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Frontiers

Home, sweet home

International Space Station receives an extensive remodel before arrival of Boeing's Starliner

Cover: NASA astronaut Scott Kelly performs maintenance outside the International Space Station on Nov. 6. The station's solar arrays are visible in the background. NASA

Photo: Inside the space station's Cupola module, NASA astronaut Terry Virts gets a 360-degree view of Earth and space. NASA

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Photography

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DESIGNER
Katie Sheahan

Online production

WEB MANAGER
Wendy Manning

WEB DESIGNER
Michael Craddock

WEB DEVELOPER
Lynn Hesby

INFORMATION TECHNOLOGY CONSULTANT
Tina Skelley

Contact information

EMAIL: BOEINGFRONTIERS@BOEING.COM
ADDRESS: BOEING FRONTIERS
MC: 5003-0983
100 NORTH RIVERSIDE PLAZA
CHICAGO, IL 60606
PHONE: 866-473-2016
WEBSITE: BOEING.COM/FRONTIERS

Advertisements

The stories behind the ads in this issue.

This ad is part of a new campaign featuring Super Hornet as the strike fighter the U.S. Navy depends on in combat. It is running in domestic publications.

Celebrating the success of the 737 MAX first flight on Jan. 29, this ad demonstrates Boeing's commitment to deliver a new era of performance to customers, on schedule.

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The fighter they send to the front.

In ongoing military operations around the globe, the Super Hornet is the fighter forces depend upon in combat. Fully networked with integrated sensors and weapons, it delivers a full range of missions from close air support to air combat and interdiction. The Super Hornet also sets a new standard of availability, maintainability and cost per flight hour—providing the U.S. Navy with combat-proven, dominant aircraft today and for generations to come.

F/A-18E/F SUPER HORNET

RAYTHEON NORTHROP GRUMMAN GENERAL ELECTRIC BOEING

The new reality

A more efficient Boeing can better weather whatever challenges come its way

As Boeing celebrates 100 years of aviation leadership, we have an opportunity to set the pace well into the future by anticipating customers' needs and adapting to new market realities. In this industry, nothing stands still. Canvas-and-wood gives way to aluminum and composites. Propellers yield to jet engines. And the global competitive landscape continues to evolve.

Lately, we're seeing a major shift in the way our customers do business—so we have to change, too. Airlines once paid a large premium for the value of Boeing airplanes, knowing their investment would pay off in the long run because of our products' capabilities and lower lifetime costs.

That dynamic has changed. In today's more-for-less world, purchase decisions increasingly hinge on price. Sales campaigns are tougher, Airbus has narrowed the value gap and new competitors are on our heels. World events, from political unrest to global economic shifts, add to the fluid nature of the aerospace industry.

Some of these forces are out of our hands, but we can lessen their impact by making smart decisions about the factors we can control—cost and efficiency. The more efficient we are, the better we can weather whatever challenges come our way—and the more competitive we will be in the orders sweepstakes. This is our new reality—not just for the year ahead, but for the foreseeable future.

Ray Conner
Boeing vice chairman
President and chief executive officer,
Commercial Airplanes
PHOTO: MARIAN LOCKHART | BOEING

We're already addressing this from several angles.

Our airplane development group is focused on breaking the development cost curve—the unsustainable growth in nonrecurring development costs—and designing airplanes that cost less and are simpler and safer to build. We've made progress and we'll continue to share lessons learned with our development counterparts at Defense, Space & Security, in a "One Boeing" approach.

We've reduced the cost of producing a single 787-9 by nearly one-third since first delivery. Working with Boeing Test & Evaluation, we have streamlined flight testing for the 737 MAX and 787-10, partly by eliminating duplication of effort. And we've developed a common flight-deck display for the 787, 737 MAX and 777X to reduce installation time, cost and weight.

As services grow, we're harnessing synergies between our Commercial Aviation Services group and its defense counterpart, Global Services & Support, to improve performance and drive costs down across Boeing.

And we continue to reap supply-chain efficiencies through the enterprisewide Partnering for Success effort.

At Commercial Airplanes, we're making fundamental shifts to meet customers' new expectations on price. We've targeted six "Keys to Winning" that customers assess when selecting airplanes: design and build quality, reliability and maintainability, airplane performance, delivery discipline, world-class customer support, and competitive pricing. Performing well on the first five Keys sets the stage for success on the sixth—competitive pricing.

Even as we adapt for a changing future, we're strengthening the cultural framework that has made Boeing an aerospace leader for 100 years. This company was built on courage, passion, integrity and the rock-solid assurance that we will keep our commitments. Markets may change, strategies evolve—but our values are timeless. ●

Right team, right talents, right time

How we unleash resources for building the BDS of tomorrow

This month I had the honor and privilege of being asked to lead the Boeing Defense, Space & Security business. I step into this amazing opportunity with gratitude for Chris Chadwick and his leadership, vision and passion, which have raised BDS to a new level of performance. I look forward to building upon the solid foundation Chris built alongside the best team in the industry.

For BDS to grow and prosper over Boeing's next 100 years we must understand the incredible market changes happening around the globe today—and take action now.

Action that builds on the foundation of our core platforms and services by evolving the heart of our business with new capabilities, continuing global expansion, and leveraging our built-in advantage of commercial derivatives.

Action that increases our focus on investments and opportunities that offer market-disrupting growth for Defense, Space & Security, where we consider new business models, apply existing technologies in new ways and embrace nontraditional partnerships.

Action that comes to life as we work hand in hand across the enterprise, leveraging strength on strength to connect, protect, explore and inspire.

While we can't change the market reality around us, we can and must change how we view and respond to sustained more-for-less budgets, limited franchise product opportunities, the intense speed of technological development and the rise of new competitors.

While others may see it as a challenge, this environment is our opportunity to transform BDS for growth. Our strategy to quickly incorporate technology into our existing platforms and services—for better information and security capabilities—is differentiating us from our competitors. We must continue making our current and future products more capable, more secure and at the right cost in the eyes of our customers.

Leanne Caret
Boeing executive vice president
President and chief executive officer,
Defense, Space & Security

PHOTO: BOB FERGUSON | BOEING

For example, we are building satellites with the most advanced digital payload in the commercial industry, allowing our customer Intelsat more flexibility than ever before. And together with Commercial Aviation Services, we are aggressively using data analytics to grow our services business—and delighting our customers.

Our new journey demands a cultural shift. We have to prevent problems, not constantly be fixing them. We must use good judgment, not allow process to consume us.

Indeed, when we build on strengths, break down barriers, and work safely with integrity and personal accountability, we will be able to deliver on time and on cost today—and unleash resources for building the BDS of tomorrow.

Not only that, but our team will be engaged and inspired—and that's how we break from the competitive pack.

We have the right team, the right talents, and this is the right time—our time—to lead a transformation at BDS.

