2021 Q3/4 | Volume 5 | Issue 18

IQ INNOVATION QUARTERLY

INNOVATION. INSIGHT. INSIDE AEROSPACE.

Uncrewed but Not Alone

Meet the team who empowers the Loyal Wingman to fly on its own

Excellence, Technically Speaking
New honorees in the Boeing Technical Fellowship

The Eagle II Has Launched
F-15EX turns “how” into “wow”

Moon Shop
Resources are just a rocket ride away

PLUS: Sound Check
How the Apache team quiets a 15,000-pound attack helicopter

OUT FRONT IN THE OUTBACK
Flight test engineer Taylah Griffin with the Loyal Wingman on the Woomera Test Range in South Australia.

A publication of The Boeing Company

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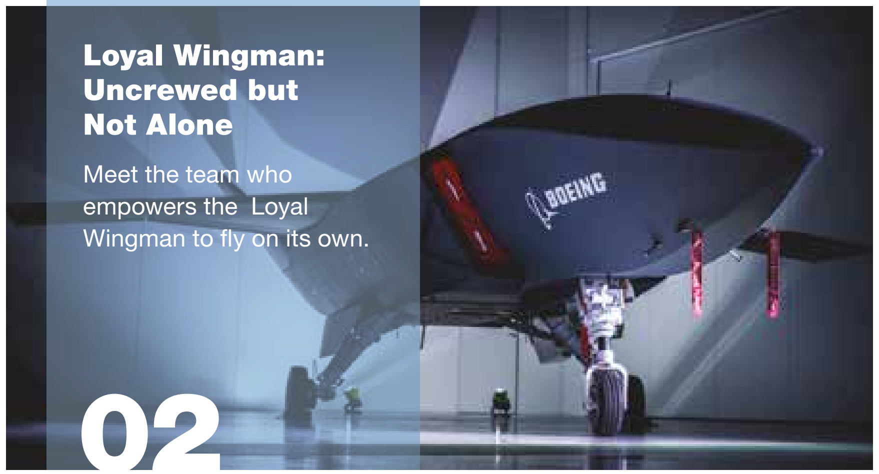


Recovery of Stability

Whether walking down the street or flying thousands of feet in the air, stability is an innate human desire. And our collective stability has been shaken recently, for sure. To thrive, we need to feel secure, solid, safe.

But on the horizon, recovery is ahead. That sense of stability appears on every page of this edition of Innovation Quarterly.

Our engineering teams leverage their expertise to help defend and protect the stability of the very world in which we live. A first-of-its-kind uncrewed aircraft known as Loyal Wingman is making aerospace history in the middle of the Outback. It will complement and extend air combat and other missions.

And the latest and greatest in the history of a legendary fighter, the F-15EX Eagle II is a paragon of digital design. The team follows a digital thread to more efficiently create an even better jet.

Humankind's journeys to the moon could be key to improving life on Earth. By exploring and utilizing what's out there, life gets better down here.

And life is better on the factory floor where the Apache helicopter is made. Thanks to the ingenuity of the team, hearing safety is greatly improved by an invention originally crafted from repurposed materials found on-site.

We will be tested. Our footing may waver. But together, we stand strong. **IQ**

Lynne

Lynne Hopper
Vice President,
Engineering Strategy & Operations

UNCREWED but Not Alone

Meet the team who empowers the Loyal Wingman to fly on its own

OUT OF THE SHADOWS
The Loyal Wingman posed for its unveiling.
PHOTO: WOODROW WILSON /BOEING

A few miles away from the Woomera Test Range runway, at the flight-test ground station in the middle of the Outback in South Australia, Taylah Griffin is as nervous as on the first day of school. She can only see a blip moving on the display monitors as an uncrewed aircraft known as the Loyal Wingman flies overhead toward history. But she can hear the familiar roar of a jet engine.

Griffin is part of the flight-test crew for the Boeing Airpower Teaming System. And yes, the uncrewed aircraft very much needs a crew on the ground.

Designed to fly autonomously alongside crewed aircraft, including fighter jets, the first-of-its-kind system deploys fighterlike abilities and performs a range of missions.

READY FOR ACTION
The first Loyal Wingman aircraft being prepped for flight.
PHOTO: TIM STANDING/BOEING

Designed to fly autonomously alongside crewed aircraft, including fighter jets, the first-of-its-kind system deploys fighterlike abilities and performs a range of missions. Named for its ability to support other aircraft as a faithful ally, the Loyal Wingman plugs the expertise and collective effort of the entire Boeing Australia network of research and development hubs into the manufacturing site in Melbourne and advanced analysis capabilities in Brisbane.

Together they've worked tirelessly alongside the Royal Australian Air Force and an Australian industry team to achieve both Australian and Boeing firsts.

FIRST FLIGHT OF THE FUTURE
The Loyal Wingman soars over South Australia during its first voyage in February 2021. The project used a digital twin to flight-test missions and advanced from design to flight in three years.
PHOTO: DEPARTMENT OF DEFENCE/ COMMONWEALTH OF AUSTRALIA

MEET THE AUTHORS

Brad Thompson, Ari Pipilikas and Taylah Griffin are among the team of proud Australian innovators and engineers. They reveal the inside story of an aerospace pioneer and the digital thread that binds simulation, flight data and digital design to create this spiral-development agile program.

BRAD THOMPSON

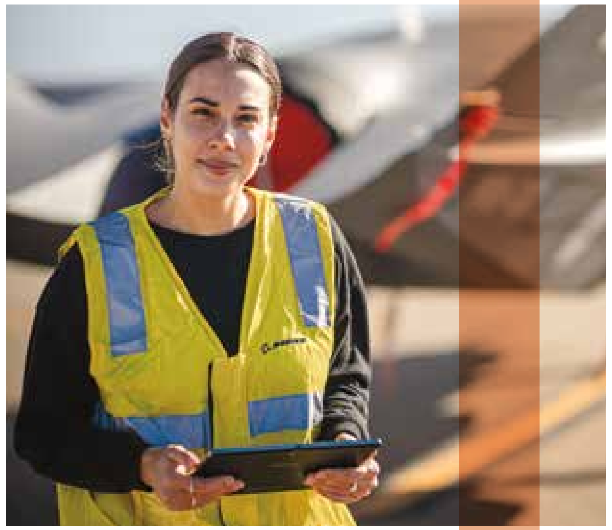
As Phantom Works International's chief capability architect, Thompson is responsible for operationalizing the aircraft system to meet the mission needs of global customers.

PHOTO: BRUCE GIBSON/BOEING

ARI PIPILIKAS

As air vehicle segment leader, Pipilikas is responsible for the major structural design engineering components for the aircraft at Boeing Aerostructures Australia.

PHOTO: WOODROW WILSON/BOEING



TAYLAH GRIFFIN

A flight test engineer and test conductor in training, Griffin monitors aircraft systems and performance during the flight tests to ensure everything is within set limits and runs as expected.

PHOTO: TIM STANDING/BOEING

FIRST SKETCH: Drawings to design to defence

BY BRAD THOMPSON, PHANTOM WORKS INTERNATIONAL

The exact genesis of the concept currently known as the Airpower Teaming System is impossible to pin down, with many intelligent, thoughtful contributions from a range of people. While there were many inputs, the guiding principles were the development of an Autonomous Systems strategy and operational analysis we conducted that identified a number of serious capability challenges faced by our customers.

We rapidly translated this into a minimum set of key performance parameters, which led us to develop pre-conceptual designs. The first of these exists as a sketch in my notebook and a basic sizing spreadsheet, beginning the accelerated journey to first flight of the Loyal Wingman.

With a preliminary set of requirements, sketch and spreadsheet in hand, we asked the engineering team at Boeing Aerostructures Australia to kick off conceptual design.

I distinctly remember the first meeting was equal parts excitement and nerves.

We started as a quite small team of highly motivated personnel with a breadth of experience from across the Boeing enterprise. We shared a genuine belief in the concept and a "why not" attitude.

FIRST FUSELAGE

The first Loyal Wingman aircraft starts to take shape with the major fuselage structural assembly.

PHOTO: BARON WALTON/BOEING

AIR SHOW AND TELL
The first Loyal Wingman representative model appeared at the 2019 Australian International Airshow.

PHOTO: BOEING

Of course, without customer engagement, an idea stays just that — an idea. We worked with some visionary members of the Royal Australian Air Force to transform our conceptual design into an actionable development program.

I'm proud of how we've been able to leverage our emerging technologies and processes to achieve rapid capability development across software and vehicle design.

While flying always generates public interest because it's tangible, we've spent a great deal of time in the digital landscape progressing our mission system development. This included working with multiple suppliers to develop different payloads and semi-autonomous behaviours and refining how the crewed-uncrewed teaming will operate in theatre.

For me, this spirit of collaboration is the key to a successful capability with the Airpower Teaming System. It will enable us to accelerate our product life-cycle development from design to production and continue to rapidly iterate our designs and mission behaviours that are crucial to supporting our customer in the future battlespace.

For me, this spirit of collaboration is the key to a successful capability with the Airpower Teaming System.

BLANK CANVAS: Digital design, 3D printing, sustainable materials

BY ARI PIPILIKAS, BOEING AEROSTRUCTURES AUSTRALIA

Being part of the first military combat aircraft in half a century to be developed from a clean sheet is what most Australian aerospace engineers dream about. It's allowed my airframe teammates to consider the art of the possible when designing all aspects of the air vehicle.

We're a mixed group of engineers from a range of disciplines — from early-career graduates with energetic, fresh ideas to seasoned aerospace veterans with international experience on aircraft programs as well as from aircraft and systems designed and built at Boeing heritage companies at Fishermans Bend in Melbourne. A few of the team also love to build hobby craft airplane models on the weekend, and we've often joked around the office that we've gained inspiration from that as well in our designs.

What's been really exciting is the chance to apply technologies in new ways.

Our Boeing Melbourne team has focused on design and assembly cost efficiencies as well as sustainable aerospace as part of our design process with regard to how we've used composites and other materials. And our use of digital engineering enabled testing of our work before we ever made our first real part.

Because some of those parts are large and complex, we took advantage of the advanced simulation and resin-infusion techniques we learned manufacturing 787 control surface components. It helped reduce consumable waste and introduced new concepts, including how we produce the tools used to make parts as well as the parts themselves. That's something the team is really proud of.

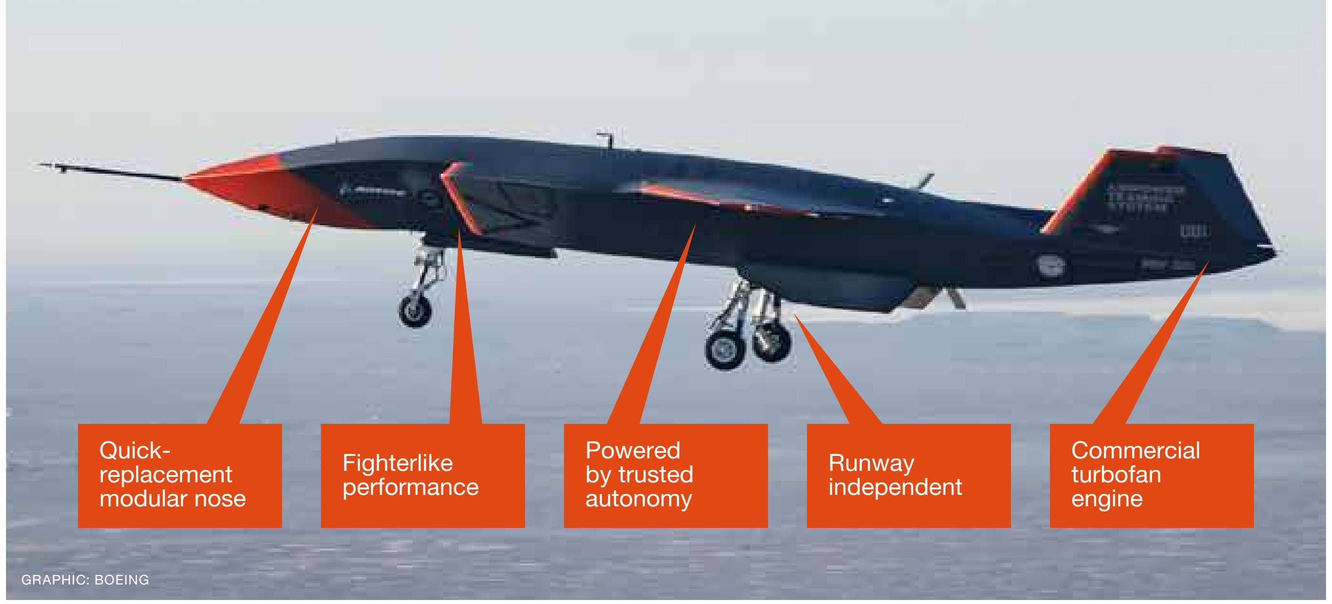
A blank canvas also gave us the freedom to introduce new technologies into our manufacturing process.

