

# IQ INNOVATION

QUARTERLY

INNOVATION. INSIGHT. INSIDE AEROSPACE.

## Matters of Precision

**A focus on near-microscopic levels of detail was the catalyst in resuming 787 Dreamliner deliveries**

**PLUS: All Hands on Deck**  
Flight deck updates up front appeal to pilots' senses.

### POINT OF LIGHT

787 chief mechanic Kevin Landy inspects a forward pressure bulkhead join surface.



**PUBLISHER**

Greg Hyslop  
Chief Engineer

**EDITORIAL DIRECTOR**

Gary Wicks

**EDITOR**

Michael King

**DEPUTY EDITOR**

Ed Muir

**DIGITAL EDITORS**

Melissa Boban, Vienna Catalani

**CREATIVE LEAD**

Dave Sizer

**PROJECT MANAGER**

Cassie Moore

**DESIGN TEAM**

William Crane, Cierra Johnson,  
Tony Tino

**COPY EDITORS**

Valeria Peterson, Teresa Stanker

**DIGITAL TEAM**

Jan Bartko, Casey Gilman

**LEGAL ADVISER**

Ewa Davison

**CONTRIBUTING EDITORS**

Sara Chaney, Maribeth Davis,  
Colton Engelke, Annie Flodin,  
Maks Goldenshteyn,  
Rafael Gonzalez, Josh Green,  
Rob Gross, Nate Hulings,  
Mike Irvine, Brianna Jackson,  
Junu Kim, Michael Lombardi,  
Norm Mah, Lisa Maull, CJ Nothum,  
Julie O'Donnell, Joanna Pickup,  
Josh Roth, Carmen Smith,  
Kelsey Swanson, Derek Wing

**COVER PHOTO**

Joshua Drake/Boeing

**JOIN US**

jobs.boeing.com

**LET'S TALK**

Feedback is welcome at  
IQ@exchange.boeing.com

**IQ IN YOUR INBOX**

Subscribe at Boeing.com/IQ



**BOOST YOUR IQ!**  
Boeing.com/IQ

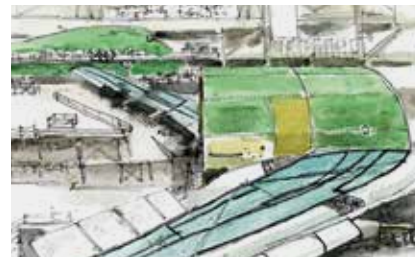
**Cover Story**

A focus on near-microscopic levels of detail was the catalyst in resuming 787 Dreamliner deliveries.

04



18



30

**All Hands on Deck**

Step inside to explore five flight deck technologies in development for the 777X.

**TimeTravel: The Final 747**

Though production is ending on the last 747, the first jumbo jet's legacy will endure for decades.

**14 | Eye on Autonomy**

Innovation in autonomy thrives at the new Boeing Aerospace & Autonomy Center at MIT.

**40 | Taxi! Testing Efficiency Solutions**

Capabilities could reduce ground time, cost and fuel consumption for airlines on the tarmac.

**44 | Insight: That's the Idea!**

You can be an idea-generating machine.

**54 | TopShot: Moonlight Landing**

An EA-18G Growler arrives on an aircraft carrier off the coast of Virginia.

# Progress

The right steps  
in the right time



PHOTO: BOEING

**Progress is a fascinating word.** One can make progress, accomplishing what you set out to do, with an eye on the past. One can also progress, moving in a direction of growth, focusing on the future.

We know the importance of doing both at Boeing. Achieving what we said we would do, coupled with forward momentum, is vital to our success. Progress appears on every page of this edition of Innovation Quarterly.

Our cover story chronicles the recent journey of the 787 Dreamliner — an example of the exacting level of precision our engineering designs require every day. We invite readers to discover how we identify and solve an issue as we continue to provide the airplane's industry-leading technology.

In this issue, our photographer captures a moment in time when an EA-18G Growler arrives on an aircraft carrier in the moonlight.

We also delve into two new digital capabilities being tested on the 2022 Boeing ecoDemonstrator. With safety and sustainability in mind, these taxiing solutions in the flight deck can increase pilot situational awareness and decrease turnaround times, saving fuel.

So as we mark our progress, we very much progress into the future. We invite you to join the journey. **IQ**

**Howard McKenzie**

Vice President and Chief Engineer,  
Boeing Commercial Airplanes

**IQ IS ...**

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

**GREEN MEANS GO**

787 technician TJ Heyward evaluates a passenger door surround of a Dreamliner being built at Boeing South Carolina. The green light indicates the surface meets specification.

# Matters of Precision

**A focus on near-microscopic levels of detail was the catalyst in resuming 787 Dreamliner deliveries**

ALL PHOTOS: JOSHUA DRAKE/BOEING (UNLESS INDICATED)

# Matters of Precision



PHOTO: BOEING

## Boeing resumed 787 Dreamliner deliveries in August 2022,

thanks to the efforts of Boeing teammates across the enterprise to find innovative solutions addressing nonconformances in some of the airplane's joins. Those solutions included using tools in the build process that are capable of confirming tolerances to near-microscopic levels.

"When Boeing designs an airplane, we do so to ensure the airplane will meet all requirements," said Steve Chisholm, vice president and chief engineer for Mechanical and Structural Engineering.

"We have a responsibility to our customers and regulators to ensure the airplanes we deliver conform to engineering design specifications. That is the level of precision our teams work to every day."

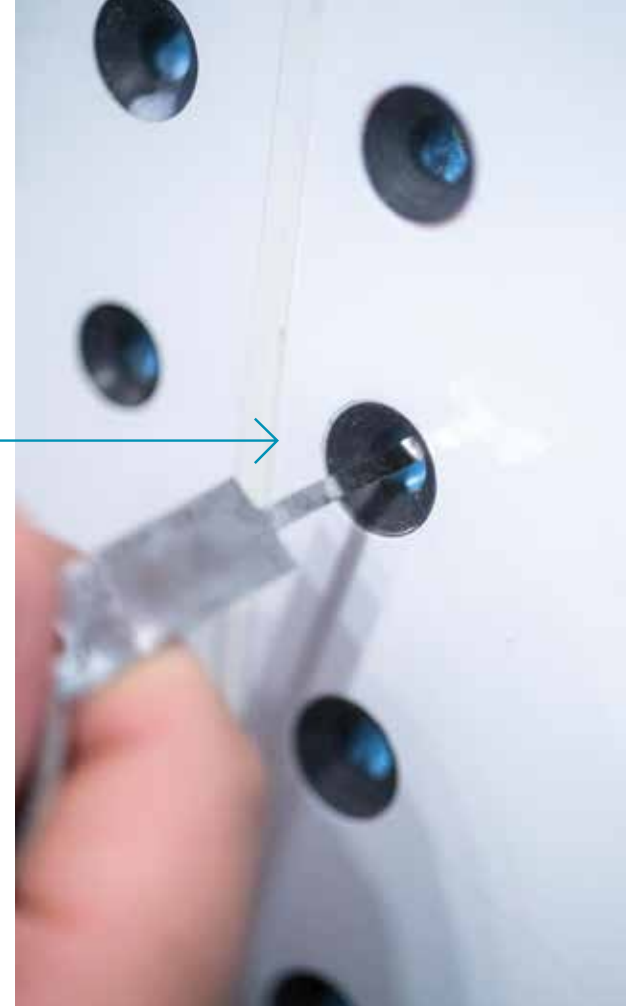
## OPEN-DOOR POLICY

Manufacturing engineer Anna Svanidze (left) and technician Isabel Lopez check for conformance during fit-up of the aftbody fuselage passenger door surround structure.

Close enough is not good enough when it comes to building a commercial airplane, even when measuring to the thousandth of an inch (fractions of a millimeter).

In 2020, the Boeing 787 team discovered some instances of nonconformance. Certain parts of the fuselage joins, where the airplane's primary sections are connected, did not meet the program's exacting design specifications.

Through the use of precision measuring equipment, the team detected some areas that were beyond the maximum tolerance defined by the airplane's design requirements and accepted by the U.S. Federal Aviation Administration (FAA) as part of the airplane's certification.



## TIGHT-SPOT TOOL

A feeler gauge is used to check for near-microscopic gaps between surfaces to be joined.

Although the immediate safety of the airplane was not compromised, the join did not meet the design standard. Despite the potential business impact, the decision was made to pause deliveries, inspect yet-to-deliver airplanes and correct any nonconformances. The objective is perfection.