Bring on the next 100 years—we're ready. ●

Mad for MAX

As employees cheer it on, Boeing's new 737 MAX 8 lifts off Jan. 29 on its inaugural flight from Renton Field in Renton, Wash. The 737 MAX 8 is the first member of Boeing's new family of single-aisle airplanes—the 737 MAX 7, MAX 8, MAX 200 and MAX 9—to begin flight testing. Boeing has over 3,000 orders from more than 60 customers for the MAX, which incorporates fuel-efficient engines, Boeing-designed Advanced Technology winglets and other improvements. Southwest Airlines is scheduled to take delivery of the first MAX next year. **PHOTO: JIM ANDERSON | BOEING**

“We’ll do the next 100 in half the time.”

—Beverly Wyse, vice president and general manager of Boeing South Carolina, at ceremonies for delivery of the site’s 100th 787 Dreamliner. The South Carolina plant delivered its first 787 in October 2012. Between its South Carolina and Everett, Wash., factories, Boeing will be delivering 12 787s a month by midsummer. Reuters, Feb. 16

“This plane has a personality like no other.”

—Alexandre De Juniac, president of the Air France–KLM Group. Air France recently retired the last of its 747 passenger jets, but KLM still operates the passenger plane, as do many other international carriers, including United, Lufthansa, Japan Airlines, British Airways and Singapore Airlines. Bloomberg, Jan. 14

“I served 24 years in the U.S. Submarine Service … I could not have a ‘normal’ job. I needed something bigger, something profound. Boeing was that.”

—John Camara, an Electrical Engineering systems design engineer for the Space Launch System. Read his story and those of others on Boeing’s centennial story sharing website at boeing.com/our-stories.

Photos: (Below) Boeing seamstresses contributed to the war effort by sewing fabric onto the wings of Model C trainers destined for service with the U.S. Navy. (Far right) Attaching fabric onto the upper wing of an MB-3A fighter plane in 1922. BOEING ARCHIVES

A stitch in time

Seamstresses played vital role in the pioneering days of airplane manufacturing

BY MICHAEL LOMBARDI

Working in the loft of what is now known as the Red Barn in Seattle, a small group of women helped make some of Boeing's earliest airplanes, attaching fabric to wings built in an adjoining area of the loft. Their tools were thimbles, scissors, a long needle and a length of wax-covered thread.

These seamstresses were a critical part of manufacturing airplanes during the first two decades of the company, when the wood-framed wings and metal-framed fuselages had to be meticulously covered to exacting specifications for planes to operate efficiently and safely.

After sewing together reams of linen to create the large pieces needed to cover the wings and fuselage, the women would attach the fabric to the wings. Working the sewing machine was a bit of a promotion and a welcomed escape from the tedious and uncomfortable job of doing the stitching—which required frequent rest to alleviate eyestrain and numb hands.

In the 1920s, it was uncommon for women to work outside the home. Typically, women made up about 20 percent of the workforce in the United States and at Boeing. Many of the women who came to Boeing did so because they needed work to survive—most were single or widows supporting families. Some were immigrants, including Russians who fled the communist revolution and were trying to make a new start.

Typically, it took 10 women two working days to cover a wing. First they stretched the fabric tightly across the wing, taking care to line up seams to run between the ribs rather than on top of them. The women then would use a baseball, or herringbone, stitch to attach the fabric to the wing. Next, they would pair up on either side of the wing and pass the needle back and forth to secure the fabric to the wing ribs; on thicker wings this was done separately. After they completed the sewing, they sent the wings over to the "dope" shop where the fabric was covered in a cellulose acetate solution, creating a rigid and waterproof surface. (Cellulose acetate has a variety of uses today including in motion picture film and sunglasses.)

The work environment was demanding. They worked an eight-hour day and half a day on Saturday, with only a half-hour for lunch. The women also had to put up with the men chewing snuff and spitting—a habit of the day they found annoying. The work for the seamstresses, as well as other employees, was highly cyclical; when a contract finished, their job was over—at least until the next batch of airplanes was ready to be built.

With the introduction of all-metal airplanes in the early 1930s, work for the seamstresses declined, although some continued through World War II. In Wichita, Kan., for example, seamstresses covered the wings of Kaydet trainers. And in Seattle, a handful of seamstresses, who represented some of the longest-serving veterans of The Boeing Company, sewed fabric onto the control surfaces of B-17 Flying Fortresses. After the war, the art of sewing was limited to airplane interiors. The skills necessary to sew fabric onto airplane wings is now a mostly lost art.

Those early Boeing seamstresses are gone now, but a wonderful example of their work hangs in the center of Seattle's Museum of History and Industry—the original Boeing B-1 mail plane built in 1919, later restored to the same exacting standards by the company in 1951. 100

MICHAEL.J.LOMBARDI@BOEING.COM

To see a related video, visit boeing.com/frontiers/videos/march16.

BOOM TIME

Boeing's new KC-46A tanker makes air refueling easier and safer

Photos: (Above) A KC-46A tanker refuels an F-16 aircraft in flight.
PAUL WEATHERMAN | BOEING
(Far right) Kate Lowry, in the air refueling operator station behind the flight deck of a KC-46A tanker, wears 3-D glasses for a more in-depth refueling picture.
COLLEEN PFEILSCHIEFTER | BOEING

BY KYM VANDLAC

Kate Lowry, one of the Boeing Test & Evaluation team's newest members, is not one to take things lying down. However, she did just that before joining Boeing as a KC-46A air refueling operator.

Last month, when the Boeing tanker program conducted a series of refueling flights on the KC-46A, Lowry witnessed firsthand the new capabilities built into the aircraft—and a new way of being an air refueling operator.

Serving in the U.S Air Force, Lowry operated the KC-135 Stratotanker aircraft refueling boom. The job required her to look out a small glass window while in a prone position in the tail section of the plane and guide the boom into a receiver aircraft's refueling receptacle.

Today, in the next-generation KC-46A Pegasus tanker Boeing is building for the Air Force, Lowry and fellow operators can sit comfortably as they fly the boom and operate the hose and drogue systems to refuel aircraft. A state-of-the-art air refueling operator station, or AROS, is located behind the flight deck at the front of the aircraft and includes 24-inch displays with a 3-D refueling picture.

"The AROS console brings much greater situational awareness," Lowry said. "And it's much easier on the body, too. Lying down throughout a refueling mission definitely caused some aches and pains. Still, I do sometimes miss the view through the KC-135 window."

Great views … but in an aging aircraft.

The KC-46A tankers will eventually replace the Air Force's fleet of KC-135s, many of which were built when Dwight Eisenhower was the U.S. president, back in the 1950s. Boeing is scheduled to deliver the first 18 of 179 KC-46A tankers to the Air Force by August 2017. The ongoing refueling tests are critical to meeting that schedule.

On Jan. 24, Air Force Lt. Col. Daniel Alix, flying an F-16 fighter, pulled up behind the KC-46A to take on fuel. It was the first time Boeing's new tanker delivered fuel to another aircraft.

"I would describe the refueling as rock solid," Alix said later. "It was very easy to connect to the KC-46 boom, stay connected and take fuel from the tanker."

Sean Martin, Boeing Test & Evaluation KC-46 chief air refueling operator, who was on the other end of the boom, said the KC-46 aerial refueling boom handled extremely well during flight.

