2022 Q2 | Volume 6 | Issue 20

IQ INNOVATION QUARTERLY

INNOVATION. INSIGHT. INSIDE AEROSPACE.

Welcome Aboard

Inside the evolution of the passenger experience

PLUS: License to Drive the MQ-25
Moving the first-of-its-kind aircraft aboard an active carrier is a joy (stick)

CABIN COLLABORATION

(From left) Cabin team members Zach Kilcer, Katie Faires and Brenna Wynhof showcase a 787 Dreamliner cabin at the Boeing Customer Experience Center in Renton, Washington.

BOEING

IQ INNOVATION QUARTERLY

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IQ IS ...
Innovation Quarterly invites readers to go inside the future of aerospace with the people who make it happen.

The Power of Purpose

Purpose animates. It motivates. It inspires. Importantly, it fills in the "why" of what we do, and it keeps us on track when we have hard decisions to make. At Boeing, we share an extraordinary purpose: to protect, connect and explore our world and beyond. This amazing "why" for all the work we do each day leaps off every page of this edition of Innovation Quarterly.

The cover story invites us along on a journey through time, as it appears from an airplane seat. We consider the experiences of the millions of passengers who rely on our airplanes to safely connect with family, friends, customers and associates all across the world.

The MQ-25 team invites us aboard an aircraft carrier to demonstrate the autonomous future that lies ahead for the U.S. Navy's carrier air refueling wing.

A flight test conductor, a software engineer and a former watchmaker turned aerospace artisan share their enthusiasm for "Why Boeing," reminding us how very personal purpose is.

Guiding our 50,000-strong engineering team, Boeing's Chief Engineer gives his views on leadership, transparency and inclusion — and our commitment to engineering excellence.

Above everything is safety. We delve into the critical role safety analytics plays, enabling us to discover issues before they become incidents. And we look at new technologies improving workplace safety.

What powerful reminders of why we do what we do. Enjoy the issue! **IQ**

Marc.

Marc Allen
Chief Strategy Officer
Senior Vice President,
Strategy and Corporate Development

ALL SET

T1, the MQ-25 test aircraft, is connected to the catapult with the jet blast deflector up on the USS George H.W. Bush flight deck. The carrier-based demonstration showed how a new remote-controlled deck handling system can move the unmanned aircraft into the catapult.

PHOTO: TIM REINHART/BOEING

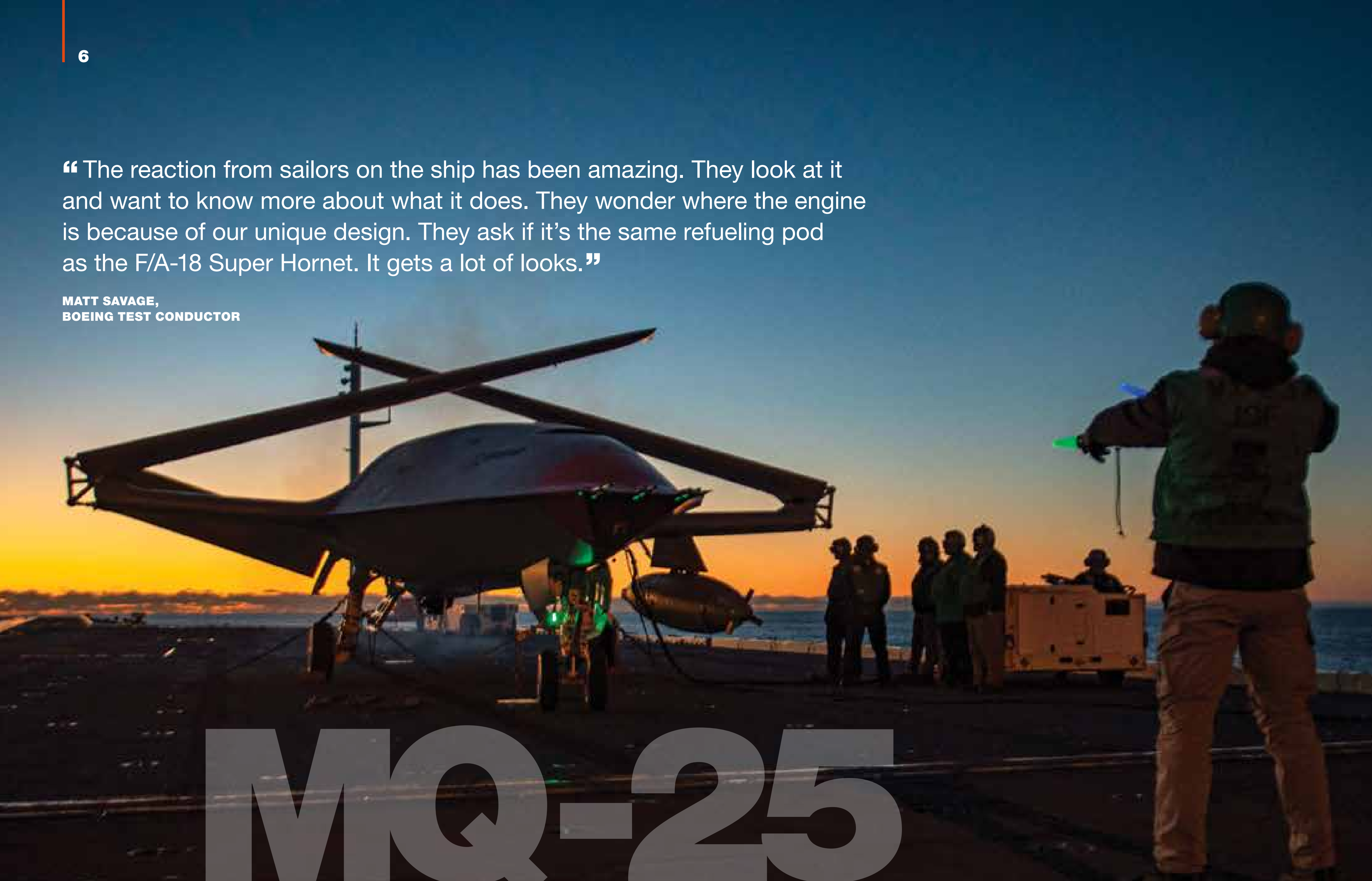
License to drive the **MQ-25** Stingray

Moving this first-of-its-kind aircraft aboard an active carrier is a joy (stick)

BY ASHLEE ERWIN, BOEING WRITER

It's an all-hands-on-deck situation, but no hands touch the star of the show. With its smooth lines, stout frame, and flat and forklike nose, the unconventional vehicle looks like nothing else on the deck of the aircraft carrier USS George H.W. Bush. Most noticeable is what is not on an MQ-25: the customary bump where a pilot might sit.

The carrier is alive with activity as teams of flight deck directors, known as yellow shirts, and the new MQ-25 deck handling operators move the Navy's newest aircraft — which indeed has no cockpit — without touching it.



“The reaction from sailors on the ship has been amazing. They look at it and want to know more about what it does. They wonder where the engine is because of our unique design. They ask if it’s the same refueling pod as the F/A-18 Super Hornet. It gets a lot of looks.”

**MATT SAVAGE,
BOEING TEST CONDUCTOR**

MQ-25

CHECK ONE, TWO

Boeing and Navy specialists position T1 on the flight deck in preparation for testing.

PHOTO: U.S. NAVY/MASS COMMUNICATION SPECIALIST 3RD CLASS BRANDON ROBERSON

SUNRISE AND SHINE

Teams perform a test on T1 in the early morning on the Bush flight deck.

PHOTO: U.S. NAVY/MASS COMMUNICATION SPECIALIST 3RD CLASS BRANDON ROBERSON

“The reaction from sailors on the ship has been amazing,” said Boeing test conductor Matt Savage. “They look at it and want to know more about what it does. They wonder where the engine is because of our unique design. They ask if it’s the same refueling pod as the F/A-18 Super Hornet. [It is.] It gets a lot of looks.”

It’s a look into the future of the U.S. Navy’s carrier air wing.

ON THE HOOK

With its tailhook extended to simulate catching the wire during an arrested landing, T1 prepares to taxi clear of the landing area in a safe and timely manner.

PHOTO: TIM REINHART/BOEING

MQ-25

The MQ-25 is a fighter jet-sized aircraft designed to be a gas station in the sky. Instead of using an F/A-18 fighter jet to refuel other aircraft — a process used today called “buddy tanking” — the MQ-25 will take over the refueling role.

The Boeing-owned MQ-25 test aircraft on the deck of the Bush had previously proved its aerial refueling credentials, transferring fuel to three different Navy aircraft — an F/A-18F Super Hornet, an E-2D Advanced Hawkeye and an F-35C Lightning II — in a span of three months in 2021. Known as T1, it became the first unmanned aircraft in history to refuel another aircraft.

A big test remained, however. Yes, T1 could connect to other aircraft at 10,000 feet (3,048 meters) and autonomously transfer fuel. But could it move quickly and easily in what has been described as a “ballet of chaos” — an aircraft carrier deck — with a remote control system?

Boeing engineers and specialists reveal how this MQ-25 predecessor aced this critical test.

HISTORY MADE

T1 transferred fuel to an F/A-18F Super Hornet on June 4, 2021, becoming the first unmanned aircraft in history to refuel another aircraft.

PHOTO: KEVIN FLYNN/BOEING

The MQ-25 is a fighter jet-sized aircraft designed to be a gas station in the sky.

A TAIL TALE

T1 is parked with its tail off the Bush to conserve space. The flight deck of an aircraft carrier is a busy, cramped space, requiring unique parking.

PHOTO: TIM REINHART/BOEING

“To drive the MQ-25, we have a unit that’s mounted on a belt, and it also has a display that mounts to your right arm as well as a control unit that we hold in our right hand. It has a joystick that controls the nosewheel steering, wing folding, tailhook and launch bar.”

RYAN HANNEKEN, MQ-25 TEST ENGINEER AND DECK HANDLING OPERATOR

Remote Control Beginnings

The streamlined, modular, handheld control design debuted on the Bush was the result of multiple iterations with Boeing, the Navy and the deck control device supplier, SECO USA.

Ryan Hanneken, MQ-25 test engineer and deck handling operator: “To drive the MQ-25, we have a unit that’s mounted on a belt, and it also has a display that mounts to your right arm as well as a control unit that we hold in our right hand. It has a joystick that controls the nosewheel steering, wing folding, tailhook and launch bar.”

Rich Bubenheim, MQ-25 support equipment engineer: “Refining that design was a challenge. As an engineering team, we were held accountable every step of the way. We worked with subject matter experts from Boeing and the Navy to define the system requirements and specifications that were essential for a carrier-based system. The sailors who will use this device are working in one of the most stressful environments in the world, so we knew we had to build an intuitive system that’s easy to use and carry. It also has to be compatible for the carrier environment. For example, we took steps early on to strengthen the electromagnetic interference shielding design.”

ALL IN THE WRIST

Boeing engineers Brad Whittington (left) and Adam Finck run diagnostics before a deck handling test. A display unit on the right arm provides various startup and shutdown commands, but “driving” the unmanned aircraft is done head-up with a handheld device (not pictured). Radios on the belt send signals from the handheld device to the aircraft.

PHOTO: U.S. NAVY/MASS COMMUNICATION SPECIALIST 3RD CLASS BRANDON ROBERSON

MQ-25

Savage: "Everybody who's in engineering wants to figure out how the world works, how it all fits together. On the test side of the house, we get to play with these airplanes and try to push them to their limits. We want to know where those limits are so we can design a safe product. We put the vehicle through its paces so when we deliver the production variant to the Navy, they know MQ-25 can be trusted to do what it's supposed to do."

Coy Wilhelmy, MQ-25 flight operations mechanic and deck handling operator: "The diversity of the integrated test team is incredible — both Boeing and Navy personnel, veterans and civilians, engineers for every technical specialty, pilots serving as air vehicle operators, mechanics like me."

MQ-25

Driver's Ed

Learning to "drive" T1 was an amped-up version of learning to drive a car — requiring a lot of practice, multiple tests and a diverse team.

Chantel Iwen, MQ-25 courseware development and training lead: "Sometimes training is taken for granted, but we have such an amazing team that worked hard to make this event safe and successful. Some of the drivers had never been on a carrier, and only a few of the flight deck directors had experience with this unmanned aircraft. Our team helped develop and provide the training on everything from the deck handling device itself to handoff procedures to flight deck operations — resulting in the official 'driver's license' to operate T1 on the carrier."

Part of the testing involved simulation work in St. Louis, with deck handling operators using the real hardware to move a simulated MQ-25 around on a simulated carrier deck. The team then graduated to moving T1 around MidAmerica St. Louis Airport in Mascoutah, Illinois, using lines painted on the concrete as the carrier boundaries. This was repeated at Naval Station Norfolk, Virginia, right before T1 was craned aboard the Bush.

Bubenheim: "In addition to operator training, the simulator helped us refine the product and mature the deck control design. Members of the Navy Fleet Integration Team got their hands on the system early and provided valuable feedback throughout the development process."