There can be a variance of no more than 0.005 inch (0.13 millimeter) — roughly the width of a human hair — over a given 5-inch (13-centimeter) span along the join surface.

## LIKE PAPER

A technician demonstrates the overall thickness of airplane shims — comparable to a sheet of paper or a human hair.

"We have a responsibility to our customers and regulators to ensure the airplanes we deliver conform to engineering design specifications. That is the level of precision our teams work to every day."

**STEVE CHISHOLM,**  
VICE PRESIDENT AND CHIEF ENGINEER,  
MECHANICAL AND STRUCTURAL ENGINEERING

# Matters of Precision

## MINDING THE GAPS

787 chief mechanic Matthew Bucalo checks for gap tolerance between join surfaces.



## FITNESS

Bucalo inspects shims before a structure pre-join fit-up check.



To understand whether this was an isolated condition or it existed in other parts of the airplane, Boeing reached out to 787 suppliers that fabricate other portions of the Dreamliner fuselage.

“We asked our suppliers to inspect the join surfaces on the fuselage sections they produce, and what we found was a skin flatness variance that was present in multiple locations,” said Mark Stockton, senior director for 787 Engineering. “This variance could result in minute gaps in the join which, while no thicker than a human hair or a sheet of paper, were outside of our design requirements.”

Boeing instigated a tip-to-tail review, with production and quality teams checking thousands of points on each undelivered airplane. Anything found beyond design tolerance was reworked to ensure conformance. Technical expertise from across the Boeing enterprise was engaged to help fully understand the condition and develop solutions.

“ We asked our suppliers to inspect the join surfaces on the fuselage sections they produce, and what we found was a skin flatness variance that was present in multiple locations. This variance could result in minute gaps in the join which, while no thicker than a human hair or a sheet of paper, were outside of our design requirements.”

**MARK STOCKTON,  
SENIOR DIRECTOR,  
787 ENGINEERING**



## UP TO SPEC

787 chief mechanic Kevin Landy checks measurements during the installation of a 787 forward pressure bulkhead.



New capabilities were tested and incorporated into the production process to verify skin flatness conformance following the fabrication of the fuselage section. The team adapted a tool, originally developed in the automotive industry, as a shop aid to identify areas where the join surface potentially didn't meet flatness requirements. Following the final preparation of the fuselage join surface, a laser scanner is now used to confirm conformance to design specifications.

"I was extremely proud to see the company live our values in identifying the issue and proactively taking the actions that we did to address them," said Lisa Fahl, senior director for 787 Quality. "Some of those actions included the adoption of new tools and processes to ensure conformance with even greater fidelity than before."

With Dreamliner deliveries resumed, the future of the 787 program is bright. The Boeing Commercial Market Outlook forecasts a need for more than 7,000 twin-aisle airplanes over the next 20 years. The Dreamliner's combination of efficiency, reliability, capability and sustainability makes it a favorite among airlines and passengers around the world and positions the airplane favorably to capture a significant share of that market.

**PURPLE POWER**

The scanning tool Heyward is using was adapted from the automotive industry. The purple light indicates the machine is calibrating.

# Matters of Precision

**"I was extremely proud to see the company live our values in identifying the issue and proactively taking the actions that we did to address them. Some of those actions included the adoption of new tools and processes to ensure conformance with even greater fidelity than before."**

**LISA FAHL,  
SENIOR DIRECTOR,  
787 QUALITY**



With Dreamliner deliveries resumed, the future of the 787 program is bright. The Boeing Commercial Market Outlook forecasts a need for more than 7,000 twin-aisle airplanes over the next 20 years. The Dreamliner's combination of efficiency, reliability, capability and sustainability makes it a favorite among airlines and passengers around the world and positions the airplane favorably to capture a significant share of that market.

**LINING IT UP**

Heyward uses a scanning tool to verify the join surface meets design tolerance for flatness.

# Matters of Precision

“There are some characteristics of Boeing that will never change,” said Lane Ballard, vice president and general manager for the 787 program. “We will always prioritize safety and quality, and we firmly believe in a culture of continuous learning and improvement.”

#### GUIDING LIGHT

A technician uses a laser scanner to perform a final confirmation on the aftbody fuselage join surface.

“There are some characteristics of Boeing that will never change. We will always prioritize safety and quality, and we firmly believe in a culture of continuous learning and improvement.”

**LANE BALLARD,  
VICE PRESIDENT AND  
GENERAL MANAGER,  
787 PROGRAM**



“The 787 join verification work has given our team an even greater understanding of this airplane, something that will be invaluable as we look to the program’s future. The learnings are driving additional stability across our 787 production system and will benefit other current and future Boeing commercial airplane programs.” **IQ**

# How can you find your purpose?



Join a global team working to enable all of humanity to take flight.

**[Boeing.com/careers](https://www.boeing.com/careers)**

Boeing is an Equal Opportunity Employer. Employment decisions are made without regard to race, color, religion, national origin, gender, sexual orientation, gender identity, age, physical or mental disability, genetic factors, military/veteran status or other characteristics protected by law.



# Eye on Autonomy

## Advancing innovation at a new Boeing center



“ This exciting new space will strengthen our relationship with MIT and further our partnership with some of the best minds in the industry. It’s another collaborative step forward to ensure a safe, sustainable aerospace industry for future generations.”

**DAVID CALHOUN,  
BOEING PRESIDENT AND CEO**

### OPENING CEREMONY

Boeing Chief Engineer Greg Hyslop (left) and Boeing President and CEO David Calhoun make it official.

PHOTO: EVAN RICHMAN/BOEING

### Innovation in autonomy thrives at the new Boeing Aerospace & Autonomy Center at MIT.

In October 2022, Boeing subsidiary Aurora Flight Sciences opened the new office space located at the gateway to the Massachusetts Institute of Technology campus.



# MIT

### BAAC IN BUSINESS

The Boeing Aerospace & Autonomy Center (BAAC) opened on the top (17th) floor of the 314 Main St. building in Cambridge, Massachusetts. Boeing plans to move into the 16th floor in 2023.

PHOTO: MARLISE SORIA/AURORA FLIGHT SCIENCES





**VIRTUAL VISION**

Boeing AvionX Product Development Vice President Per Beith, previously Aurora president and CEO, tests an augmented reality headset, part of Aurora's exploration into the interactions between humans and autonomy.

PHOTO: MARLISE SORIA/AURORA FLIGHT SCIENCES



**Autonomy Innovation**



**Aurora works on cutting-edge research programs at the new center**

**Pilot Monitoring**

Using a low-fidelity flight simulator and a prototype pilot monitoring and cognitive-state estimation system, engineers are providing insights into real-time monitoring of pilot cognition to enhance safety. Noninvasive sensors, such as eye trackers and heart rate monitors, are being used to estimate a pilot's workload and situational awareness.

**Urban Air Mobility**

Autonomy technology is being developed for electric vertical takeoff and landing (eVTOL) unpowered air taxis that can take off, cruise and land with oversight from multivehicle supervisors on the ground. Autonomy software can also manage real-world conditions, including navigating other air traffic and redirecting the air taxi's flight path, if an issue arises.

**Multivehicle Advanced Teaming**

Aurora's onboard autonomy software enables uncrewed aircraft to team with other crewed and uncrewed aircraft, no matter the mission and environmental complexity. Aurora is developing technology requirements so that uncrewed vehicles can work together with Boeing aircraft and others to bring advanced capabilities to customers faster.

**Boeing Aerospace & Autonomy Center**



**AI ON DISPLAY**

The all-new MIT Museum occupies the first three floors of the 314 Main St. building. The artificial intelligence (AI) exhibition, called "AI: Mind the Gap," explores the links — and the gap — between human and machine intelligence.

PHOTO: ANNA OLIVELLA



**AI EXPLORATION**

The museum's AI exhibition includes an interactive display showing how Aurora's AI fighter pilot (left) stacks up against the skill and intuition of a human pilot (right, larger).

IMAGE: MIT MUSEUM



# All Hands on Deck: Updates Up Front Appeal to the Senses

Flight deck innovations keep data within reach

BY QUEENA JONES, BOEING WRITER

## PILOT'S-EYE VIEW

A 777-9 simulator, also known as an engineering cab, is ideal for testing and training.

PHOTO: JIM ANDERSON/  
DJ & COMPANY

**When passengers board an airplane**, they pass by the pilots' seats and marvel at the myriad levers, switches, knobs and glowing lights in the flight deck. Pilots walk into the flight deck and see their office for the day. And thanks to the Boeing Flight Deck team, it's a space in which pilots will feel increasingly at ease.