"The performance was

outstanding," Martin said. "It handled just as all the modeling predicted—smooth and precise."

Following the F-16 refueling flight, the KC-46A refueled an F/A-18 using both its boom and its hose and drogue systems. Additionally, the KC-46 was refueled by a KC-10 tanker. The refueling tests, which are required before the program receives its first low-rate initial production contract, were led by Martin, and Rickey Kahler, Boeing Test & Evaluation KC-46 air refueling operator.

The responsibility of transferring fuel to another aircraft in flight is literally "in the hands" of the operator.

Kahler, who also has refueled aircraft during testing, echoed Martin's observations.

"The refueling boom's handling qualities were exceptional," Kahler said. "The boom was extremely stable—it handled like it was an extension of my arm."

Improved awareness is critical, considering air refueling operators are lining up two airplanes in proximity at

Photos: (Clockwise from top left) Using its hose and drogue system, a KC-46A tanker refuels a Boeing F/A-18 in flight. **JOHN PARKER | BOEING** An overhead view of a KC-46A tanker; Boeing and Air Force team members disembark from a KC-46A tanker following air refueling testing. **JIM ANDERSON | BOEING**

Photo: A KC-46A tanker takes off for an air refueling test mission.
JIM ANDERSON | BOEING

about 25,000 feet (7,600 meters) and 450 mph (725 kilometers per hour), all while coping with turbulence and weather. When the receiving aircraft is within a half-mile (0.8 kilometers), the air refueling operator takes over and guides it into position for refueling behind the tanker.

"One of the most hazardous aspects of our job is the lack of visibility on legacy aircraft," said Kate Lowry. She's an experienced U.S. Air Force and Air National Guard KC-135 boom operator, or boom, now working at Boeing and testing the new KC-46A Pegasus tanker, along with teammates Martin and Kahler.

A benefit of the KC-46A air refueling operator station is that it allows a panoramic 185-degree field-of-view. Additionally, to help with visibility, the KC-46A has sophisticated LED lighting that guides aircraft into the proper position when they take on fuel. "The KC-46 is lit up like a Christmas tree when required," Lowry said.

"It not only has visible lights like other tanker aircraft; it has covert lighting and low-light camera systems. That allows receiver pilots to see the aircraft from a distance and perform refueling operations using night-vision goggles. I can't imagine there will be

a time where we will be unable to see a receiver aircraft due to low visibility. We now have the ability to refuel in greatly reduced lighting conditions."

Before joining Boeing in 2014, Lowry spent 15 years as a boom operator—nine of them in active military duty and six with the Air National Guard. In addition to working at Boeing, Lowry still serves as an operator part time in the Air National Guard.

"Being a boom operator is one of the best jobs in the Air Force," Lowry said. "Now, to have the opportunity to work at Boeing as an air refueling operator on board the KC-46—I have my dream job."

Besides aerial refueling, operators are responsible for cargo handling, tending to passengers and aiding in aeromedical evacuations. The multi-role KC-46A will make these parts of the job much easier as well.

"The KC-46 has so many features," Lowry said. "I have just scratched the surface in terms of learning all of the nuances." ●

KYMBERLY.Y.VANDLAC@BOEING.COM

ABOVE and BEYOND

Boeing engineers aim to keep the International Space Station operating safely for a long time

BY DAN RALEY

The International Space Station hurtles through space at 5 miles (8 kilometers) per second, while dealing with radiation exposure and extreme temperatures, reason enough it was expected to last just 15 years.

Yet as it easily passes that milestone and prepares for the scheduled 2017 arrival of Boeing's Crew Space Transportation vehicle, known as the CST-100 Starliner, the station is receiving an extensive remodel with the installation of two International Docking Adapters.

It is no simple upgrade.

"Imagine taking a house you've lived in for 15 years and deciding to move the master bedroom from the first floor to the second floor, detach the attached garage and add a mother-in-law apartment," said Dave Clemen, Boeing manager of development projects and NASA docking systems for ISS, explaining the complex reshuffling involving the adapter.

The international adapter will

Photo illustration: A view of the International Space Station. SHUTTERSTOCK

allow not only Boeing's Starliner to dock with the station but other commercial crew vehicles that bring astronauts to and from the orbital laboratory.

Boeing was NASA's prime contractor for the station and built all of the U.S. modules, as well as several other major station elements, including the trusses. Boeing also has a NASA contract to provide engineering support for the station through 2020.

Occupied by a revolving six-person crew while serving as a microgravity research lab since 2000, the space station continues down a familiar pathway, circling Earth 16 times per day. At the same time, it has ventured into decidedly new territory, withstanding the rigors of its harsh environment and handling systems decay better than anticipated.

NASA is committed to using the space station through 2024 and has asked Boeing to verify, through analytical study, that the station can operate safely through 2028. The space station was designed to last 15 years, matching the life span of its predecessor, Russia's Mir Space Station. It might double that forecast, if not survive even longer, according to Boeing engineers.

"Right now, we don't see any weak links that in 2030 would make us have to stop flying," said Dave McCann, Boeing senior manager of space station structures and flight-control mechanisms. "We don't have anything on the radar screen that worries us."

Nearly as long as a football field

Illustration: An artist's concept of the CST-100 Starliner. BOEING

at 357 feet (108 meters) and wider than a 777-300 wingspan at 240 feet (73 meters), the International Space Station has encountered no major structural issues, an important gauge for extended use. Its thick trusses remain robust, McCann said. In 2009, it shook violently when a main engine "reboost" misfired, but no damage resulted. The reboost regularly maneuvers the station to its proper orbit. McCann likened the episode to a commercial jetliner making a hard landing—the airplane is built to withstand that sort of stress; it just shouldn't happen repeatedly.

When the Starliner docks with the station, the coupling will be less demanding on the station's structure than dockings that involved the much larger space shuttles, which are no longer operational, said Matthew Duggan, Boeing's manager of ISS integrated analysis.

"We track everything obsessively," Duggan said. "Every single vehicle docking has a measurable stress on its physical life."

While a meteor or debris strike is always a possibility, safeguards keep the probability low for surface penetration. Five times per year, on the average, the space station is moved in its orbit to avoid space debris. Thick shields protect sensitive elements. Leak patch kits are accessible if something invasive happens. Crew members are installing an ultrasonic system that uses small microphones to assist in pinpointing leaks.

"We got very lucky on the structure," said Brad Cothran, Boeing director of sustaining engineering for ISS. "They're beefy, large trusses, naturally designed to survive the ascent."

To ready itself for the coming Starliner flights, the space station took delivery of 31 modification kits. They have been used to reconnect power to different sources, move certain elements into orbit and reattach them, replumb the system, add new antennas, and install docking adapter parts, Clemen said.

Installation of the International Docking Adapter will require a spacewalk and a delicate operation, he said. The 1,021-pound (463.1-kilogram) part will be removed robotically from a cargo trunk and positioned within 10 inches (25 centimeters) of the connection, at which point crew members will attach it manually and carefully—something as small as a human hair could prevent a proper fit, Clemen said. The space station is no stranger to this type of work; visitors have performed 192 spacewalks, according to NASA.

