Innovation Quarterly

2018 May
Volume 2, Issue 8
A publication of
The Boeing Company

TECHNICAL FELLOWSHIP

Faces of Boeing Technical Achievement

Introducing the 2018 class of Senior Technical Fellows

DOING THE INSIDE JOB
P.J. Wilcynski

FIELDING AN INTELLIGENCE
Joe Brinker

RUNNING INTERFERENCE
Janice Karty

STEERING THE WAY
Len Inderhees

BRINGING IT ALL TOGETHER
Michael Drake

MAKING THE MATH ADD UP
Ian Fialho

ACCESSING THE INFORMATION
Ian Willson

SOLVING MORE THAN PROBLEMS
Jay Lowell

MAKING THE CONNECTION
John Sullivan

INNOVATING BEHIND THE SCENES
Kevin Paxton

PUTTING PIECES TOGETHER
Don Farr

On the **cover**

The 2018 class of Boeing Senior Technical Fellows, recognized as the company's top experts in their fields. Read about each of them beginning on page 6.

Innovation
Quarterly

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SPECIAL THANKS
Boeing photographers worked across the country to capture images of the company's latest Senior Technical Fellows for this issue's front cover.

Featured

6 | Meet the experts

Every other year, Boeing selects the company's top technical experts in essential technology domains to become Senior Technical Fellows. In 2018, 11 experts were elevated to this post, all recognized as global industry authorities in their fields.

18 | A dome with a view

Boeing engineers collaborated with researchers from the Smithsonian, Carnegie Institution and a variety of other organizations on the infrastructure supporting one of the world's largest and most powerful telescopes now under construction. Using computational fluid dynamics, the team worked to validate the structural design of the telescope's critical enclosure.

26 | Brazil in the future of aerospace

We ask Boeing Brazil's director of research and technology about a partnership that is quickly demonstrating agility and mutually beneficial innovation on both sides. The strength in working together is expected to lead to game-changing technologies, in turn nurturing the aerospace ecosystem around the world.

Technical Papers

32 | Methods for Estimating a Probability of Rare Accidents in Complex Non-Stationary Systems

Estimating a probability of failures with aerospace systems is necessary for new designs, as with autonomous aircraft. If the design is safe—as it is supposed to be—accident cases are hard to find. Such analysis needs some variance reduction technique and some algorithms to be successful. However, these solutions cannot be used for models of short-lived, non-stationary system operations where independent agents have finite autonomy, likely with the presence of humans.

35 | Global Cognizance of Chemical Restrictions Drives Future Business

Public awareness of toxic chemicals in everyday household goods is increasing and government agencies are responding. Over the last 10 years the number of regulations specific to chemical uses has increased from less than 100 to more than 2,500 globally. A significant number of these impact the aerospace industry during production, or in aftermarket maintenance and repairs.

39 | Advancing Environmental Technology with IAEG and Our Competitors

The International Aerospace Environmental Group (IAEG), established in 2011, is an organization that focuses on issues and regulations within our industry. This group seeks continual improvement in the processes used by the industry, thereby delivering consistently high-quality products and regulatory compliance with reduced environmental impacts. Working Group 2 of IAEG focuses on replacement technologies for hazardous materials. This paper reviews replacement technology efforts and new development technologies that were kicked off in 2016.

Technological partnership across the pond

Allies and **air power**

Boeing has maintained a close relationship with the United Kingdom dating from the introduction of the North American Harvard military training aircraft in 1938. The company is now celebrating 80 years of partnership with British customers, suppliers, the Armed Forces and air transport industry.

Having first sent overseas field representatives to England on assignment for the B-17 Flying Fortress in 1941, Boeing has since helped to shape the future of aerospace by developing cutting-edge products and services with its partners in the U.K.

The company supplies products, services and technology to U.K. customers in the commercial and defense sectors and research industries and is building the first Boeing European manufacturing facility in Sheffield.

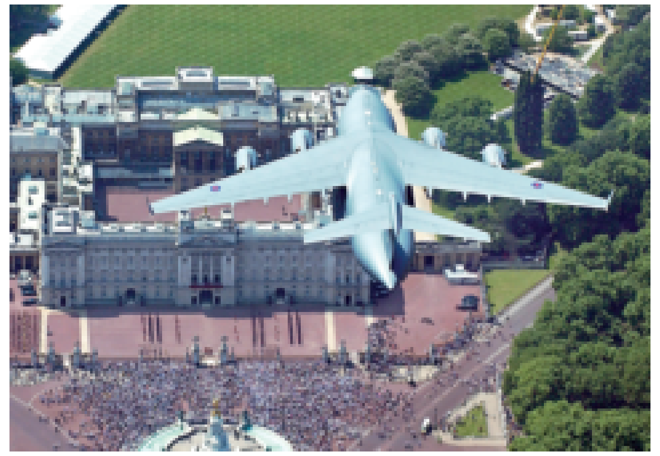
The Boeing footprint in the U.K. continues to grow through programs such as the 787 Dreamliner, Chinook Through Life Customer Support, The Boeing Portal and the Support Chain Information Services delivery partnership, formerly known as LogNEC. IQ

–MIKE LOMBARDI AND VIENNA CATALANI

PHOTO: BOEING

POSTWAR COMMERCIAL AIR CONNECTION
In 1949, Pan American Airways inaugurated transatlantic service, flying New York to London, with its new Boeing 377 Stratocruiser, developed from the Boeing B-29 Superfortress bomber.

PHOTO: BOEING



A ROYAL FLYPAST
A Royal Air Force C-17 Globemaster transporter aircraft flies over crowds at Buckingham Palace in London.

A world of **discovery**

At Boeing, we have a worldwide view of our business. Our mission—to connect, protect, explore and inspire the world through aerospace innovation—calls out this global perspective. And for us to accomplish this mission, we collaborate with colleagues and partners from every corner of the world.

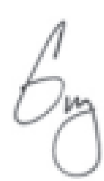
That's the way of a global industrial champion. And that's the way Boeing applies its breadth of experience and expertise across borders to generate world-changing innovation for humankind.

I'm pleased to say that this edition of IQ explores some of our international collaborations. Among the projects you'll read about in this issue are:

- Our research partnerships in Brazil, where we're researching many diverse yet strategically important topics such as aeroacoustics, sustainable materials and additive manufacturing.
- The making of the "Dynamic Ocean," a UK-created virtual environment to develop new capabilities for maritime products.
- A first-person account from Shane Arnott, a Boeing Senior Technical Fellow in Australia, about the fast creation of a ground-based system that allows multiple autonomous unmanned air vehicles to operate safely and avoid collisions.

The reason why Boeing works with entities across the planet is simple: In order for our products and services to be the best in the world, we need to partner with the best of the best across the world. When these collaborators work together with the bright, diligent members of the Boeing team, whose collective talents are as broad as they are deep, amazing things happen.

