing
STARTS 26 FEBRUARY

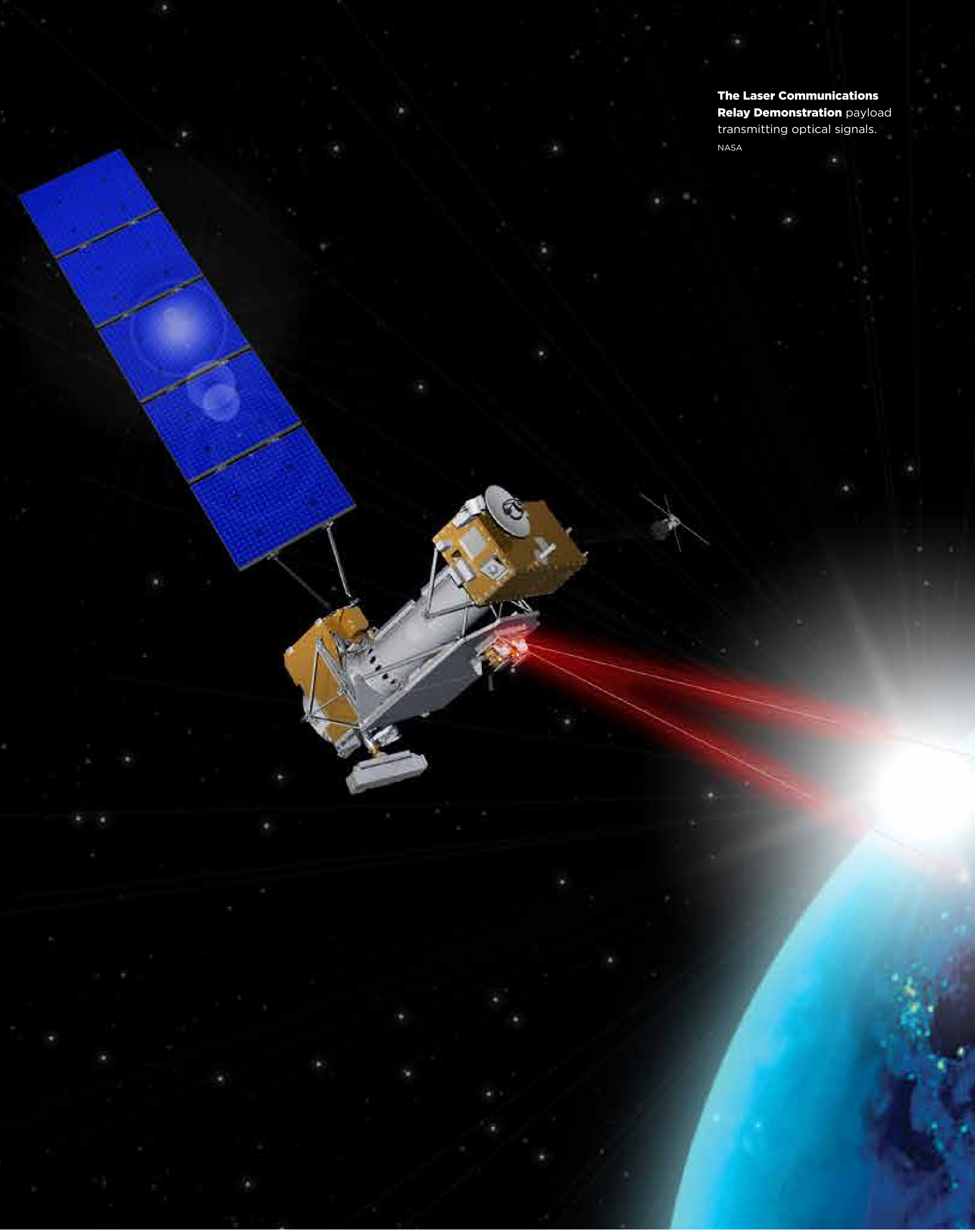
Hypersonics: Test and Evaluation
STARTS 18 MARCH

AIAA
SHAPING THE FUTURE OF AEROSPACE

Test time for optical comms

Fiber might not have reached your neighborhood, but anyone who does business in space will need a wireless version in the cosmic neighborhood and soon. After decades of experimentation, 2021 could become the long-sought pivotal year for optical communications in space, notwithstanding an early setback. Debra Werner tells the story.

BY DEBRA WERNER | werner.debra@gmail.com



The Laser Communications Relay Demonstration payload transmitting optical signals.
NASA

In the space business, bad news sometimes arrives in dry language. Two minifridge-sized experimental optical communications satellites that were supposed to reach orbit in January "were damaged during launch processing at Cape Canaveral," DARPA confirmed weeks before launch in a brief statement.

If or when the satellites, Able and Baker, reach low-Earth orbit, they'll bounce invisible near infrared laser light encoded with telemetry between each other via intersatellite links, a challenge that requires precise attitude control and laser pointing. This ambitious optical demonstration is part of DARPA's Blackjack program to demonstrate a high-speed communications constellation in low-Earth orbit. It also could have broad civilian applications and its lessons could apply to the Pentagon's proposed "Transport Layer" of communications satellites. Military commands, intelligence collections and more would bounce through space over this layer and to users on the ground at rates up to 100 times faster than with today's radio frequency satellites.

"Optical is really good at building a point-to-point, high-bandwidth connection," says Stephen Forbes, DARPA Blackjack program manager. "That's where I see the immediate sweet spot for optical, connecting nodes that need to share a lot of data, whether that is from satellite to ground or from ground to ground through a satellite."

If these broadband rates were once viewed as a mere convenience, they could soon become a must-have, and for more than military and intelligence applications. Miniaturized electronics and falling launch prices for small spacecraft are boosting the numbers of satellites in low-Earth orbit and making factories and mining operations suddenly seem feasible in some opinions. In deep space, NASA is planning its series of Artemis human missions to the moon, and Elon Musk wants to colonize Mars.

With the future of Able and Baker now in question, hopes among optical technologists for a pivotal year in optical communications that could impact all those users have shifted to another upcoming launch, this one under NASA's Laser Communications Relay Demonstration, or LCRD, project. A payload consisting of two optical telescopes and communications electronics will receive and transmit data-encoded laser light while operating from the latest of the U.S. Space Force-managed (formerly Air Force-managed) Space Test Program satellites, due for launch in late February. If all goes as planned, the telescopes will bounce video, images, voice and text among ground stations, low-Earth orbit satellites and also the International Space Station at rates as high as 1.2 gigabits per second, or about 10 times as fast as the Wi-Fi setup in the typical U.S. home. The experiment will be a step in NASA's plan to expand optical communications to deep space, especially Mars.

It can be frustrating that consumers often have higher data rates than NASA, "but this has always been a fact of life for all space missions," says David Israel, LCRD principal investigator at NASA's Goddard Space Flight Center in Maryland. LCRD is a step toward making sure that future "communications and navigations capabilities are not constraints on the science and exploration missions," he adds.

Hungry for bandwidth

What's missing in all the planning for enormous satellite constellations and deep-space exploration is a commensurate increase in bandwidth to funnel data from space to scientists or business interests on Earth as well as software and commands out to the spacecraft.

The rise in demand is no longer theoretical. Consider, for example NASA's 9-year-old Curiosity rover and its frequent sampling stops to, among other tasks, scoop rocks and sand, and parse these samples for chemical details at a rate of 50 times per second. That sounds like lots of data until one looks at plans for the Mars Organic Molecule Analyzer from the German Max Planck Institute for Solar Systems Research set for launch in September 2022 on the European-Russian ExoMars rover. It will generate 50,000 data sets per second.

Showing how so much data can be transmitted through space and to the ground and vice versa will be the job of LCRD. While geosynchronous orbit is a small fraction of the distance to Mars, "characterizing and modeling the performance of the links through the Earth's atmosphere and weather will apply to all Earth-space laser communications links," Israel says by email. During the experiment, the space station and satellites in low-Earth orbit will be connected via laser with ground stations built in dry, mountainous areas to avoid the clouds that block optical transmissions. "Our experience operating the ground stations and flight terminals" — which contain the optical telescopes on the satellites — "will also directly apply, as well as the design, integration and test of space-qualified components."

Testing technology

LCRD will be NASA's most extensive optical communications demonstration since 2013, when the Lunar Laser Communications Demonstration transmitted high-definition video from lunar orbit to New Mexico at a rate of 622 megabits per second, about half as fast as what will be attempted with LCRD. Still, that was six times as fast as previous RF transmissions from the moon. But unlike the barely monthlong 2013 experiment, the LCRD tests will run for two years and possibly as long as five, giving

NASA's Curiosity Mars Rover generates data at a rate of 50 times per second, much slower than future missions will require.
NASA

It can be frustrating that people in offices often have higher data rates than NASA, "but this has always been a fact of life for all space missions." LCRD is a step toward making sure that future "communications and navigations capabilities are not constraints on the science and exploration missions."

— David Israel of NASA's Goddard Space Flight Center

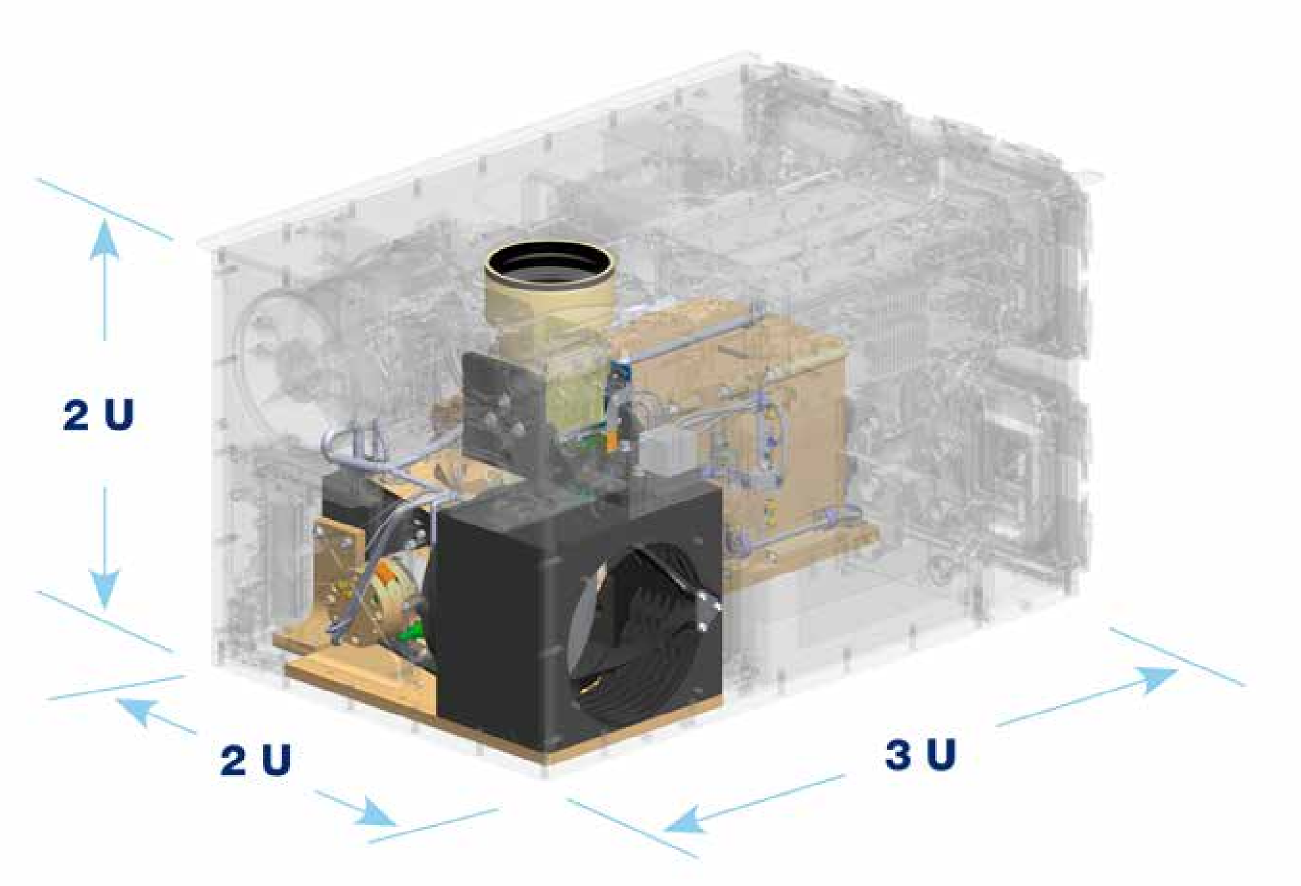
researchers time to figure out whether optical communications could speed up delivery of imagery and telemetry from Earth orbit and establish internet connections between Earth and the International Space Station.

