2022 Q3 | Volume 6 | Issue 21

IQ INNOVATION QUARTERLY

INNOVATION. INSIGHT. INSIDE AEROSPACE.

Reality Show

'X-ray vision' can see through metal — and see the future

PLUS: Add It Up
Discover how additive manufacturing will shape aerospace — and already has.

POINT WELL TAKEN

Boeing engineer Kennedy Woodward uses augmented reality glasses to see digital elements superimposed on real-world surroundings.

IQ INNOVATION QUARTERLY

2022 Q3 | Volume 6 | Issue 21

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IQR

Cover Story
"X-ray vision" can see through metal — and see the future.

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

PHOTO: BOEING

Forward Together

The art of the possible

The future is something none of us know but all of us imagine.
We do our best to plan for the unknown with what we have today. But no matter what our best algorithms and experience tell us, everything about tomorrow is an educated guess.

You may have heard the world described as VUCA: volatile, uncertain, complex and ambiguous. Opportunities and challenges come at a rapid-fire pace.

At Boeing, we boldly own the challenge of the unknown by, above all, staying curious. We're able to move forward together by using data, ingenuity and innovation to improve our aircraft and the structures and ways we work that support our people. We must look at what is possible in new ways — aiming to simplify the process while being mindful of the complexities and absolute quality required in our business.

I believe in the power of "and" versus the power of "or" — the ability to hold two opposing ideas by asking the right questions to find solutions. It's understanding the true job that needs to be done and figuring out how, instead of settling for what can't be done.

South Africa's first democratically elected president, Nelson Mandela, said, "It always seems impossible until it's done." Sometimes the hardest thing to do is move forward against all odds, resistance or doubt. The key is embracing challenge and change.

Just ask our teams leveraging the power of augmented and virtual reality as they envision the future of aerospace (page 8) or a Boeing engineer who helped a world-champion drag racer set a new world record by reimagining what's possible, even if one loses the ability to see (page 29).

To play chess, you must make a move; no game is won by standing still. To move forward, we must start. And we start with dreaming big and putting one foot (or one thought) in front of the other. We move forward by designing and delivering products with the end user in mind — integrating their needs from the beginning — and working with cross-functional teams to produce what we used to only dream of, always operating with empathy for our customers and teammates.

This is how we win. The secret is thinking about not what you want to change but rather what the end result of that change will be.

The future is an incredible place that we can make better together, moving forward every day with every idea.

That is why we need you. What impossible things do you dream? What does "forward" mean to you? And how can we help get there, together? **IQ**

Susan

Susan Doniz
Chief Information Officer
Senior Vice President,
Information Technology & Data Analytics

SIDE BY SIDE

The AH-64E Apache (right) and CH-47F Chinook took center stage in the Department of Defense display.

EXHIBIT A

The immersive Boeing pavilion highlighted the company's commitment to safety, quality, innovation and sustainability.

Farnborough 2022

Boeing unveils the future at international air show

For the first time in four years, innovators, leaders, exhibitors and visitors came together in person at the Farnborough International Airshow in late July.

RISE AND SHINE

The 777-9, ready for a new day in Farnborough, UK.

ALL PHOTOS: BOEING

Farnborough 2022

BACK PORCH

Visitors got a look inside the CH-47F Chinook.

E-TENT

The Boeing-backed Wisk electric vertical takeoff and landing (eVTOL) aircraft was on display.

CANINE CO-PILOT

Hobson the security dog visits the 777-9 flight deck.

STEEP TAKEOFF

Air show visitors watch the 737-10 during its flying display.

THE VIEW

F-22 engineer Kennedy Woodward, formerly a manufacturing industrial engineer with Missile and Weapon Systems, dons an augmented reality headset at the Weapons Visualization Center in St. Charles, Missouri.

PHOTO: ERIC SHINDELBOWER/BOEING

REALITY SHOW

‘X-ray vision’ can see through metal — and see the future

Floating hands, holograms and headsets are increasingly becoming part of the aerospace process. Boeing teams in the United States and Canada have the future in their hands — and on their heads.

Boeing's virtual, augmented reality center:

Advanced capabilities enhance design, production, training and safety

BY JOSH ROTH, BOEING WRITER

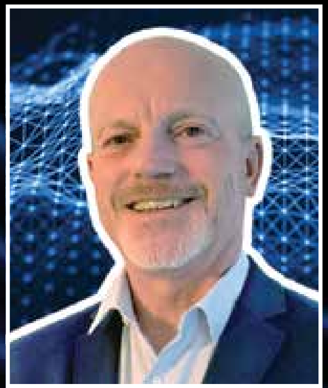
At the Weapons Visualization Center in St. Charles, Missouri, engineers are designing tools, products, assembly stations, production lines and even factories in virtual reality (VR) and augmented reality (AR) environments.

Before the Build
See It 'Finished' First

"VR and AR give us the ability to more closely view and scrutinize everything before we build it," said Scott Seddon, production engineer and virtual manufacturing specialist. "By placing our engineers into virtual environments, they're able to refine the function and accuracy of our designs and processes, eliminating risks and defects prior to 'bending metal.'"

Using the same technology, new employees can also train before ever stepping foot on an actual production line. Donning headsets and wands, employees learn processes, build skills and gain the muscle memory needed to perform tasks faster than previously possible.

"It can take people up to a couple of years to become proficient at all of the stations on a complex production line," said Kristi Shepard, production engineer and former mechanic. "By learning to do the work consistently well in a virtual setting first, we can drive down costs and defects significantly while improving safety and quality."



SCOTT SEDDON

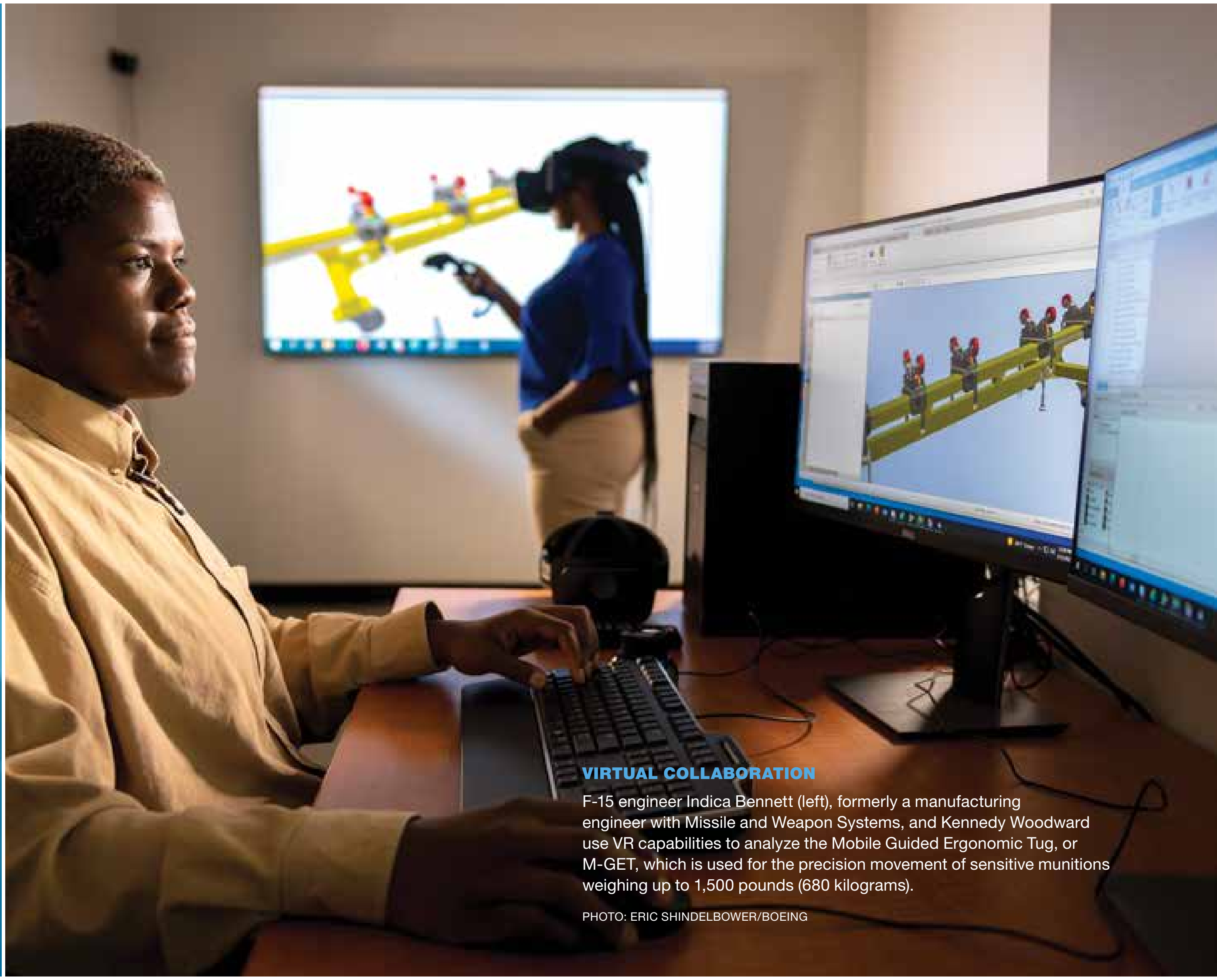
Production engineer and virtual manufacturing specialist, Weapons Production Engineering

PHOTO: BOEING

KRISTI SHEPARD

Production engineer, Weapons Production Engineering

PHOTO: KRISTI SHEPARD



VIRTUAL COLLABORATION

F-15 engineer Indica Bennett (left), formerly a manufacturing engineer with Missile and Weapon Systems, and Kennedy Woodward use VR capabilities to analyze the Mobile Guided Ergonomic Tug, or M-GET, which is used for the precision movement of sensitive munitions weighing up to 1,500 pounds (680 kilograms).

