

# Innovation Quarterly

2018 February  
Volume 2, Issue 7

## Creative Notes

Improvisation at the heart  
of engineering success

## Ocean Robot

Ready for rough seas

## Beyond Our Horizon

Accelerating the pace  
of change

A publication of The Boeing Company

# Innovation Quarterly

2018 February | Volume 2 | Issue 7  
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## **ON THE COVER**

Matt Harris is a Boeing Associate  
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development in the field of avionics.  
He is based in Everett, Washington.

PHOTOGRAPHY BY PAUL PINNER

## Featured

### **6 | A rough and ready robot**

Designing an ocean robot to autonomously collect data from the deep ocean for months at a time, while acoustically communicating in real time from the seabed to space, is a challenge in itself. Now try designing one to operate in extreme polar sea conditions. That's exactly what Liquid Robotics has done with its next generation Wave Glider.

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A year ago, Boeing launched a strategic investment program designed to keep pace with breakthrough technologies across a variety of sectors. Boeing HorizonX identifies, partners with, and offers capital funding to promising startup companies.

### **22 | Jazzed up about the future of flying**

To an engineer like Matt Harris, inventing an elegant solution to a technical problem can be a lot like innovating a fine piece of music. Improvisation on a melody, like manipulating the laws of physics, takes intellectual curiosity and creativity, as well as a lot of tinkering in the basement.

## Technical Papers

### **28 | Ubiquitous Broadband Communications and the Development of Boeing Phased Arrays**

Before the internet revolution and with the development of smart devices, the dream of many in industry, academia and the government was of a global information grid or the networked "Internet-of-Things"—wirelessly linked anywhere, anytime, securely connected with enough bandwidth to support live entertainment and a variety of streaming services. The complexity of this ongoing challenge requires many pieces of key technology and large infrastructure of critical assets. This paper describes the enabler for this or any other mobile communications and networking system—the phased-array antennas developed by Boeing—to make ubiquitous broadband connectivity a reality.

### **33 | A History of Boeing Commercial Transport Flight Deck Lighting and Display Optics Innovation**

The past three decades have produced much-needed innovation and advances in aircraft lighting technologies, including the implementation of solid-state lighting and display optics into the flight deck. This progress is capping a 100-year technology evolution that began with electromechanical gauges and incandescent bulbs. Improvements over a century have resulted in significant benefit to airplane customers and their pilots.



# Disrupting how we innovate

You hear a lot of talk these days about innovation and disruption. Being a “disruptor” has become a buzzword in business. But it is happening all around us. Through disruption, an innovative product, service or business model creates a new market that upends an industry’s existing structure—delivering a new product or service in a new way that totally changes the way things have been done before.

Disruption is happening actively in industries such as lodging, transportation and on-demand entertainment—and, closer to home, space launches.

At Boeing, we welcome these disruptors to aerospace because competition has always driven our industry forward. But if we are to win in this new marketplace, we have to disrupt ourselves.

This edition of IQ explores our efforts in internal disruption, like a look at our HorizonX team, which considers emerging business models or strategies that can disrupt aerospace, as well as for partners or markets that can create new business opportunities for Boeing. HorizonX colleagues were part of a cross-Boeing team that recently unveiled a cargo unmanned air vehicle prototype.

The edition also includes reports from some of our subsidiary companies, including Liquid Robotics, which offers the Wave Glider unmanned surface vehicle that runs completely off of renewable energies (wave and solar power).

Boeing was once a startup, and as we enter our second century, we are going to act like a startup again as we embrace the challenge of disruption and continue changing the world. **IQ**

**GREG HYSLOP**

Boeing Chief Technology Officer  
Senior Vice President, Engineering, Test & Technology

## Recognizing Advanced Developments and Research

# Technology RADAR



### 3D Printed Wireless Sensors Without Electronics

#### LOCATION

Seattle, Washington

#### PROJECT URL

[printedwifi.cs.washington.edu](http://printedwifi.cs.washington.edu)

#### MESSAGE

University of Washington electrical engineers and computer scientists have developed 3D printed objects that can communicate over Wi-Fi using mechanical and backscatter techniques in lieu of electronic components.



### Atomically Sharp Tweezers

#### LOCATION

Minneapolis, Minnesota

#### PROJECT URL

[experts.umn.edu](http://experts.umn.edu)

#### MESSAGE

Researchers at the University of Minnesota College of Science and Engineering have developed graphene tweezers that are sharp and sensitive enough to feel and grasp nanometer-scale biomolecules.



### Thermochromic Windows

#### LOCATION

Golden, Colorado

#### PROJECT URL

[nrel.gov](http://nrel.gov)

#### MESSAGE

The National Renewable Energy Laboratory has created windows using advanced materials (such as perovskites and single-walled carbon nanotubes) that capture electricity from sunlight while self-tinting.



### Simulating Quantum Magnetism

#### LOCATION

Cambridge, Massachusetts,  
and College Park, Maryland

#### PROJECT URL

[nature.com](http://nature.com)

#### MESSAGE

Quantum computers at Harvard University and the University of Maryland have demonstrated their power by simulating quantum magnetism at the 50-atom scale, which is far more complex than the capability of conventional computers.

People working in Boeing's Technology Intelligence and Trends community of practice are human sensors in the world of science and technology. We make it our business to watch for innovations in practice, new business models and new ways of thinking. Here's a peek at a few signals on the screen.



### Circuits in Fabric

**LOCATION**

Cambridge, United Kingdom

**PROJECT URL**[cam.ac.uk](http://cam.ac.uk)**MESSAGE**

Researchers at the University of Cambridge, working with Italian and Chinese colleagues, have incorporated electronic circuits into washable, wearable fabric. The circuits can be printed with conventional inkjets.



### Self-Healing Automobile

**LOCATION**

Bologna, Italy

**PROJECT URL**[lamborghini.com](http://lamborghini.com)**MESSAGE**

The Lamborghini Terzo Millennio can detect and repair cracks in its own body.



### Living Portraits

**LOCATION**

Tel Aviv, Israel

**PROJECT URL**[english.tau.ac.il](http://english.tau.ac.il)**MESSAGE**

Tel Aviv University computer scientists, in partnership with researchers from Facebook, have developed a method that automatically generates emotionally expressive photo-realistic videos from still photo portraits.



### Monitoring Volcanos from Space

**LOCATION**

Aluto volcano, Ethiopia

**PROJECT URL**[riftvolc.geos.ed.ac.uk](http://riftvolc.geos.ed.ac.uk)**MESSAGE**

RiftVolc, a consortium of Ethiopian and UK universities, has used satellite radar techniques to monitor geothermal activity in the Great Rift Valley.

# In for a **rough ride**

## **Designing unmanned surface vehicles for sea states 6+**

**BY TIM ONG, VICE PRESIDENT OF ENGINEERING  
LIQUID ROBOTICS, A BOEING COMPANY**

### **Call it an ocean robot.**

Specifically, it's the Wave Glider from Liquid Robotics, an unmanned surface vehicle (USV) and part of Boeing's autonomous systems technology portfolio.

This ocean robot runs 100 percent on renewable energies—wave and solar power. Without the need for refueling, the Wave Glider is able to stay at sea for many months at a time collecting and transmitting data from across the globe and from the seafloor to space.

The Wave Glider has a unique two-part system with a float on the surface of the ocean connected to a "sub" or wing rack 8 meters (26 feet) below via an umbilical. This two-part system converts the up and down motion of the waves into forward propulsion. No fuel required, no engine noise or emissions produced.

Onboard communications, computing and sensor payloads are powered by solar energy. Through underwater acoustic communications it acts as a communications router for subsea sensors and vehicles relaying data in real time

from the seabed to space. Fleets of Wave Gliders can operate autonomously or more directly through remote piloting depending on mission requirements.

With over 1.4 million miles at sea—which roughly equates to 65 times around the Earth—and a Guinness World Record for the "longest journey by an unmanned autonomous surface vehicle on the planet," Wave Gliders have covered a lot of the world's ocean. From listening for submarines or illegal fishing vessels, or helping scientists better understand the weather and the environment, the Wave Glider is recognized as the industry's most proven unmanned surface vehicle.

Wave Gliders have covered a lot of the world's ocean, but even with this extensive experience, customers are asking for more capabilities. Their missions require





We had the mantle to go big or go home. We weren't going home.

**ROUGH WINTER**

Testing the Wave Glider in the North Atlantic.

PHOTO: LIQUID ROBOTICS

persistent operations in the most northern and southern high latitudes in the early winter months. During this time, the conditions, as measured against the WMO (World Meteorological Organization), reach sea states 7, 8, and even 9. These seas have significant wave heights exceeding 14 meters (46 feet) and in some cases, with random or rogue waves being encountered, this wave height can be doubled. For perspective, 14 meters is equal to the average height of a four-story building. These are conditions so severe that no sailor would willingly enter.

With this as backdrop, my mechanical engineering team was empowered to take on the task of designing the

next generation Wave Glider that could operate reliably in these high sea states. We had the mantle to go big or go home. We weren't going home.

Think of the challenge to design an ocean robot that must autonomously collect data from the deep ocean, stay at sea for many months and communicate in real time from the seabed to space. Add operating in corrosive salt water to this, and do all of it safely and sustainably with no harm to the ocean. Raise the bar even further to achieve this in extreme sea states (WMO 6+) for missions in the highest latitudes on the planet (Arctic and Antarctica).

The Wave Glider is recognized as the industry's most proven unmanned surface vehicle.



This engineering task was monumental. One of our biggest issues was a void of existing data on the actual mechanical loads. Our goal was to enhance our core Wave Glider platform for extreme conditions and for environmental loads that were unknown. We needed to design for an environment that's so inhospitable there is no data characterizing the operating conditions. We had to think of the worst corner case and double it. My team had to consider the most remote possibilities and design for it.

As we began the planning for our initial prototype testing, we enlisted the help of Eric Terrill, director of Coastal Observing Research and Development Center Research at the Scripps Institution of Oceanography, an expert in extreme sea states. Together, the Liquid Robotics engineering and mission operations teams joined Terrill to test our prototypes offshore of Iceland. As noted, in the winter, the ocean conditions are incredible—producing continuous sea states of 8 and 9.

In our early testing, we learned what it truly means to be at the mercy of the ocean. The extreme force and continuous pounding waves resulted in bent wing spines and tubes (part of the sub). These problems were easier to fix. It was a straightforward mechanical engineering task to strengthen key structural components of the sub; however, other elements were much more difficult.

One of the most difficult problems to solve was to achieve the proper glide dynamics of the sub. The sub, or “glider,” uses the forces caused by the float rising and falling with the waves to produce a thrust vector forward. With such chaotic and volatile sea states, waves can come in sets causing the sub to pitch to extreme angles due to differentials in wing lift. The sub would actually stall and once in this condition, the vehicle was very unstable and able to entangle with the umbilical. Tank testing, video capture, brainstorming, and lots of hard work to build prototypes quickly led to a design that would consistently glide properly.