After a couple of months of in-orbit checkout by controllers at Goddard, NASA plans to spend two years experimenting with data transfer among Earth, geosynchronous orbit and low-Earth orbit. LCRD's modems will encode data for optical modules that will generate the infrared laser beams. Those beams will be steered by lenses and mirrors with the aid of algorithms and a star tracker, the target being either a ground station or an optical communications receiver and transmitter scheduled to be mounted on the exterior of the International Space Station in 2022.

This optical payload will be tasked, for example, with relaying video, voice and text messages between the California and Hawaii ground stations. In addition, mission operators will experiment with coding and network protocols to figure out how to take full advantage of an orbiting optical communications node.

"LCRD is about to give us long-term operational experience to understand how to make the most of this optical technology," says Israel, the LCRD principal investigator who is also the Goddard Exploration and Space Communications Projects Division architect.

▼ **Two Laser Communication Terminals** built by General Atomics Electromagnetic Systems are scheduled for launch in March under a contract with the Pentagon's Space Development Agency.
GA-EMS



Making sense of the basics

Should you say optical or laser communications?

The terms are used interchangeably, but not everyone's happy about that.

"There's a lot of internal debate about which term to use," says David Israel, NASA Laser Communications Relay Demonstration principal investigator.

Some prefer the term laser communications because optical could make someone think the signals are visible to the human eye, when in fact they are invisible near infrared waves.

To distinguish optical communications for spaceflight from fiber optic cables on Earth, which also transmit in the near infrared, experts sometimes refer to "free space" optical links.

Are the signals safe?

Laser communications pose little threat to people, aircraft or satellites, those in the field say. The most popular wavelength for laser communications, 1550 nanometers, is considered eye safe by the International Electrotechnical Commission, a standards organization.

Plus, these are not powerful lasers. The Lunar Laser Communications Demonstration on NASA's Lunar Atmosphere and Dust Environment Explorer satellite sent video imagery to Earth in 2013 with a 0.5-watt laser transmitter. That's approximately the power draw of an LED night light.

Even so, NASA engineers will perform a safety analysis of the optical communications links to ensure the optical terminals they plan to send to the International Space Station in 2022 pose no threat to astronauts or equipment onboard. For example, no laser communications links would be scheduled when astronauts are outside the spacecraft performing space walks or extravehicular activities. "Even if there are no astronaut safety concerns, if astronauts were to get in the path of the link, they would block the connection and it wouldn't work," Israel says.

The space agency also refrains from transmitting signals when aircraft or spacecraft pass through the optical links. While there's no risk of lasers blinding pilots, laser uplinks can overwhelm infrared sensors on planes or satellites because they are more powerful than the objects on the ground or in the air that the sensors are designed to detect. NASA coordinates transmissions with other government agencies to determine when it's safe to transmit signals.

Do commercial satellites transmit data via lasers?

Not yet routinely, but SpaceX and Ottowa-based Telesat, two prospective broadband providers, plan to move communications through their networks with optical inter-satellite links. SpaceX said last year that it tested "space lasers" on two of its Starlink satellites with good results.

"The Starlink satellites were able to transfer hundreds of gigabytes of data," Kate Tice, SpaceX senior certification engineer, said in a September webcast. "Once these space lasers are fully deployed, Starlink will be one of the fastest options available to transfer data around the world."

— Debra Werner

▲ **The Laser Communications Relay Demonstration** package was joined to the Space Test Program Satellite at Northrop Grumman's site in Virginia. The two optical modules are at top under protective coating.

Northrop Grumman

With LCRD approaching its launch date, the civil and commercial space community in the United States and abroad has voiced interest in participating in the experiment. LCRD managers posted an invitation online for researchers to try out optical communications hardware and software with LCRD, including optical terminals that companies are developing for satellites and ground stations. Dozens of NASA researchers and people from other government agencies and companies have responded, including General Atomics Electromagnetic Systems, or GA-EMS, in Colorado, the company owned by General Atomics Corp. of San Diego that builds small satellites, laser weapons and more. GA-EMS wants to connect a commercial ground terminal with LCRD and to test various laser-pointing techniques.

"We certainly have no shortage of things we want to do, but there may be some overlap," Israel says. "And people may propose things that we haven't thought of."

Until the 2013 Lunar Laser Communications Demonstration, some satellite communications experts questioned the suitability of laser communications for spaceflight. Would satellites be able to keep a narrow beam of light aimed directly at another optical device in space or on the ground? It turns out they can with the help of fast-steering mirrors and algorithms to stabilize and direct the light beam, but it's not easy.

"When you add in vibration and the relative motion of the spacecraft, that becomes technically challenging," Israel says.

Atmospheric turbulence and terrestrial weather further complicate matters. Turbulence scatters light waves, and clouds block them completely. To ensure optical beams have a clear path from geostationary orbit, NASA established one LCRD ground station at the Table Mountain Observatory in the San Gabriel Mountains above Los Angeles and another at Haleakala, a dormant volcano on the Hawaiian island Maui. In addition, NASA has developed models for predicting weather, which engineers hope to improve through LCRD experiments.

"Between the pointing, acquisition and tracking challenges and dealing with the atmosphere and weather, that is where the cost comes in," Israel says.

Flight terminals, meaning the optical telescopes, amplifiers and modems that spacecraft must have to send and receive science data or other information via laser, remain large and expensive. Each of LCRD's telescopes will measure 10-centimeters. LCRD ground stations must be larger. The one in Maui is housed in a 5.5-meter-diameter dome.

Companies are developing optical terminals that will be as small as a flashlight to avoid taking up precious volume on a satellite, and will be far less expensive. About 15 years ago, NASA budgeted about $90 million for the swiveling telescopes, computers and amplifiers that would transmit laser light from the car-size Mars Telecommunications Orbiter, decode the signals and forward the data. Laser terminal prices have fallen since then but high-reliability terminals like the ones NASA developed and integrated for LCRD with help from Northrop Grumman and the Massachusetts Institute of Technology Lincoln Laboratory, a federally funded research and development center, still can cost $15 million to $20 million apiece.

Driving down costs

Through the Blackjack program, DARPA hopes to drive costs down further, perhaps to "a couple hundred thousand dollars" each, Forbes says. "That will enable a larger number of satellites to take advantage of" optical signals to quickly send and receive data.

Optical equipment manufacturers call that price target ambitious, but say the keys to reducing terminal prices are commercial vendors and mass

"Optical is really good at building a point-to-point, high-bandwidth connection. That's where I see the immediate sweet spot for optical, connecting nodes that need to share a lot of data, whether that is from satellite to ground or from ground to ground through a satellite."

— Stephen Forbes of DARPA

▲ **The two optical modules** on the Laser Communications Relay Demonstration include telescopes for receiving and transmitting optical, or laser, signals.

NASA

production. "We're able to figure out how to build things much more efficiently from top to bottom," says David Czajkowski, founder, president and chief operating officer of Space Micro, a small San Diego company that builds spacecraft components. "We took a series of very reliable parts from data centers and found a way to qualify them for a 100-gigabit-per-second laser communication modem, which has been launched." He says he's not permitted to identify the customer.

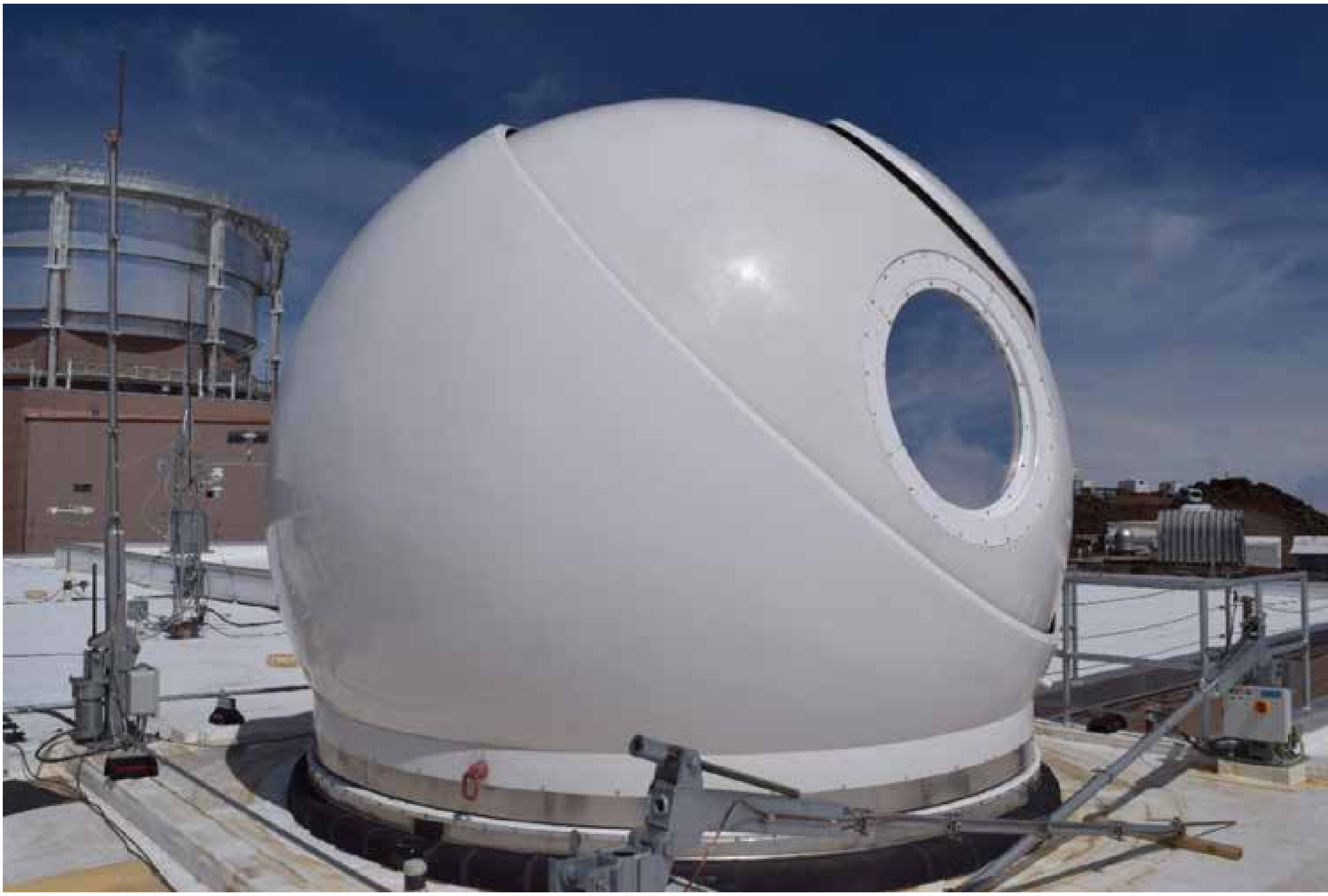
GA-EMS, the General Atomics company, meanwhile, is also focused on reducing the cost of the optical terminals through high-volume production. "You don't need a couple of these, you may need hundreds of these laser communication systems per year," says GA-EMS President Scott Forney.

Under a $5.5 million contract from the Pentagon's Space Development Agency, GA-EMS built two toaster-oven-size satellites with infrared cameras and optical terminals. The satellites, scheduled for launch in March, will gather and process infrared imagery day and night of objects on the ground and in the air, relay imagery back and forth, and transmit and receive data from optical terminals on the ground. In a future constellation with dozens or hundreds of satellites, what SDA calls a proliferated low-Earth orbit architecture, satellites and ground stations would have multiple pathways to transmit data directly among themselves and through optical terminals on aircraft, which is another technique to bypass clouds.

In addition to the promise of transferring video, voice and text messages between satellites as well as from space to the ground faster than RF, optical communications promise size, weight and power advantages. Optical signals stream from smaller telescopes backed up by smaller amplifiers in space and on the ground, compared with large RF dish antennas with powerful amplifiers.

The power savings comes from the laser focus, whether the optical signal is traveling from geosynchronous orbit or the moon. If it's the moon, an optical beam might be a few hundred meters in diameter when it reaches Earth, as opposed to an RF beam that might be a five hundred or so kilometers in diameter.

"The primary advantage is that most of the power" — and therefore data — "gets to the receiver" in the optical terminal, says Tom Wood, senior director for optical communications and network-



ing at CACI, a government contractor based in suburban Washington, D.C., that provides engineering services, IT support and mission support for U.S. and international government agencies.