PHOTO: ERIC SHINDELBOWER/BOEING

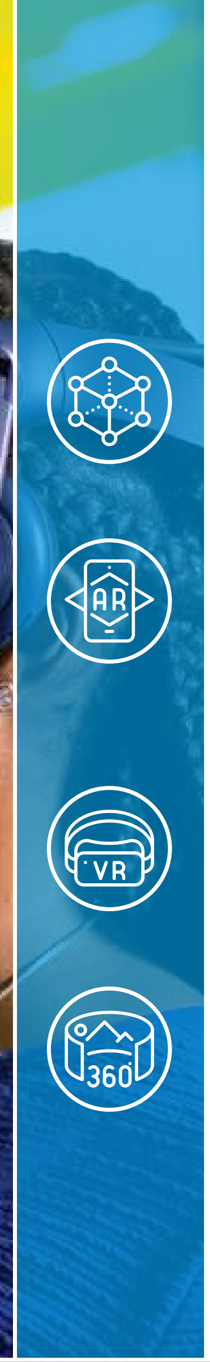
> "By placing our engineers into virtual environments, they're able to refine the function and accuracy of our designs and processes, eliminating risks and defects prior to 'bending metal.'"
>
> **SCOTT SEDDON, PRODUCTION ENGINEER AND VIRTUAL MANUFACTURING SPECIALIST, WEAPONS PRODUCTION ENGINEERING**

Additionally, engineers can use the same virtual training system to test design changes and possible improvements before implementation — the feedback they receive from operators is invaluable, helping to avoid rework and allowing for agile adjustments.

"Practical feedback from our mechanics is essential to make things easier and more efficient for them," Shepard said. "Part of the reason this training is so valuable is that it gives them an avenue to provide input, as they are the ones actually doing the work."

REAL-WORLD WORK
With virtual reality headsets, teammates can place a marker, like a red dot, to precisely investigate specific areas.

PHOTO: ERIC SHINDELBOWER/BOEING



What's the difference?
The FYI on XR, AR, VR, MR

EXTENDED REALITY (XR)

Production engineer Kristi Shepard calls XR "all encompassing" and said it is applied in the digital engineering world "to use digital applications to better the business." XR is the umbrella term that includes AR, VR and MR.

AUGMENTED REALITY (AR)

According to Shepard, AR overlays digital elements onto the already existing surroundings. Production engineer Scott Seddon added, "AR brings digital content into the real world with precise alignment, and the digital content is not the user's primary focus. The digital content is 'augmenting' something in the real world."

VIRTUAL REALITY (VR)

"This is computer-generated, lifelike images and sounds that simulate a user's physical presence in a virtual or imaginary environment," Seddon said. "VR immerses users in a fully artificial digital environment and often occludes the real world."

MIXED REALITY (MR)

"It's a mix between AR and VR, where there are digital elements in the headset laid over the real environment," said Shepard. Seddon also pointed out that the digital content is the user's focus. "It is not merely 'augmenting,' as the user is able to interact with virtual objects," he said.

"Practical feedback from our mechanics is essential to make things easier and more efficient for them. Part of the reason this training is so valuable is that it gives them an avenue to provide input, as they are the ones actually doing the work."

KRISTI SHEPARD,
PRODUCTION ENGINEER,
WEAPONS PRODUCTION ENGINEERING

Employee Benefits
Safety at the Center

Moreover, the center is beginning to use motion capture technology to analyze employee interaction with products during the build process.

"Things like posture, vision and reach analysis give us insight into the physical impact of different movements and lifting requirements so we can make adjustments that increase safety and well-being for our employees," Seddon said.

The technology was recently used to design a new manufacturing facility in St. Charles, which was completed last year to support increased production for the Harpoon missile program and the restart of the Standoff Land Attack Missile Expanded Response, or SLAM ER, production line.

"Because we were able to simulate production flow and move these products through the virtual facility layout during the design process, we were able to identify less-obvious issues like space and turning radius requirements, which would have been costly discoveries after the fact," Shepard said. "That insight early on allowed designers to avoid major redesigns and resulting scheduling delays."

Moving forward, the center is looking at developing manufacturing digital twins to support entire product life cycles — including design and production processes, shop floor activities, logistics, and tool and workstation use. By modeling entire process flows and facility layouts, the team hopes to analyze complete production systems and harness the power of predictive analytics.

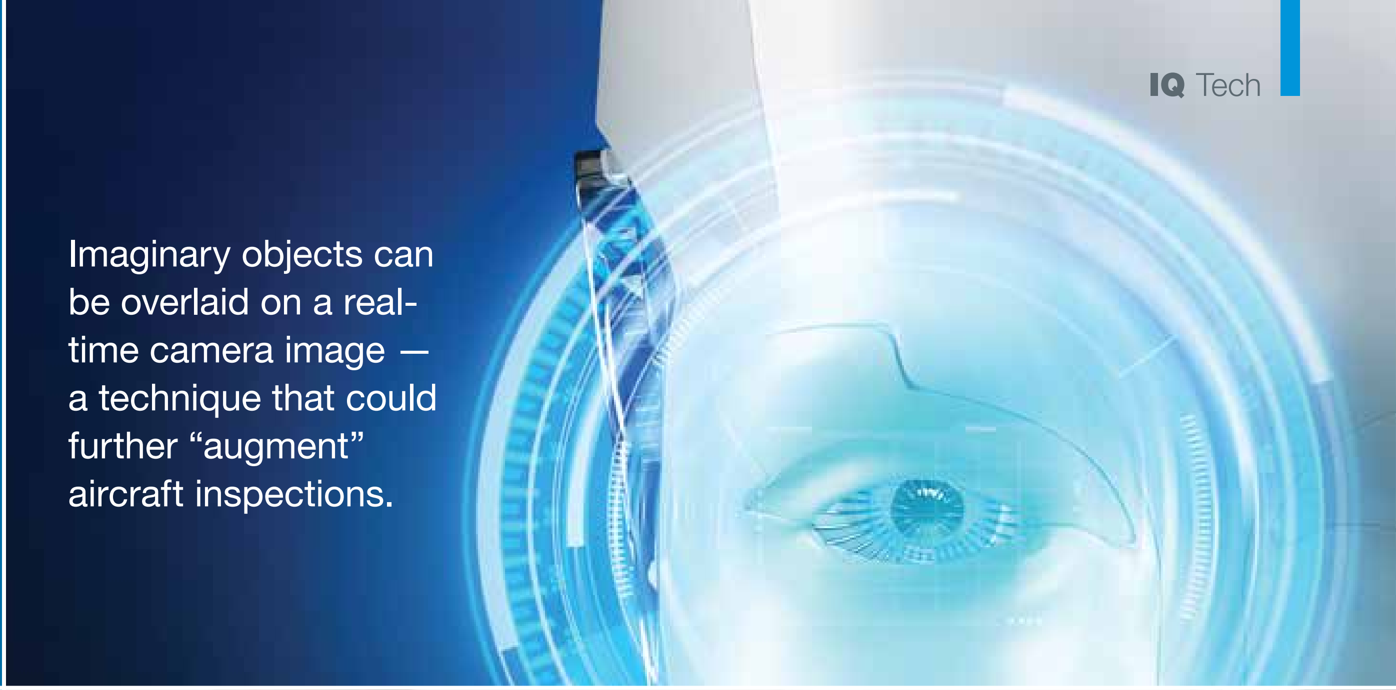
The center's underlying value is found in the seamless integration and collaboration of operations, production and engineering experts through shared virtual environments.

"We're really just scratching the surface of what's possible, and we're eager to find new opportunities to apply these capabilities," Seddon said. "The sky is the limit on what can be done in here."

A vision in Vancouver:
AR for inspection and maintenance

BY JACK HSU, BOEING VANCOUVER

Augmented reality (AR) for aerospace production happens in a constant, controlled environment. But maintenance and inspection happen in dynamic settings, inside different hangars, sometimes outdoors in changing weather conditions and lighting, with different liveries on aircraft. These are the challenges a team in Vancouver, Canada, is approaching.



Imaginary objects can be overlaid on a real-time camera image — a technique that could further “augment” aircraft inspections.

Imagine if an aircraft mechanic had something like X-ray vision. Circling with a digital device in hand, a mechanic could “see” under an aircraft’s skin on a real-time camera image. As the camera moves, it reveals previously identified defects or damage as the operator records newly discovered issues.

This approach may be the future of aircraft inspection.