We leveraged additive manufacturing to produce more than 30 flyaway parts using various thermoplastic materials. We 3D-printed complex ducting and wiring harness supports on-site at Boeing Aerostructures Australia. Based on this success, we've since grown the capability further, and we'll look to apply it to other aircraft structural designs.

Throughout the next phase of the program, we'll also continue to take the data and analysis from our flight-test program to transform the digital landscape of our design. We're continuing to improve simulations of vehicle systems in the digital environment to advance key structural components and aircraft systems, with the goal of improving the reliability and robustness of our future designs for the platform.

Future-Forward Features

PHOTO: DEPARTMENT OF DEFENCE/COMMONWEALTH OF AUSTRALIA



GRAPHIC: BOEING

PASSING TESTS: Out front in the Outback

BY TAYLAH GRIFFIN, BOEING DEFENCE AUSTRALIA

My work has definitely been the talk of the family barbeques. It's a privileged, rare opportunity to be part of Australian aerospace history. Even if my friends don't really understand the enormity of our work, they all know it's something special and unique.

It's been exciting, nerve-wracking and a lot of hours.

It's not every day you get to start your test career with the first flight of an uncrewed aircraft.

Since earning my aerospace degree in 2018, working at Boeing has afforded me an exponential learning curve — I wouldn't get this opportunity anywhere else. I have to pinch myself that this is my job.

It's a fulfilling experience to be part of bringing a brand-new platform to the world. I have been lucky to be accepted into Boeing's two-year Engineering Career Foundation Program, which will help grow my engineering leadership skills. Joining the program and being involved in the Loyal Wingman flight testing have urged me to become a test conductor on future flight tests.

We're not just about developing teaming in the aircraft. It's also about the people. We've supported each other on a development program that navigated complex engineering and now logistical feats due to the pandemic.

When we were at the Woomera Range Complex for flight testing, I couldn't wait to see how the aircraft performed operationally. First flight had its unique pressures. As test planners, you do everything you can to prepare for a safe, quality flight. But in the case of this aircraft, once you've engaged the systems ready for flight, it's time to focus on data collection and let the aircraft's smarts take over and perform as intended.

Part of my task is to capture the data that feeds back into the digital twin. Brad's team will use the data to model and simulate missions to prepare the vehicle for operational capability. This will then pass through the loop to Ari's team, which will input improvements for the vehicle design.

We're not just about developing teaming in the aircraft. It's also about the people. We've supported each other on a development program that navigated complex engineering and now logistical feats due to the pandemic. The chance to work on this program has meant being away from home for extended periods and completing two-week quarantines. But we've all pulled together, and I'm proud to be part of this group.

Adding to the challenge, we tested in a remote environment with strong winds that cause dirt storms. And when the wind isn't present, it comes with an enormous number of flies. Our testing grounds also offer a fair share of Australian snakes and creepy-crawlies. One afternoon, we were alerted to not go outside the ground facility because a deadly brown snake was having a rest at the door.

But it's most definitely worth it to see the aircraft go farther, go faster and push boundaries.

For me, it's times like this when the enormity of our team's contribution becomes real. **IQ**

The Loyal Wingman program continues to accelerate, including manufacturing, flight tests, payload development and mission planning in the digital environment.

START YOUR ENGINE
The Loyal Wingman during its initial engine test.
PHOTO: BRUCE GIBSON/BOEING

Night Light

MOMENT OF REFLECTION
A 777X basks in the glow of
a Seattle night at Boeing Field.
PHOTO: DAVE SIZER/BOEING

The Eagle II has launched

F-15EX turns 'how' into 'wow'

BY TYRA HOLMES, BOEING DEFENSE, SPACE & SECURITY ENGINEERING

A challenge from the U.S. Air Force: To outpace future threats, take the battle-proven F-15 and make it even better.

DELIVERING TODAY FOR TOMORROW'S MISSIONS
With its large weapons capacity, digital backbone and open architecture, the F-15EX Eagle II will be a key element of the U.S. Air Force's tactical fighter fleet for decades to come.

IMAGE: MARK SIGYARTO/BOEING

Challenge accepted.

Enabled by innovation and forward-thinking processes, Boeing and the U.S. Air Force formed a collaborative effort to deliver the F-15EX Eagle II. The newest version of the legendary fighter incorporates the most advanced systems available, including next-generation design and technology built on a digital thread that will ensure the U.S. Air Force will fly it for decades to come.

Incorporating the latest in software development and Open Mission Systems architecture, the F-15EX is ready today to prosecute the most demanding missions of tomorrow. To get to this point, to support customers' needs, the Boeing team transformed its culture with initiatives such as agile innovative software, open architecture systems and digital engineering.

CLEARED TO CLIMB
Still in its testing colors, the F-15EX Eagle II begins its ascent into a "Viking takeoff" above St. Louis during its February 2021 first flight.

PHOTO: ERIC SHINDELBOWER/BOEING

Agile Software

The U.S. Department of Defense has outlined a National Defense Strategy that delivers capabilities to the warfighter at the "speed of relevance."

Boeing is paving the way, producing the software at a faster pace than ever before.

POISED AND READY
The F-15EX Eagle II incorporates advanced avionics such as an electronic warfare system, an all-glass digital cockpit, the world's fastest mission computer and fly-by-wire flight.

IMAGE: JIM STEITZ/BOEING

Early in 2020, F-15 Mission Systems engineers began the transition to agile software development, including hardware, software integration and test. The process is part of the DevSecOps road map, an engineering practice that unifies software development (Dev), security (Sec) and operations (Ops), allowing Boeing to develop and release capabilities to the customer more efficiently and quickly.

ON POINT
(From left) U.S. Air Force pilots Lt. Col. Chris “Bluce” Wee and Maj. Brett “Spear” Hughes get ready to take off in the F-15EX.
PHOTO: ERIC SHINDELBOWER/BOEING

A main driver in the transition to software development has been collaborating with the Air Force regularly during program increment planning events. The ultimate goal is to align the engineering team around developing the features and capabilities for the F-15EX platform that advance the program solution. The sessions should ultimately:

- **Reduce development time to production —** the average time it takes from when new software features are contracted until they are fully functional capabilities.
- **Increase deployment frequency —** how often a new release can be deployed into the production environment.
- **Fully automate risk characterization —** monitoring and mitigating challenges of software development early and often across the application life cycle.

Using this approach, the Boeing team delivered the F-15EX software in less than half the time of the typical four-year software development cadence.

CLEARED FOR TAKEOFF
Maintainer Matt Zakrzewski clears an F-15EX for takeoff in St. Louis.
PHOTO: BOEING

Open Architecture

A key feature of the F-15EX platform is its ability to rapidly incorporate future technologies. Its open architecture will change the way the Air Force inserts future applications and capabilities and will protect warfighters by keeping them ahead of threats.

The F-15 Mission Systems software developers have created an autonomous test environment and are laying the groundwork for Open Mission Systems (OMS) architecture, which can host DevSecOps containers and orchestration — all in preparation for the future of cloud-based development. These tools also support third-party application integration — a must-have for the modern defense mission.

OMS-compliant technology also provides a standard interface between components that allows participants to develop capabilities using a common open architecture approach. By adopting this philosophy on the F-15EX, Boeing will advance and grow its legacy platform to allow rapid capability of new features in the form of containers and microservices that can be developed and deployed on the fighter jet.

Software containers package software code to allow it to run independently of any infrastructure or, in Boeing's case, any platform. Containerization is a popular concept, gaining wide use in software development. Containers function like a smartphone app for the mission computer, as adapted by the software defense industry.

Boeing has recently demonstrated the ability to deploy the same software container on F-15EX aircraft without any recompilation. The containerized service is the same and agnostic to the platform or mission computer hardware. The container is processed through OMS-compliant messages, a uniform construct employed by the DOD.

OMS architecture enables maximum flexibility, interoperability and connectivity. The F-15 team is employing this process as a catalyst for the culture change and development process improvements required in next-generation software development across Boeing Bombers & Fighters programs.

BRINGIN' THE HEAT
An F-15EX soars above St. Louis Lambert International Airport.
PHOTO: ERIC SHINDELBOWER/BOEING

Digital Engineering

It is critical to continue to support model-based system engineering concepts to complete Boeing's safety-critical functional thread analysis. This allows the enterprise to model all the safety-critical functions of the mission computer and trace them to determine safety impacts as a result of software changes to avionics equipment.

Using this methodology, Boeing engineers can investigate risks electronically, before any physical code changes, and work to understand the challenges that lie ahead and hence develop mitigation plans.

Ultimately, this process lends itself to first-time quality, as explicit documentation traces and tags are added to source code, satisfying new process steps that ensure safety-critical code is not modified without further review.

The Air Force has voiced the urgent need for downloadable program code that functions just as safely and predictably in an aircraft as it does in a remote test environment. F-15 Missions Systems engineers innovate in this space every day. And the next iteration of the digital model could see Boeing engineers enhance the mission systems process for functional modeling.

The teams plan to prototype the interface control documentation for the entire platform, improving the visualization of new avionics hardware onto the aircraft. The tool will house block diagrams to account for the configuration.

This will improve communication about the interfaces, reduce design errors and minimize disconnects across the subsystems. The goal is to have the F-15 mission systems architecture laid out digitally and make a full transition to model-based systems engineering.

Why It Matters

The Air Force laid out its digital acquisition strategy in clear and compelling terms, which emphasized plans designed to disrupt input/output carrier signals of analog thinking. The strategy also explained how the so-called “digital trinity” of agile software, open architecture and digital engineering results in better ways of building systems.

The benefits: faster design, seamless assembly and easier upgrades for air forces of the 21st century.

This enables two acquisition objectives for F-15EX: First, rapid fielding will quickly recapitalize the current F-15C fleet with launch-ready configuration plus rapid production ramp-up. Second, technology insertion means the fleet maintains operational relevance.

DRIVER’S SEAT
The F-15EX’s modern avionics feature a state-of-the-art advanced cockpit system, with an all-glass large area display that gives the warfighter significantly enhanced situational awareness, day and night.

PHOTO: BOEING

The F-15EX's role as a technology demonstration test bed ensures the Air Force can powerfully leverage its unique air vehicle infrastructure. This includes future innovations such as user experiences (UX) to improve and modernize the human-machine interface.

Also, a newly developed large area display (LAD) is part of the Advanced Cockpit System (ACS). These software improvements to the displays and symbols boost the sensor input and display capability previously constrained by the legacy hardware.

The first F-15EX fighter jet was delivered in March 2021, with the second joining it at Eglin Air Force Base, Florida, in April. The aircraft feature fly-by-wire controls, ACS, best-in-class weapons carriage, the world's fastest mission computer, improved radar and advanced electronic warfare protection, and the newest version of the F-15 software operational flight program. Only two months after delivery, the Eagle II demonstrated its proficiency at a major Air Force exercise.

The fighter's next-generation design makes it an ideal fit for the Air Force's vision. For its part, Boeing is looking forward to providing a robust tactical aircraft capable of incorporating the latest advanced battle management systems, sensors and weapons.

Boeing is changing its processes and, more important, changing its culture to become more adaptive and innovative.

This road map of continual development will provide the tools needed to win the future fight. **IQ**

SCAN CAM HERE, BOOST YOUR IQ!

Video: Unveiling the F-15EX Eagle II

IQR

ABOUT THE AUTHOR

Engineer Tyra Holmes is director of F-15 Mission Systems. In this role, she leads the development and implementation of avionics hardware and software across the F-15 program.

PHOTO: BOEING

Engineers at Boeing in Seattle in 1949.