CACI is building the bidirectional LCRD optical communications terminal for the space station under a NASA contract, optical terminals for NASA Orion crew capsules and a laser transmitter to send images and data directly to Earth from NASA's Psyche spacecraft that in 2022 will be launched to the asteroid 16 Psyche. Because scientists think Psyche consists mainly of nickel and iron, like the cores of terrestrial planets including Earth, they want to inspect it in part to test their suspicion that it's the exposed core of an early planet.

In addition to streaming data from deep space, satellite developers are eager to move data among satellites in Earth orbit because the technology can reduce the size, weight and power consumption of communications devices by 90% compared to RF, says Czajkowski, CEO of Space Micro, which manufactures RF and optical terminals.

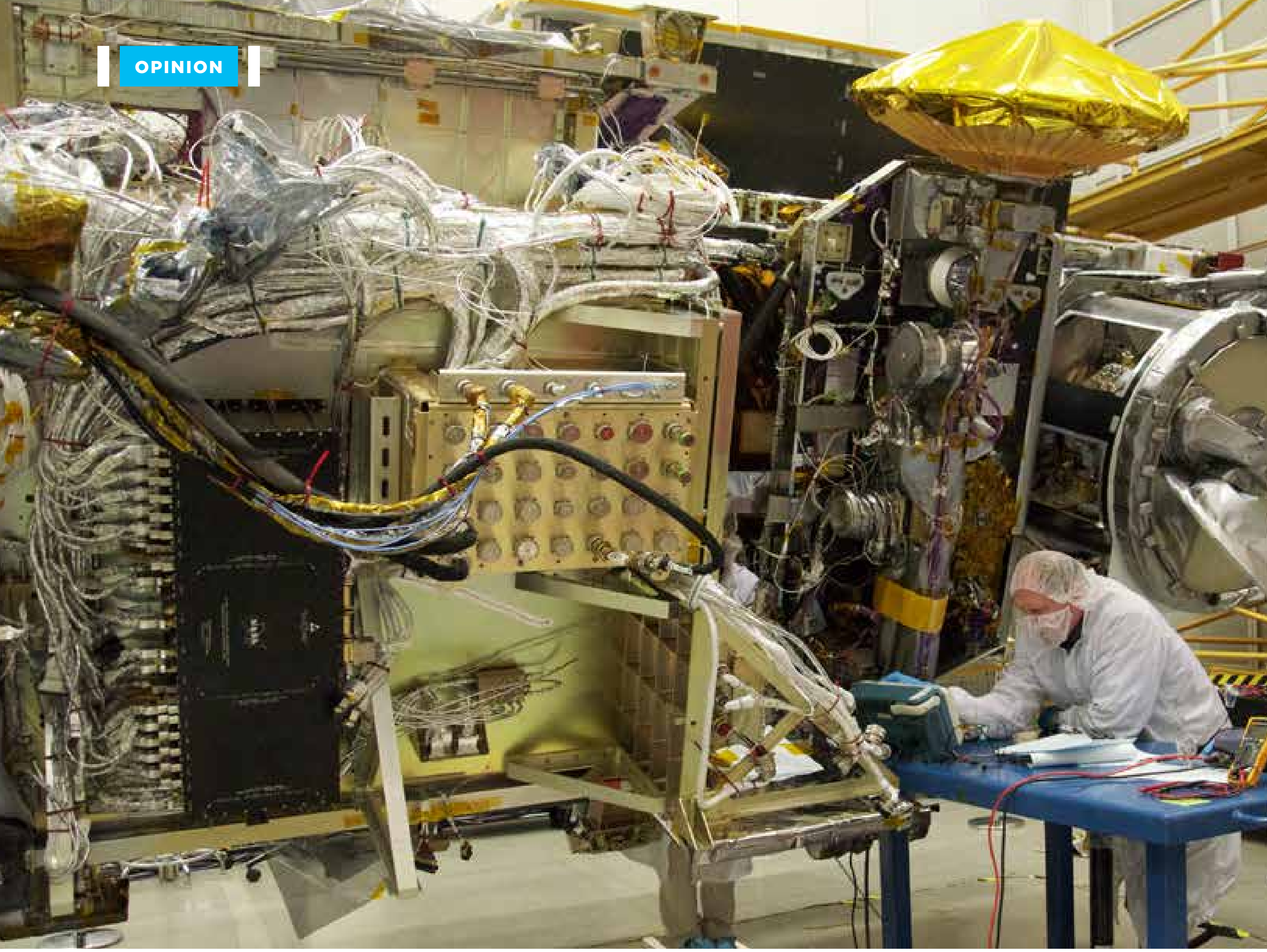
Equally important for military customers is the enhanced security laser communications offer. In contrast to RF antennas, which transmit energy over a wide area, optical communications travel through a narrow beam, making them difficult to intercept or jam.

Imagine "looking down a soda straw," Czajkowski says. "If someone shines a light from a different angle, it doesn't interfere with light in the soda straw."

In spite of all that promise, optical communications technology has yet to be widely deployed operationally, at least as far as the public record shows. The European Space Agency established the first optical link in 2001 between its Artemis geostationary telecommunications satellite and one of the French Spot Earth-observation satellites in low-Earth orbit. In 2001, the U.S. National Reconnaissance Office launched Geosynchronous Lightweight Technology Experiment or GeoLITE, a satellite equipped with an optical terminal to transmit data to the ground. NRO did not respond to requests for comment on whether its current fleet transmits data through optical links.

All told, advocates of optical technology want LCRD to be more than just the next in a long series of optical experiments. They want its launch later this year to mark a turning point year in the long history of this technology. ★

▲ **NASA's optical ground station** in Haleakala, Hawaii, was built to collect data transmitted by the agency's Laser Communications Relay Demonstration package that will ride on a military satellite. Another station is in California.
NASA



OPINION

Why today's systems engineers should remember their pioneers

Systems engineering and mission assurance were born in the days of large rockets and ever-larger spacecraft. The United States could not have caught up to the Soviet Union and reached the moon without these disciplines. Today, SE and MA remain relevant, but one must think about them differently. Retired U.S. Air Force Maj. Gen. Thomas "Tav" Taverney explains.

BY THOMAS "TAV" TAVERNEY

▲ **The ultimate** goal of systems engineers and mission assurance practitioners is to build a quality product that meets requirements and performs the mission.
NASA

As the U.S. space community shifts toward smaller satellites operating in larger, more resilient constellations, we need to be sure we don't forget lessons from the past. Whether we work for NASA or NOAA in the civil space arena, for a corporation in the commercial marketplace, or for the military or National Reconnaissance Office in national security space, our SE roots lie in Southern California. There, in 1954, U.S. Air Force Gen. Bernard Schriever, the father of military space, teamed up with Simon "Si" Ramo, the uncle of military space and the R in TRW Inc., since acquired by Northrop Grumman Corp.. Together, Schriever and Ramo began developing the concept of SE, especially as it applied to the development of technically complex space systems. An independent group of engineers would provide engineering oversight, requirements management, configuration control and interface control, the figurative glue that would bind the components of rockets, satellites or any complex mechanism into a smoothly functioning system. SE ensured that all the players worked together to properly produce the complex components that seamlessly form the final system. Therefore, when integrated as a whole, the system has a high probability of operating at the performance levels intended by the designers. The new SE discipline provided the foundation for the successes of the Thor, Atlas, Titan and Minuteman rockets, as well as the Defense Support Program missile warning satellites and the Defense Meterological Satellite Program weather satellites. SE was embraced by NASA in 1961 for the Mercury human spaceflight program. Along with SE, the modern field of mission assurance was born, and "Failure is not an option" became NASA's mantra. If Apollo 13 flight director Gene Kranz did not say it, he probably thought it.

In these early days, SE practitioners began working with their colleagues in the mission assurance field with some urgency, given that the first space components were of uneven and inconsistent quality. Later, these processes were expanded to assure repeatable workmanship in complex systems. The emphasis of SE was to ensure the developed product fulfilled the requirements by verifying the interfaces, and the fit and tracking of components in multiple steps during development.

The emphasis of MA became validation, checking the actual and expected performance of the product. When we put the satellite in a thermal vacuum chamber for the final system checkout, we must be certain the components will work together to fulfill the mission, and that the final integrated product will indeed meet performance requirements.

The ultimate goal of SE and MA is, of course, to build a quality product that meets requirements and performs the mission. For space systems, that means assuring that capabilities are available to, for instance, a soldier with a GPS unit, a scientist scouting for evidence of life beyond Earth, or a consumer with a smartphone who lives out of range of cell towers.

Ensuring that failure was not an option did not come cheaply. For successful programs, managers typically spent 8% to 12% of the contract value on SE, according to studies by the federally funded Aerospace Corp. in Los Angeles.

Exploiting new tools

Now it's time to recognize that the advent of digital engineering and model based systems engineering tools have improved SE efficiency and cut costs without cutting rigor. We can utilize MBSE's strengths by employing its modeling and simulation tools to make it an integral part of the technical baseline that includes the requirements, design, analysis, interfaces, implementation and verification. Taken together, these advances will add up to robust SE that will improve cost, schedule performance, speed and agility.

Digital twins have emerged as a major component of digital engineering. We can test hardware on these precise renderings before we build the hardware and can therefore identify any problems early on. We also can decide what physical changes should be made to a system to improve it.

While historical levels of SE have been relatively consistent for successful programs, MA levels have always varied widely, with space launch vehicle programs having the largest amount of MA due to the conclusive nature of a failure. That level will likely remain consistent for the vehicles entrusted to deliver large, expensive satellites to orbit, something that won't change until we fully move to resilient mission constellations. Likewise, MA investments will remain high for the large, expensive satellites themselves. Each satellite must be tested fully, and while that leads to longer schedules, it is necessary because there are not many of them, and no spares if they fail on orbit. But once there's a production line of dozens or a hundred small satellites, managers can — or maybe must — be more tolerant of a launch failure or an occasional, underperforming satellite. The cost of reducing failure rates must be weighed against the operational impact of a failure, and the cost it would have taken to prevent that failure. Maybe we need to certify at the component level and pull random satellites off the production line to test. It is probable that some very small number of problems will get through, but with cost and schedule as the big drivers, we likely can accept low failure rates versus adding significant costs to each and every satellite.

“The cost of reducing failure rates must be weighed against the operational impact of a failure, and the cost it would have taken to prevent that failure.”

Looking to the auto industry

To perform SE and MA for these large production builds, we need to look outside the standard processes and procedures in the space industry. We should look to other industries that have confronted quality assurance for large production runs. SpaceX pioneered this approach in aerospace by bringing in experts from the automotive industry to help set up higher rate production capabilities. After all, the auto industry has high quality and robust digital engineering in its production facilities. While rockets and satellites will never be built in quantities like refrigerators or washing machines, we can look to such industries to sharpen our processes. Where quantities are large, and affordability is critical, each and every item likely will not be inspected, but representative systems will be pulled from production lines and heavily tested. Launch, however, is a uniquely space activity. Nothing was more damaging to success as low launch rates. As we increase launch rates, history has shown that reliability increases. Therefore, as we go to a much higher operating tempo, we need to do some rethinking or re-engineering of launch mission assurance.

As we move to proliferated constellations, we will apply SE and MA with digital engineering to accomplish robust processes while reducing the amount of testing for the hardware. Even so, we should not forget what Schriever, Ramo and Von Braun taught us about the criticality of SE in particular. In fact, SE will become even more critical but, in a different sense, supported by a combination of smart people and powerful tools, since it will have to apply across large constellations.

Greater need for speed

The new tools have arrived just in time, because we are moving into an era in which Russia and China have developed threats to our infrastructure, through hypersonic missiles. We are also in a situation in which our space assets, on which we have become so dependent, can be denied or eliminated by a determined adversary, like Russia or China, either temporarily or permanently. Significantly they are also building these systems this on short development cycles of three to four years. Therefore, we must not only provide high-technology solutions, but we must field them quickly, affordably and in large enough numbers so that we can absorb losses and continue to operate our missions and assure capability availability to users. This evolution will require a bold shift away from today’s premium on stable requirements and the disdain for “requirements creep,” as it’s known. Our resilient large constellations will consist of many satellites built over years. Replenishment must be driven not just by satellite lifetimes, but by significant changes in the threats. New and innovative thinking will be required. We no longer will develop identical clones. MBSE and digital engineering will enable processes for managing configuration changes between these builds.

As for MA, when we build larger quantities, we need to focus on building in quality during production, versus focusing so heavily on inspections or testing to find performance shortcomings. Adopting a continuous product improvement approach and anchoring it with strong MBSE makes every engineer a systems engineer. I suspect Schriever and Ramo would love this approach, and wish they had MBSE and digital engineering tools in their day.