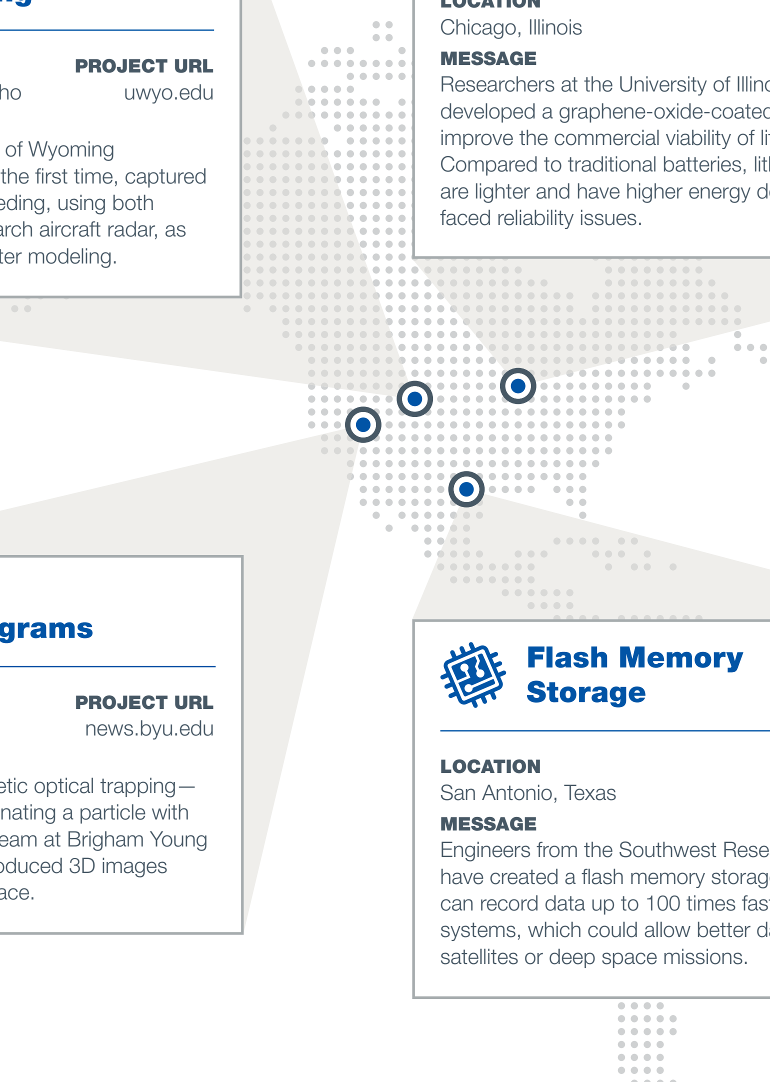
Technology breakthroughs are taking place not just within Boeing facilities, but also at institutions and companies worldwide. Look for Boeing to continue partnering with colleagues across the globe so that, together, we can change the world. IQ



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

Recognizing Advanced Developments and Research

Technology RADAR



Quantified Cloud Seeding

LOCATION
Laramie, Wyoming; Boise, Idaho

PROJECT URL
uwyo.edu

MESSAGE
A partnership of the University of Wyoming and Idaho Power Co. has, for the first time, captured direct observation of cloud seeding, using both ground-based radar and research aircraft radar, as well as high-resolution computer modeling.

Reliable Lithium-Metal Batteries

LOCATION
Chicago, Illinois

PROJECT URL
today.uic.edu

MESSAGE
Researchers at the University of Illinois at Chicago have developed a graphene-oxide-coated “nanosheet” that may improve the commercial viability of lithium-metal batteries. Compared to traditional batteries, lithium-metal batteries are lighter and have higher energy density, but have faced reliability issues.

True Holograms

LOCATION
Provo, Utah

PROJECT URL
news.byu.edu

MESSAGE
Using photophoretic optical trapping—moving and illuminating a particle with laser beams—a team at Brigham Young University has produced 3D images that levitate in space.