**Here are five flight deck technologies in development for the 777X**, Boeing's newest commercial airplane family member.

## PED Mounts: Keeping Data at Pilots' Fingertips

# 1

### PERFECT PLACEMENT

The mount in the center can accommodate many types of PEDs, which conveniently tuck into the recessed opening, as in this 777-9 rendering.

GRAPHIC: BOEING



Just a decade ago, pilots carried hefty notebooks of paper maps and charts and kept pertinent flight data on a clipboard in the flight deck window. Now, crew members keep this ever-changing information at their fingertips via a personal electronic device (PED).

Since pilots had begun to increasingly use PEDs for current information, airline customers asked Boeing to design a holder that would keep the device safely within reach of the pilot and in a stable position. Senior design engineers Brandon Boekelman and Chris Haus worked together to design a prototype that would fit the most commonly used devices.

The Flight Deck team worked with a diverse group of pilots, engineers and human factors specialists to gauge the usability of the design. They tested the location of the holder in the flight deck to make sure it wouldn't be in the way or be cumbersome to access, and they evaluated different designs, fabrication materials and mounting styles.

Then they asked the airline customers which styles best met their needs. Multiple airlines have embraced the usage of mounts, and Boeing now offers a variety of options.

**"Listening to the customer is essential to ensure we deliver the right products," said Boekelman. "We work to understand what they want, then we figure out how to do it."**

After 15 years with the Flight Deck team, Boekelman said working with so many different people to find new solutions keeps the design process interesting and rewarding. "We've figured out ways to make customers happy, and we've come up with functional, elegant designs."



**BRANDON  
BOEKELMAN**

Senior design  
engineer, Flight Deck  
PHOTO: KATIE BOEKELMAN



**CHRIS  
HAUS**

Senior design  
engineer, Flight Deck  
PHOTO: DEE DEE VASQUEZ

# 2

## Touch Screens: Cutting the Clutter and Making Way for Future Improvements

Boeing began working on introducing touch screens into the flight deck about 10 years ago.

While it's hard to believe in today's touch-screen world, they were initially deemed a fad that had no place in the flight deck. But soon, flight crews preferred the technology that mirrored how they were already using personal phones and other electronic devices.

**"Touch screens are everywhere," said engineer Pamela Pulla, recalling that pilots would get frustrated with other displays if a screen did not respond to touch.**

"Crews performed much better with the touch screens," said Pulla. "The old devices could respond only to bare fingers, but the touch screens respond if a pilot is wearing gloves or using a stylus."

They are also less likely to be damaged by accidental liquid spills.

Pulla believes touch screens are a steppingstone to future innovations to further reduce visual clutter, lessen the environmental footprint of the flight deck and improve crew efficiency.



### SCREEN TEST

Pilots can directly interact with electronic checklists with the touch of a finger.

PHOTO:  
JIM ANDERSON/  
DJ & COMPANY

### TOUCH UP

Engineer Pamela Pulla interacts with a touch screen on a 777-9 simulator in Seattle.

PHOTO: JUSTICE  
OFOSU/BOEING



**PAMELA  
PULLA**

Engineer, Flight Crew  
Operations  
PHOTO: STEPHANIE SU



**FORE CAST**

A PED hosts the Jeppesen FliteDeck Pro EFB application, which is cast onto the forward display.

PHOTO: JIM ANDERSON/DJ & COMPANY

# 3

## Crew Information Gateway: Gathering All Flight Data in One Place

Touch screens are integral to the Crew Information Gateway (CIG), which collects Electronic Flight Bag (EFB) data from a pilot's portable device onto the main flight deck displays, right in front of the pilot.

**“The CIG helps the pilot see the EFB information together, and it really helps improve overall crew situation awareness,” said human factors engineer Peter Batsakes.**

He and teammates have been testing the integrated gateway for about two years and are continuing to improve its overall look and feel. Other engineers are working with software developers to create original software applications for aviation — for example, apps that suggest shorter routes and thus reduce fuel consumption.

Batsakes said the gateway minimizes a crew's actual handling of a separate electronic device and keeps all the information in front of them. All members of the flight crew see the same information on the forward display, and they can cross-check performance data easily.

In addition to the convenience of having all the information in a single display, the CIG offers safety benefits. Crew members don't need to move to see or access a second display, touch or handle another device, or risk dropping an unmounted PED.



**PETER BATSAKES**

Human factors engineer, Flight Crew Operations

PHOTO: JIM ANDERSON/DJ & COMPANY

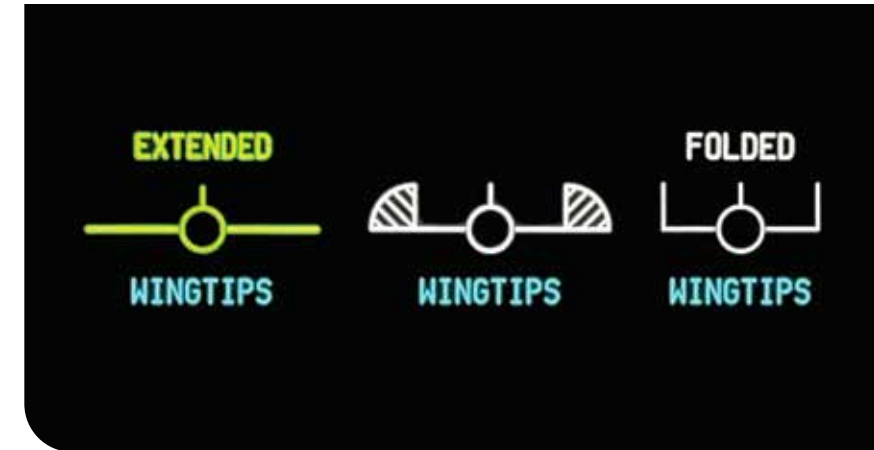
# 4



### TIP SWITCH

Engineer Paul Burkhead shows the folding wingtip control. It is intentionally shaped like a wingtip to provide a visual cue.

PHOTO: SARA CHANEY/BOEING



### ABOVE THE FOLD

Simple, clear indicators on the flight deck forward displays show the status of the wingtips: extended, in motion or folded.

## Folding Wingtip Control: Indicating Position of Unique Design

The 777X is the first commercial airplane with folding wingtips. When extended, the wingtips increase the wingspan to further enhance aerodynamic efficiency, thereby reducing fuel use, emissions and engine thrust. After landing, the wingtips fold automatically so that the airplane can fit into the same gates as its predecessor, the 777-300ER (Extended Range), providing an operational advantage for customers.

During development, airlines requested that Boeing evaluate automating the wingtips to reduce crew workload. But pilots still needed the ability to control the wingtips in certain situations. Human factors engineer Paul Burkhead worked with dozens of test pilots, airline customers and regulators to understand standard flight procedures, asking questions to learn when and how pilots could most safely and efficiently operate the wingtips.

**“We were open to every suggestion and eager to be creative,” Burkhead recalled. “As the only airplane manufacturer of a commercial airplane with folding wingtips, it was fascinating to begin with a blank slate.”**

From the flight deck, crew members can't see the wingtip position, and visual confirmation isn't sufficient. An indicator is the only way to verify that wingtips are both extended and locked into position.

Burkhead and teammates created a first-of-its-kind control that is safe and easy to use. Test pilots asked for an indicator that signals when the wingtip is extended or folded. A color-coded display does just that and is visible to the pilot from the flight deck seat.



**PAUL BURKHEAD**

Human factors engineer, Flight Crew Operations

PHOTO: THE HIDDEN LENS PHOTOGRAPHY



PHOTO: JOEY JETTON/BOEING

# 5

## Contemporary Pilots' Seats: Enhancing Safety, Comfort

Like passengers, pilots are required to wear seatbelts during taxi, takeoff and landing, but they must be able to reach every control and see every display in their forward field of view. A secure yet comfortable seat is a necessity.

Starting with a request for the 777X, senior design engineers Mark Wolf and Jonathan Knopp worked with supplier Ipeco to develop a better seat for pilots. Wolf and Knopp adapted a standard seat design to allow adjustments for lumbar support, seat tilt, side bolsters and thigh supports. With plush upholstery, the new seats have wider, extendible armrests and sculpted headrests that crew members can adjust vertically and horizontally.

"I don't recall any other seat design project having this much customer input," said Wolf, who has been with the Flight Deck team for most of his 33 years at Boeing. Having pilots in his family and working closely with customers and test pilots, Wolf has heard many requests for a softer seat cushion.