As we move forward with missions that must continue to operate in a now-hostile environment, we must respond with proliferation for resilience and a greater tolerance for failure. Schriever would say that we must still make SE and MA a critical part of that thinking, just in a different and more effective way. ★

Thomas “Tav” Taverney, a retired U.S. Air Force major general, is a member of the Air Force’s Broad Area Review team and a former vice commander of Air Force Space Command. In the late 1960s, he designed the Airborne ASAT, an antisatellite weapon that was demonstrated twice, once in 1985 when it destroyed the U.S. Solwind satellite at 555 kilometers. Congress terminated the program in 1985. In the early 2000s, he helped elevate the mission assurance of the Atlas V and Delta IV launchers to militarily acceptable levels. He was recognized in 2018 by AIAA with the Von Braun Award for Program Management Excellence.

REGISTER FOR AIAA'S

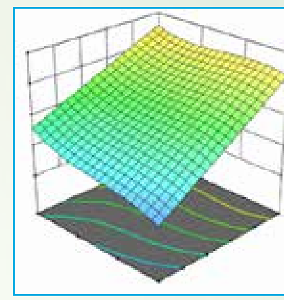
Design of Experiments

ONLINE SHORT COURSE

OVERVIEW

IMPROVED EXPERIMENTAL METHODS IN AEROSPACE TESTING

Improve the quality of your research and productivity through learning about statistically based experiment design. AIAA's new course Design of Experiments: Improved Experimental Methods in Aerospace Testing ensures empirical model adequacy, quantifies variability in predictions, and identifies all possible independent variable interactions. The course will review specific studies that illustrate resource savings, quality improvements, and enhanced insights from well-designed experiments.



DETAILS

- Every Friday, 26 February – 16 April 2021
- 1300–1500 hrs Eastern Time USA
- All sessions will be recorded and available on demand
- Cost: $845 USD Members
$495 USD Student Members
$1,045 USD Nonmembers

OUTLINE

- Statistics Fundamentals
- Single Factor Experiments
- Introduction to Factorial Designs
- Experiment Planning
- Wind Tunnel Testing Example
- 2^k Design and Analysis Details
- Second Order Modeling
- Fractional Factorial Designs
- Blocking
- Response Surface Methods
- Assign Optional At-Home Experiment
- Introduction to Experiments with Restricted Randomization

REGISTER NOW

learning.aiaa.org

AIAA

SHAPING THE FUTURE OF AEROSPACE

AIAA Bulletin

DIRECTORY

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

To join AIAA; to submit address changes, member inquiries, or renewals; to request journal fulfillment; or to register for an AIAA event. Customer Service: 800.639.AIAA (U.S. only. International callers should use 703.264.7500).

All AIAA staff can be reached by email. Use the formula first name last initial@aiaa.org. Example: christinew@aiaa.org.

Addresses for Technical Committees and Section Chairs can be found on the AIAA website at aiaa.org.

Other Important Numbers: Aerospace America / Karen Small, ext. 7569 • AIAA Bulletin / Christine Williams, ext. 7575 • AIAA Foundation / Alex D'Imperio, ext. 7536 • Book Sales / 800.682.AIAA or 703.661.1595, Dept. 415 • Communications / Rebecca Gray, 804.397.5270 • Continuing Education / Jason Cole, ext. 7596 • Corporate Programs / Nancy Hilliard, ext. 7509 • Editorial, Books and Journals / Heather Brennan, ext. 7568 • Exhibits and Sponsorship / Paul doCarmo , ext. 7576 • Honors and Awards / Patricia Carr, ext. 7523 • Integration and Outreach Committees / Nancy Hilliard, ext. 7509 • Journal Subscriptions, Member / 800.639.AIAA • Journal Subscriptions, Institutional / Online Archive Subscriptions / Michele Dominiak, ext. 7531 • K–12 Programs / Sha'Niece Simmons, ext. 7590 • Media Relations / Rebecca Gray, 804.397.5270 • Engage Online Community / Luci Blodgett, ext. 7537 • Public Policy / Steve Sidorek, ext. 7541 • Section Activities / Lindsay Mitchell, ext. 7502 • Standards, Domestic / Hilary Woehrle, ext. 7546 • Standards, International / Nick Tongson, ext. 7515 • Technical Committees / Angie Lander, ext. 7577 • University and Young Professional Programs / Michael Lagana, ext. 7503

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

Calendar

DATE	MEETING	LOCATION	ABSTRACT DEADLINE
2021			
8 Feb	AIAA Webinar—Sustainability in Flight: Our Journey to Decarbonization	VIRTUAL EVENT (aiaa.org/webinars)	
26 Feb–16 Apr	Design of Experiments: Improved Experimental Methods in Aerospace Testing Course	ONLINE (http://learning.aiaa.org)	
4 Mar–28 Apr	Fundamentals of Classical Astrodynamics and Applications Course	ONLINE (http://learning.aiaa.org)	
6–13 Mar*	2021 IEEE Aerospace Conference	VIRTUAL EVENT (www.aeroconf.org)	
15–19 Mar	AIAA Congressional Visits Day	VIRTUAL EVENT (aiaa.org/cvd)	
16 Mar	ASCENDxSummit: Next-Generation Workforce	VIRTUAL EVENT (ascend.events)	
18 Mar–8 Apr	Hypersonics: Test and Evaluation Course	ONLINE (http://learning.aiaa.org)	
24 Mar–14 Apr	Technical Writing Essentials for Engineers Course	ONLINE (http://learning.aiaa.org)	
24 Mar	AIAA Aerospace Perspectives Series Webinar: Hypersonics	VIRTUAL EVENT (aiaa.org/webinars)	
26–27 Mar	AIAA Region III Student Conference	Ann Arbor, MI (VIRTUAL)	5 Feb 21
26–27 Mar	AIAA Region IV Student Conference	Stillwater, OK (VIRTUAL)	1 Feb 21
2–3 Apr	AIAA Region V Student Conference	Iowa City, IA (VIRTUAL)	21 Feb 21
3–4 Apr	AIAA Region VI Student Conference	Long Beach, CA (VIRTUAL)	6 Feb 21
6–8 Apr*	AIAA SOSTC Improving Space Operations Workshop	VIRTUAL EVENT (https://isow.space.swri.edu)	
6 Apr–13 May	Design of Space Launch Vehicles Course	ONLINE (http://learning.aiaa.org)	
7–16 Apr	Fundamentals of Data and Information Fusion for Aerospace Systems Course	ONLINE (http://learning.aiaa.org)	
8–9 Apr	AIAA Region II Student Conference	Tuscaloosa, AL (VIRTUAL)	23 Feb 21
9–10 Apr	AIAA Region I Student Conference	New Brunswick, NJ (VIRTUAL)	19 Feb 21
9, 16, 23 Apr	Understanding Space: An Introduction to Astronautics and Space Systems Engineering Course	ONLINE, 3 full days (http://learning.aiaa.org)	
12–14 Apr*	55th 3AF Conference on Applied Aerodynamics (AERO2020+1)	Poitiers, France (http://3af-aerodynamics2020.com)	
13–29 Apr	Fundamentals of Python Programming with Libraries for Aerospace Engineers Course	ONLINE (http://learning.aiaa.org)	
14– 30 Apr	Missile Aerodynamics, Propulsion, and Guidance Course	ONLINE (http://learning.aiaa.org)	
15–18 Apr	AIAA Design/Build/Fly Competition	Tucson, AZ (VIRTUAL)	
20–22 Apr*	Integrated Communication, Navigation, and Surveillance (ICNS) Conference	VIRTUAL EVENT (https://i-cns.org)	

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.).

21 Apr	ASCENDxWorkshop: Maximizing Payload Success	VIRTUAL EVENT (ascend.events)	
5–7 May*	POSTPONED to 2022: 6th CEAS Conference on Guidance Navigation and Control	Berlin, Germany (https://eurognc2021.dglr.de)	
5–28 May	Electrochemical Energy Systems for Electrified Aircraft Propulsion: Batteries and Fuel Cell Systems Course	ONLINE (http://learning.aiaa.org)	
7, 14, 21 May	Foundations of Model-Based Systems Engineering (MBSE) Course	ONLINE, 3 half days (http://learning.aiaa.org)	
18 May	AIAA Aerospace Perspectives Series Webinar: Sustainability	VIRTUAL EVENT (aiaa.org/webinars)	
31 May–2 Jun*	28th Saint Petersburg International Conference on Integrated Navigation Systems	Saint Petersburg, Russia (elektropribor.spb.ru/en)	
5–6 Jun	3rd AIAA Geometry and Mesh Generation Workshop (GMGW-3)	Washington, DC	
5–6 Jun	4th AIAA CFD High Lift Prediction Workshop (HLPW-4)	Washington, DC	
5–6 Jun	1st AIAA Ice Prediction Workshop	Washington, DC	
6 Jun	2nd AIAA Workshop for Multifidelity Modeling in Support of Design & Uncertainty Quantification	Washington, DC	
7–11 Jun	AIAA AVIATION Forum	Washington, DC	10 Nov 20
21–23 Jun*	3rd Cognitive Communications for Aerospace Applications Workshop	VIRTUAL (http://ieee-ccaa.com)	
22–25 Jun*	ICNPAA 2021: Mathematical Problems in Engineering, Aerospace and Sciences	Prague, Czech Republic (icnpaa.com)	
9–11 Aug	AIAA Propulsion and Energy Forum	Denver, CO	11 Feb 21
17 Aug	AIAA Fellows Dinner	Washington, DC	
18 Aug	AIAA Aerospace Spotlight Awards Gala	Washiington, DC	
6–10 Sep*	32nd Congress of the International Council of the Aeronautical Sciences	Shanghai, China (icas.org)	15 Jul 19
13–15 Sep*	3rd IAA Conference on Space Situational Awareness (ICSSA)	Madrid, Spain (http://reg.conferences.dce.ufl.edu/ICSSA)	15 Jun 21
14–16 Sep	AIAA DEFENSE Forum (Postponed from April)	Laurel, MD	17 Sep 20
25–29 Oct*	72nd International Astronautical Congress	Dubai, UAE	
15–17 Nov	ASCEND Powered by AIAA	Las Vegas, NV, & ONLINE	30 Mar 21
2022			
3–7 Jan	AIAA SciTech Forum	San Diego, CA	
8–9 Jan	1st AIAA High Fidelity CFD Workshop	San Diego, CA	

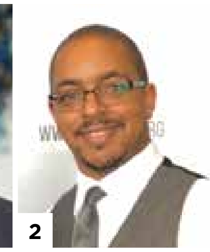
● AIAA Continuing Education offerings

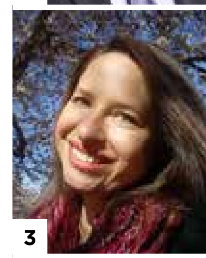
Meetings cosponsored by AIAA. Cosponsorship forms can be found at aiaa.org/events-learning/exhibit-sponsorship/co-sponsorship-opportunities.

Diversity Scholars Attend AIAA SciTech

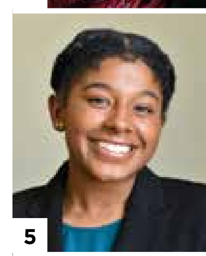
Scholars meeting virtually with the some of the AIAA Diversity & Inclusion Working Group

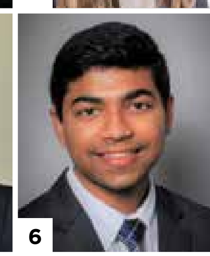

1


2


3


4

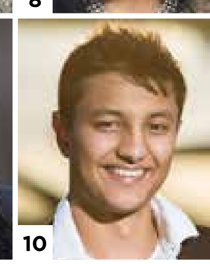

5

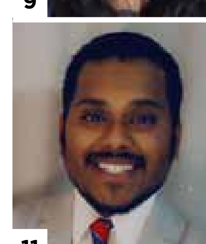

6

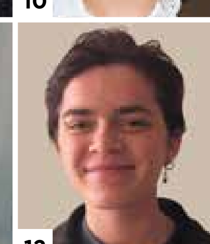

7


8

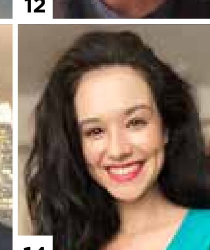

9


10


11


12


13


14

Fifteen AIAA Diversity Scholars attended the AIAA SciTech Forum, 11–15 & 19–21 January 2021. Scholars participated in the virtual AIAA SciTech and attended special panels and networking sessions geared specifically for the scholars.