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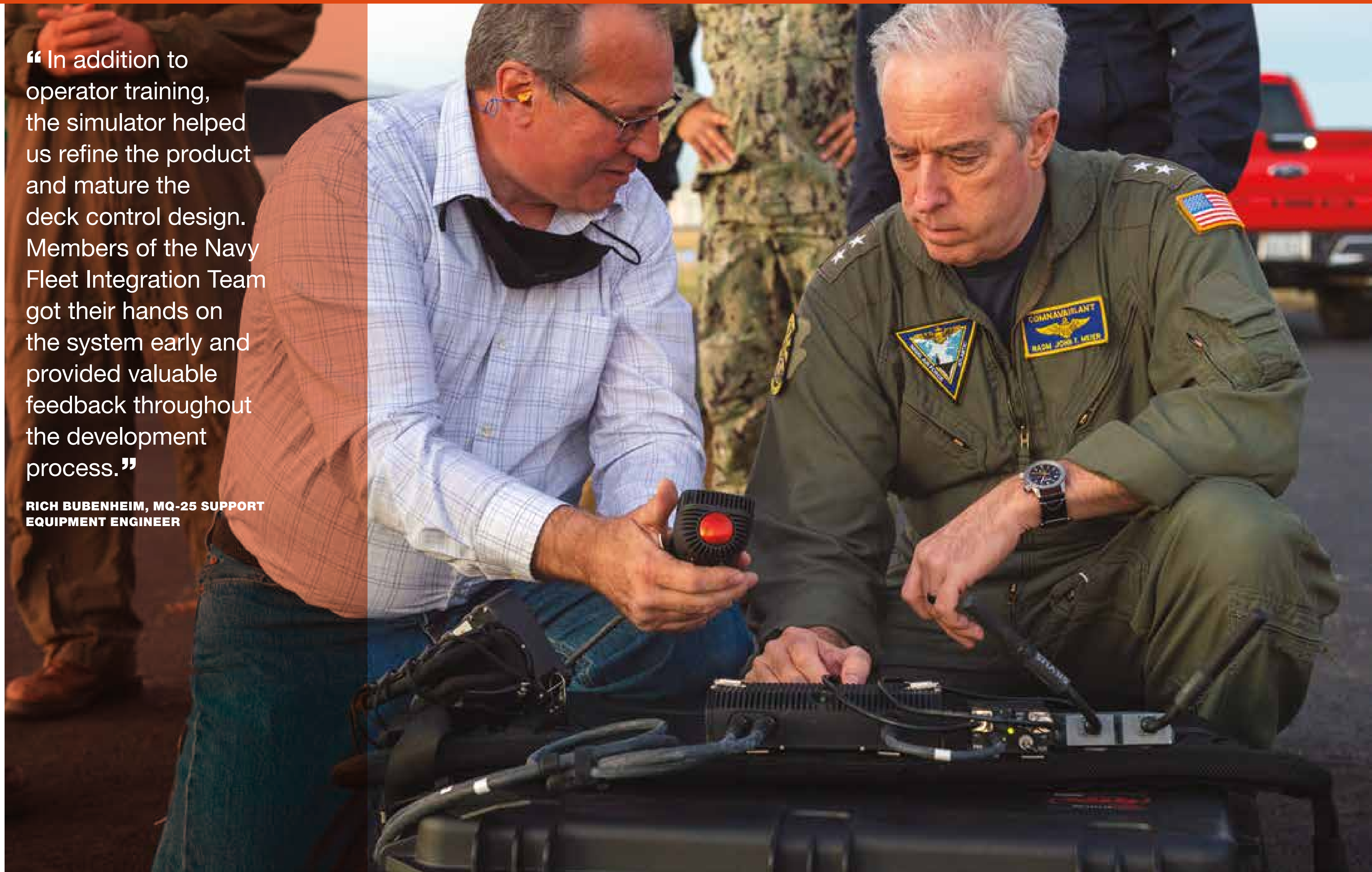
>
> **RICH BUBENHEIM, MQ-25 SUPPORT EQUIPMENT ENGINEER**



DEVICE DEMO

Boeing service systems electrical lead Rich Bubenheim (left) briefs Rear Adm. John Meier, commander of Naval Air Force Atlantic, on the deck control device for the MQ-25 Stingray at Chambers Field on Naval Station Norfolk, Virginia.

PHOTO: U.S. NAVY/MASS COMMUNICATION SPECIALIST 2ND CLASS SAM JENKINS

Test Time

For more than a week at sea, the Boeing and Navy team tested T1's ability to integrate into normal carrier operations. Six trained Boeing deck handling operators donned the remote control system and worked with eight Navy flight deck directors to move T1 around the deck using the Navy's well-established system of hand signals.

Hanneken: "We drove T1 around the deck, starting small and increasing our difficulty along the way. We tested the differential breaking to see how that software will work in the carrier environment. We drove T1 into the catapult, never once overshooting the entry. The catapult safety officer gave us the turnup signal, which allowed us to signal the air vehicle operator [AVO] below deck to go to full power as if we were ready for takeoff."

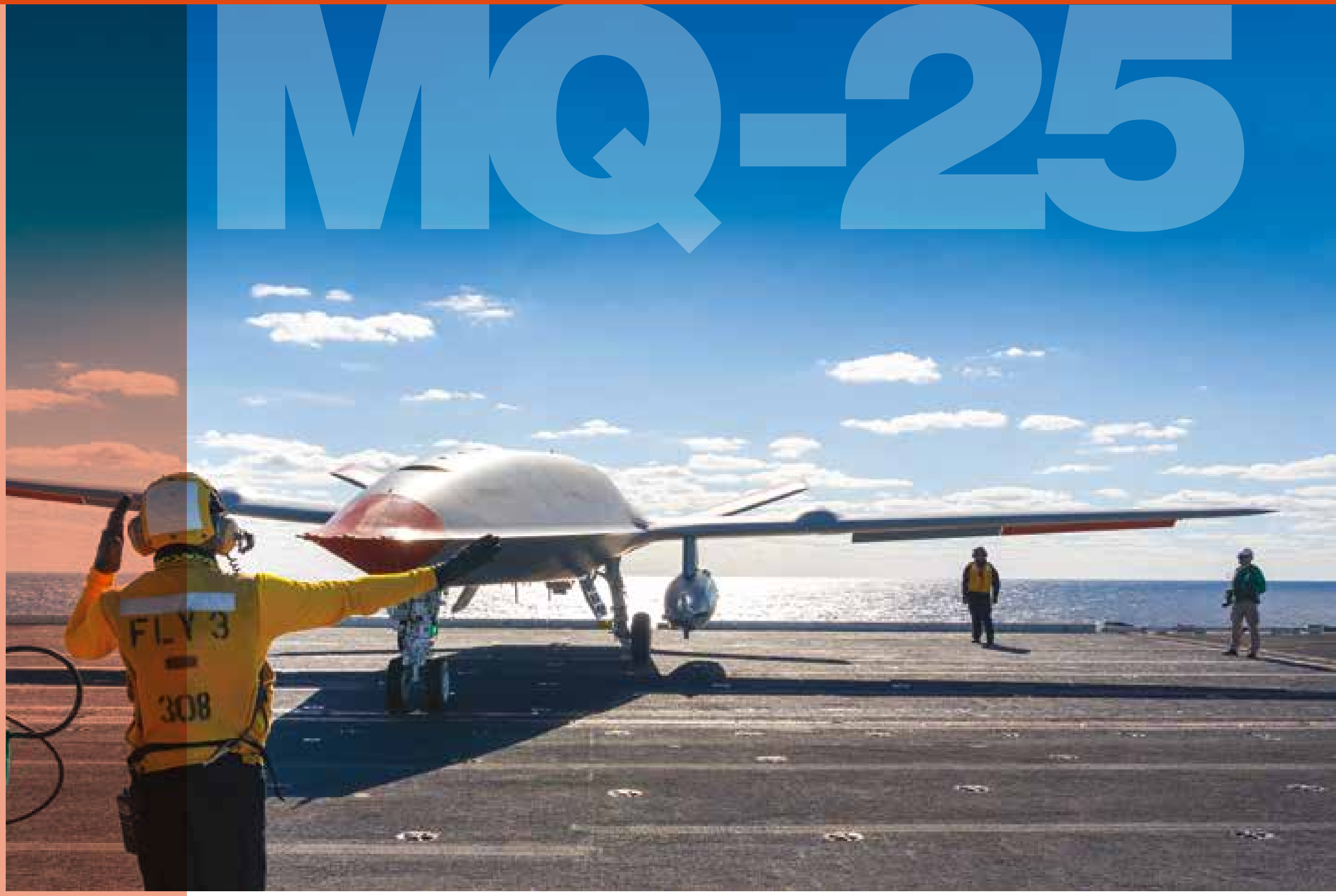
Cedric Cook, mission systems engineer: "While the AVO has control over the vehicle in flight using the ground control station [GCS], movement on the carrier deck is different; the deck control devices are the source of control. Even with this, the GCS still monitors the vehicle, and AVOs can do emergency controls if necessary — it's part of the safety redundancy built into aircraft operations."

Iwen: "Every single day, we learned something new, like deck obstructions and other situations we didn't think of when developing the training. The aircraft directors on the ship had to get used to not looking at an actual pilot, instead knowing that someone right behind them is driving the aircraft."

Savage: "We ran all kinds of test points on the carrier, both day and night scenarios. And what we saw was within our predictions of how MQ-25 would operate. The deck handling system performed like we practiced. We showed we can move this unmanned aircraft on the deck using existing Navy procedures. We have valuable feedback from the Navy on potential improvements in terms of turn radius, speed and device brightness that we'll use in this next phase of development."

"Every single day, we learned something new, like deck obstructions and other situations we didn't think of when developing the training. The aircraft directors on the ship had to get used to not looking at an actual pilot, instead knowing that someone right behind them is driving the aircraft."

CHANTEL IWEN, MQ-25 COURSEWARE DEVELOPMENT AND TRAINING LEAD



HANDS UP

U.S. Navy flight deck directors — known as yellow shirts — move aircraft on the carrier deck using a system of hand signals. The MQ-25 will also be moved using hand signals, with deck handling operators standing behind the yellow shirts entering the commands into the deck control device.

PHOTO: TIM REINHART/BOEING

Mike "Hank" Schmank, flight test safety lead: "The carrier deck is one of the more unique and challenging test environments that I have been involved with. The environment is remote, loud, slick, cold, windy and extremely dynamic. The combined test team invested a great deal of effort to ensure the safety of all test participants, both prior to embarking and while underway. I was extremely proud of how laser-focused on safety the team was, and we adjusted test operations from daily learnings. That effort paid off and was a huge part of the overall success of the mission."

Hanneken: "Being out here for this demonstration is pretty historic. In the future, when this aircraft regularly flies on and off the carrier and is part of daily life, I'll look at the person driving it on the deck and be able to say I was one of the first to do that."

Cook: "When you look around at this team and the amazing things we're doing, you realize you're bringing up the next generation of engineers and innovators. These are the people who will carry on the legacy of naval aircraft development."