IMAGES COURTESY OF BOEING EXCEPT WHERE NOTED

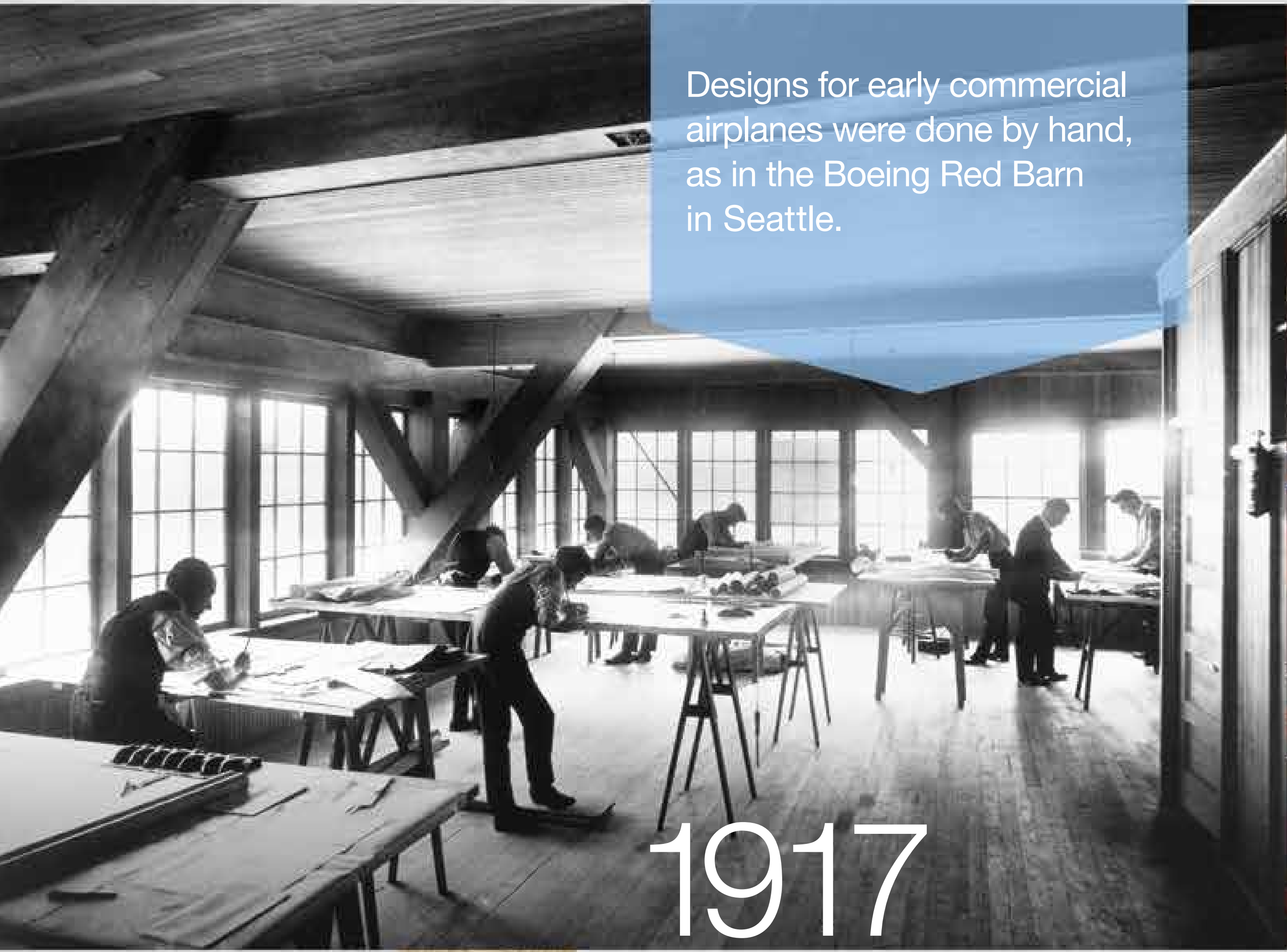
Drawings to digital

PHOTO: GETTY

EVOLUTION OF ENGINEERING: PENCILS WERE STILL A THING JUST 40 YEARS AGO

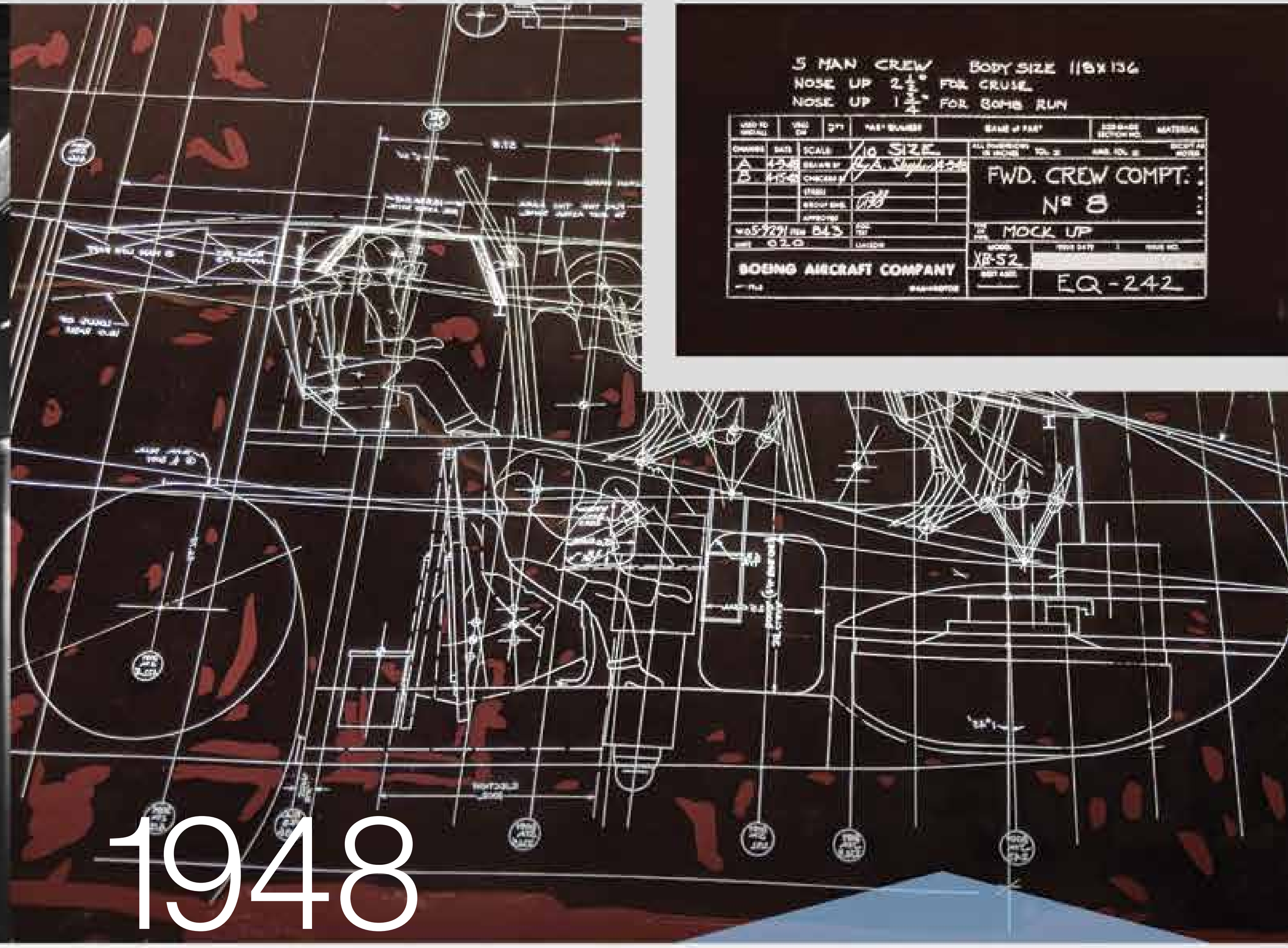
BY LESLIE HAZZARD, BOEING HISTORICAL SERVICES

Before there were wings and wheels, flight decks and fuselages, there was a pencil. In the early days of aerospace, the first step in design was to find something to write with. And that didn't change until relatively recently.



Designs for early commercial airplanes were done by hand, as in the Boeing Red Barn in Seattle.

1917



1948

PENCIL POWER

The media for airplane design remained surprisingly static from the start of the 20th century until the 1980s, when the physical drawings began the shift to digital files.

Pencil or pen and paper were the currency of engineers in the Red Barn, Boeing Airplane Co.'s first building. Standing at large drafting tables to create early flying machines such as the B & W seaplane, designers shared the building with seamstresses who sewed the airplane's wood-and-linen wings.

TRANSITION TIME

Later programs such as the McDonnell Douglas F-15 Eagle and the Boeing XB-52 Stratofortress transitioned to ink on polyester film to illustrate geometry.

INSET: STRATOFORTRESS STATS

Used for the XB-52 prototype, this identification block is for the forward crew compartment.

On the back side of polyester film, red paint was used to block out any pinholes or errors that let light through.

FORM AND FUNCTION

For many decades, drawings for commercial, defense and space products — such as this illustration of the Mercury space capsule — were painstakingly handcrafted by talented drafters and artists.

1953

DUCKS IN A ROW

The design process continued to rely on physical drawings for several more decades, with some hand-drawn lettering and drawings so stylized that teammates could tell which designer had created them. Signed or unsigned, they were often works of art.

At Boeing in Seattle, engineers hold the spline (a flexible curve) in place with weights known as "ducks" because of their shape.

1960s

TOOLS OF THE TRADE

Even in the 1960s on both commercial and defense programs such as the McDonnell F-4 Phantom II fighter jet, drawings were created on vinyl film. A pointed instrument known as a scribe removed material from the film to depict product geometry, and flexible paint was used to erase drawing content for design changes.

The red and gray tools on the right were used for drawings on vinyl film. The ink pens and black electric eraser applied or removed ink on polyester film.

1980s

NO MORE PENCILS

Over the last four decades, electronic technology replaced drawings as the basic means of conveying design. The transformation began with the advent of computer-aided design, or CAD. Related advancements included CATIA, the computer-aided three-dimensional interactive software used to create the 777 widebody airplane — the first all-digital design of a commercial jetliner.

Early computer-aided design steadily began to replace handmade drawings.

Supercomputers generated so much heat while processing data that they required their own temperature-controlled rooms to operate properly.

1990s

MAKE ROOM

The evolution has continued steadily, with a marked transition from early supercomputers that filled a room to modern programs that allow engineers to design airplanes using special software on their laptops.

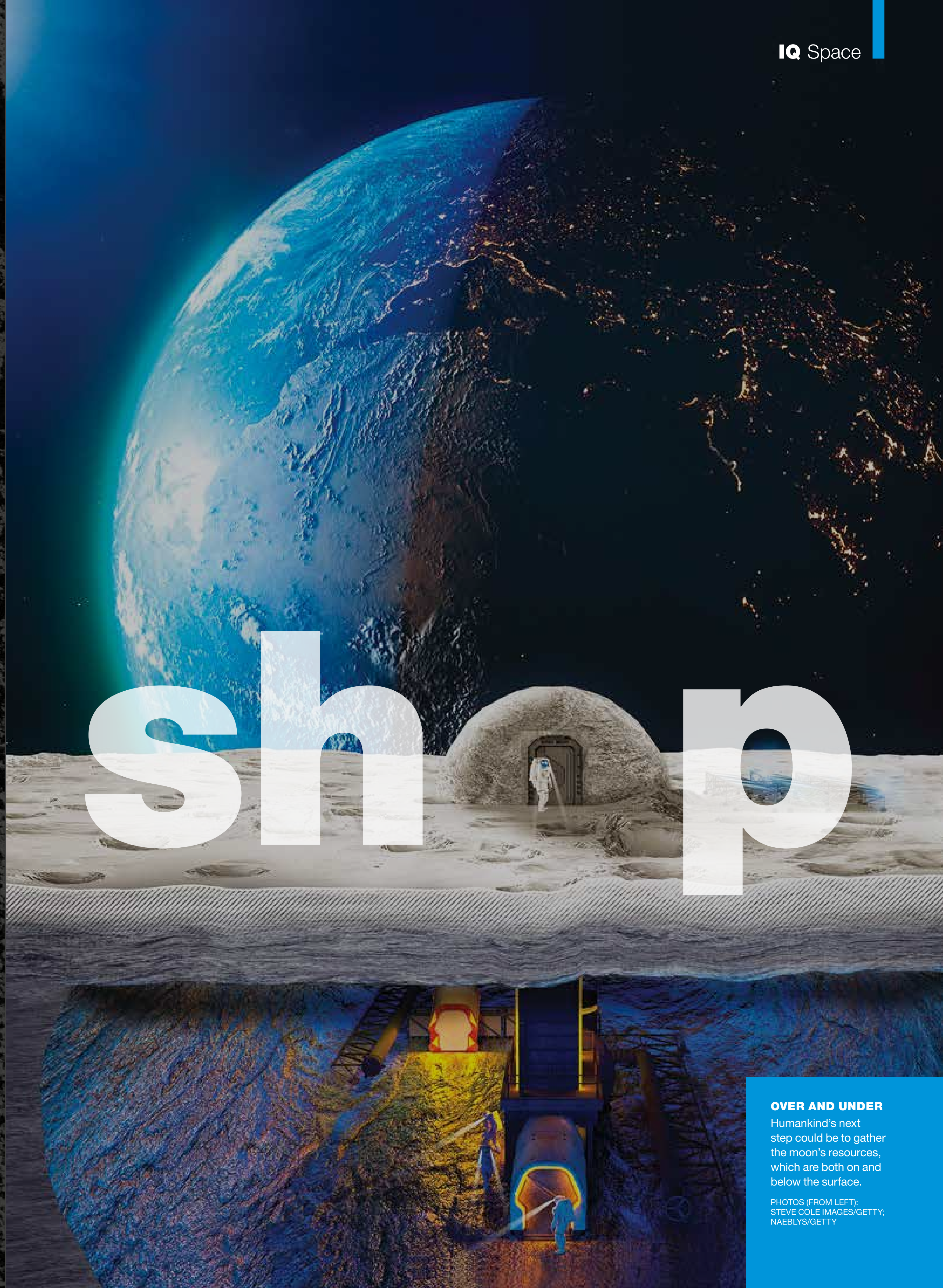
And if you long for the good old days, you'll be pleased to know those laptops often come with what looks a lot like a digital pencil. IQ

We're going back to the moon, maybe with a shopping cart. In December 2020, NASA named 18 astronauts to begin their training for the upcoming return of humans to our closest neighbor in space. The opportunity to return and stay this time is unprecedented. It's a turning point in history as we, a space-faring society, figure out how to lower the cost of exploring the cosmos to enable the current seeds of space commercialization to blossom. By the year 2050, we hope to harness lunar resources to provide rare elements, metals and water.