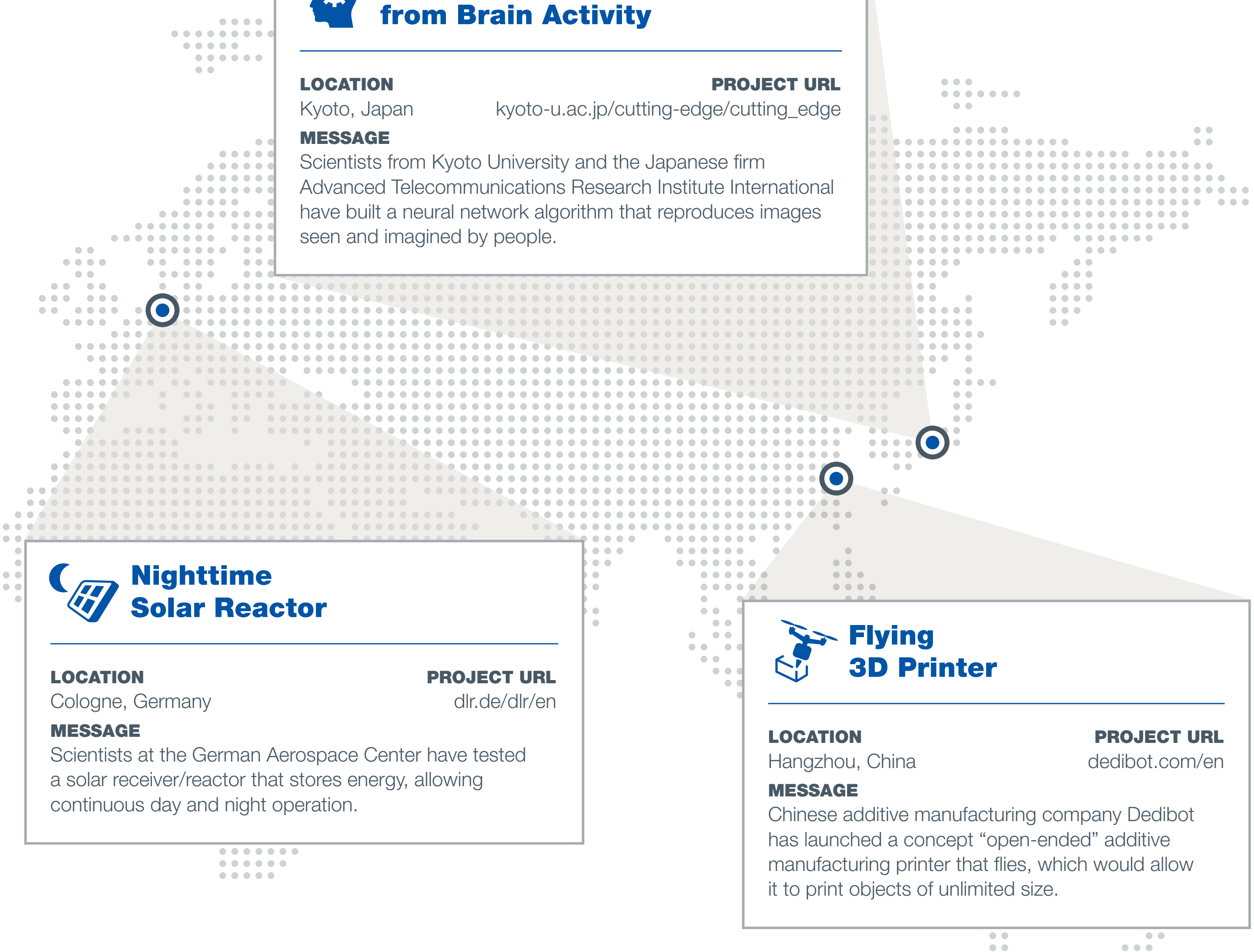
Flash Memory Storage

LOCATION
San Antonio, Texas

PROJECT URL
swri.org

MESSAGE
Engineers from the Southwest Research Institute have created a flash memory storage system that can record data up to 100 times faster than existing systems, which could allow better data gathering by satellites or deep space missions.

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.



Images Constructed from Brain Activity

LOCATION
Kyoto, Japan

PROJECT URL
kyoto-u.ac.jp/cutting-edge/cutting_edge

MESSAGE
Scientists from Kyoto University and the Japanese firm Advanced Telecommunications Research Institute International have built a neural network algorithm that reproduces images seen and imagined by people.

Nighttime Solar Reactor

LOCATION
Cologne, Germany

PROJECT URL
dlr.de/dlr/en

MESSAGE
Scientists at the German Aerospace Center have tested a solar receiver/reactor that stores energy, allowing continuous day and night operation.

Flying 3D Printer

LOCATION
Hangzhou, China

PROJECT URL
dedibot.com/en

MESSAGE
Chinese additive manufacturing company Dedibot has launched a concept "open-ended" additive manufacturing printer that flies, which would allow it to print objects of unlimited size.

Having the **customer's** point of view

A pilot gives his first-person perspective on operating the aircraft he supports as a Boeing engineer.

BY BEN GOELLER, MATERIALS, PROCESSES AND PHYSICS ENGINEER BOEING RESEARCH & TECHNOLOGY

When developing or improving our products, it's important, yet often difficult, to truly understand the customer's perspective.

But when it comes to the H-47 Chinook helicopter—an aircraft I support as an engineer—that customer is actually me.

I fly the CH-47 Chinook for the Army National Guard and recently returned to work at Boeing after a year of active duty supporting Operation Freedom's Sentinel in southern Afghanistan.

In flight school, I selected the H-47 as my platform over other airframes because I was already working for Boeing in Philadelphia supporting the Chinook line. I thought seeing both sides of the coin would be fun.

I was actually slotted to be a Black Hawk pilot until I worked a deal to switch over to Chinooks. I'm glad I did; I didn't know it at the time, but in the coming years I'd learn that the H-47 is by far the most capable and mission-essential vertical lift platform in the U.S. Army inventory.

Nowhere was this more evident to me than in Afghanistan.

I had trained for years within the safety of U.S. airspace and had hours of table talk with more experienced instructor pilots about what systems are available and how to use them. But I never truly learned what the aircraft could do and what actually worked best until I left the training environment and entered the operational theater.

Imagine for a moment that you're piloting a Chinook in Afghanistan. You're in a flight of three aircraft, you have 35 to 40 Afghan and American soldiers in the back, and you're on your way to a confined and dusty landing zone only a few hundred feet from the enemy objective.

There's no moon, little man-made lighting. Even with night vision goggles, it's dark and you can barely make out the contour of the mountainous ground.

As you get low on approach to land, you encounter several obstacles on your touchdown point that you weren't expecting. While reacting, you're engulfed in a dust cloud and can no longer see anything.

At this point you take enemy contact. Under fire and without good eyes on a place to land, you decide to do a go-around, taking off to come around and try again.

The five different radios you're listening to go crazy with F/A-18s and AC-130s covering your movements from overhead. They're trying to understand your course of action. Your flight engineers in the back are calling out what they can see. The ground force commander is looking for an update because half of his force is on the ground, and he needs to know when and where the other half will be able to join the fight.

> Turning back inbound, now the valley is completely obliterated in a dust cloud 500 feet high and a mile wide. (Those watching from the video feed at the base would later describe it as looking like an H-bomb had gone off.) And you're looking at this dust cloud trying to figure out how you're going to get back in there and complete the mission.

PHOTOS: BEN GOELLER

AN HONOR TO SERVE

Top left: Capt. Ben Goeller in the cockpit of a CH-47 flying across the Registan Desert in southern Afghanistan.

ABOVE: Goeller's CH-47 unit in Kandahar, nicknamed "Southern Cargo," comprised aviators from the National Guard's B Company, 3rd Battalian, 126th Aviation Regiment, out of Maryland and New York, and Army Reserve's B Company, 7th Battalion, 158th Aviation Regiment, out of Kansas.

It's in moments like these, reactive high-stress situations where things are not going as planned—where a pilot truly comes to appreciate the situational awareness and capabilities that the Chinook provides. I ask you to try to visualize this, but it is not possible to fully understand it until you've lived it as I and many other Army aviators have.

Dust is extremely dangerous in aviation. With degraded visibility, pilots get disoriented, run into obstacles or land with lateral motion, which causes the aircraft to roll over. The dust was so bad overseas that, after landing, our ramp gunners would often use the infrared pointers on their rifles to help the troops on the ground find the aircraft.

To alleviate this situation, the F model Chinook has advanced flight control and inertial systems that allow the pilots to hover confidently and make controlled landings in a dust cloud even in confined landing zones.

Back to this particular dust cloud, though: We were able to input a prior coordinated alternate landing zone into the system; navigate to it using the moving map and terrain avoidance features of the aircraft; and land safely while maintaining some level of calm, cool and collected decision-making—all with brain power left over to communicate our actions to the players involved.

It's an amazing airframe and has been the workhorse in Afghanistan for over 15 years. The Chinook's ability to move cargo in high hot conditions was highlighted whenever we flew with Black Hawks. We'd watch those crews load eight passengers and then claim to be right at their max gross weight. Meanwhile, my Chinook would be loaded like a clown car for a half-hour and filled with anything that was needed, including the personal cargo of those eight Black Hawk passengers.

Now how does this experience overlap with my Boeing job? I've seen situations where imperfections from the factory have caused issues for us in the field. In the short term, sharing those experiences with colleagues on the floor helps drive home the purpose behind production specs and the importance in understanding and adhering to them.

It's been a great honor and privilege to be just a small part of this 55-year-old program. And the primary lesson from my experience is long term. When we design and build, it's important to involve people who have operated our products within their various mission sets. Not just high-ranking decision-makers, but people using our products regularly in the operating environment. Establishing a dialogue and shared understanding with these users can only enhance our products. (We still don't have cup holders in the cockpit!) IQ

Meet the **experts**

Boeing names 11 new Senior Technical Fellows.