The space station's eight power channels face as much scrutiny as any system, according to Jeffrey Donoughue, Boeing's manager for ISS avionics.

Each channel consists of a solar array, which is a wing-like collection of solar panels, and three batteries. The solar arrays power the space station and regenerate the batteries when facing the sun; the batteries take over when the station is in the dark.

The arrays, composed largely of fabric and glass, were damaged early on in 2000 but were effectively repaired and are closely monitored through photographs. Controller boxes, which determine the amount of power the arrays need to provide, still fail periodically and require a risky fix, Donoughue said.

This year, the space station will begin replacing its original nickel hydrogen batteries with those made of lithium ion. The new battery, Donoughue said, offers twice the energy density and half the size of the nickel hydrogen battery, which weighs several hundred pounds, resembles a two-drawer filing cabinet and is approaching the end of its life span.

The station's environmental control and life-support system, which controls air, water and waste, is crucial to its longevity. The original system was not regenerative. The current system has the ability to turn condensation and urine into drinkable water and reuse carbon dioxide to help generate oxygen, among other sustaining functions, all someday critical to deep-space exploration.

Transformation was not an easy

Photo: NASA astronaut Kjell Lindgren corrals a supply of fresh fruit inside the International Space Station. NASA

process, according to Duggan. The water system literally had bugs growing in it. Filters were replaced and valves redesigned.

"All regenerative life control systems, in general, have been more complicated than we envisioned—not at a component level, but at a system level," Cothran said.

One of the bigger lessons learned was finding the proper lubricant for the gears that hold the station together. Engineers originally went with a solid lubricant, such as gold and other soft metals, deciding that grease wouldn't work. The gold failed and gear bearings were destroyed and had to be replaced. Grease, as it turned out, works the best in a vacuum, Cothran said.

The space station, launched during the time of dial-up modems, has made steady software and hardware upgrades as the technology has changed. The station started out with Intel 386 class processors on board; it now has Pentium class processors. Efforts are being made to double the data speed rate of 300 megabits per second. Overall, the performance of the space station's computers and other electronics has been positive.

"I'm surprised that the radiation environment has not been more disabling," said Boeing manager Clemen. "The electronics we put up there have performed remarkably well."

Mark Mulqueen, Boeing's ISS program manager, said the future of the International Space Station could be determined by the availability of alternative future commercial space platforms in low Earth orbit, which would allow the continued discovery of science and research in a zero-gravity environment.

The International Space Station already is assisting in preparations for a manned mission to Mars. Studies are being conducted on the long-term skeletal effects on humans in space well ahead of the two- to three-year future journey to Mars. In addition to testing critical systems, answers must be found for the effects of zero gravity on our muscular skeletal tissue and bone densities. The space station is a crucial stepping stone to deep-space exploration, Mulqueen noted.

"Low Earth orbiting laboratories can still thrive for medical or pharmaceutical research, or even become a future vacation destination, depending on commercial markets and costs to operate and maintain," Mulqueen said.

Other space stations, such as Mir and Skylab, were purposely destroyed by burning up in Earth's atmosphere once their systems had worn out and usefulness had come to an end. Barring the unknown, the International Space Station could postpone that fate for decades, suggested John Vollmer, Boeing's ISS chief engineer.

"As long as we're willing to continue to upgrade and sustain the station," Vollmer explained, "the design of it by nature will allow us to continue operation for a very long time." ●

DANIEL.W.RALEY@BOEING.COM

INFLATION STATION

BY KEN ULMER

It might just be the future of private habitats in space. Once in orbit, it will blow up like a giant air bag.

The journey to get the Bigelow Expandable Activity Module, or BEAM, launched and safely attached to the International Space Station, or ISS, began many months ago for Boeing engineers. The inflatable habitat is NASA-developed technology that's exclusively licensed by Nevada-based Bigelow Aerospace.

Boeing is responsible for ensuring the successful integration of all new hardware and software on the space station, including components from contractors. Boeing engineers worked with NASA and Bigelow to prepare, plan and integrate the inflatable module on the space station.

"As NASA's prime contractor for ISS, maintaining a safe environment for crews on-orbit is our top priority," said John Vollmer, ISS chief engineer for Boeing. "When new hardware is developed, our Boeing team provides the expertise and skills to determine how to integrate it successfully."

The Bigelow module is scheduled to be launched later this year by a Falcon 9 booster on an unmanned SpaceX cargo resupply mission to the space station.

For Bigelow, it represents a key test in its quest to provide expandable space habitats. The company believes this technology will someday be used as living quarters by explorers on the moon, and perhaps eventually on Mars, and maybe even as an orbiting hotel for tourists.

The packed dimensions of the Bigelow module are 5.7 feet long and 7.75 feet in diameter (1.7 by 2.4 meters), according to NASA. Once pressurized on the space station, that will increase to 12 feet long and 10.5 feet in diameter (3.7 by 3.2 meters). It weighs about 3,000 pounds (1,360 kilograms) and has 560 cubic feet (15.9 cubic meters) of pressurized volume. The module's skin is made up of multiple layers of soft material and it has a shield to protect from micro-meteoroids, according to NASA.

And it should be quieter. The fabric skin, according to NASA, can better absorb noise than the aluminum walls of the space