Moonshop

Lunar commercialization is on the horizon

BY CINDY MAHLER, BOEING RESEARCH & TECHNOLOGY



OVER AND UNDER
Humankind's next step could be to gather the moon's resources, which are both on and below the surface.

PHOTOS (FROM LEFT): STEVE COLE IMAGES/GETTY; NAEBLYS/GETTY

The History

In the past, space commercialization has been limited to satellites in Earth's orbit because they provide value to users on Earth: communication, weather data, navigation, radio, television, remote sensing and more. As for human space exploration, governments have led the effort — putting people in space, building space stations and walking on the moon.

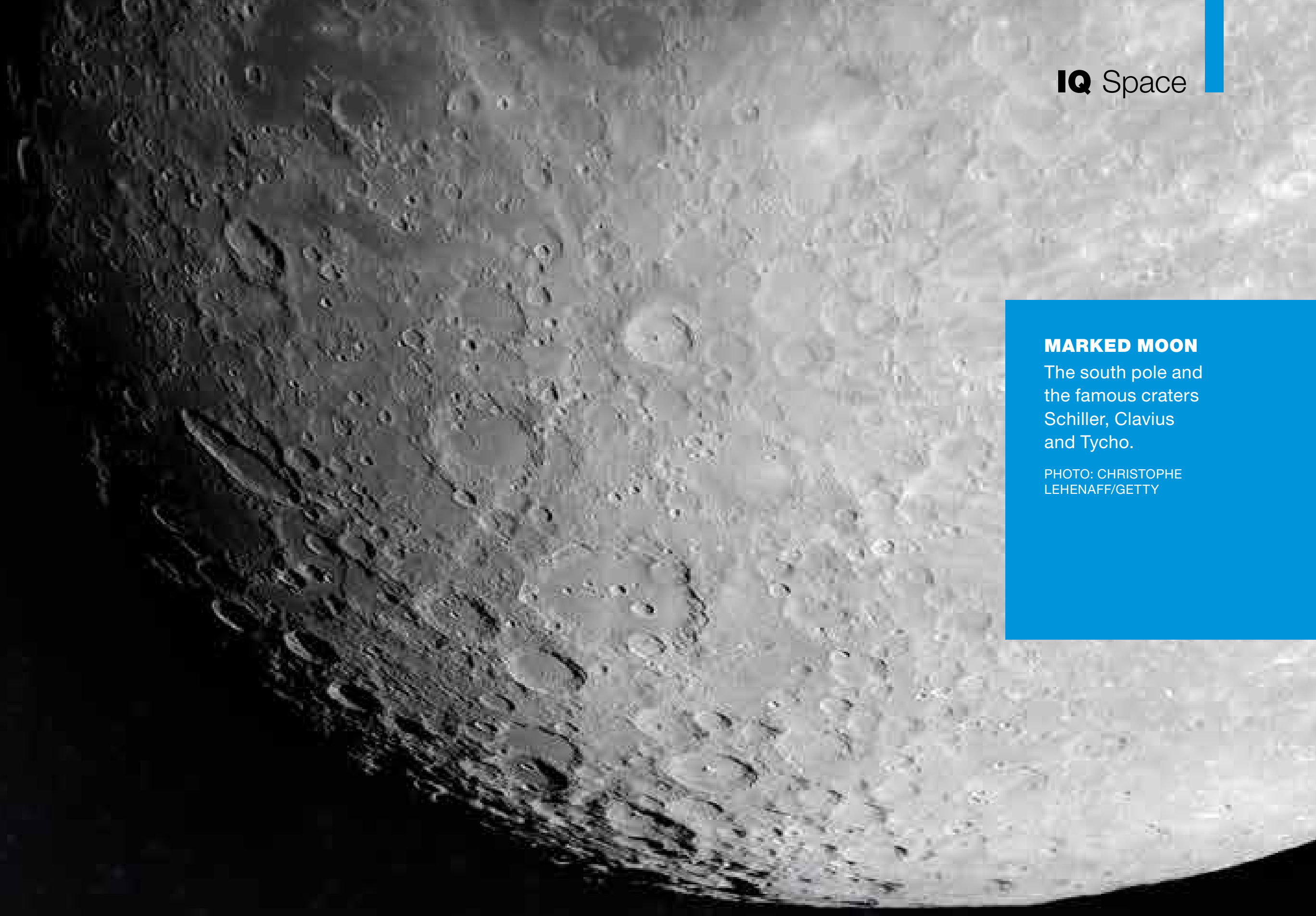
Government space programs provide the opportunity to expand the boundaries of what we know and determine where we drive humanity to explore the unknown, discover new worlds, and push the boundaries of our scientific and technical limits. While we have needed our governments and the political willingness for human space exploration to get to where we are today, now we must answer the fundamental question: What more can we do?

The Journey

Due to the cost of needed infrastructure to survive in the harshness of space, business cases are difficult to close in a time frame that meets investors' desires.

Many space companies are on independent journeys to achieve their vision, which often includes lowering the cost of access. In addition, companies generally divide space into commercial satellite, human exploration, military and other markets. As a result, they miss an opportunity to scale space commercialization by considering the interconnectivity between space markets.

What is missing is an integrated strategy to incrementally build up capabilities and technologies to enable commercialization.

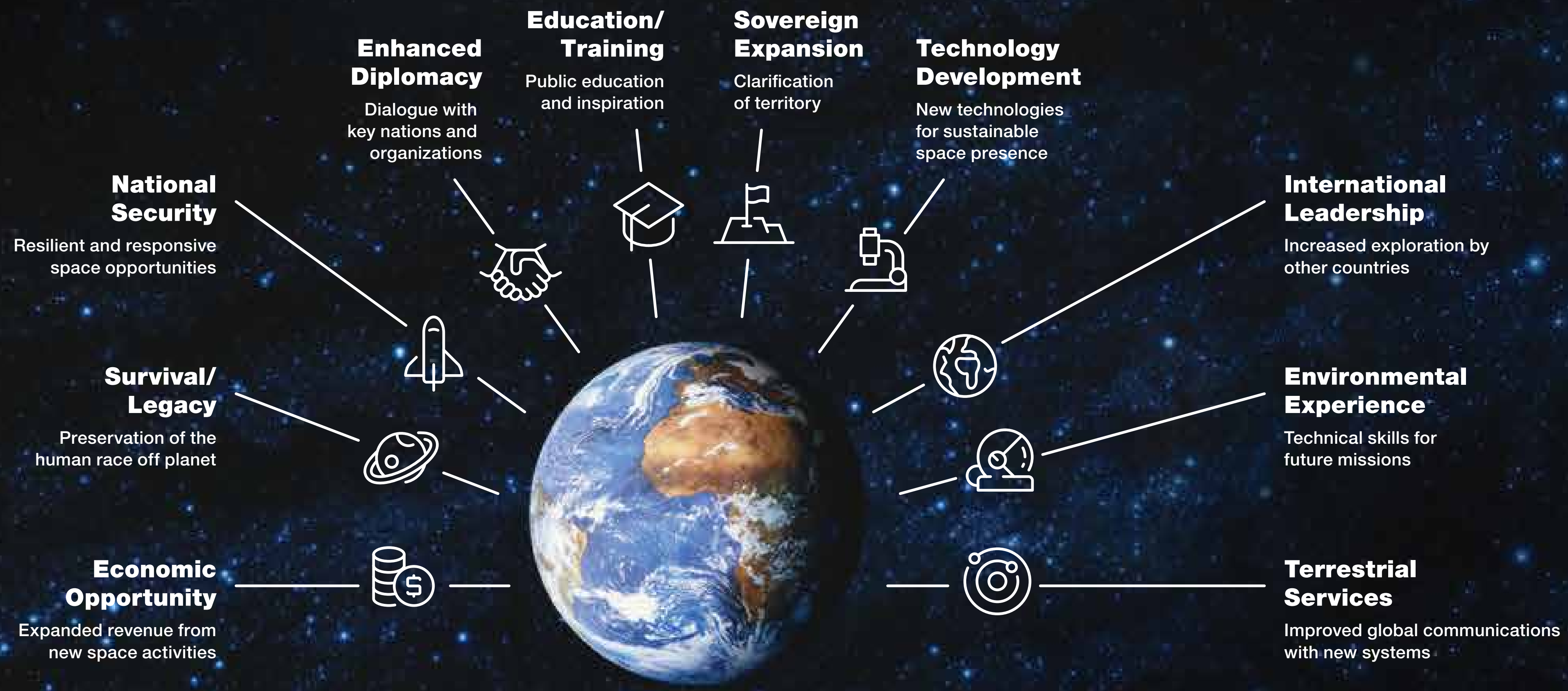


MARKED MOON
The south pole and the famous craters Schiller, Clavius and Tycho.

PHOTO: CHRISTOPHE LEHENAFF/GETTY

Why Space

Top 10 reasons to go up and out



GRAPHIC: BOEING

The Moon

Historically, expansion by governments on Earth occurred for three reasons: accumulation of land, access to natural resources and national security. For example, the development of railroads in the northern United States aided the growth of cities over time by providing a mechanism to move goods and resources across the country. The development of a transportation network between Earth and its moon can grow space commercialization in a similar manner.

When it comes to expanding humanity's presence in space, land on other bodies cannot be owned or militarized, according to the United Nations Outer Space Treaty. But the 1967 treaty did specify that all U.N. members were free to explore and use the moon and other celestial objects in outer space.

Assuming all governments abide by the agreement, two of the reasons for expansion, land and national security, are immediately ruled out. That leaves us to explore the resources available off planet.

And the moon is the ideal place to start.

REGULAR REGOLITH
Moon rock, known as lunar regolith, is in plentiful supply and is useful as construction material in space. This sample was collected by Apollo 15 from the Hadley Rille, near the edge of Imbrium Basin.

PHOTO: GERALD CORSI/GETTY

The moon offers water, which can be used for life support and agriculture and can be converted into propellant. Ilmenite is a lunar compound that can be broken down to yield iron, titanium and oxygen.

Lunar surface rocks and soils, known as regolith, contain raw materials such as magnesium, aluminum, silicon and iron. These elements can be used for building infrastructure for use on the moon or in space.

Imagine a not-so-distant future where we could use lunar resources to meet our needs on the surface to sustain human operations. We could even stand up automation (robotics, remote operations, machine learning) such that resource extraction, refinement and production would take place, akin to remote mining operations on Earth. And we could resolve transportation, storage and waste issues as well.

Thanks to metallic asteroids that have crashed into the moon over time, there are platinum-group elements left behind. The moon also offers what we call rare earth metals (REMs), including scandium, yttrium and the 15 lanthanides. These metals can be used to manufacture electronics and electric batteries. REMs are difficult to mine on Earth because it is unusual to find them in concentrations high enough for economical extraction. Conditions for mining on Earth are also highly toxic for humans.

The Response

In recent years, countries such as the United States and Luxembourg have passed regulations supporting the use of space resources by those who extract them. Luxembourg is even offering financial incentives to space companies that open offices there and reimbursement of 45% of a company's reseach and development investment.