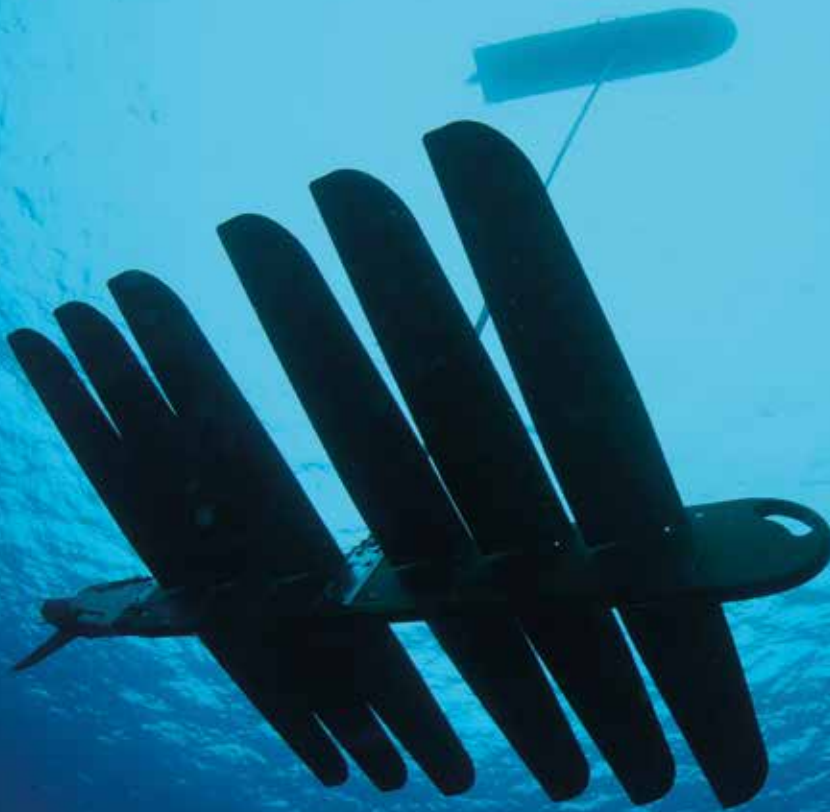
Keep in mind, we're trouble-shooting an entire system that includes mechanical, electrical and communications components, as well as onboard and towed sensor payloads. This combination makes for a sophisticated data and communications platform that needs to perform in significant wave heights reaching in excess of 10 meters (33 feet).

We collected a massive amount of data, including hours of video, which provided us with significant insight into the operational environment and the unique stresses it placed on the vehicles. (A video of the extreme sea state testing, “Wave Glider in High Sea States” can be found at [liquid-robotics.com](http://liquid-robotics.com).)

From our prototype testing and with a lot of engineering elbow grease, the result was our next generation Wave Glider. The platform was fortified and strengthened to battle the pounding forces of seas in excess of WMO 6. To achieve this, we made the following engineering enhancements:

- Increased the strength and glide performance of the sub. The result was twofold: increased glide stability in high sea states; and more robust spine to take the continuous battering from heavy seas.






#### CONVERTING WAVE MOTION

Wave energy is greatest at the water's surface, decreasing rapidly with increasing depth. The Wave Glider's two-part architecture exploits this difference in energy to provide forward propulsion.

- New navigation for high latitudes and wave states. To operate through the high sea states the Wave Glider must travel back and forth to manage the oncoming waves. Filtering out the platform's activity improves navigation while conserving power. Both are critical as you near the polar North.
- Increased float payload capacity by 30 percent by incorporating novel buoyancy additions.
- Applied anti-biofouling enhancements with new coatings.

The reality is that no vessel is indestructible to the harsh and unpredictable ocean. This is especially true in high latitudes during the winter months. As Terrill told us, this is "ongoing evolution to tackle the planet's most harsh oceanic environment."

The next generation Wave Glider is being deployed in the defense and commercial markets. With this additional high-sea-state and high-latitude capability, Wave Gliders will help customers explore and secure regions of the ocean that have been off limits because of the danger, cost and risk of traditional surveillance and exploration. They will serve as a tool for navies to provide persistent maritime surveillance. As Terrill is demonstrating, they will help scientists observe the conditions of Antarctica. 

Liquid Robotics is often described as a place where rocket science meets marine science. Whether airplane designers or electrical engineers, oceanographers or cloud computing software experts, the team comes together to design the best long duration ocean robot on the planet.

When you put this diverse group of thinkers together and empower them to create products that make a difference in the world, some interesting and challenging problems can be solved. Core to who we are is this freedom and commitment to thinking big and trying new designs without fear of failing.

Always learning from new deployments, Liquid Robotics continues to help our customers solve big problems. Our company culture gives us the freedom to try new things, learn and adapt quickly. This helps us to improve our product, push limits and deliver an autonomous system that has a chance to change the world.

-TIM ONG

# Cyber war games for another kind of digital theater

**To effectively address threats to the defense industry,  
cyber warriors prepare for battle.**

**BY AL LEWIS, CYBER INTELLIGENCE AND ANALYSIS MANAGER  
BOEING INFORMATION SECURITY**

Cyberspace is so large that it has become not only its own ecosystem but its own battlespace, as well.

To help position companies against cyber-attacks and practice preparedness, Boeing conducted the inaugural Defense Industry Cyber War Game in August 2017. The exercise, which was the first of its kind, provided an opportunity to examine and address a large number of different cyber-attack methods that can occur simultaneously and, if left unchecked, accelerate out of control.

Boeing led and hosted the exercise, which featured participants from BAE Systems, Lockheed Martin, Northrop Grumman and Raytheon, all of whom are members of the U.S. Defense Industrial Base.

Members of these companies work in the same fast-paced, chaotic, and continual cybersecurity attack environment as our government and military customers. Through the exercise, participants were able to engage in a cyber-based drill designed to test and validate their company's ability to successfully respond to a cyber-attack. It also tested their respective abilities to share information effectively and quickly, both internally and externally.

The companies and players were placed on a joint defense program, working in a shared collaboration space. These conditions debunked the myth that incident response is driven exclusively by technicians, and showed the broader group of stakeholders engaged in the incident resolution, including board of directors, chief information security officers, and legal and communications representatives.

The exercise also challenged conventional lines of authority, as the adversary leveraged four different attack vectors, crossed organizational hierarchies, and incorporated simultaneous

events, actions and requests. This operational cadence encouraged proactive communication as the best method to spread awareness of the threat and how to combat against it.

The day-long exercise, comprising two scenarios modeled after real-world events, encompassed both large-scale ransomware and destructive attacks. The adversaries were indicative of today's nation-state-sponsored actors, and were characterized as highly capable, motivated and intent on achieving military parity with the United States through a combination of economic and intellectual property espionage. The adversaries were also seeking to reduce the United States' ability to produce and deploy key technologies through destructive attacks.

The methodologies employed by the threat actors were aligned to real-world trends and had deployments both through cyber and physical means, including spear phishing, compromising a downstream supplier, infecting an update patch, and theft of sensitive printed documents.

The adversaries attempted to gain access by leveraging an insider with access to the shared lab environment, and through various hacking techniques to gain remote access. This combination of internal and external attack vectors highlighted the necessity for awareness across

organizational and traditionally defined boundaries. Similarly, the ability to maintain persistence and use diversionary tactics was employed as a means to induce stress and add complexity to the scenario while maintaining realism.

Adding to the realism, the exercise was modeled on the current geopolitical environment. Escalating tensions surrounding the deployment of missile defense capabilities provided not only foreshadowing for impending retaliatory actions, but set the stage for collusion among various nations—a concern among all critical infrastructure sectors.

A vigorous information campaign ensued that sought to draw out potential threats, forcing intelligence teams to analyze the significance of these communications within the context of their respective organizations, as well as provide a basis for organizational messaging and operational decision-making. Additionally, as social media and news reporting gained momentum surrounding the potential incidents, customer queries began to mount, introducing another level of complexity into the scenario.

The findings from the Cyber War Game illustrated many positive trends, chiefly the strong understanding of the technical steps needed to investigate and respond to a cyber-security incident.

Each organization recognized and embraced the need to adhere to defined processes and procedures. Additionally, the participating companies had incident response playbooks that formalized their approach, enabling a common understanding of community best practices.

Future focus on executive-level response planning was emphasized by the companies, as was the integration of all physical and cybersecurity data to reduce response times. The war game exercise truly illustrated the importance of understanding when to report an incident and how this can reduce liability. It also showed that collaborating enables priorities to be set and reduces confusion across the board. **IQ**

Cyberspace is so large  
that it has become not only its  
own ecosystem but its own  
battlespace, as well.

ILLUSTRATION: BOEING



# Peter Kunz

talks the virtues of  
innovation and bringing  
flight closer to home

## By thinking differently about problems and the possible solutions, Boeing's broad experience and expertise is positioned to enable rapid innovation and disruption in aerospace.

BY WILL WILSON, BOEING WRITER | PHOTOGRAPHY BY DARIN HARTLIEB

**Q&A** with  
Peter Kunz, Boeing  
HorizonX chief  
technologist, on  
creating a culture of  
problem-solving

**Q**

### How do you define innovation?

**A**

We define innovation as delivering what really matters for customers. It is more than coming up with ideas; it is about finding new solutions to existing and future problems.

Try telling someone to 'go be innovative,' and see what happens. We don't want to sacrifice utility and value for the customer for a vague notion of technical awesomeness as the metric of innovation.

A solution can often seem simple, if only at the surface. There's an elegance that sometimes belies the technical complexity—but what matters is creating significant, positive change.

**Q**

### So how do you spur innovation?

**A**

As much as we often lean on technology, I see innovation as a byproduct of culture. Innovation comes from how we think about a problem, dissect it, and attack it in ways we have not thought of before.

We innovate most successfully when every individual believes they have a role in creatively solving high-value problems. That encourages the expression of ideas and a diversity of thought that helps us achieve our end goal as a team.

When we bring a team together, all ideas are welcome, even if you're not the expert. We're seeking solutions, and technical expertise is only a piece of that.

“ I’m a fan of making small bets and taking small risks in the journey to finding the big win. ”

**PETER KUNZ**

#### **VERTICAL TAKEOFF**

Kunz recently assembled a team of diverse technical experts in St. Louis to rapidly prototype a cargo unmanned aerial vehicle and fly it.



**Q**

**That’s easy to say. How can you create that culture?**

**A**

A simpler way to say it is that we should strive for a learning culture—one that maximizes opportunity to gain knowledge about the work we do and the solutions we’re trying to deliver. That’s part of what knowledge sharing really means. What are we working on? What are we trying to achieve? What are the challenges we need to overcome? The more we experience and the more ideas we have, the stronger they become.

This also means falling down more. I’m a fan of making small bets and taking small risks in the journey to finding the big win.

This does not mean prioritizing learning over risk—we don’t celebrate recklessness—but it does mean proactively managing risk, more from a consequence side than a likelihood side, to make it safe to learn more, and learn faster.

**Q**

**What is HorizonX’s role within Boeing?**

**A**

As a driver of Boeing’s growth and innovation, Boeing HorizonX is investing in and partnering with other businesses—from startups to corporations—to accelerate our capacity toward delivering innovative solutions. In doing so, we’re also helping to accelerate that culture of innovation—leaps forward compounded by our existing internal innovation efforts, especially with respect to emerging technologies and technology enablers like autonomy, AI, electric/hybrid-electric propulsion, advanced materials and production technologies.

These connections also build on our diversity of thought: more diversity from our investments and collaboration with startup ecosystems around the world. That then connects across Boeing when we have the opportunity to create within Boeing through these partnerships and investments.



Q

**Can you give me a concrete example of an innovative application of these technologies that will change how we live and work?**

A

We fast-tracked the development of a new electric vertical-takeoff-and-landing (eVTOL) cargo unmanned air vehicle (CAV) prototype. I say “we” because it was a real collaboration of Boeing HorizonX and our teammates in Boeing Research & Technology, Boeing Commercial Airplanes and Boeing Defense, Space & Security—designing and building the CAV prototype in less than three months.

We blended electric propulsion with Boeing custom-designed batteries, vertical takeoff and landing capabilities, and unmanned systems technologies in a multi-copter envisioned to carry up to 500 pounds over land and sea.

The CAV prototype successfully completed initial flight tests inside Boeing’s Collaborative Autonomous Systems Laboratory in Missouri.

We are using it as a test bed to drive the future of autonomous air travel and transport. It will open up new possibilities for the delivery of time-

sensitive and high-value goods, autonomously, and in remote or dangerous environments, and enable many other cargo and logistics applications.

What was amazing to me as a technologist was seeing it go from a concept on paper to prototype so rapidly. Within Boeing, we’ve got the resources and technical acumen to integrate these new technologies into our core competencies and lead the way in emerging markets.