DECK CHECK

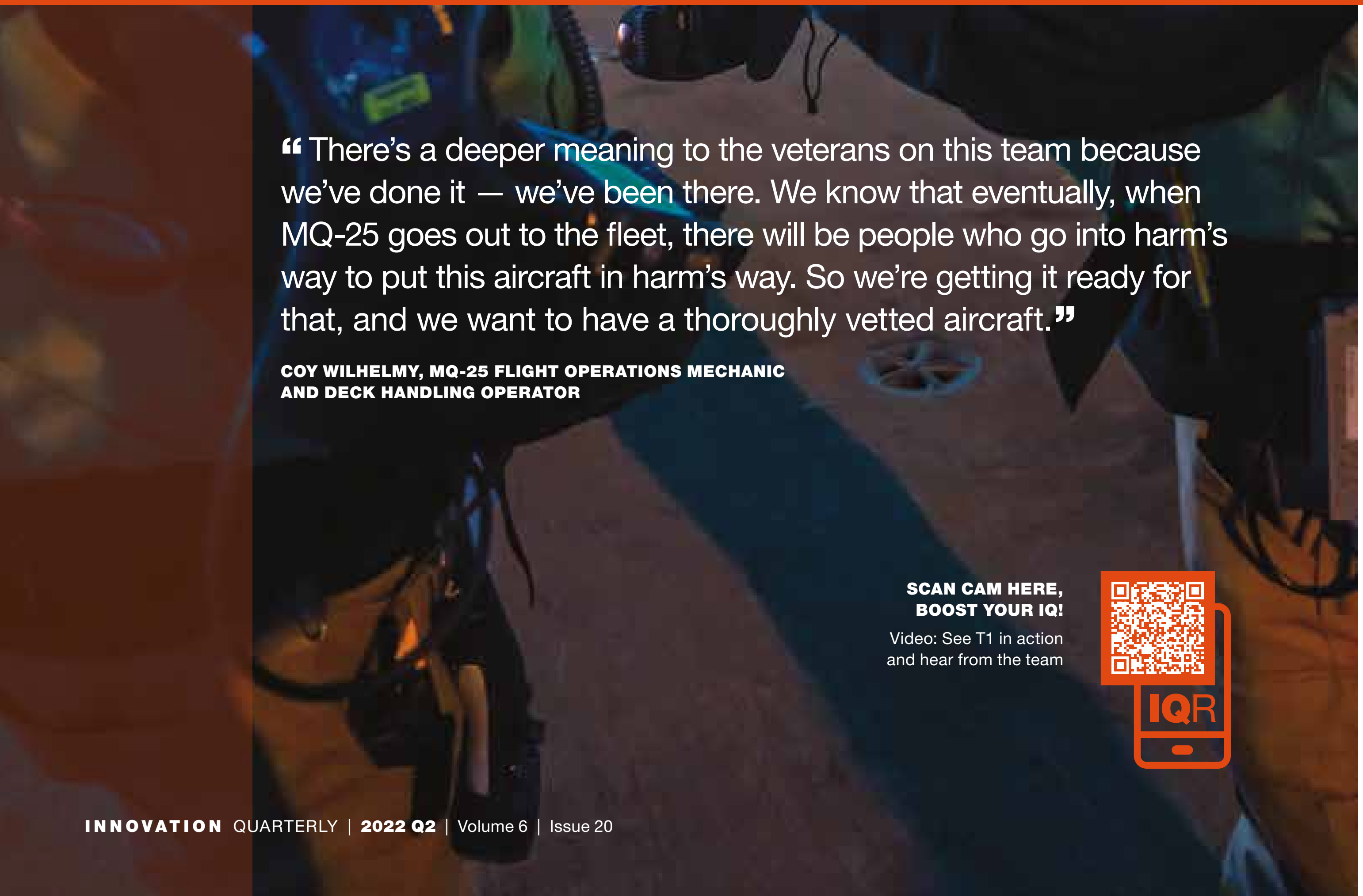
Boeing engineer Sam Hainline (right) and flight operations mechanic Coy Wilhelmy consult the display of the MQ-25 deck control device during startup procedures.

PHOTO: TIM REINHART/BOEING

REFUELING ROLE REVERSAL

The MQ-25 will take over aerial refueling currently performed by F/A-18 fighter jets (like the two in the foreground). This will allow the Super Hornets and their pilots to return to their original strike fighter roles.

PHOTO: TIM REINHART/BOEING



"There's a deeper meaning to the veterans on this team because we've done it — we've been there. We know that eventually, when MQ-25 goes out to the fleet, there will be people who go into harm's way to put this aircraft in harm's way. So we're getting it ready for that, and we want to have a thoroughly vetted aircraft."

COY WILHELMY, MQ-25 FLIGHT OPERATIONS MECHANIC AND DECK HANDLING OPERATOR

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Video: See T1 in action and hear from the team

IQR

One Step Closer

The successful carrier demonstration was another step forward in bringing the MQ-25's capability to the fleet — and a moment of reflection for the veterans on the team.

Bubenheim: "Having spent six years active duty, it was gratifying to see the professionalism of all the sailors on the carrier, as well as how our MQ-25 team worked together to carry out the mission. When T1 was in the catapult at full engine power with wings spread, it was a moment I will never forget."

Wilhelmy: "There's a deeper meaning to the veterans on this team because we've done it — we've been there. We know that eventually, when MQ-25 goes out to the fleet, there will be people who go into harm's way to put this aircraft in harm's way. So we're getting it ready for that, and we want to have a thoroughly vetted aircraft."

Brad Whittington, ship suitability engineer and deck handling operator: "Representing Boeing to the U.S. Navy, the organization I was proud to be a part of for 20 years, is coming full circle. I'm ensuring that the product the Navy gets is the best, and MQ-25 is a game-changer. It's altering how we employ aircraft in operations from ships at sea. Unmanned aircraft are very likely going to be a staple of the fleet. We're on the ground floor of integrating unmanned aviation into the Navy, and it's going to increase the capability of everyone in the fleet."

Iwen: "Being on a carrier brought back a lot of memories — things I didn't even know I missed. It's a family, and we take care of each other. Our team has a close relationship with the Navy. We work collaboratively on everything we do. I am lucky enough to be part of this historic program and give back to the Navy all the experience and exposure they gave to me." **IQ**

WHY BOEING

Flight test conductor lives her dream

Diverse engineering paths enable world-changing innovation

> "It's exciting, the diversity of opportunity. You can have five careers at Boeing. I am one who likes to try different things."

PHOTOS: BOEING

Every day is the future for Emily Schnieders. She spends her working hours as a flight test conductor for the Boeing T-7A Red Hawk advanced trainer, a digital engineering pathfinder. In a recent conversation in St. Louis, Schnieders explained how she's living her dream.

Boeing was my goal. I was passionate about airplanes, rocket science. …

… I started at Boeing as an intern out in Seattle working on 787. I did a two-year rotational program. My first job was working in the Final Delivery Center. And just walking past the F-15s and F-18s as I walked into work, that was definitely a mind-blowing experience. …

… It's exciting, the diversity of opportunity. You can have five careers at Boeing. I am one who likes to try different things, go to commercial, defense, space. …

… A lot of the new technologies we're working on and that have been developed by Boeing are changing the world. **IQ**

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Video: See and hear more from Emily.

IQR

Have a seat

HOW AIRPLANE INTERIORS EVOLVED TO MAXIMIZE SAFETY AND COMFORT

BY LESLIE HAZZARD, BOEING HISTORICAL SERVICES

The magic and safety of flight for passengers have improved exponentially throughout the past century.

PHOTOS COURTESY OF THE BOEING ARCHIVES UNLESS OTHERWISE NOTED.

The Boeing Model 40A, which first flew on May 20, 1927, was the first Boeing airplane to carry airline passengers. Originally designed to carry mail, the plane had room for two passengers in a tiny cabin.

Just a year later, Boeing introduced America's first airliner designed specifically for passenger safety, comfort and convenience. The Model 80 carried 12 passengers in a spacious cabin appointed with leather upholstery, reading lamps, forced-air ventilation, and hot and cold running water.

Ellen Church, a registered nurse, convinced Boeing managers that women could work as stewards, so nurses serving aboard the Model 80A became aviation's first female flight attendants, helping to comfort passengers who felt ill and enhancing the safety of all onboard. The nurses earned $125 for flying 100 hours a month.

Boeing led the way in the development of modern all-metal, semi-monocoque, cantilever monoplanes, beginning with the Monomail. Originally a mail plane and later a six-passenger transport, the Monomail was a pioneer of all-metal design, which is more durable and resistant to damage and corrosion. All-metal construction quickly surpassed wood structures.

1920s

BOEING MODEL 40A

1930s

BOEING MODEL 80

FOKKER F-10

Boeing heritage company Fokker Aircraft Corporation of America was an early adopter of seat belts. Note the seat on the center right.

In 1933, Boeing delivered the revolutionary Model 247. It was an all-metal, twin-engine airplane and the first modern passenger airliner, ushering in the age of speed, reliability, safety and comfort in air travel. The Model 247 flew at 189 mph (304 kph), making its trip between New York and Los Angeles 7.5 hours shorter than earlier airplanes' trips, dramatically improving the experience for passengers.

The DC-1 (Douglas Commercial Model One), also introduced in 1933, was designed to compete against the Model 247. The DC-1 was advanced for its day, and its plush seats, kitchen and restroom set a new standard for passenger comfort. Great efforts were made to insulate the passenger compartment from the noise of the plane's engines. Passenger seats were mounted on rubber supports, while the cabin was lined with noise-absorbing fabric. Carpet covered the cabin floor, and even the engines were mounted on rubber insulators.

Inspired by the technical success of the Douglas DC-1, Douglas introduced the DC-2 less than a year after the DC-1's first flight. The new plane was similar in shape to the DC-1 but had more powerful engines, was faster and was capable of longer flights. The DC-2 was an instant hit, establishing 19 American speed and distance records in its first six months of service.

In 1934, Transcontinental & Western Air (TWA) put DC-2s on overnight flights from New York to Los Angeles. The airplanes, called "Sky Chiefs," left New York at 4 p.m. and, after stops in Chicago; Kansas City, Missouri; and Albuquerque, New Mexico, arrived in Los Angeles at 7 a.m. For the first time, passengers could fly from coast to coast without losing a business day.

The Douglas DC-3, which made air travel popular and airline profits possible, is universally recognized as the greatest airplane of its time. The first DC-3 built was the Douglas Sleeper Transport also known as the Skysleeper by airline customers — and it was the height of luxury. Fourteen plush seats in four main compartments could be folded in pairs to form seven berths, while seven more folded down from the cabin ceiling. The plane could accommodate 14 overnight passengers or 28 for shorter daytime flights.

1930s

BOEING MODEL 247

DOUGLAS DC-2

DOUGLAS DC-3 SKYSLEEPER

BOEING MODEL 307 STRATOLINER

The next major advancement in the passenger experience came with more powerful airplanes that could fly at higher altitudes. The Boeing Model 307 Stratoliner was the world's first high-altitude commercial transport and the first four-engine airliner in scheduled domestic service.

Its pressurized cabin allowed the airplane to safely soar above rough weather at an altitude of 20,000 feet (6,096 meters) — higher than any other transport of its time. And a circular fuselage provided maximum space for the five crew members and 33 passengers. The nearly 12-foot-wide (3.7-meter-wide) cabin had space for comfortable berths.

As airplane travel became popular during the mid-1930s, passengers wanted to fly across the ocean, so Pan American Airways (Pan Am) asked for a long-range, four-engine flying boat. In response, Boeing developed the Model 314, nicknamed the "Clipper" after the great oceangoing sailing ships.

Clipper passengers looked down at the sea from large windows and enjoyed the comforts of dressing rooms, a dining salon that could be turned into a lounge and a bridal suite. The Clipper's 74 seats converted into 40 bunks for overnight travelers. Four-star hotels catered gourmet meals served from the Clipper's galley.

1930s

BOEING MODEL 314 CLIPPER

DOUGLAS DC-6

The Douglas DC-6 was one of the first airplanes to offer passengers a regularly scheduled around-the-world route. The DC-6 could fly 90 mph (145 kph) faster than the DC-4 and 850 miles (1,368 kilometers) farther. It could also maintain a cabin pressure of 5,000 feet (1,524 meters) while flying at 20,000 feet (6,096 meters). Pan Am used the DC-6 to start tourist-class service across the North Atlantic.

After Boeing introduced the Model 367-80, or Dash 80 — the prototype for the world's first successful jet transport, the 707 — the rest of the company's 7-series jets soon followed. As the 707, 727 and 737 arrived in the 1950s and 1960s, all incorporated passenger improvements, including the ability to fly faster and at higher altitudes. For example, the 737 engines were mounted under the wing. This engine placement buffered some of the noise and decreased vibration.

1940s 1950s 1960s

BOEING 707

The 747 — the largest civilian airplane in the world at the time and the "Jumbo Jet" that made travel affordable for the masses — was built in roughly 16 months during the late 1960s.

Boeing connected the upper level of the 747 with the main cabin by a graceful spiral staircase that was based on a similar design from the Boeing 377 Stratocruiser. Starting with the 747, Boeing replaced hat racks in its commercial airplanes with overhead bins for increased convenience and safety. The bins kept baggage and other items secure during turbulence, preventing them from falling onto and injuring passengers.

HISTORY OVERHEAD

On the 747, overhead bins replaced the conventional hat rack-style storage, securing luggage in case of turbulence.

1960s

BEFORE

Early 727 interiors featured open storage above.

1970s

AFTER

Later 727 interiors featured overhead bins that closed for safety and convenience.

BOEING 747

Qantas Captain Cook interior

Decades later, in 2011, the last member of the 747 family — the 747-8 Intercontinental, serving the 400- to 500-seat market — made its first passenger flight. The cabin's sculpted ceilings, bigger overhead and side stow bins, a redesigned staircase and dynamic LED lighting all added to an enhanced passenger experience.

Both Boeing and Douglas (later McDonnell Douglas) went on to produce several more jetliners, including the 767, 777, DC-9, DC-10, MD-11, MD-80 and MD-90.

1980s

After various airplane accidents in which fire contributed to loss of life, the U.S. Federal Aviation Administration (FAA) implemented new regulations in 1984 and 1986 for fire-resistant properties. Accordingly, manufacturers began testing seat cushions for oil burn, representing a fuel-fed fire.

Additionally, testing also began on large panels throughout the cabin to evaluate heat release and smoke emission. Although these regulations initially only applied to new type certificates after the mid-1980s, all airplane cabins comply today.

In 1988, the FAA issued a regulation to require actual crash-testing of airplane seats after reviewing "areas where possible improvement in passenger safety could be achieved on transport airplanes in survivable accidents." In response, Boeing first started requiring crash-tested 16 G-force (16 times the force of gravity) seats on the 777, replacing the 9 G-force seats previously used in the industry.