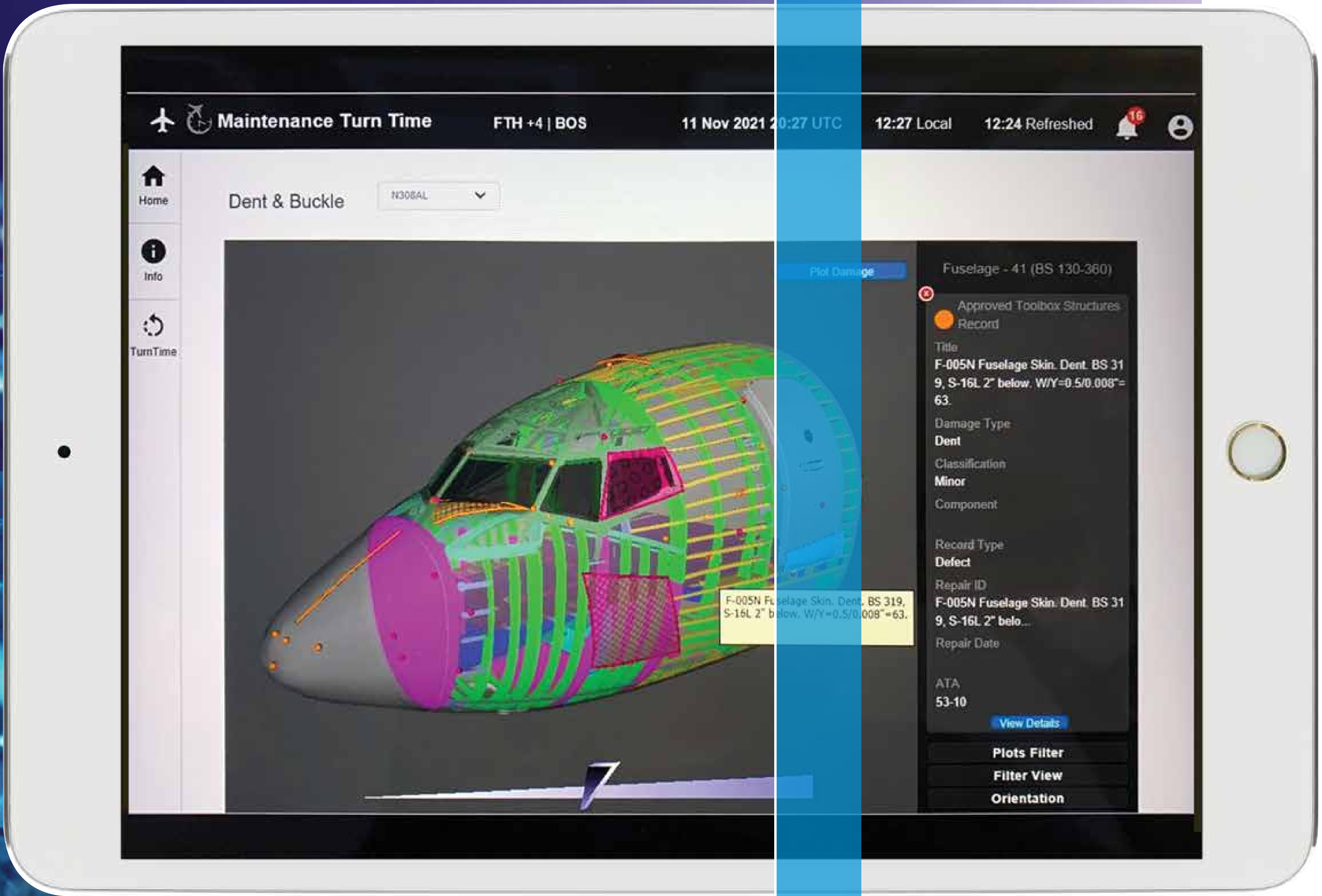
The Boeing Vancouver team is inventing a process where repair indicators can be recorded and displayed directly on the surface of an aircraft when viewed through an AR digital device. Imaginary objects can be overlaid on a real-time camera image — a technique that could further “augment” aircraft inspections, with benefits to both quality and efficiency.

Aircraft Inspection
Augmenting Efficiency and Quality

A typical aircraft inspection involves maintenance technicians and engineers walking around an aircraft, recording new defects or damage with a pencil in a notebook. This constant and critical operation must also cross-check defects that have already been recorded to avoid replication.

Locations are often described in language like “3 inches from the fifth left side window.” Depending on the size of the structure, the inspection often takes hours, even days.

LAYERED APPROACH
An airplane’s past and present could be superimposed during a walk-around inspection, leading to future recommendations.
PHOTO: BOEING



PENCILS DOWN

Operators can replace literal notebooks with virtual ones that can gather all inspection information in one place and precisely pinpoint issues.

PHOTO: STEPHANIE TOWNEND/BOEING

But what if you could simply hold up a digital device and see locations of all previous damage and repairs highlighted in 3D — and, with the touch of a screen, note newly discovered issues? Damage/repair indicators could appear as dots projected directly on the surface of the aircraft itself. The virtual dots would "augment" reality and dramatically increase efficiency.

The idea starts with a virtual 3D model (or digital twin) of the aircraft. Graphics software then places highly visible damage indicator dots (with locations coming from a previously recorded damage database) onto the surface of the model. The 3D model lines up with the actual image of the aircraft coming from the camera of the AR device.

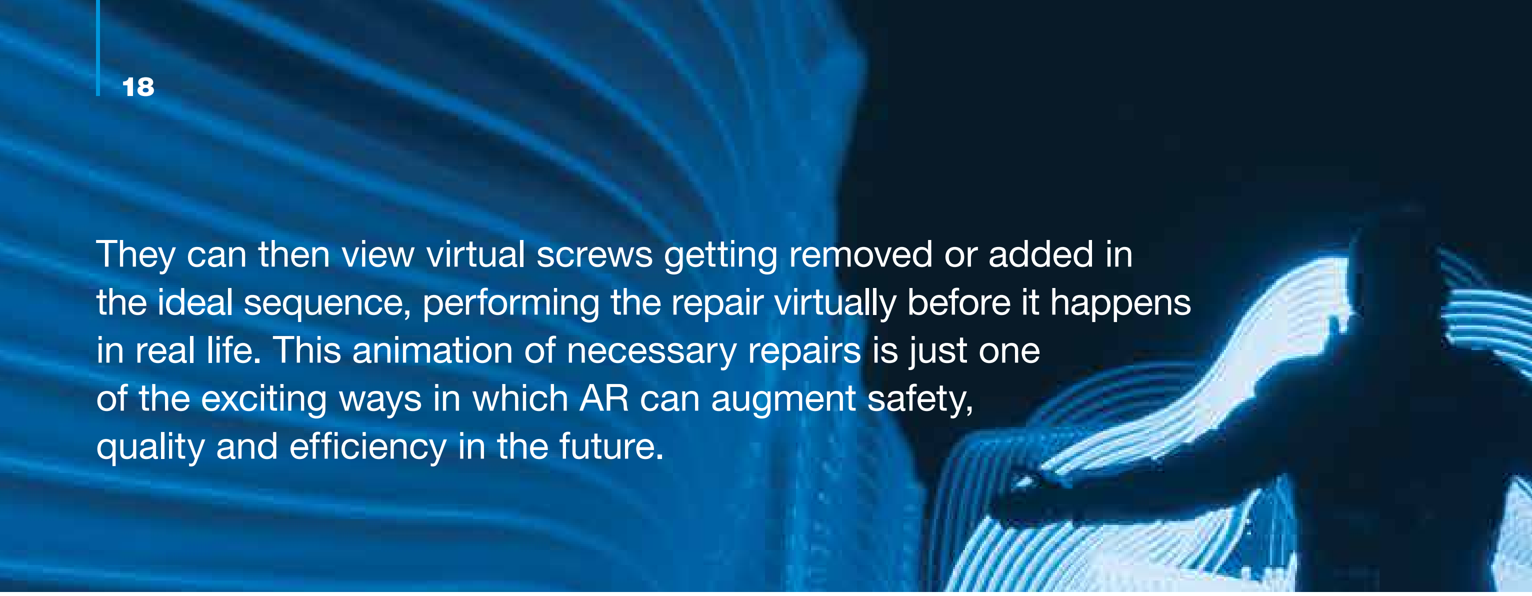
An operator could graphically remove the 3D model "mesh" of the aircraft but leave the indicator dots, which then gives the user the illusion the dots are actually painted on the surface of the plane. The dots would remain "anchored," indicating the location of damage, even as the mechanic and the device could move around the aircraft, adding new data.

Artificial Intelligence Needs a Human Touch

Placing damage markers on a 3D model of an aircraft is the easy part; the challenge turns out to be positioning the model over the actual aircraft image while moving around the plane.

It is critical that the 3D model and the real-world image align precisely to accurately record the position of new and existing damage. Current software is dependent on the working environment. In a relatively small indoor location such as an office, an app can easily track multiple feature points, such as furniture or window corners. But with a large airplane that has a shiny surface and is often sitting in a large open environment, the technology struggles.

The team came up with a solution to use artificial intelligence (AI) to train a machine learning algorithm. The trained algorithm, the team hoped, would be able to recognize the orientation and position of the aircraft based on the stream of images coming from the camera — an area of AI technology called "pose estimation."



They can then view virtual screws getting removed or added in the ideal sequence, performing the repair virtually before it happens in real life. This animation of necessary repairs is just one of the exciting ways in which AR can augment safety, quality and efficiency in the future.

This technique means a mechanic's manual intervention wouldn't be required to use special equipment or markers to orient the position of the device to the aircraft. The technician should, just by looking at the aircraft through the camera, be able to determine exact location. And once that is known, the virtual 3D model can be positioned in the appropriate spot.

Boeing partnered with Simon Fraser University (SFU), Unity and Canada's Digital Technology Supercluster to explore this solution on the Augmented Reality for Maintenance and Inspection project, started in 2020. SFU researchers Ali Mahdavi-Amiri, Anil Ufuk Batmaz, Johannes Merz, Wolfgang Stuerzlinger and Richard Zhang worked together to research and develop the pose estimation algorithm; Unity worked on software implementation for a holographic device and synthetic data generation; and the Digital Supercluster provided project funding.

Cloud Confusion
Seeking a Silver Lining

As with all machine learning algorithms, significant data is needed to train the pose estimation algorithm. Driven by the restrictions caused by the pandemic, the team found an aircraft that was still accessible, a Douglas DC-3 in the Canadian Museum of Flight's collection at Langley Regional Airport east of Vancouver. SFU researchers were tasked with capturing the images and positional data and feeding them into the pose estimation algorithm they had developed.

After long hours of image capture, data cleansing and algorithm training, the results looked initially promising. But after analysis, researchers determined that the algorithm was confused because the clouds were different when the images were captured compared to the test session, resulting in different lighting.