BY DAN RALEY, BOEING WRITER

Among nearly 50,000 engineers, scientists and technical professionals working for Boeing around the world, the Technical Fellowship represents the best of an already formidable technical team.

This year, Boeing advanced 11 of the company's top talent to the role of Senior Technical Fellow, the highest achievement for technical leadership. They are recognized for their commitment to personal and professional excellence and are major contributors at an industry level. They are recognized as authorities on the national and international stage.

Senior Technical Fellows demonstrate routinely their ability to overcome technical barriers and stand up for the tenets and values of Boeing's Engineering Code. And their continuing dedication to innovate drives Boeing's leadership in aerospace.




TECHNICAL FELLOWSHIP



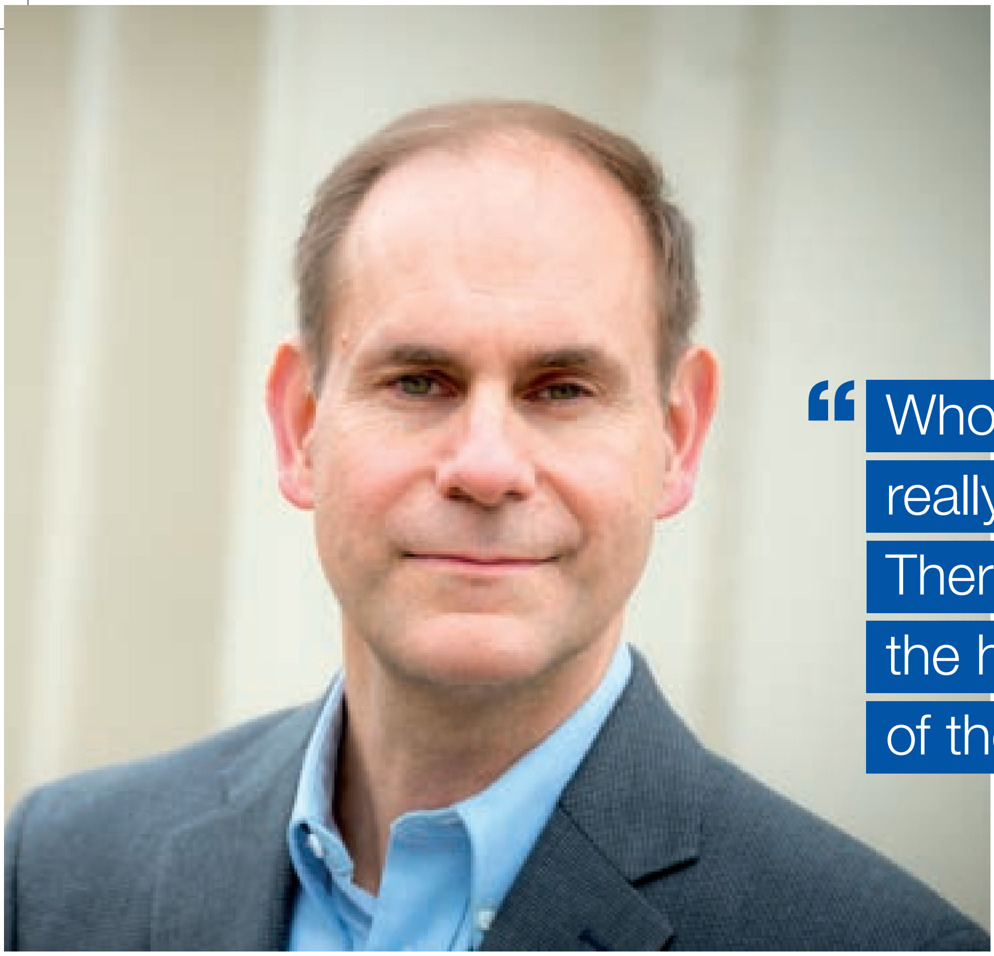


PHOTO: BOEING, ERIC SHINDELBOWER

> "Whole areas have really exploded. There's interest at the highest levels of the company."
>
> **JOE BRINKER**

Joe Brinker

AUTONOMY AND UNMANNED SYSTEMS

Fielding an intelligence

Joe Brinker might be the best person to stop and pester for directions. Among his many achievements, he makes a living out of automated route planning.

As the chief architect for Boeing's Battle Management Optimization Services, Brinker creates algorithms that can send an unmanned aerial system on a designated path through contested airspace, enabling it to perform various functions without engagement.

Solving an even harder problem, he will direct multiple vehicles through the same unsecured environment, one where they figure out how to divvy up tasks and work in concert effectively.

The Illinois native earned the role of Boeing Senior Technical Fellow for his ability to gauge the needs of a fast-moving unmanned marketplace and provide ready solutions.

"Whole areas have really exploded," Brinker said. There's interest at the highest levels of the company, where autonomy and artificial intelligence are considered second century projects. It's a wide-open field with broad applications."

Brinker spent the first part of his career at Boeing developing guidance, navigation and control capabilities for multiple defense projects.

As an STF in autonomy and unmanned systems, he expects his role to encompass more of the enterprise.

"There is a lot of commonality in terms of problems in military and commercial (products)," he said. "Being able to develop common solutions for autonomy and artificial intelligence provides more benefit and leverage to Boeing in the end. It also enables technical excellence." IQ

PHOTO: BOEING, PAUL GORDON

Michael Drake

AIRCRAFT CONFIGURATION DESIGN

Bringing it all together

Michael Drake accompanied his father to work at times, and this experience had a profound effect on him and his own career choices. They were together at higher altitudes.

Dad, a pilot, did Boeing flight crew training in the late 1960s and early 1970s. And the younger Drake sometimes got to ride in the jumpseat with his dad when he worked for Iran Air in the mid-1970s.

"I kind of always knew I was going to do something with flying," he said.

For more than three decades, Drake has been a Boeing configuration designer, working nearly every major airplane project during that time, including some that weren't pursued. The Sonic Cruiser. The 600- to 800-seat New Large Airplane. He also worked on the 787 Dreamliner, and recently the 737 MAX 10.

"My job is one everybody wants—I configure, lay out and architect airplanes," Drake said. "I like the creative process of designing. I love a challenge."

Drake doesn't have to be an expert in every area of airplane building, but he needs to know something about everything. His expert ability to grasp the big picture is one reason he was selected as a Senior Technical Fellow, the first from his field in several years.

As an STF, Drake can provide solutions on an even wider level across the company. He can be a leader without giving up his grass-roots work.

