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Frontiers

Rolling out the future

Boeing welcomes a new member to its jetliner family—the 737 MAX

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PHOTO: BOB FERGUSON | BOEING

PHOTO: SHUTTERSTOCK

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Cover: Employees celebrate the rollout of the first 737 MAX 8 in early December. **MARIAN LOCKHART | BOEING**

Photo: Clyde Goble, mechanic, readies the 737 MAX flight deck for installation of large-screen displays. **MARIAN LOCKHART | BOEING**

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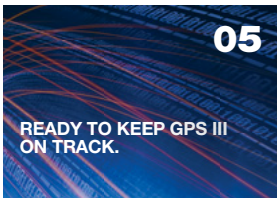
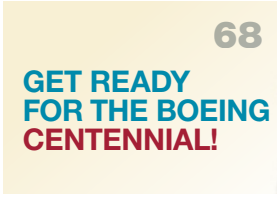


This new ad features GPS III and highlights Boeing's commitment to, and experience with, GPS. It is running in domestic trade publications.

Depicting a blueprint design of the Space Launch System, this recruitment ad marks Boeing's first 100 years and invites future employees to be part of its next century of innovation. The ad primarily will run in program guides at recruiting, diversity and college career fair events.

Part of the "A Better Way to Fly" campaign, this 777 ad is the latest in a series showcasing the many ways Boeing airplanes and services enable opportunity and success for customers. The ads are running in trade publications and online.



In anticipation of Boeing's 100th birthday in July 2016, this ad showcases the Centennial Collection, a variety of limited-edition collectible merchandise available only through the Boeing Store (or online at BoeingStore.com).

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John Tracy
Boeing chief technology officer
Senior vice president, Engineering, Operations & Technology

PHOTO: BOB FERGUSON | BOEING

Innovation: Our key to continued success

Boeing breakthroughs have changed and advanced the world—here's what's needed for another century of great achievements

Thanks to you and all our Boeing team, our company over the past 100 years has brought to life world-changing products and services that billions of people across the globe count on for safe, efficient travel; instantaneous communication; the exploration of space; and the defense of freedom. The things we do are difficult—but they are meaningful and important.

They are also innovative, providing sought-after capabilities that help our customers succeed. That's why I think of Boeing as a global leader in not just aerospace but also technology—and especially innovation. Our products and services make a tremendous positive difference for our customers and our society. They make me proud to work for Boeing—and proud to be on the same team as you. Thank you for your efforts!

There's only one thing that could be better than our 100-year legacy of innovation leadership, technical achievement and engineering excellence: another 100 years—and more—of these accomplishments.

We may be approaching the start of our second century, yet our ultimate goal remains the same: We must safely, efficiently and effectively out-innovate our competitors in order to grow and sustain our business, and make the world a better place. Innovation is at the core of why we've been successful, and it will continue to be at the core of why we'll be successful. And by out-innovating our competitors, we will continue to deliver for our customers, our partners, our shareholders—and, of course, the family members, friends, neighbors and communities that depend on us.

That objective of out-innovating our competitors isn't merely a wish for the future; it describes what we're doing now. Today is the golden age of Boeing product development as we work on market-setting products such as the 777X, 787-10 Dreamliner, 737 MAX, KC-46A Pegasus tanker, Starliner space vehicle, Space Launch System rocket and so many others. Those new products and services are complemented by innovations in our tools and our processes, such as the advanced manufacturing technologies and design tools highlighted in *Frontiers* in 2015. (See Page 46.)

So as we enter 2016, the year of our centennial, let's reaffirm our commitment to the actions and values that make us even better at innovation. We must:

- Know our customers, so that we recognize what capabilities the marketplace demands.
- Use our vision, creativity and boldness to envision solutions that meet these demands.
- Collaborate among ourselves and with the right partners to ensure we have access to mature technologies that enable the capabilities our customers want.
- Create our products and services safely, efficiently and effectively, so that we continue to provide first-time quality—and generate the value that lets us invest in our future.
- Support these solutions once they're with our customers.
- Model strong leadership by holding ourselves and our colleagues to the highest standards of workplace safety, ethics, inclusiveness and technical excellence.
- Strengthen our focus on continuous improvement in our products, processes, tools—and our individual capabilities.

As we recognize numerous Boeing-devised wonders from the past 100 years, let's build on these achievements and set the stage for another century of awe-inspiring innovations. That way, we'll provide the accomplishments the Boeing team of 2116 will be proud to celebrate. ■

High performer

An aerial display during the November Dubai Airshow provided a dramatic backdrop for Qatar Airways' recently delivered 25th 787 Dreamliner, on static display. Just before the air show, Qatar took delivery of its 24th and 25th Dreamliners in a ceremony at the Everett, Wash., factory—nearly three years to the day that it became the first airline in the Middle East to fly the 787. The airline has five more 787s on backlog. PHOTO: USCHI IRANI

QUOTABLES

"In every respect, the 787 has become a game changer."

—Akbar Al Baker, Qatar Airways chief executive officer, at a delivery ceremony for the airline's 24th and 25th Dreamliners. He said the 787 has exceeded early fuel efficiency estimates from Boeing. (See photo at left.) *Puget Sound Business Journal*, Nov. 4

"The P-8 is absolutely the essential next-step intelligence, surveillance and reconnaissance aircraft for the Navy."

—Adm. Harry Harris, commander of U.S. Pacific Command, talking about Boeing's sub-hunting maritime patrol aircraft. He said the Navy's growing P-8A Poseidon fleet is proving important for operations in the Asia-Pacific region, where many countries are focusing on submarine and antisubmarine warfare. *Aviation Week & Space Technology,* Nov. 4

"Boeing continues to change the world with revolutionary ... aircraft for passengers like me."

—Kevin Meno, aerospace enthusiast. Read his story and those of others on Boeing's centennial story sharing website at boeing.com/our-stories.


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777-300ER. A BETTER WAY TO FLY. The Boeing 777-300ER's unique combination of superior range, outstanding fuel efficiency and passenger-preferred comfort has created long-range success for carriers around the world. And with recent upgrades that further reduce costs and boost revenue, now's the perfect time to add to that success, in the air and on the bottom line. The 777-300ER makes every fleet a more profitable fleet. That's a better way to fly.

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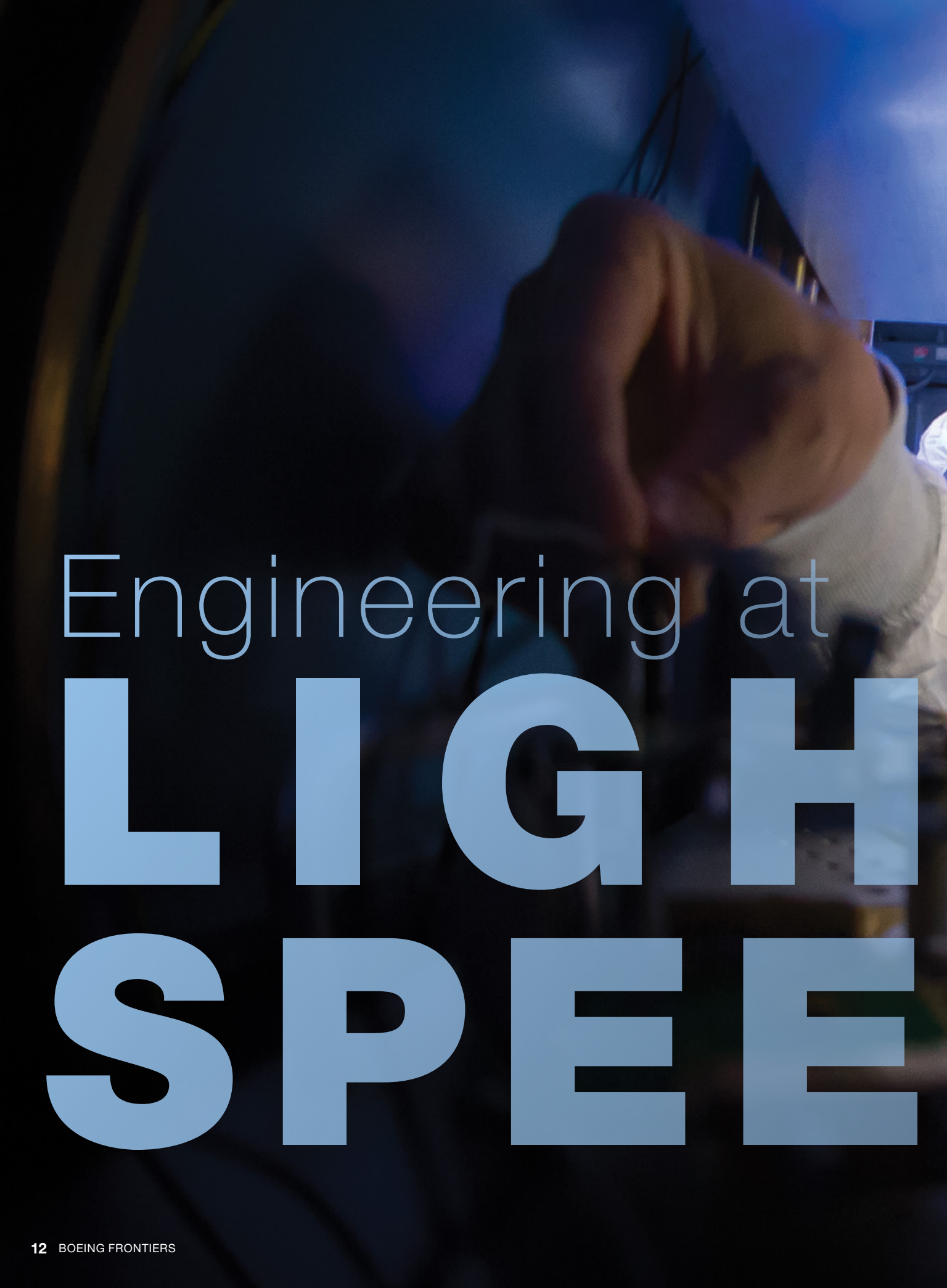

Engineering at LIGH SPEE

Boeing laser research program could revolutionize communications—both on Earth and in deep space

BY DAN RALEY

Inside a windowless, gray building near Los Angeles International Airport, Boeing engineers insist they can see the future—it offers deep-space exploration to Mars and beyond, Wall Street stock prices and other financial information delivered at lightning speed, and Internet that reaches every corner of Earth.