**"Pilots spend an enormous amount of time in these seats," he said. "Anything we can do to make their experience more comfortable is worth the effort upfront."**

The redesigned seats went through rigorous safety, quality and environmental testing, including 16 G-force (16 times the force of gravity) testing, which requires the seat to withstand significant lumbar loads without compressing the seat cushion. A cushion that is too soft will "bottom out," or cause the occupant to press upon the rigid seat structure underneath the cushion.

By layering the improved cushions instead, the new seat meets the stringent 16 G-force requirements and is about two times softer. The softer cushions relieve pressure on the tailbone, and the adjustable seats and extendible thigh pads alleviate discomfort in the upper back, hips and thighs. Additional lumbar support relieves lower back pain as well.



**FRONT-ROW SEAT**

Considering the hours crew members spend in them, flight deck seats are designed for maximum comfort and safety in the 777X.

PHOTO: IPECO

**"Boeing listened to the customers' concerns and devoted great effort to incorporate everything the customers wanted," said Wolf, who reviewed the final design with customers.**

Seat development and certification includes rigorous structural and occupant injury testing, environmental testing, life-cycle testing, multiple design reviews, ergonomic assessments and numerous flight tests.

"While we strive to meet all the schedule commitments, safety is always our No. 1 priority," Wolf said.

"Our methods are extremely robust, and that's how we prove the finished product will be reliable. It's essential for these designs to stand the test of time, because what we design today will be flying for decades to come."



**JONATHAN KNOPP**

Senior design engineer, Flight Deck

PHOTO: JONATHAN KNOPP/BOEING



**MARK WOLF**

Senior design engineer, Flight Deck

PHOTO: MARK WOLF/BOEING



**GOT YOUR BACK**

Engineer Jonathan Knopp leveraged his experience on the 777-300ER simulator (shown here) to help design the enhanced-comfort pilot's seat featured in the 777X.

PHOTO: STEVE SWEM/BOEING

# Engineering Cabs: Bringing It All Together

As Boeing continually upgrades its airplanes, the team works regularly with pilots, regulators and airline customers to make sure each part of the flight deck looks and feels just right the moment pilots take their seat.

After months of development, testing and reconfiguration, all flight deck innovations and upgrades come together in an engineering cab, or e-cab, complete with all the flight controls, navigation instruments and display systems for each airplane.

These simulators are so realistic, they offer a dry run during development, in preparation for first flights and beyond.

## Flight Deck vs. Cockpit: What's the Difference?

Engineer Justice Ofosu said it's simple: "You climb into a cockpit, whereas you walk into a flight deck." He added that a large commercial airplane has a flight deck, but a fighter jet has a cockpit.

And the flight deck itself is a Boeing original. In the 1930s, the XB-15 experimental bomber was the first airplane with a flight deck. A flight deck engineer joined the pilot and co-pilot in what was then called a "control cabin," later known as a flight deck.

BOEING HISTORICAL SERVICES

The Flight Deck team works with Boeing teams such as Avionics, Flight Controls and Safety, as well as customer pilots and regulators. It takes years to design, develop and plan each airplane's flight deck and customized e-cab.

Senior engineer Mark Henderson makes sure these next-level simulators can demonstrate standard and optional features of a Boeing airplane. He ensures that the e-cabs are ready to support system engineers, test pilots and human factors engineers as they assess all the prototype hardware elements and software systems that are under development.

E-cabs are used to evaluate and test new features, make design changes, prepare for flight tests and give an overall view of the flight deck without going on an airplane. The team determines if switches are too fragile or too rigid, if controls are too sensitive or too resistant, and if lights and indicators are bright enough.

They work through countless flight procedures and sequences to see how well the final designs will perform, allowing time for modifications and alterations before the airplane goes into production. After an airplane enters production, the e-cab is continually used for testing of new software updates, for development of new features and to support the airplane's production.

Justice Ofosu is one engineer who will never forget his first experience in an e-cab with Henderson. When Ofosu joined the Flight Deck team in 2021, he was fascinated by the e-cab's realism.

**"Not only are the physical aspects of the e-cab realistic, the software systems actually simulate the sensations of flight," he said.**

When asked how the e-cab systems rival movement, Henderson said, "It's all up here, in your mind." The user feels the e-cab turning, responding to airspeeds or other air commodities, but it's stationary; it's all a cognitive response.

As he's worked on e-cabs since 2013, Henderson appreciates how important they are to the airplane programs.

"The pilots practice different maneuvers in the e-cabs, and the system actually emulates the response of the systems to the pilots' input in a hard turn, for example," Henderson explained. "This realistic environment allows pilots to evaluate all the flight deck hardware and software before taking an actual test flight."



### TESTING FOR TAKEOFF

Boeing engineers Brandon Boekelman (left) and Chris Haus are shown in a 777-9 simulator. E-cabs are identical to an actual airplane flight deck.

PHOTO: JIM ANDERSON/DJ & COMPANY

After a year with the Flight Deck team, Ofosu is still impressed by the engineering expertise of his peers and the way they work through design challenges.

**"I ask lots of questions to understand an issue, then I lean on my teammates to bounce around ideas and evaluate possible solutions," said Ofosu. "I'm constantly amazed by this team, at how they navigate issues and how they work. I know I can learn something from everyone."**

The collaborative process pays off when the teams of engineers assimilate the various airplane systems into the e-cabs, which are large enough for about a dozen people to gather around at one time. A test director, aero stability and control expert, two test pilots and multiple flight test engineers can use the e-cabs to verify and validate the flight deck design and to rehearse for flight tests. **IQ**



**MARK HENDERSON**

Senior engineer,  
Flight Crew Operations

PHOTO: JUSTICE OFOSU/BOEING



**JUSTICE OFOSU**

Engineer,  
Flight Deck Design

PHOTO: CYRUS MAJD/BOEING

## Quick Turn: Engineer Origin Story

Thirty-three years ago, senior design engineer Mark Wolf took his last finals at Washington State University on a Friday afternoon. That same evening, he drove 75 miles (120 kilometers) from Pullman to Spokane.

After a cold night sleeping in his car, he took the Engineer in Training test the next morning. He passed. "Boeing asked if I could start on Monday," he said. "And I've been here ever since."

**WING WORK**

One of the engine mounts for the last 747 rests on the shop floor at the Boeing factory in Everett, Washington.