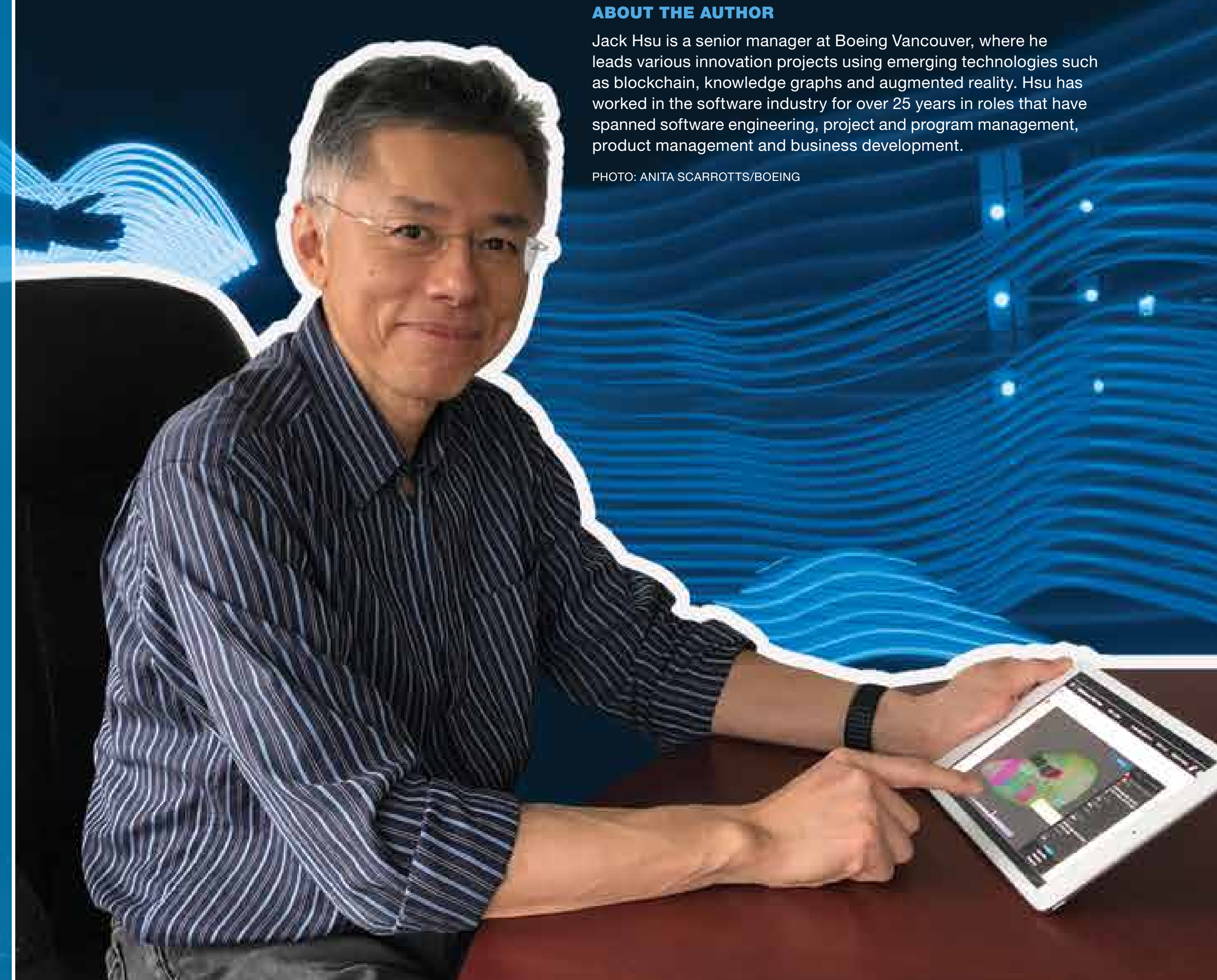
The teams realized the machine learning algorithm would require hundreds of thousands of images of planes from different angles, lighting, liveries and background hangars in order to obtain robust pose estimation. To collect these images with real aircraft, it would take an impractical amount of time.

Synthetic Solution
Enabling Machines to Learn

After identifying this issue, the teams decided to confront the data problem with synthetic data generation, a burgeoning area in machine learning. The concept is to create a synthetic, computer-generated image — like a cat, a car or a plane in a video game — that is convincing enough for a machine learning algorithm to accept it as real.

Fortunately, Unity is a leader in this new area of AI, using graphics-rendering technology. Working with the project team, Unity graphic artists and developers synthetically created images of the DC-3 with different liveries and various environments, lighting conditions and viewpoints.

Synthetic data generation quickly creates not only more diversity but also many more images; Unity generated 100,000 synthetic images in four to five hours, compared to about 3,000 real images collected over the course of eight hours at Langley Airport. Another advantage of synthetics is that the position of the camera relative to the virtual aircraft is known — much more difficult to achieve with real images.



ABOUT THE AUTHOR

Jack Hsu is a senior manager at Boeing Vancouver, where he leads various innovation projects using emerging technologies such as blockchain, knowledge graphs and augmented reality. Hsu has worked in the software industry for over 25 years in roles that have spanned software engineering, project and program management, product management and business development.

PHOTO: ANITA SCARROTTS/BOEING

Even so, to train the algorithm properly, synthetic images must be mixed with real images, with the optimal ratio of real to synthetic images still to be determined as the effort continues.

Next
Augmenting the Future

Using AR to display damage/repair indicators virtually on the surface of aircraft would be the first step in applying the technology to aircraft maintenance. Once accurate anchoring of a 3D model to an aircraft image is accomplished, many possibilities will open up, including the ability to display the structure and components or parts under the skin of the aircraft so repairs or modifications can be completed with less risk.

Accurate anchoring will also enable 3D maintenance "work guidance," where technicians will be able to see virtual 3D components anchored on top of real components. They can then view virtual screws getting removed or added in the ideal sequence, performing the repair virtually before it happens in real life. This animation of necessary repairs is just one of the exciting ways in which AR can augment safety, quality and efficiency in the future. **IQ**

10 YEAR ANNIVERSARY
ecoDemonstrator

Decade of Demonstration

The newest Boeing ecoDemonstrator will serve as a test bed for 30 new technologies to help decarbonize aviation

BY JOSH GREEN, ELISA HAHN AND TED LAND, BOEING WRITERS

CLOUD LAB
The Boeing-owned 777-200ER (Extended Range) will enhance safety and sustainability as the 2022 ecoDemonstrator.
IMAGE: BOEING

In June, Boeing unveiled its 2022 ecoDemonstrator airplane, marking 10 years of testing technologies through the program.

30

new technologies

The Boeing-owned 777-200ER (Extended Range) will serve as a test bed for 30 new technologies, including a water and weight conservation system and new additively manufactured (3D-printed) parts that help reduce fuel consumption and weight. The team will also test new methods using ultraviolet light for disinfecting, an environmentally preferred refrigerant and new tools to improve operational efficiency.

30-70

blend of sustainable aviation fuel and conventional jet fuel

"Everything we do supports the legacy of Boeing's engineering excellence with safety and quality as the cornerstones," said Ricole Johnson, a project engineer and technology integration leader for the ecoDemonstrator Program.

The team plans to power the 777-200ER throughout its test period using a 30-70 blend of sustainable aviation fuel and conventional jet fuel. The program is continuing its multiyear partnership with NASA to study the emission improvements of sustainable aviation fuel.

2050 goal

to reach net-zero carbon emissions

"When the industry talks about 2050 goals for getting to net-zero carbon emissions – 2050 isn't really an abstract idea to me," said Addison Salzman, an airplane platform leader with the program. "That's going to happen well before I retire. So when I think about 2050 goals, I think about what are the goals for my career. It's really all of our jobs to think about sustainability and how it affects our work so that we can make the right choices."

SCAN CAM HERE, BOOST YOUR IQ!

Video: Meet some of the ecoDemonstrator team.

HERE TOO FOR MORE IQ!

Video: See the paint job happen.

Throughout the next year, Boeing will highlight some of the technologies now in use that were proved with the ecoDemonstrator Program. Some of those include a split-tipped winglet that is now on the 737 MAX family, touch screens now on the 777X family and continuous testing that has already led to better understanding of how to eliminate noise from airplanes.

"Since 2012, we've tested more than 200 technologies, and a third of those made it into our products and services, and those technologies aid in reduction of noise, reduction of fuel, cleaner emissions, safety of the passengers and environmental impacts," said Rae Lutters, the ecoDemonstrator program manager. "Our ecoDemonstrator motto is 'innovate, collaborate and accelerate,' and we've held to that motto since we started in 2012." **IQ**

Since 2012

the Boeing ecoDemonstrator has tested more than 200 technologies, a third of which are now part of Boeing products and services.

FRESH PAINT

The Boeing 2022 ecoDemonstrator is towed out of a paint hangar at San Bernardino International Airport in California in early June.

PHOTO: PAUL WEATHERMAN/BOEING

STARLINER'S IN HIS EYES

The Boeing Crew Space Transportation (CST)-100 Starliner spent six days in space during Starliner Orbital Flight Test-2 (OFT-2). The spacecraft autonomously docked with the International Space Station for the first time, orbited the Earth 94 times and covered a total distance of 2,467,406 miles (3,970,905 kilometers).

BY TODD KELLEY, BOEING WRITER

PAUSE FOR REFLECTION

Boeing firefighter Jon Riggsby stands just steps away from the Starliner minutes after it landed in the New Mexico desert in May.

PHOTO: ERIC SHINDELBOWER/BOEING

LANDING AND RECOVERY TEAM
HONES TALENTS DURING OFT-2

Boeing Fire Assistant Chief J.R. Hudgins says his team is ready for astronauts to be on board.

Hudgins has been working for more than six years to recruit, prep and train select members of the Boeing Fire Department to be part of the Starliner Landing and Recovery Team that greets astronauts returning aboard the space capsule from the International Space Station (ISS).