DOUGLAS DC-10

BOEING 737
Boeing Sky Interior

1990s

By 1993, Boeing was developing the Next-Generation 737s — the 737-600, -700, -800 and -900. Later models of the family included the 737 Boeing Sky Interior, featuring a change in ceiling architecture, resculpted sidewalls and window reveals, and lighting to help connect passengers to the magic of flight.

2000s

The design, now the standard cabin on the 737 MAX family, offers larger, pivoting overhead bins that add to the openness of the cabin. The bins tuck up and out of the way when closed, resulting in a roomier experience. There's also an option for larger pivot bins called Space Bins — available as a production or aftermarket modification offering — that provide up to 50% more overhead storage.

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

All-LED cabin lighting, which brought color into the cabin as a baseline offering, was introduced on the 787 Dreamliner, which also features larger, electronically dimmable windows in lieu of window shades. Pivot bins were redesigned to maximize their volumetric size, creating a space for every passenger's bag.

The 787, the world's first commercial airplane with 50% of its primary structure made of composite materials, also introduced advanced technology enabling passengers to arrive at their destinations more rested and comfortable. The cabin environment was reinvented for the passenger, lowering the effective cabin altitude, increasing humidity in the cabin, creating cleaner air through gaseous filtration and creating a smoother ride for passengers through technology known as vertical gust suppression.

Boeing has delivered airplanes with true high efficiency particulate air (HEPA) filters since they became available for airplanes in the mid-1990s. The company's in-production airplanes all incorporate true HEPA filters in their cabin air systems. The filters remove more than 99.9% of viruses and particulates from air.

Inside the cabin, the volume of cabin air is exchanged every two to three minutes and flows primarily from ceiling to floor before leaving through the floor grilles near where it enters. Combined with seatback geometry, this cabin design helps to limit the potential spread of contaminants.

2010s

DREAM DOME

The 787 Dreamliner cabin can include an iconic full-height dome.

PHOTO: BOEING

DREAM TEAM

(From left) Interior architect Zach Kilcer, cabin marketer Brenna Wynhof and airplane product strategist Katie Faires showcase a 787 Dreamliner interior. Airline representatives can walk through the latest offerings at the Boeing Customer Experience Center in Renton, Washington.

PHOTO: DAVE SIZER/BOEING

BOEING 777X OVERHEAD BINS

PHOTO: BOEING

More recent cabin enhancements include reclining seats, increasingly bigger bins (with reduced closing forces in the upcoming 777X interior), in-flight entertainment, internet access, and power outlets for laptops and other personal electronic devices. The 777X will, like its predecessor, significantly enhance the passenger experience.

BOEING 777X

2010s 2020s

BOEING 787 DREAMLINER
Adient Aerospace's Ascent business-class seats on a Qatar Airways 787-9 Dreamliner.
PHOTO: QATAR AIRWAYS

2010s

Nearly a century after passengers were willing to hop inside an airmail plane to experience the thrill of flight, Boeing continues to evolve the cabin environment. In addition to continued research and customer feedback, the company tests new technologies in its Concept Center, including the validation cabin, or "VCabin."

The VCabin demonstrator is a product development initiative designed to accelerate the technical feasibility, refinement and completion of cross-model, cross-functional cabin technologies and features that enhance the cabin experience and value of the airplane from design to end of service.

2020s

In 2016, Boeing formed a new Cabin and Interiors team focused on increasing product life-cycle value for airlines and other airplane operators by providing more options, greater capacity, improved quality and on-time delivery.

In 2018, Boeing launched the Adient Aerospace joint venture with car seat manufacturer Adient to design, manufacture and sell innovative production and retrofit aircraft seating for Boeing and other original equipment manufacturer aircraft models. Since its inception, Adient Aerospace has brought several new seating products to market, including Ascent, an award-winning lie-flat business-class seat that entered service with Qatar Airways in 2021.

In 2019, Boeing acquired EnCore, now Boeing EnCore Interiors, to expand manufacturing capabilities and market growth opportunities for other cabin products, including galleys (food and beverage preparation areas), panels, ceilings and monuments (other built-in structures).

To provide a more efficient cabin products evaluation process for its customers, Boeing EnCore Interiors recently developed a virtual interactive environment that allows airlines to easily view and model different galley design scenarios by selecting from numerous pre-qualified modular features and options.

Today, the Cabin and Interiors team includes more than 1,000 employees in multiple locations around the world, supporting development and delivery of new in-line production and retrofit seating and interiors products for both Boeing and non-Boeing commercial airplanes. Driven by continuous innovation and customer focus, the team is developing an integrated and industry-leading suite of cabin products, providing a broad array of options to enhance the passenger experience while also offering flexibility to adapt to each airline's business objectives.

Boeing Global Services also offers airplane interior modifications services and the company's own digital cabin services offering, Boeing Digital Direct, which provides wireless in-flight entertainment and e-commerce capabilities for operators.

And nearly 100 years after the Boeing Model 40A flew its first two passengers, the CST-100 Starliner team has designed a visionary passenger experience for spaceflight. Developed in collaboration with NASA's Commercial Crew Program for missions to low Earth orbit, the spacecraft offers room for seven passengers or any combination of crew and cargo. It also features wireless internet and tablet technology for crew interfaces.

The Starliner seats are some of the most advanced models ever developed for a spacecraft. Made to fit the sizes of 95% of the population, they are strong enough to bear the increased weight of launch dynamics as well as the vibrations of reentry and landing.

From sky to space, Boeing continues to invent and enable new ways to invite passengers to have a seat. **IQ**

2010s

2020s

BOEING CST-100 STARLINER

STARLINER RECLINER

Each Starliner seat is made to work in unison with the spacesuits that crew members will wear.

Photo taken before Boeing implemented COVID-19 pandemic safeguards.

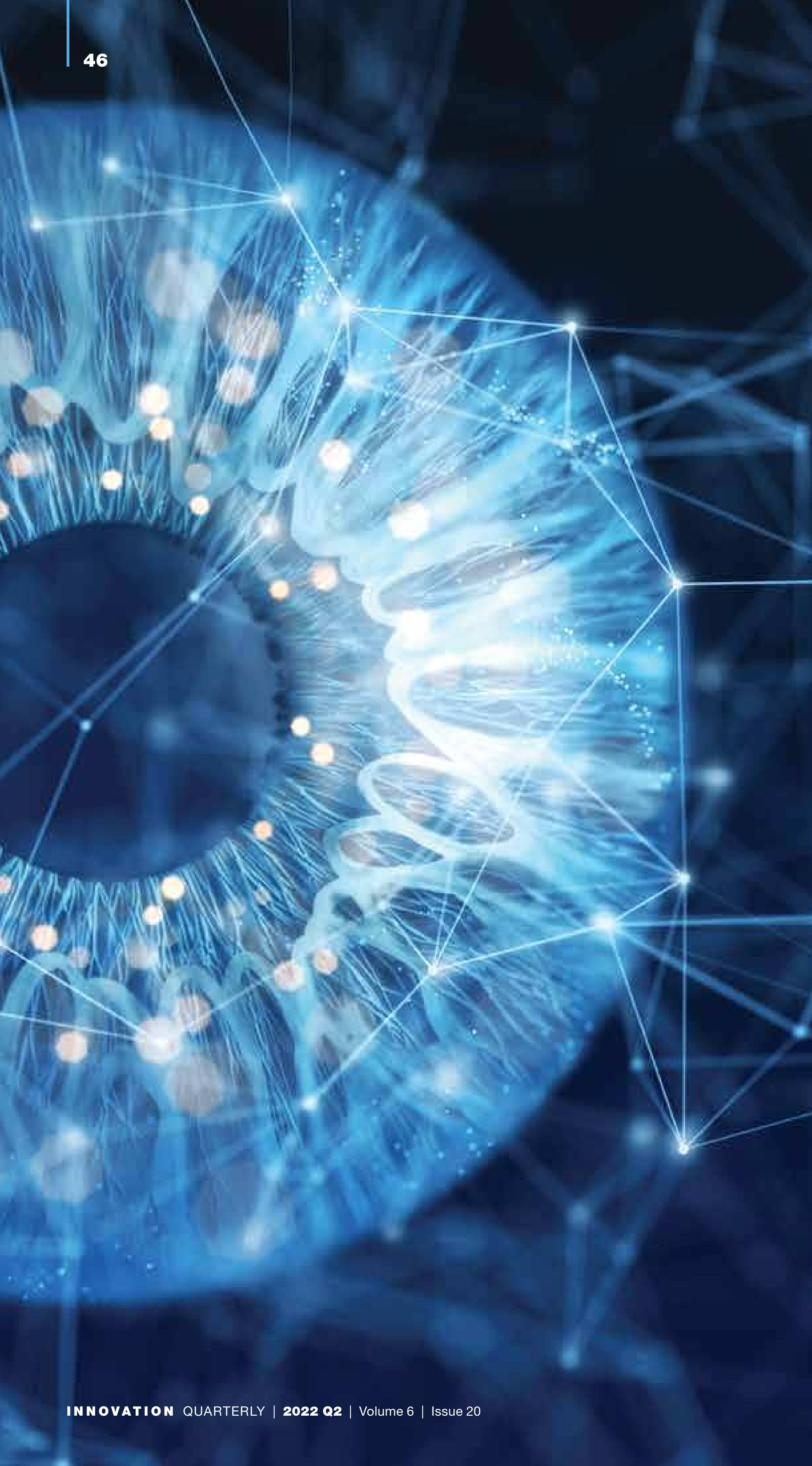
PHOTO: BOB FERGUSON/BOEING

PHOTO: TIM MCGUIRE/D.J. & COMPANY

4p + 3c = Engineering Excellence

A conversation about leadership, vision and the future with Boeing's Chief Engineer

Dr. Greg Hyslop is Chief Engineer of The Boeing Company and executive vice president of Engineering, Test & Technology. Hyslop leads the Engineering function, including more than 50,000 engineers worldwide, and oversees technology vision, strategy and investment. His responsibilities also include oversight of all aspects of safety and technical integrity for Boeing products and services. Engineering, Test & Technology is an incubator for businesses that will define the future of urban, regional and global mobility, as well as those aimed at near-term opportunities.



> “Modeling technical curiosity is critically important as an engineering leader. I must always be an engineer first, constantly learning and pushing myself into new areas of engineering or fields related to our industry.”

GREG HYSLOP, BOEING CHIEF ENGINEER

IQ: As Boeing’s Chief Engineer, what does leadership mean to you?

GH: Probably the most important characteristic of an engineering leader is curiosity, in all its dimensions. The best part of my graduate program at Washington University was working on my dissertation. The sense of discovery that came with seeing results that no one had seen before was tremendous. But it was work that was not solitary; it was done alongside my thesis adviser and another faculty member. I still remember the day when I made my breakthrough. I walked down the hall to review the result with my adviser; he shook my hand and said, “Congratulations! You got it.” And then he immediately gave me more work to do!

Modeling technical curiosity is critically important as an engineering leader. I must always be an engineer first, constantly learning and pushing myself into new areas of engineering or fields related to our industry. While I will not become an expert, I need to be informed so I can ask the right questions and assess the risks and opportunities.

But curiosity extends beyond technical fields to leading your team, especially when you are leading change. The higher you go in any organization, the more your job becomes identifying and leading change. But to effectively lead change, you have to know what your team is thinking at every level. This means being curious and seeking out their input. Have they heard the message? Is the message clear? Do they know what to do to implement this change? Do they understand why this change is necessary? Demonstrating this genuine curiosity is essential in leading change.

IQ: How does this play out in your role as Chief Engineer?

GH: Aerospace will always present some of the toughest engineering challenges. It was this way when our industry and company started, and it continues today. If the product can’t be built with first-time quality, it probably isn’t designed right. And if it can’t be operated or maintained in the field properly, it probably isn’t designed right. It all comes back to engineering.

This is why our values state right up front that we start with engineering excellence. We continue to strengthen and elevate engineering in our company. We recently unified all of engineering functionally and, two years ago, established four engineering priorities (the 4p):

- Safety Management System
- Design Practices
- Engineering Across the Value Stream
- Investing in and Empowering Our Team

All of these actions are designed to further strengthen our engineering, to continuously improve and act consistent with our values.

Our **Safety Management System** (SMS) will provide the framework and structure under which we can gather data from the operation and production of our products and the systems that design them. From that, we can identify risks and implement mitigation steps to avert incidents or accidents.

Our SMS has already led to significant changes and, in many respects, defines how we run the company now. SMS is how we work.

Our work on **Design Practices** is meant to capture the best of what we know from our history and to be the place to collect lessons learned from our SMS and our Quality Management System. Over the years, we've had a number of best practices and design guides across engineering, but in some cases, they weren't kept up to date and there was no uniformity in their format.