The AIAA Diversity Scholarship provides students from underrepresented groups with the opportunity to attend AIAA forums and receive additional targeted programming that may help them succeed in the aerospace industry. This program is a collaboration between the AIAA Foundation and our sponsor, The Boeing Company.

Diversity scholarships will be offered for AIAA AVIATION Forum and ASCEND in 2021. Applications are welcome from students in all disciplines with an interest in aerospace. Please visit **aiaa.org/Diversity-and-Inclusion** for more information.

DIVERSITY SCHOLARS

1 **Kreston Barron,** Georgia Institute of Technology
2 **Dion Bumpus,** University of Alabama
3 **Donna Coyle,** University of Washington, Bothell
4 **Cosette Geesey,** Virginia Polytechnic Institute and State University
5 **Rachel Harvey,** University of Maryland - College Park
6 **Anoop Kiran,** SUNY University at Buffalo
7 **Kelly McCarthy,** Illinois Institute of Technology
8 **Noshin Nawar,** University of Arkansas - Fayetteville
9 **Teresa Nguyen,** Portland State University
10 **Rishi Patel,** Virginia Polytechnic Institute and State University
11 **Mohammed Razzak,** Illinois Institute of Technology
12 **Adrien Redmond Stein,** Columbia University
13 **Rachael Trujillo,** University of Central Florida
14 **Eszter Varga,** Virginia Polytechnic Institute and State University

Not pictured: Mesfin Melaku, Eastern Michigan University

2021 International Student Conference Winners Announced

The AIAA International Student Conference took place 11–13 January in conjunction with the 2021 AIAA SciTech Forum. Students whose papers won first place at one of the 2020 AIAA Regional Student Conferences presented their papers at this professional technical conference, which offers students a chance to showcase their research at an event where they can also network with potential employers and colleagues. The winners were announced at an awards presentation on 14 January. Steve Frick, director of Space Operations at Lockheed Martin Space Systems, delivered a guest lecture to students as part of the awards program.

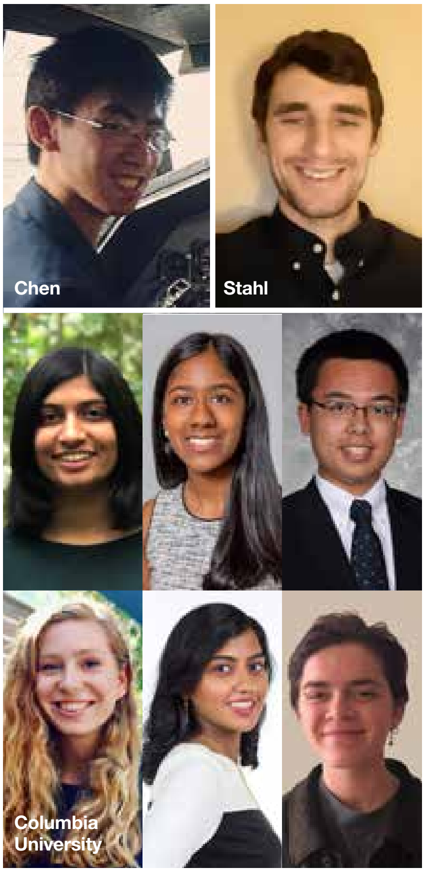
In the Undergraduate Category, the winner is **Jeffrey Chen** from Embry-Riddle Aeronautical University (Prescott, AZ) with his paper, "Bréguet Range Equation in Constraint Analysis Form for Power-Rated Aircraft for Power-Rated Aircraft."

In the Masters Category, the winner is **Spencer Stahl** from Ohio State University (Columbus, OH) with his paper, "Effects of Fountain Flow Interaction on Dual Jet Impingement at Mixed Operating Conditions."

In the Team Category, the winner is **Columbia University** (New York, NY), with their paper "Sharp-edge Handheld Identifier and Remover in Low-gravity Extravehicular Environments." The team members from Columbia University are Natasha Dada, Kalpana Ganeshan, Matthew Groll, Sophia Kolak, Swati Ravi, and Adrien Stein.

Dates for the 2021 Regional Student Conferences can be found on **pages 48–49**. For more information, contact Michael Lagana at michaell@aiaa.org.

Thank you to Lockheed Martin Corporation for sponsoring the 2021 conference. AIAA also would like to thank the professional members who gave their time to be judges on this program and evaluate student presentations. Without their participation, this program would not be possible. 2021 judges are Allen Arrington, Chris Thames, Dakshina Fernando, G. Alan Lowery, Joe Marshall, Prashanth Bangalore Venkatesh, Steve Triolo, and Thomas Snitch, with Chris Tavares, Paul Park, and Jane Hansen serving as session chairs.



2021 AIAA Key Issues and Recommendations

The U.S. aerospace and defense (A&D) industry is a multi-trillion-dollar enterprise that supports millions of direct and indirect jobs nationally and many more globally. The coronavirus pandemic has had a huge economic impact on A&D. It is critical that substantial action be taken in a timely manner to address the needs of the industry during this uncertain time and to return us to some version of normalcy. Failure to act will likely lead to economic decline and emboldened international threats. Consequently, to protect A&D, the following *Key Issues* are focused on recovery and sustainment, including leveraging A&D as a catalyst to lead other segments of the economy back to health and growth in the coming years.

The industry has and will continue to directly address critical issues facing our nation. This includes stepping up in response to the crisis by rapidly producing and transporting needed Personal Protective Equipment, developing and delivering critical ventilators, and now distributing the COVID-19 vaccines. The sector is critical for addressing climate change by developing the necessary new technologies that reduce aviation carbon emissions and provide for a more sustainable future. In addition, the sector provides significant opportunity for young people of all races and economic conditions to tackle the complex challenges of defending our way of life and consistently improving our society.

Actions taken (or missed) now for the A&D sector will affect the nation for many years to come. AIAA urges decision makers to enact and support policies that will allow sustainment of this vital industry during these difficult times and result in a robust and world-leading A&D sector. More specifically, the Institute recommends:

- Providing stable and sustained **funding for the entire A&D sector** (DOD, NASA, FAA, other applied research and development, small businesses) to ensure the United States emerges from the pandemic with its global leadership in this area intact.
- Supporting initiatives for national and global cooperation to enable the **commercial aviation market** to return to full operation – such as standardized health management measures and tasking the FAA to lead the harmonization of regulations and policy.
- Continuing to invest in **A&D research and development** – this is the source of new technologies and products that will ensure future job growth, address climate change, provide needed opportunities for young people of all backgrounds, address evolving threats, and global leadership.
- Developing **public/private partnerships** at national, state, and local levels to dramatically improve (in quality and quantity) the STEM pipeline – our future workforce.

The full set of 2021 Key Issues can be found at ***aiaa.org/advocacy/Key-Issues*** *and Supplemental Information Papers can be found at* ***aiaa.org/advocacy/Policy-Papers/Information-Papers****.*

23rd AIAA Congressional Visits Day (CVD)

15–19 March • Register: aiaa.org/cvd

Your voice is important to hear. Our members' participation in the 23rd annual Congressional Visits Day will be invaluable during a time when COVID-19 is weakening the resilient aerospace and defense industry. The program will be unlike any previous year—it will be entirely virtual and take place over an entire week.

AIAA FOUNDATION 25 YEARS
Advancing Aerospace

Roger W. Kahn Scholarship

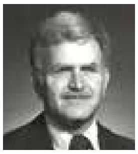
AIAA is excited to announce the Roger W. Kahn Scholarship to honor the memory of Roger Kahn and his passion for aviation and entertainment. Kahn spent his career at Grumman Aircraft Engineering Corporation as a test pilot and then managing the technical service and sales division. In the 1940s, Kahn was actively involved with the Institute of the Aeronautical Sciences (one of the predecessor organizations of AIAA) and later became its vice-president. Kahn was also an accomplished jazz musician, responsible for composing the song “Crazy Rhythm” from the movie *Casablanca*.

AIAA will award up to four $10,000 Roger W. Kahn Scholarships to **high school seniors** who enroll in an accredited college or university and intend to pursue an aerospace or STEM major. AIAA will also furnish a $2,500 travel stipend for the students to attend an AIAA event such as AIAA SciTech Forum, AIAA AVIATION Forum, or ASCEND. The Institute will provide each student with a mentor from AIAA’s professional members to help guide the student to achieve a career in aerospace. The application is open until **1 March 2021**. Underrepresented students are encouraged to apply.

To apply, visit **aiaa.org/get-involved/k-12-students/scholarships**. For more information, email K-12STEM@aiaa.org.

Obituaries

AIAA Associate Fellow Hale Died in May 2020



Francis J. Hale died 5 May 2020.

Dr. Hale entered the United States Military Academy at West Point in 1941, and was commissioned in the Corps of Engineers on D-day, 6 June 1944. He served the Army and Air Force for 22 years, rising to the rank of Colonel.

During those years he completed Parachute School at Fort Benning, GA, and served with a combat engineer battalion in Europe until mid-1945. Thereafter, he retrained with the Army Map Service and was the officer in charge of mapping uncharted islands in the Philippines. By order of President Truman, he was one of 62 officers selected by Major General Leslie Groves to develop a military capability to assemble and deploy atomic bombs at the research facility at Sandia AFB, NM. He spent five months on Eniwetok Atoll during Operation Sandstone where the United States tested three atomic bombs.

Transferring to the Air Force at its creation in 1947, he became a flight instructor in the P-51 at Nellis AFB, transitioning to the early jet fighters. From there, he was sent to the Massachusetts Institute of Technology for his Master of Science. Upon graduation from MIT, he went to Eglin AFB as Director of Ballistics. In 1956 he was transferred to Los Angeles as a member of the Western Development Division (code name for the USAF Ballistic Missile Division, Air Research and Development Command) where he served first as deputy director of the Thor missile program and later in the development of the Minuteman.

In 1959, he returned to MIT where he earned his Ph.D. in Mechanical and Aerospace Engineering with a thesis on the boundary layers of an MHD accelerator for space propulsion. His next assignment was to the USAF Academy as the Professor and Head of the Department of Astronautics. In 1962, he was assigned to the Pentagon as Deputy Director for Research and Development, Directorate of Development Plans, Headquarters USAF.

In 1965 he retired from the Pentagon and joined the faculty of North Carolina State University (NCSU) where he remained as a Professor of Mechanical & Aerospace Engineering until his second retirement in 1989. At NCSU, he called upon his military experiences to create new and effective aerospace engineering courses, and to write three textbooks and collaborate on a fourth with Dr. Jesse Doolittle. During his years at NCSU, Dr. Hale left the campus for a year on three occasions; in 1972 to the Middle East Technical University in Ankara, Turkey, in 1976 to West Point as the first civilian Professor of Mechanics, and in 1982 to Wrightsville Beach, NC, to serve as the Technical Director of the Desalination Test Facility of the Department of the Interior. In 1990, he taught at the U.S. Naval Academy as a Secretary of the Navy Fellow in Aerospace Engineering. He taught two professional development courses each year for AIAA on aircraft design and space flight until 2013.

Dr Hale was also a member of the American Society of Mechanical Engineers and the Society of Automotive Engineers (Ralph R. Teeter Educational Award, 1985), In 2006 he was named to the Air Force Space and Missile Pioneers Hall of Fame, Peterson AFB.

AIAA Honorary Fellow Tellep Died in November

Daniel M. Tellep, retired Chairman and CEO of the Lockheed Martin Corporation, died on 26 November 2020. He was 89.

Tellep attended the University of California at Berkeley, graduating magna cum laude with a degree in Mechanical Engineering in 1954 and then earned his Master of Science degree the following year. He credited his professors at Berkeley for a transformative opening of his mind to the "elegance of mathematics and equations." In 1971, he completed advanced management studies at Harvard University, Graduate School of Business Administration.

In 1955, Tellep began his 43-year career in the aerospace industry working on re-entry technology at Lockheed Corp. as a principal scientist in the Missiles & Space Co. subsidiary. Tellep was named president in 1984, and in 1989, he was selected to lead Lockheed Corporation as CEO and Chairman.

Following the collapse of communism and in an era of shrinking defense budgets, Tellep reached out to his friend and competitor Norm Augustine (CEO, Martin Marietta) and proposed a merger, resulting in the formation of Lockheed Martin Corporation in 1995. Tellep and Augustine spent a year secretly negotiating the deal, using fake names to meet in off-the-radar cities to discuss the details. The merger created the world's largest defense company, with a combined rich history dating back to the early days of aviation. Tellep became Lockheed Martin's first chairman and CEO in 1995. He served as CEO for only nine months, but he remained as chairman until 1998.