In addition, in November 2020, the European Space Resources Innovation Centre (ESRIC) was officially launched in Luxembourg. The center's website says ESRIC "aims to become the internationally recognised centre of expertise for scientific, technical, business and economic aspects related to the use of space resources for human and robotic exploration, as well as for a future in-space economy."

And in December 2020, NASA announced contracts with four companies to collect moon rocks as part of the Artemis program, its effort to establish a sustainable presence on the moon. NASA's official announcement says the moon propels us to Mars: "The ability to extract and use extraterrestrial resources will ensure Artemis operations can be conducted safely and sustainably in support of establishing human lunar exploration. Moreover, in-situ resource utilization (ISRU) will play a vital role in a future human mission to Mars. Like many other operations, ISRU activities will be tested and developed on the Moon, building the required knowledge to implement new capabilities that will be necessary to overcome the challenges of a human mission to Mars."

Moon Mine

Lunar environment has a lot to offer

ELEMENTARY
There are more than two dozen accessible elements and compounds on the moon. Some can be used on Earth. Others can sustain operations in space. All must be extracted and processed before use.

Earth Use

Light Rare Earth Metals

57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.243	62 Sm Samarium 150.36

Current and Potential Use
Catalysts, lasers, electrodes, cancer treatment, magnets, nuclear shielding

Platinum Group

44 Ru Ruthenium 101.07	45 Rh Rhodium 102.906	46 Pd Palladium 106.42	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.085

Current and Potential Use
Catalytic converters, catalysts, jewelry, radiation shielding, corrosion-resistant metals, alloy strengtheners

Heavy Rare Earth Metals

21 Sc Scandium 44.956	39 Y Yttrium 88.906	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	68 Er Erbium 167.259

Current and Potential Use
Radiation shielding, electronic components, lasers, super conductors, dental applications

Pathway
Develop and demonstrate technologies to support efficient prospecting, extracting and delineation

GRAPHIC: BOEING

In-Space Use

Water

H_2O

Potential Use
Environmental Control Life Support System necessity

Hydrogen Peroxide

H_2O_2

Potential Use
Monopropellant

Hydrogen

1 H Hydrogen 1.008

Potential Use
Propellant production

Oxygen

8 O Oxygen 15.999

Potential Use
Propellant production

Pathway
- Develop and demonstrate technologies to support efficient prospecting, extracting, processing and delineation
- Support frequent revision of planned architectures to leverage in situ resource utilization (ISRU) developments
- Support exploration architectures that rely on ISRU
- Develop and mature systems and technologies to utilize resources capable of supporting multiple critical aspects of potential architecture

Helium-3

^3He

Potential Use
Fusion fuel

Pathway
Develop/support development of power-generating He-3 fusion reactor

Aluminum

13 Al Aluminum 26.982

Potential Use
- Electronic components
- Solid rocket fuel

Pathway
Develop and demonstrate extraction technology

Iron

26 Fe Iron 55.845

Potential Use
- Tools/structures
- Additive manufacturing

Pathway
Support development of energy-efficient additive manufacturing

Silicon

14 Si Silicon 28.086

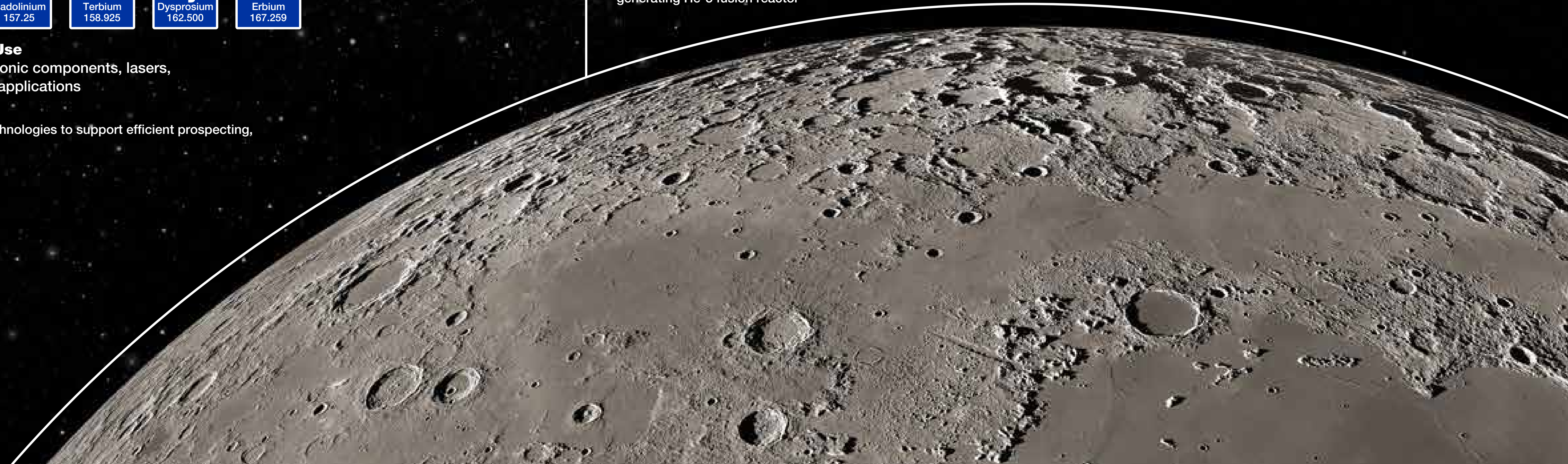
Potential Use
Component of solar arrays, glass, ceramics

Pathway
Develop/support development of systems for in situ purification and manufacturing

Lunar Regolith

Potential Use
Construction material

Pathway
- Develop/support development of systems for in situ processing and use
- Support use in exploration architectures



In February 2021, the Defense Advanced Research Projects Agency (DARPA) announced its Novel Orbital and Moon Manufacturing, Materials, and Mass-efficient Design (NOM4D, pronounced “nomad”). The official announcement outlines a 54-month contract opportunity: “The effort … seeks to pioneer technologies for adaptive, off-earth manufacturing to produce large space and lunar structures.”

The program assumes an established space ecosphere by 2030. According to the DARPA press release, this includes “rapid, frequent launch with regularly scheduled lunar visits; mature robotic manipulation tools for building structures in space and routine on-orbit refueling of robotic servicing spacecraft … and the availability of in-space, non-destructive evaluation methods for in-process monitoring of manufacturing and near real-time design adjustments.”

Companies can strategically align with their country’s lunar goals to start and build up commercial strategies, using NASA and other space agencies as anchor customers to substantiate technologies and capabilities.

Space resources such as water and metals will inspire a sustainable commercial space strategy. However, due to the complicated nature and required infrastructure to make space mining and manufacturing a reality, this cannot be accomplished by one or even a handful of companies. It requires a mindset shift, supported by government regulations or incentives. Traditional space manufacturing and operations companies, heavy machinery and mining, power, communications, 3D printing, machine learning and artificial intelligence must also join forces.

By integrating a space exploration and commercialization strategy around resources, opportunity arises to build up capabilities in low Earth orbit (LEO) and on the moon both to support resource-based operations and to start the journey for future expansion of humanity’s off-planet presence.

The Testing

Before the COVID-19 pandemic, Boeing performed market studies to test assumptions about how space commercialization could evolve in the next three decades. Integration, interactions and interdependencies between LEO and beyond Earth orbit (BEO) space activities were assessed.

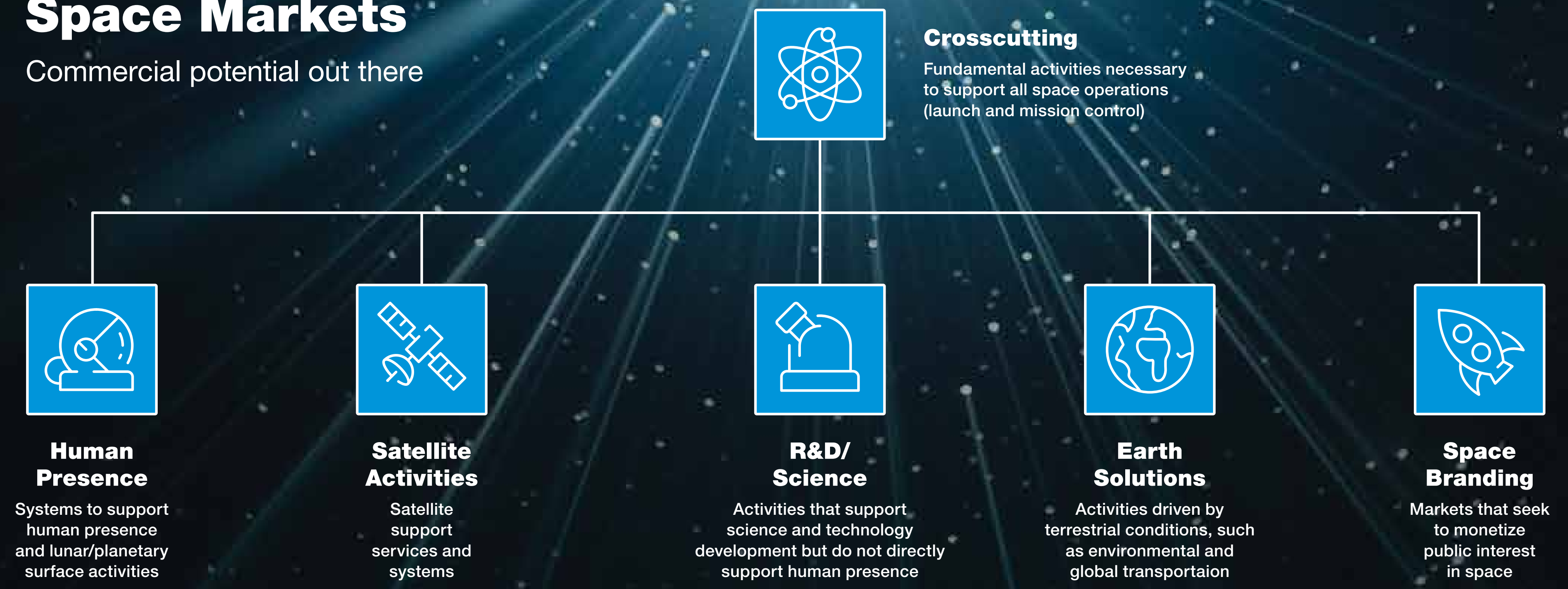
- We considered space activities in six space market categories to fully evaluate their potential interactions and whether each drives new commercial activity. This includes a broader market that cuts across the other five, primarily launch and mission control activities necessary to support space operations.
- We determined if commercial innovation could change the path of the current commercial space ecosystem trajectory.
- We considered if interactions between numerous space markets could speed and scale a commercial space economy.
- We determined which International Space Station (ISS) payload facility gaps would unlock commercial benefits for the LEO/BEO ecosystem.

The Results

Our studies concluded that the current trajectory of human space exploration will continue to remain government led and funded unless industry changes how it approaches space markets. There is not an instantaneous ramp-up to a trillion-dollar space economy.

Space Markets

Commercial potential out there



GRAPHIC: BOEING

A commercial space strategy must identify value creators and/or generate demand in order to be viable. Highlighting the benefits of being in space will enable the maturation of nascent space markets. Then, lunar resources can be utilized and demand generated by leveraging low Earth stations, starting with the ISS, and capitalizing on government and NASA goals and investment (return to the moon and LEO commercialization).

However, no one company or government can do this alone. It will take a network committed to a unified vision to reach the next level. This means companies across multiple industries bringing their individual strengths and coming together in partnership. First, that vision must be agreed upon.