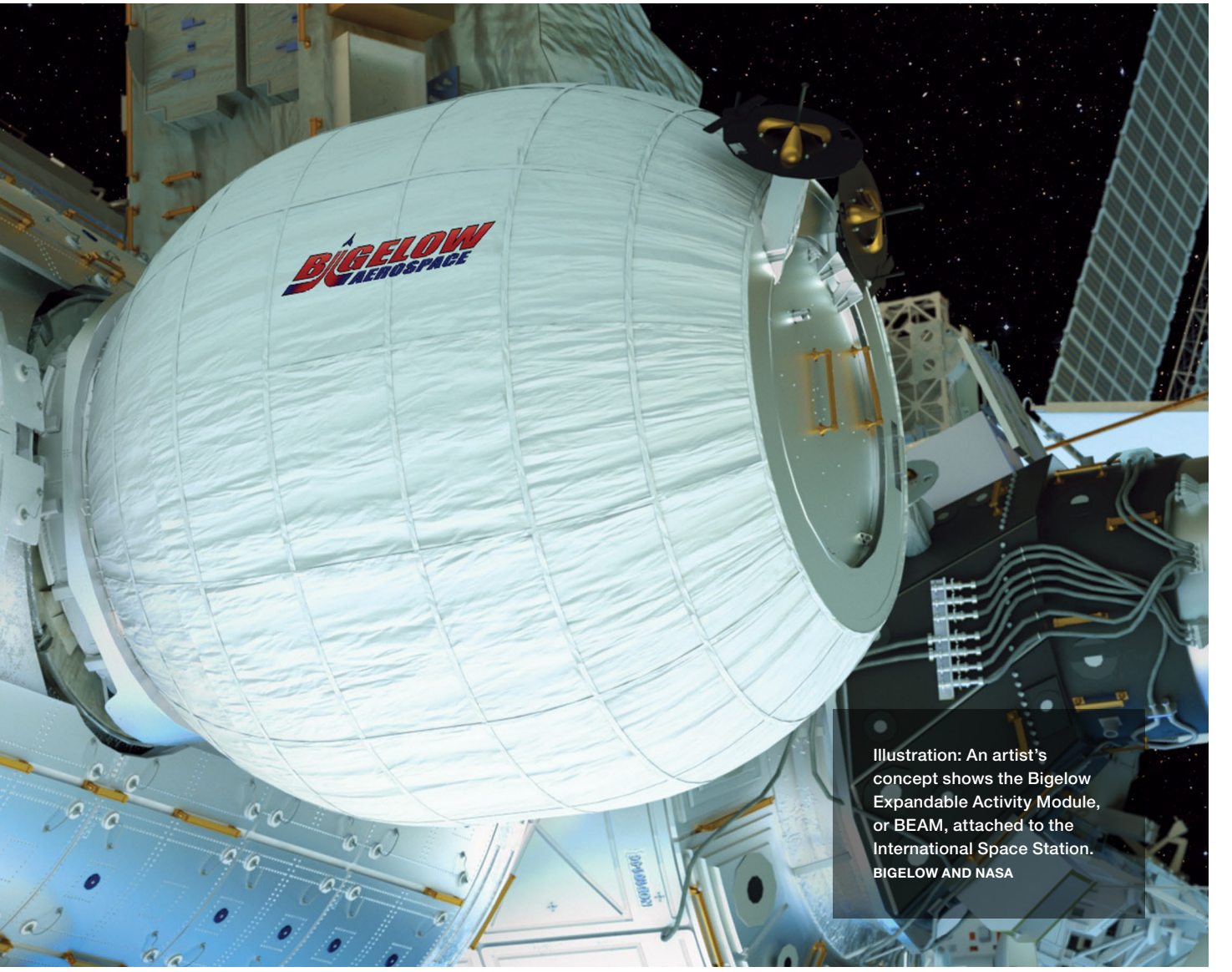


Illustration: An artist's concept shows the Bigelow Expandable Activity Module, or BEAM, attached to the International Space Station.
BIGELOW AND NASA

station's other habitat modules.

Once the SpaceX Dragon supply vehicle is docked to the station, ground controllers will use the station's robotic arm to extract the Bigelow module from Dragon's unpressurized trunk compartment and attach it to a port on the Tranquility node.

Boeing engineers helped develop a method to use the air on the station to inflate the module. The original design included an air tank, which would inflate the module after it was in place. When NASA engineers identified the possibility of high loads or force during inflation, the Boeing team refined the analysis. Boeing engineers created models to mirror the unfolding process and confirmed the deployment could happen too rapidly and possibly damage the station, according to Robert Clark, Boeing Technical Fellow and ISS associate chief engineer.

Instead, the crew will open a valve on the hatch and slowly allow lower-pressure station air to fill the module, Clark said.

During a two-year test period, crews routinely will enter the Bigelow module to take measurements for pressure, temperature and radiation, and monitor its performance.

"No one had ever done anything like this before," said David York, Boeing's manager for ISS Loads and Dynamics. "Being an engineer on a unique project with brand-new challenges and solutions was very rewarding."

The inflatable module is the most extensive addition to the International Space Station since assembly was completed in 2011. Following the test period, BEAM will be jettisoned from the station and will burn up on re-entry to Earth's atmosphere.

Bigelow already is working on larger inflatable habitats, including its "Olympus" module that would provide almost 80,000 cubic feet (2,265 cubic meters) of internal living space. ●

KENNETH.ULMER@BOEING.COM

PATHFINDERS

Today's GPS network began with the launch of a satellite made by a Boeing heritage company

BY DAN RALEY

A U.S. Army Special Forces soldier parachutes behind enemy lines and immediately sets his Global Positioning System watch for extraction. A farmer in the middle of Nebraska uses GPS to plow and plant the family acreage, plus check fertilizer distribution. GPS is essential for steering driver-less cars now in development.

Following its launch last month from Cape Canaveral Air Force Station in Florida, the last of a dozen GPS Block IIF satellites, built by Boeing in El Segundo, Calif., aligned with 30 others to further bolster a navigational network that affects nearly every aspect of life on Earth.

GPS makes the world a smaller place—over four decades, its accuracy in pinpointing a location has improved from 800 feet (250 meters) to fewer than 20 inches (50 centimeters), Boeing engineers say.

"If you're fortunate enough to have a smartphone or a receiver, you don't get lost anymore; that's not a part of life anymore," said Eric Watts, Boeing GPS chief engineer in El Segundo. "You punch in where you want to go and you get there."

GPS is so ingrained in everyday activity that without it, mobile phones and the Internet would quit working or be disrupted, unable to locate transmission signals, according to Munzir Badawi, IIF program manager and acting manager for Civil programs. Financial transactions would ground to a halt, with automated teller machines unable to access time stamps. Aircraft operations would be curtailed, they note.

"Boeing is one of the largest users of the GPS signal," Badawi said. "Just about every product we provide, if intelligent, utilizes GPS of some sort."

The inclusion of the final IIF satellite in the orbiting constellation was bittersweet, a moment marked by the latest upgrade for GPS but also the end of a program line for Boeing. Lockheed Martin is under contract to build the next eight satellites for GPS IIIA, though production delays have reopened the door for the program bidding, and the Boeing GPS III team is developing a proposal for the next GPS program.

Also, Boeing continues to support its existing fleet and focus on next-generation GPS technology—primarily the full-scale conversion from an analog to a digital satellite payload, or circuitry, similar to what took place with the modernization of standard telephones and televisions.

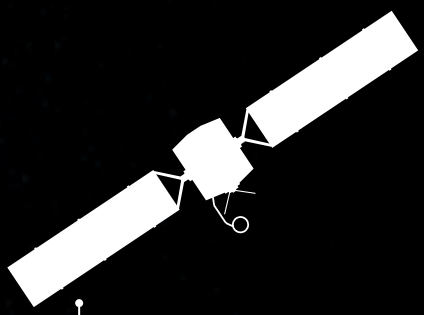
This would lead to smaller satellites in size and weight, and the creation of small GPS payloads that could be hosted on other satellites, according to Dan Hart, vice president, Government Satellite Systems, Boeing Network & Space Systems.

"That will allow a new flexibility never seen in the constellation," Hart said. "It's all eyes to the future."

Boeing has been connected to GPS since its inception, when heritage company Rockwell International launched the first navigational satellite in 1978 to support military activity only. Made available for civilian use five years later, the system now transmits geographic coordinates to more than 3 billion users worldwide, practically reversing its original directive.

Twenty-four satellites, each equipped with multiple atomic clocks, are required to provide full coverage of Earth, with the seven additional orbiting vehicles used to fill in gaps or serve as backups. They travel 12,000 miles (20,000 kilometers) above the surface at 7,000 mph (11,300 kilometers per hour). They make two full passes around the planet each day.