When reflecting on his career, he reveled in the camaraderie and respectful collegiality of his fellow men and women scientists. He loved the challenge of finding creative solutions with his teams. As a manager and executive, he was known for his handwritten notes of acknowledgment and gratitude to employees, as well as his initiation of the morale building annual "Beat the Boss" run.

Though honored with many awards for aerospace engineering, management and manufacturing throughout his career, he cherished the AIAA Lawrence B. Sperry Award conferred on him in 1964, when he was 32. The award recognized his contributions to re-entry technology and thermodynamics in aerospace programs. His legacy as a scientist and scholar continues through the University of California Berkeley Daniel M. Tellep Distinguished Professorship in Engineering endowment fund. He was also recognized with the 1986 AIAA Missile Systems Award for for over 25 years of major technical and leadership roles in the research and development of advanced missile/payload systems and for his contributions to the success of each generation of Fleet Ballistic Missile programs.

Outside of work, Tellep was an accomplished pilot who loved to fly sailplanes above the slopes of the High Sierras and Colorado Rockies. His logbooks record over 600 hours of soaring and more than 4,500 miles of cross-country flight.

AIAA Fellow Clayton-Townsend Died in December

JoAnn Clayton-Townsend, former director of the Aeronautics and Space Engineering Board (ASEB) at the National Academy of Sciences, died on 21 December.

Townsend received her B.A. at the University of Tulsa. She travelled extensively with her husband who worked for United States Information Service, a division of the State Department's Foreign Service. While in Israel, Townsend attended the Ulpan Hebrew language training for immigrants and she also worked on several archaeological digs. She was president of the Turkish-American Women's Society for a year, and the following year, she and a friend established the first English language travel magazine in Turkey. Returning to the United States, Townsend worked as the personal assistant to the Foreign Secretary of National Academy of Sciences from 1963 until 1966. Between 1974 and 1977, Townsend worked for several years on Capitol Hill as Legislative Assistant to Congressmen Berkeley Bedell from Iowa, Charles Whalen of Ohio, and Matthew Rinaldo from New Jersey.

After the death of her first husband, Townsend decided to re-join the staff of the National Academy of Sciences (NAS). One of her first assignments was as a staff officer for a committee writing a report for NASA on President Reagan's decision to cancel the U.S. portion of the NASA-ESA International Solar Polar Mission (ISPM). As her fascination with the space program grew, she pursued a Master's degree in Space Policy at George Washington University. Within a few years of completing her degree she rose to become the director of the Aeronautics and Space Engineering Board (ASEB) at NAS.

Townsend's contributions to the U.S. space program were recognized by her peers when she was elected as a Fellow of AIAA in 2003. Women in Aerospace presented her with its Outstanding Achievement Award in 1991 and Outstanding Member Award in 1997. She was a member of the International Institute of Space Law and editor of its annual proceedings for many years. She also was a member of the International Academy of Astronautics.

While working at ASEB she married Dr. John (Jack) Townsend, a former director of NASA Goddard Space Flight Center, a Fairchild Industries Vice President, and also a Fellow of AIAA. In 1997, Townsend retired from ASEB to pursue her dream of becoming an artist. She remained involved in AIAA as a member of the AIAA International Activities Committee (2001–2005) and the AIAA Public Policy Committee (1993–2005).

AIAA Fellow Vaughan Died in December

William W. Vaughan Jr., 90, died on 23 December.

Dr. Vaughan graduated from the University of Florida with honors in Mathematics and Physical Science. He then obtained a graduate degree at Florida State University in Atmospheric Science and received his Ph.D. in Engineering Science from the University of Tennessee.

During his career, Dr. Vaughan served as Captain in the U.S. Air Force, Chief of the Atmospheric Science and Aerospace Environment Divisions with NASA, and was a charter member of the Federal Senior Executive Service. His responsibilities included the establishment and interpretation of aerospace environment requirements for the design and operation of space vehicles and spacecraft including Jupiter vehicles, Apollo-Saturn vehicle, Space Shuttle, National Aerospace Plane and the International Space Station.

After retiring from NASA, Dr. Vaughan became a NASA Emeritus, Director of the Research Institute as well as professor of atmospheric science at the University of Alabama in Huntsville. Following his retirement from the University of Alabama, he enjoyed being senior docent at the U.S. Space and Rocket Center in Huntsville.

A long-term AIAA standards volunteer, Dr. Vaughan was the first chairman of the AIAA Standards Executive Council (2010–2012). He was a Fellow of AIAA and the American Meteorological Society (AMS). He was a former member of the International Space Standards Organization and professional member of the American Geophysical Union, American Association for Advancement of Science, Standards Engineering Society and American Society of Mechanical Engineers. He authored or co-authored more than 120 technical reports and journal articles. He was also former Associate Editor of the *Journal of Aerospace Technology and Management.*

He was recognized with many awards including the AIAA Distinguished Service Award (2007), the AIAA Excellence in Aerospace Standardization Award (2003), and the AIAA Losey Atmospheric Sciences Award (1980). He also received Outstanding Performance Awards (NASA, Air Force, Army), NASA Exceptional Service Medal, the AIAA Hermann Oberth Award, and IES Maurice Simpson Technical Editors Award.

AIAA Associate Fellow Vachon Died in December

Reginald "Reggie" Vachon died on 24 December.

Vachon attended the United States Naval Academy, Auburn University, and Oklahoma State University. He earned a bachelor's in mechanical engineering, a master's in nuclear science, and a Ph.D. in mechanical and aeronautical engineering. He augmented these degrees with an LL.B. at Jones Law School in Montgomery, AL, and certificates from the U.S. Army Command and General Staff College and the U.S. Army War College.

He was an engineer with NASA and the U.S. Army, and the founder and chair of several engineering companies. He was a registered engineer in six states, Europe, and Asia. Vachon was a member of the Alabama State Bar. He had a distinguished academic career as chaired professor of mechanical engineering at Auburn University and adjunct professor at Purdue University.

He served in leadership positions as president of the American Society of Mechanical Engineers, chair of the American Association of Engineering Societies, president of the Pan American Academy of Engineers, vice president north (US, Canada, Mexico) of the Union of Pan American Engineering Societies, and executive vice president of the World Federation of Engineering Organizations. Vachon was also a Fellow with the National Society of Professional Engineers, the American Society of Civil Engineers, and an Associate Fellow of AIAA. He was a life member of the American Society of Engineering Education, and a member of IEEE, the UK Institution of Mechanical Engineers, the Institute of Engineers Singapore, the Hong Kong Institute of Engineers, and the International Nuclear Energy Academy.

Vachon proudly served his county and retired as a colonel in the U.S. Army Corps of Engineers. His last duty was during Desert Storm.

Vachon was a recipient of the Outstanding Teacher Award from ASEE. He held a patent in his field and was the author of numerous technical papers. In 2019 he was awarded the ASME Medal for eminent and distinguished achievement in engineering.

AIAA Senior Member Carruthers Died in December

George R. Carruthers, an astrophysicist and engineer who was the principal designer of a telescope that went to the moon as part of NASA's Apollo 16 mission in 1972 in an effort to examine Earth's atmosphere and the composition of interstellar space, died on 26 December. He was 81.

At the University of Illinois at Urbana-Champaign, he received a bachelor's degree in aeronautical engineering in 1961, a master's degree in nuclear engineering in 1962, and a doctorate in aeronautical and astronautical engineering in 1964. He then became a research physicist at the Naval Research Laboratory.

Dr. Carruthers led a team that designed a telescope that could electronically amplify images from space through a series of lenses, prism and mirror, just three inches in diameter. By converting photons to electrons, the images could be recorded on film. In 1970, an early model of his telescope was included in an unmanned rocket flight that found the first evidence of molecular hydrogen in interstellar space.

When mounted on a tripod, Dr. Carruthers's lightweight magnesium telescope stood about four feet high. It was covered in gold plate to protect it from the moon's extreme temperatures. It was used on 21 April 1972, on the Apollo 16 lunar mission, and captured more than 200 images of Earth's atmosphere, hundreds of stars and distant galaxies.

Dr. Carruthers continued to refine his telescopes and develop experiments at the Naval Research Laboratory for decades. In 1986, one of his instruments captured an ultraviolet image of Halley's comet. He also designed instruments used aboard Skylab and space shuttle flights and for satellites measuring polar auroras and luminescence in the upper atmosphere.

Beginning in the 1980s, Dr. Carruthers worked extensively with science outreach programs, particularly in schools with large numbers of Black students. He developed an apprentice program for high school students at the Naval Research Laboratory and taught summer courses for science teachers in D.C. public schools.

After retiring from the research laboratory in 2002, he taught Earth and space science for several years at Howard University. Dr. Carruthers received the NASA Exceptional Scientific Achievement Medal and was named to the National Inventors Hall of Fame. He also received the National Medal of Technology and Innovation, presented by President Barack Obama at a White House ceremony in 2013.

AIAA Fellow Moore Died in December

Raymond Gilbert "Gil" Moore, 92, died 28 December. He had been a member of AIAA and its predecessor organization the American Rocket Society for 70 years.

Mr. Moore began his career as a rocket propulsion engineer in 1947 as a student assistant at New Mexico State Physical Science Lab. As a student he performed radio telemetry data reduction and installed upper atmospheric and solar research instrumentation in captured German V-2 rockets. In 1949 after graduating with a B.S. degree in chemical engineering, he became professional staff at the laboratory. During the next 13 years he supervised teams of students and professionals in instrumenting and launching hundreds of flight test and upper atmospheric research sounding rockets from the White Sands Proving Grounds in New Mexico as well as from locations in the Pacific and Atlantic oceans.

In 1962, Mr. Moore became the founding general manager of the Astromet Division of Thiokol Corporation. During the next 20 years, this organization built and launched several hundred sounding rockets and six satellite experiments from sites around the world to measure various characteristics of the Earth's ionosphere, thermosphere and magnetosphere. The division also manufactured, installed, and operated radio telemetry systems for monitoring meteorological and hydrologic variables in the mountains of the Western United States and Canada. In 1981, Mr. Moore transferred to Thiokol's Wasatch Division, where he served as special projects manager for the Space Shuttle solid rocket motor program and as principal investigator for gossamer space structures. He became the Thiokol Wasatch Division's director of external affairs in 1985 and represented the corporation to the press and public during the Space Shuttle Challenger accident investigation before retiring in 1987.

In 1987 Moore co-founded the highly successful Small Satellite Conference. After retiring from Thiokol, Globesat (the first smallsat company in the U.S.), and the Utah State Space Dynamics Lab, Moore was appointed the General Bernard A. Schriever Chair in Astronautics at the Air Force Academy.

After retiring from the Academy he created Project Starshine, a volunteer student satellite project designed to measure the response of Earth's atmosphere to storms on the sun during an 11-year solar cycle. Some 25,030 children in 660 schools in 18 countries worked on the satellite. In addition to introducing students to space research, important data was gathered for the science community on the effects of solar extreme ultraviolet radiation on satellite orbital decay.

In 2014 Mr. Moore was awarded an honorary Doctor of Physics from USU. He was a past member of the AIAA Hybrid Rockets Technical Committee and the AIAA Balloon Systems Technical Committee. He was recognized by AIAA in 1981 as a corecipient of the Distinguished Service Award for exceptional service to the Utah Section and the Institute, and specifically for his dedicated and highly successful efforts to promote use of "Getaway Special" Space Shuttle payloads for student experiments.

CONTINUED FROM PAGE 64

When Rudolf Emil Kalman, co-inventor of the Kalman filter so important in trajectory estimation, accepted the Kyoto prize in 1985, he shared his perspective about data in his acceptance speech. If data were exact and complete, he said, then only one minimal, or simple, hypothesis could explain their cause. He called this the "Uniqueness Principle" of minimal modeling, and it is an idealization. Kalman went on to say, "uncertain data cannot provide exact models" and he cautioned against allowing prejudice to influence the scientific process of deducing a unique model from uncertain data, highlighting Bayesian processes as an example of prejudiced inference. You see, in statistics, Bayesian formulation requires a prior belief to be conditioned by evidence. Kalman, and I for that matter, argue that in reality it is unlikely that the traits ascribed to this prior belief are real or even knowable. Therefore, the conclusion of any Bayesian process is correct by luck or flawed because the result is forcefully prejudiced by the inferer's prior belief.