OFT-2 gave Boeing firefighters real-world practice before the first crewed flight recovery.

This is a special duty for the firefighters, one with a rich history. The team follows in the footsteps of U.S Navy SEALs, who recovered returning Mercury, Gemini and Apollo astronauts as they splashed down in the ocean in the 1960s and '70s.

"Boeing firefighters were chosen for this duty because they possess the skills to handle hazardous materials situations and provide emergency medical support," Hudgins said. "Astronauts will be returning after long stays at the ISS. As a result of being in a weightless environment so long, they may need assistance exiting the spacecraft."

CST-100 STARLINER

LEAK CHECK
Four firefighters are the first to approach Starliner after it lands at White Sands Space Harbor in New Mexico. The first four firefighters, in hazmat suits, test for hydrazine leaks before they approach the capsule to prepare for astronaut extrication.
PHOTO: BILL INGALLS/NASA

FUNCTIONAL FLAG
The American flag on the access platform not only is patriotic but also gives teams an indication of wind direction in the event of a hydrazine leak.
PHOTO: ERIC SHINDELBOWER/BOEING

TEAM WILL BE FIRST 'EARTHLINGS'
ASTRONAUTS SEE UPON RETURN

After the Starliner lands on Earth, a team of four firefighters in hazmat suits first test the capsule for hydrazine leaks. Hydrazine is part of the crew module propulsion system that feeds the thrusters and poses an extreme exposure risk.

Once it is safe to approach the Starliner capsule, additional members of the Landing and Recovery Team, which includes members of the Boeing Fire Department, move in to stablize the capsule, place the mobile access platform up against the spacecraft and assist the returning astronauts out of the capsule.

CST-100 STARLINER

SELECT GROUP

The Boeing firefighters chosen for astronaut extrication represent sites from all over the United States.

PHOTO: ERIC SHINDELBOWER/BOEING

"Being a part of this team is a great honor," said Boeing firefighter Ivan Stephenson. "We've put a lot of sweat equity into this, and OFT-2 was a huge win for our team and the company as a whole. We're ready!" **IQ**

READY TO RECOVER

The broader team includes three rotating subteams from the Boeing Fire Department: X-Ray, Yankee and Zulu. Two teams are on duty when and where the Starliner lands. The third team supports a predetermined backup landing site in the event the spacecraft needs to divert to another location.

Members of the Boeing Starliner Landing and Recovery Team:

LEADER
J.R. Hudgins, Renton, WA

TEAM X-RAY
Rodney Profit, Charleston, SC
Ryan Elter, Renton, WA
Scott Holmes, Philadelphia, PA
Lacey Crick, Frederickson, WA
Javier Vasquez, St. Louis, MO
Jon Riggsby, Renton, WA

TEAM YANKEE
Jason Kestle, Everett, WA
Derek Hanson, Seattle, WA
Ivan Stephenson, El Segundo, CA
Shawn Tobias, St. Louis, MO
Genevieve Cox, Everett, WA
Marquise Hardin, Mesa, AZ

TEAM ZULU
Thor Petersen, Seattle, WA
Cory DeMarco, Charleston, SC
Todd Bark, St. Louis, MO
Gordon Wallace, Renton, WA
Gabe Moss, Philadelphia, PA
Cole Williamson, El Segundo, CA

SCAN CAM HERE, BOOST YOUR IQ!

Video: Experience Orbital Flight Test-2, launch to landing.

IQR

At the Speed of Sounds

World-champion drag racer finds a new vision and a new world record with help from a Boeing engineer

On March 31, 2012, during a race at Alabama International Dragway, world-champion drag racer Dan Parker was nearing the end of the track when his modified 1963 Chevrolet Corvette veered into a concrete retaining wall at about 180 mph (290 kph).

The car burst into flames. Parker narrowly survived.

HUGS ALL 'ROUND

Just after setting the new record, driver Dan Parker (left) embraces his fiancée Jennifer Stegall. Behind is friend Kevin Peckham.

PHOTO: RICK HEAD

PLAYING IT BY EAR

Dan Parker beat the previous record by 10 mph (16 kph) in his 2008 Chevy Corvette at Spaceport America in New Mexico. The car was equipped with an audio guidance system designed by Boeing engineer Patrick Johnson.

PHOTO: RICK HEAD

Parker wanted to keep driving fast — on his own.

SALTY START

In August 2013, just 16 months after losing his eyesight during a racing accident, Dan Parker (aboard the motorcycle) arrived at the Bonneville Salt Flats in Utah. The custom-built motorcycle was equipped with an early version of an audio guidance system created by Boeing engineer and friend Patrick Johnson (right).

PHOTO: PATRICK JOHNSON

Two weeks later, he awoke from a medically induced coma with no memory of the accident and no vision. He was told that swelling in his brain had damaged his optic nerve.

But he hasn't let blindness slow him down. Previous land-speed racers with vision loss had relied on steering instructions conveyed via two-way radios.

Parker wanted to keep driving fast — on his own.

"I thought, 'Well, who's the smartest person I know?'" he said. "It was Patrick Johnson. I called him and he said, 'That's easy. I can do it.'"

An electrical engineer who now works in the Boeing AvionX division, Johnson spends his spare time inventing custom electronics for dragsters. A car with his controller for an electronic fuel injection system won the very first race in which the controller was used. Parker helped prep that car and came away impressed. That's how the two met.

Now Johnson's friend needed help.

Johnson went to work designing an audio guidance system that pairs GPS with tones to let Parker know in his ears if he's drifting off-center.

Parker used that system recently to achieve the "fastest speed for a car driven blindfolded," according to Guinness World Records. (No category exists for drivers with blindness or low vision.) The average of his two top speeds — 211.043 mph (339.64 kph) — on a runway at Spaceport America in New Mexico set the new mark.

"I was bawling like a baby," Parker said. "Everything was emotional. It hit me all at once." **IQ**

WIRED FOR SPEED

The audio guidance system Boeing engineer Patrick Johnson created for Dan Parker's race car includes a standard two-person intercom connected to a custom system that tracks Parker's real-time position against a virtual centerline. If the car veers to the left or right, an audio tone plays in the corresponding earbud that Parker wears under his helmet. The louder the tone, the farther from the centerline. It is still up to Parker to make necessary corrections.

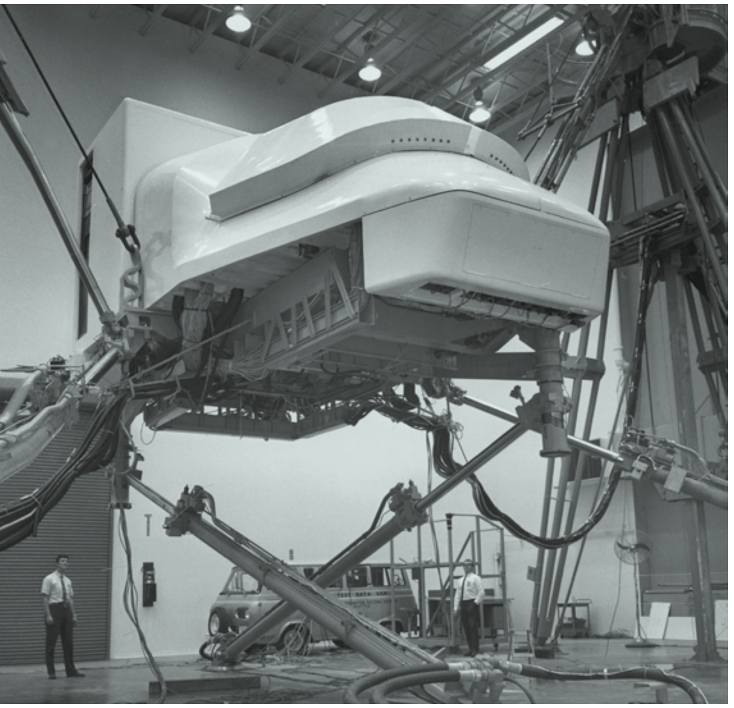
PHOTO: PATRICK JOHNSON

Safety Firsts

Production of the storied 747 will come to an end as 2022 draws to a close. With more than five decades of service so far, the iconic "Queen of the Skies" leaves a lasting legacy of safety firsts.

The 747 was the first airplane with:

- Triple redundancy in all major systems.
- Quadruple redundancy in the control and hydraulic systems.
- Three wing spars, with the third spar extending to the outboard engine.
- Four main landing gear (the plane can operate with just two) that contribute to a soft landing.
- Enclosed overhead bins replacing open hat racks.
- Full-motion simulators for training.



MOTION PICTURE

The 747 team created the industry's first full-motion simulator. During development of the airplane, Boeing invested millions of dollars in a flight training program, including behavioral flight training (instead of procedural) and a cadre of top flight instructors. The "Test Data Van" is at the ready in the background.

PHOTO: BOEING ARCHIVES

A Fond Farewell

HOME STRETCH SKETCH

One of the last 747s under construction, in Everett, Washington, as seen through the pencil, pen then paint of Jeff Barlow from Boeing Creative & Digital.

IMAGE: JEFF BARLOW/BOEING

Boeing's Safety Journey

The company's first Chief Aerospace Safety Officer Report outlines progress made to strengthen product safety

From: **Mike Delaney, Boeing Chief Aerospace Safety Officer**

Subject: **Safety**

Date: **2022**

Boeing implemented a series of meaningful changes to strengthen its safety practices and culture and bring lasting improvements to aerospace safety. The company says it is a journey of continuous improvement and that it is dedicated to making daily progress and holding itself accountable to the highest standards.

Strengthening Engineering

A strong engineering foundation enables Boeing to design, develop, build and maintain its products with safety, quality and integrity. In September 2019, Boeing realigned its 50,000 engineers into a single integrated organization, reporting to the company's Chief Engineer. The realignment strengthens engineering expertise and promotes continued companywide focus on customer, business unit and operational priorities.