Schriever Air Force Base near Colorado Springs, Colo., houses the GPS master control station. Personnel from the 50th Space Wing operate



HOW GPS WORKS

A Global Positioning System receiver uses at least three orbiting satellites to calculate a 2-dimensional position (latitude and longitude) and track movement. With four or more satellites, a receiver can determine a 3-D position (adding altitude). Once a user's position has been pinpointed, information such as direction, speed, distance and distance to a destination becomes available.

"The most important result of all of the calculations is that GPS gets us home safely to our families and keeps our nation and world secure," said Mark Smith, GPS IIF engineering manager in El Segundo, Calif.

GPS satellites circle Earth twice a day in a precise orbit, transmitting information to Earth. An estimated 3 billion users rely on the technology.

Photo: A U.S. Air Force protective shroud encapsulates the last Boeing GPS IIF satellite before its launch in February. UNITED LAUNCH ALLIANCE

1973
United States begins GPS program

1978
First experimental GPS Block I satellite launched

1983
President Reagan issues directive making GPS available for civilian use

1989
First modern GPS Block II satellite launched

1991
GPS used for first time militarily in Gulf War

1995
GPS constellation expands to 24 satellites, becomes fully operational

1996
President Clinton issues directive to stop degrading civilian signal

2004
Successful tests performed for adding GPS to mobile phones

2016
Last of 12 Boeing Block IIF satellites launched

the ground systems that control the satellites. More than two dozen Boeing employees provide on-site support, examining data and offering technical advice.

Vandenberg Air Force Base near Lompoc, Calif., supplies an alternative GPS control station. Four ground antennas are located globally, mostly in remote island locations. Six Air Force monitor stations, eight Air Force Satellite Control Network tracking stations and nine National Geospatial Intelligence Agency monitor stations, strategically placed across the world, fill out the network.

In 1991, GPS was first used militarily during the Gulf War. Fifteen satellites were overhead when American troops launched the "Left Hook" mission, where an armored brigade, guided through the vast, featureless terrain by the navigational tool, rushed around the Iraqis' left flank to help defeat enemy ground forces. "They would do a quick GPS read, fire off rounds, pack up everything and go, with everything done in a 10th of the time it would have taken to do it without GPS," said Marc Drake, GPS Space Vehicle Operations manager at Shriever Air Force Base. "It had an enormous impact on the Gulf War."

The final IIF satellite replaces the last operational IIA, which was built by Rockwell and has been in orbit for 25 years—since the Gulf War. The new GPS constellation will consist of Boeing's 12 IIFs and Lockheed Martin's 19 2Rs.

The IIF satellite is similar in size to a sports utility vehicle, only taller. It is designed for 12 years of operation, yet has the ability to double or triple that.

Each new satellite block pursues stronger military coding to prevent adversaries from jamming or spoofing GPS signals, according to Boeing experts. Allies are permitted to use portions of the U.S. military signal in certain circumstances. Anyone can freely use the American civilian signal.

The GPS benefit to the American economy is estimated to be $55 billion per year, said Larry Davidoff, Boeing sales and marketing lead for navigation.

"We don't take the performance of these satellites lightly," said Doug Skinner, Boeing GPS program manager. "They're counted on by a large portion of the population, and not just the United States but around the world. They have to be accurate and always be there."

The IIF was the first reprogrammable satellite, with new software uploaded to its memory bank while it orbited overhead. In the future, GPS satellites might be completely modified in space, reducing the amount of new satellites built, said Harry Brown, GPS IIF program chief engineer.

Brown has worked on GPS satellites for 32 years for Rockwell and Boeing. He's been involved in all but the original Block I program. He never envisioned that he was building anything other than a military resource. He's witnessed GPS receivers shrink from the size of a brick to a postage stamp and all of the electronics become miniaturized, the satellite production line convert from two work cells to something similar to a jetliner pulse line, and the atomic clocks double in power.

He sees unlimited potential in GPS. Long-haul aircraft navigation over oceans and uninhabited terrain currently relies on gyro-based "inertial" and GPS systems, or close to land, radio beacons. Over the next decade, he expects GPS to become the sole guiding system for aviation and air traffic control.

"With new civil signals," Brown explained, "we'll someday be able to take off and land airplanes anywhere in the world using a GPS signal alone." ●

DANIEL.W.RALEY@BOEING.COM

Photo: The 12th Boeing-built GPS IIF satellite lifts off from Cape Canaveral Air Force Station in Florida aboard a United Launch Alliance Atlas V rocket in February. UNITED LAUNCH ALLIANCE

Air of confi

New orders will have production lines humming again for the super-reliable and continually improving 767

BY DAN RALEY

Dave Abelson, dressed in a bright green safety vest, knit cap and earmuffs on a brisk day in Everett, Wash., stands in front of a newly built 767 Freighter for FedEx Express, directing other ground-crew members as they prepare to move the jet from the Customer Delivery Center.

Abelson has worked on the 767 for each of his 35 years at Boeing, almost since the program's inception. Someday soon he may retire. The same cannot be said for his airplane.

While Boeing is building 767-based air-refueling tankers for the U.S. Air Force, the commercial jet version has defied expectations and experienced a rebirth.

"The world loves this airplane," said Steve Johnson, regional director for Boeing Commercial Airplanes product marketing and originally a 767 flight-deck engineer. "It won't give up."

In July 2015, FedEx invigorated the program by ordering 50 freighters, with an option for 50 more. This came on top of the shipping company's previous orders for 54 of these cargo jets.

Other potential cargo-hauling customers began mulling new orders, too, according to Boeing.

"I've had customers calling because they're worried the skyline is full," said Brad Zaback, 767 vice president and general manager, referring to his production-line capacity. "Our team is focused on winning-together strategies, and we believe we can deliver the 767 for decades to come."

That wasn't so obvious not too long

ago to those who work on the airplane. The program delivered its last passenger version to Kazakhstan's Air Astana in June 2014. (No more orders for the passenger jet are in hand.) At that point, the 767 production rate dropped to one per month. Nothing beyond a 179-unit tanker order for the KC-46A by the U.S. Air Force was in place to keep the line going. The 757, a sister program created nearly the same time as the 767, had ended its production run in 2004.

Three years ago, the 767 even moved to a smaller assembly line in the Everett factory, to free up space for the 777. A natural end to this line appeared forthcoming, according to 767 mechanics and others, but people remained hopeful.

"Everyone still seemed very positive," said Helanea Combs, 767 join and installation manufacturing manager. "We were able to move over here and get a fresh start."

Indeed. Boeing delivered 16 of the freighters in 2015 and the 767 production rate is scheduled to increase to two

Photo: Production of the Boeing 767 is increasing following a sizable Federal Express order and renewed customer interest in the freighter version. The airplane first flew in 1981.
BOB FERGUSON | BOEING

Photos: (Clockwise from top) The 25th 767 Freighter built by Boeing for FedEx awaits delivery outside the Customer Delivery Center in Everett, Wash.; Boeing provides a symbolic "key to the plane" as a keepsake to the customer and program employees when delivering an airplane. **BOB FERGUSON | BOEING** Employees prepare 767-300 Freighters for final assembly and rollout at the Everett factory. **GAIL HANUSA | BOEING**

airplanes per month this month and to 2.5 per month in late 2017, Boeing said.