But for all of this to happen, and much more, the men and women at Boeing's Satellite Development Center in El Segundo, Calif., must convert current laser communications technology into something more

Photo: Laser communications, or Lasercom, electrical engineer Yongqiang Shi works on laser communications system technology at the team's lab in El Segundo, Calif.
BOB FERGUSON | BOEING

adaptable and cost-efficient, they say.

Boeing's Laser Communications program, known as Lasercom, has given itself two years to get a product ready—a quest potentially so rewarding and historically relevant that other countries and companies have joined in the competition, according to Jamal Madni, Lasercom business development lead and engineer.

"It's a race to the laser," Madni said.

What the Lasercom process entails is this: Information packets are beamed from space into fiber-optic communications networks on the ground, which, when fully developed, have the ability to bring far faster data rates than signals currently transmitted from space on federally controlled radio frequencies. Plus, lasers offer nearly unlimited data capacity, as opposed to existing bandwidth-limited radio-frequency systems now stretched to their boundaries, according to the program.

Simply put, although radio waves travel at the speed of light, their capacity is limited. On the other hand, huge amounts of data can be transmitted in much less time using a light beam, or laser, Madni said. In some cases, he added, a laser can send 100 million times more data (in bits) than radio waves over the same amount of time.

"When we're talking about gigabits and terabits of information, such as images and video, we are talking about getting information months faster from deep space, for instance," Madni explained.

Added Chris Johnson, director of Global Sales and Marketing, Boeing Government Space Systems: "It's like going from dial-up at a few kilobits per second to the broadband we have today with tens-of-gigabits-per-second capability."

In a trial run in June, an Optical Payload for Lasercom Science instrument, built by NASA and the Jet Propulsion Laboratory, sent a beam from the International Space Station to an optical bench—a series of lenses and mirrors that stand upright on a platform—connected to a telescope at Table Mountain Observatory near Wrightwood, Calif. An adaptive optics system, created by Boeing Internal Research and Development and linked to the Table Mountain receiver, corrected for atmospheric disruptions (such as weather), allowing for high-rate data transfer. Everyone involved came away encouraged by the system's performance, Johnson explained.

"It demonstrated that laser communication from the space station to a ground site aided performance by our adaptive optics system, paving the way for what space and satellite capabilities can be in the future," Johnson said.

A fundamental challenge now is to refine the technology so Lasercom can correct itself in the presence of a variety of atmospheric interferences, according to Johnson and Madni. Bad weather, for example, can make it difficult to secure a good connection.

Peter Chu, Advanced Technologies manager and optics expert with the Boeing program, said Lasercom will need to create cost-effective optical assemblies, which will fit on satellites or aircraft or ground stations, to steer data in different directions, including from the ground to space. Different shaped mirrors and power adjustments help guide the intricate transmissions.

"Because the LEO-to-ground link is only in view of a ground station for a fraction of its orbit, we need a very fast system," Chu explained, referring to low Earth orbit. "We need to acquire quickly, maintain contact throughout the entire pass and get the data into the fiber optic terrestrial network. A lot of people thought it couldn't be done."

The need for more sophisticated communications touches nearly every aspect of society, from commercial and financial needs to general aviation, military and space sectors, Madni said.

Military transmissions, using narrow Lasercom beams, would have a much lower probability of being detected and intercepted, better protecting troops, said Ron Burch, director of Advanced Military Satellite Communications. "It's very difficult to jam light," Burch said. "We're using infrared light, which is invisible to the human eye."

Military jets, such as the EA-18G Growler, could leverage the system to communicate with other aircraft and not put its electronic warfare missions at risk, according to Burch and others on the program. Boeing passenger jets

Photos: (Clockwise from top left) Lasercom testing took place in June at Table Mountain Observatory near Wrightwood, Calif.; the telescope, connected to an optical bench, received a large amount of data transmitted from the International Space Station; optical lenses and mirrors are part of the Lasercom technology. PAUL PINNER | BOEING


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could use the technology to upgrade data options and entertainment capabilities on board, such as video streaming to passengers.

Lasercom terminals also could accelerate the exploration of Mars and the rest of the solar system, Chu said. Space missions could obtain higher-quality data and images from these distant planetary destinations while reducing transmission time from weeks or days to hours. Spacecraft could be built differently to accommodate Lasercom.

"We see it as the next step for everything," Chu said.

Indeed, brokerage firms could use Lasercom to buy and sell stocks worldwide and faster than ever before, according to Madni. That Lasercom uses frequencies with unrestricted capacity means these brokerage firms would not be limited by today's federal restrictions in the amount of information being transferred over a certain period of time, a true Wall Street game changer, Madni said. Social-media companies such as Facebook and Google, which regularly have pursued more data capacity, could expand operations, he said.

Just a third of the planet has Internet access today, according to Boeing. Large pockets of people in Africa and South America go without it. Geographical and socioeconomic obstacles prevent the installation of the necessary technology. Within 20 years, however, Lasercom has the potential to bring everyone together in cyberspace. Among other advantages, it would create major educational advances, Johnson said.

"Connecting the rest of the world will be revolutionary," Johnson said. "Think of all the online courses in the past five to 10 years that have become part of everyday life. If we were able to connect the rest of the world with classes at USC (University of Southern California) or Stanford or the London School of Economics, and provide them the ability to gain that knowledge, think of the barriers that would be broken."

In the highly secure Lasercom lab in Southern California, fans hum loudly overhead. Engineers, dressed in white lab coats, hairnets and safety glasses share tight quarters with large computer components, display monitors of every kind, and yards of fiber, wires and cords. A miniature Lasercom terminal, with an optical bench attached, sits on a stand in the middle of the busy activity, as if to constantly remind everyone of what they're creating and modifying.

The satellite division of Boeing, formerly Hughes Aircraft, was one of the first to work with laser communications, beginning in the early 1970s. Parallel efforts at McDonnell Douglas, another Boeing heritage company, also brought early Lasercom developments and hardware experiments, according to

Steve Lambert, Lasercom chief engineer. In the early 2000s, he said, Boeing developed space Lasercom terminals for the U.S. Air Force's Transformational Communications Satellite program, which was discontinued in 2009. Despite these efforts, Lasercom has historically evolved slowly and methodically because of fluctuating customer interest, technology maturity and unchanging funding levels, Lambert noted.

Over the past decade, however, technology advances—such as the leveraging of commercial telecommunications products in Lasercom designs and renewed customer interest in its potential benefits of bandwidth, spectrum and security—have brought laser communications back to the forefront, Lambert said. Increasing talk of Mars exploration and the need for communications bandwidth played a big role.

"We're leveraging everything we've learned in our past 30 years," Lambert said. "We're really positioning ourselves to be there when the door opens up and the customer needs that we foresee become absolute."

The goal, Lambert said, is to have a mature Lasercom system available within the next two to three years. This includes applications for the military, the commercial market and NASA deep-space missions.

"There are so many benefits and the technology has improved so much in the past 10 years, at some point it will be indispensable," Burch said.

If successful, Burch added, Lasercom won't supplant radio-frequency communications; the two will co-exist. Broadcast mediums, such as television, still are better-suited for transmission across radio frequencies.

In 1963, scientist Harold Rosen and Hughes Aircraft were responsible for a major communications breakthrough—the launch of a geostationary satellite. The technology enabled overseas TV transmissions for the first time and more dependable telephone service from country to country.

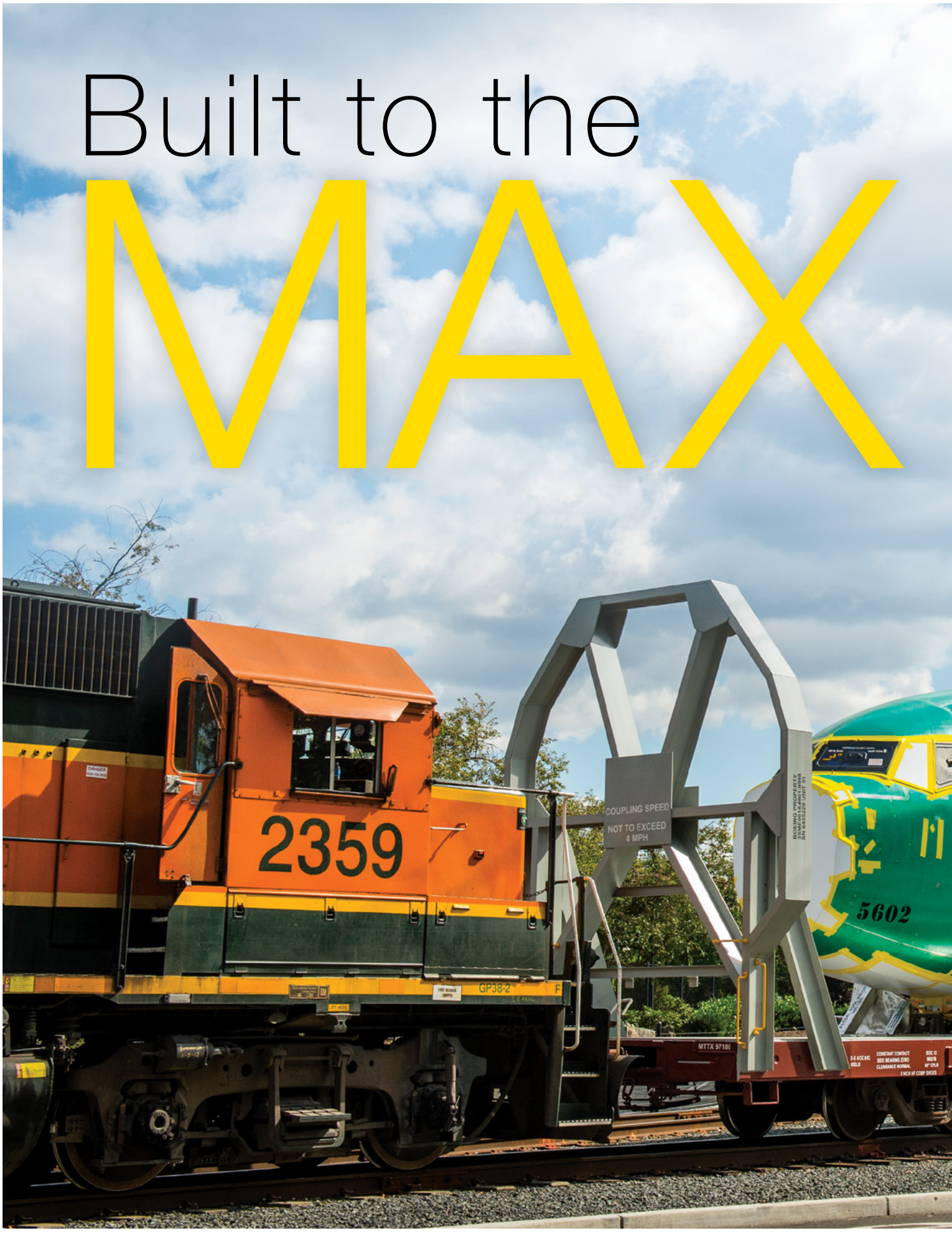
Lasercom could be the next major communications milestone, with its potential to bring people on Earth closer together while sending its explorers deeper into the universe, according to program managers.