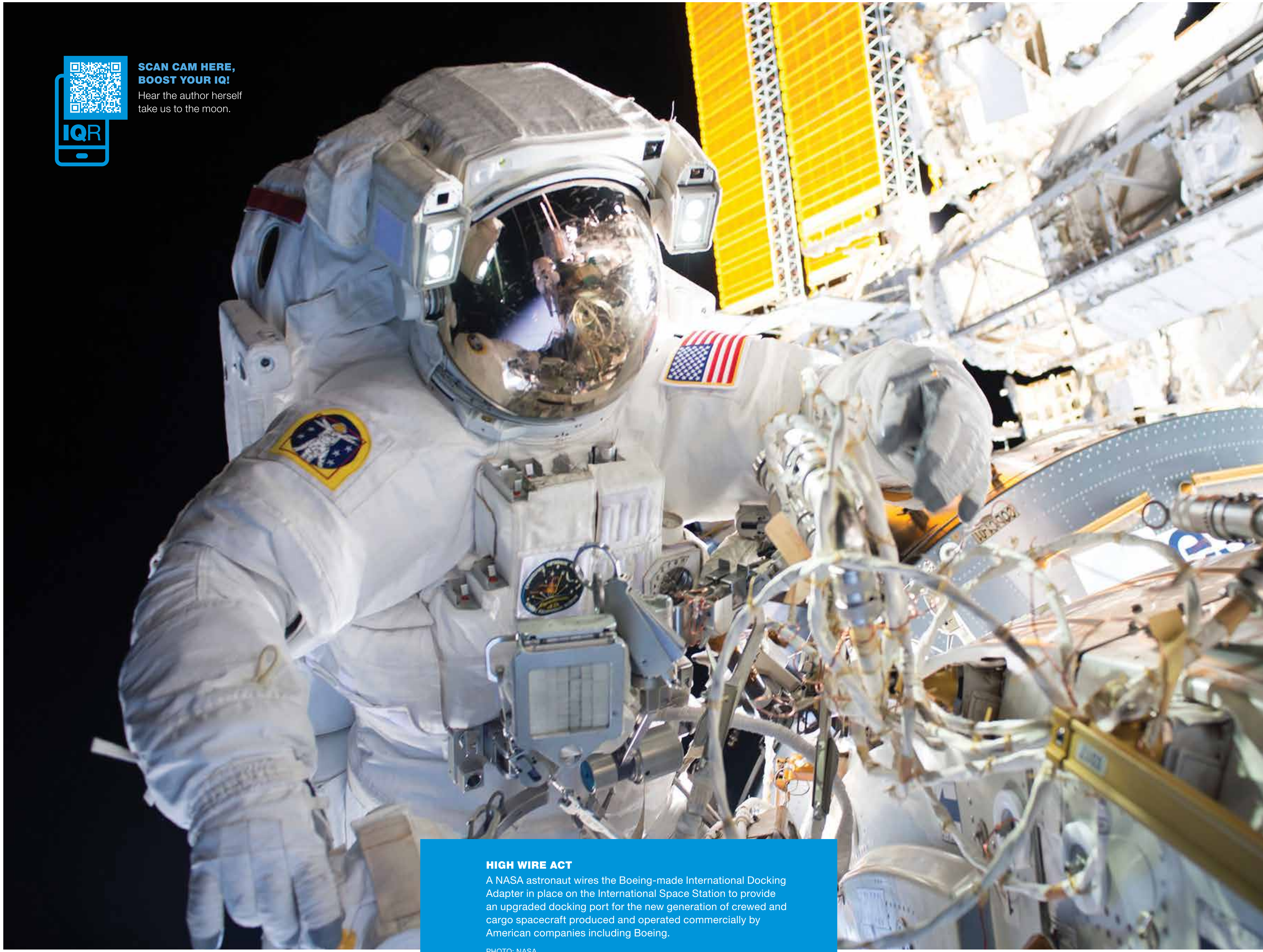
The following are starting places for an industry consortium to contemplate when working toward a unified commercial space strategy with 2050 on the horizon:

- Consider the full value chain when assessing emerging ecosystems.
- Expand the frame of analysis to consider the full range of business models when assessing new markets.
- Focus analysis on identifying unmet customer needs.
- Inform and shape customer and commercial strategies.
- Aggregate supply chains to fill needs.
- Invest in nascent technologies and pursue nontraditional investment strategies.

Together, we can work toward a unified space commercialization vision. Together, we can bring our strengths to the partnership to enable a future we've only dreamed about. **IQ**

ABOUT THE AUTHOR

Cindy Mahler, a commercial space innovation strategist, has worked as a systems engineer on multiple NASA collaborations with Boeing, including Commercial Crew, Constellation and International Space Station.



HIGH WIRE ACT

A NASA astronaut wires the Boeing-made International Docking Adapter in place on the International Space Station to provide an upgraded docking port for the new generation of crewed and cargo spacecraft produced and operated commercially by American companies including Boeing.

PHOTO: NASA

Watch This Space

Commercialization's already happening on the International Space Station

BY STEVE SICELOFF, BOEING WRITER

ABOVE IT ALL
The International Space Station has orbited Earth with a crew aboard for more than 20 years. In that time, it has routinely been upgraded to maintain its cutting-edge lab facilities and to accommodate increased uses, particularly by commercial organizations wanting to perform research in an environment devoid of gravity.
PHOTO: NASA

The International Space Station (ISS) is a pioneer. During more than 20 years of operation in low Earth orbit, the largest spacecraft ever built has achieved scores of scientific discoveries and opened access to space science to more people than ever before.

The ISS has also served as a proving ground for commercialization efforts in orbit, opening the microgravity environment to a wider range of experimentation by private companies and research organizations. NASA established the ISS National Laboratory to match the enormous research capabilities of the ISS with opportunities sought by private companies to advance their products or decipher problems in a microgravity environment.

ISS research has ranged from growing protein crystals to testing medicines on disease cells to 3D-printing fiber-optic cables that are able to carry a hundred times more information than Earth-made counterparts.

What started merely as offering room aboard the ISS for privately funded research projects grew to include launching microsatellites from the orbiting lab and incorporating an experiment airlock for commercial enterprises. NASA also instituted a pricing list for supplies and even crew time to support nonprofessional astronauts and private missions visiting the space station.

The purpose of the private missions will vary widely, from enhanced research by scientist crew members to weeklong sightseeing missions by space tourists, a signal of growing access to space.

Although the permanent crew of the ISS is set at seven, there is plenty of room inside for more on temporary stays. In fact, the ISS recently hosted 11 people at once. The record crew size stands at 13. With an interior volume equal to an empty 747 jumbo jet, the ISS won't likely run out of space out in space.

On the horizon are privately built modules that will connect to the ISS, plugging into its power and service infrastructure before disconnecting after several years to fly independently. Even with other orbital platforms in operation, the ISS is well positioned to continue its role as the cornerstone of research and commerce as well as shepherd the growth and operation of new capabilities in space.

Excellence, Technically Speaking

Meet the experts

Up close with the newest leaders in the Boeing Technical Fellowship

The recently honored Senior Technical Fellows represent expertise in a variety of fields, such as aerodynamics, active-integrated electronics, propulsion and fuels, structural analysis and digital enterprise analytics. The Fellowship provides a technical career path that cultivates innovation and advancement.

Recognized as technology leaders inside and outside the company, they assume new roles in the executive tier of the Boeing Technical Fellowship, which represents less than one-tenth of 1% of the technical workforce. They are trusted consultants, advisers and mentors and will play an even more important role in the future as stewards of the company's technical priorities.

SENIOR TECHNICAL FELLOWS

PHOTO: KRISTIAN MARSON

Sharon Arroyo, Ph.D.

Senior Technical Fellow
Advanced Mathematics and Optimization

It is an honor to be part of a team that helps define technical vision and innovation strategy while driving progress towards success and building the next generation of inclusive and diverse talent.

I have always loved math and solving technical problems that have a clear impact on business results. In the future, automation, autonomy and data-driven systems will be even more ubiquitous. Artificial intelligence will play a much larger role than it currently does, and machine learning will enable discovery of trends in data and behavior that current technologies don't see.

All these technologies rely extensively on mathematics, and none will be realized without skilled and creative mathematicians developing and implementing the core algorithms. **IQ**

PHOTO: KRISTIAN MARSON

Nathan R. Brooks, Ph.D.

Senior Technical Fellow

Electromagnetics and Antenna Systems

Earning the distinction of Senior Technical Fellow is an honor and blessing. The Fellowship provides me a means to impact the company and our communities in transformative ways.

As a team lead, mentor, colleague or teammate, I find our work most satisfying when knowledge is freely shared and spirited discussions are frequent. I have been fortunate to collaborate throughout the enterprise with many talented individuals I have both learned from and taught.

One of my most memorable projects was the development of an ad hoc power-based geolocation system that would provide situational awareness using common military radios — high tech using old tech. Electromagnetics remain fundamental to critical engineering fields, where there is a shortage of expertise, and the next-generation technology of the digital era, where interest is currently focused. **IQ**

PHOTO: JOHN HARRINGTON

Darin Brekke

Senior Technical Fellow

Guidance, Navigation and Control

I have been intrigued by space and spaceflight since I could check out books from my elementary school library. Of course I wanted to be an astronaut, like most any kid in the ’60s. But that slowly evolved into a love of electronics and a desire to design spacecraft.

Boeing has given me great opportunities to live that dream. My work on the Inertial Upper Stage program has included shaping design modifications for planetary missions and the Chandra X-ray Observatory and serving on console for over a dozen missions on Space Shuttle and Titan launches.

An especially memorable moment was working overnight in the payload bay of Discovery while it was on the pad to troubleshoot payload issues. After solving the problem, our team walked out of the payload airlock on the launch tower to an amazing Florida sunrise.

This honor will open up even more occasions to collaborate with my many talented technical teammates across the enterprise. **IQ**

Steve Kirchmeier

Senior Technical Fellow

Production Engineering

I dreamed of becoming a pilot or an astronaut as a child. Little did I know I'd enjoy making aircraft even more than flying.

Innovation requires knowledge of physics, math, modeling, and the history of past issues and solutions. All this, combined with my love of aircraft, led me into engineering and aerospace.

I am energized by the process of solving a puzzle where a seemingly simple need presents itself in a vast, complex system. To design and implement a solution people want, use and rely on is most rewarding. **IQ**

PHOTO: BRUCE HERSHEY

PHOTO: KRISTIAN MARSON

Ko-Wei Liu

Senior Technical Fellow

Durability and Damage Tolerance

Engineers get to transport the wonders of the future into reality. My career offers the opportunity to create, innovate and use creativity to solve challenging problems — I will never be bored.

Every day, I work with smart, passionate and inspiring people around the world. As a result, I continuously gain expertise, skills and experience.

I am happy, grateful and honored to receive company recognition for my work and contributions. I see this as an avenue to expand my knowledge and help shape Boeing products, technology development and mentoring. **IQ**

PHOTO: BRUCE HERSHEY

Darren Macer

Senior Technical Fellow

Predictive Maintenance and Health Management

I always knew I would be an engineer. As a kid, I would try to make my own machines and also take things apart, figure out how they worked. I have always been curious and wanted to make life easier, and I think that's the hallmark of an engineer.

In my career, I have always strived to see what is around the corner. With the availability of big data, artificial intelligence, machine learning, high-power computing and the right people, we can now see over the digital horizon. I grew with this field as data and capabilities allowed us to move from reactive to predictive.

As we continue to invent new ways of more deeply understanding the health of aircraft systems and components, we can strive to make unscheduled maintenance a thing of the past and create a future of operations and maintenance without surprises. **IQ**

PHOTO: KRISTIAN MARSON

Melanie Koh Lorang

Senior Technical Fellow

Data Analytics and Product Lifecycle Through Digital Thread

Early in my career, I was part of a team to market launch services to a South Korean customer. I was the translator, given my Korean heritage and fluency in the language. As a result, our team won the launch of two Delta II rockets for the Koreasat 1 and 2 satellites.

My engagement spanned the entire contracted effort, from initial technical review meeting to launch support, including broadcasting the countdown activities in Korean. Through this experience, I learned how the understanding of diverse cultures and languages is critical to meet others' needs and build successful relationships.

Utilizing my experiences in engineering, art and data science, I am passionate about developing data analytics solutions to provide insight into how we design, build and maintain our products. It is even more gratifying to see how we use these insights to design and deliver better products and services and enable self-service analytics so that everyone can do what I do. **IQ**

Randy Marion

Senior Technical Fellow

Electrical and Electronic Engineering

I am truly honored and look forward to working with an exceptional group of people. The opportunities to both learn and teach are outstanding. This is a significant step on my journey from balsa airplanes to my home electronics kit to grinding my own telescope mirror in eighth grade.

As I've progressed, I've enjoyed the privilege of mentoring some exemplary colleagues in new ways of approaching challenges. This recent selection will allow me to collaborate even more with teams across the enterprise on issues of great importance. After 38 years with the company, a new horizon allows one to stay fully engaged in the work. **IQ**

PHOTO: DAVE PRESTON

PHOTO: DAVE PRESTON

Rich Massey

Senior Technical Fellow

Product Security Engineering

Some of my initial work at Boeing was with intercom, displays and video avionics. As those became more digital, I became more of an expert in the digital domain. That led to mission systems architectures, and security was an emerging attribute. As a result, I have had the opportunity to bake security and resilience into the products we build.

I never imagined it was even a possibility to be part of this elite group of aerospace technical leaders until recently. Even then, it felt like a long shot to even be considered, much less selected. So it is humbling and a most meaningful responsibility. **IQ**

PHOTO: DAVE PRESTON

Don Palmer, Sc.D.