"New technology gives us the opportunity to do new airplanes different than before," he said. "Electric propulsion and autonomous operations are two exciting developments, to see where they're market visible. It's an exciting time." IQ

Don Farr

SYSTEMS ENGINEERING

Putting pieces together

Don Farr is a systems engineer who delivers model-based solutions for multiple enterprise programs, specifically relating to the way Boeing is revolutionizing manufacturing. He determines how different systems should fit and interact together. He's a details guy.

"You approach design from multiple directions," Farr said. "Model-based engineering is all about early integration of multiple domains into a design for performance, while accounting for manufacturability. If you design it right, then it's inexpensive to build and make."

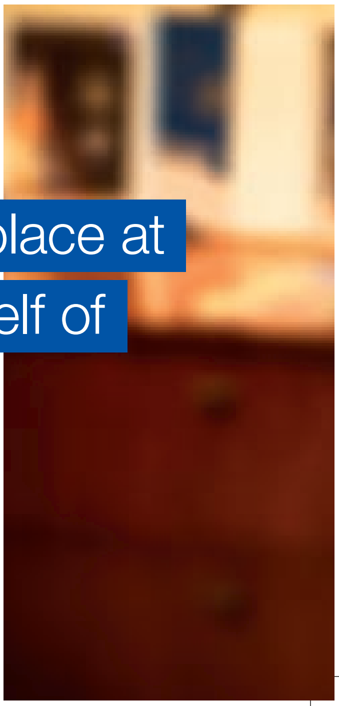
Based in Huntsville, Alabama, Boeing's hub for systems engineering, Farr has lent his expertise to a wide variety of projects, many of them proprietary. He's served as chief technologist for the next-generation Ground-based Midcourse Defense weapon system, developed a state-of-the-art computing lab to address tech development in data analytics, and led a research team to implement Boeing's first enterprise digital thread using the 777X folding wingtip.

Farr has treated the arc of his aerospace career much like the specifics of his work, deciding when and how it should come together, always with the future in mind. He took on bigger assignments and harder problems with the goal of someday becoming a Senior Technical Fellow. He now has the opportunity to help shape the company's strategic direction, especially digitally.

"It's the ultimate of where I want to be in my career," Farr said. IQ

PHOTO: BOEING, ALAN MARTS

PHOTO: BOEING, ELIZABETH MORRELL



> "People like me are very fortunate to be in the right place at the right time. I remind myself of that every day."

IAN FIALHO

Ian Fialho

MODELING AND SIMULATION

Making the math add up

Ian Fialho joined Boeing 20 years ago because it offered him a chance to work on some of aerospace's most challenging projects, to provide multidisciplinary modeling and simulation for complex dynamic systems.

As a newly installed Senior Technical Fellow, he lends his expertise to the International Space Station, the Space Launch System, the CST-100 Starliner, tankers, bombers, airliners and more.

"What appealed to me is that the math is very similar in all of these fields," Fialho said.

He's studied hose-drogue and boom refueling performance, spacecraft engine thrust vector control and debris analysis from the Space Shuttle Columbia incident. No less important, he used his knowledge of vibration isolation to help build a necessary piece of equipment suitable for the Space Station—a treadmill.

"When you run, you generate a lot of force when you hit the treadmill," Fialho said. "The Space Station can't take that kind of movement. We built a really fancy shock absorber, like in a car, to absorb the energy."

As an STF, he feels great responsibility to make sure technological excellence is driven across all of Boeing. In his mind, his timing couldn't be better.

"We've seen the rapid evolution of humankind over the last decade—it's a huge opportunity," he said. "People like me are very fortunate to be in the right place at the right time. I remind myself of that every day." IQ

PHOTO: BOEING, PAUL GORDON

Len Inderhees

GUIDANCE, NAVIGATION AND CONTROL

Steering the way

Len Inderhees wanted to study flight control, but his university didn't offer classes on the subject. The aspiring aerospace engineer joined the military—as an intern, not an airman—at Wright-Patterson Air Force Base near Dayton, Ohio, to complete his education.

In this capacity, Inderhees took every class the Air Force had to offer on control theory. He was the only civilian seated among pilots. A promising career was launched that eventually directed him to Boeing. He was drawn to how all of the systems interact.

"I saw the potential in using active controls on airplanes," he said. "That's really been a shaper of the industry over the last 50 years—going from simple, mechanically controlled airplanes to heavily integrated fly-by-wire."

Inderhees guides all commercial flight control projects in progress at Boeing, among them the 777X and a potential new airplane program. He learns what works and doesn't work on an Iron Bird, a flight control simulation built in a spacious Boeing facility near Seattle.

His flight control expertise led to his selection as a Senior Technical Fellow, a reward that brings greater opportunity.

"I recognize that I can contribute on a wider level than I have been," he said. "The breadth of what I'm able to see and the type of project that's underway is quite impressive. As I work on them, I'm more and more impressed by the capability of The Boeing Company." IQ

PHOTO: BOEING, ERIC SHINDELBOWER

Janice Karty

ELECTROMAGNETIC ENVIRONMENTAL EFFECTS

Running interference

As a young girl filled with curiosity, Janice Karty regularly traveled with her family on vacations to national parks in the West and gazed at the stars. Her interest in the galaxies overhead grew so strong she considered becoming an astrophysicist.

Today, Karty still fixates on the atmosphere—only at lower altitudes and in a slightly different capacity. As a Boeing electrophysics engineer and scientist, she ensures that aircraft systems are protected in the event of natural or man-made intrusions—everything from lightning strikes to adversaries jamming the frequencies.

“When you had old antenna TVs, you turned on a blender and you could see electromagnetic interference,” Karty said. “The same kinds of things happen when you have electromagnetic interference working into an aircraft. It can happen to any piece of equipment.”

In devising ways to keep people safe in the skies, Karty is an expert in the theory, analysis and application of electromagnetics. Karty’s skill and expertise in this work earned her a spot as a Boeing Senior Technical Fellow, the first woman named to the position from Boeing’s St. Louis campus.

“I figure if I have the qualifications, it doesn’t matter how I look,” Karty said. “I was the only girl in a lot of my math classes in high school. I never let it bother me because I was so interested in learning the material. If you show you’re capable, you will be noticed, respected and understood.” IQ

PHOTO: BOEING PAUL GORDON

Jay Lowell

SYSTEMS, SUPPORT AND ANALYTICS

Solving more than problems

Jay Lowell studied and taught atomic physics.

He worked for a software company that made first-person shooter video games to learn how to use the technology to enable Special Forces units to rehearse aoperations. He also served for two decades as a U.S. Air Force physicist and a DARPA program manager, developing new technologies based on quantum mechanical effects.

All of this brought him to Boeing, where in six years the systems engineer has engaged in problem-solving for three major projects—commercial airplanes electromagnetic effects, 777 fuselage upright automated build and 787 battery incident response.

What he solves are puzzles, mysteries and dilemmas.

"I call it forensics systems engineering," Lowell said. "The most interesting and challenging problems are not software or hardware; they're both. You have to understand how both work to make an impact on the world."