"This is right in line with Boeing and our values," Madni said. "In satellite history, we've built the backbone of our brand on a legacy of firsts, starting with Rosen. We've always pushed the envelope." ■

DANIEL.W.RALEY@BOEING.COM

Photos: (From top) Engineers Matthew Robinson, left, and Yongqiang Shi confer on Lasercom technology in their lab in El Segundo, Calif.; Jamal Madni, Lasercom business development lead and engineer, uses a mock-up telescope to demonstrate how the technology will work. BOB FERGUSON | BOEING

Built to the MAX



Follow the journey of the first 737 MAX through final assembly

BY LAUREN PENNING
PHOTOS BY MARIAN LOCKHART

On Aug. 21, a 737 fuselage assembly arrived by freight train at the Renton, Wash., plant from Wichita, Kan. It looked like any of the hundreds of fuselage sections of Boeing's best-selling, single-aisle jetliner that arrive in a steady flow from Wichita to meet record production rates.

But this one, Wichita line No. 5602, was different.

It was the fuselage for the first 737 MAX, which Boeing says promises to raise the bar to an even higher standard of efficiency and capability. The world's airlines have already ordered nearly 3,000.

The MAX represents the culmination of more than four years of design and engineering—as well as the immense transformation of the Renton site that makes possible not only the seamless assembly of a new jetliner but the uninterrupted production in the same factory of 42 737s every month. A rate that will be going even higher.

That first 737 MAX 8, fresh from the paint shop, made its debut to Renton employees, and to the world, in early December.

In this photo essay, meet the newest member of Boeing's jetliner family. See it take shape as employees transform that first fuselage into an airplane that Boeing is counting on to carry its rich tradition of innovation into its second century. ➤

LAUREN.L.PENNING@BOEING.COM

Photo: The first 737 MAX 8 fuselage, line No. 5602, arrives in Renton, Wash., by rail in August.

Photos: (Top) Employees stage the first 737 MAX 8 fuselage to switch tracks near the Renton, Wash., factory, where the airplane will be assembled. (Bottom, from left) Overhead crane operators lift the fuselage over to the three-story fuselage systems installation tool; the fuselage is loaded into the fuselage systems installation tool.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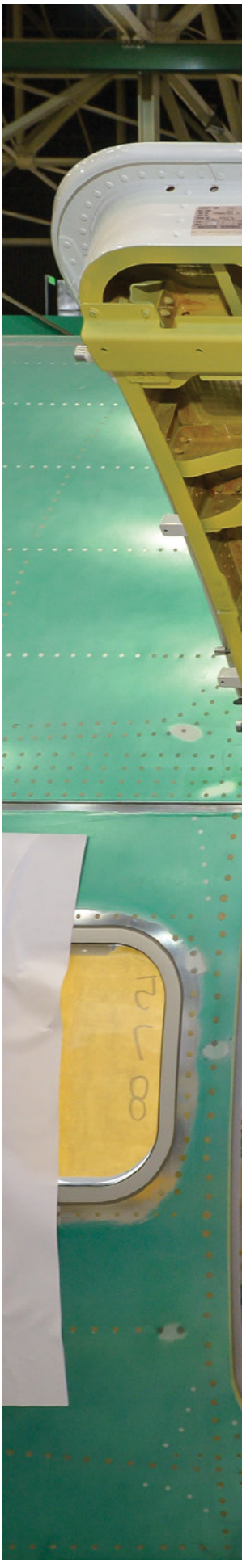
Photos: (Left, from top) Installing insulation blankets inside the first 737 MAX; Tuynh Doa, mechanic, installs wiring during fuselage systems installation. (Far right) Mike Carter, mechanic, continues system installation.

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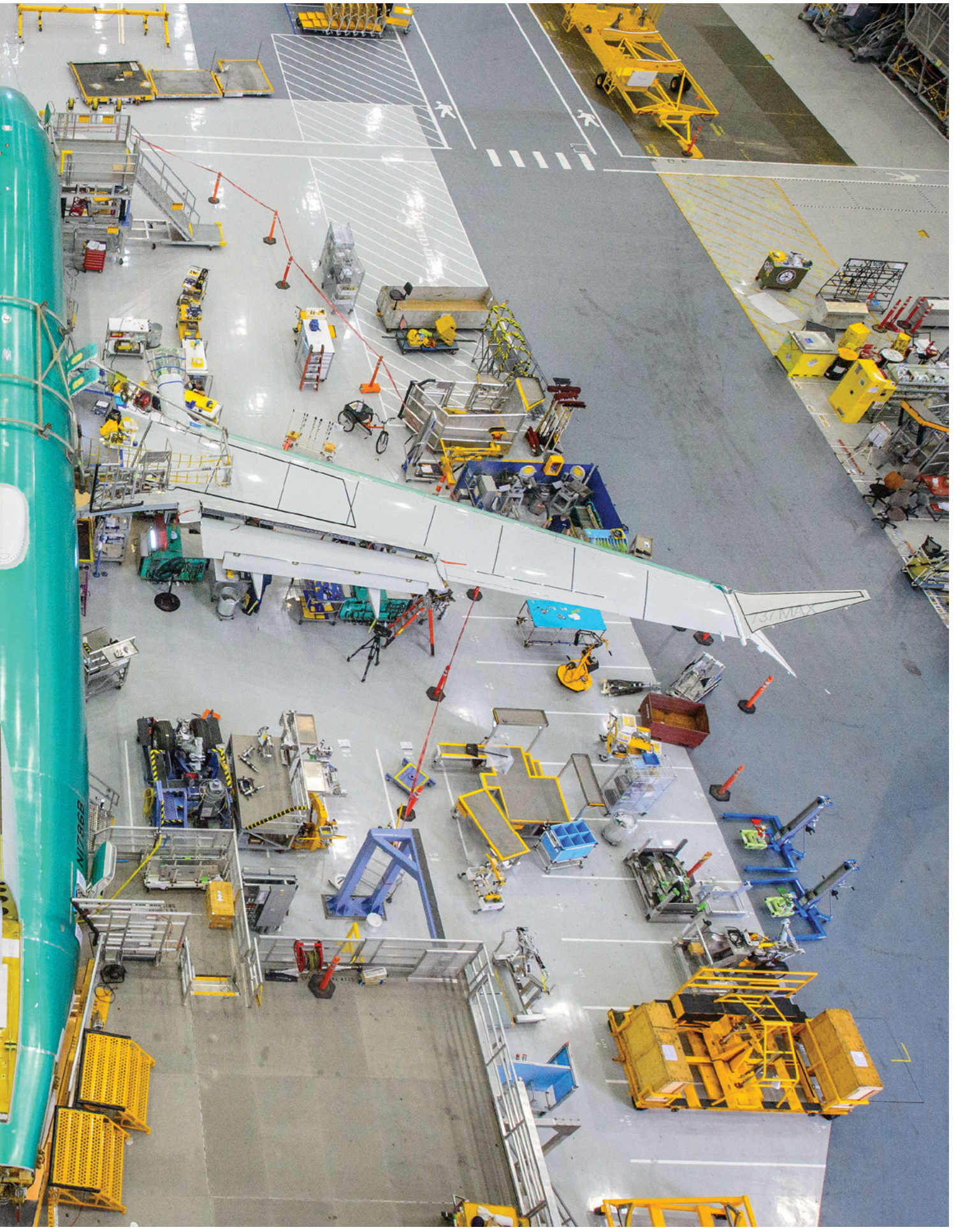
737 MAX


737 MAX
786B
5602

Photos: (Clockwise from top left) Renton Wings employees attach the first 737 MAX AT winglet to a crane so it can be mated to the completed MAX wing inside Renton's Wings facility. Alan Parliman, left, team lead, and Daryle Arthalony, mechanic, work on the wing-to-body join; the wings are attached to the first airplane.