In deductive reasoning, one derives b from a, where b follows logically from a. Let's assume that a are the data or evidence and b is the cause or model. Methods such as maximum likelihood estimation always deduce a unique model given the data. But as Kalman stated, we cannot conclude an exact model given uncertain data, unless we apply some measure of prejudice to remove this intrinsic uncertainty. Alternatively, inductive reasoning allows us to infer b from a, but there is no requirement or guarantee that b follows logically from a. Lastly, abductive reasoning reverses this by allowing us to infer a as an explanation of b without guarantees of its truth or even uniqueness. This is why I'm a fan of abduction. It allows me to let go of prejudice and sculpt my way to what seems true by forcing me to subject all of my prejudices to evidence and making me reject those that fail to explain it. With abductive reasoning, I can have multiple hypotheses co-existing as long as they can explain the evidence, like in our Abraham Lincoln example. Now, if you were forced to choose one of your surviving hypotheses, there is what is known as Occam's razor. The razor is meant to figuratively cut away all but the simplest of explanations to the evidence. This is attributed to an English Franciscan, William of Ockham, who favored simple explanations over complicated ones. However, applying Occam's razor is also prejudiced because the evidence hasn't discarded your other choices, even if they're less simple.

There are only two ways to be prejudice-free, either by making absolutely no assumptions or by making every possible assumption. Making all possible assumptions has been my approach to knowledge sculpting, using abductive reasoning, freeing the truth residing within the original block of ignorance. The data guide my chisel and my goal is to remove all the ignorance possible, but knowing that I'll never be free of it entirely because there will always be uncertainty. To become a master knowledge sculptor should be the path of every data renaisscientist. ★

LOOKING BACK

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN

1921

1 **Feb. 21** Lt. W.D. Coney, flying a de Havilland DH-4B, takes off from Rockwell Field in San Diego to attempt the first one-day transcontinental solo flight. He sets the record 22 hours, 27 minutes later when he arrives in Jacksonville, Florida, after refueling in Bronte, Texas. Eugene M. Emme, ed., **Aeronautics and Astronautics, 1915-60**, p. 13; **Flight**, April 14, 1921, p. 256.

2 **Feb. 22-23** Pilots of four airmail planes set out to prove the mail can be flown coast to coast across the United States in record time by flying day and night by relay. One pilot crashes his plane and dies. Inclement weather stops the flights of two others. The fourth flight makes it from San Francisco to New York in 33 hours, 20 minutes. It would usually take the mail 4.5 days by train and three days by air/rail (flown by day and shipped by train at night) to make it across the country. F.R. van der Linden, **airandspace.si.edu**

During February 1921
An early air ambulance, a modified Vickers Vimy, is introduced. It has a large red cross painted on its fuselage and is powered by two Napiers engines. It can remain aloft for five hours and carry a pilot, mechanic, doctor, nurse, four stretchers and medical supplies. The plane is built at the request of the British Air Ministry for use by the Royal Air Force in operations in Mesopotamia. **Flight**, March 17, 1921, pp. 187-188.

1946

3 **Feb. 3** A TWA Lockheed Constellation sets a commercial speed record of 7 hours, 27 minutes, 48 seconds, while flying from Los Angeles to New York. It is the first time a plane has flown this fast with a large passenger load. The plane carries 45 passengers and a crew of seven and has a gross weight of 40,700 kilograms. **American Aviation**, Feb. 15, 1946, p. 16.

Feb. 4 Pan American Airways opens its first scheduled passenger-carrying trans-Atlantic service with a Lockheed Constellation, flying from La Guardia Airport in New York, to Hurn in Hampshire, England, via Newfoundland and Ireland in a flight time of 14 hours, nine minutes. F.K. Mason and M. Windrow, **Know Aviation**, p. 52.

4 **Feb. 28** The Republic XP-84 Thunderjet makes its first flight from Muroc Dry Lake in California. The XP-84 is a straight-winged fighter-bomber equipped with a General Electric J35 turbojet engine that gives it a top speed of 939 kph (584 mph). Gordon Swanborough and Peter Bowers, **United States Military Aircraft Since 1909**, p. 462.

1971

Feb. 2-4 Natosat-2, a military communications satellite, is launched on a thrust-augmented Thor-Delta rocket by NATO and NASA for the U.S. Air Force from Cape Canaveral in Florida. NASA, **Astronautics and Aeronautics, 1971**, pp. 36-37.

Feb. 4. A Lockheed P-3 Orion, an anti-submarine and maritime surveillance aircraft, flies to a world altitude record 13,686 meters, surpassing the record of 12,900 m set by a Soviet Union Ilyushin Il-18 in June 1969. **Air Force Magazine**, April 1971, p. 15.

Feb. 4 Britain's Rolls-Royce Ltd. Co. is placed into receivership, primarily because of steep developmental costs for its RB211 high-bypass turbofan engine, intended for Lockheed's L-1011 Tristar wide-body airliner. Subsequently, the British government nationalizes the company to maintain production. Rolls-Royce becomes a multinational company and the world's second largest manufacturer of aircraft engines after General Electric. NASA, **Astronautics and Aeronautics, 1971**, p. 38.

5 **Feb. 9** The Apollo 14 command module Kitty Hawk, with astronauts Alan Shepard, Ed Mitchell and Stuart Roosa on board, splashes down in the South Pacific after a nine-day mission to the moon in which Shepard and Mitchell explored the Fra Mauro region. NASA, **Astronautics and Aeronautics, 1971**, p. 42.

6 **Feb. 16** Japan's second satellite, Tansei, is launched from the Kagoshima Space Center at Uchinoura by a four-stage solid-propellant Mu-4S rocket. The 63-kilogram satellite is to perform a verification of the Mu-4S vehicle and conduct research on the space environment and satellite performance. **Washington Star**, Feb. 16, 1971, p A7.

Feb. 22 President Nixon accepts the resignation of Apollo 11 astronaut Michael Collins as the assistant secretary of state for public affairs so he can become the director of the Smithsonian Institution's National Air and Space Museum. NASA, **Astronautics and Aeronautics, 1971**, p. 52.

7 **Feb. 22** Boeing begins six weeks of acceptance testing on the final flight model of the Lunar Roving Vehicle before its April 1 delivery to NASA. The LRV is designed to transport two astronauts on three rides over the lunar surface during the Apollo 15 mission in July. **NASA Release 71-25**.

1996

Feb. 9 Adolf Galland, a German World War II ace with 104 victories to his credit, dies at age 83. Adolf Hitler promoted him to major general and placed him in charge of the Luftwaffe's fighter operations. **Aviation Week**, Feb. 19, 1996, p. 17; **Aeroplane Monthly**, May 1996, p. 73.

8 **Feb. 17** The Near Earth Asteroid Rendezvous, or NEAR, spacecraft is launched by a Delta II from the Kennedy Space Center in Florida toward the asteroid Eros. This will be the first mission to rendezvous with Eros (at right in photo by NEAR camera). **Aviation Week**, Feb. 12, 1996, pp. 48-49.

Feb. 23 The space shuttle Columbia, STS-75 mission, lifts off and, on Feb. 26 the crew attempts to deploy a tethered satellite, TSS-1R. The first attempt was made on STS-46 in 1992, but the tether jammed. On STS-75, the tether was nearly fully deployed when it snapped, ending experiments prematurely. NASA, **STS-75 Mission Report**; **New York Times**, June 5, 1996.

Feb. 24 A Cuban Air Force Mig-29UB intercepts three Cessna 337 Skymasters flying just outside of Cuban air space near Havana, downing two and killing all aboard. The third Cessna escapes. The Skymasters were flown by the Cuban exile group Brothers to the Rescue. Miami Herald, Feb. 25, 1996, p.1.

Feb. 29 In Canada, WestJet, a new low-cost domestic airline, opens its first service flying from Vancouver to Calgary and Edmonton. The airline operates a small fleet of three leased Boeing 737-200s. By the end of the year, WestJet will fly 760,000 passengers and make a small profit. R.E.G. Davies, **Airlines of the Jet Age**, p. 308.

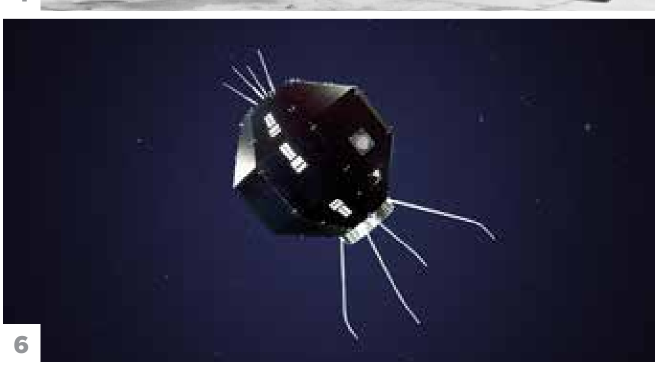

1

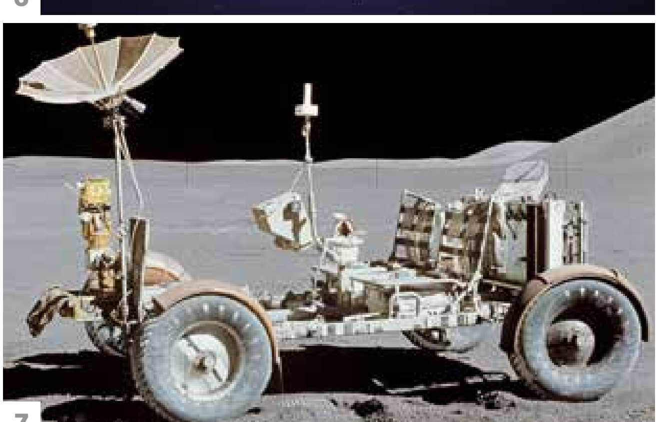
2


3

4


5


6


7


8

1921

During March Russian chemical engineer Nikolai Ivanovich Tikhomirov begins his research into the development of smokeless powder solid-fuel rockets for the Revolutionary Military Council. He begins work in Moscow but moves his lab to Leningrad and it becomes the basis for the Gas Dynamic Laboratory, where research is performed on liquid-fuel rocket engines. Frederick C. Durant, III and George S. James, eds., **First Steps Toward Space**, p. 91.

1946

March 8 The first commercial helicopter certificate is granted to a Bell Model 47 by the Civil Aviation Authority. Alain Pelletier, Bell Aircraft Since 1935, p. 65.

March 8 British aviation pioneer Frederick William Lanchester dies in Birmingham, England, at age 77. In 1894 he presented a paper before the Physical Society that is considered part of the basis of modern lift and drag theories. Lanchester was a member of the British government's Advisory Committee for Aeronautics from 1909 to 1920 and the only member of the Royal Aeronautical Society to win its bronze, silver and gold medals. **Flight**, March 14, 1946, p. 266.

March 10 The prototype of the Avro Tudor II makes its first test flight near Manchester, England. Like the Tudor I, the plane has a gross weight of 35,000 kilograms and is powered by four Rolls-Royce Merlin engines; but this model is 6 meters longer and has a larger diameter to accommodate more seats and bunks for longer routes. Seventy-nine of these craft are ordered for the Ministry of Civil Aviation. **The Aeroplane**, March 15, 1946, p. 324.

1 **March 19** Princess Elizabeth launches the HMS Eagle, the latest and largest of Britain's aircraft carriers, at Belfast. The Eagle carries a crew of 2,000. **The Aeroplane**, March 29, 1946, p. 368.

1971

2 **March 1** NASA announces the selection of its Mississippi Test Facility near New Orleans, now known as the Stennis Space Center, as a site for the sea-level testing of the space shuttle rocket engines. It plans to conduct about 1,200 developmental and acceptance tests there between 1973 and 1979. Testing at simulated altitude conditions will be at the Air Force's Arnold Engineering Development Center at Tullahoma, Tennessee. The Space Shuttle Main Engines will be reusable and powered by liquid hydrogen and liquid oxygen. **NASA Release 71-30**.

March 3 The People's Republic of China launches its second artificial satellite, known in the West as the Chicom 2, from Shuangch'eng. The country's first satellite, known as China 1, or Mao 1, was launched in April 1970 with its Long March vehicle and made China the fifth nation to launch a satellite. The second satellite, which China calls the ShiJian, weighs 221 kilograms and is a scientific satellite equipped with a magnetometer and cosmic-ray and X-ray detectors. **New York Times**, March 4, 1971, p. 1.

March 5 A cold-cathode ion gauge left on the moon by the Apollo 14 astronauts has registered the first confirmed evidence of a gas escaping from the lunar surface, according to an announcement made at NASA's Marshall Space Flight Center by Gary Latham, the Apollo program's chief seismic investigator. **Washington Post**, March 6, 1971, p. A1.