Our work now is to:

- Define a taxonomy for how we organize what we know.
- Establish an infrastructure and format for us to write it down.
- Create a means for peer review by our technical fellows.

I recall an early-career engineer described a design practice as the "journal of an engineering career."

When we talk about **Engineering Across the Value Stream**, there is a near-term and a long-term aspect. In the near term, we want engineers shipside in the factory, doing what they can to help stabilize our production system and achieve predictability. This means evaluating quality up close or perhaps identifying ergonomic concerns and then addressing issues by changing the design or modifying the work.

Longer term, this is about the digital transformation that is underway. When we're complete, we will apply the same level of rigor and modeling to our production system design as with the airplane itself. This will let us flatten the learning curve and bring our production system up to rate much faster.

As for **Investing in and Empowering Our Team**, this is how we recruit the best and brightest and how we retain the great talent we have and then provide training. We provide opportunities for growth, invest in continuing education, and offer a depth and breadth of experience that is unique to our industry. We want to provide the best environment for people to build a career in aerospace.

IQ: What behaviors or attributes do you look for in Boeing engineers?

GH: Not too long ago, a colleague sent me an image from a recruiting brochure from the late '80s. Yes, that's me in this photo!

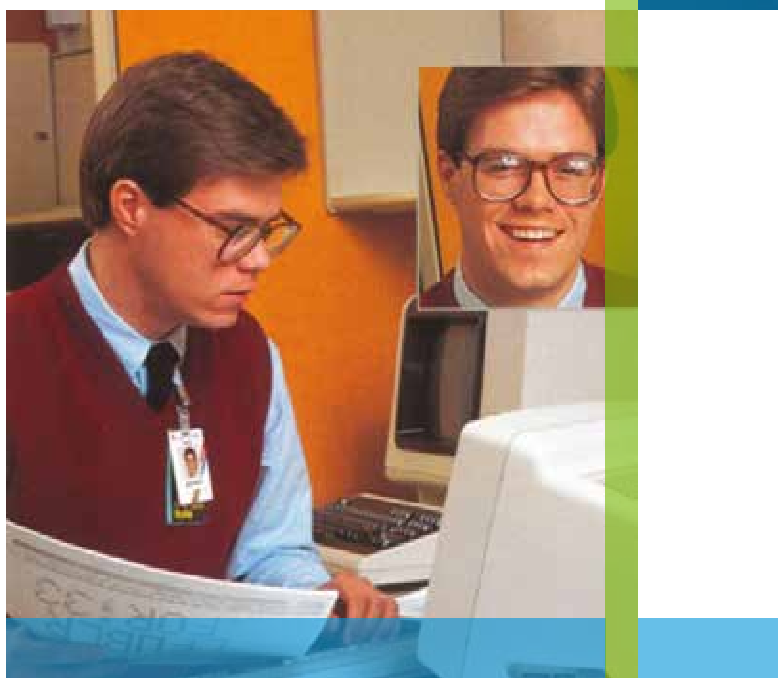


PHOTO: BOEING

It made me think back about what it was like for me as an early-career engineer. One of the biggest highlights during that period — apart from starting a family — was the publication of my first technical paper in a peer-reviewed journal. But professionally, I was even more excited by seeing algorithms I devised being implemented in our products.

I was energized by knowing that the math was being put to work to control real systems. I felt that thrill of discovery that comes with solving a tough problem for the first time and was invigorated to have it validated by peers. It couldn't get much better for an early-career engineer. Even today, more than 30 years later, I still remember that feeling of amazement and accomplishment.

It's an experience that starts with being curious, creative and courageous (the 3c). These characteristics will manifest themselves in our team as we connect to our four priorities.

For example, we want our engineers not only to understand their design of a part but also to be **curious** about how the part is fabricated, how it is assembled into the system, and how the system is operated and maintained. A Design Practice will give any engineer a place to start with what we know works, but it is built upon years of experience and lessons learned, from which new **creative** designs will emerge.

Finally, **courage** will manifest itself within our SMS and as we Invest in and Empower Our Team. An empowered engineering team has the courage to speak up when it comes to any issue around product safety, but everyone needs support. This is why we've created a robust functional organization and design board structure rooted in our Boeing Technical Fellowship, so no engineer should ever feel alone when raising an issue.

IQ: As you look back at your career of 40 years, what changes or developments stand out?

GH: The most significant changes I've witnessed are:

- The advent of GPS.
- The first steps toward autonomous flight.
- The dramatic increase in computing power for flight systems.
- The advances in composite materials leading to the 787 and the success of the point-to-point model for air travel.

One of my first assignments was integration of GPS into a cruise missile guidance system. This was the first application of this technology for a weapon and led to the advent of precision munitions. But think about what being able to reliably answer the simple question "Where am I?" has unlocked. From precision approaches in aviation to ride-sharing apps, none would be possible without GPS.

One of the enablers for integration of GPS into guidance systems was the ever-increasing capability of onboard computer processors. In addition to navigation, this computing power is being used for more and more autonomy in flight.

COMPOSITIVELY SPEAKING

Soaring above Charleston, South Carolina, a 787-10 makes it first flight in 2017. The 787 is 50% composite by weight, which significantly reduces fuel consumption and maintenance costs.

PHOTO: BOEING

My first jobs were with autonomous weapons, but the autonomy there was restricted to navigation, guidance and control along preprogrammed routes. But it was the precursor to what we see today and continues to expand, not only capabilities for flight but also processing of inputs from various sensors.

As for materials, the widespread use of carbon-fiber composites in aerospace stands out. And beyond the materials themselves, their far-reaching impact on commercial aviation is remarkable. The big bet between Boeing and Airbus was whether passengers would continue to fly to hubs on jumbo jets and then connect to their final destination or would they prefer point-to-point travel on ultra-efficient jetliners. The 787 has shown that we were right, enabled by the efficiency provided by a composite airframe.

IQ: What near-term and longer-term technologies stand out as offering immense promise?

GH: What's next? The great challenges facing aerospace as we proceed through our second century will be sustainable aviation and the digital transformation of our industry with all of its implications. For sustainable aviation, there will be multiple solutions, depending on the range and payload required for the mission, but it's amazing to see how far we've already come.

Through our joint venture with Kitty Hawk Corp., Wisk is the first company in the U.S. to develop and successfully fly an autonomous, all-electric vertical takeoff and landing (eVTOL) aircraft. This two-passenger eVTOL air taxi has flown more than 1,500 successful test flights and is on track to be the first autonomous passenger-carrying vehicle to be certified in the United States.

EDITOR'S NOTE

For more on Wisk, see Page 90.

When we think about digital transformation, there is no better testament to the advances in computing and modeling than Boeing's T-7A. This advanced pilot training system is truly a modern marvel. It completed more than 300 flight-test hours in our two preproduction jets before a single piece of metal was assembled on the first production jet. And the results are:

- A **75% improvement** in first-time engineering quality.
- An **80% reduction** in assembly hours.
- A **50% reduction** in software development and verification time.

Once we are free from obsolete constraints, and quantum computing takes hold, even more complex optimization will be possible. We'll also see machine learning become a standard part of every engineer's toolkit, regardless of their specialty.

The use of models based on large datasets, when combined with traditional physics-based models, will yield even more creative solutions to the challenges of the industry's second century. This is an exciting time to be in aerospace! **IQ**

DIGITALLY DESIGNED

The T-7A Red Hawk will lead future U.S. Air Force fighter and bomber pilots in their training for decades to come.

PHOTO: DAVID TORRANCE/BOEING

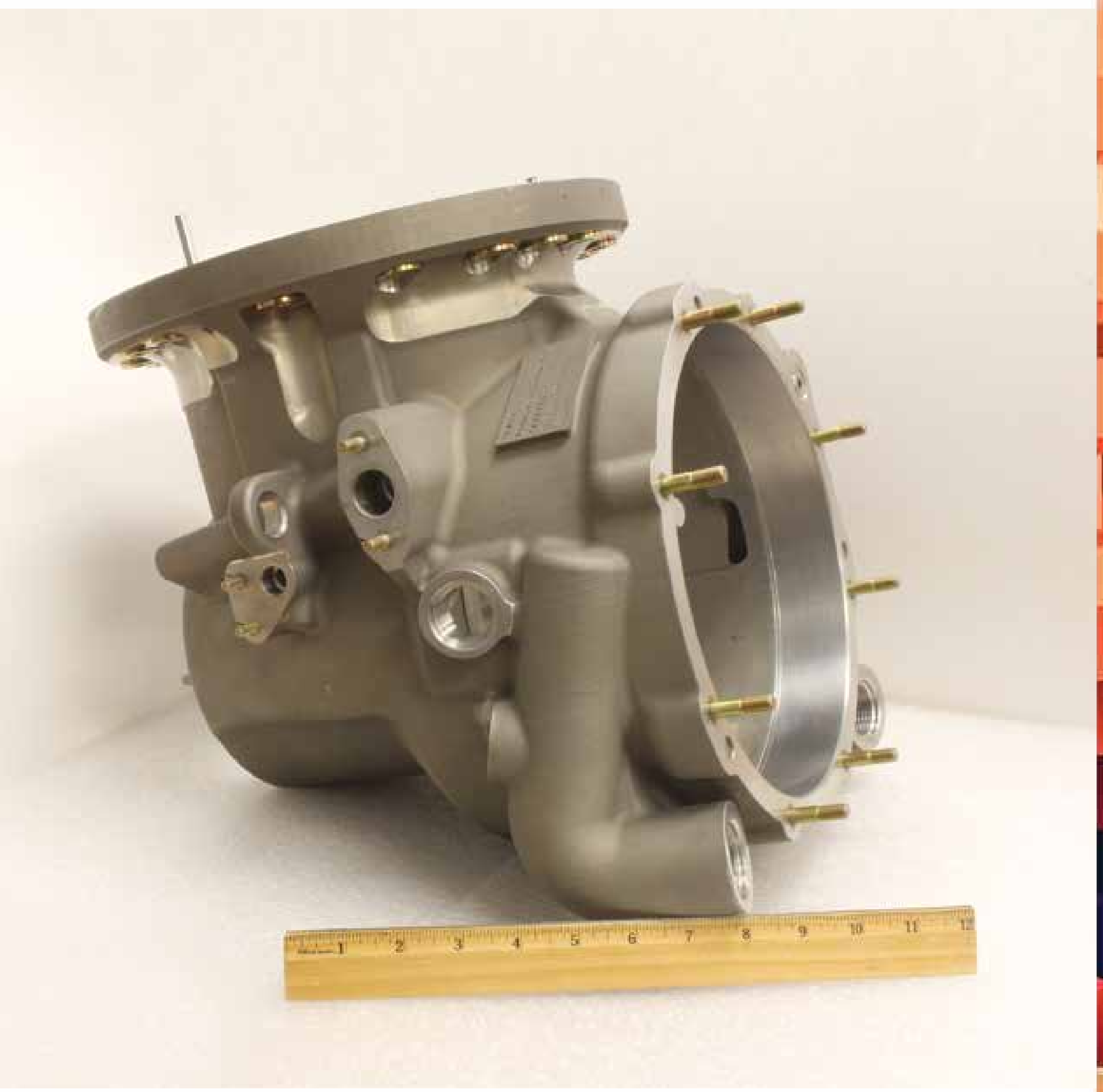
Integral part: A 3D-printing first

Chinook took 3D-printed, flight-critical part for a spin during test flights — a helicopter first

"Light on wheels" and "wheels off ground" were two phrases **Todd Harder** had been waiting years to hear. A Chinook drive systems engineer, he led the team that developed the first 3D-printed, flight-critical component used in rotorcraft. That part, an additive-manufactured transmission housing, took flight in multiple Chinook tests after years of development and bench testing to prove its airworthiness before it ever left the ground.

MAKING WAVES
U.S. Air Force Special Tactics operators conduct helocast training from the ramp of an MH-47G Chinook in Florida. The advanced helicopter could be enhanced by additive manufacturing.

PHOTO: U.S. DEPARTMENT OF DEFENSE



HISTORIC HOUSING

Flight tests proved this 3D-printed transmission housing could withstand the stress of rotorcraft flight, opening doors for additional 3D-printed advancements for the Chinook.

PHOTO: BOEING

Additive manufacturing lowered lead times and machining time plus enabled design improvements that improved quality for these Chinook test flights.

In the future, additive manufacturing could also help improve component costs and component weight and enable production of spare parts in the field, not just in a factory.

But what exactly is additive manufacturing? And why is this the first time it's ever been used to make a flight-critical part for a rotorcraft? In a recent conversation, Harder answered these questions and more.

Additive manufacturing lowered lead times and machining time plus enabled design improvements that improved quality.

TRANSMISSION TEST

Equipped with a 3D-printed transmission housing, this Chinook became the first helicopter to take flight with an additive-manufactured, flight-critical component.

PHOTO: U.S. DEPARTMENT OF DEFENSE

IQ: How does additive manufacturing compare to traditional manufacturing?