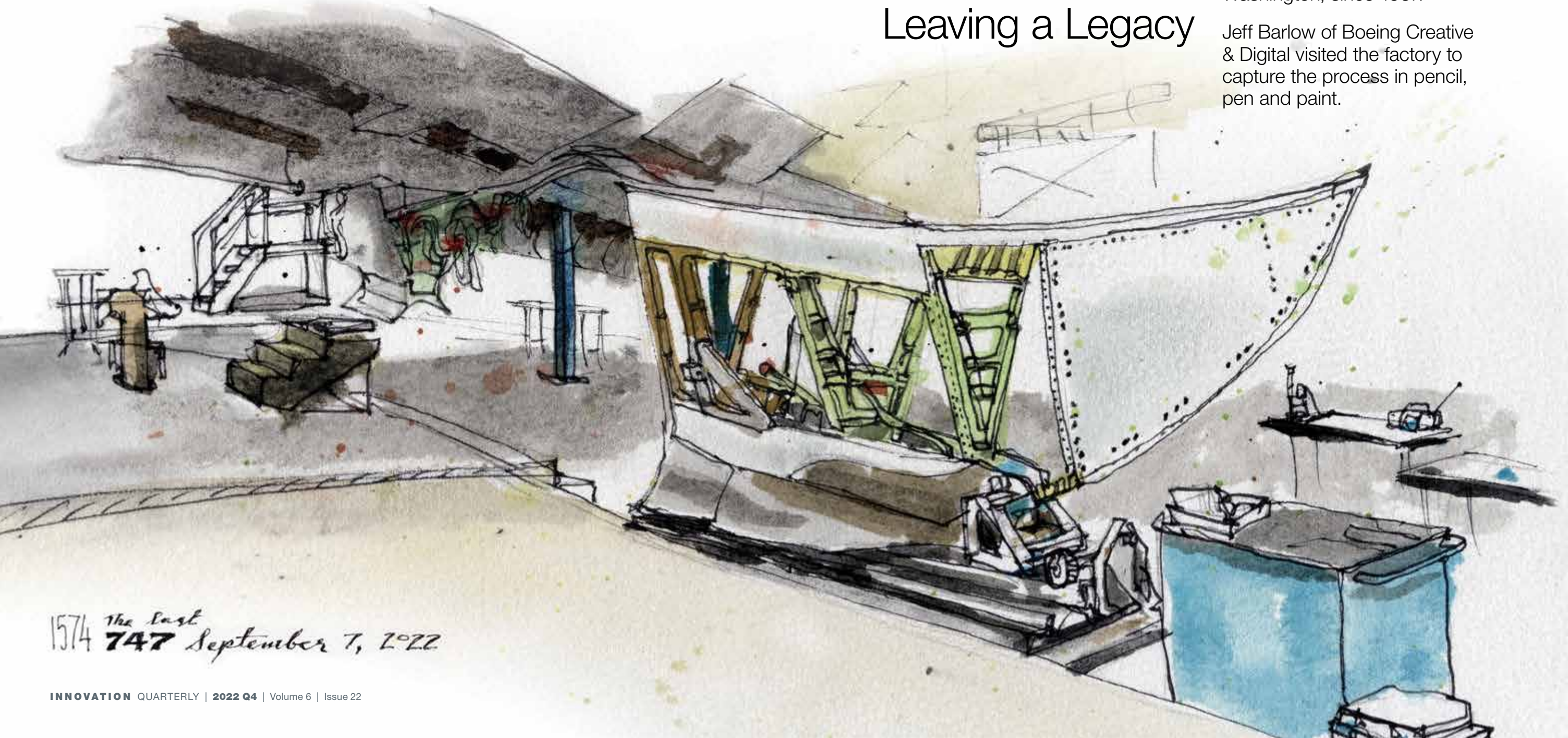
# The Final 747

## Leaving a Legacy

Though production is ending on the 747, the first jumbo jet's influence will endure for decades.

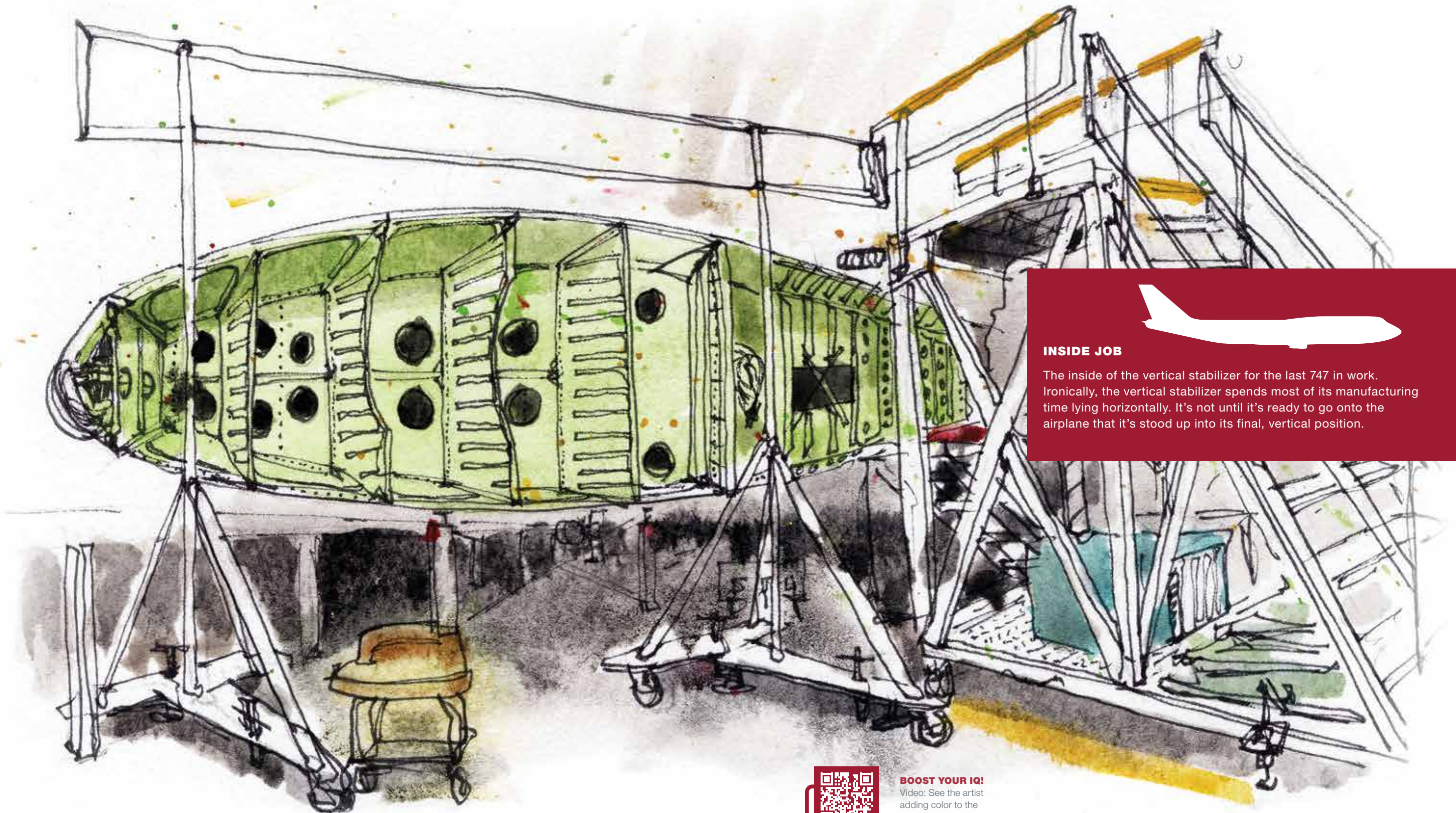
The final airplane is known as "1574," as it's the 1,574th 747. All have been assembled in Everett, Washington, since 1967.

Jeff Barlow of Boeing Creative & Digital visited the factory to capture the process in pencil, pen and paint.



1574 *The Last*  
**747** September 7, 2022





### INSIDE JOB

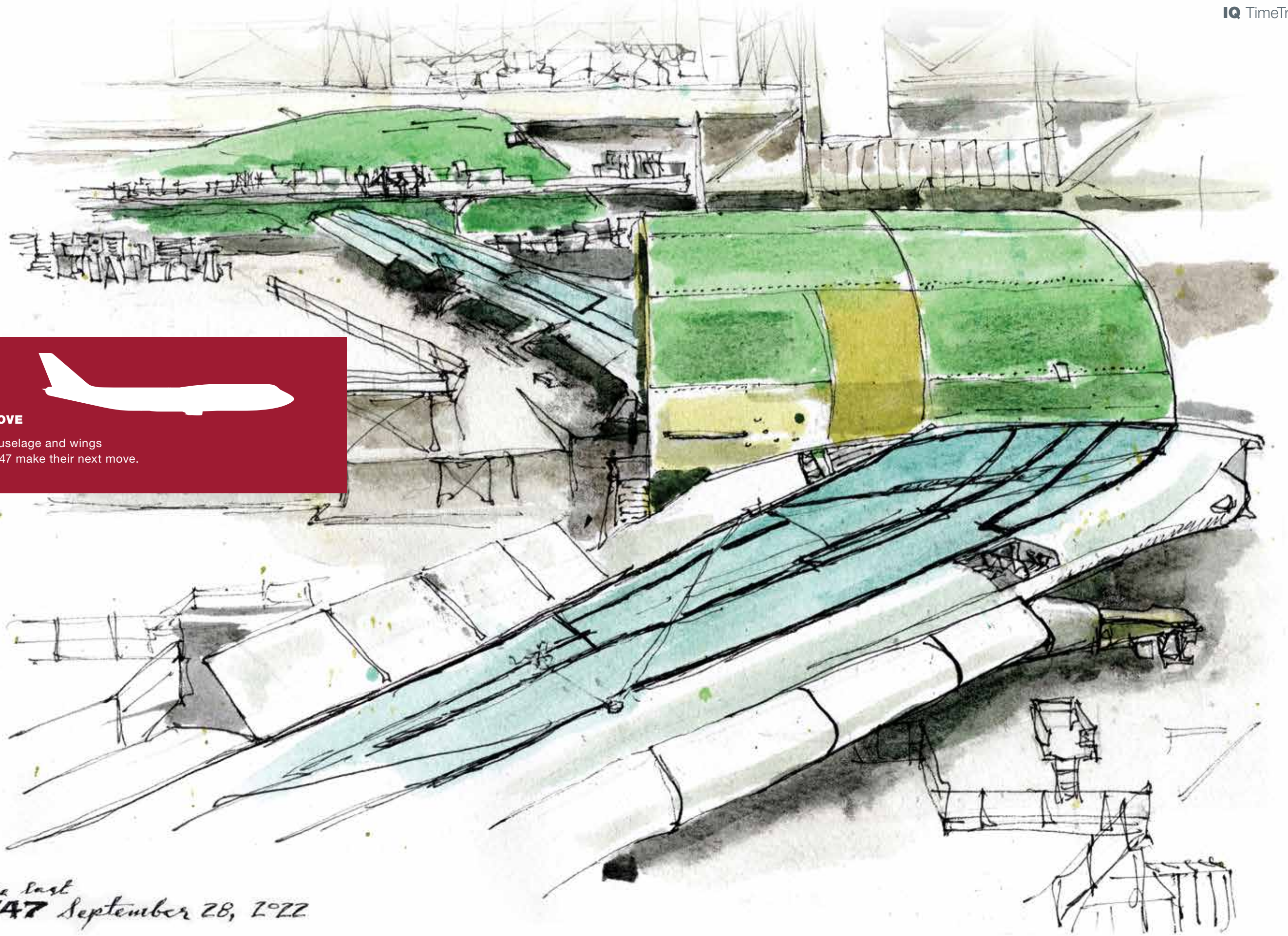
The inside of the vertical stabilizer for the last 747 in work. Ironically, the vertical stabilizer spends most of its manufacturing time lying horizontally. It's not until it's ready to go onto the airplane that it's stood up into its final, vertical position.