Q

**What else is on the horizon?**

A

Our vision is to bring flight closer to home—more connected transport and travel—and to make flight simpler. I feel like we’re at this moment of convergence, from artificial intelligence to advanced materials and manufacturing to alternative energy. The opportunities and technologies are meeting at the same time, and we are poised to take advantage and lead. **IQ**

# Seeing beyond the horizon

**By investigating and investing in promising technologies, Boeing looks to disrupt the industry, and itself.**

BY DAN RALEY, BOEING WRITER

Men outfitted in jetpacks soar above the desert in the United Arab Emirates. In this popular YouTube video, they circle Dubai's tallest buildings and even fly in formation alongside the wings of a low-altitude jetliner approaching the city, providing matching contrails.

Daring examples like this demonstrate the next wave of aerospace technology advancing across the global landscape. It includes autonomous air vehicles, augmented reality and electric propulsion—a wave of bold ideas pointing to remarkable change.

Peter Kunz, chief technologist for Boeing HorizonX, likens this moment to one 50 years ago, where advancements in software and computer science brought a new world order to technology, spurring business development, investment and ultimately an industrial revolution.

"You're seeing a penetration and acceptance of technology from a much broader segment of society than you saw in the past," Kunz said. "There's an excitement that new things are coming."

To harness the power of these emerging technologies, Boeing launched HorizonX to invest in startup companies, forge nontraditional partnerships and assess aerospace industry disruption.

"This team strengthens our ability to innovate, compete and win, and change the world," said Greg Hyslop, Boeing chief technology officer. "Our Boeing HorizonX colleagues augment our own ability to innovate by looking for emerging business models or strategies that can disrupt aerospace, as well as for partners or markets that can open new opportunities for Boeing."

Formed in April 2017, Boeing HorizonX takes a highly aggressive approach in singling out projects for venture capital investment—in its first 10 months, the group of nearly 40 employees evaluated 1,800 opportunities and invested in eight companies. Boeing has a particular interest in moving forward with autonomous vehicles, additive manufacturing, machine learning and wearable devices, said Steve

## INVESTMENT EMPHASES

All the ways the game is changing.



### DISRUPTIVE COMMERCIAL MOBILITY

Innovative space, air, ground, and maritime solutions to move people and goods.



### AUTONOMOUS SYSTEMS

Safe and secure autonomy through the strength of multiple disciplines.



### ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Advanced computing and algorithms.



“You’re seeing a penetration and acceptance of technology from a much broader segment of society than you saw in the past. There’s an excitement that new things are coming.”

PHOTO: GETTY

**PETER KUNZ, CHIEF TECHNOLOGIST FOR BOEING HORIZONX**

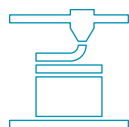
Nordlund, Boeing HorizonX vice president.

HorizonX operates under the guise of creating technological disruption rather than being disrupted by it. This requires a new way of thinking about innovation, which this new organization has fully embraced, explained Logan Jones, senior director within the group.

“People often miss the disruption because they define things in ways that experience has taught them,”

Jones said. “It might be a perfect way to look at the past, but it is not a predictor of the future. We’ve been very broad. We’ve been purposefully nebulous in how we define focus areas. We want to open the aperture.”

HorizonX operates three related missions: Boeing HorizonX Ventures, which identifies startup opportunities and provides investment; New Business Horizons, which builds strategies with nontraditional partners; and Disruptive



**ADVANCED MANUFACTURING AND MATERIALS**

Stronger, lighter products made more efficiently.



**SPACE**

Products and services that bring the awe of what lies beyond our atmosphere a little closer.



**ADVANCED LOGISTICS**

Enhanced product life-cycle experience.



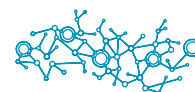
**CYBERSECURITY**

Cyberthreat protection for our products.



**INDUSTRIAL INTERNET OF THINGS**

Sensors, effectors, and edge computing for industrial applications.



**CONNECTIVITY**

The world connected with faster and higher bandwidth capabilities.

Horizons, which supplies alternative approaches to traditional business opportunities.

“Part of this group’s purview and vision is to look at all of the supporting elements— aerospace in general,” Kunz said. “We’re one of the few tech industries tied to an end product as opposed to specific technology.”

Digital advances seem to be driving this latest era of innovation, which could transform air travel and space exploration, if not transform the overall quality of life and human interaction. This potential is attracting funders. Since 2000, new investors have put \$13 billion into space startups, according to The Tauri Group, an industrial consulting firm. By all signs, other areas of aviation stand to benefit next from forward-thinking financial support.


“We see the big explosion from the investment in space startups,” said Ben Iannotta, editor-in-chief for Aerospace America, the magazine of the American Institute of Aeronautics and Astronautics. But “when we look at aviation and see all the great challenges—of getting people into less-developed countries, traveling on aircraft, tracking aircraft, improving safety by beaming cockpit audio and video to the ground—are we on the cusp of seeing a similar trend?” 

PHOTO: C360 TECHNOLOGIES



# Innovation put to action

**Here are some examples of how Boeing HorizonX is helping to upend traditional aerospace models:**

## Expanding autonomy capabilities

As autonomy continues to evolve and becomes mainstream, Boeing is identifying, funding and developing unmanned technologies with the potential to provide aerospace innovation. Examples of Boeing HorizonX Ventures investments include:

- Near Earth Autonomy, from Pittsburgh, enables aircraft to inspect, map and survey terrain and infrastructure, as well as transport cargo, all autonomously. It currently provides autonomous systems that are operated by Insitu and Aurora Flight Sciences, both Boeing subsidiaries.
- C360 Technologies, another Pittsburgh startup, specializes in 360-degree, high-density video and distribution. This includes live and on-demand augmented and virtual reality on multiple platforms to support autonomous systems.
- Texas-based SparkCognition focuses on artificial intelligence and machine learning in the fields of information technology security and industrial operations. It analyzes the impact that artificial intelligence will have on the aviation sector. Possible applications include autonomous vehicle behaviors focused on leveraging AI to assist or automate pilot decisions.

**C360 TECHNOLOGIES’** immersive video has been used by professional sports broadcasters and major television networks.



### ELECTRIFYING

Zunum Aero's vision is electric-hybrid aircraft powering faster regional travel.

PHOTO: ZUNUM AERO

## Improving manufacturing

Boeing has invested in Gamma Alloys, a company in Valencia, California, that pursues breakthroughs in nano-reinforced aluminum alloys for greater strength and improved wear resistance across a wider range of temperatures. Boeing spotted an opportunity in Gamma Alloys to further reduce the weight of its products. Upskill, another startup receiving investment, makes software for augmented reality eyewear. The products by the Washington, D.C., company can enhance productivity, quality and safety in manufacturing, field service and logistics.

## Incubating and accelerating startups

Moving forward, HorizonX will continue to host open-pitch competitions that encourage smaller companies to present innovative ideas and pursue venture capital investment from Boeing. These events enable Boeing to forge commercial agreements with startups and offer them visibility with a wide variety of business lines and customers, as well as establish connections with Boeing's vast network.

The Boeing HorizonX India Innovation Challenge 1.0, launched in November 2017, is aimed at energizing aerospace innovation in India's startup ecosystem. Finalists will receive funding to participate in a three-month accelerator program at T-Hub, one of the largest startup ecosystem builders in India.

## Supporting a more connected world

Zunum Aero, another Boeing HorizonX Ventures portfolio company, is developing alternative propulsion systems with the potential for performance and efficiency improvements in a range of aerospace applications. Based in Kirkland, Washington, Zunum Aero is studying where hybrid and fully electric propulsion technologies can influence the market, primarily in smaller regional aircraft segments below Boeing's current product line.

The latest investment in advanced battery technology startup Cuberg represents Boeing's commitment to electric propulsion technology development. In its Berkeley, California, lab, Cuberg developed a high-energy battery cell that could prove to be a safe, stable solution for future electric air transportation.

### ACCELERATING ABROAD

Steve Nordlund (third from right), vice president of Boeing HorizonX, speaks with industry partners at the India Innovation Challenge launch in Hyderabad, India.

PHOTO: BOEING



# The quest for **stronger,** cheaper titanium alloys

## Joint development of VST2-based alloys in Russia.

**NATALIA MITROPOLSKAYA AND ROBERT BRIGGS, MATERIALS, PROCESSES AND PHYSICS ENGINEERS  
BOEING RESEARCH & TECHNOLOGY**

Titanium's properties in strength versus density make it one of the most desired metals for aerospace applications. But the cost considerations have prevented its widespread use. Improvements to Ti processes and alloys that lower cost and make use of the metal more feasible could allow for game-changing innovation in aircraft design.

Around 40 percent of the cost of an aerospace titanium part is the cost of sponge used in ingot fabrication. Within the cost of sponge, only about 5 percent is the cost of the ore (titanium dioxide); the rest of the cost owes to the process used to reduce

the oxide to metallic form.

At the same time, the buy-to-fly ratio (the difference between the amount of material that is purchased and amount that is thrown away as scrap) for titanium parts is typically so high that around 70 percent of the metal in a semi-product goes to chips during machining. Recycling titanium scrap, therefore, warrants serious attention from titanium suppliers.

However, with the conventional method of ingot fabrication—vacuum arc remelting (VAR)—scrap reuse accounts for only around 30 percent

of total ingot production because the cost to clean and sort the scrap would not be compensated by the savings on sponge beyond that level.

The Boeing–VSMPO Innovation Center— a Boeing partnership with VSMPO-AVISMA, the world's largest titanium producer—was established in 2000.

PHOTO: BOEING



PHOTO: BOEING




VSMPO supplies its products to the markets of 50 different countries and is deeply integrated into the world's aerospace industry.

About 10 years ago, Vladislav Tetyukhin, then general director of VSMPO-AVISMA, and his research team, created a concept of a new lower cost alloy, VST2, aimed at replacement of Ti 6Al-4V, which could be produced with the use of scrap of various titanium alloys serially produced by VSMPO at the level of about 75 percent.

The key enablers for this concept were the technology of scull melting of ingots (available at VSMPO and characterized by much higher than VAR scrap refining ability) and development of the VST2 chemistry range, which is wide enough to accommodate the increased oxygen and the alloying elements getting into charge with scrap of various alloys and yet capable of providing for mechanical properties comparable with these of Ti 6Al-4V.

Also, an important factor to the advantage of using this concept at VSMPO was the opening of the joint venture Ural Boeing Manufacturing in 2009, a machining facility at the VSMPO site, supplying tons of chips of Ti 6Al-4V and Ti 5553.

In 2010, Tetyukhin presented the concept of VST2 to Boeing. Soon, the research teams from Boeing and VSMPO started development of compositions that could be produced with high scrap utilization and hence reduced ingot cost. 

#### **URAL BOEING MANUFACTURING**

Given the difficulties with machining titanium, new alloy die forgings are assessed for machinability.

This partnership has resulted in development of three new lower-cost titanium alloys: Ti 6Al-4V Modified, VST2L-B and VST2F

#### **Ti 6Al-4V Modified**

Ti 6Al-4V Modified is production ready and approved for use in selected 787 parts made from plate as a lower-cost option along with Ti 6Al-4V.

While initially the goal of the development was to stay as close as possible to the Ti 6Al-4V chemistry and benefit only from saving on the sponge use in ingot, it soon became clear that it made more sense to take advantage of the wider chemistry range associated with using scrap of several alloys and turn it to the benefit of properties for specific applications. Thus, VST2L-B alloy (for superplastic formable sheet) and VST2F alloy (for fasteners) were developed by selecting the chemistries that provide for improved superplastic formability and manufacturability of fasteners compared to Ti 6Al-4V.