Enhancing Oversight Mechanisms

In August 2019, Boeing's Board of Directors established an Aerospace Safety Committee (ASC) to increase the effectiveness of its oversight of safety in all aspects of operations, including engineering, design, development, manufacturing, production, maintenance and delivery of products and services. The ASC comprises independent directors with relevant knowledge and experience.

MIKE DELANEY, BOEING CHIEF AEROSPACE SAFETY OFFICER

GRAPHIC/PHOTO: BOEING

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More: Visit the safety journey webpage.

Implementing the Safety Management System

Boeing is implementing an enterprisewide Safety Management System (SMS) that is grounded in a positive safety culture that encourages employees to speak up and report hazards and concerns. Recognized worldwide as an industry best practice, SMS is an integrating framework for managing safety risks.

Investing in a Safer Industry

A critical part of strengthening the safety culture within Boeing and across the broader aerospace industry is collaboration with the common goal of improving the global aviation safety ecosystem. Through its Global Aerospace Safety Initiative, Boeing is collaborating with airline customers, regulators, academia and other industry stakeholders to develop and implement comprehensive solutions to enhance aerospace safety.

Fostering Transparency and Openness

As part of the Safety Management System, the company is fostering a positive safety culture that is grounded in humility, inclusion and transparency. A positive safety culture enables proactive identification and mitigation of risks in order to prevent accidents, injuries or loss of life. It is an environment where everyone feels comfortable communicating safety issues, learns from errors and successes, and acknowledges that safety is a top priority.

All of these changes are an important part of the ongoing Boeing safety journey. They are making a difference in how teams work together; how the company makes decisions; how it collaborates with customers and other stakeholders; and how it achieves its commitments to improving safety, quality, integrity and transparency. IQ

Passengers to Pallets

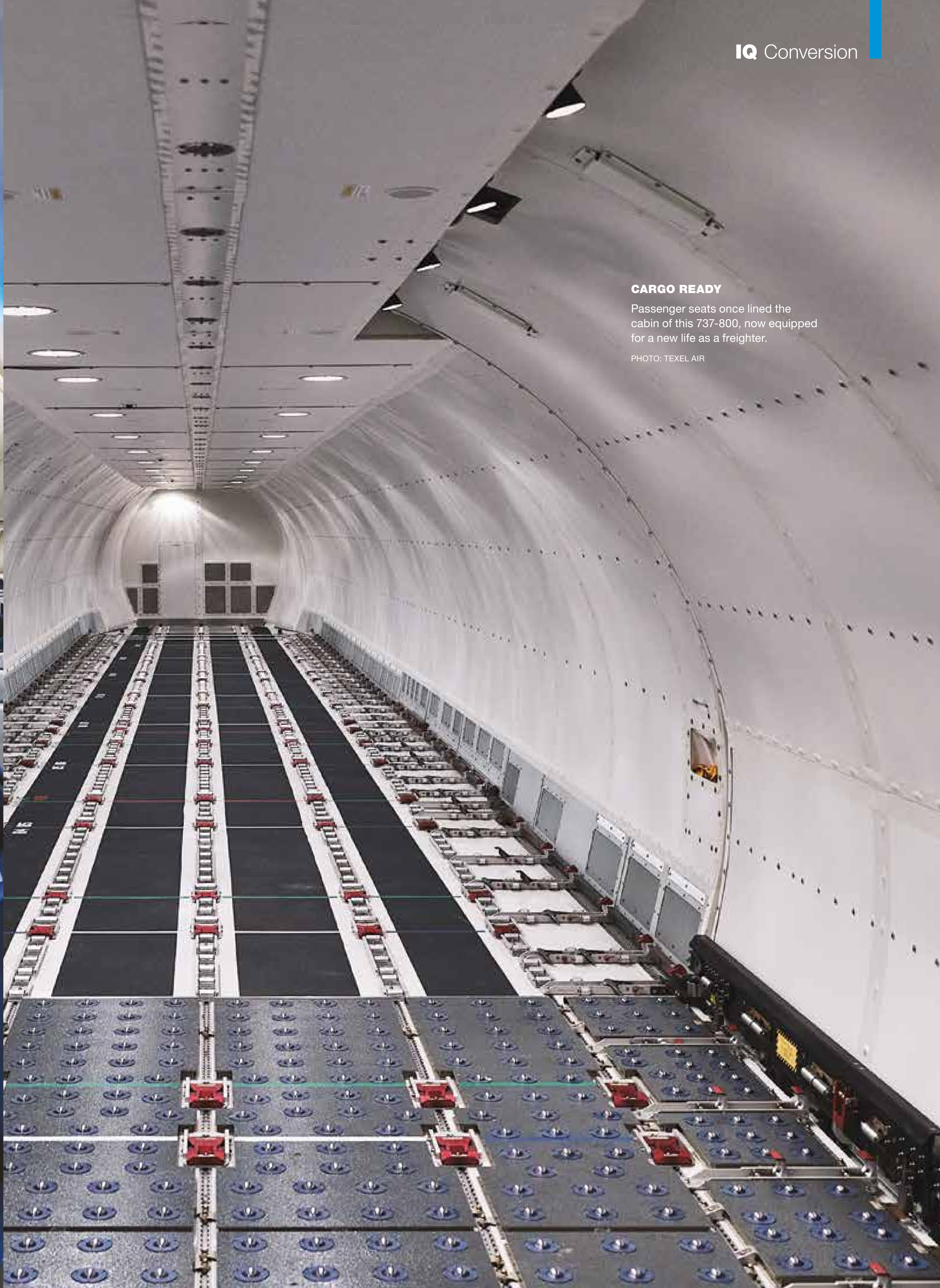
Freighter conversions can add two decades to an airplane's life

Engineers offer glimpse into how they build blueprints for Boeing converted freighters

BY BRIAN RANTALA, BOEING WRITER

When a passenger airplane nears the end of its initial purpose, it can either end up in a desert "parking lot," destined for an uncertain future, or it can be transformed into a freighter, potentially adding over 20 years to its lifespan.

PHOTO: ADOBE STOCK



CARGO READY

Passenger seats once lined the cabin of this 737-800, now equipped for a new life as a freighter.

PHOTO: TEXEL AIR

Last year, Boeing received more than 100 orders and commitments for its two active freighter conversion programs, the 737-800 Boeing Converted Freighter (BCF) and the 767-300BCF.

OPEN FOR BUSINESS

A 141-inch (358-centimeter) wide main deck cargo door was installed on this 737-800BCF.

PHOTO: TEXEL AIR

FREIGHT FLIGHT

A 767-300BCF in flight.

IMAGE: BOEING

The 52,800-pound (23.9-tonne) capacity 737-800BCF is a popular model for conversion, as it contributes to operator sustainability goals through lower fuel consumption, is highly reliable and offers lower operating costs, compared with other standard-body freighters. The larger 124,600-pound (56.5-tonne) capacity 767-300BCF, meanwhile, shares a large cargo door design and other common elements with the popular 767-300 Freighter, manufactured specifically for cargo. The 767-300BCF, like the 737-800BCF, offers the range and operational versatility required by general, e-commerce and express cargo markets.

MAIN DECK ACCESS

The door on this 9G rigid cargo barrier provides main deck access from the crew area on this 737-800BCF for ground operations and for optional in-flight access.

PHOTO: TEXEL AIR

But how is a complex commercial jet converted for something different than its original purpose? And how does that happen cost-effectively and efficiently? Boeing Freighter Conversions chief engineer Jimmy Williams and senior project technical lead engineer Paul Garcia ask and answer those questions every day.

Because each airplane varies slightly depending on the original configuration at delivery, every airplane gets its own tail-number-specific drawing that contains the actual engineering to perform the conversion.

> “Our goal is to have each freighter have a similar look with a standard set of option choices, to speed up the conversion process.”
>
> **PAUL GARCIA,**
> **SENIOR PROJECT TECHNICAL LEAD ENGINEER,**
> **BOEING FREIGHTER CONVERSIONS**

BRINGING DRAWINGS TO LIFE

At Boeing Shanghai Aviation Services, mechanic Liu Jixiang uses installation drawings to mark a cutline in the main deck cargo door frame area.

PHOTO: CURTIS CARTIER/BOEING

HEAVY LIFT SUPPORT

At Boeing Shanghai Aviation Services, mechanic Zhang Ruibang readies the floor beams that will be used to reinforce cargo areas near the back of the airplane.

PHOTO: CURTIS CARTIER/BOEING

“Our goal is to have each freighter have a similar look with a standard set of option choices, to speed up the conversion process,” said Garcia.

Engineering teams collaborate and produce an engineering drawing, specific to each airplane, using Boeing Production System guidelines. “In the world of freighter conversions, a priority exists to stabilize and standardize,” said Williams.

Following the engineering drawings for the conversion, parts are created and procured, enabling the modification to begin. All seats are removed from the airplane, as are lavatory facilities, and flooring is reinforced to withstand additional cargo weight. A large main deck cargo door is installed in the side of the fuselage so that pallets and containerized cargo can be loaded onto the converted airplane.

FLOOR MODEL

Freighter floors are lined with an interlocking network of ball mats and pallet locks that comprises the cargo loading system. The pallet locks (red) guide and align pallets before they are pushed over the roller balls (blue), which allow heavy containers and pallets to move with greater ease.

PHOTO: TEXEL AIR

SEALING THE DEAL

During conversion, it is not unusual for an operator or lessor to perform routine maintenance. At Boeing Shanghai Aviation Services, mechanic Zhu BoTao applies sealant.

PHOTO: CURTIS CARTIER/BOEING

> “Our freighter lines sell like hotcakes, and the appetite keeps growing. When a customer first comes to us, they ask about the availability for a conversion slot. Once we determine the slot availability and the customer’s needs for the conversion, we sign an agreement, and the clock starts ticking.”