1574 *The Last*  
**747** September 21, 2022



### BOOST YOUR IQ!

Video: See the artist adding color to the stabilizer sketch.



**ON THE MOVE**

The partial fuselage and wings on the last 747 make their next move.

1574 *The Last*  
**747** September 28, 2022



#### Widebody Design

As the first twin-aisle airplane, the 747 lowered the per-seat cost and made air travel more accessible. Passenger capacity was twice that of any existing commercial airplane.

#### Hemispherical Hump

As the 747 was also designed to be a freighter, the ideal way to load cargo was through the nose. Engineers then determined the best place for the flight deck was on its own second level, allowing the nose door to open without interference, hence the iconic hump.

#### Cargo Transformation

Nose loading allowed for the transportation of huge objects. As a result, the 747 catalyzed a new era in cargo shipping.

#### Redundancy

Triple redundancy in all major systems and quadruple redundancy in the control and hydraulics systems improved safety.

#### High-Bypass Turbofan Engines

These more efficient, quieter engines helped improve takeoff acceleration.

#### Simulators

The 747 team designed the world's first full-motion simulator to offer pilots immersive flight training.

#### Behavioral Training

The customer training organization created a new behavioral-based program, focused on end-of-training competencies. It resulted in what became colloquially known as "need-to-know" training.

# Seven 747

## Innovations That Changed the Industry



#### ALL HAIL

The first 747 greets the crowd on Sept. 30, 1968, outside Boeing's then-new factory at Paine Field in Everett, Washington. The airplane now resides at the Museum of Flight in Seattle.

PHOTO: BOEING ARCHIVES

**MOUNTAIN CLIMBER**

The original 747 soars high above Mount Rainier in Washington state in 1974. Boeing engineer Joe Sutter, known as the “Father of the 747,” said this was his favorite photo.

PHOTO: BOEING ARCHIVES



# 747



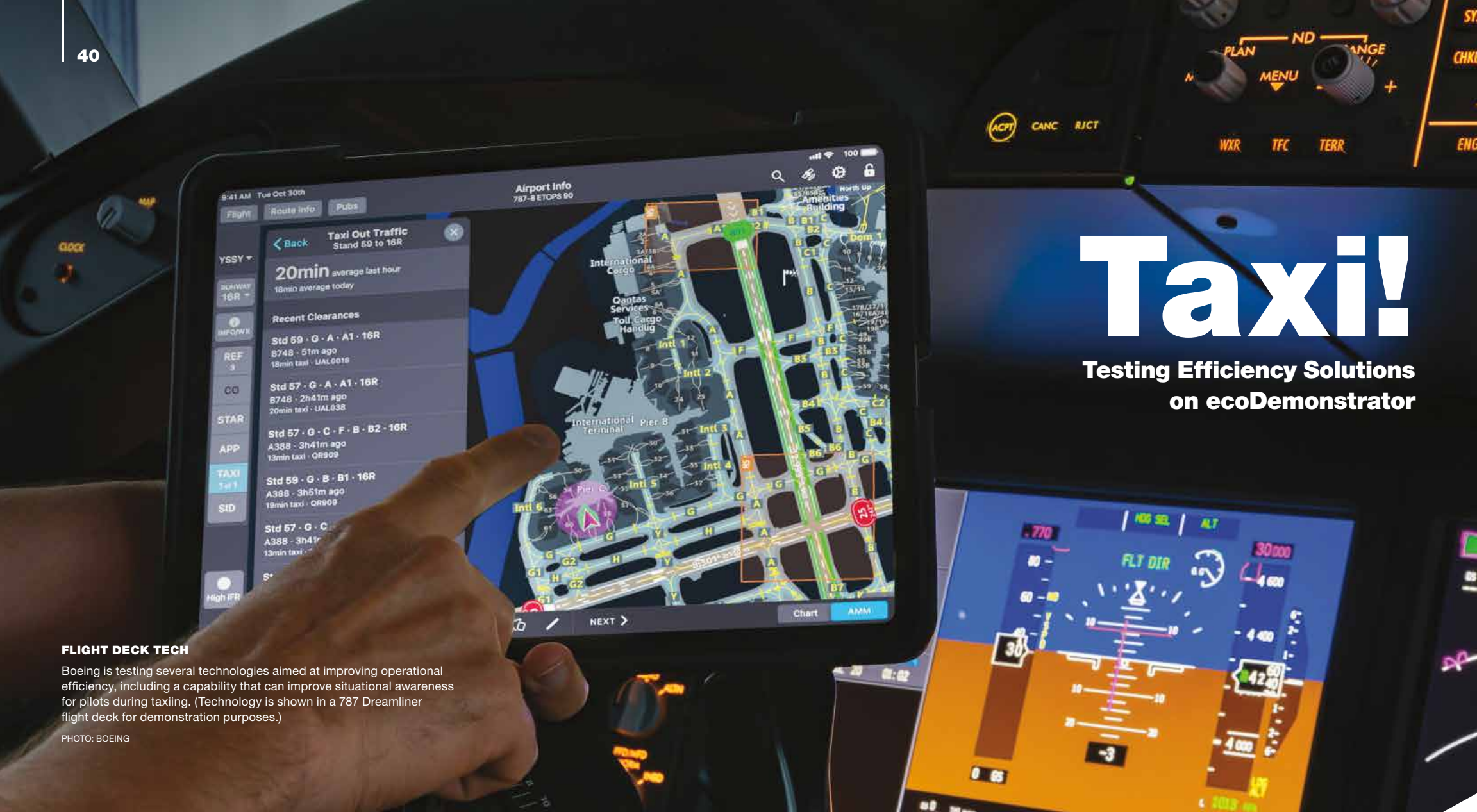
## Commemorative Coin

**The limited-edition “Boeing 747 Forever Incredible” coins sold out in two days.**

The coins contain shavings from one of the last 747s built in the Boeing factory in Everett, Washington. (See under the 747 logo in the second image.)



PHOTOS: BOEING



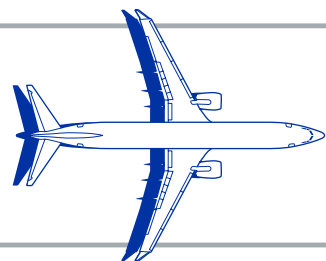
# Taxi!

## Testing Efficiency Solutions on ecoDemonstrator

### FLIGHT DECK TECH

Boeing is testing several technologies aimed at improving operational efficiency, including a capability that can improve situational awareness for pilots during taxiing. (Technology is shown in a 787 Dreamliner flight deck for demonstration purposes.)