Lowell, named a Senior Technical Fellow this year, does work that ensures a lightning strike is contained and doesn't reach a fuel cell. He separates good and bad behaviors exhibited by 777 robots, seeking ways for them to be more efficient. He expects more high-level challenges to come his way.

"I came to Boeing to work on solving big, hard problems," he said. "The diversity of things I'll see in the future will be much higher. If it's still an interesting problem, then I'm happy." IQ

> "I came to Boeing to work on solving big, hard problems."
>
> **JAY LOWELL**

Kevin Paxton

WEAPONS AND SURVEILLANCE

Innovating behind the scenes

Kevin Paxton has done a lot of innovative things in his Boeing career, and it is reflected on his resume. However, his work history doesn't always explain exactly what he's accomplished.

As a chief scientist and engineer for weapons and surveillance, Paxton is known as an industry leader for his design of electro-optical systems for small satellites.

He also was the lead engineer in the development of the kill vehicle as part of the American nuclear missile defense system.

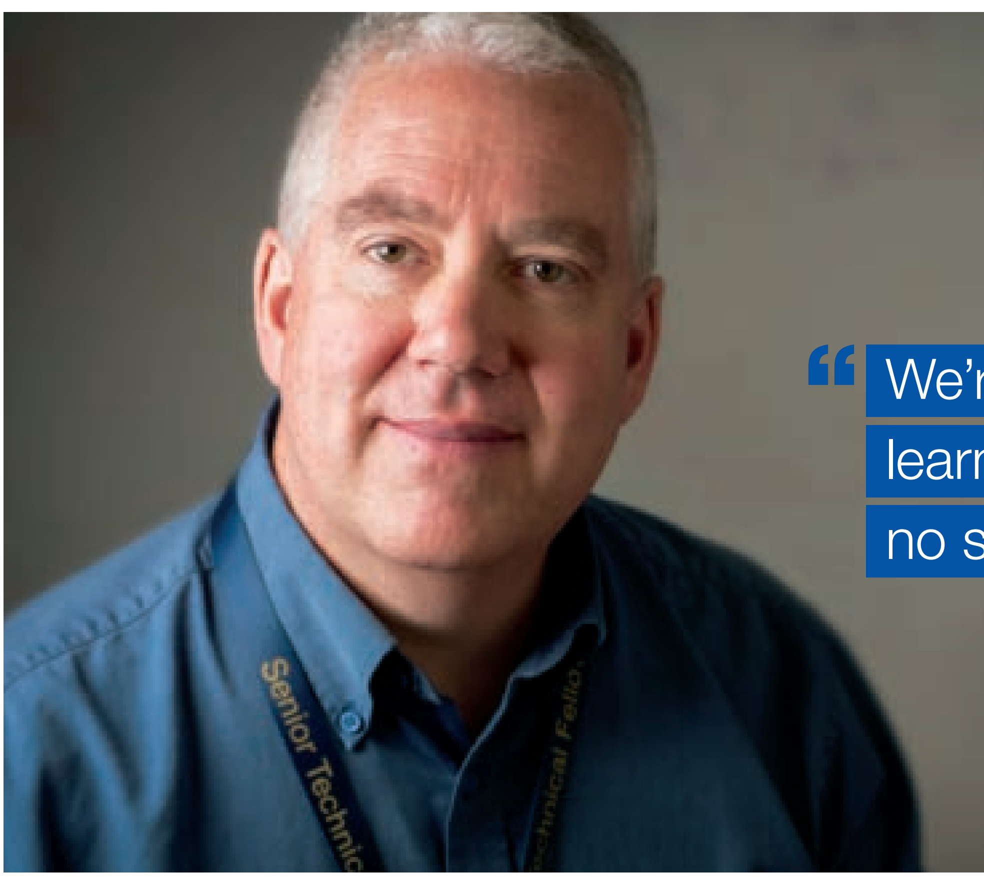
Paxton has recently focused on the growth of small satellites that use new advanced sensor processing technologies to find and photograph targets, and operate more autonomously than ever before.

During these developments, he has helped build a vertical capability to design and test advanced sensor technologies suitable for satellites and weapon systems. As a new Senior Technical Fellow, he has been able to share the technology to see where it fits other programs across Boeing.

"The technology is complicated, it's very complicated, and I think that's what appeals to me," Paxton said. "We're always learning.

"There is no standing still. There's always new technology—it's all about how we will bring it into our system," he added. IQ

PHOTO: BOEING, PAUL PINNER



"We're always learning. There is no standing still."

KEVIN PAXTON

PHOTO: BOEING, PAUL PINNER

John Sullivan

SPACE AND MISSILE SYSTEMS

Making the connection

John Sullivan is chief engineer for Boeing end-to-end systems, which means he finds creative ways to connect the world.

As an internationally recognized expert in large-scale satellite communications, Sullivan weaves together algorithms, software, hardware, sensors, optics, antennas, radios, signal processing and other intricate technologies to create one-of-a-kind products.

Colleagues and customers alike refer to the California-based Sullivan as “the problem solver.” Fellow engineers credit him with continually challenging them and offering valuable suggestions and critiques that lead to positive defense and commercial project development. This recognition led to his designation as a Boeing Senior Technical Fellow.

Sullivan was a driving force behind Mexsat, a satellite wireless system that connects government aircraft, maritime and vehicular platforms for multiple Mexican agencies; and Thuraya, a data services system centered in the United Arab Emirates that involves satellites, mobile phones and an operations center.

He also has worked on countless classified projects and is considered a pioneer in protected communications. He led the development of an anti-jam communication system now utilized on multiple Boeing-developed platforms. Early on in his career, he enabled a 10 percent increase in satellite solar power with no modifications to the original design, leading to his first patent. IQ

P.J. Wilcynski

PAYLOADS CHIEF ARCHITECT

Doing the inside job

P.J. Wilcynski will never forget his first airplane ride. The commercial flight carried him and his family from Syracuse, New York, to a vacation in Miami. The experience also went a long way to determining his career path.

As a boy that day, Wilcynski was fascinated with the interior of the airplane, how the flight attendant efficiently worked the galley, how all the different sections neatly fit together.

"Everything seemed like it was designed for a purpose and there was a place for everything," he said. "It was life-changing, it really was."

Wilcynski is a Boeing Senior Technical Fellow based in Everett, Washington, the first STF with payloads expertise. He's an airline industry expert in interior architecture, configuration, and airline operational and regulatory requirements. He's worked at Boeing for almost four decades, knowing all along exactly what he wanted to do. He joined Boeing after graduating from MIT with an architectural design degree.

For nearly two decades, Wilcynski has immersed himself in interiors product development, beginning with the Sonic Cruiser and carrying over to the ensuing twin-aisle programs, making advancements with each new design. As an STF, Wilcynski has the added responsibility of inspiring colleagues to share in his devotion to interiors.