3 **March 9** NASA's supercritical wing is flown from the Flight Research Center at Edwards Air Force Base in California on a TF-8A jet aircraft, a modified Vought F-8 Crusader, and is piloted by NASA test pilot Thomas McMurtry. The new airfoil is designed to reduce buffeting at subsonic speeds and increase aircraft performance. NASA, **Astronautics and Aeronautics, 1971**, pp. 65-66.

March 11 The Goddard Memorial Trophy for 1971 is presented by Esther Goddard, the widow of the U.S. rocket pioneer, to James Webb, NASA administrator from 1961 to 1968, at the 14th annual Goddard Memorial Dinner in Washington, D.C. The Goddard Trophy is given to Webb for "unprecedented accomplishments" in spaceflight, including his management of the Apollo program leading to manned lunar landings. **Washington Star**, March 13, 1971, p. C1.

March 13-17 Explorer 43, also called the Interplanetary Monitoring Platform, is launched by NASA on a three-stage thrust-augmented Thor-Delta. The satellite's primary objective is to investigate the nature of the interplanetary medium and interplanetary magnetospheric interaction during a period of decreasing solar activity. This is the first in a series of second-generation spacecraft to study solar-lunar-terrestrial relationships **NASA Release 71-35**.

March 17 For the first time, two missiles are used in a Safeguard test when two Sprint missiles intercept an intercontinental ballistic missile nosecone over the Pacific Ocean. The target was launched from Vandenberg Air Force Base in California over a 6,700-kilometer distance. NASA, **Astronautics and Aeronautics, 1971**, pp. 77-78.

March 28 Sherman Fairchild, the founder and board chairman of Fairchild Hiller Corp., dies. Fairchild invented the first aerial camera and had been honored in 1970 for 50 years of work in aviation. He founded 70 companies, including Fairchild Aircraft and Fairchild Instrument and Camera Corp. The Fairchild Corp. developed the Fairchild Lunar Mapping Camera used in the Apollo program. **New York Times**, March 29, 1971, p. 53.

1996

March 5 The government of Belarus nationalizes the Belarus directorate of the former Soviet Union airline Aeroflot, thus forming Belavia. R.E.G. Davies, **Airlines of the Jet Age**, p.151.

4 **March 15** One of the oldest names in aircraft manufacturing, Fokker, declares bankruptcy and goes out of business. Formed by famed Dutch pilot Anthony Fokker in 1912 while a student in Germany, Fokker became one of the most significant builders of German fighter aircraft during World War I, including the Fokker Eindecker, Dr.1 Triplane and the D.VII. Fokker smuggled his company across the border into the Netherlands where he reestablished his factory to make fighters and bombers, primarily for the Dutch military. **Flight International**, March 26, 1996, p. 5.

5 **March 21** NASA begins its joint experimental supersonic civil airliner research program with Russian design bureau Tupolev. The program will use a reconditioned Tu-144 supersonic transport to gather data during a series of test flights. The idea of a joint program originated with Tupolev to support NASA High-Speed Research Program. Over the course of the next two years, 27 research flights are flown with the modified Tu-144LL, generating significant data on supersonic flight. **www.nasa.gov**

6 **March 22** Biochemist Shannon Lucid, who joined the astronaut corps in 1979 and a veteran of four space shuttle flights, is launched on STS-76, which docks with the Mir Russian space station. She remains aboard Mir until Sept. 26 as board engineer 2, thus becoming the first American woman to work on a Russian space station. **Aviation Week**, March 18, 1996, pp. 60-61 and April 1, 1996, pp. 24-25.

March 29 The Lockheed Martin RQ-3 DarkStar reconnaissance drone is flown for the first time, at Edwards Air Force Base in California. **Aviation Week**, April 8, 1996, pp. 20-22.

COMPILED BY FRANK H. WINTER and ROBERT VAN DER LINDEN


1

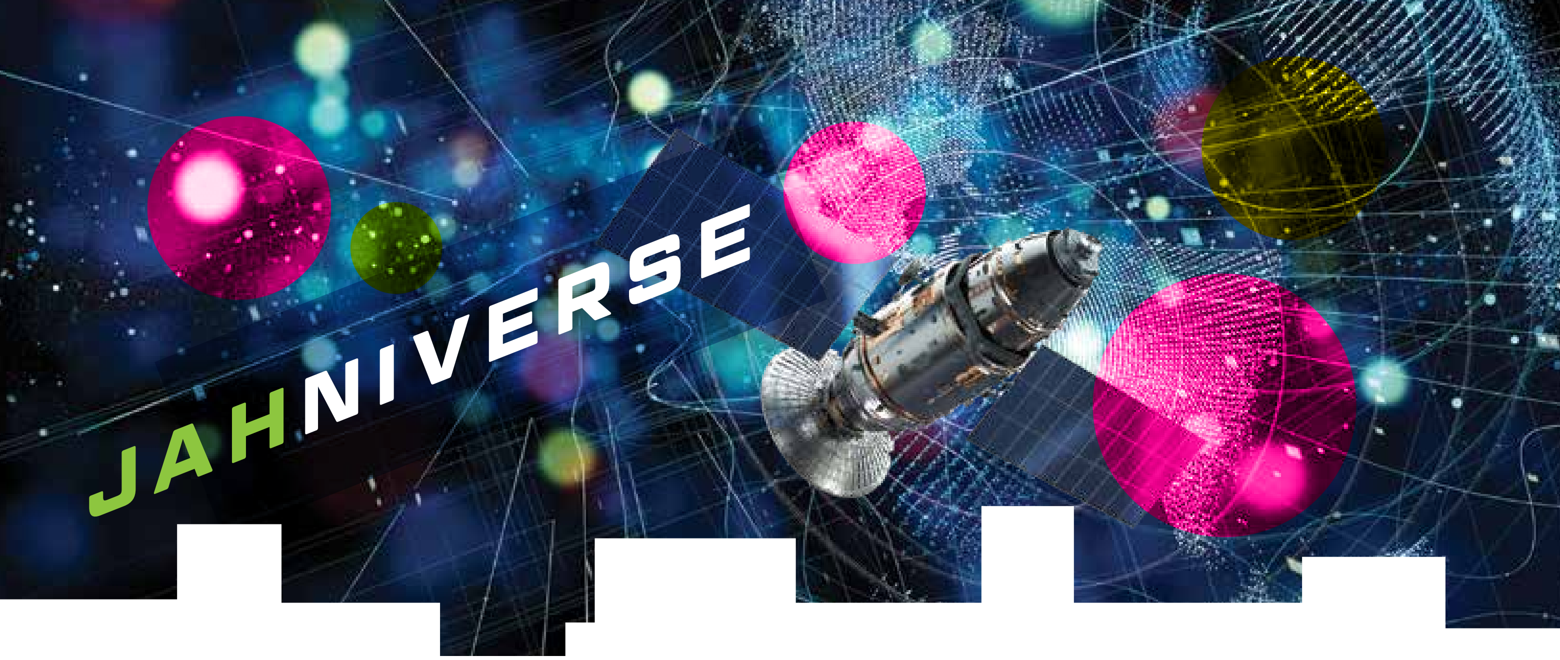

2


3


4


5


6



Data renaisscientists, the modern day knowledge sculptors

BY MORIBA JAH

The genius of Italian sculptors was not in carving the statues but in removing the portions of marble that trapped them, to set them free, as Michelangelo himself is said to have described it. As an astronautical data scientist, I too am a sculptor except that my statues are freed bodies of knowledge, my block of enslaving marble is ignorance, and my tools to chip away at the ignorance are data. In an ideal world, I would have exact information so as to remove all ignorance and what would remain is truth and knowledge, free and exposed for all to see. However, what actually remains is not complete knowledge but rather partial knowledge because complete knowledge is so cloaked in the data and model's intrinsic uncertainty.

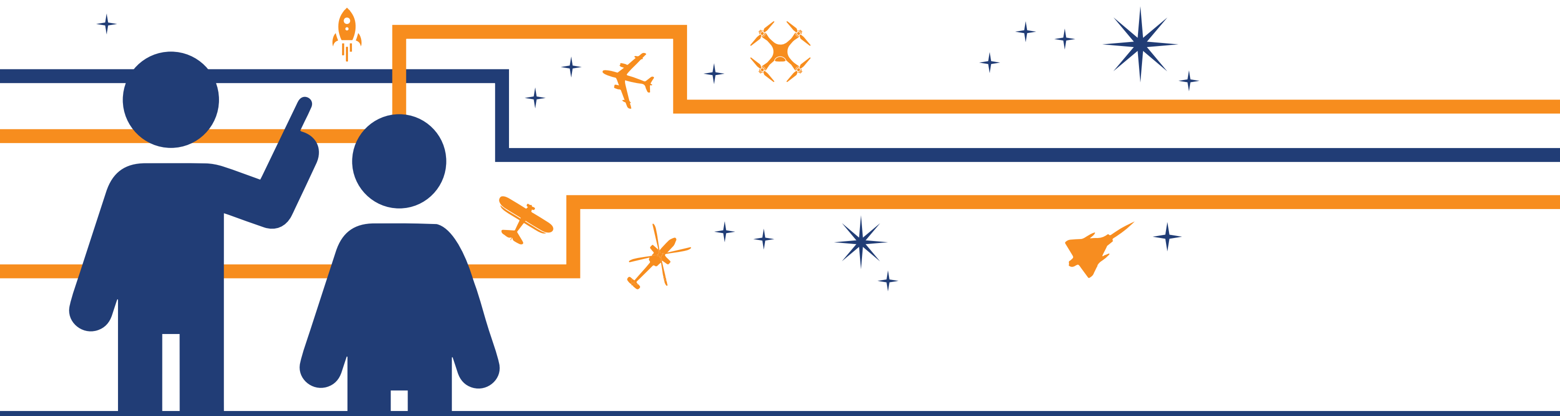
In order to sculpt these knowledge statues, I make use of abductive reasoning. Much like a refrigerator indirectly cools by incrementally removing heat over time, I seek to learn by incrementally removing ignorance over data. If I were to ask you to choose where Abraham Lincoln was born, you may not actually know. However, if along with the question I provide several hypotheses, such as Beijing, China; Dallas, Texas; Hodgenville, Kentucky; and Lexington, Kentucky, you'd quickly remove the obviously wrong answers and be left with Hodgenville and Lexington. You might want to ask more questions at this point that could remove the next wrong answer, but this is an example of you using data for its power to highlight the wrong answer. Any surviving hypothesis must explain the evidence. Otherwise, it fails the test.

In my professional experience, data tend to be much more powerful in telling you what something is not rather than what it is. Often times, people ask me how I knew I wanted to become an astrodynamicist, and I tell them that I tried a list of things, determined and discarded what I disliked, and astrodynamics remained on my list. I've always enjoyed the musical talent of Michael Jackson, and scrolling through some of his interviews online I came across one where he was asked what he hears when he listens to any given song, and he answered, "I hear what's missing." From my artistic or even metaphysical perspective, he created his masterpiece songs by removing silence from them. It's like the songs already existed but were trapped by silence and as he removed the silence, he freed them, like a sculptor.

CONTINUED ON PAGE 59

Moriba Jah is an astrodynamicist, space environmentalist and associate professor of aerospace engineering and engineering mechanics at the University of Texas at Austin. He holds the Mrs. Pearlie Dashiell Henderson Centennial Fellowship in Engineering and is an AIAA fellow. He also hosts the monthly webcast "Moriba's Vox Populi" on SpaceWatch.global.

AIAA ENGAGE



Make Lasting Connections Across the Aerospace Industry with Mentor Match

PARTICIPATE IN THE AIAA MENTOR MATCH PROGRAM

Now more than ever, personal connections are of the upmost importance, especially in the aerospace industry. In a world where we aren't able to meet in person as much as we would like to, Mentor Match helps you easily find, connect, and share experiences with others in your field. Mentor Match is user driven, allowing registered Mentees to search among registered Mentors. Likewise, registered Mentors can search for and identify potential Mentees. Whether you're seeking advice on which school to attend, looking to give back and share your knowledge, or anything in between, we encourage you to participate in the AIAA Mentor Match Program.

YOU CAN GET STARTED IN FOUR SIMPLE STEPS.

1. COMPLETE YOUR PROFILE
2. ENROLL IN MENTOR MATCH
3. SEARCH FOR A MATCH
4. CONNECT

IT'S THAT SIMPLE.

Sign Up at
engage.aiaa.org/mentor-match/getting-started

AIAA
SHAPING THE FUTURE OF AEROSPACE