PHOTO: BOEING

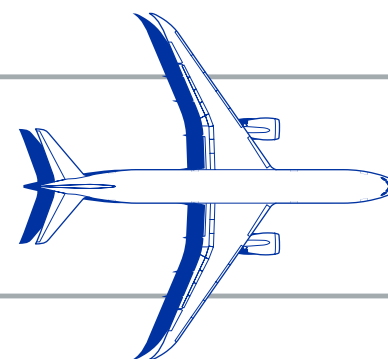


## Capabilities could reduce ground time, cost and fuel consumption for airlines

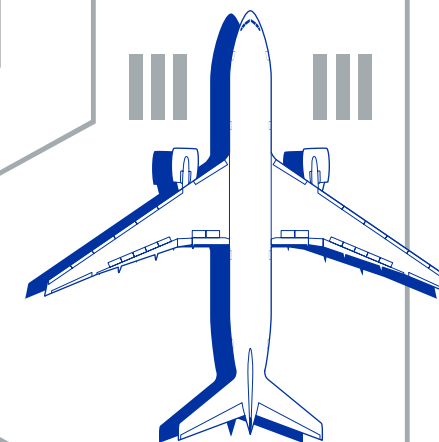
BY BRIAN RANTALA, BOEING WRITER

**Every time the 2022 Boeing ecoDemonstrator taxis to the runway, pilots will have several new flight deck technologies to test that could help airlines increase operational efficiency and reduce their carbon footprint.**

The flying test bed, a Boeing-owned 777-200ER (Extended Range), includes two new digital capabilities — Taxi Time Information and Taxi Clearance — designed to help airlines reduce turnaround times on the ground and eliminate delays, leading to better fuel efficiency.



**BOOST YOUR IQ!**  
More on Boeing sustainability.

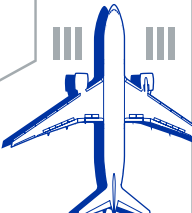
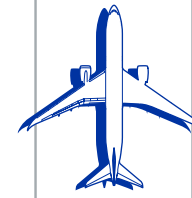


21



“ Our flight deck capabilities on board the ecoDemonstrator this year include technologies aimed at improving efficiency and pilot situational awareness during airplane taxiing, which could in turn reduce fuel consumption.”

THORSTEN WIESEMANN,  
DIRECTOR,  
SMART DATA SERVICES



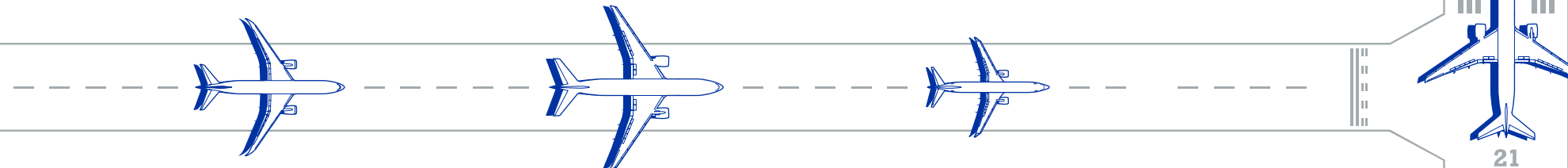
For example, the Taxi Time Information capability is designed as a better way for flight crews to anticipate their inbound clearance and taxi times. Using averages compiled from the current day, or even the current hour, to plan their gate maneuvers, pilots will be able to estimate the taxi time needed to travel between their parking stand and their assigned runway.

“Looking at sustainability through the operational-efficiency lens, we are helping customers realize cost, time and fuel savings,” said Marco Gärtner, a senior product manager for Smart Data Services. “Taxi Time Information could provide pilots the ability to better manage slot and pushback requests, with a greater understanding of the prevailing taxi situation. This would support single-engine taxi operations and, as a result, would reduce fuel consumption on the ground.”

The new capabilities being tested build on the Boeing foundation of helping customers plan the most efficient route, optimize flight planning, and provide real-time weather and traffic information to pilots. Combined, these tools help lower fuel consumption and minimize the carbon footprint of airplanes in service. **IQ**

“ Taxi Time Information could provide pilots the ability to better manage slot and pushback requests, with a greater understanding of the prevailing taxi situation. This would support single-engine taxi operations and, as a result, would reduce fuel consumption on the ground.”

MARCO GÄRTNER,  
SENIOR PRODUCT MANAGER,  
SMART DATA SERVICES



TARMAC TESTS

The 2022 Boeing ecoDemonstrator is testing 30 technologies to enhance safety and sustainability.

PHOTO: BOEING

“Our digital solutions deliver on our commitments and support Boeing’s sustainability goals and those of our customers and our industry, including to achieve net-zero carbon emissions by 2050,” said Thorsten Wiesemann, director of Smart Data Services for Boeing Global Services.

“Our flight deck capabilities on board the ecoDemonstrator this year include technologies aimed at improving efficiency and pilot situational awareness during airplane taxiing, which could in turn reduce fuel consumption.”

Airlines typically spend up to 25% of their operating budgets on fuel alone. The Digital Aviation Solutions team at Boeing Global Services has a suite of fuel-efficiency solutions available to customers today. The team is also developing tools that can help operators reduce this cost and alleviate environmental impacts.



EXPLORE  
Boeing’s fuel-efficiency solutions.



DISCOVER  
ecoDemonstrator.

# That's the Idea!

You can be an idea-generating machine

BY MARNA KAGELE, BOEING ENGINEERING, TEST & TECHNOLOGY

**A blank whiteboard looms over a group of engineers gathered** in a conference room. They're generating ideas for how to improve the aerodynamic performance of a revolutionary wing design. One engineer in particular feels the blank whiteboard staring back. The more the engineer concentrates on coming up with an idea, the more an empty, gray thought wall appears.

**The wall grows wider.**



A thought wall like this is not uncommon. In fact, even those who are known for brilliant ideas will admit to its unwanted visits. So how can you overcome it? How do you find pathways to fresh approaches, processes and ideas?

### What are the secrets of those who seem to always be inspired, insightful and prolific?

The truth is, anyone can improve their idea generation and problem-solving skills. There are proven actions known to spark new, relevant thinking in yourself and others. The methods described here can help you get there.

PHOTO: THOMAS BARWICK/GETTY

## Formal Methods: Time-Tested Innovation Pathways

Methods categorized as formal contain distinct, well-described steps that have been published or are otherwise known to be effective.

**1 TRIZ:** This method was first developed in the 1940s and has since evolved into several forms. Named from a Russian acronym that translates loosely to “Theory of Inventive Problem Solving,” TRIZ, at its core, is the idea that patterns underlie all innovation. A structured approach can thus be used along with supporting tools that guide a problem-solver to promising solutions.

There is a deep philosophy and methodology to fully employ TRIZ. But one can appreciate and benefit from its usefulness by simply understanding the first step, which is to generalize the problem.

### Dig down to the root of your challenge.

For example, you may have a problem statement that says you need a material that can withstand 500 degrees Fahrenheit (260 degrees Celsius) for a new oven mitt. Digging deeper may reveal, however, that you actually need a material that significantly reduces heat transfer. This reframing of the problem statement can show the way to solutions you hadn't previously considered.

You may even look closer at your problem statement and determine that you actually need a way to remove very hot items from a very hot surface. That opens the door for many solutions beyond just an oven mitt. A wealth of information and training is available, should additional exploration of this method be of interest.

**BOOST YOUR IQ!**  
More IQ TRIZ talk.





**2 LATERAL THINKING:** Maltese physician, psychologist and inventor Dr. Edward de Bono formalized this tool set. He spent much of his career enhancing creative thinking.

**His lateral thinking tools, in particular, aim to help people escape patterns of thought that block innovative ideas.**

De Bono's approach offers several tools for overcoming these blocks. One is random entry, which can be done anywhere or anytime by an individual or group. Start with a well-defined problem or challenge. Then select a random word. You can use a book, website or other method to come up with a word. Nouns tend to be good choices.

Now, no matter how odd the word, generate a list of ideas that resolve your problem by incorporating something about your word. This can be challenging at first, but it gets easier as new associations come to mind.

**Feel free to let those associations take you in different directions.**

And don't analyze the ideas as you go. Just capture them for the time being. Try additional words. If you are more visual, perhaps try a random image or object as your inspiration. The intent is to nudge your brain out of its go-to patterns and find a new path to solutions.

Using a random word to spark a new thought about a problem or forcing yourself to create that lateral connection between seemingly unrelated things could result in a viable idea. At least that's what de Bono says.