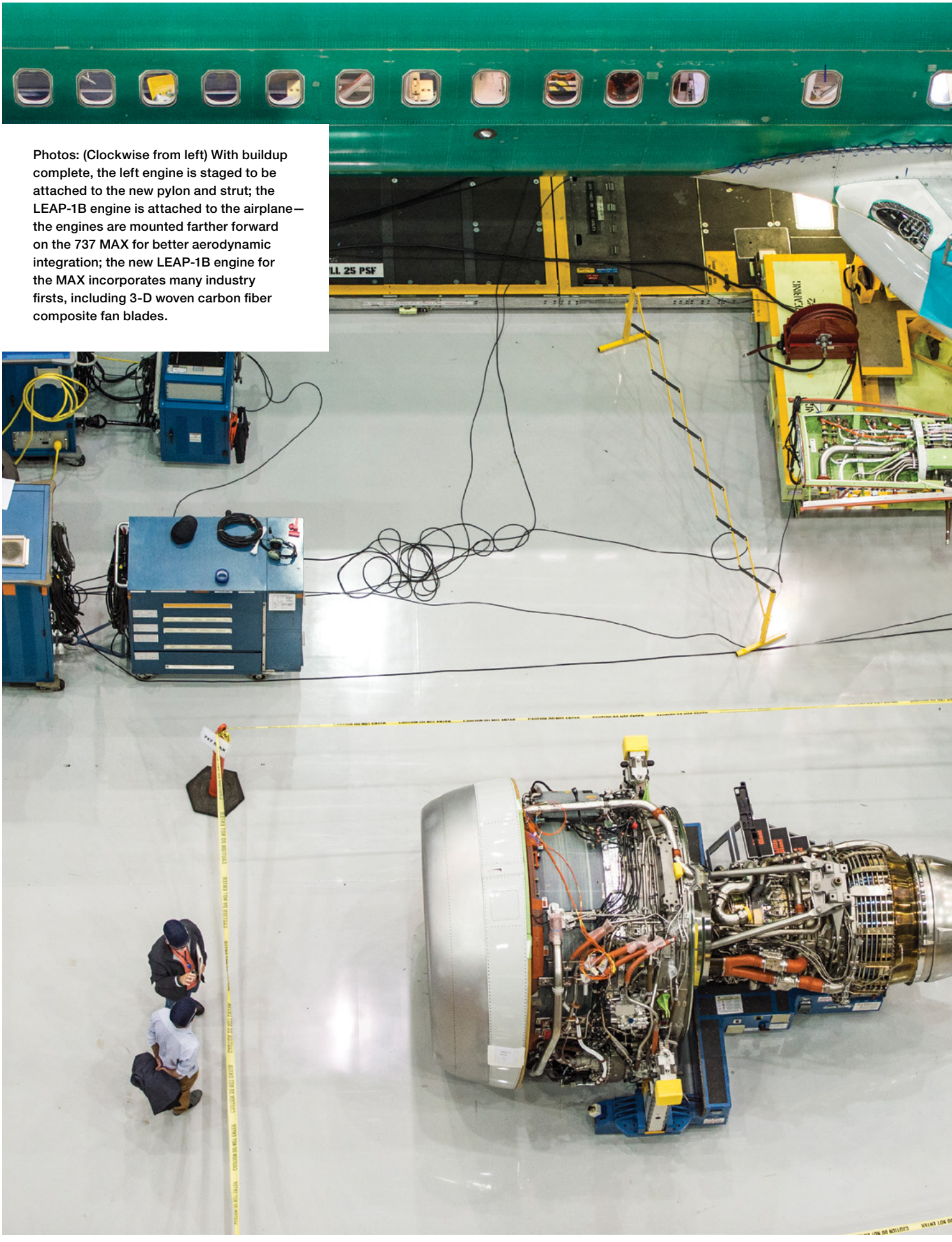
Photo: Top view of No. 5602, with wings newly attached, in the wing-to-body join position on the new central production line. Temporary tape on the winglet and wings helps ensure correct installation.


737 MAX

Photos: (Left, from top) The new tail cone designed for the 737 MAX is installed—the more aerodynamic design will save up to 1 percent in fuel use; Sheila Gayda, Quality inspector, gauges readiness of the fuselage for vertical stabilizer fitting. (Far right) Employees lower the vertical stabilizer onto the 737 MAX, providing the first glimpse of the airplane's signature "8" marking.

Photos: (Clockwise from left) Employees prepare the right main landing gear for installation; testing the functionality of the newly attached landing gear; new, larger-screen flight-deck displays are powered on as part of functional testing of the new airplane.


BEFORE FLIGHT



Photos: (Clockwise from left) With buildup complete, the left engine is staged to be attached to the new pylon and strut; the LEAP-1B engine is attached to the airplane—the engines are mounted farther forward on the 737 MAX for better aerodynamic integration; the new LEAP-1B engine for the MAX incorporates many industry firsts, including 3-D woven carbon fiber composite fan blades.

Photos: (Left, from top) The 737 MAX is towed out of the Renton factory en route to the site's nearby paint facility; Renton field employees position the airplane inside the paint hangar. (Above) A Boeing painter sprays the final clear coat on the forward section of the airplane.

Photos: (Clockwise from top left) The "Spirit of Renton" is named after the city where employees design and build the 737 MAX; employees inspect the newly completed airplane; customer decals and one decal designed by employees decorate the side of the plane.


787
N870Q

Photo: The 737 MAX 8 debuts to employees in early December. According to Russell Martin, a Renton maintenance utility worker, “It was cool being part of a new airplane coming out of the doors.”


737
N8701Q

Innov AN oppor

Germany is a leader in technology and innovation—and a key market for Boeing

BY ASHLEY JOHNSON

It was the kind of innovation and engineering that can change the world. And did.

All commercial jetliners—whether a 747-8 Intercontinental operated by Lufthansa or an Air Berlin Next-Generation 737—have their roots in an aircraft design breakthrough that underscores the ties between Boeing and Germany.

In the spring of 1945, Boeing aerodynamicist George Schairer entered Germany just before the war ended as part of a fact-finding mission with other scientists. Inside a research center they found wind-tunnel data confirming the advantages of airplane wings that were swept back rather than straight. Schairer shared the findings with his Boeing colleagues, aiding the company in designing the B-47 Stratojet, the world's first large swept-wing jet. Combined with engines mounted in pods under the wings, the innovations propelled Boeing into the jet age with the subsequent development of the 707 commercial jetliner.

Some 70 years later, German

technology continues to influence innovation at Boeing. The country in western Europe is home to world-class manufacturing and automation technology that is helping shape Boeing's future.

"If you look at the technology that is on our airplanes and the innovation that comes from Germany, it's just staggering," said Matthew Ganz, president of Boeing Germany and Northern Europe and vice president of European Technology Strategy.

Germany is the largest economy in Europe, and Ganz said the real strength lies in small- to medium-sized businesses, known as the Mittelstand. Many of Boeing's local suppliers fall in that category. Ganz pointed to Liebherr-Aerospace Lindenberg, which Boeing selected to design and manufacture the folding wingtip system for the 777X, as well as the advanced jetliner's leading and trailing edge actuators.

"These are important 777X systems and they'll be built here by our suppliers," he said.

In 2014, Boeing and its supply chain partners spent more than $800 million with German suppliers in support of Boeing

Photo: A view of Berlin, the home of Boeing Germany headquarters. SHUTTERSTOCK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products and services. Notably, Diehl makes the LED lighting for the 787, and KUKA developed a new robotic system for building 777 fuselages that is helping improve both quality and safety at the Everett, Wash., factory, according to Ganz.

Boeing also recently acquired Peters Software (based in Cologne, Germany), a market-leading provider of European Aviation Safety Agency–based training content for early stage ("ab-initio") pilot training.

Marc Allen, president of Boeing International, underscored how Boeing's relationships in Germany affect not only its commercial models but also the process and knowledge behind them.

"Germany has one of the richest traditions around manufacturing excellence and research," Allen said. "It's positioned itself as a world leader in additive manufacturing, Lean+ technology, automation and robotics. We need all of those strengths to build our second-century design and manufacturing capabilities."

The connection between Boeing and Germany goes all the way back to Boeing founder William Boeing's father, Wilhelm Böing, who was born in Hagen-Hohenlimburg and emigrated to the United States in 1868. Germany also builds on a rich history of aviation pioneers such as Otto Lilienthal, the first person to make repeated, successful flights with a glider he designed, and Hugo Junkers, who developed the first successful all-metal airplane.

From a commercial standpoint, Germany represents an extremely important but challenging market, said Todd Nelp, vice president of European Sales for Commercial Airplanes.

Boeing delivered its first airplane to Germany—a 247 operated by Lufthansa—in 1934. Lufthansa was a launch customer for the 737, and in 2012 it became the first airline to put the 747-8 Intercontinental into revenue service.

Lufthansa also was one of the first airlines to sign up for the new 777X. The Lufthansa Group includes SWISS and Austrian Airlines, the largest airlines in Switzerland and Austria, respectively. SWISS is scheduled to receive its first of nine 777-300ERs (Extended Range) in early 2016.

Additionally, Air Berlin flies the 737, and TUI Group, which owns six European airlines and is headquartered in Germany, has an all-Boeing fleet. Berlin-based Germania operates the Next-Generation 737 and Condor operates the 757 and 767. Germany, an economy that is strongly based on exports, is the base for leading cargo airlines such as Lufthansa Cargo, AeroLogic and EAT/DHL Leipzig, all of which operate Boeing freighters.

But Germany also is a home market of Airbus, and Boeing must differentiate itself by highlighting the performance of its airplanes, according to Nelp. "If you look at our twin-aisles," he said, "we have the most fuel-efficient airplanes, and airplanes that have the range and capacity to do all of the missions out of Germany."

Calling Airbus a "strong and worthy competitor," Ganz noted investments from the European company as well as the German government have created a first-class technology and production environment in the country.

"It's a wonderfully rich environment to be in, in terms of technology and skilled people," Ganz said. "We're not the home team, but for an aerospace manufacturer this is a part of the world that we have to be operating in and be comfortable in."

Boeing also may have an opportunity with the German military in upgrading its current heavy-lift helicopter fleet. Joe McAndrew, vice president of Europe, Israel and Central Asia, International Business Development for Boeing Defense, Space & Security, said early indications are the CH-47 Chinook would be an excellent replacement.

"Whoever buys Chinooks always comes back for more," McAndrew said, adding that it has been tested both in combat and humanitarian missions. "The product speaks for itself. Boeing is keenly interested in finding German companies to work with and to broaden our involvement in that marketplace."

Many of Boeing's partnerships in Germany involve research and

Photos: (Clockwise from top left) A street in Hagen-Hohenlimburg, the birthplace of Boeing founder Bill Boeing's father, Wilhelm Böing, is named after the family; students sing a song dedicated to Boeing during an event celebrating the opening of a learning lab at their school in Germany. BOEING Lufthansa recognizes the 1,500th 747 built by Boeing with a special livery. SHUTTERSTOCK

development. German airlines long have contributed to Boeing's product lines. For example, during development of the 747-8, Boeing worked with Lufthansa and other operators to incorporate efficiency improvements. Lufthansa now is providing input on the 777X.

"German airlines have been extremely valuable in guiding us to build, design and certify products that are accepted by the broader market," Nelp said. "That's just based on the expertise in the German aviation market that they've been able to share with Boeing."

The auto industry is another research partner. In 2012, Boeing and BMW began working together to study carbon fiber recycling, of particular interest to Boeing because the lightweight material comprises most of the fuselage of the 787 Dreamliner.

Likewise, application of automation to composite materials manufacturing is the primary focus of Boeing Research & Technology–Europe employees based in Germany.

"One of our business imperatives is to reduce our production costs, and automation can bring some clear gains in that," explained José Enrique Román, managing director of BR&T-Europe.