TH: For years and years and years, you start with a block of material, and you're whittling away and whittling away, machining, a lot of different processes, to get down to a final geometry.

With additive, it turns it on its head.

You're looking at taking very small amounts of material and depositing it, layer by layer, and building up this complex geometry without any … external machining processes.

IQ: Why did you use additive manufacturing for this part?

TH: For any development effort like this, the transmission is usually the longest lead component. And then when you drill down another level, the transmission housing is normally the longest lead component of the transmission itself. … So in this case, we wanted to utilize this new technology to create better lead times, to establish the fact that this is an applicable technology to that type of effort that could help us in the future and not just on this program.

IQ: What's fatigue life, and how is that important when designing additive-manufactured parts?

TH: For rotorcraft, that particular gearbox — or any gearbox in general — you have extremely quickly rotating components that are undergoing a lot of loading and unloading, speaking of gears specifically. But that translates out, of course, to the transmission housing. So the whole housing is then fatigue life driven.

The difference between a rotorcraft component and a space component, a space component is really undergoing a lot of load during liftoff. And then, once it's out of the atmosphere, for the most part it's free to live its life without being loaded.

Whereas for a rotorcraft component, it's seeing load continuously, continuously, continuously. So for our efforts, … not as much work had been done on the fatigue properties and how to improve those versus the ultimate, the yield strengths of the materials in general.

For a rotorcraft component, it's seeing load continuously, continuously, continuously.

SNOWBIRD

A CH-47F Chinook finds a perch in the Alps in Germany. 3D printing could make production of the rotorcraft more efficient.

PHOTO: U.S. DEPARTMENT OF DEFENSE

IQ: Other than your team, who helped make this 3D-printed part happen?

TH: There was a lot of collaboration within Boeing to get this done. … The Boeing Drive Systems team. The Boeing Metals Lab here in Philadelphia, as well as a lot of work done by the Boeing St. Louis folks to develop some of the material properties that we leveraged early on in this effort. Additionally, Boeing Mesa was even involved really early on with some non-flightworthy components. …

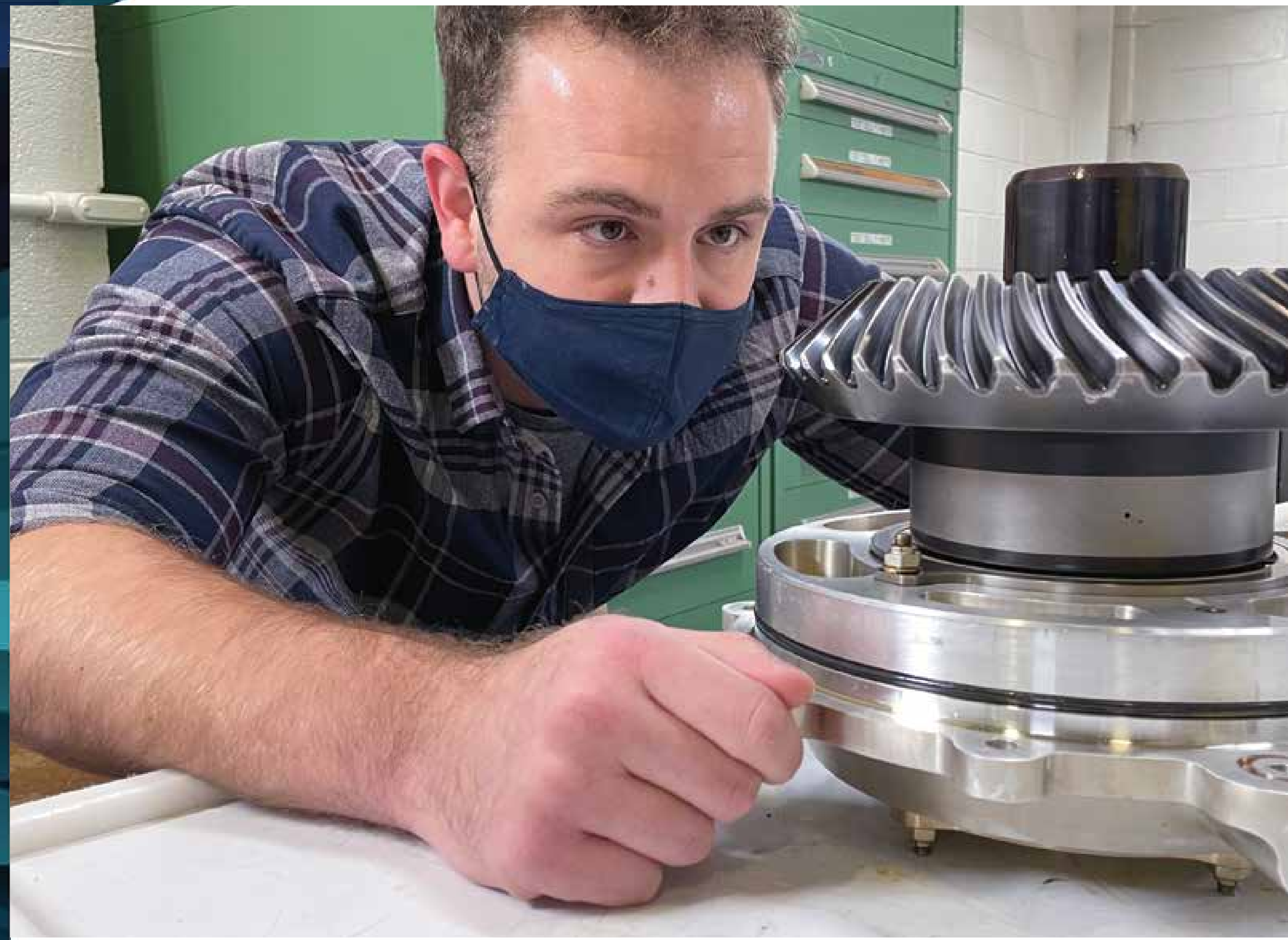
… We utilized all this knowledge that we'd accrued over the past several years and really applied it towards this end goal of getting these load-bearing, flightworthy transmission housings going.

And while it was a major effort for Boeing, we definitely couldn't have done it without cooperation from our Army customer. They brought a mindset that they were open to this new technology. They wanted it done correctly, of course. They wanted it to be a very robust, repeatable process where we proved out all of our material properties time and time again. We proved out that we could provide quality inspections on these components and that we did not have a risk of failure in flight.

SCAN CAM HERE, BOOST YOUR IQ!

Video: Todd talks more 3D printing.

We proved out that we could provide quality inspections on these components and that we did not have a risk of failure in flight.



INNOVATIVE ENGINEER

Todd Harder, a Chinook drive systems engineer at the Philadelphia Design Center, uses additive manufacturing to enhance safety and efficiency.

PHOTO: ANDREW AFRICK/BOEING

IQ: What do tests like this mean for the future of Chinook?

TH: The Chinook is still an innovative platform. … We're looking at new manufacturing technologies in this respect. We're looking at a lot of other available areas to get us to the next 50 years of flight. …

… There's a lot of capability within the Chinook platform that's going to be valuable to our customers in the future. **IQ**

WHY BOEING

Aerospace and modern computing

Vice president of software engineering explains mission-critical and human safety-critical applications

"You've got systems that carry our families, and you've got systems that defend our families. Those things need to work."

PHOTOS: BOEING

Thousands of software engineers led by Jinnah Hosein work to harness the power of modern computing and apply it in mission-critical and human safety-critical applications. In a recent conversation in Seattle, Boeing's vice president of software engineering explained the importance of software in aerospace.

There's a tremendous amount of honor and responsibility in being someone who knows something that really no one else in the industry knows, about how to produce a complex and safe system using modern software techniques. …

… You've got systems that carry our families, and you've got systems that defend our families. Those things need to work.

This isn't an environment where we move fast and break things. It's an environment where things can never break. …

… It's what makes software engineers at The Boeing Company so valuable and so special, is the things you learn here, you can only learn here. …

… We have to leverage modern techniques and apply them in human safety-critical applications. And we capture that in our people. And we capture that in our processes. And both are constantly evolving. …

… I think that is the experience that a lot of people have here, is that every day, they are surrounded by and exposed to other brilliant people, people who push them to be their best. …

… If you want to change the world, you have to work at a place like Boeing. **IQ**

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Video: See and hear more from Jinnah.

IQR

Predict to prevent

Aerospace safety analytics: Proactively identifying hazards and analyzing risk to improve safety

PHOTO: TIM MCGUIRE/D.J. & COMPANY

Vishwa Uddanwadiker is the safety analytics lead in Boeing's Chief Aerospace Safety Office (CASO). He is responsible for strengthening the Safety Management System for Boeing products and services through the use of data science and data analytics. He leads the development of the Boeing Safety Intelligence Solution that uses advanced modeling techniques and machine learning algorithms to identify hazards and risks through data.

In the following Q&A with Innovation Quarterly, Uddanwadiker outlines how safety and, in particular, safety data travel from engineers to the factory floor and into the sky.

“The keyword is prevent — to accomplish that, deep knowledge of critical causation models helps proactively identify hazards and monitor risks.”

VISHWA UDDANWADIKER, SAFETY ANALYTICS LEAD, CHIEF AEROSPACE SAFETY OFFICE

PHOTO: TIM REINHART/BOEING

IQ: How has Boeing’s aerospace safety analytics approach changed?

VU: We always start with CASO’s mission:

Drive aerospace safety to prevent accidents, injury or loss of life, with our Boeing culture and actions rooted in safety.

Advanced analytics enable this mission. The keyword is prevent — to accomplish that, deep knowledge of critical causation models helps proactively identify hazards and monitor risks. Then, the feedback loop runs through safety risk management and safety assurance processes and ultimately back into design practices and engineering teams.

It’s all part of our overall Safety Management System (SMS), a top-down, organizationwide approach to managing safety risk. SMS offers the vision. Aerospace safety analytics brings that vision to life.

As for a fresh approach, we are first studying key system engineering and accident causation models.

Second, the right hypotheses and questions are being developed to interrogate the data.

Third, external collaboration with industry partners and regulators provides diverse perspectives.

Fourth, an integrated product team pulls in talent from all corners of the company to ensure the right mix of functional and technical subject matter experts.

IQ: How does Boeing proactively identify potential safety issues and then take preventive action?

VU: The aerospace industry represents a complex system with many data sources and potential safety issues. A holistic look at the data will reveal correlation and causation, rather than a needle-in-a-haystack approach.

It is about identifying the right signals in the midst of the noise. We combine systems engineering and domain knowledge with advanced analytics to model safety risk.

The timeline is a three-step process. In the short term, signals from the operations environment are fed back to engineering. This feedback loop ensures the engineering is working on the factory floor.

In the medium term, we track our Continued Operational Safety Program (COSP) through our customer support function. This is data we examine carefully to identify potential safety issues.

In the long term, sometimes spanning decades, an airplane model’s performance over its lifetime informs future product and service design. All of this information is collected as operational metrics and risk models in the Boeing Safety Intelligence Solution, an effort to gather learnings in one living document. This aligns with the International Civil Aviation Organization’s (ICAO) standard as expressed on the organization’s website:

“The new era of computers and monitoring systems now allows to collect a huge amount of safety data, which, when correctly analyzed, can be transformed in what we called ‘safety intelligence’ and/or precursors to better address and monitor these risks.”

IQ: Explain the Aerospace Safety Analytics Roadmap and where Boeing hopes to be by 2025.

VU: The roadmap has three horizons. The first, which the company completed in 2021, aimed at developing demonstrators — building on previous work and extending it to move toward more proactive analytics. Assessing sources of data helped identify which different types are needed. We also looked at system engineering models and how to apply them and built on work with external stakeholders.

In the second and current horizon, the focus is the build-out of the Boeing Safety Intelligence Solution and the risk models that plug into it. Interrogating various types of data divulges more about correlations and causations of safety risk. The SMS team can then determine how to best inculcate its vision into our business units.

The third and future horizon is about actively identifying hazards and risks through data, then tracking and mitigating through the SMS processes. This horizon will be more integrated and visible outside the company.

By 2025, the goal is an SMS run completely with the Boeing Safety Intelligence Solution as its central nervous system — monitoring design, build and operations to predict and prevent safety issues. This will have strong integration as design practices and feedback loops connect back to engineering teams.

IQ: What important work is your team working on right now?

VU: The Boeing Safety Intelligence Solution stands on four pillars: **Compliance**, **Conformance**, **Fleet Safety** and **SMS Performance**. The first three run parallel to Design, Build and Operate. The fourth is about how well the SMS is functioning in the real world.

In the context of these four, insight into hazards, safety performance and building risk models will provide predictive and proactive input into the safety risk management and safety assurance processes.

IQ: What are some of the team's most pressing challenges?

VU: It is a rare opportunity to work in a field with such a clear and compelling mission that helps us rally together:

Drive aerospace safety to prevent accidents, injury or loss of life, with our Boeing culture and actions rooted in safety.