"My focus for the near term is creating a space and environment for others to learn from my experiences and carry on with what we do," he said. IQ

PHOTO: BOEING, PAUL GORDON

> "My focus for the near term is creating a space and environment for others to learn from my experiences and carry on with what we do."

P.J. WILCYNSKI

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Ian Willson

DATA ENGINEERING

Accessing the information

Boeing has no shortage of analytical data. In some cases, trillions of rows of information are accessible, just waiting to be shared.

For Ian Willson, the challenge has been getting this rapidly expanding data warehouse that he oversees in front of the rest of the enterprise and showing programs how it can help them.

Willson, chief data strategist for Analytics & Information Management Services and the Boeing AnalytX platform, is the first Boeing Senior Technical Fellow for data engineering.

"As an STF, I'm involved in bringing us all together," he said. "Other STFs and chief engineers are calling now and saying, 'We want to do analytics, and we want to do something with you.'"

Willson has proved nimble in heading up parallel data analytics, a fast-moving technological tool for Boeing and for aerospace in general.

Once the founder of the first online air travel booking service, the Canadian native sees his Boeing role as two-fold: providing a digital thread, or connecting all aspects of design, manufacturing and service for an airplane; and offering a digital twin, or providing simulation and analysis to optimize design, flight test and troubleshooting.

"You can't slap it together," Willson said of a data solution. "You have to understand quality and data engineering at a scale to effectively build solutions on shared data. Otherwise, you could spend a million dollars trying to solve one problem." IQ

PHOTO: BOEING, MARIAN LOCKHART

The world's **biggest eyes** on the sky

Engineering the pursuit of astrophysical knowledge and the fundamental question of life.

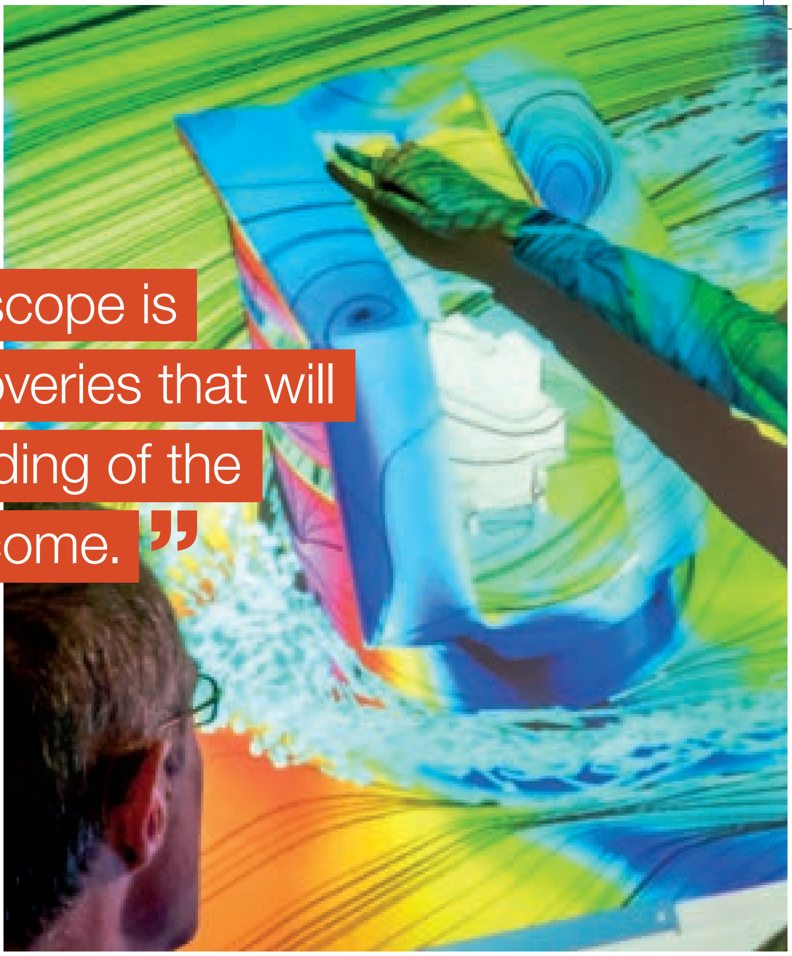
**BY ABDOLLAH KHODADOUST, AEROMECHANICS PROJECT MANAGER
BOEING RESEARCH & TECHNOLOGY**

Boeing engineers specializing in computational fluid dynamics are used to analyzing the aerodynamics of airplanes designed for low drag and high lift.

But they have recently been using their high-performance computing systems and labs in Missouri and California to provide valuable assistance to an international consortium of institutions with dreams of discovering extrasolar planets with the potential for sustaining life.

THE LONGEST SIGHT
The Giant Magellan Telescope, when completed in the Atacama Desert in Chile, is expected to offer, at least briefly, Earth's deepest view into the cosmos.

ILLUSTRATION: GIANT MAGELLAN TELESCOPE – GMTO CORPORATION



> "The Giant Magellan Telescope is going to make new discoveries that will shape human understanding of the cosmos for decades to come."

BILL NORBY, A SENIOR MANAGER WORKING IN BOEING'S ADVANCED RESEARCH ORGANIZATION

COLORS OF THE WIND
Boeing Technical Fellow John Ladd explains results from a CFD simulation showing the path of air as it hits and flows around the enclosure of the Giant Magellan Telescope.

When operational, the Giant Magellan Telescope should produce images at 10 times the clarity of the orbiting Hubble Space Telescope, potentially answering some of the most inspired and elusive questions in science: How were the first stars and galaxies formed? And where did the chemical elements that make up everything we know come from?

In short, what is the origin of life?

"The Giant Magellan Telescope is going to make new discoveries that will shape human understanding of the cosmos for decades to come," said Bill Norby, a senior manager working in Boeing Research & Technology, the company's advanced research organization. "We're excited to contribute to this multinational scientific endeavor."

The Giant Magellan Telescope, which will be built at the Las Campanas Observatory in the southern Atacama Desert in Chile, is one of three massive, ground-based telescope projects currently in work. Another one, aptly named the Extremely Large Telescope, is also being sited in the Atacama Desert. The third—the Thirty Meter Telescope—is planned for the summit of Mauna Kea in Hawaii.

The Giant Magellan Telescope Organization (GMTO) was started in 2004 by the Smithsonian, Carnegie Institution, the University of Arizona and Harvard.

Since then, several other project partners have joined. By the time the telescope sees first light, targeted in 2023, it would be the largest known to humankind, until the other two come online.

The Really Big Ones

	APERTURE DIAMETER	COLLECTING AREA	TARGET DATE
Giant Magellan Telescope (GMT)	24.5 m	368 m^2	2023
Extremely Large Telescope (ELT)	39.3 m	978 m^2	2024
Thirty Meter Telescope (TMT)	30 m	655 m^2	2027

PHOTO: BOEING, TIM REINHART

Because the dry and windy climate at Las Campanas can compromise the quality of images that the telescope will provide, a protective enclosure is being constructed to divert wind around the structure and away from the mirrors. That's where Boeing comes into play.