Driving improvements in manufacturing is the basis for many of the research and development projects at German universities and institutions. In particular, Boeing in 2008 co-founded the Direct Manufacturing Research Center at the University of Paderborn to advance additive manufacturing, also known as 3-D printing. With this process, parts are built layer by layer instead of forging, machining or casting a material into the desired shape.

Román said additive manufacturing can create lightweight parts and allow for more functionality. Although Boeing has been conducting R&D work in 3-D printing since the late 1990s and has tens of thousands of 3-D printed parts flying on its products, the technology represents a significant change for engineers educated in traditional design and fabrication processes.

"We are already shaping the industry and research environment around 3-D printing," he said.

Boeing also is stimulating young minds through its work in the community. Through a program with the Citizens Foundation of Berlin, Boeing encourages children to develop math and science skills by having retired engineers teach them fun physics experiments they can do at home. In collaboration with the German Children and Youth Foundation, Boeing recently opened a "learning lab" in Hohenlimburg to teach students science topics through hands-on activities.

Another way Boeing is shaping the future is through technology development at Jeppesen. The subsidiary employs approximately 500 of the 600 Boeing employees in Germany. The Jeppesen Research and Development team based in Neu-Isenburg has developed and brought to market products like Airport Moving Map, which uses a database and GPS technology to display a dynamic map showing pilots their position at the airport.

Bernd Bührmann-Montigny, director, Global Operations Integration, and managing director of Jeppesen Germany, highlighted Jeppesen's digital transformation project to provide all materials that pilots need on board, such as maps and airport data, electronically. He said the team also is looking into door-to-door service for pilots—giving them the tools and information they need before, during and after the flight, all in one system.

Bührmann-Montigny credits Boeing with driving R&D into Jeppesen's operations in Germany. Before Boeing acquired Jeppesen in 2000, he said, Jeppesen had one patent pending; now it holds 105, with more pending.

"Boeing brought true R&D to Jeppesen, which we didn't have before, and that's really powerful," he said. "What both companies do is make the airplane more efficient, so when we connect our systems with Boeing airplanes this optimization is even stronger." ■

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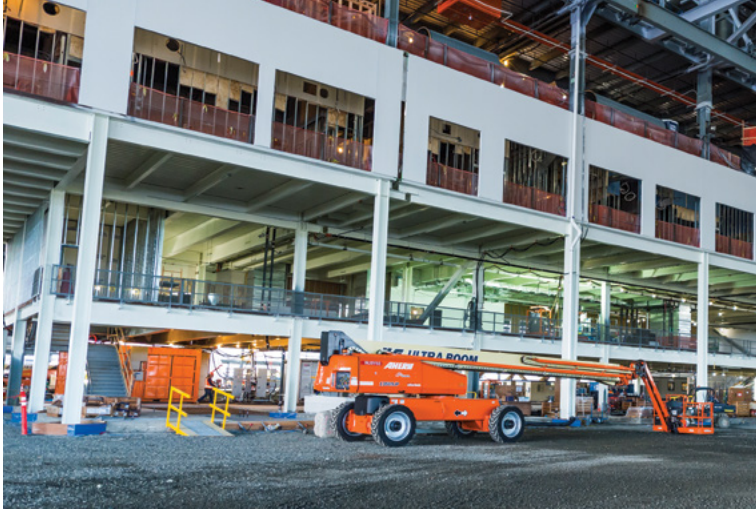
Photos: (Top left) Boeing co-founded the Direct Manufacturing Research Center at the University of Paderborn to drive advances in additive manufacturing, a process that can create lightweight parts that have more functionality; shown are representations of the types of components the center creates. (Top right) A statue of famed aviator and founder Elrey Jeppesen greets visitors at the Jeppesen site in Germany. (Right) Boeing Global Corporate Citizenship supports Fliegen Lernen, or Learning to Fly, a program that teaches students science concepts through hands-on experiences. BOEING


Fliegen lernen
Wer wird denn gleich in die Luft gehen?



Getting ready for the 777X

Everett site prepares for future work with new buildings, tools

BY ERIC FETTERS-WALP

A flock of multistory cranes has roosted just north of the landmark Boeing factory building in Everett, Wash., over the past year. Those cranes, countless trucks weighed down with construction materials and hundreds of workers have helped the new Composite Wing Center rise.

Not far away, advanced manufacturing equipment is streamlining fuselage drilling in a recently completed addition to the Everett final assembly complex. A third building, for manufacturing, test and delivery support, is due for completion in early 2016 south of the Everett Delivery Center.

Nearly a half-century after Boeing started building its new 747 assembly factory 25 miles (40 kilometers) north of Seattle, the company is making large investments in facilities at the site as it prepares to make 777X airplanes, in addition to the 787, 777, 767, 747 and KC-46 tanker lines.

"When I decided to join the 777X program, I had no idea of the magnitude of this project," said Veronica Leclerc, an executive staff analyst who moved from Boeing Portland to help Composite Wing Center Operations. "It has been exciting to see how many people must

Photos: (Top, from left) The first of three large autoclaves used for manufacturing composite wings is installed in the Composite Wing Center; the central office tower. GAIL HANUSA | BOEING (Bottom) Another view. ANDREW NESS

More than 2.7 million hours worked to date with no lost workdays due to injury

come together to start this new factory, the amount of details required to ensure everything is ready for day one."

Construction of the Composite Wing Center is the single-largest change to the Everett complex. The center encompasses 1.3 million square feet (120,800 square meters) and stands 100 feet (30 meters) tall at the roof line. Scheduled for completion in mid-2016, the $1 billion building will allow Boeing to fabricate its longest wings ever—more than 235 feet (72 meters)—with the help of three giant autoclaves, which bake composite materials.

A vital part of the 777X production line, the wing center is important to the site's future. But the construction project has made for a busy present as well. Commercial Airplanes and Boeing Shared Services Group (SSG) Site Services oversee the project, which has involved hundreds of construction workers and scores of suppliers and contractors, said Jeffrey Nunn, SSG Everett Site Services Project Implementation director.

"From approval in 2014, the team cleared the construction site of three office buildings, acquired new off-site leased buildings, relocated about 3,000 displaced employees, completed site work ... and is completing specialized foundations and utilities to support new advanced manufacturing equipment and tooling, which will begin arriving soon for installation," Nunn said.

Together, Commercial Airplanes and SSG coordinate infrastructure changes—rerouting miles of utility lines, constructing a chiller building to supply cold water for manufacturing and air conditioning, finding new work areas for displaced employees, resolving disruptions to site parking and transportation, and more, said Jeanette Westrup, an SSG project manager for the wing center's central tower.

"This is a challenging project," she said, "but it will be beneficial to the success of the 777X program. It's incredible to watch all the construction and airplane production ongoing at the same time."

The new buildings are only part of what is happening at the site. Employees say the changes to the site go well beyond just an expansion.

"I'm impressed that Boeing is setting itself up for the next phase of airplane manufacturing—in new technologies and aircraft materials," said Florent "Flo" Briand, a 777X manufacturing engineer who first worked in Everett on the 747-400 program in the late 1980s. "There was a time when Boeing made airplanes out of wood and fabric ... We now go from aluminum and 787 composite assembly to new composite fabrication methods that will expand the breadth of what is done here."

On the east end of the complex, a new 325,000-square-foot (30,000-square-meter) building is home to the Fuselage Automated Upright Build, or FAUB, tools, designed to reduce safety risks and improve quality on 777 fuselage sections. This fall, the first fuselage sections went through the new drilling and fastening area, which will ramp up to replace the current process as production of the 777X nears in the coming years. Everett's other airplane production lines are integrating new technology, tools and practices as well.

For those who work at Everett and live in the area, the changes and additions show that Boeing's original and largest widebody site is prepared to compete in a future of faster, more efficient production rates, noted SSG's Westrup.

"I believe the addition of the new manufacturing technology at the Everett site will bring Boeing into our next 100 years of business," she said, "and help set us apart from our competitors." ■

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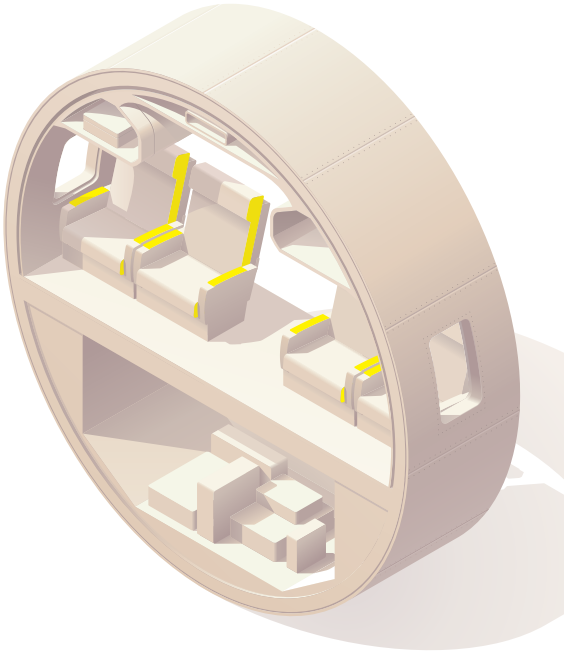
Photos: (From top) A construction worker places the last major steel structure for the Composite Wing Center in Everett, Wash., in September; construction is slated to be complete mid-2016. GAIL HANUSA | BOEING

WHERE IDEAS TAKE FLIGHT



Boeing's 737 Configuration Studio helps customers streamline cabin decisions

BY DAN RALEY | PHOTOS BY MARIAN LOCKHART

People check in at the front counter, some carrying luggage. A reader board announces their arrival. Soon they will seek out a seat, a stowage bin or even a lavatory—yet there's no flight involved.

Inside the 737 Configuration Studio in Renton, Wash., the only things that take off are ideas.

Airlines come to this facility to choose customized cabin designs and preferred equipment for their new Boeing single-aisle jets. Or they can use the products and features to retrofit existing fleets. They sort through the latest innovations,

Illustration: (Above) An aircraft cabin cross-section. (Below) Alaska Airlines flight attendants, from left, Simon Heppell, Todd Horn and Blair Kimball compare seating choices in Boeing's 737 Configuration Studio in Renton, Wash.

consulting with suppliers and studio personnel. They applaud the efficiency.