JIMMY WILLIAMS,
CHIEF ENGINEER,
BOEING FREIGHTER CONVERSIONS

Once an agreement is in place, Boeing teams get to work. About six months ahead of starting the conversion, program managers work with the customer to identify, as part of the “ship’s record,” tail numbers of passenger airplanes identified for conversion (feedstock) and manufacturers’ serial numbers.

After an airplane is designated for conversion, Boeing manages engineering and design work. When it’s time for the plans to come to life, maintenance, repair and overhaul (MRO) facilities, such as Boeing’s London Gatwick facility, induct a passenger airplane and execute the plans designed by the Boeing engineers to transform the airplane into a freighter.

Conversion at the MRO facility begins by taking the starting weight of the airplane. Once in the hangar, the airplane is lifted and stabilized using an intricate process known as jacking and shoring. This process provides engineers with the baseline information they need to continue the conversion.

Finding the proper location for the new cargo door required additional engineering due to the length of the airplane and other factors. The 737-800BCF main deck cargo door was designed to facilitate loading of cargo on the main deck, ensuring a wide, clear opening with adequate clearance and guidance when loading pallet positions. Additionally, the 767-300 Freighter and the 767-300BCF both share a main deck cargo door design placed at the same location on the airplane to maintain consistency.

“Our freighter lines sell like hotcakes, and the appetite keeps growing,” said Williams. “When a customer first comes to us, they ask about the availability for a conversion slot. Once we determine slot availability and the customer’s needs for the conversion, we sign an agreement, and the clock starts ticking.”

TRANSFORMATION

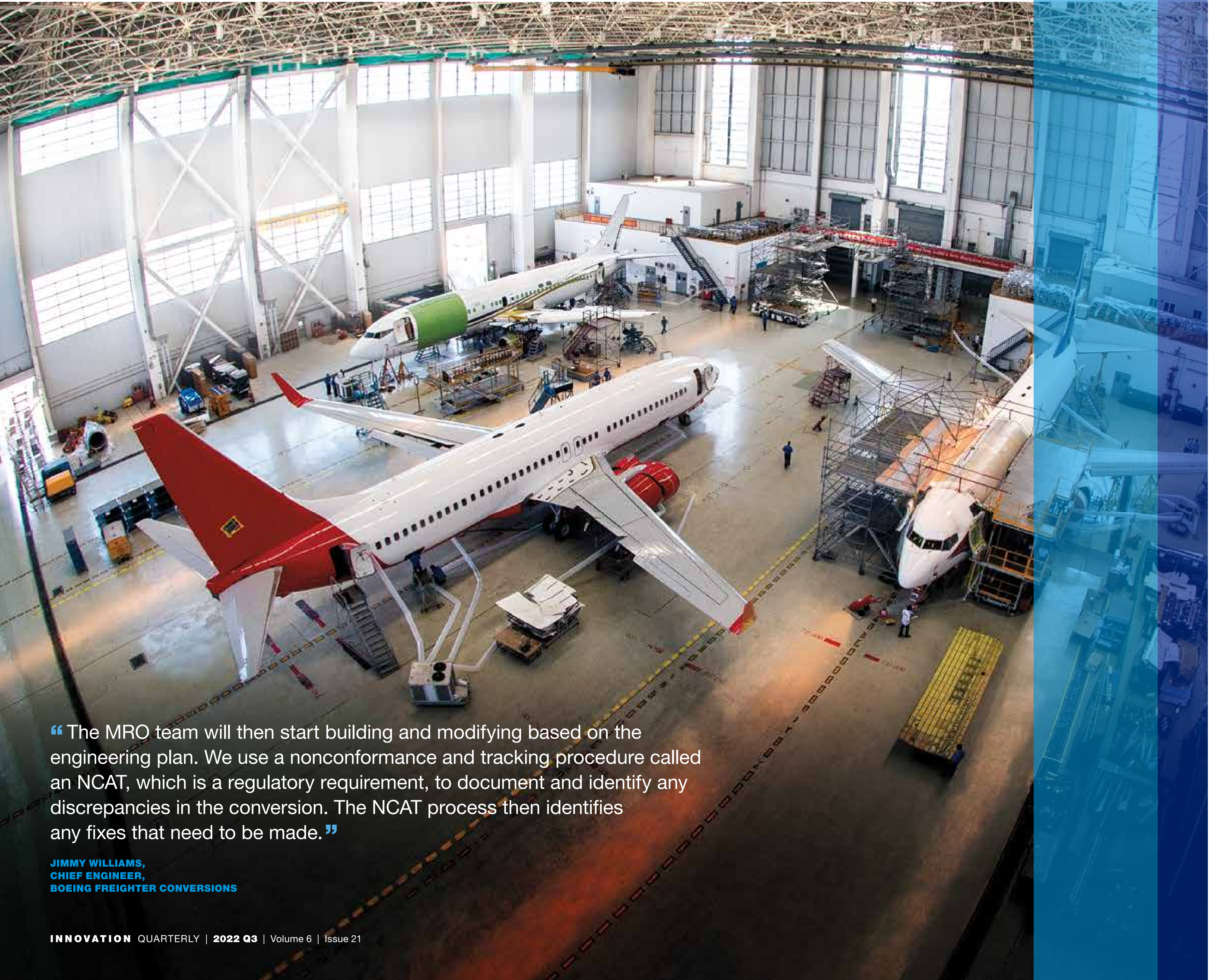
Inside Boeing’s London Gatwick facility, a passenger 737-800 becomes a freighter.

PHOTO: ROSS MUNNERY/BOEING

CONVERSION ZONE

Completed in 2019, Boeing’s London Gatwick facility was designed for efficient MRO operations, a perfect fit for the 737-800BCF.

PHOTO: BOEING



“The MRO team will then start building and modifying based on the engineering plan. We use a nonconformance and tracking procedure called an NCAT, which is a regulatory requirement, to document and identify any discrepancies in the conversion. The NCAT process then identifies any fixes that need to be made.”

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CHIEF ENGINEER,
BOEING FREIGHTER CONVERSIONS**

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The execution of these drawings, known as “touch labor,” is conducted by trained technicians, who are able to interchange positions along the MRO conversion line, adding efficiency to completion rates.

The MRO network and touch-labor supply chain for Boeing converted freighters prioritize quality and on-time delivery while offering convenience and potential cost savings by being closer to customers and the airplanes they intend to convert. There are active conversion lines for 737-800BCFs in Asia, Europe and the Americas, and more are planned in locations including Costa Rica, Canada and the UK. For the 767-300BCF, there are conversion lines open in Singapore and China, with more on the way.

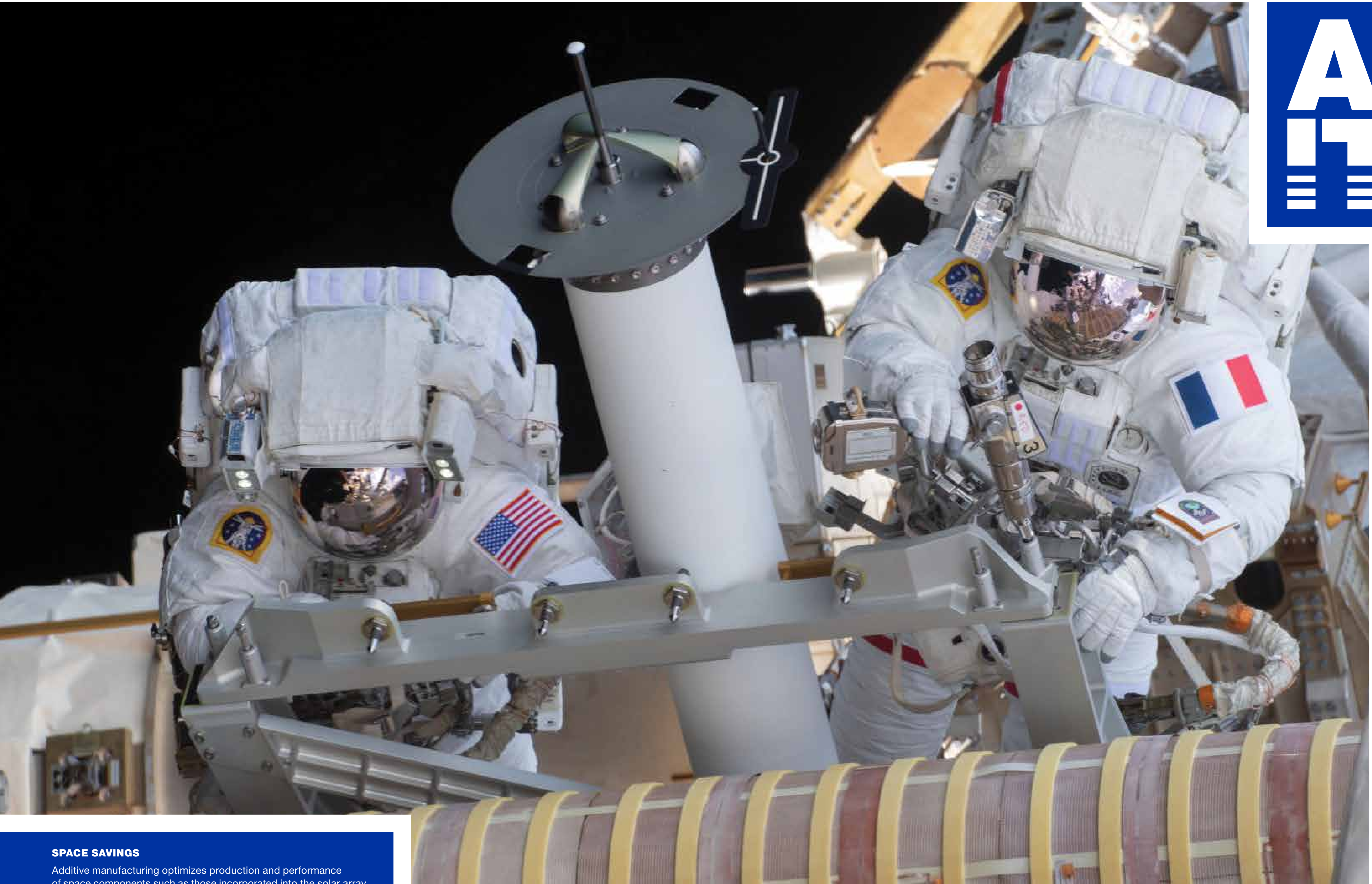
Each step in an airplane’s journey through conversion benefits from Boeing’s expertise as the original manufacturer. Before leaving the MRO for customer delivery, the airplane is weighed again to confirm weight and balance requirements. All paperwork is completed, and any additional work is discussed with the customer, including maintenance, paint and other tasks. With oversight of work provided by the Boeing Quality organization, the newest Boeing converted freighter is then ready to hand back to the customer and take to the skies.