#### **VST2L-B**

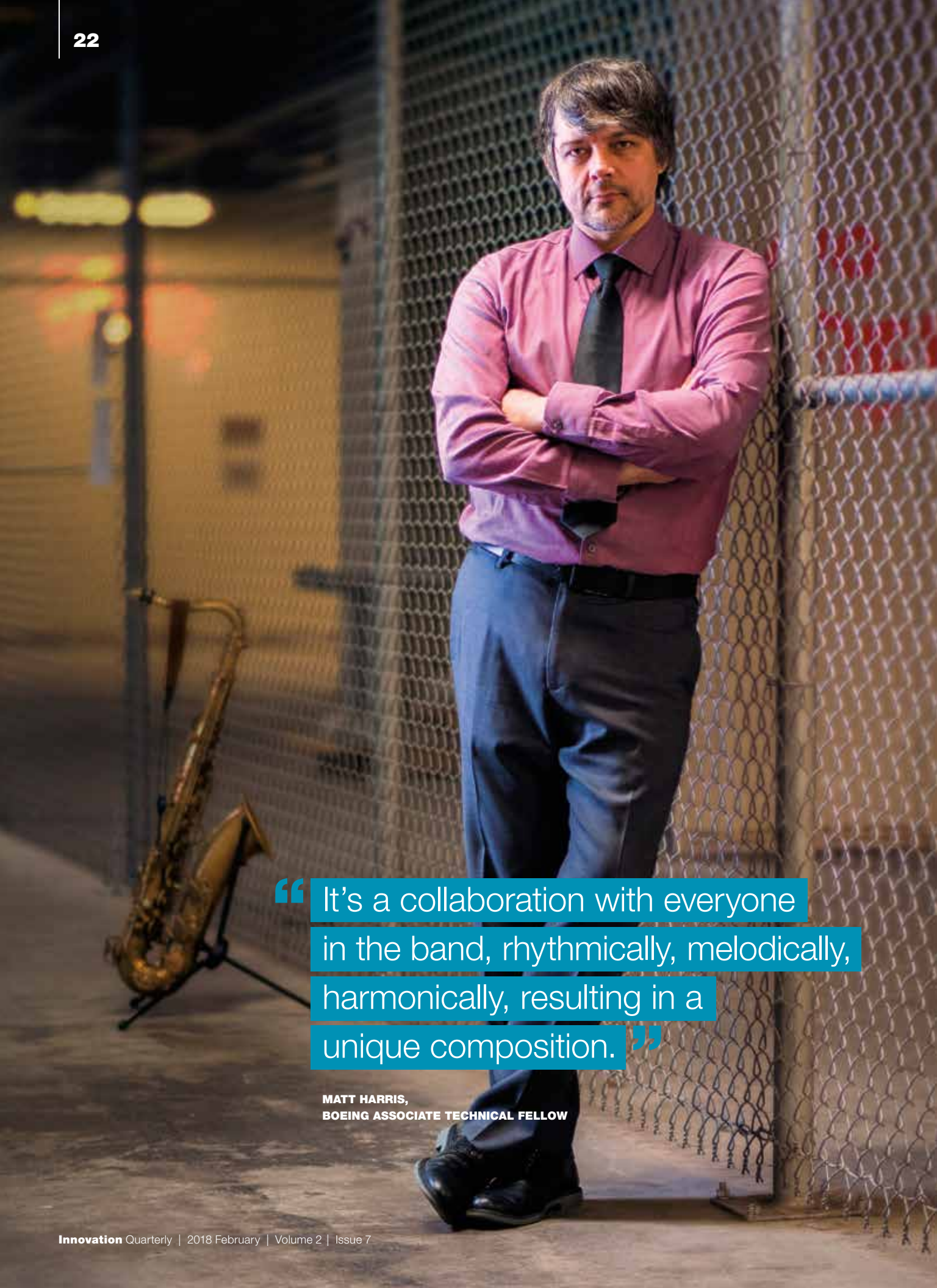
Superplastic forming (SPF) of Ti 6Al-4V sheet is a critical technology at Boeing and is used extensively. The cost of superplastic forming (SPF) dies is the major impediment to expanded applications, so the main solution is to lower the forming temperature. Reduction of the forming temperature was previously accomplished by reducing the grain size of Ti 6Al-4V. VST2L-B displaying superplastic formability at a lower temperature without being processed to fine grain represents an alternative solution with the cost reduction obtained due to both a cheaper sheet fabrication process and the saving on sponge in ingot fabrication.

#### **VST2F**

Titanium fasteners are an important commodity to all of Boeing's commercial programs. Ti 6Al-4V fasteners represent the vast majority of structural fasteners used on airframes, with annual usages in the millions

VST2F, a new titanium fastener stock material, is capable of meeting the tensile and shear strength requirements to Ti 6Al-4V displaying higher ductility, thus lowering the risk of producing metallurgical defects during thread rolling.

The expansion of Ural Boeing Manufacturing—announced in 2016—will include a new facility based in the Titanium Valley special economic zone in the Sverdlovsk region. The facility, expected to open in 2018, will carry out a complete machining cycle (previously it was rough machining only), and represent an optimal logistics arrangement to take advantage of the VST2 alloy breakthrough for commercial product applications.



“ It’s a collaboration with everyone in the band, rhythmically, melodically, harmonically, resulting in a unique composition. ”

**MATT HARRIS,**  
**BOEING ASSOCIATE TECHNICAL FELLOW**

# On being in tune:

## An electronic systems integration engineer applies his philosophy for creating acoustic harmony to advancing avionics.

BY VIENNA CATALANI, BOEING WRITER | PHOTOGRAPHY BY PAUL PINNER

Sitting at his workbench, Matt Harris tinkers away on a software-based radio setup while losing himself in the free-flowing notes of jazz in the background.

To Harris, innovation and engineering are akin to improvisation and music—similar and symbiotic. As both a systems architecture engineer and established jazz musician, he has a similar approach to both disciplines.

The innovation of developing and integrating systems comes when team members with diverse experiences and perspectives play off of one another, listening and sharing ideas to improve on a design.

“It’s a collaboration with everyone in the band, rhythmically, melodically, harmonically, resulting in a unique composition,” Harris explained. “Your improvised solo is, by definition, a musical innovation.”

For Harris, jazz is about question-and-answer, listening and interplay. He starts with a known song—a structure or process—listens to others, then integrates his answers with a solo.

Harris brings this process of creativity as an engineer with an automated perspective to design and problem-solving through data analysis. Harris, a Boeing Associate Technical Fellow, uses large-scale, multi-dimensional simulation, data analysis and data visualization to improvise solutions.

In his role as a principal investigator for commercial product development, Harris helps shape what aircraft navigation

systems will look like in the future. This means certifying new technologies, integrating complex systems, and planning for potential industry disruptors like software-defined radios and autonomy.

For example, use of software-defined radio technology could be a paradigm shift in radio navigation, Harris said. The emerging technology gives relatively easy and cheap access to the vast amount of radio signals that saturate the air and were once difficult to tap into.

Widely available, open-source software gives instruction on how to build a device that receives a huge range of radio signals—from a wireless mouse to GPS satellites—being broadcast around it.

The technology raises enough cybersecurity concerns to have made the Defense Advanced Research Projects Agency hold a hackfest exploring software-based radio applications last December.

To get in front of this growing tech, Harris drew inspiration from his high school days playing with high-voltage circuits scrounged from copy machines at the local electronics surplus store.

Starting with an inexpensive parts list—a couple of Raspberry Pi boards, digital television tuners, computers, antennas and open-source software radio code—Harris improvised a software-based radio.

“He’s one of the smartest guys I’ve ever met; it’s almost scary smart in terms of how quick he figures things out,” said Tim Murphy, a Boeing Senior Technical Fellow and industry expert in guidance, navigation and control technology.

Murphy recruited Harris at Ohio University where Harris studied electromagnetics and navigation systems as a

graduate student. Since Harris's arrival at Boeing, Murphy has served as his mentor. As a musician himself, Murphy is also his bandmate.

Harris started playing the saxophone in middle school, and dedicated himself to studying jazz. By high school, he was playing with university and civic big bands.

Decades of research has shown a correlation between music and math. While it is still unclear whether studying instrumental music causes enhanced mathematical capability, the creative streak runs through many engineers who excel at both.

In preschool, Harris impressed family by correctly answering math equations, and he eventually skipped kindergarten for first grade, where his teacher described him as a "divergent thinker."

Despite a tight family budget growing up, Harris's mom bought him the saxophone he still treasures and uses today. "It's a classic and coveted Selmer Mark VI that's a little older than me," as Harris described it.

Seventeen years after meeting Murphy—and dozens of performances later—Harris has watched his ideas come to life at Boeing.

"The coolest new capability that I've helped develop is the ability to automatically land aircraft in the lowest visibility conditions using GPS with Ground Based Augmentation System," Harris said.

To accomplish this, Harris used several complex simulation models in conjunction with analysis of massive amounts of flight data to develop requirements for airborne and ground systems, ensuring that any position errors could be bounded with high probability.

The team used models to assess the impact of ionospheric anomalies on landing system errors, and to determine the impacts of errors due to GPS signals reflecting and refracting off the airframe surfaces before reaching the GPS antenna.

#### ALWAYS ON

Harris and his intellectual curiosity flow freely from his lab at work to his lab (i.e., basement) at home.







“He’s one of the smartest guys I’ve ever met; it’s almost scary smart in terms of how quick he figures things out.”

**TIM MURPHY,  
BOEING SENIOR TECHNICAL FELLOW**

#### **CREATIVE COLLABORATION**

Harris and Tim Murphy both work and play together to innovate technical solutions, as well as experiment with modern jazz.

The Ground Based Augmentation System (GBAS) was the solution to a decades-long pursuit, and is now being integrated at airports worldwide. Harris and many others would go on to enhance the innovation with a Portable Ground Based Augmentation System (PBGAS), teammate William Peterson explained.

“It took a close-knit group of technical experts who leveraged each other’s skillsets and capabilities,” Peterson said.

Peterson worked on the team to develop PGBAS, which was replicated in a second-generation system that complies with new RTCA-DO-246D standards, enhances satellite navigation, and provides an alternative to the Instrument Landing System supporting the full range of approach and landing operations.

“It’s kind of an evolution in technology,” Peterson said.

“Matt worked on this GPS technology in college, and even Tim (Murphy) began working on it when he was in college.”

Harris’s work on GPS systems made him the perfect candidate to inherit Murphy’s role as special committee representative for the Radio Technical Commission for Aeronautics (RTCA). The RTCA is an organization that provides guidance for government and industry standards.

As a working group chairman of RTCA Special Committee 159, Harris provides leadership and guidance on GNSS-based navigation systems at a national and international level.

A lot of work that Harris and Murphy have done, Peterson said, has been offsetting challenges presented to them.

Growing up in a small town in Ohio, Harris remembered playing a combination of tag and hide-and-seek with CB radios, using the signal strength to determine where someone was hiding, and driving around town to find them.

He also studied the specs of audio electronics in catalogues, and took an interest in the interfaces of audio systems as they transitioned from analog to digital.

“With systems engineering and integration, I’m still basically working to connect boxes to other boxes, making interfaces, and building compatible systems,” Harris said.

His daily work, however, is much more complex than connecting boxes, as he applies automation to data

analytics and system design trades that result in smaller, more accurate and robust boxes.

Reducing equipment size reduces space and weight on an aircraft, but Harris is more interested in finding new ways to automate the use of large amounts of data the equipment generates. He wants to intelligently integrate measurements from various equipment and, eventually, automate decisions made from those measurements.

This will be a building block toward inflight automated decision-making in real time, which will require technological advancements not yet realized.

As test data began to pour in from new navigation radio lab and flight testing, and the need for analysis grew, Harris and his team found a way to use automation as a solution. Their tool is capable of auto-analyzing all the data sent by the box, though not in real time.

“It was Matt’s brainchild,” said Matt Miltner, Harris’s mentee and teammate. “The tool gave us the ability to find problems that you can’t find in the lab and may not find on a flight test, saving time and money by catching the potential problems in development.”

With Harris’s guidance, Miltner wrote code for the tool and is responsible for its maintenance and upgrades.

It has been used to determine acceptability of new MMRs for certification on various Boeing airplanes, and its agnostic qualities have proven to be valuable, Miltner said, as it’s portable to any data system on Boeing airplanes, not just navigation systems.