Opened in March 2014, the 737 Configuration Studio has succeeded in streamlining a selection process for airplane interiors that was once lengthy and cumbersome, according to Chase Craig, Alaska Airlines director, brand experience–onboard.

"Prior to the studio, you had four or five places in Seattle you had to go, where now you can go to one place in one afternoon," Craig said. "In having one-stop shopping, Boeing really understands the value of our time."

Similar to the 787 Dreamliner Gallery in Everett, Wash., the configuration studio can be as busy as an airport terminal. More than 5,000 visitors from 50 airlines have used the cheery, spacious facility, among them chief executive officers, board members, marketing directors, interiors specialists and flight attendants. Groups range from two to 20 people.

The studio offers showrooms that display seating, galley, lighting and fabric choices. It also provides four conference rooms for airline employees to meet and brainstorm in or confer with personnel back at their corporate offices.

"It's like being on an airplane," said Kent Craver, Boeing regional director for cabin experience. In the front of the galley room are nine ovens and four beverage machines, each readily movable to illustrate cabin fit, positioning and accessibility. Electrical and water connections enable cooking trials. Four suppliers have cordoned-off sections with their cabin products on display. It's a hands-on area, with an airline once bringing in 20 flight attendants simply to move beverage carts around, cycle galley systems and perform cabin services to see what worked best, Craver said.

In the fabric room, customers pick out color schemes for walls, seats, carpets and curtains. It's not unlike a homeowner outfitting a new residence. Samples are organized in bins or hang in a closet-like space. Airlines often compare their flight attendant uniforms and other color palettes to the studio fabrics.

The light lab is an extension of the fabric room. It's a mock airplane cabin that holds three rows of seating of six seats each, plus windows and stowage bins. Customers can check fabric colors against different levels of lighting, such as dimming the cabin before takeoff, so there are no issues later. The interior color has to be precise.

"It's where they get to set themselves apart from other airlines," said Aubrey Davis, project manager for Teague, Boeing's longtime interiors partner that

helped design and build the configuration studio for Boeing. “It’s all about brand.”

In the light lab area, Boeing recently unveiled its new Space Bins, which are larger overhead stowage containers able to hold more carry-on luggage than the existing 737 bins. Alaska is the launch customer for the Space Bins, which hang 2 inches (5 centimeters) lower from the ceiling to accommodate passenger reach and have room to store six standard-size carry-on bags, two more than before.

The largest studio showroom is for seating. Five suppliers have different configurations in place, mixing first-class with economy options. Airlines measure seat pitch (legroom) and comfort. They experiment and rearrange the number of seats. This room is as busy as any.

“One thing we’ve taken advantage of is the seat gallery room,” Craig said. “We’ve done a couple of different seat mock-ups and pitch mock-ups. The value of being able to do it and get it really accurate is important to us.”

In-flight entertainment options are featured in large colorful displays that are mounted across the back wall of the seating room. Three suppliers promote numerous products, which include privacy screens, user controls, handsets and power plugs.

A mock lavatory has a curved wall, demonstrating a space-saving concept. Also under consideration is a smaller aft galley, which could lead to more seating.

In a far corner of the seating showroom are two smaller, secure rooms where customers can conduct cabin consultations in private. “We use this specifically for a new seat when airlines don’t want competitors to see it,” said Steve Pickard, 737 interiors engineer.

The configuration studio was built to be comfortable and functional, but not too flashy—mirroring the airplane it serves, the 737. A cafe area facilitates catered events; separate phone rooms ensure confidential conversations.

Everything is considered when it comes to meeting the needs of the customer, including cultural differences. Visiting airline personnel sometimes need space to pray multiple times per day, while others won’t eat a meal at a table where they do business, requiring ready solutions, Davis said.

Overall, the studio gives airlines a true indication in how their jets will appear on the inside, leading to confident decisions and fewer late changes. These are significant cost-savers both for airlines and Boeing, according to Craver. Bringing the cabin selection process together in one well-organized location also has made everything more productive and comfortable.

“The whole experience matters,” said Alaska’s Craig. “The configuration studio is a safe haven for creativity. In the studio, you can allocate time, bring in partners and have tea.” ■

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Photos: (Far left) Alaska Airlines’ Stephanie Cootsona and Matthew Coder examine galley options at the 737 Configuration Studio. (Above) Coder, left, and Chase Craig sort through cabin fabric samples at the 737 Configuration Studio.


Fly DC JETS


WELCOME TO DOUGLAS Long Beach


TEXACO

Wings that changed the world

Douglas left enduring legacy of airplane design and production

BY MICHAEL LOMBARDI

When the last C-17 rolled off the assembly line in Long Beach, Calif., in August, it was not just the end to a long-running and successful airplane program; it also was the final verse of the epic saga of Donald Douglas and the production of aircraft with roots in his company.

In 1920, a young Douglas had already attended the U.S. Naval Academy, completed a four-year engineering degree at MIT in two years, served as the chief civilian engineer for the U.S. Army Signal Corps during the First World War, and designed the United States' first bomber, the MB-1. He was 28 years old and determined to build his own airplane company.

Douglas started this company, Douglas Aircraft, in the back of a barber shop on Pico Boulevard in Los Angeles. There he designed his first airplane, a commercial transport called the Cloudster.

The Cloudster first flew in February 1921 and gained fame for being the first transport to lift a load equal to its empty weight. Although not a financial success, it served as a foundation for a follow-on and very successful U.S. Navy torpedo bomber—the DT-1. In all, 93 DT-1s were built, but the DT-1's greatest claim to fame was being chosen by the U.S. Army for the historic first around-the-world flight. In 1924, two of the planes, called Douglas World Cruisers, completed the epic flight—an event that was commemorated in a logo that has evolved over the years and contnues today as the symbol in the Boeing trademark.

In those early years, Douglas had success building mail planes, Army observation planes and amphibians, including the Dolphin that was so superior William Boeing bought one for his personal airplane.

Following those was the most famous Douglas airplane and one of the most famous airplanes of all time—the DC-3.

In 1933, Boeing had introduced the Model 247, the first modern airliner. Overnight, almost all other commercial planes were obsolete. To face this challenge, Douglas committed to build a better plane, and from the genius of Arthur Raymond and Dutch Kindelberger, who later headed his own company, North American Aviation, came the design for the DC-1. It led to the DC-3, the plane that launched an aviation dynasty and near monopoly of the commercial airliner market. By 1939, 93 percent of the air travel in the United States was on a Douglas airplane.

In 1940, with Europe at war, France and Britain came to Douglas Aircraft with orders for the DB-7, or A-20, light bomber, and with that the company began an unprecedented period of mass production in support of the war effort. Commercial production ended, DC-3s

Photos: (Far left, clockwise from top) The famous "Fly DC Jets" over the MD-80/90 final assembly line at the Douglas plant in Long Beach, Calif. BOEING ARCHIVES A DC-3 purchased by Texaco gets fueled on the ramp at the Douglas plant in Santa Monica. BOEING Launch of a Douglas Thor booster topped by an Agena upper stage—the Thor began as the United States' first land-based ballistic missile and evolved into the Delta rocket family still in use today; Family Day at the Douglas Long Beach plant in July 1944. (Below) Douglas A-4 Skyhawks of the U.S. Navy Blue Angels demonstration team fly in formation with a U.S. Air Force KC-10 Extender, a military derivative of the Douglas DC-10. BOEING ARCHIVES

and DC-4s were modified into military C-47s built in Long Beach and Oklahoma City, and C-54 transports built in Santa Monica, Calif., and Chicago, respectively. Douglas also manufactured SBD Dauntless dive bombers in El Segundo, Calif. B-17 Flying Fortresses were built to Boeing specifications in Long Beach. Consolidated B-24s and, later, A-26 Invaders were produced in Tulsa, Okla. In all, Douglas built 30,000 airplanes in five years.

More than just an airplane builder, Douglas Aircraft became a world leader in research and innovation, highlighted by the formation of Project RAND in October 1945, which later was spun off as a not-for-profit that continues today as the Rand Corp.

That same spirit of discovery and innovation continued across the company in programs such as the XB-43, America's first jet bomber, and high-speed research aircraft including the D-558-1 and -2, the latter the first aircraft to fly at twice the speed of sound, or Mach 2.

Following the war, Douglas built two of the finest carrier-based attack airplanes of modern times, the A-1 Skyraider and A-4 Skyhawk. Both were the designs of famed engineer Ed Heinemann, who was honored with the 1953 Collier Trophy for his pioneering supersonic carrier-based fighter, the F4D Skyray. Douglas, which had commanded the military transport market during the war by building 10,000 C-47s, continued that legacy with the Globemaster series, which included the C-74, C-124 and, 70 years later, the C-17 Globemaster III.

War-surplus C-47s and DC-3s served as the backbone of many of the world's postwar airlines. These soon were joined by the DC-4, DC-6 and DC-7, which, along with the Lockheed Constellation, dominated commercial air travel. When Boeing re-entered the commercial market with the 707 four-engine jetliner in 1958, Douglas remained a top contender with the DC-8 and later was the first to market with a small jetliner, the DC-9. When Boeing introduced the 747, Douglas quickly responded with the widebody DC-10 tri-jet.

In 1967, Douglas merged with McDonnell Aircraft, beginning the decline of the Douglas commercial business. The DC-10 proved to be the last all-new member of the DC family; all commercial airplanes going forward were derivatives, including the MD-80/90/95 series and MD-11.

While Douglas Aircraft is best-known for the DC airplane family, another important and enduring legacy is the company's development of rockets and its role in the exploration of space.

Douglas was an early leader in rocket and missile technology with the pioneering Thor missile and Delta booster, as well as the Nike missile, which served as the U.S. primary air defense system during the Cold War. Douglas also built the third stage of the Saturn V rocket that hurled Apollo spacecraft and U.S. astronauts on voyages to the moon.

Today, a Boeing-Lockheed alliance builds the Delta IV, which continues the Douglas family of rockets and will propel the Douglas legacy into the next generation of space travel. A modified Delta IV will be used as an interim upper stage of the Space Launch System, now in development by NASA, Boeing and others.