From service entry as a freighter and throughout the airplane’s in-service life, every Boeing converted freighter operates with the advantage of being associated with the industry’s largest portfolio of services and technical support that helps owners and operators maximize return on their investment. **IQ**

IN PROGRESS

Boeing Shanghai Aviation Services repairs and modifies airplanes. The two 737-800 jetliners on the perimeter are being converted to freighter configuration.

PHOTO: BOB FERGUSON/BOEING



ADD IT UP

Discover how additive manufacturing will shape aerospace — and already has

Dr. Melissa Orme is vice president of Boeing Additive Manufacturing. She is responsible for growing and scaling additive manufacturing (AM) capabilities and helping to rapidly expand understanding of the unique features that AM can bring to Boeing factories and production lines. An early AM pioneer, Orme is listed as an inventor on 15 U.S. patents.

In the following Q&A with Innovation Quarterly, Orme outlines how Boeing has been at the forefront of AM for aerospace for decades and continues to be a pathfinder for future applications.

SPACE SAVINGS
Additive manufacturing optimizes production and performance of space components such as those incorporated into the solar array carrier pallet for the International Space Station.
PHOTO: NASA

**IQ: Let's start at the start.
Why is it called additive manufacturing?**

MO: It's called additive manufacturing because you build a part and a material, one layer at a time. You're adding material, microlayer by microlayer, as opposed to subtractive manufacturing, which [includes many] traditional processes, where you take a block of material and you cut it away until you have your final part.

So you're adding material layer by layer. It could be polymer. It could be a metal. There are many different modalities, but that's basically what we're doing. And that allows you then, when you add it layer by layer, cross section by cross section, it allows you to have really complicated geometries that you're not able to have traditionally. It enables you to have some really complex internal features that improve performance of the part that you can't have traditionally. And it allows you to make things in really odd shapes so that you can fill in some odd cavities of a spacecraft or aircraft to become more efficient and streamlined.

IQ: Is there a difference between additive manufacturing and 3D printing?

MO: Additive manufacturing is 3D printing. But 3D printing has sort of come to be regarded as more hobbyist. People can buy 3D printers for polymer on Amazon. And they put them in their garages. And they can make all kinds of neat things for their home, for example. That's 3D printing.

Additive manufacturing, by definition, is also 3D printing. But when you think of manufacturing and additive manufacturing, we're really referring to, especially for aerospace, flight hardware. We're producing quality parts that can go onto vehicles. They're certified for flight. And so there's a whole quality process that goes behind that, more than just 3D printing.

IQ: So we're definitely not doing that in our garages.

MO: No, we're not.

PROOF OF CONCEPT

This additively manufactured prototype of an extreme environment heat exchanger features complex geometry that cannot be produced by conventional fabrication methods.

PHOTO: BOEING

It's called additive manufacturing because you build a part and a material, one layer at a time. You're adding material, microlayer by microlayer, as opposed to subtractive manufacturing, which [includes many] traditional processes.

AIRPLANE APPLICATION

This 787 manifold used to be three separate pieces assembled together. Additive manufacturing allows the manifold to be produced as a single part.

PHOTO: BOEING

INTRICATE SHAPE

This upper Y bracket is one of three additively manufactured parts on the deployable ion engine mount for a recently launched satellite. Additive manufacturing optimized the design — printing material only where needed — resulting in an overall 28-pound (12.7-kilogram) reduction.

PHOTO: BOEING

IQ: Why is additive manufacturing ideal for aerospace?

MO: It's ideal for aerospace really because carrying weights into space is expensive. We're continuously trying to make our planes, our satellites, our helicopters lighter in weight. And because additive manufacturing has this capability [through topology optimization], it's really a mathematical methodology, where you place material only where it's needed in the part to support the loads and you remove it from all other parts.

Sustainability in 3D

Additive manufacturing (AM) is changing the way Boeing designs and builds aerospace products, allowing the company to use less raw materials, create less waste and improve fuel efficiency.

Significantly less material is required to create a part with additive methods, reducing the carbon footprint at the front end. As for the end product, AM enables highly innovative designs that add functionality, reduce weight and volume, and consolidate many parts into one, further adding to Boeing's sustainability goals.

DR. MELISSA ORME, VICE PRESIDENT, BOEING ADDITIVE MANUFACTURING

COMMAND PERFORMANCE

The command horn antenna consolidated numerous components into a single monolithic design.

PHOTO: BOEING

And so now you have a highly optimized part. It's incredibly lighter ... and is really beneficial to the aircraft by reducing this weight.

Also in aerospace and in space, oftentimes these platforms are highly customized. The production rates lend themselves to additive manufacturing. If we're talking about satellites, usually there's not a whole lot of vehicles. So spooling up tooling for that wouldn't be very efficient. And we can customize each one. So it really makes a lot of sense.

And then for airplanes, it's really a matter of removing weight and making the airplane lighter ... and more streamlined. And that not only makes the airplane more efficient, but it really adds to our sustainability goals, right? Because it's using less fuel to get it where it needs to be. It's a positive sustainability driver.

IQ: So it sounds like Boeing is doing a lot in this space. What is most exciting to you? What is the one thing you tell family and friends? "We're doing this with additive manufacturing"?

MO: Oh, actually, it's a really long list. We're doing a lot. ... I'm not sure everybody knows that Boeing has additive-manufactured products onto our platforms for 30 years. And we have 70,000 parts right now, and a lot of those are polymer, and a lot of those are different modalities, also metal. We have actually a robust history of additive manufacturing. And it's almost a well-known secret that I'm trying to open up and advertise a little more.

But the most recent things have really come out of satellites. We've created a new 3D-printed satellite, which is a product that transforms how satellites of this size are manufactured. And we are consolidating many, many parts into one for other satellite applications like Wideband Global SATCOM.

Those are really exciting — well, there are two more. For MQ-25, we have a heat exchanger, and the reason why that's exciting is because it's [on] an airplane with a different loading environment.

And another one which is really important to me — we have a Chinook helicopter searchlight which is in a harsh environment, really high fatigue. And it's in flight right now. We have 15 of these on helicopters in duty.

EXCHANGE OF IDEAS

Complex internal geometries are achievable using additive manufacturing. Such is the case for the phased array antenna heat exchanger (below) created for the MQ-25 (above).

PHOTOS: (ABOVE) KEVIN FLYNN/BOEING; (BELOW) BOEING

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LIGHTER LIGHT

Boeing designed, manufactured, tested, qualified and delivered several metal, additively manufactured searchlights currently in service on CH-47 Chinook helicopters. The high-intensity lights represent the company's most advanced metal additive manufacturing application to date for use in a harsh environment.

PHOTO: BOEING

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IQ: If we dig into your resume, we can see from your background that you could have gone anywhere. Why did you choose Boeing? What drew you to the company?

MO: I began in academia. I was a tenured professor. And then I went into small business. And everything that I've always done with respect to my career has been a move that really challenges me, that pushes me out of my comfort zone. I really think that you just need to keep growing and learning as an Individual. At least that's how I feel about myself. And I had never worked in a large corporation before. I knew there would be challenges I wasn't even aware of. And I wanted to face that.

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Audio: Hear the entire 3D conversation.

SEE THE LIGHT

The searchlights hang under the middle of the nose on a CH-47 Chinook helicopter.

PHOTO: BOEING

And so that's, that's one answer, but there's another slightly sweeter answer. And that is that my father worked at Boeing during the SST, the Supersonic Transport. It was a really good period in my family's life. And I've always had a bit of nostalgia about that. I lost my father when he was quite young. And I was young. I like to think that he would be proud, knowing that I'm here. **IQ**

We have a Chinook helicopter searchlight which is in a harsh environment, really high fatigue. And it's in flight right now. We have 15 of these on helicopters in duty.

HERE TOO FOR MORE IQ!

Video: See additive manufacturing happen.

Sky-High Silver Anniversary

XXV

Raptor teammates lead modernization

Sept. 7, 2022, marks the 25th anniversary of the first flight of the F-22 Raptor. Lockheed Martin and Boeing designed and built the F-22, which features Pratt & Whitney engines. Pictured is an F-22 (foreground) with the first 757 ever built, which has served as a flying test bed for the F-22 program for nearly 25 years. The 757 still routinely tests alongside Raptors to help development and fielding of new capabilities to the warfighter. **IQ**

NOSE JOB

The highly modified 757 features an F-22 radar nose and sensor wing, which have enabled it to conduct extensive in-flight evaluation of avionics systems before they are installed on F-22s.

PHOTO: BOEING ARCHIVES

PHOTO: DARIN RUSSELL/LOCKHEED MARTIN