“So far, Moore’s Law of exponential growth in computing power for exponentially decreasing cost, size, weight and power has allowed us to automate data analysis for the purposes of complex system design and data visualization and analysis—albeit in a slower-than-real-time fashion,” Harris explained.

In other words, computers have come a long way since the Radio Shack TRS-80 Harris learned to code on.

Harris believes that next-generation airplane systems will better support safer, more-automated flight by pilots, and they will lead to aircraft that require pilot intervention in only rare cases.

“Artificial intelligence is really just complex automation, enabled to be real-time by high-powered computing,” he said.

Harris is optimistic to see autonomous flight on a commercial airliner in his lifetime, but in the meantime, solving problems, researching and developing tools to get there is what keeps him satisfied.



Murphy said he wishes he could have 10 more engineers like Harris. So, it’s only fitting that Harris’s work team—his band of engineers is referred to by others as, “The Matts.”

“He’s the kind of guy you can hand a relatively ill-formed problem to, and he’ll come back with all kinds of original thought, and even more important, defining the problem, and identifying multiple approaches to exploring it,” Murphy said.

It’s the process of both improvising music, and innovating as an engineer that Harris enjoys the most, and he credits his success to the support and talent that surrounds him.

“If you’re stuck just following processes, you may never have an innovative idea. But when you’re working with groups of people that want to hear your ideas and bounce some off of you, and you have people propping you up, you can foster innovation like a good jazz band fosters a soloist to be the best they can be,” Harris said. **IQ**

# Selections from the Boeing Technical Journal

The Boeing Technical Journal is a peer-reviewed periodical for Boeing subject matter experts to capture and leverage knowledge. Research coverage includes all manner of commercial and defense product development, and products and services spanning land and sea, to air and space, and cyberspace.

## Contributing Authors

### UBIQUITOUS BROADBAND COMMUNICATIONS AND THE DEVELOPMENT OF BOEING PHASED ARRAYS



**Julio A. Navarro** is a Boeing Senior Technical Fellow for phased-array sensors. He is a global expert in critical radio frequency and microwave technologies and applies this expertise to advanced aerospace development programs.

### A HISTORY OF BOEING COMMERCIAL TRANSPORT FLIGHT DECK LIGHTING AND DISPLAY OPTICS INNOVATION



**Steve D. Ellersick** is a Boeing Associate Technical Fellow for commercial flight deck display optics and lighting systems and has worked on the 737, 747, 757, 767, 777, KC-46A Tanker, and 787.

The Journal is a proprietary publication, but the articles on the following pages are summaries of technical papers approved for public release and available online at Boeing.com.

# Ubiquitous Broadband Communications and the Development of Boeing Phased Arrays

## Summary

BY JULIO A. NAVARRO

The start of Boeing's second century puts us at the beginning of the next big leap in connectivity and presents us with the challenge to continue pushing active electronically scanning antenna (AESA) technology further.

As the commercial sector begins to drive this technology for 5G and IoT applications, many critical custom pieces will become commodities for use in integration. This is an opportunity for Boeing to leverage its broad packaging experience and use the resulting technologies for further development of affordable phased-array antennas (PAA).

In the near-future, reducing the size, weight and power may will reduce cost and make the dream of ubiquitous communication anywhere, everywhere, all of the time, finally a reality.

Compared to a mechanical dish or flat-plate antenna, which must physically adjust to acquire a moving target, phased arrays are entirely electronic and have no moving parts. They allow simultaneous tracking of multiple targets, with higher reliability and a lower physical profile.

Phased-array antennas combine radiating media, transmission media plus analog and digital electronics all into a flat package. For the designer, the heterogeneous integration of an antenna, electronics and packaging makes the technology exciting and challenging. For the user, this high-level of integration has, in the past, increased the cost and complexity of the system.

For the most part, phased-arrays have served as the technology of the future—delivering high-end performance for those willing to pay for it. This trait has kept it in mostly niche applications where performance matters more than cost (such as military uses). Typical commercial applications, which are primarily driven by cost, struggle to justify the benefits that PAAs deliver to the end user.

Boeing has made significant improvements to PAAs over the last four decades and has established a good base of intellectual property. Boeing's innovations address cost and affordability and have brought the technology a step closer to the commercial sector.

Before the onset of microwave monolithic integrated circuits (MMIC), wide-scanning phased arrays were very large, bulky and relegated to lower frequencies or high-value radar systems. As MMIC technology advanced, the advantages of PAAs could be achieved for a broader set of applications. PAAs provide unmatched beam-scanning speed enabling mobile access, directional networking, multi-platform synchronization and advanced radar sensing.

PAAs also mitigate critical platform challenges because they can be made thin with a low physical-profile, operated over widebandwidths and include multiple simultaneous beams scanned in independent directions over a large field-of-view. With some reasonable integration complexity, PAAs can also include low sidelobe levels and signal nulls in arbitrary directions. These qualities ensure low probabilities of signal interception and detection and minimize the effects from co-site interference or intentional external jamming.

In general, any platform consisting of hundreds of antennas at various

frequencies and with a broad range of coverage volumes and power levels can benefit from the use of PAAs with functions and capabilities beyond just ubiquitous communications.

Co-locating many transmitters can create a harsh, noisy and dangerous electro-magnetic environment that will not function effectively without significant levels of coordination in spectrum, time allocation and location assignments. For example, the prime real estate in most naval platforms is the center mast which enjoys an unobstructed view in all azimuth directions.

Every system lobbies for this prime location that is typically reserved for a high-power multi-function radar sensor. The sensor performs many different functions including volumetric search, cued search, missile track, target illumination, track-while-scan, air traffic control, missile communications and many more.

All of these functions are meticulously controlled and optimized to maintain platform protection and survivability in adverse environments. A modern multi-function, multi-octave high-power PAA enables the platform to quickly and better coordinate each of these functions, while delivering directional communications and avoiding co-site interference. However, such high-levels of integration adds cost and complexity the AESA system.

Most systems do not require the complexity nor the high-power levels of military-grade communications. In many instances, to reduce costs and complexity, communication PAAs trade high-element power levels for larger surface area to spread out active devices and reduce thermal management concerns. This simplification has helped Boeing make inroads into affordable phased-array technology.

As communications and wireless applications advance and mature,

more opportunities to leverage AESA technology will arise. This trend will continue as society's hunger for improved connectivity and streaming live content increases along with the military's need for tracking larger numbers of targets at longer distances. The cost pressures placed on PAAs help drive solutions to lower power densities over larger apertures and push the needle away from the conventional high-power radars.

As phased arrays transition to the commercial sector, commercial practices will replace the typical military specifications, and the vast commercial manufacturing base will drive down the cost of the typical PAA. The standardization of key components and the use of open system architectures with interchangeable pieces will reduce costs. The opening of new markets, such as the automobile market, driverless cars, flying drones and the expansion of cellular services, will also help to make PAAs a commodity.

The continuous advancement of silicon in application specific integrated circuits (ASICs) and the advent of silicon-germanium (SiGe) for radio frequency integrated circuits (RFICs) has leveled the playing field in millimeter-wave packaging and AESA integration. The result is a much larger pool of contributors, including large and small companies working with academia.

Moreover, the larger players in the commercial sector have moved into this technology space with 5G and LTE and the ever-increasing demand for more bandwidth. The commercial sector is rapidly moving from the lower bands up into K- and Ka-bands to provide higher-quality services with more bandwidth to increase content and speed.

Boeing has developed a wide range of PAAs to address both sensors and communications. Boeing has simplified and reduced the cost of phased-arrays and was the first to field them in the commercial aviation sector. Boeing has specifically focused on the design of wide-angle, beam-scanning PAAs for mobile airborne SATCOM.

The concept of heterogeneously-integrated phased arrays was introduced in the 1990s to address the complexity and affordability of phased arrays.

The first innovations in the late 1980s were inline, single-beam, circularly polarized K-band receive and Q-band transmit phased-arrays for the U.S. Air Force. The designers realized early on the need for thinner and lower-profile tile architectures with dual polarization. There was a need to develop processes to address the short-comings of the electronics industry and packaging technology of the day. The result was

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In the near-future, such advancements may make the dream of ubiquitous communication anywhere, everywhere, all of the time, finally a reality.

## AHEAD OF THE GAME

In the last three decades, Boeing has achieved many industry-firsts in wide beam-scanning phased arrays including the following applications:

- The first production PAAs for commercial aviation connectivity
- The first AESA for Low-Earth-Orbit Satellite communications
- The first simultaneous dual-beam PAA for 20 GHz and 30 GHz SATCOM
- The first simultaneous quad-beam PAA for directional networking applications
- The first PAA to close the MILSTAR link at 45 GHz for Submarine SATCOM

These industry-firsts came at a time when the cost to participate in the design of PAAs was high and dominated by the major aerospace companies. The cost of the design, fabrication and development of custom electronic components set the bar high for entry into this field. These technologies include Gallium-Arsenide (GaAs), Gallium-Nitride (GaN) and Indium-Phosphide (InP) monolithic integrated circuits, as well as the high cost of packaging the various levels of electronics from the antenna front-end to the back-end power supplies, RF, logic control, power and cooling distribution infrastructure.

As phased arrays experience a synergy with the commercial sector similar to that previously seen in personal computers, smartphones and digital tablets, and electronic components, certain parts of the PAA will be commodities for general use. As cost of these commodities decrease, more applications will spring up increasing the volume further.

a clever design referred to as the “Can & Sleeve.” It addressed performance and manufacturing issues which provided a baseline for future designs.

With the receive side of the equation completed, the next key development in the commercial SATCOM system allowed it to offload data from the platform—thereby “closing the loop” and providing the platform with true networking capability. Finally, the capability to provide consumers with an office in the sky.

The need for in-flight connectivity for Boeing’s commercial airlines business unit was a monumental task in the early 1990s due to difficulties in platform integration, extensive federal regulations, FAA certification issues, tight cost constraints, and a slowly developing market. Several immature technology areas contributed to the difficulties and complexity. Without any external options, Boeing tackled and successfully developed the first production phased arrays for commercial aviation.

In 1999, The Boeing Company filed with the International Telecommunications Union (ITU) its intent to provide such service to the public through the newly created business: Connexion by Boeing. This was done in the era before the invention of the iPod, iPhone, iPad, smartphone, or the success of start-ups such as Google, Facebook and Twitter. Late in 2001, the Federal Communications Commission granted Boeing a two-way license for mobile broadband satellite services to commercial airlines and executive jets. The license enabled real-time, high-speed internet and intranet access, television and email above U.S. territory and waters.

After the tragic events of Sept. 11, 2001, from a military stand-point, Connexion-By-Boeing became an indispensable system to have in

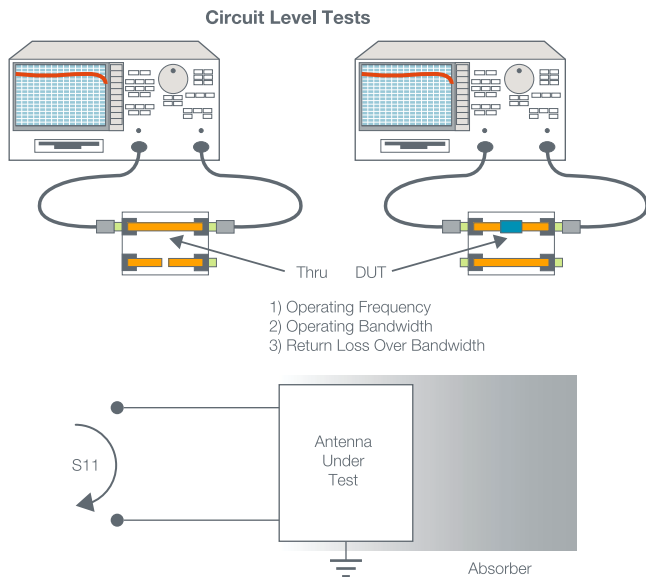
our country’s arsenal—a system for full-mobile connectivity to critical government platforms with unmatched system availability and performance. However, the impact of high-fuel prices and the business disruption was too much for many airlines to digest. Over time, commercial interest in Connexion faded away and what remained is now part of the Boeing Broadband SATCOM Network (BBSN), serving the United State’s VIP/SAM fleet.