In terms of technical challenges, data needs to be cleaned and normalized before comparison with other datasets is possible. In this industry, there is also a lot of information in natural language format, human-speak that a computer may not be able to process.

Building the right tools to ingest, translate and classify the language appropriately is important. Also, data quality is good over the last few years. But comparing information from the previous decade to today is difficult but necessary work.

Another significant challenge is the breadth and depth of expertise required to model the diversity of risks across design, production and operations. The work spans many engineering, operations and analytics disciplines and other sciences such as anthropology, immunology and more. An agile development program and integrated product team structure helps connect stakeholders from across Boeing and external partners within each study and development effort.

A single team cannot be big or broad enough for this mission — it requires the whole company and industry working together.

And finally, functionally speaking, it is a daunting task to craft the right questions and hypotheses upfront. In most cases, it becomes cyclical — as you get a feel for the data, you have to go back and refine the hypothesis. Also, validating the conclusions of the risk models is quite complex in this field.

Fortunately, talented team members self-select and enthusiastically accept some of the toughest challenges. The mission and purpose of the effort help overcome technical and functional challenges every day. **IQ**

GRAPHIC: BOEING

COMPLIANCE, CONFORMANCE AND SAFETY DEFINITIONS ADAPTED FROM NATIONAL AEROSPACE STANDARD 9927

Award Winner

Vishwa Uddanwadiker was recently selected as the 2022 Asian American Executive of the Year. The award is presented as part of U.S. National Engineers Week to honor outstanding Asian American professionals in academia, public service and industries.

PHOTO: TIM REINHART/BOEING

Recent CASO Projects

- A deep study of landing performance calculations and runway overruns
- A closer look at system engineering models that describe normalization of deviation and interrogating how it shows up in the data
- Comparison of several predicted hazard probabilities and observed event frequencies based on fault trees and operational data
- Natural language processing applied to large quantities of text found in Continued Operational Safety Programs and potential safety issues and potential safety issue mining in public datasets

Create to correct

Boeing engineers automate perfect Dutch roll flight-test maneuver to advance flight safety

BY MICK BOROUGHS, BOEING WRITER

Ice skaters use the outer edge of their skates to propel themselves across the ice, rocking from side to side while also moving to the left, then to the right and back again. Airplanes can make similar lateral and directional motions in flight, rolling and yawing much like a traditional Dutch ice skater rhythmically swaying down one of Amsterdam's frozen canals.

This movement is called a Dutch roll. The lateral movement of the airplane is the roll, or bank angle. The directional movement — the airplane's nose moving left or right — is the yaw angle. Just as skaters avoid swaying too far and losing their balance, airplanes are designed to keep roll and yaw within regulatory requirements to ensure safety — and potentially reduce the risk of airsickness.

DUTCH ROLL DETAILED

An airplane moves in two axes if it experiences a Dutch roll, which is caused by wind or pilot input. The nose may go left to right as the airplane simultaneously banks side to side.

GRAPHIC: BOEING

PHOTO: TIM REINHART/BOEING

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Video: Footage from 1925 in Holland shows where the Dutch roll got its name.

“We intentionally stir up large Dutch rolls to gather data to update the aerodynamic model and safety margins. But the oscillations have to be perfectly formed for us to get the information we need.”

DARREN MCDONALD, BOEING TECHNICAL FELLOW AND FLIGHT TEST ENGINEER

SIMULATION INTEGRATION

(From left) Boeing flight test engineers Brock Larson, Tom Esser, Darren McDonald and Dunes Wijayratne hook up the Dutch Roll Initiator to the 737 flight simulator in Seattle so pilots and test engineers can validate the system and develop test procedures before putting the system on the 737-10 test aircraft.

PHOTO: LIZ WOLTER/BOEING

Dutch rolls are caused by any asymmetric input, such as wind or pilot commands, causing a series of oscillations that will continue until the movement fixes itself or the pilot corrects it. This phenomenon is important for engineers to study in simulations and flight tests.

Perfecting Imperfection: Intentionally Designing Dutch Rolls

“We intentionally stir up large Dutch rolls to gather data to update the aerodynamic model and safety margins,” said Darren McDonald, a Boeing Technical Fellow and flight test engineer. “But the oscillations have to be perfectly formed for us to get the information we need.”

To create these perfect Dutch rolls that can be initiated both in simulations and during real flight tests, Boeing Test & Evaluation’s Flight Test Engineering team based at Seattle’s North Boeing Field created the Dutch Roll Initiator (DRI) in 2019. Engineers first deconstructed the maneuver and then moved to desktop and piloted simulations before flying for two days in November 2021 onboard a Boeing 737-10.

“We learned which parameters define a quality maneuver then studied how to effect the most predictable, highest-quality maneuver,” said flight test engineer Jordan Stringfield. “We conducted trade studies with the desktop simulator and talked with the design engineers who require the data.”

Simulation and Validation: Going Beyond Compliance

The team used engineering simulators throughout project development, testing and training. They introduced the rudder actuation signals to start a Dutch roll through most of the same hardware that is used on the 737-10. They also performed end-to-end validation and crew training on the system before boarding the airplane.

The DRI commands a carefully timed rudder input in one direction and then an identical rudder input in the opposite direction at a rate that matches the airplane’s natural response frequency. The precise symmetry required for the maneuver is difficult to perform manually, especially when paired with aircraft structural limitations.

HAND-HELD SUPPORT

In a 737 simulator in Seattle, flight test engineer Darren McDonald monitors the Fault and Function Generator control, which controls the DRI input. The red emergency stop button is one of several ways the DRI signal can be removed.

PHOTO: LIZ WOLTER/BOEING

"We improved the quality of the maneuver by developing a system to directly send a signal to the rudder actuator without the pilot making the input," McDonald said. "This improved maneuver quality enables the team to increase safety margins while reducing the flight-hours that would normally be required to run multiple tests."

Digitization projects such as DRI are supported by Flight Test Engineering's Model-Based Test and Automation strategy to further the use of flight-test maneuvers to validate models rather than simply show compliance.

Just the Start: Dutch Roll Efforts Leading to a Library

The team chose the Dutch roll to start because the maneuver requires inputs to only one control surface, without requiring any feedback, and is predictable enough to allow for pilot abort and recovery if necessary.

Developing an automated system requires a robust and thorough safety analysis, so the Seattle team selected the Systems Theoretic Process Analysis (STPA) methodology as a new approach.

MEETING OF THE MINDS

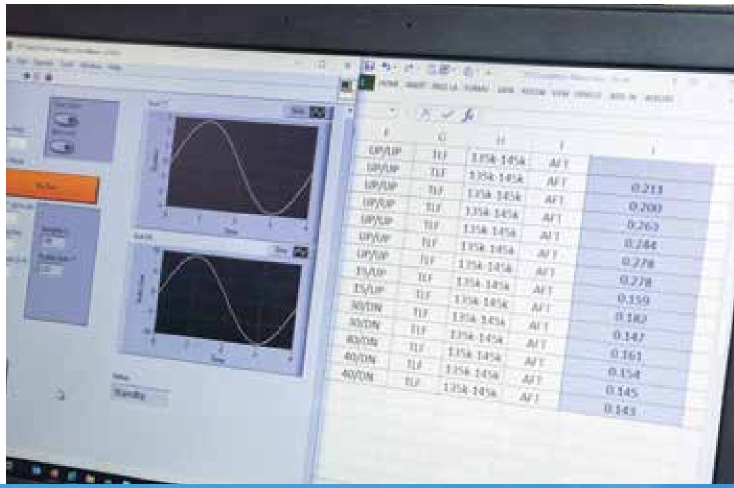
(From left, front) DRI flight test engineers Dunes Wijayratne, Sean Richardson, Shannon Clark, (back) Tom Esser, Brock Larson and Darren McDonald gather at Seattle's Boeing Field. The DRI is part of flight tests aboard this 737-10.

PHOTO: LIZ WOLTER/BOEING

ON BOARD

Flight test engineer Dunes Wijayratne operates the DRI system on a 737-10.

PHOTO: LIZ WOLTER/BOEING



DRI CLOSE-UP

The DRI rudder signal can be manipulated using a custom DRI software client, which controls the Fault and Function Generator system commonly used for other flight testing.

PHOTO: LIZ WOLTER/BOEING

STPA is a relatively new hazard-analysis technique based on an extended model of accident causation. It assumes that accidents can occur from not just component failures but also the unsafe interactions of system components, none of which may have failed. STPA, developed by professors at the Massachusetts Institute of Technology, is being adopted by a growing number of industries as well as numerous Boeing organizations.

"The final result is a more detailed understanding of all aspects of a Dutch roll — something we're documenting so we can add this knowledge to a library of flight-test maneuvers that will grow over time," McDonald said. "Having this library will simplify the process for implementing a maneuver on a new aircraft model."

Saving the Test for Last: Repetition Is the Key to Learning

The Flight Test Engineering team saved the most difficult Dutch roll flight-test condition for last, as it required an aircraft dive of more than 5,000 feet (1,524 meters) to achieve the target speed of 5 knots (5.8 mph or 9.3 kph) below the maximum operating speed with landing gear extended.

"Thanks to the DRI system, the pilot is able to safely and efficiently initiate a Dutch roll," said Jennifer Henderson, 737 chief pilot for the tests. "The system allows us to gather test data in a repeatable manner for each test condition."

Boeing design engineers also appreciate the DRI project because the improved data quality streamlines their efforts to update and validate the models.

"The DRI produced nice, crisp rudder inputs that resulted in clean conditions. Automating flight-test maneuvers is a big step forward for repeatability and data quality," said stability and control engineer Craig Plendl.

Where Does DRI Go From Here?

"The DRI system is the first maneuver of many that will follow," McDonald said. "Each maneuver will get progressively more complicated, with a transition to closed loop and multiple surfaces, multiple axes and multiple parameters included in the control loop.

"Our goal is to build the capability to fly any quantitative flight-test maneuver that our customers require, enabling improved designs, increased safety and a better customer experience for our future aircraft." **IQ**

Devillers in the details

Former watchmaker offers an artisan's approach to missiles and more

BY MEGAN GESSNER, BOEING WRITER

PRECISION PERSONIFIED

Chip Devillers zooms to solder a high-voltage cable for a gyro can at the Boeing Guidance Repair Center in Heath, Ohio.

PHOTO: MIKE ROSS/BOEING

Attaching a wire no bigger than a strand of hair, Christopher "Chip" Devillers peers through a microscope at his tiny world of work. This former watchmaker is most comfortable in small spaces.

Devillers is a technician at the Boeing Guidance Repair Center (BGRC) in Heath, Ohio. Or if you ask him, he'll tell you he is an electrostatically supported gyro navigator replacement, inertial navigation electronics cabinet lead technician, an appropriately precise role.

His up-close expertise ensures the readiness and modernization of guidance and navigation systems for a variety of platforms, including aircraft, submarines and Minuteman III intercontinental ballistic missiles.

“ Gyroscopes and accelerometers have moving parts that could be complicated to make and repair. Watchmakers like me have experience working on small complicated items. **”**

CHIP DEVILLERS, TECHNICIAN, BOEING GUIDANCE REPAIR CENTER

Comfort in Close Quarters: An Eye for Guidance and Navigation

During his 22 years at the BGRC, Devillers has intentionally gotten into tight spots. With his steady hand and eye for precision, he uses a microscope to solder cup terminals to accelerometer leads. Some components are smaller than a grain of rice.

“The instruments used in guidance systems are mechanical in nature,” Devillers said. “Gyroscopes and accelerometers have moving parts that could be complicated to make and repair. Watchmakers like me have experience working on small complicated items and an understanding of what ‘clean’ means when it comes to small items.”

Detail Oriented: Destined for Watchmaking

Devillers is at home in a world of detail because he spent much of his childhood tinkering with tiny watch pieces — wheels, gears, cogs and springs — to make them work in perfect harmony, offering a nearly imperceptible tick-tock to any who chose to listen. He listened closely.

“I enjoyed hobbies that required working with my hands,” he said. When he turned 16, his parents entrusted him with his grandfather’s watch. That gift was a spark.

GRANDFATHER’S GIFT

Devillers holds a pocket watch that belonged to his grandfather. When he received the gift at age 16, it sparked his love of timepieces.

PHOTO: MIKE ROSS/BOEING

MINUTEMAN MAINTENANCE

Devillers and team help maintain the guidance system for Minuteman III intercontinental ballistic missiles.

PHOTO: U.S. AIR FORCE

“The people we have working here are all true artisans, meaning they work with their hands to repair hardware.”

MIKE MURASKY, SITE LEAD,
BOEING GUIDANCE REPAIR CENTER

CLOCKWISE (From above left)

The Mount Vernon News featured Devillers during his early years as a watchmaker in Mount Vernon, Ohio.
PHOTO: MOUNT VERNON NEWS

The pocket watches that belonged to Devillers’ maternal (left) and paternal grandfathers.
PHOTO: MIKE ROSS/BOEING

Devillers says in the world of timepieces, lady’s wristwatches, such as this one, are made of some of the smallest components he’s ever worked with.
PHOTO: MIKE ROSS/BOEING

The internal components of a watch that belonged to Devillers’ grandfather who carried it as a conductor on a coal train.
PHOTO: MIKE ROSS/BOEING

“My parents let me go into the watchmaker’s shop so I could ask questions,” Devillers said. In those moments, surrounded by watches and clocks, he says time stood still. He would often dismantle then rebuild watches on his own to visit a world many never notice.