Even though the last airplane with Douglas roots has left the factory, it is a fitting tribute to Donald Douglas and his company that the Douglas legacy will, at least at the start, be part of a powerful new rocket that could one day send humans to Mars. ■

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Photo: First flown on May 16, 1946, the almost unknown XB-43 was an important milestone—the first U.S. jet-powered bomber. BOEING ARCHIVES

Growth takes off

With an all-Boeing fleet, Bolivia's national airline is experiencing tremendous growth

BY JIM PROULX

A new, modern and growing airline has risen in the Andes Mountains, and it is helping the people of Bolivia become more connected with one another and with the world—on the wings of Boeing airplanes.

Boliviana de Aviacion (BoA) began service in March 2009 with two leased 737-300s, connecting the Bolivian cities of Cochabamba, La Paz and Santa Cruz. By the end of that year, the airline was serving six destinations within Bolivia. The following year, BoA launched its first international routes, opening service to Buenos Aires in May and São Paulo in November.

In 2012, the airline launched its first routes outside South America, with service to Madrid and Miami.

Since its launch only six years ago, BoA has achieved extraordinary growth. The airline operated about 3,300 flights in 2009 and by 2014 was flying more than 23,000. It carried about 260,000 passengers in its first year, and more than 2.2 million in 2014.

With nearly full flights, the airline has an opportunity for further growth, according to Ronald Casso, the airline's CEO.

"Boliviana de Aviacion is dedicated to helping our country achieve success in the key elements of a national commercial aviation industry—safety, transparency, quality and strong management," Casso said. "BoA will contribute significantly to helping our country achieve its strategic targets and to the well-being of all Bolivians by offering high-quality, reliable air services."

Boliviana de Aviacion now operates an all-Boeing fleet of 18 airplanes, including 10 737 Classics, three Next-Generation 737-700s, two Next-Generation 737-800s and three 767-300ERs (Extended Range).

That fleet continues a 60-year relationship between Boeing and Bolivia, going back to Lloyd Aereo Boliviano's acquisition of C-47 and DC-3 airplanes in 1945 from Douglas Aircraft, a Boeing heritage company.

Casso explained that BoA launched with the help of the Bolivian government, which understands the strategic importance of commercial aviation in helping the nation and its 10.5 million inhabitants grow their economy and connection to the world.

BoA's growth shows its commitment to the people and economy of Bolivia, said Van Rex Gallard, vice president, Sales, Latin America, Africa & Caribbean, for Boeing Commercial Airplanes.

"BoA and Bolivians understand that growing commercial aviation and growing a nation's economy go hand in hand," Gallard said. "Commercial aviation and a growing economy feed one another. Every dollar that aviation directly brings to a country's gross domestic product generates four dollars more indirectly, and for every job directly created by aviation, there are seven more created indirectly.

"We take great pride in partnering with Boliviana de Aviacion," he added, "and we are dedicated to helping them grow with all of Bolivia for years to come." ■

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Illustration: Boliviana de Aviacion uses the Next-Generation 737 and other Boeing jetliners to connect Bolivian cities such as La Paz (shown) with the world. BOEING

The Mercury 6

Project Mercury engineers reflect on those early steps toward the moon

BY DAN RALEY

On Jan. 12, 1959, NASA selected McDonnell Aircraft to build America's first manned spacecraft for Project Mercury. Although the Soviet Union would send a man into space first, Project Mercury helped chart the course for the U.S. to land the first astronauts on the moon in July 1969. Six of the Project Mercury engineers with McDonnell recently spoke with *Frontiers* about those exciting and challenging early days of the space race, when humankind first ventured into a new frontier.

They were the engineers behind the scenes of Project Mercury, in the beginning mere 20-somethings barely out of college. There was no age limitation on winning the race to space.

They carpooled to work together, sometimes passing through the gates of Cape Canaveral Air Force Station in Florida with five people crammed inside a Volkswagen and drawing funny looks. From Hangar S to the blockhouse launch station, they encouraged and challenged the older and more celebrated seven Mercury astronauts.

Embracing a new frontier, Norm Beckel, Dean Purdy, Earl Robb, Jerry Roberts, Bob Schepp and Ray Tucker had to be extra creative as electrical and mechanical engineers for McDonnell Aircraft, the Boeing heritage company. It was rocket science that brought them together, and there was no precedent.

"We were doing something that had never been done before—and something that's not going to happen again," Roberts said.

Project Mercury was America's first pursuit of space travel—sending an astronaut into orbit around Earth and returning him safely to Earth, while learning as much as possible about this new and hostile environment of space.

McDonnell employed 300 engineers for Project Mercury in St. Louis and a similar number of people at Cape Canaveral. The team would build 20 Mercury space capsules in St. Louis. Two carried chimpanzees into space, two carried astronauts Alan Shepard and Gus Grissom on short suborbital flights, and four took astronauts into orbit, starting with John Glenn on Feb. 20, 1962.

Each Mercury astronaut named his capsule and added the numeral 7.

About five dozen of the Project Mercury engineers with McDonnell are alive today. They refer to themselves as Mac's Old Team, a salute to company founder James S. McDonnell. Among them are Beckel, Purdy, Robb, Roberts, Schepp and Tucker.

In 2011, these six men reconnected at the 50th anniversary celebration for Grissom's suborbital flight in his Liberty Bell 7 capsule, held in the late astronaut's Indiana hometown. Each of the former McDonnell engineers still lived in the St. Louis area and they formed another bond. They meet monthly now for lunch. They support a space museum south of the city. They regularly appear together on request to recount their careers, including one such event that the American Institute of Aeronautics and Astronautics held in early October at Boeing's St. Louis Building 100. They share matching journeys.

"Looking back, it was like the Flintstones," Tucker said of Project Mercury. "It was maddening, but we got the job done."

One by one, the engineers came to McDonnell from college, most of them to work on aircraft. Robb, the lone mechanical engineer among the six, helped build Model 119/220, a business jet originally intended to be a military plane. Demonstrating a rapidly changing aerospace world, this proved a landmark moment for him.

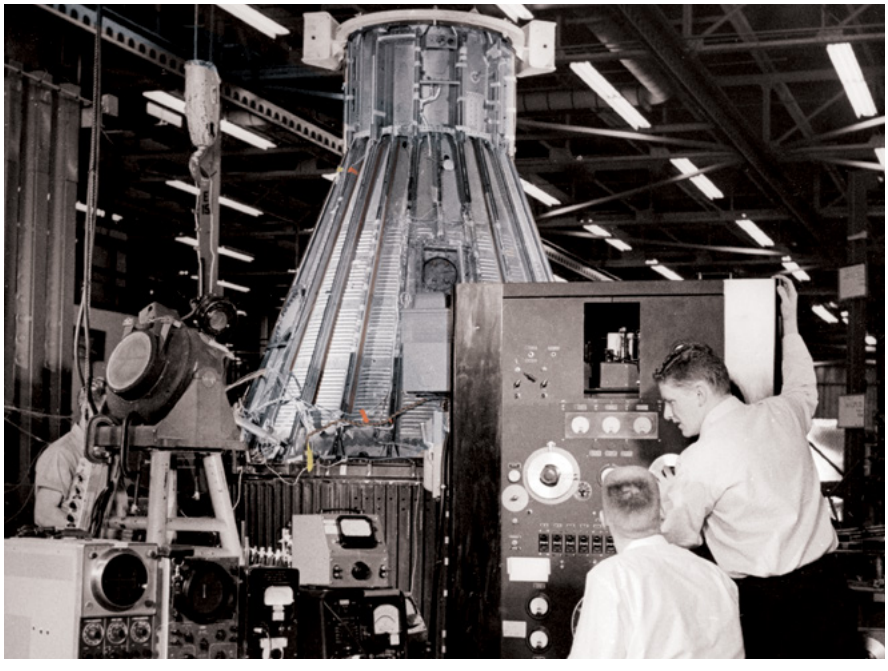
"The first jet I rode on was the one I worked on," Robb said.

When NASA selected McDonnell to build the country's first manned spacecraft, the company began recruiting engineers. Some were already working for McDonnell. The chosen engineers sometimes made their own test equipment, Roberts said. They pulled materials off the shelf and customized them. They

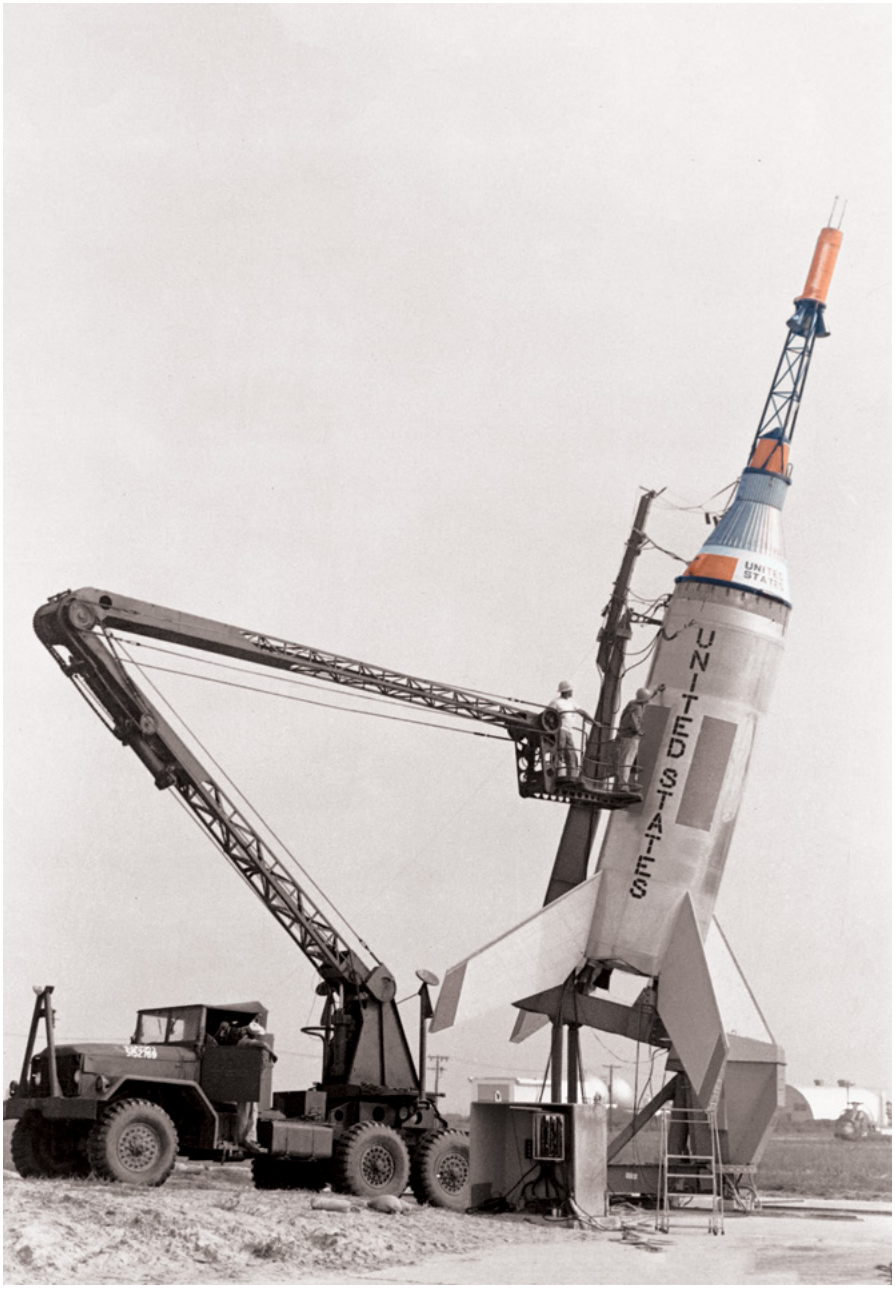
did what was needed in a hurry-up fashion, he said.