Senior Technical Fellow

Nondestructive Evaluation and Measurement

My team and I had 24 hours to figure out a way to determine if corrosion was present in the wings and horizontal stabilizers of a VIP aircraft without removing paint and coatings. This task was successfully completed using a new, on-aircraft, ultrasonic array-based scanning approach.

Nondestructive Evaluation processes such as this are intertwined with quality assurance and structural safety of flight. The work we do is critical in keeping airframe structures flying — and flying safely.

I find this level of responsibility and teamwork invigorating. Because of this recent recognition from the Boeing Technical Fellowship, I will be able to interact even more with technical experts across many technical disciplines who are nationally and internationally recognized leaders in their fields. **IQ**

Brian Riedel

Senior Technical Fellow

Structural Design and Technology

One of the highlights of my career was the opportunity to play a lead role in the invention, design and build of noise-reduction technology. To see the team's work implemented on several commercial airplane models to reduce the environmental impact is most gratifying. And flying on the test airplane was a thrill.

The productivity and teamwork that are unlocked when teams function at a high level is remarkable. It is a privilege to lead cross-functional teams to successfully solve complex issues or bring new technology or product architecture to fruition.

I am excited about the challenge that lies ahead to innovate new product architectures and technologies in a model-based environment that achieve the right balance of product/production system performance and sustainability. **IQ**

PHOTO: PAT BLACK

Adam Sawicki

Senior Technical Fellow

Structural Analysis, Testing and Certification

I spent much of my early career supporting the V-22 Osprey. So it was a great thrill for me to watch my wife Michele's reaction the first time she saw a tiltrotor fly, transition and land. I will always remember how amazed she was by an aircraft I helped create.

Many of us who were children in the 1970s were inspired by the Apollo program and dreamed of becoming astronauts, and I was no exception. Later I became fascinated by unmanned planetary science programs and dreamed of helping to create machines that could fly through the air and explore the solar system.

I chose a career in structural engineering because I find I can more easily understand engineering concepts if I can relate them to something I can visualize and build. This honor enables me to collaborate even more with some of the brightest, most innovative minds in engineering. **IQ**

PHOTO: BILL STREICHER

PHOTO: BOEING

Tanni Sisco

Senior Technical Fellow

Advanced Materials and Manufacturing for Assembly

I have always enjoyed pulling things apart and putting them back together. Perhaps that is how I ended up in mechanical engineering.

The most memorable moment of my career was 787 rollout day. Never had I experienced such outstanding teamwork for a common goal.

It is most rewarding for me to create new technologies and then see those ideas become reality on an aircraft. And this new position expands my opportunities to influence future strategies and technology development, positively impacting production quality and output. **IQ**

PHOTO: JOHN HARRINGTON

Ahmad R. Yaghoobi

Senior Technical Fellow

Digital Enterprise Analytics

It is a tremendous honor and privilege to be selected as Senior Technical Fellow. It will provide me with the opportunity to address key technical challenges and set technical strategies and direction within my field of expertise.

There is nothing more rewarding to me than to help build future technical leaders through mentoring, to offer a path to achieve business transformation objectives through digitization, automation, standardization and data analytics.

I look forward to encouraging pervasive use of data analytics, artificial intelligence, machine learning and automation in every aspect of our business to create new opportunities for developing and delivering new, safe and high-quality products and services to our customers. **IQ**

PHOTO: KRISTIAN MARSON

Anduin Touw, Ph.D.

Senior Technical Fellow

Electronics Reliability

Most people don't initially think of Boeing as an electronics company, but as our products increase in complexity, electronics are becoming more and more central to our business. We design boards, select parts, write parts and material requirements for subcontractors, and even build boards at some sites.

The electronics industry is changing rapidly with new technologies that we need to evaluate and decide if they are appropriate for our products. Working with other Boeing experts to create processes and tools to support these changes will be exciting.

The most rewarding aspect of my work is mentoring and being mentored by great people. I have learned more from my Boeing colleagues than from any of my educational institutions. I hope to continue to engage with the next generation, through mentoring, helping out in the Technical Fellowship program and sharing knowledge with program engineers. **IQ**

PRINCIPAL SENIOR TECHNICAL FELLOWS

PHOTO: KRISTIAN MARSON

Robb Gregg

Principal Senior Technical Fellow

Aerodynamics

I grew up outside of Chicago and always looked up at the aircraft on approach or climbing out from O'Hare Airport. I still remember the first model airplane I put together was the X-15; the second, a 727. I was always interested in why airplanes are shaped the way they are.

When I became an aerospace engineer, my first development program was for the C-17. I had the opportunity to size the wing; use early computational fluid dynamics tools to help define the aircraft; create the final aero surfaces of the wing, winglets and tail; and participate in wind tunnel testing to validate early design. I'll never forget the C-17 first flight.

Being named to the Fellowship is an honor but also a challenge — to step up to improve our competitive capabilities and leverage model-based engineering to predict and design better products. **IQ**

PHOTO: BRUCE HERSHEY

R. (Ken) Li, Ph.D.

Principal Senior Technical Fellow

Positioning, Navigation and Timing/Guidance, Navigation and Control

We at Boeing are at the center of the efforts to define the future.

A friend recently pointed out to me that the systems I designed have been operating on more than 30 spacecraft programs with a combined hundreds of years of in-orbit operations without a single anomaly.

It has been my passion to develop new technologies with innovation and assured quality, and I am proud it has been yielding results.

Indeed, I love to constantly create new technologies that can be used enterprisewide. This honor will enable even more opportunities to leverage my skills and knowledge to push out more innovative and quality products and, in the meantime, help grow the next generation of leaders and experts in my fields. **IQ**

Julio A. Navarro, Ph.D.

Principal Senior Technical Fellow

Radio Frequency Circuits, Antennas and Active-Integrated Electronics

I always wanted to be a professional soccer player. I even played one year at Texas A&M. But as I competed against some of the best, it became abundantly clear I should concentrate on my studies, not soccer.

I had been inspired by my high school math teacher to consider engineering. He saw potential in me and told me so. This propelled me to find my passion in antennas in college and in my career.

We are in extremely interesting and difficult times which demand clear and steady leadership. Our guidance can empower the next generation to go farther, perform better and positively impact our world. **IQ**

PHOTO: KRISTIAN MARSON

DISTINGUISHED SENIOR TECHNICAL FELLOW

PHOTO: KRISTIAN MARSON

Steve Clark

Distinguished Senior Technical Fellow

Propulsion and Fuels

My father was a civil engineer (bridge designer), so I was naturally drawn to engineering. I eventually had to admit to him that I preferred things that moved. Airplanes are the ultimate choreography of moving parts.

I've been continuously associated with propulsion since the day I graduated from the U.S. Naval Academy, serving on a gas-turbine-powered destroyer. This led to nearly four decades of service at Boeing, always in propulsion or fuels.

Since these disciplines play central roles in aircraft performance, I've been afforded great opportunity to see nearly every aspect of aircraft design. Propulsion and fuels will greatly impact the future of sustainable aviation — arguably the most significant long-term challenge for our industry. **IQ**

Into the sunset ...

into the spotlight

Celebrating 75

The Blue Angels are celebrating their 75th season with a new ride.

LASTING LEGACY

After 34 years representing the Blue Angels, F/A-18 Hornets, such as this one in Pensacola, Florida, are now part of the flight demonstration team's storied past.

PHOTO: ERIC SHINDELBOWER AND SCOTT GIRARD/BOEING

FUTURE FORWARD

During training over Naval Air Facility El Centro, California, the Blue Angels perform the Line Abreast Loop in the F/A-18 Super Hornet, now the 10th flight demonstration aircraft in team history.

PHOTO: MASS COMMUNICATION SPECIALIST 2ND CLASS CODY HENDRIX/U.S. NAVY

NAVAIR Public Release 2021-365 Distribution Statement A - Approved for public release; distribution is unlimited

F/A-18E/F Super Hornet Stats

Speed:	Mach 1.6 (1,228 mph/1,976 kph)
Combat Ceiling:	>50,000 feet (15,240 meters)
Supersize:	30% larger airframe than legacy F/A-18A/B/C/D Hornets
Formation First:	First operational Super Hornet squadron formed in June 2001

SOUND CHECK

How the Apache team quiets a 15,000-pound attack helicopter

The AH-64 Apache helicopter is loud and proud. Sometimes too loud. So the team in Mesa, Arizona, decided to go beyond earplugs.

PHOTO: BOB FERGUSON/BOEING

Engineer Jason DeStories from Boeing Research & Technology describes how he and his teammates created an award-winning, cost-effective innovation, repurposing scraps of shipping foam and polyvinyl chloride (PVC) pipe tied together with zip ties.

QUIET CONFIDENCE

(From left) Dylan Bacon, industrial engineer; Chris Allen, Apache Delivery Center technician; Jason DeStories, Manufacturing Research & Development engineer; Israel Limon, Manufacturing Research & Development technician; and Parvin Wallum, industrial hygienist and Hearing Conservation Program coordinator, with their "hush kit" next to an Apache helicopter.

PHOTO: BOEING
Photo taken before Boeing implemented COVID-19 pandemic safeguards.

IQ: Describe the early thought process?

JD: I had worked previously with Talmadge Ryan, a repair technician in Mesa. He experienced the noise issue during experimental tests. When he was named the on-site "safety champion," he made it his top priority to find a solution. Talmadge's original idea was to line a box with shipping foam. I added baffles with PVC pipe wrapped in the foam. We ran with it, and it worked astonishingly well. After the prototype test, I formalized the design to handle the forces from the airflow and also confirmed with engineers that adding the devices would not limit the performance of the ECS system.

TEST 1, 2

Jason DeStories (left) and Talmadge Ryan use a chair to roll the hush kit prototype into place for early evaluation.

PHOTO: APACHE TEAM/BOEING

IQ: Where does the noise come from?

JD: The Apache's environment control system (ECS) is used to keep the aircraft's electronics and cabin cool. This air conditioning system must operate while the aircraft is powered up, undergoing testing, sometimes for up to eight hours. But the ECS emits a high-pitch noise, in excess of 100 decibels, about the same level as a jet taking off, a motorcycle or a jackhammer. The sound reverberates throughout the manufacturing workspace, impacting workers' safety and ability to communicate.

IN AND OUT

During testing, noise escapes from the air conditioning system of the aircraft from the inlet (left) and exhaust (right).

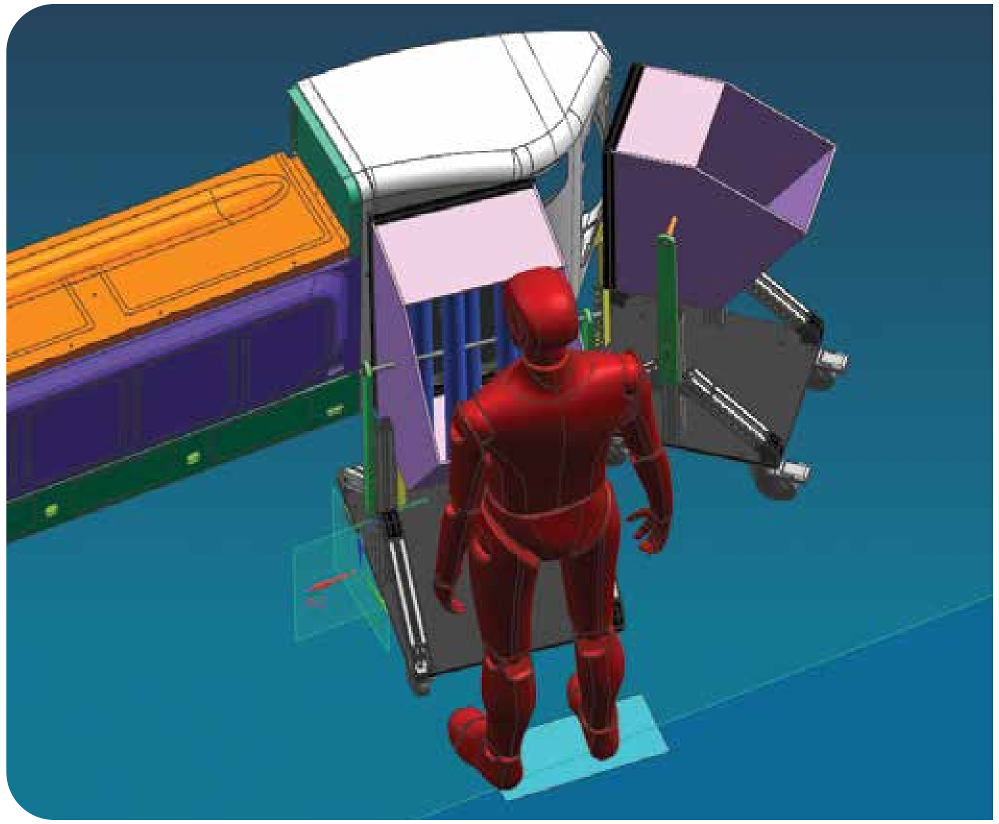
PHOTO: BRIANNA MEYER/BOEING

"Talmadge's original idea was to line a box with shipping foam. I added baffles with PVC pipe wrapped in the foam. We ran with it, and it worked astonishingly well."