There is a need for continued innovation and improved packaging to achieve lower costs, more electrical efficiency, higher operating frequencies, improved thermal dissipation and other key metrics. The final application and its use to society matters, and successfully providing the product to deliver broadband mobile connectivity is an achievable goal for us to reach in the near future.

Perhaps the most important trend is in consumer demand for more connectivity. Commercial giants in 5G and LTE are moving up to higher and higher operating bands. Satellite services for mobile platforms are also providing links at K- and Ka-band. These pressures are already driving industry to design and develop dedicated chipsets with complete System-on-Chip (SOC) solutions—RF to bits near or at every element. Such advancements break through the packaging limitations of analog PAAs and may help us drive costs down enough to make them a commodity. **IQ**

## Antenna basics: Common tests and measurements

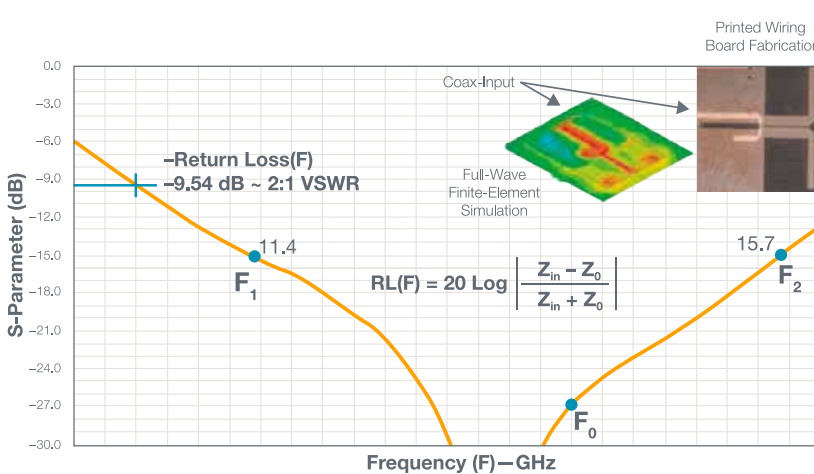
Antennas come in all shapes and sizes using all sorts of metals and dielectrics. They operate over specific bands with a bandwidth determined by a circuit and radiating properties. The size and shape defines the radiator’s field-of-view, as well as the quality of transition from guided media to free space. The following is a sample of detailed exposition available in the full paper.



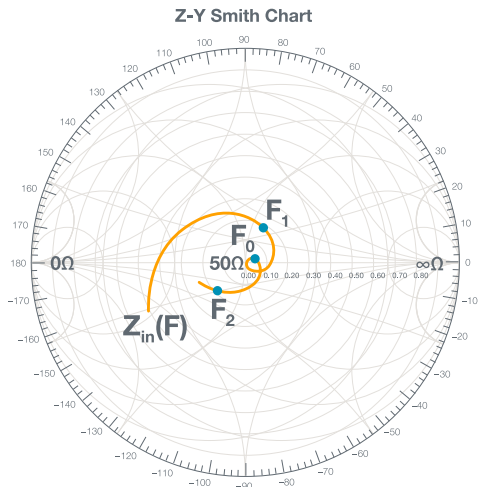
**FIGURE 7.** Circuit level test set up for an AUT.

A device or Antenna-Under-Test (AUT) includes both circuit and radiation properties. Circuit level characteristics are measured using a network analyzer and a test setup shown in Figure 7. There are several types of test sets available including waveguide, coaxial and microstrip. Each setup includes the load standards (short, open, load) and delays used in calibration and for setting the measurement reference planes.

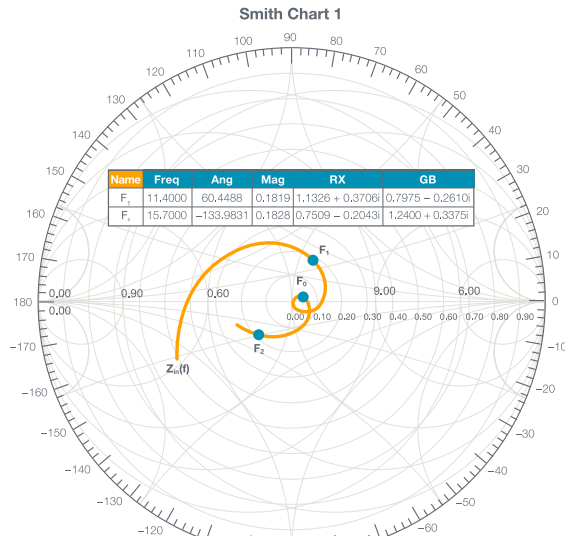
Once calibrated, the antenna port is injected with RF signals—the network analyzer measures the return or reflected signal off of the antenna port. The magnitude of the reflection coefficient (S11) is plotted in Figure 8 in dBs over the frequency range.



**FIGURE 8.** Magnitude plot of return loss (-dB) over frequency (GHz).



**FIGURE 9.** Reflection coefficient and Input Impedance of a coaxial-fed dipole element.



**FIGURE 10.**

Far-field test setup and principal plane cuts for a 64-element Ka-band microstrip patch antenna array.

Figure 9 is a polar plot called a Smith Chart which plots the complex input impedance ( $Z_{in}$ ). It includes both the phase and magnitude of the measurement. The Smith Chart x-axis represents real resistance values with the left-most limit of the chart defined as a short circuit ( $0 \Omega$ ) and the right-most limit defined as an open circuit ( $\infty \Omega$ ).

Key numbers highlighted in the two-plots are -15 dB Return Loss

at  $F_1$  and  $F_2$  which corresponds to 97 percent of the energy reaching the load. A value often used is -9.54 dB to represent nearly 90 percent of the energy reaching the antenna. This value corresponds to a voltage-standing wave ratio (VSWR) of 2:1 and represents a mismatch loss of 0.5 dB at the antenna. The same -15 dB points are shown on the Smith Chart and listed in terms of magnitude and angle, as well as real and imaginary

impedance values referenced to the center of the chart.

Circuit level measurements provide us with the characteristics of the antenna as a load. To confirm how much of the energy reaching the load radiates efficiently into free space, the AUT radiating properties are measured in a near-field or far-field anechoic chamber as shown in Figure 10. **IQ**

To read and download the complete Boeing Technical Journal paper titled:

“Ubiquitous Broadband Communications and the Development of Boeing Phased Arrays”

Please visit [boeing.com/IQ](http://boeing.com/IQ).



# A History of Boeing Commercial Transport Flight Deck Lighting and Display Optics Innovation

## Summary

BY STEVE D. ELLERSICK

That the pilot's vision is critical for efficient and safe operation of an airplane appears to be obvious. However, one might not understand how exceptionally challenging it is to provide optimal visibility because of the tradeoffs between pilot vision capability; visual human factors; lighting technology; weight, power and cost constraints; the extreme ambient lighting environments ranging from the darkness of night to bright sunlight; and the dynamic nature of flying (moving in and out of clouds, for example).

Traditional flight deck equipment used media that can be viewed by ambient light with internal lighting provided to enhance visibility, particularly when the ambient light level is low. Electromechanical-type instruments have been on Boeing flight decks since 1916 and are still in aircraft in 2018. New solid-state electronic controls and displays have replaced the older mechanical-type instruments and offer many advantages by reducing crew workload, improving flight operations and safety, reducing cost, and providing greater flexibility.

This innovation has been made possible by innovation in lighting and display technology.

The past 30 years have been exciting, challenging, productive, and enjoyable for lighting and display engineers. They have worked the transition from over 70 years of incandescent-based lighting and gauges to solid-state LED (light emitting diode) lighting and liquid crystal-based, graphical, electronic, flat-panel displays.

Avionics technologies, requirements, design and analyses methods, test equipment, and methods have never been better. All of this yields a win-win situation for both Boeing and the customer by enhancing work effectiveness, aesthetics and crew comfort, making an efficient and truly integrated design possible.

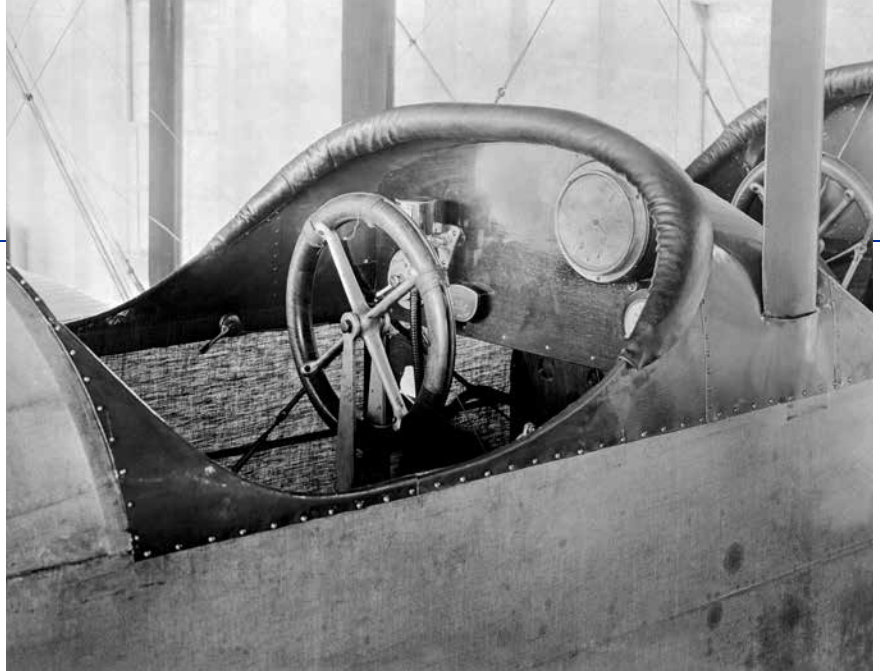
The full version of this paper (available online) provides an overview of the significant past, present and future lighting and display technologies and design approaches along with their impact to business and crew operations. The primary flight instrument progress takes center

stage, telling the flight deck design story. Boeing commercial flight deck design is the paper's focus, with some mentions of military, exterior, interior lighting and display optical designs. The evolution of flight deck design, from the B&W to the 787, is full of accomplishments and challenges as evidenced by the following historical milestones.

### Early vision

Even the earliest Boeing airplanes had pilot controls and indications. The first Boeing airplane, the B&W 1916 cockpit is shown in Figure 1 with round dials. These mechanical instruments had painted white lettering on black background, which were readable in the daytime when the sun was shining due to the reflectivity difference.

As night flying became more prevalent and available, man-made lighting was increasingly needed for the cockpit instruments. In 1925, the first landing lights were installed on a mail plane and powered by a charged car battery. At the same time, greater and greater demand for airfield lighting was



**FIGURE 1.**  
B&W cockpit.

PHOTO: BOEING

driven by the pilots having to perform these difficult tasks. The early years of airplane lighting were based on the incandescent lamp as a light source shining on painted white-on-black, electromechanical instruments. A cover glass was placed over the dial gauge to protect the pointer movements. The cover glass needed anti-reflection coating to minimize reflections from the air-to-glass interface. Early lighting needs were covered by floodlights, post lights and flashlights.

In the late 1930s, Boeing began selecting more effective, but awkward, indicator lights for system status that were being used by the telephone company. The move into the turbo jet era was significant for many reasons, but displays and instruments remained relatively unchanged.

After the 707 and DC-8, the turbo jet transport continued to evolve with larger numbers and varieties of lighting leading to designs such as the 1969 747 flight deck that consisted of a “thousand” lights, gauges and switches.