Many of the jets in use are receiving upgrades, further extending their commercial life. Delta, United and Icelandair recently retrofitted their 767s with new cabin configurations. Overall, deliveries of the 767 stand at 1,082 airplanes, with 911 of them in service, with 135 operators.

FedEx ships up to 25,000 packages per flight on its 767s, and the 767 offers a much higher dispatch reliability rate than the aircraft it is replacing, Boeing said. The order "will enable us to reduce structural costs, improve our fuel efficiency and enhance the reliability of our global network," FedEx Express Chief Executive Officer David Bronczek said in a statement last July.

The 767-300ER (Extended Range) Freighter operated by FedEx also is substantially more fuel-efficient than the airplanes it is replacing, according to Boeing and FedEx.

It provides capacity similar to FedEx's current MD-10s, with a 30 percent increase in fuel efficiency. Furthering efficiency is the fact that the 767 shares spare parts, tooling and flight simulators with the Boeing 757, which also is a part of the FedEx Express air fleet.

"I was sent down to FedEx, to Tennessee, and all I heard were good things about the six-seven," recalled Kirk Schadt, a 767 mechanic. "They said our bird was better than anything they had."

Conceived as a smaller, more economical option to the 747, the 767 flew for the first time on Sept. 26, 1981, with test pilot Tom Edmonds at the controls. The jetliner provided a number of aviation firsts for a twin-aisle jet when put into commercial service: a two-person (rather than three-) flight crew; "glass," or electronic, flight deck; all-digital autopilot system; full-authority flight management computer system; extended-range twin-engine operations certification to 180 minutes (time over water away from the nearest alternative airport); and vacuum toilets.

The introduction of the six Rockwell Collins CRT (cathode-ray tube) screens in the 767 to display electronic flight instrument system and engine data, as well as crew alerts, allowed the two pilots to handle monitoring tasks previously performed by a flight engineer.

Edmonds was impressed with the quieter ride and the more colorful instrument panel, but said the new toilet initially distracted him—when flushed, it sounded like a shotgun was fired, bringing a design change. Other pilots raved to him about the 767's wings, which created a lighter ride and have stood the test of time in their original form. First constructed during an oil crisis, the airplane has always been economically sound in terms of fuel consumption, according to Boeing.

"The 767 allowed us to change and correct a lot of things," said Edmonds, who retired in 1989. "All of that made the airplane real popular. It was a nice plane to fly."

Boeing later made upgrades to the 767 flight deck with the introduction of LCD (liquid crystal display) screens and in 2012 Boeing and Rockwell Collins began another upgrade to the flight deck based on the 787—bigger screens that provide more information. This latest flight-deck technology is on the aircraft operated and on order by FedEx. Boeing now installs the system in the factory, enabling the customer to put the jet into service two to three weeks sooner than with post-delivery installation.

Abelson, who joined the 767 flight-test program in 1980, said he still learns something new about the 767 every day. He's fiercely loyal to the jet.

"It's like an old friend," said Abelson, now 767 mechanical lead. "To me, it's the best aircraft in the fleet."

Others such as Johnson, who knows as much about the 767 as anyone and is pursuing global orders for the freighter, believes the airplane has a good chance to someday become Boeing's most continuously built twin-aisle jetliner product.

"In 2030, it will be 50 years old," Johnson said. "That really positions the 767 to set a record."

Mike Moore, a 767 flight-deck electrician, said it often makes more economic sense to repurpose an existing airplane with a proven track record rather than build a new jet.

"We've got a lot of skilled people who have been on this airplane a long

time," he said. "They know it like the back of their hand. They're smart. They care."

As the 767 production line ramps up again, mechanics and engineers are building the freighter in a streamlined, creative manner. They work on the front fuselage section and flight deck in a sunken third-floor workstation. They fabricate the wings behind a bank of nearby offices. All of the pieces are brought together by crane onto the main floor and lowered to an assembly line. The entire line is shared with the 767-2C, a new commercial freighter that is the platform for the U.S. Air Force KC-46A tanker.

Actually, employees say, they could assemble the 767 just about anywhere. They're pleased it is seeing a production resurgence.

As Dennis Howell, a 767 mechanic put it: "With the tanker, I figured the 767 had eight years of work left. With the increased freighter order, it looks like we'll build this plane as fast as we can build it for a long time." ●

DANIEL.W.RALEY@BOEING.COM

Photo: Shedrick Reed, a 767 structural mechanic, attaches a bracket to a sidewall liner on the main cargo deck of a freighter.
BOB FERGUSON | BOEING

Illustration: An artist's concept depicts a Boeing 787-8 (top) and 787-9 in Norwegian Air livery. BOEING

Success tails

Norwegian Air is Europe's third-largest low-cost carrier—and climbing

BY DAN MOSELY

Wherever Norwegian jets fly, celebrities are hot on their tail.

From "Scream" painter Edvard Munch to Danish comedian and pianist Victor Borge, some of the leading lights of Scandinavian and wider European heritage are immortalized as "tail-fin heroes" on Norwegian's fleet.

The tradition began in 2002 when Norwegian used a Boeing 737-300 to break into the country's well-established domestic market and pursue a self-described "out-of-the-box approach" to doing business.

Today, Norwegian is Europe's third-largest low-cost carrier, and still climbing.

"It felt only natural for us to adorn the tails of our aircraft with heroes who have pushed the boundaries, challenged the established and inspired others," said Norwegian CEO Bjørn Kjos. "These are the very values that the success of Norwegian is based upon."

Last month, Swedish-born actress Greta Garbo, whose image had been on the tail of a Norwegian Boeing 737-800, was on the tail of the airline's first 787-9 Dreamliner—an airplane that, according to Kjos, promises to open a new chapter in the airline's history.

That first 787-9 is leased, and the airline plans to operate 10 more under such agreements. That's in addition to the 19 jets Norwegian ordered in October—the largest single order for 787-9 Dreamliners ever placed by a European airline. The deal quadrupled the size of Norwegian's future long-haul fleet and enabled the creation of new routes.

A month later, the Oslo-headquartered carrier received a license to operate in the United Kingdom, opening up traffic rights to potential new markets in Asia, South America and South Africa from its U.K. base at London-Gatwick.

"The order for 19 787-9s is a major milestone and enables Norwegian to offer a wide range of new routes to travelers worldwide," Kjos said.

The airline served a record number of passengers last year—nearly 26 million. Kjos said flights from Europe to the United States and Asia have averaged more than 90 percent full during the past two years.

The airline has grown rapidly since its beginning in 1993 when it offered flights across Norway's west coast with a small fleet of Fokker 50s. In 2002, Norwegian expanded its domestic network with 737-300s and later offered short- to medium-haul flights across Europe. In 2013, the airline launched long-haul flights to the U.S. and Asia.