Captivated, he decided to become a horologist, which he calls a “fancy name for watchmaker.” After earning his degree, he worked near his home in Mount Vernon, Ohio, at a local jewelry store — which he would eventually buy and operate himself before providing his expertise to Boeing.

Collective Knowledge: Timely Gifts

Over the years, he’s accumulated a few old American pocket watches. “Not a large collection, but geared more toward my interest in the history behind them,” Devillers said. His favorites are heirlooms from both grandfathers. He even restored one of them — a railroad watch that belonged to his mom’s dad, a conductor on a coal train.

Watchmaking is an art not often found in today’s digital world. But his talent has stood the test of time. He’s proud to be able to transfer those skills to benefit the BGRC, where he’s a pivotal part of a team that provides high-quality products and services supporting everything from large systems to the smallest components.

“The people we have working here are all true artisans, meaning they work with their hands to repair hardware,” said Mike Murasky, BGRC site lead.

The team’s collective expertise ensures the continued smooth operation of enduring products, some that have been around for five decades or more. Original parts, or the suppliers or designs themselves, may not even exist anymore, affirming the BGRC’s importance.

Devillers believes that, like an attractive timepiece, the look of the products he works on is just as important as their function.

“You’d think they were originals straight from the factory,” Murasky said. **IQ**

25

SILVER ANNIVERSARY

The Boeing Guidance Repair Center in Heath, Ohio, celebrated its 25th year in 2021. In addition to maintaining the guidance system for the Minuteman III intercontinental ballistic missile, the site is also home to component assembly, integration and test activities for several Boeing aircraft production programs, including the KC-46A tanker, the T-7A Red Hawk advanced trainer and the MQ-25 unmanned aircraft system.

SCAN CAM HERE, BOOST YOUR IQ!
News from the BGRC.

SAFETY TOUR
Carla Davis-Madgett, Boeing's Environment, Health & Safety vice president, recently walked through Boeing South Carolina with Paul Rollerson, a fabrication specialist.

PHOTO: JOSHUA DRAKE/BOEING

Safe at work

Leveraging technology to improve workplace safety

BY TENLEY TORRE, BOEING WRITER

For over a century, Boeing has empowered employees to incorporate the latest technology into production processes to increase safety, efficiency and quality simultaneously.

"Human beings have certain limitations that can cause risks to their safety," said Carla Davis-Madgett, vice president of Boeing's Environment, Health & Safety organization. "We don't always have the wherewithal to know the risks that exist all around us. Technology can help bridge that gap and keep us safe in the workplace."

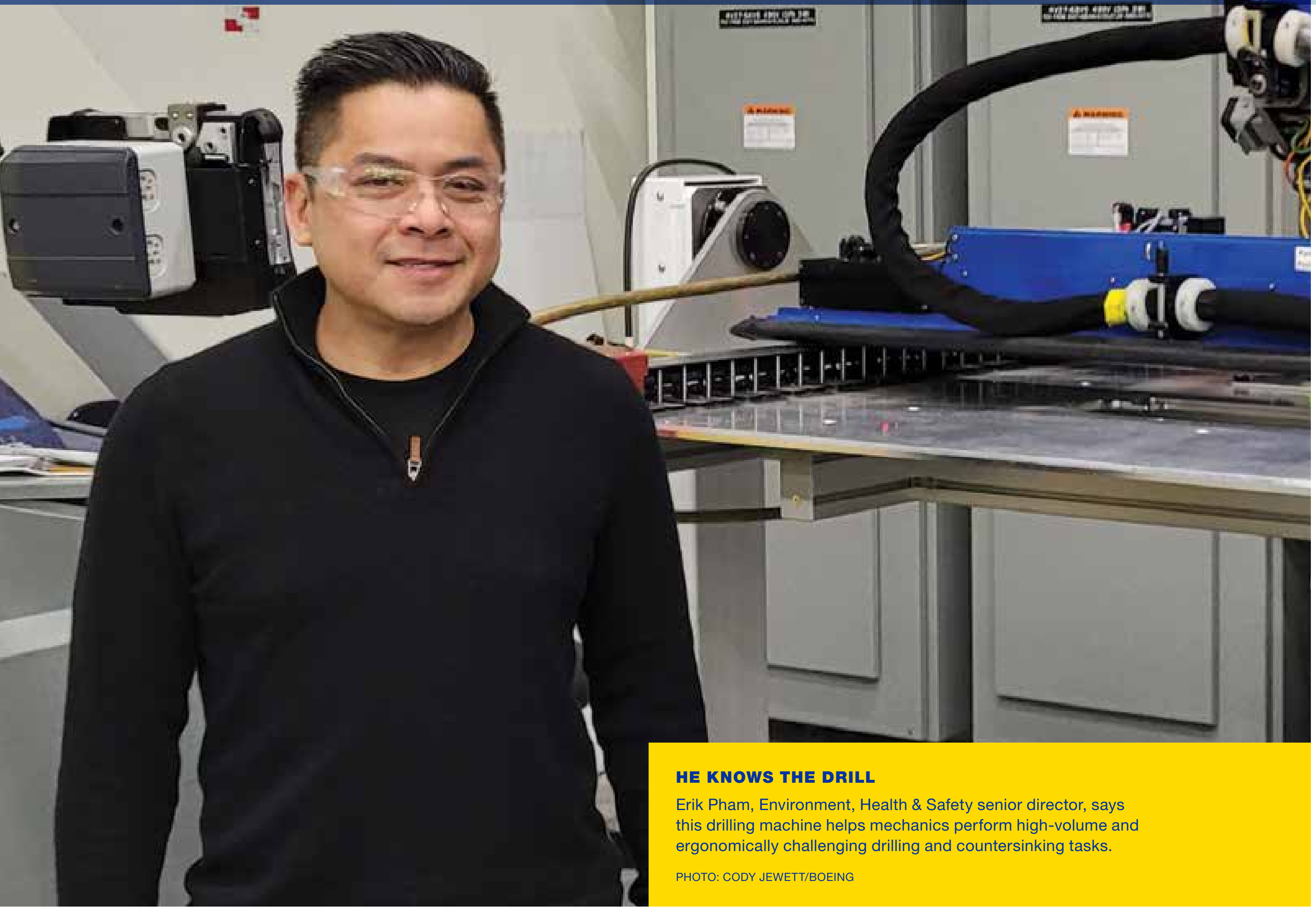
FABRICATION CONVERSATION

Paul Rollerson guides Carla Davis-Madgett through the 787 manufacturing process.

PHOTOS: JOSHUA DRAKE/BOEING

> “Technology has tremendously impacted all of our lives, and it has really changed how we work and how we connect. The way in which people receive their information, especially those on the manufacturing floor, has been improved drastically.”

ERIK PHAM, SENIOR DIRECTOR, ENVIRONMENT, HEALTH & SAFETY



HE KNOWS THE DRILL

Erik Pham, Environment, Health & Safety senior director, says this drilling machine helps mechanics perform high-volume and ergonomically challenging drilling and countersinking tasks.

PHOTO: CODY JEWETT/BOEING

“Technology has tremendously impacted all of our lives, and it has really changed how we work and how we connect. The way in which people receive their information, especially those on the manufacturing floor, has been improved drastically,” said Erik Pham, Environment, Health & Safety senior director.

Out of Harm’s Way: Embracing Automation and Robotics

Boeing also takes employees out of harm’s way using automation and robotics during the production process.

“Incorporating automation and robotics into our production process has been extremely beneficial. It allows us to reduce the number of hazardous tasks our employees are exposed to and reduces those tasks that are ergonomically strenuous on the body,” Pham explained.

“For example, there are millions and millions of holes drilled at Boeing. In the past, this was done by hand. By incorporating automation, we have machines and automated tools doing the repetitive hard drilling. This reduces the physical stress a person would endure and eliminates the risk of injuries, allowing them to perform other work that is less physically stressful. We no longer have to put that strain on our teammates.”

BETWEEN THE LINES

Autonomous ground vehicles, or AGVs, follow a safe path along the factory floor, performing duties such as transporting products or materials within a manufacturing facility or warehouse.

PHOTO: AL SALOUR/BOEING

VESTED INTEREST

Working on a 767 in Everett, Washington, mechanic Jason Turner is much more comfortable thanks to a shoulder-support exoskeleton vest.

PHOTO: PAUL CHRISTIAN GORDON/D.J. & COMPANY

> “Exoskeleton technology helps protect our employees by relieving pressure, improving posture, and providing more comfort and support. It targets repetitive motion that could cause ergonomic issues, and by alleviating some of that burden off the user, we minimize some risks and injuries.”
>
> **ERIK PHAM, SENIOR DIRECTOR, ENVIRONMENT, HEALTH & SAFETY**

Worth the Wear: Exoskeleton Tech Eases Ergonomic Stress

Currently, the majority of workplace injuries are ergonomic. This is another key area Boeing is focusing on and using technology to improve.

“We’ve worked to make advancements to the tools and equipment our employees use daily by developing ergonomically designed tools and other personal protective equipment,” said Pham. “But we also take advantage of our exoskeleton technology. This wearable technology, like an external body suit or vest, assists employees with strenuous work.

“Exoskeleton technology helps protect our employees by relieving pressure, improving posture, and providing more comfort and support. It targets repetitive motion that could cause ergonomic issues, and by alleviating some of that burden off the user, we minimize some risks and injuries.”

A Safe Future: Tech on the Horizon

According to Davis-Madgett, the company has made great strides to use tech to improve workplace safety, but there is more to come.

“We are excited about the future of incorporating technology and how we can bridge the gap between what people can see versus what they can’t,” Davis-Madgett said. “Augmented reality (AR) is a tech we are moving toward. This would allow us to approach scenarios in a safe and virtual space.

“This would allow us to identify risks without exposing employees to those risks. Additionally, I see this as a way to train employees. AR gives us the ability to test different scenarios in an augmented space and build the muscle memory to create an emotional response or reaction. That way, in the real world, employees are aware of the risks before they happen.”

The company is also considering sensor tech for hazardous chemical detection in the environment, real-time presence detection, hazard proximity for employees, and other occupational and environmental uses.

“The value of sensors is incredible,” Davis-Madgett said. “Human beings have limitations, and we can’t see everything. Sensor tech allows us to see a lot more and helps our team members focus on the work while protecting their body.”

“Sensor technology monitors and provides real-time communication,” Pham said. “For example, it can provide a notification when someone is too close to an edge or safeguards like shutting down a machine if someone enters an unsafe area.”

Pham said reducing employee exposure to some high-hazard risks resulted in a significant decrease in recordable injuries.

Move to Digitalization: No More Piles of Paper

“When I first started here, I remember there being a lot of paper,” recalled Pham. “All the instructions for building our products were printed on reams and reams of paper. There was so much paper that employees had to use carts to haul these instructions to and from their work areas, creating a safety hazard in the process.

“Now, due to the advancement of technology, all of that paper has been digitized and moved to portable devices. This alone is an amazing transformation of technology advancement in the workplace.

“As a result, we are able to provide more accurate, detailed and efficient information and data that is timely and easily accessible. This enables employees to make better decisions by being more aware of their environment, equipment, processes and potential dangers.”

Strength in Numbers: Injuries Are Down, Safety Is Up

Pham said the company strives to go beyond regulatory compliance to mitigate or eliminate workplace safety risks and injuries. Technology is instrumental in preventing fatalities and reducing serious and acute injuries.

“Technology has changed the way we keep our employees safe in the workplace, from physical application to process efficiencies,” Davis-Madgett added. “But no amount of tech can replace human performance. Our goal is to create a workplace where employees can come to work, make the products that makes Boeing successful, and go home at the end of their day as safe and healthy as when they arrived. We’ve made significant progress, but we’re always looking for new and emerging ways to keep our teams safe.” **IQ**

IQ INNOVATION QUARTERLY

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As a thank you for completing our IQ survey, we'd like to offer you a discount at the Boeing Store.

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Wisk away!

AUTONOMOUS ELECTRIC FLIGHT

Shown in Mountain View, California, Wisk's fifth-generation electric vertical takeoff and landing (eVTOL) aircraft is the first self-flying, all-electric air taxi designed in the United States for passenger use.

PHOTO: WISK AERO

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Video: See Wisk fly.

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WISK LIST

- **Mission:** Air taxi
- **Lift:** From 12 wing-mounted fans
- **Thrust:** From single rear propeller
- **Speed:** About 100 mph (160 kph)
- **Support:** Backed by The Boeing Company and Kitty Hawk Corp., including a recent investment of $450 million from Boeing


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