### **Quest for Electronic and Flat-Panel Displays**

The reflective needle-and-dial mechanical gauges of most early aircraft needed repeated maintenance to keep their intricate clockwork mechanisms operating properly.

Yet for all their mechanical complexity, they were still reliant on ambient, aimed or integral back light in order for the pilot to see them. These devices ultimately made use of incandescent lamps shining on or integrally backlighting them for readability at night and in dark ambient lighting conditions. This was a huge step forward for flying in all ambient lighting environments; however, incandescent lamps do not last long because the heated metal filament will degrade over time and usage. These lamps can also generate a surprising amount of heat. For these reasons, both Boeing and customers were always interested in some way to improve performance.

To address these design issues, lighting and display engineers continuously investigated and drove the state-of-the-art technology of the day, always looking for more reliable light sources and instruments. A major step forward for the industry came about in the form of new display types that could provide all the information previously presented via gauges and number readouts. According to industry display expert Larry Tannas, “Boeing was a driving force as a customer for electronic and flat-panel display technology.”

“Electronic” means there are no moving mechanical parts to the device. Panel displays were gaining in prominence in consumer goods at the time, but this was not a case where a new

technology could be directly applied as is. Tannas pointed out, “The most taxing application for an electronic display is the aircraft cockpit.” The vibration, thermal, space and weight demands placed on these devices even in a flight deck environment are extreme. The benefits to their deployment, however, meant that Boeing had to pursue them.

So, during the late 1960s and early 1970s, Boeing research pursued electronic displays for commercial transport airplanes. This early research work ultimately led to the implementation of electronic displays (color cathode ray tubes, or CRTs) on the Boeing 757 and 767 airplanes.

Boeing display and human factors experts Lou Silverstein and Robin Merrifield were instrumental in defining the display optical characteristics needed for the 757 and 767 flight deck during this time. This was a bold step for Boeing, as these would be the first color CRTs ever used for flight instruments in any type of aircraft, military or commercial.

Although the general trend was for avionics and flight deck technology to trickle down from military programs to commercial flight decks, Boeing decided to jump ahead of the military programs and associated government-funded research and development to develop the Boeing Electronic Flight Instrument System using color CRTs.

All of this effort led to the introduction of the Boeing 757 and 767 in the 1980s with two-crew glass cockpits for airline service. The term “glass cockpit” came about from this development due to this increasing use of cathode ray tube displays for most of the primary instruments in lieu of the old-fashioned steam gauge electromechanical instruments used on other airliners. The concept caught on beyond Boeing circles, with McDonnell Douglas later introducing similar approaches with the use of CRTs on the MD-90.

Boeing continued this evolution in electronic displays on Boeing airplanes like the 747-400. Depicted in Figure 9 are two versions of the 747, the original model with a “thousand” lights, gauges and switches, and the upgraded 747-400. These electronic displays enabled the integration of data into information that is far more readily understood and interpreted by the flight crew.

### Liquid crystals and light-emitting diodes

Around 1985, with the rapid pace of display technology progress that was occurring in consumer circles, Boeing

selected AMLCDs (active-matrix liquid crystal displays) as the technology to replace CRTs for the next airplane, the 777. The 777 was the first airplane to use AMLCDs as primary flight instruments.

Tannas’s thesis is that the AMLCD is the only flight deck display that can do all the things ever wanted in the flight deck because it has two new performance features:

1. Logarithmic dimmability over the full mesopic (.001 cd/m<sub>2</sub> to 3.4 cd/m<sub>2</sub>) and photopic visual range.
2. Immunity to ambient illumination without loss of contrast or color separation.

No other display technology to date has this capability without loss of some other performance parameter, such as loss in resolution as exhibited in CRTs. The AMLCD can be made as bright or dim as the backlight can be made to perform. A 4,000-to-1 dimming range is available.

All current AMLCDs on Boeing commercial planes are now backlit with LEDs, as this technology has rapidly gained maturity,

acceptance and ability to produce white. AMLCD technology has improved tremendously since initial introduction, with LCDs everywhere in our lives now—cellphones, personal computers, laptop computers and TVs. These successful commercial applications have helped flight deck display technology, MVA (multi-domain vertical alignment) and IPS (in-plane switching), improve with better area and viewing angle uniformity.

LEDs improve service life, reliability, touch temperature, reduce power consumption, reduce weight and reduce maintenance costs. LEDs and the miniaturization of electronics allows new brightness control architectures that reduce weight, part count, and address the historical problem of brightness mismatch between panels.

Other innovative advances to flight deck lighting and display optics include new psychophysics-based display and area light dimming curves, created to ensure the pilots have the needed brightness and control. Display brightness automatically adjusts to reduce workload, and increase reliability,

PHOTO: BOEING



PHOTO: BOEING



**FIGURE 9.** 747-400 and 747-200 flight deck comparison.



### VISUAL PERFORMANCE FACTORS

The visual interface is the most important pilot and airplane interface. Execution of flight crew visual performance tasks and procedures are measured in terms of accuracy, speed and comfort. Visual performance factors include:

- Task (who, what, when, where, task surface).
- Visibility, readability, legibility.
- Font (visual size, viewing angle, distance, amount of lighted area).
- Luminance, illuminance, polarization, contrast.
- Color, spectral, temporal.
- Glare, stray light, reflections.
- Uniformity, balance.
- Dimming.

### THE ABC'S OF LIGHTING

Based on pilot human factor studies conducted at Boeing, effective automatic brightness control (ABC) avionics systems were found to be required to maintain acceptable image brightness without the penalty of frequent manual brightness adjustments. The Boeing ABC system automatically adjusts the displayed-information luminance based on three factors:

- 1. AMBIENT ILLUMINANCE COMPENSATION:** Changes the display luminance as a function of the level of ambient illuminance incident on the display as detected by a display bezel-mounted light sensor. The emissive display luminance automatically adjusts to match that of surrounding reflective information like lightplates or to what is needed by the pilot.
- 2. ADAPTATION MISMATCH COMPENSATION:** Changes display luminance as a function of the luminance level the pilots see out the window, adapted to their forward-field-of-view, as measured by forward-facing light sensors.
- 3. MANUAL COMPENSATION:** Accommodates the wide range of individual vision differences and preferences in the luminance sensitivity of pilots, as well as the use of sunglasses or sun visors.

### 787 FLIGHT DECK LIGHTING AND DISPLAY OPTICS

The 787 flight deck (see above) lighting design advancement provides significant benefits for the airline customer and pilot's "office in the sky" because it:

- Uses LED (light emitting diode) light sources.
- Implements new brightness control architecture.
- Was designed based on user feedback.
- Takes into account the latest visual human factors.
- Extensively utilized lighting computer modeling for design, analyses, and to visualize the design before metal was bent.

by compensating for adaptation mismatch and ambient illuminance by using light sensors. Individual manual brightness adjustment is provided to account for user vision capability and personal preferences. Master brightness control allows simultaneous adjustment of all emissive display lighting. The 787 flight deck also sports a low-gloss, three-layer, new warm-gray reflective color scheme based on human factors research and employed new verification methods. Computer modeling was beneficial to analyze window and display reflections, and to visualize and communicate the area lighting design.

Using LED solid-state lighting for high-intensity landing lights has long been a vision for commercial aircraft and represents a major shift in lighting technology since the first incandescent lights were implemented approximately 90 years ago. Airlines currently replace halogen landing lights approximately every 100 hours or roughly every two weeks.

In 2015, for the first time, LED landing, taxi, and runway turnoff lights were certified and delivered on large transport aircraft, bringing tremendous benefit to customers due to long life and high reliability compared to current incandescent lamps. The introduction of these lights paves the way for other models to replicate the application, bringing benefits across the entire Boeing fleet. Because of the high intensity required, and the time it took for LED efficiency to improve, landing lights were the last lighting design area on the airplane to go LED. The new LED landing lights are a tremendous improvement in maintenance frequency and total labor hours for our airline customers.

Most Boeing commercial planes now use LED light source technology for navigation, position, beacon, anti-collision lights, passenger cabin, cargo and emergency evacuation. Some planes use photo-luminescent wireless light source technology for emergency evacuation lighting.

### Future lighting and display optics

The current visual human factors and metrics are not perfect representations of the human visual system and performance. Because of this, lighting and display optics designs usually need to be visually evaluated with observers. Scientific progress continues to better understand and model our eye-brain system for colors, color rendering, brightness, glare, gloss, visibility and alertness.

As an example, at the August 2017 IES (Illuminating Engineering Society) annual conference, a 2020 goal was established to improve the photopic response  $V(\lambda)$  because it is based only on the center foveal 2 degrees of our vision and excludes peripheral vision that is known to affect vision and health.  $V(\lambda)$  was first adopted in 1924 and is the basis for intensity, luminance and illuminance metrics. It is expected that it will take three to six more generations to achieve complete understanding and to develop the associated metrics. This will allow innovative products to be created to better match human needs with improved requirements. For example:

- LED light sources and electronic flat-panel displays have enabled significant progress in safety, efficiency and human interface within the aerospace industry. It is predicted that solid-state LED lighting and LCD technology will continue to dominate flight deck visual media technology over the next 20 years. It is expected in the future there will not be any “heated

The far future for the flight deck may be that there are no pilots on the plane. Then, there would be no need for flight deck lighting and displays on these unmanned vehicles except to make them visible and for repair and maintenance.

wires” on the airplane and all light sources will be electronic, solid-state LED.

- Camera video systems are becoming more prevalent and will continue to proliferate. Key for good performance is system design integrating the camera, display and ambient lighting. Better color rendering, brightness and dynamic range are key.
- Displays are not easily readable in some sunshine conditions. Future display improvements are needed to improve this situation.

The future will see continued and more extensive use of lighting modeling using computers. Modeling is used to visualize and communicate the lighting design. It is used to conduct

engineering design and analyses before building mockups, prototypes and hardware. Optical modeling and photometric analyses is the study of electromagnetic radiation, and its interaction (reflection, refraction, diffraction) with objects, and ultimately its perception by the human eye, camera or sensor. Aircraft have numerous design aspects that rely on predicting the behavior of light.

The far future for the flight deck may be that there are no pilots on the plane. Then, there would be no need for flight deck lighting and displays on these unmanned vehicles except to make them visible and for repair and maintenance. **IQ**

To read and download the complete Boeing Technical Journal paper titled:

“A History of Boeing Commercial Transport Flight Deck Lighting and Display Optics Innovation”

Please visit [boeing.com/IQ](http://boeing.com/IQ).

A young man with dark, curly hair is looking over a stack of books. The books are stacked horizontally, with the top one having a red cover. The man's face is partially obscured by the books, but his eyes and a slight smile are visible. The background is a blurred indoor setting, possibly a library or bookstore, with warm lighting and bokeh effects.

# STACK THE FUTURE IN YOUR FAVOR.

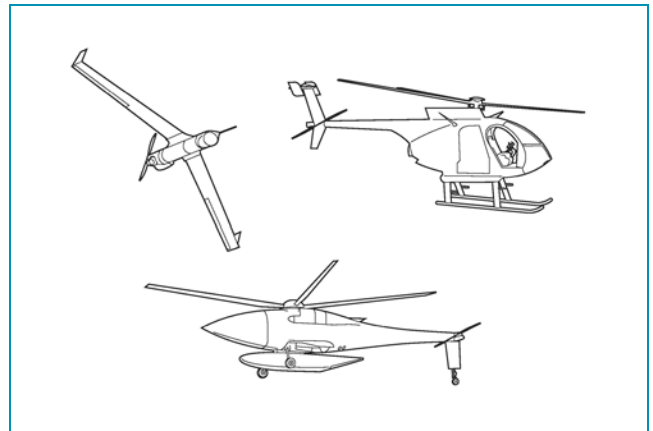
When we invest in others, we build a better future for everyone.  
Boeing is proud to support those who are committed to enabling  
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 **BOEING**

# Patent spotlight

**Check out a few of Boeing's latest ideas and technical breakthroughs recently granted by the U.S. Patent and Trademark Office.**



## Wildfire arrest and prevention system

**U.S. PATENT 9,833,647 B2**  
**INVENTOR: GRZEGORZ M. KAWIECKI**

The cost of fighting wildfires in the United States topped \$2 billion in 2017, according to the U.S. Forest Service. The instances of wildfires, and their subsequent devastation, have increased in many countries around the world over the last decade.