Today, Norwegian has a fleet of more than 100 737-800s and eight 787-8s. Its Dreamliner fleet is set to expand to nearly 40 airplanes in the next five years. In 2012, it ordered more than 120 additional 737s, including 100 737 MAXs that will open new medium-haul markets, Kjos said. Norwegian also has 100 of the Airbus A320neo on order.

Kjos said the range of the 737 MAX will enable Norwegian to connect smaller cities in the U.S. with smaller cities in Europe. "And it creates opportunities to connect Europe and Asia," he said. "Travelers will have access to intercontinental travel at an affordable fare." ●

DANIEL.MOSELY@BOEING.COM

Eagle eye

Steve Sliwa led Insitu to become a pioneer in unmanned aircraft

BY DAN RALEY

As Boeing approaches the start of its second century in July 2016, *Frontiers* visits with some of the men and women who have helped make Boeing a global leader in aerospace.

A woman knocked on the front door of Insitu, builder of unmanned aircraft systems in Bingen, Wash., and insisted on speaking with the head of the company. She said she wasn't leaving until this happened.

Steve Sliwa, then chief executive officer, met with her in his office. The woman proceeded to tell him how her son grew up nearby and currently served in the U.S. Marine Corps. Two nights earlier, she explained, her son and his unit were ambushed during an overseas mission.

Her reason for the unannounced visit: Insitu's ScanEagle had provided an escape route and saved everyone's lives.

The mother shared how the Marines called the unmanned aircraft their "guardian angel." Her son was a heroic figure to the others because he and Insitu practically shared the same address. Most of all, she told Sliwa, her son was safe.

"I'm here and I need to start hugging people—and I'm going to start with you," Sliwa recalled the woman telling him. "My son's coming home and it's because of you."

Sliwa had joined Insitu in 2001, shortly after the 9/11 terrorist attacks, at the urging of Tad McGeer, the company founder and friend who sought his business acumen.

Insitu, which today is a Boeing subsidiary, had been started in the late 1990s. The first employees, who loved to windsurf in the nearby Columbia River Gorge, designed and built a small unmanned aircraft with a high-quality video camera that could be launched and retrieved from a fishing boat to track tuna. It was called SeaScan.

When Sliwa joined Insitu as the president, he was convinced video camera-equipped unmanned aircraft would become a necessary military resource, particularly for surveillance. Sliwa said he saw widespread potential for military and civilian customers, domestically and internationally.

The mother who sought out Sliwa and offered her story was heartfelt confirmation that Insitu—Latin for "in place"—was headed in the right direction, Sliwa said.

"It doesn't get any bigger than that, to know our unmanned airplane is saving lives," he said. "That felt really awesome."

As Boeing prepares to celebrate its centennial, Sliwa is among the many men and women who have made milestone contributions to Boeing or its heritage companies. His direction and enthusiasm largely have been responsible for establishing Insitu as a leader in unmanned aircraft system (UAS) development and production, according to Steve Nordlund, vice president of strategy for Boeing Defense, Space & Security and a former Insitu executive.

"Steve's involvement is such that you can't have a sentence about Insitu without his name in it," Nordlund said. "He was the lifeblood of the company. It was not uncommon on Christmas day to see his car out front."

For a decade, Sliwa presided over Insitu. He had been the fifth employee; there are more than 800 now. He recruited people from different disciplines, such as automotive and optics experts, enabling a company initially geared to assist the fishing industry to move in other directions; he helped raise five rounds of venture capital at a challenging financial time—when he left, the company had compiled $800 million in sales, with revenues doubling each year; he was involved in bringing Insitu and Boeing together as partners in 2008.

The company's biggest break came in 2004, when the Marines agreed to use the newly developed ScanEagle, a small but sophisticated unmanned aircraft system, on a trial basis during the battle of Fallujah in Iraq. Weighing only 40 pounds (18 kilograms) but with a 10-foot (3-meter) wingspan, ScanEagle was quiet and could

Photos: (Above) Steve Sliwa, former Insitu chief executive officer, shows off the Integrator, one of several models of unmanned aircraft systems kept in a display case at his Arizona home. ASSOCIATED PRESS (Below) Sliwa displays one of the earliest ScanEagles in 2003. INSITU

operate in weather that negated other surveillance systems, flying undetected below cloud cover. It was well-received—Marine leaders credited the ScanEagle with limiting the casualty rate by 30 percent.

Insitu received another boost to its reputation when the U.S. Navy used a ScanEagle in 2009 to help rescue Capt. Richard Phillips, who was kidnapped from his U.S. cargo ship by pirates in the Indian Ocean. The tense standoff later was made into a Hollywood film.

Other militaries decided they had to have this unmanned aircraft, too, according to Sliwa.

"Our program grew, doubling over time," he said.

A native New Yorker, Sliwa was the son of a Navy pilot, a connection

that pulled him into the aviation world. He flew gliders in high school. He obtained a private pilot's license. He became a flight instructor and flight examiner. He studied aeronautical engineering. He owned gliders and turboprop airplanes.

"My first memories of cool stuff were airplanes," he said. "My first toys were airplanes. I always knew I was going to fly."

Before joining Insitu, Sliwa worked as a researcher in control theory and aircraft design and as a deputy chief for the Guidance & Control Division at NASA, founded a PC-based educational software firm, and served as president for Embry-Riddle Aeronautical University.

He retired from Insitu in 2011, three years after Boeing's purchase of the company and, he explained, having accomplished everything he set out to do. He has since formed Seeq, a big data startup. He still lives part of the year in Bingen because of the favorable climate.

Sliwa is proud to be considered a UAS pioneer. He helped establish an aviation product that he says has gone from science fair project to an essential tool for several industries. Among them are resource measurements, asset monitoring and oil exploration, not to mention the ever-increasing military needs.

The UAS, according to the former Insitu CEO, is here to stay, soon to be commonplace for everyone.

"It's going to be a huge contribution to society and life," Sliwa said. "Our grandkids are going to take it for granted that we've always had flying video cameras taking pictures around them." 100

DANIEL.W.RALEY@BOEING.COM

Photo: Steve Sliwa, the Insitu leader for a decade, shows off an evolved ScanEagle in 2006 at the Boardman Air Force Range in Oregon. INSITU


U.S. AIR FORCE
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Wing shot

Flanked by two F-15C Eagles, a KC-135 tanker refuels an E-3 Airborne Warning and Control System, or AWACS, aircraft near Okinawa, Japan, earlier this year. The aircraft, all made by Boeing, are with various squadrons of the 18th Wing at Okinawa's Kadena Air Base, the largest U.S. Air Force combat wing.

PHOTO: JIM HASELTINE | HIGH-G PRODUCTIONS

THE FUTURE LOOKS GREAT FROM HERE

On January 29, 2016, we saw the future—the first flight of the 737 MAX and a glimpse of what's to come. From lower operating costs to advanced technology, the 737 MAX is on track to deliver a new era of performance. That's a better way to fly.

See the first flight for yourself at boeing.com/737MAX

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