PROTOTYPE IN PROGRESS

An early hush kit using repurposed materials gathered from around the site.

PHOTO: APACHE TEAM/BOEING



DIGITAL DESIGN
The team created renderings early in the process to work through modifications.
PHOTO: APACHE TEAM/BOEING

IQ : What was the original prototype like?

JD: An aluminum extrusion frame had panels attached to the sides. Then, we used rods with the shipping foam attached to them with zip ties. This was a makeshift "baffle" to disrupt the airflow and maximize the amount of impact to the sound energy with the foam.

We call it a "hush kit." The foam absorbs the high-frequency noises. The baffling eliminates a direct line of sight and sound. This forces all sound energy through the foam and deflects noises internally to maximize the chance of absorption.

When we measure sound at the source at the inlets, for example, the hush kits reduce noise by 75%.

PERFECT PLACEMENT
Talmadge Ryan demonstrates that a single team member can set up the light, maneuverable hush kits.
PHOTO: BRIANNA MEYER/BOEING

> **Talmadge and I looked at each other and discovered we were onto something.**

IQ: Sounds like there was some recycling involved?

JD: We chose the materials for the prototype based on what we could find on-site for free. The aluminum for the box frame enclosure, the plastic for the side panels and the PVC pipes were all from the scrap pile in our lab. Another colleague found the shipping foam in the receiving dock trash. We used a standard office chair to hold the unit in place while we did the first, crude prototype test. Everyone, including myself, was skeptical. It wasn't until the noise was drastically reduced during that initial test that Talmadge and I looked at each other and discovered we were onto something.

Sound Thinking: Before and After

Noise measurements during AH-64 Apache testing

	No Hush Kit	With Hush Kit	Noise Reduction*
INLET	100 dB	88 dB	12 dB (75%)
EXHAUST	106 dB	96 dB	10 dB (68%)

*Noise is measured in decibels (dB) on a logarithmic scale. For every 6 dB reduction, the actual noise is cut in half.
-Noise is generated by the ECS, which operates during the electronic testing phase for the AH-64 Apache.
-Measurements were collected at the source with a calibrated CEL-254 sound level meter, in accordance with OSHA standards for instrumentation to measure exposure to noise.

Rewarding Experience

For their innovative solution, the Vertical Lift AH-64 Apache team was presented with the 2021 Safe-in-Sound Excellence in Hearing Loss Prevention Award at the 45th annual National Hearing Conservation Association (NHCA) conference.

The award is presented by the NHCA, in partnership with the National Institute for Occupational Safety and Health and the Council for Accreditation in Occupational Hearing Conservation. The award recognizes organizations that document measurable achievements in hearing-loss prevention and enable the sharing of leading-edge best practices to improve the workplace and demonstrate leadership.

IQ: What details did you consider to create a useful device?

JD: There were four design challenges. We knew it had to have a small footprint. The shop was already limited in space. Each unit needed to be smaller than 24 inches by 24 inches. To achieve this, the base plate uses half-inch steel to account for the frame and the ballast, for stability.

Each unit also needed to be height adjustable to meet a range of aircraft configurations. A simple friction slider mechanism was attached to each side arm, allowing for a range adjustment.

WHEEL DEAL
The hush kits are easily wheeled in and can be adjusted to the correct height to fit snugly and to significantly reduce noise.
PHOTO: APACHE TEAM/BOEING

Third, each unit needed to gimbal in all axes (x, y and z). This was vital because the seal needs to fit tightly to the aircraft in order for the sound suppression to work well. Axes x and y were dealt with using swivel bearings attaching the hush box to the frame. Casters on each corner of the base plate took care of the z axis.

Fourth, due to the quantity of hush kits needed, the box was designed to be plastic-welded by a supplier with the holes pre-drilled in the box. This made assembly much more efficient.

IQ: What are you most proud of?

JD: A notorious problem which plagued the site for years was solved by a relatively simple and inexpensive solution. I'm proud of Talmadge for coming up with a method to minimize sound at the source rather than accepting the status quo. And the team kept the project simple the whole way to avoid the traditional pitfalls of more complicated ideas. **IQ**

ABOUT THE AUTHOR
Jason DeStories is an engineer at the Boeing campus in Mesa, Arizona. His expertise is in rapid concept creation, mechanical/aero designs, development of emerging technologies and implementation of production processes.
PHOTO: BOEING

"A notorious problem which plagued the site for years was solved by a relatively simple and inexpensive solution."

A Quieter Future

To date 10 hush kits have been developed, with plans for the Mesa site crew to build more and generate customer awareness of their innovation.

While the noise is significantly decreased, hearing protection is still necessary at the Mesa site. The Occupational Safety and Health Administration (OSHA) requires employers to keep the noise average below the permissible exposure limit of 90 decibels.

SCAN CAM HERE, BOOST YOUR IQ!
Hear the difference a hush kit makes, before and after.

IQR

Touching moment

MQ-25 Stingray™ — ready for the mission

The Boeing MQ-25™ T1 test asset transfers fuel to a U.S. Navy F/A-18F Super Hornet, marking the first time in history that an unmanned aircraft has refueled another aircraft. T1 has also refueled two other carrier-based aircraft, an E-2D Advanced Hawkeye and an F-35C Lightning II, for the first time.

- The U.S. Navy's first operational carrier-based unmanned aircraft
- Wingspan: 75 feet (22.9 meters)
- Width with wings folded: 31.3 feet (9.5 meters)
- Length: 51 feet (15.5 meters)

PHOTO: KEVIN FLYNN/BOEING
MQ-25 and Stingray are trademarks of the Department of the Navy.

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Video: See refueling history happen.

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GO FLY

Competition's on for $1 million

Personal flyer prize still up in the air

Air Time

Team VertiCycle's device rises above Moffett Airfield during the GoFly Final Fly Off in February 2020 at the NASA Ames Research Center near Mountain View, California. The team is based in Anderson, Indiana.

PHOTO: JOSH ROBINSON/BOEING

There's a race into the future going on overhead.

The GoFly Prize competition invites innovators worldwide to create a personal flyer. And that innovation up in the air could land one team $1 million.

Thumbs Up

DragonAir Aviation team Captain Mariah Cain rides aboard the Panama City Beach, Florida-based team's Airboard during the Final Fly Off.

PHOTO: KENNETH I. SWARTZ/VERTICAL FLIGHT SOCIETY

Launched in 2017 with Boeing as its grand sponsor, the competition is to design and build a safe, quiet, ultra-compact personal flyer that can achieve near-vertical takeoff and landing (VTOL) and fly 20 miles while carrying a single person. So far, 855 teams across 103 countries have vied for the $1 million grand prize. New teams are still welcome to join.

Team TeTra Tryout

Team teTra of Tokyo won the $100,000 Pratt & Whitney Disruptor Award at the Final Fly Off. Team members (from left) Ben Grubb, Pritish Debasis Tripathy and Akihiro Mizutani display their craft, the teTra Mk-3.

PHOTO: JOSH ROBINSON/BOEING

Trek Talk

Team Trek's Jose Fierro (right) shows off his team's FlyKart 2. Trek Aerospace, of Folsom, California, completed Phase II of the GoFly competition.

PHOTO: KENNETH I. SWARTZ/VERTICAL FLIGHT SOCIETY

Scores for the grand prize will be based on:

- **Safety.**
- **Performance, including speed and endurance.**
- **The ability to achieve near VTOL.**
- **Quietness.**
- **Compactness.**
- **The experience of open-air flight.**

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More GoFly info.

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Go Teams Go

Boeing Chief Engineer Greg Hyslop and GoFly CEO Gwen Lighter speak during the GoFly Final Fly Off at the NASA Ames Research Center in California.

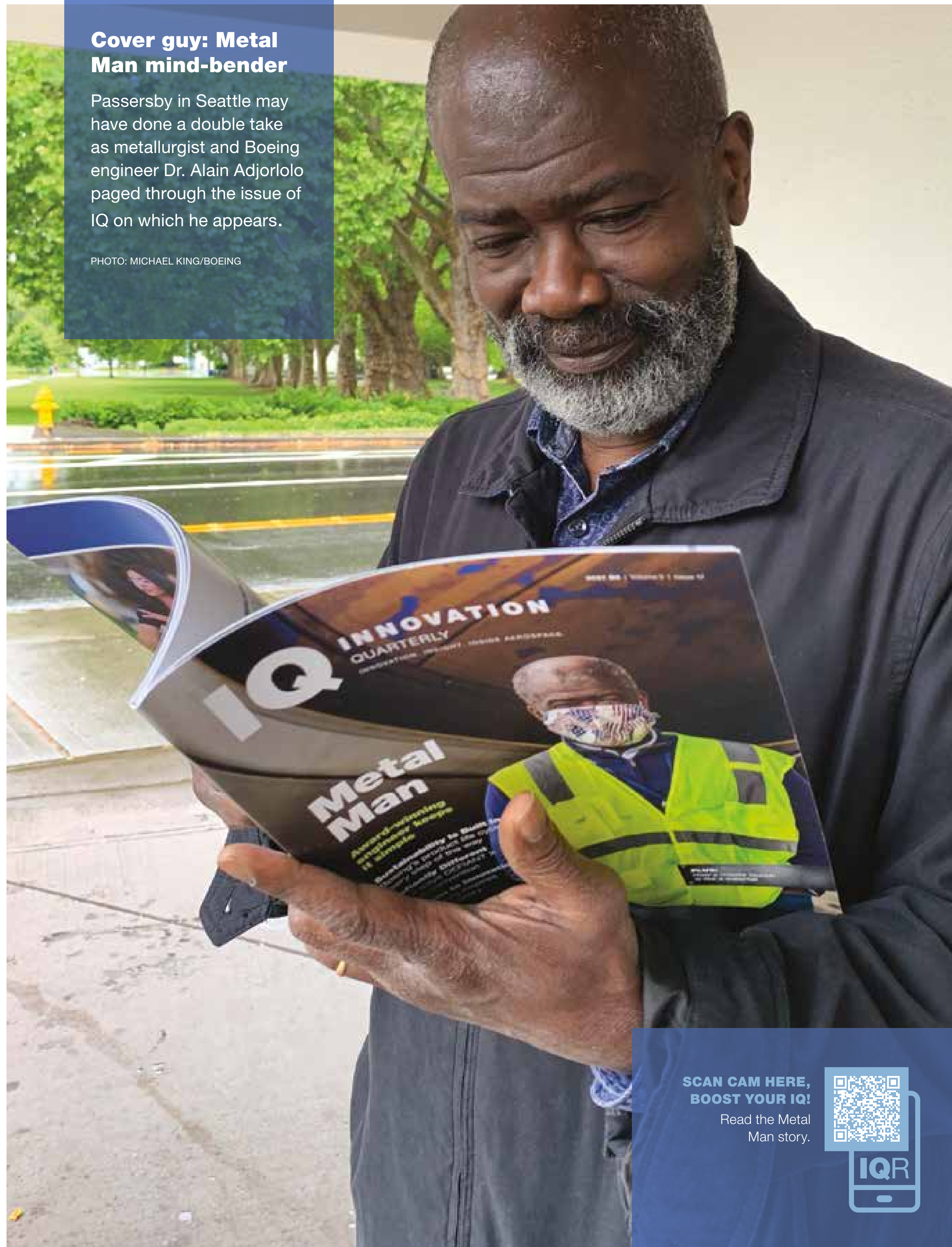
PHOTO: JOSH ROBINSON/BOEING

Boeing Chief Engineer Greg Hyslop is amped about how high this could go.

“The competition aligns with our company’s goals of inspiring people across the globe and changing the world through aerospace innovation. We’re excited to see how the visionaries of the future will take on this ambitious and exciting challenge,” Hyslop said.

Gwen Lighter, GoFly CEO, said the organizers look forward to going even bigger.

“Our teams around the globe continue to make the impossible possible,” Lighter said. “It is a privilege to support these pioneers in their flying and engineering endeavors.” **IQ**



Cover guy: Metal Man mind-bender

Passersby in Seattle may have done a double take as metallurgist and Boeing engineer Dr. Alain Adjorlolo paged through the issue of IQ on which he appears.

PHOTO: MICHAEL KING/BOEING

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Read the Metal Man story.

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