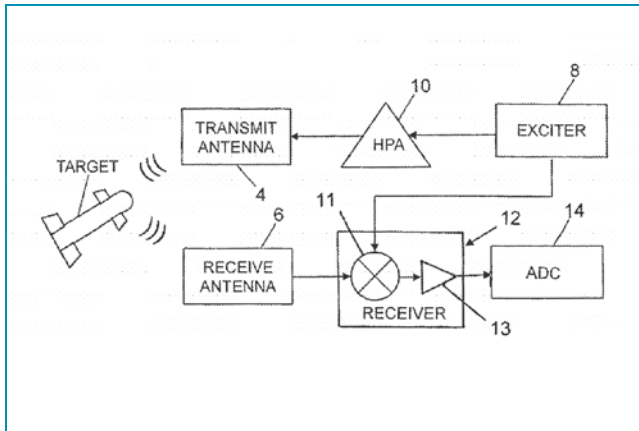
Early fire detection and monitoring has improved recently through the use of a combination of satellite data and unmanned aerial systems. However, the average time to deploy necessary fire suppression assets, often still including human firefighters, is too long, allowing the fire to escape out of control in a significant number of cases.

This patent, granted to Boeing in December 2017, describes a system using a cargo unmanned aerial vehicle, with a controller and monitoring system, to more quickly and easily deploy a fire retardant or a fire suppressant at a location of a detected fire event or risk. One or more UAVs carrying a payload of fire suppressant would be instructed to deploy at the risk location in an attempt to control a fire event or risk in a shorter time period than is required to deploy more conventional, manned assets.



### 2017 Boeing patents

With a healthy patent portfolio in the United States and internationally, Boeing has continually been acknowledged as an innovation leader by multiple third-party analysts.



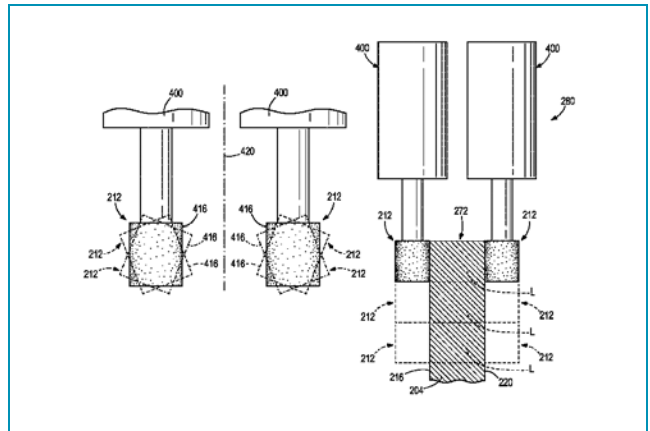
## Short-range point defense radar

**U.S. PATENT 9,810,774 B2**  
**INVENTOR: PETER S. WITTENBERG**

Radar devices transmit signals, such as electromagnetic or sonar signals, that reflect off targets and are received by the radar device to provide the position of the target. Some radar devices typically rotate the antenna through 360 degrees to pulse signals and detect targets within the area swept by the antenna. The technology of multi-beam frequency-modulated continuous wave (FMCW), however, offers some promise of lower cost, and more accuracy.

FMCW radar has multiple advantages compared to pulsed radars, including at least: a much lower peak power than pulsed radars; reduced receive digital bandwidth requirement; higher range resolutions; and design freedom to separate transmit and receive antennas. Likewise multi-beam digital beamforming has advantages compared to pulsed radar, including searching the entire field of regard in each sweep, and greatly improving tracking capability for multi-beam systems.

This patent, granted in November 2017, describes a multi-beam FMCW radar system and method designed for short range (<20 km) operation in a high-density threat environment against highly maneuverable threats. The multi-beam FMCW system is capable of providing continuous updates, both search and track, for an entire hemisphere against short-range targets.



## Additive-manufacturing systems, apparatuses and methods

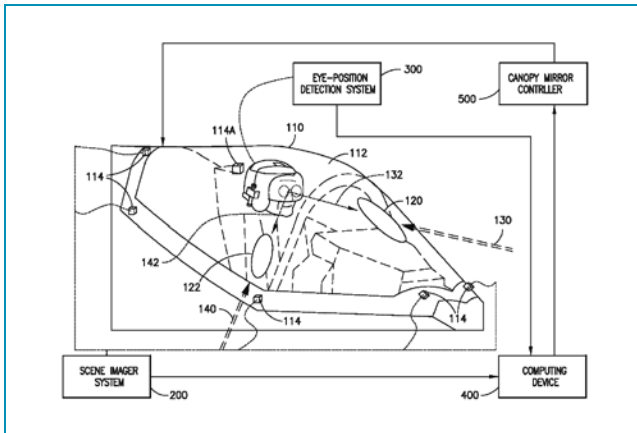
**U.S. PATENT 9,751,260 B2**  
**INVENTORS: DAVID M. DIETRICH, RUSSELL W. COCHRAN, DANIEL D. BLOCH, GARY W. COLEMAN**

Additive manufacturing is used to fabricate three-dimensional (3D) parts or products by adding layer upon layer of material. Additive manufacturing encompasses a wide variety of technologies and incorporates a wide variety of techniques, such as laser freeform manufacturing, laser deposition, direct metal deposition, laser metal deposition, laser additive manufacturing, laser engineered net shaping, stereolithography, selective laser sintering, fused deposition modeling, and multi jet modeling. Moreover, a variety of raw materials may be used, such as plastics, metals, concrete and glass.

Regardless of material or method, articles formed by additive manufacturing may require surface processing to provide a more desirable product. To improve the surface finish of a part fabricated with additive-manufacturing equipment, separate post-processing steps must be undertaken at processing location using conventional surface-finishing equipment and techniques. However, post-processing of surfaces could be cumbersome, expensive and time-consuming. In addition, conventional post-processing methods may be ineffective for reducing the surface roughness of the interior surfaces of some complex parts, resulting in products with less than desirable properties.

This patent, granted in September 2017, describes an additive-manufacturing system that includes a surface-processing device coupled to the additive-manufacturing head or to the housing to perform finishing on the new material.





## Window method and apparatus for protection from bright light sources

### U.S. PATENT 9,835,914 B2

**INVENTORS: MARK J. CLEMEN, JR., JOHN R. HULL, PHILIP E. JOHNSON, RICK L. MCGANN, GEORGE A. PERRY, ALAN F. STEWART, MARK S. WILENSKI, DONALD V. DROUIN, JR., LE LI, YONGXIN TANG, HAIPING YU, JIANGBIN ZHAO, JIE YANG, SHENGGANG WANG**

High-intensity light sources, such as laser and other photonic weapons, can jeopardize crew members' vision as they operate vehicles.

This patent, granted in December 2017, describes a system that provides active protection from these threats with a switchable mirror, minimizing disruption of aircrew line-of-sight by enforcing small mirrored spots on the canopy transparency to shade the aircrew's corneas from direct exposure.

More specifically, the patent describes an electrically switchable mirror, installed in a window or canopy, that protects crew members from a dazzling or blinding light source of arbitrary wavelength by switching successive layers made of cholesteric liquid crystals from a transmissive state to a reflective state. In addition, when a power failure occurs, the window becomes semi-transparent, providing some protection while still permitting the crew members to see through the window.

# IP intelligence

## Nearly a third of product value could come from intellectual property

Demonstrating the increasing role of intellectual property in the global economy, the World Intellectual Property Organization recently released figures showing that nearly a third of the value of manufactured goods comes from "intangible capital," such as intellectual products and reputation.

This is the first time the organization, an agency of the United Nations, has put a monetary figure on the kind of capital that is usually protected through intellectual property mechanisms.

In its biennial World Intellectual Property Report, published at the end of 2017, the agency concluded that intangible capital in the form of technology, design and branding, "permeates global value chains in important ways," ultimately determining company success.

Technology, one of the most important contributors of intellectual capital, "continues to transform global patterns of production and is bound to lead to further disruption," the report states. According to the analysis, income from intangibles increased by 75 percent from 2000 to 2014, accounting for about US\$5.9 trillion in 2014.

"Intangible capital will increasingly determine the fate and fortune of firms in today's global value chains. It is behind the look, feel, functionality and general appeal of the products we buy, and it determines success in the marketplace," said WIPO Director General Francis Gurry.

**TO DOWNLOAD THE FULL WORLD INTELLECTUAL PROPERTY REPORT 2017: INTANGIBLE CAPITAL IN GLOBAL VALUE CHAINS, VISIT: [WWW.WIPO.INT](http://WWW.WIPO.INT)**



PHOTO: HFX FORUM



PHOTO: BOEING

**From the top, left to right:**

**HALIFAX INTERNATIONAL SECURITY FORUM**

Julie Perkins, Boeing chief engineer of in-space vehicle propulsion systems, speaks alongside General John Hyten, Commander of United States Strategic Command, at the Halifax International Security Forum. The two participated in a panel discussion about dangers in space on Nov. 17, 2017.

**AMERICAN CHAMBER OF COMMERCE TO THE EUROPEAN UNION**

Tineke Bakker-van der Veen, Boeing managing director of Benelux and Nordics, in January at the fifth edition of AmCham EU's Gender Initiatives Breakfast series, addressed the lack of diversity in STEM professions: "As an aerospace engineer myself, and as someone who is very passionate about STEM, challenging young people to look out and beyond is a very fulfilling part of my job!"

**WELCOME AURORA!**

Aurora Flight Sciences, a developer and manufacturer of advanced aerospace platforms and autonomous systems, joined the Boeing enterprise in November 2017. Aurora will retain an independent operating model while benefiting from Boeing's resources and position as the leading provider of aerospace products and services. Aurora employees celebrated across their multiple global sites when the deal was finalized.

**NATIONAL HONORS**

In October 2017, Boeing Senior Technical Fellow Julio Navarro (pictured with his wife) was awarded the Engineer of the Year Award at the 29th Annual Hispanic Engineer National Achievement Awards Corporation conference in Pasadena, California.

**WILL THE ROBOTS WIN?**

Boeing Senior Technical Fellow Anne Kao speaks at the Society of Women Engineers conference "HI vs AI: Will the Robots Win?" event in October 2017. The discussion focused on the current and future relationship between artificial intelligence and human intelligence.



PHOTO: BOEING



PHOTO: BOEING



PHOTO: BOEING

## Technological journey of the commercial flight deck

# Less is more

From circuitous to simple, flight deck evolution is apparent when comparing Boeing's first successful commercial jetliner to one of its most recent.

Following its debut in 1959, the 707 helped change the way the world traveled. It took a minimum of three crew members to operate, and its flight deck is remembered by the overwhelming amount of switches and dials that adorned its ceiling and walls.

Fast forward to 2018, and you'll find a 787 flight deck that leverages electronic technology, improving safety operational capabilities and ergonomics, and providing flight crews with a clean, simplified look and feel.

Lighting and display optics have come a long way, with multi-color displays and LEDs replacing hundreds of dials and gauges. As technology advanced, computers replaced the flight engineer and navigator, eliminating seats and creating more space.

—MIKE LOMBARDI AND  
VIENNA CATALANI

PHOTO: BOEING



### BOEING 707

Pilots on the 707 recall a cramped, cluttered space with limited visibility.

PHOTO: BOEING



### BOEING 787

The 787—designed based on user feedback—boasts comfortable seats, brighter colors, a larger windshield and a heads-up display.



TOP  
100

## **Global Innovators Report 2017**

For seven years running, Boeing is one of the Top 100 Global Innovators as named by Clarivate Analytics.