"I shake my head that we could send a man into space and bring him back with that technology," Roberts said. "We didn't have computers. We did it with slide rules."

McDonnell engineers initially expected they would produce space capsules in St. Louis and follow them to Cape Canaveral, where they would hand off operations to newly



Photos: (Above) Former Mercury Project engineers, clockwise from top left, Jerry Roberts, Norm Beckel, Dean Purdy, Ray Tucker, Bob Schepp and Earl Robb, in the Prologue Room in St. Louis. RICH RAU | BOEING (Right) McDonnell engineers perform tests on a Mercury capsule. BOEING



hired NASA personnel, according to Roberts. However, NASA needed their expertise well past that point, bringing a sudden change in assignments.

The St. Louis engineers were supposed to spend nine months in Florida. Many ended up staying several years, raising their families there as the space program evolved.

"I had a Mercury little girl and a Gemini little boy," Roberts said.

Project Gemini followed Mercury. McDonnell also built the two-person Gemini space capsule.

Among their many Cape Canaveral duties, Beckel dealt with communications systems, Tucker oversaw cabling from the blockhouse to the launchpad, and Schepp and Roberts were involved with autopilot needs. Meanwhile, Robb and Purdy flew back and forth from St. Louis, Robb working on structural aspects of the spacecraft and Purdy on electrical circuits and wiring.

"It was a very exciting time and I never had a problem getting up and going to work," Purdy said.

The engineers and astronauts sometimes entered into serious debate over how things should be handled inside the spacecraft. Dissatisfied with a handrail, Grissom made sure that Robb put on an astronaut pressure suit in order to see his point, Robb recalled.

Astronaut John Glenn strongly urged Schepp and his colleagues to make a significant change to the autopilot system. The Mercury capsule had been designed to only fly backward, putting the heat shield first for safety reasons. Glenn and the other astronauts wanted the ability to travel forward in order to see where they were headed. After much discussion, Schepp said, the engineering team installed a new switch to accommodate their request.

During his Mercury flight that made three orbits around Earth, Glenn

experienced the capsule tilt sharply against its vertical reference to Earth, a pitch gyro, as he tried to go forward. Convinced the autopilot had malfunctioned, he flew the spacecraft manually the rest of the way. Later in a training simulator, Schepp said, he gently demonstrated to the astronaut what had happened: Glenn had failed to deploy the new switch. The autopilot worked just fine.

"He admitted to that," Schepp said with a smile. "Biggest day of my life."

The engineers said they worked long and hard hours, as many as 18 a day. Tucker said he once spent 37 consecutive hours making sure cables were properly connected from the blockhouse to a Redstone rocket. They couldn't go home until a problem was fully explained and resolved. Any mishaps might set the program back months, or even years, Tucker explained.

The demanding pace was worth it. Many of the engineers worked on the ensuing manned space projects, such as Gemini, Sky Lab, Manned Orbiting Laboratory, Space Shuttle and the International Space Station. Some of them turned to missile projects such as Tomahawk and Harpoon. The six Mercury engineers said they felt as responsible as anyone for getting the American space program up and running and catching the Soviet Union and winning the space race.

"End of story, we got a man on the moon," Beckel said. "They still haven't been able to do that."

The Mercury engineers worked in relative anonymity as the astronauts became storied figures who were later depicted in films and documented in countless books. However, Glenn made sure to thank them publicly—in 2012 at a Florida celebration for retired Project Mercury employees, one titled "On the Shoulders of Giants." His gesture, Roberts said, was deeply appreciated.

"John pointed at us and said, 'You guys are the giants. You are the celebrities. You had our backs,'" Roberts said. "It was the first time I had heard an astronaut say that. It was very emotional. I will never forget that moment."

The six engineers have differing opinions on what might come next for space travel: Direct flights to Mars or missions to Mars via the moon? Will it be in the 2020s or 2030s? Because of their experiences, they couldn't guess at how it might be accomplished. They had dream jobs, the engineers said, but they realize that dreams only go so far.

"When I came into the industry and hired on in 1958, do you think I could have envisioned having something like this iPhone?" Beckel said, holding up his mobile device. "Twenty to 30 years from now, what's the next step going to be? We have no concept. The breakthrough will come from the experiences in the lab.

"These iPhones will be obsolete then—and I just learned how to use mine."

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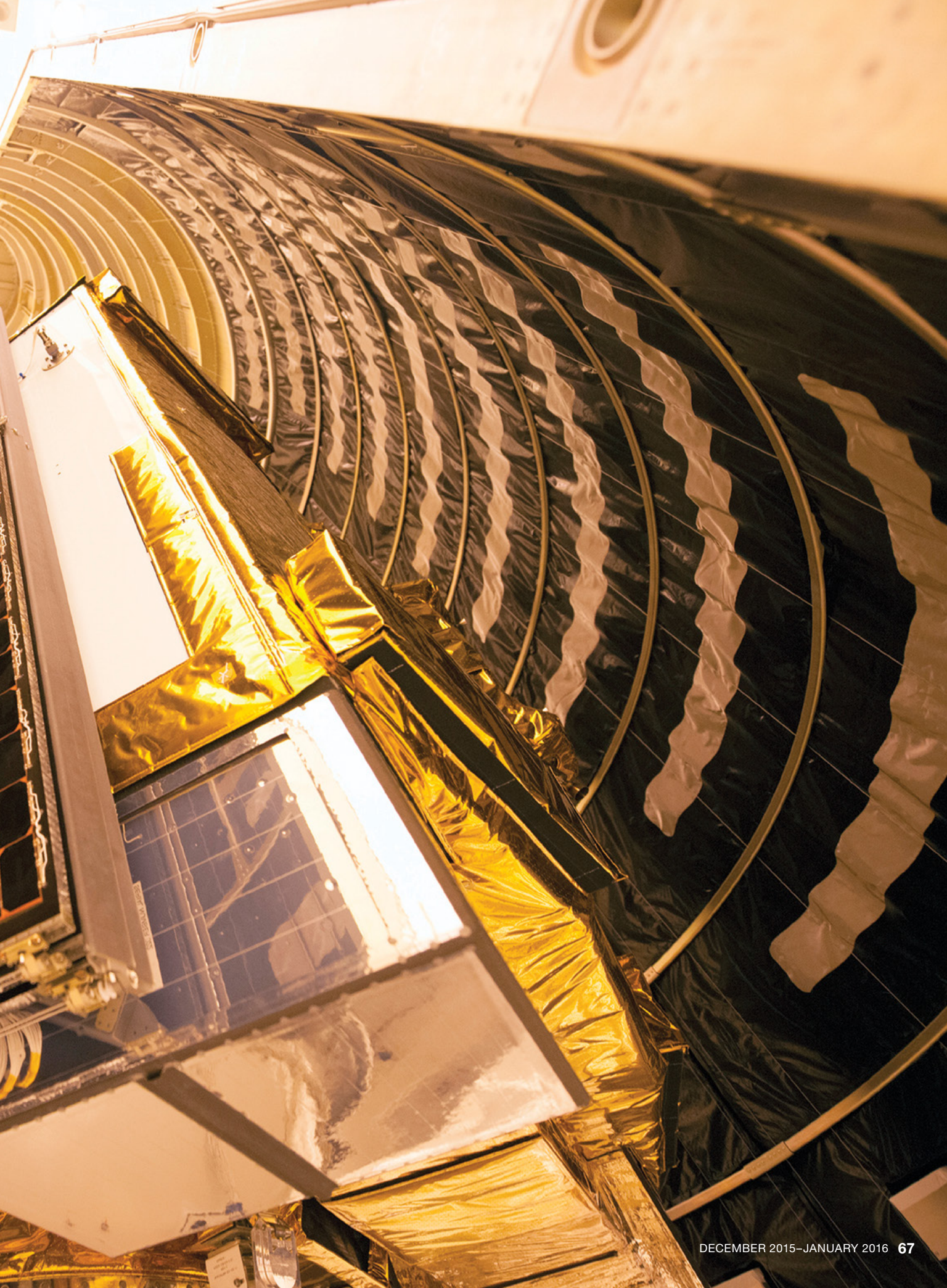
Photos: (Far left) Technicians position the NASA-designed "Little Joe" booster rocket with a Mercury capsule and escape rocket motor on top. The booster provided valuable test-flight data for the Mercury program. (Above) McDonnell workers assemble Mercury capsules in a St. Louis white room designed to keep the capsules free of contaminants and other debris. BOEING

MILESTONES

Golden eye

The 11th Boeing-built GPS IIF satellite undergoes encapsulation inside a 14-foot-wide (4-meter) payload fairing prior to its successful launch Oct. 31 on a United Launch Alliance Atlas V booster from Cape Canaveral Air Force Station in Florida. Built by Boeing in El Segundo, Calif., the satellite advances the U.S. Air Force's modernization program for the Global Positioning System, improving accuracy and enhancing security for the navigation satellite network used daily by billions of people around the world. United Launch Alliance is a partnership between Boeing and Lockheed. PHOTO: UNITED LAUNCH ALLIANCE



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