PHOTO: 10,000 HOURS/GETTY

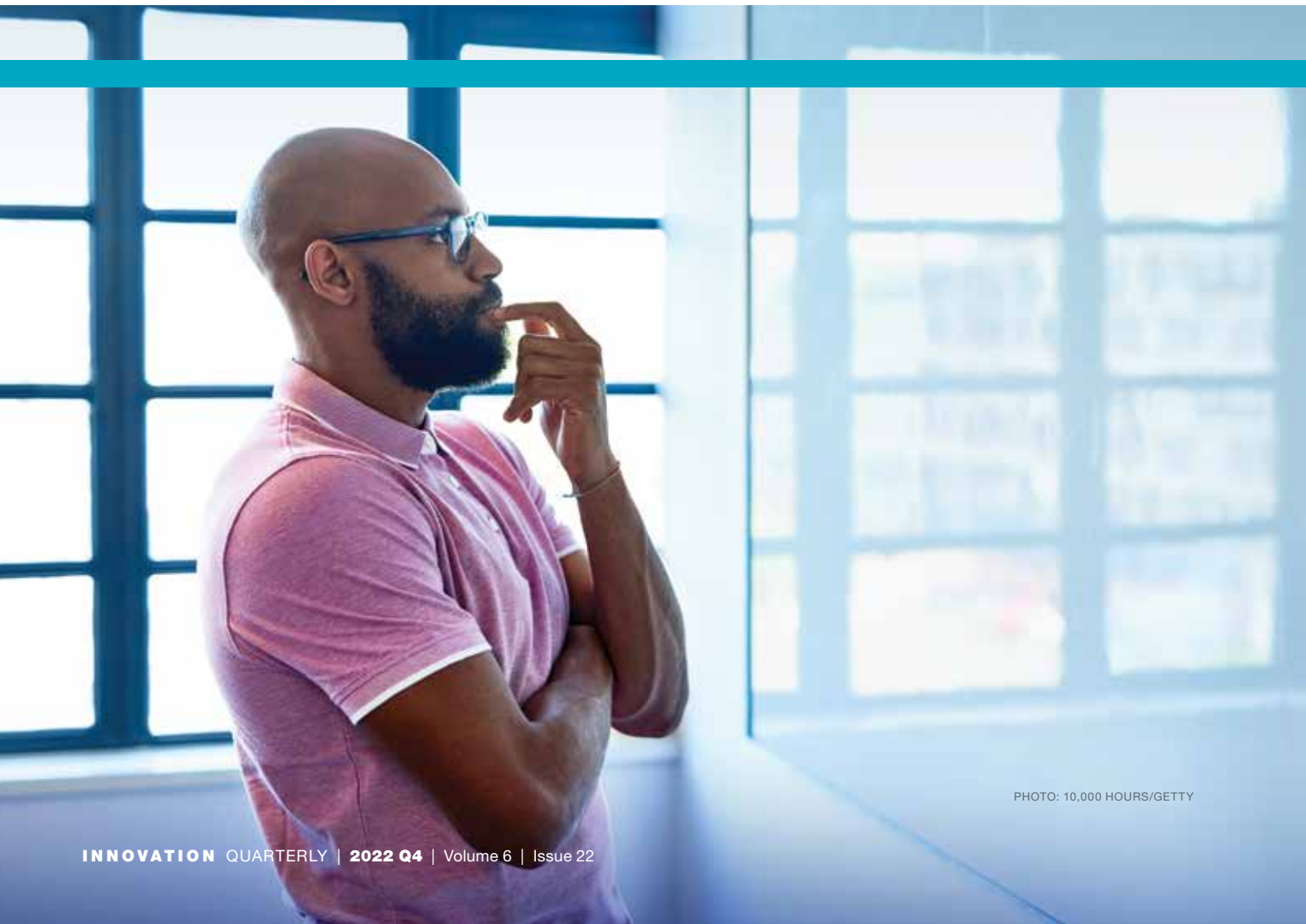


PHOTO: 10,000 HOURS/GETTY

**3 USER PERSONAS:** The field of user experience provides a tool that employs empathy as a path to new solutions. Start by generating a set of personas or fictional characters who embody the traits and behaviors of those who will use your idea, product or service.

These personas can be developed quickly, based on your knowledge or your team's knowledge, by talking with potential users or by surveying a broad population and using the results to identify clusters of similar needs or outlooks. Choose a method based on how much time you have available and your goals for the project.

Your persona characterizations should include information about what that particular user is seeking to accomplish, their current approach and what challenges they face. Include other categories of detail as needed.

Now comes the hard part. Take on each persona one at a time and imagine what the person wants. What would solve the problem? What is missing in the design? What tools would each persona use to solve the problem based on individual viewpoints and experiences? Take on all of these various user perspectives to find unique solutions and ideas.

**If working in a group, you could have each person take on a different persona and generate new ideas together from those perspectives.**



PHOTO: JGI/TOM GRILL/GETTY

**2 OBSERVATION:** There is much to be gained from simply observing people, products and processes around you. Notice when people are using anything in unintended or inventive ways. This points out gaps in current methods or products and shows you an opportunity.

If, however, you seek a solution to a particular problem, investigate other industries or even look to your hobbies for ideas. Notice what is efficient or useful. Identify elements that people gravitate to or that you see as unique. Get down to the fundamental principle that drives that idea and how it works in that system. Ask yourself if the same underlying principle could work for your situation.

**3 OUTSIDE VIEW:** Talk to those with backgrounds or expertise unlike yours. **Those outside your typical circle bring a different set of experiences and knowledge in their approach to the problem or may see it through a different lens.**

They may ask why something is done a certain way, which could lead you to revisit your assumptions.

## Informal Methods: Common Sense Approaches to Innovation

These informal methods offer suggestions for less-prescriptive but highly effective techniques to catalyze inspiration.

**1 EXPOSURE:** Creativity research shows that new ideas are most often formed by using existing methods or tools in novel ways. The more you are exposed to, the more fuel you have to draw on to develop something different.

You can improve your problem-solving potential by reading, listening and observing in a variety of settings. You may choose something closely related to the problem you wish to solve, such as a technical journal for your field. Also consider publications about other fields.

**Try a podcast that covers many different technology areas, or visit museums and art galleries.**

Systematically and consistently seeking new information will broaden your experience set and, as a result, help you solve future problems.



PHOTO: METAMORWORKS/GETTY

## 4

**BREAK TIME:** This is counterintuitive, but sometimes the harder you think, the less likely you are to have a breakthrough idea. Taking a step back, even away, may give your mind room to innovate. There is science behind this intentional timeout. In research about the creative process, it is described as the incubation stage.

Once you frame a problem or question and gather information, it can be helpful to give your unconscious self time to process and make relevant connections.

**Do something else.**

Then come back to the problem at hand. You are likely to have a fresh perspective and new approaches.

## In Summary: Find Your Focus

When considering the various methods offered here, it is best to try out several of them and practice making new connections before you are in a time crunch.

Think of a product you use, such as a mobile phone. Remember that early versions were on a trajectory of shrinking size. That was suited to their functionality — making calls and sending text messages.

Then they began to offer additional features, essentially becoming a computer in your pocket, driving the need for a larger screen and battery. What could the next new form factor look like for future mobile communication?

Whatever methods you pursue, be sure to start with a clear, crisp question to focus your new idea. If you are looking for a better power source, for example, be sure to define “better.” That could include weight, size,

producibility or other factors. If you are looking for an entirely new product, then be sure to define the intended audience.

**And when you have that innovative idea, you will want to share it.**

Congratulations! Now you are the brilliant idea machine. **IQ**



**ABOUT THE AUTHOR**

Marna Kagele is a Boeing Technical Fellow in systems engineering and strategic foresight and a real-life rocket scientist.

PHOTO: SARO 17/GETTY

**BOOST YOUR IQ!**  
Learn how to make  
your best pitch.



**MOONLIGHT LANDING**

An EA-18G Growler arrives on the aircraft carrier USS George H.W. Bush off the coast of Virginia, with other Growlers and F/A-18 Super Hornets parked on deck nearby. As the Growler makes contact with the swaying deck, the aircraft's tailhook snags one of three arresting wires, bringing the flight to a stop. Photographer Tim Reinhart used a two-second exposure to capture the streaks and shadows.

PHOTO: TIM REINHART/BOEING

# Innovation driven by inclusion

Creating the world's most innovative aerospace products and services requires a diverse and inclusive global team. Join us.



[Boeing.com/Careers](https://www.boeing.com/careers)

Boeing is an Equal Opportunity Employer. Employment decisions are made without regard to race, color, religion, national origin, gender, sexual orientation, gender identity, age, physical or mental disability, genetic factors, military/veteran status or other characteristics protected by law.