Engineers have done extensive work with GMTO using computational fluid dynamics (CFD) to model the flow of wind around the structure and help with design. They are now working on experimental testing of a model of the telescope in the water tunnel to further validate that CFD work.

Similar to how engineers validate aircraft design, the model of the telescope is placed in the water tunnel with built-in dye ports. When the tunnel is turned on, bright streams of colored dye flow around the model, simulating how wind will move around the structure.

"This is a bit outside our usual playing field," said John Ladd, a Boeing Technical Fellow who worked on the project. "Our typical CFD analysis doesn't include elements such as a huge multi-segment mirror (24 meters in diameter) and mountainous terrain with large boulders and low valleys. It was a fun challenge, and the work expanded our capabilities, which benefits Boeing and future customers with similar challenges." IQ

More scientific and technical data about the Giant Magellan Telescope is available at the project website, www.gmto.org/resources.

GIANT MAGELLAN TELESCOPE

Las Campanas Observatory:
Atacama Desert, Chile

Altitude of site:
2,516 m (8,254 ft.)

Height of housing:
63 m (206 ft.)

Moving weight:
1,100 t (2,425,085 lbs.)

Diameter of each mirror:
8.4 m (28 ft.)

Effective diameter of all mirrors:
24.5 m (83.5 ft.)

Total collecting area of mirrors:
368 sq. m (3,961 sq. ft.)

Wavelength sensitivity of telescope — near infrared and visible:
320–25,000 nm

**SHANE ARNOTT,
SENIOR TECHNICAL
FELLOW**

Autonomous **advantage** in Australia

Australia's progressive airspace regulations and wide-open spaces make it the ideal country to launch the largest autonomous systems development program for Boeing outside the United States.

In working with our customers at the Shell-operated QGC business in Australia, it became clear there was a significant opportunity for more automated capability to increase productivity and safety. Unmanned aerial vehicles (UAVs)—specifically Insitu Commercial's ScanEagle—presented a solution well suited to the vast and rugged environment of the Surat Basin.

In order to use ScanEagle flights in the field, the Civil Aviation Safety Authority (CASA)—the Australian airspace regulator—needed to ensure the UAVs would be able to detect and avoid local air traffic in manned airspace.

That's what led to Boeing, with its subsidiary Insitu to partner with the government of Queensland to develop a ground-based system for broad-area, beyond-visual-line-of-sight capability. This system provides a key element of a multilayered safety scheme that allows autonomous vehicles to safely operate while avoiding collisions with other manned and unmanned systems. It enables unmanned aerial system operators at ground-control locations to see real-time information about the local airspace and move beyond their immediate line of sight.

> This system provides radar, communications and data correlation to provide a common operating picture, giving CASA the confidence needed to grant the operation of ScanEagles in manned airspace.

Australia has become one of the leading locations for the development of autonomous systems due to its low population density, progressive air regulation by CASA and significant government support. For this program partnership, the Queensland government provided significant research and development funding that enabled Boeing, Insitu and a talented team of local suppliers to develop the system into a solution with benefits to Australia, as well as the larger global market.

We were able to take advantage of that support and the ecosystem to take the technology from idea to export within 18 months—gaining for ourselves, our partners and our customers a significant capability advantage in the rapidly growing and highly competitive marketplace of autonomous systems.

While this timeline may seem fast in the aerospace market, it's part of our DNA within Boeing, and specifically at Phantom Works International. Our role is working with global customers to rapidly understand their needs and prototype a solution that's ready for market in a short period. We use modeling and simulation to develop virtual representations of the solutions, then work with governments or industry partners to fund a rapid development program. Building off existing technology and using small, smart suppliers, we build a tight team that develops a solution to meet the need, while ensuring the original cost and schedule targets can be met.

In Australia, Boeing has a software development capability advantage in terms of competency and cost. We also have a customer with a need for autonomous systems at a commercial scale. Working together with our U.S. colleagues, we recognized that this type of need was common and in demand in their market, as well.

We pulled skills and resources from across Boeing on a long-term collaborative roadmap from the beginning. And we developed a flexible system architecture that would allow for adapting the sensor combination on the system. This was a major step toward developing the enabling architecture that could eventually lead to a smoother journey for future passengers.

Based on the early success of this program, Boeing's recently signed partnership with the government of Queensland marks the largest autonomous systems development program outside the United States.

Boeing will work with small- to medium-sized Queensland businesses to develop transformative "brain-on-board" technology. The program will complement the work undertaken by Australia's Trusted Autonomous Systems Defence Cooperative Research Centre, taking research outcomes and developing them into exportable commercial products for the global autonomous market.

The development of the system proves the success of this new model of global product development. It also uses our best strengths across the company to partner locally and develop and sustain capability in locations where we have advantage.

I expect to see many more examples to come in the near future. IQ

Shane Arnott is a Boeing Senior Technical Fellow and director of Phantom Works International. He is an international expert in modeling and simulation, and visualization technologies.

PHOTO: BOEING

THE FUTURE TAKING FLIGHT
Boeing's ground-based system for broad-area, beyond-visual-line-of-sight capability shown deployed in Australia.

We pulled skills and resources from across Boeing on a long-term collaborative roadmap from the beginning.

PHOTO: NICK FETTY, IOWA STATE UNIVERSITY

ON THE MOVE
The Iowa State University solar car, Penumbra, races across the Australian outback last fall (left).

The Iowa State University PrISUm solar car team holds up a Boeing flag at the finish line in Adelaide, Australia (right).

Boeing, can you ship my car?

Company helps Iowa State team get its solar vehicle to Australia

BY MARC SKLAR, BOEING WRITER

They were ready to start from Darwin in north Australia, sleep in the Outback, and end up 3,021 kilometers (1,877 miles) away in Adelaide. All the Iowa State University solar car team needed was to get to the starting line.

That's where Boeing stepped in to help. A Boeing logistics and global services team worked with transportation services company Landstar and logistics firms Yusen and DHL Global Forwarding to get the car Down Under and back after the race.

The car, nicknamed Penumbra, competed in the adventure-class race for cars with multiple seats. It had four seats along with four doors, a cargo area and a rear windshield.

PHOTO: NICK FETTY, IOWA STATE UNIVERSITY

Although Penumbra just missed the six-day time limit for the race, unlike the first- and second-place finishers, which broke down multiple times each, the Iowa State team showed how reliable a solar car can be with no breakdowns.

Team PrISUm spent two years building its 408-kilogram (900-pound) car to compete in the 2017 Bridgestone World Solar Challenge last fall. As PrISUm's 14th-generation car, Penumbra was designed to be a car a consumer might actually want.

"Our solar electric vehicle incorporates a rear window, increased passenger space, ease of access, and complete with significant storage in the rear hatch," the team described on its race page. "PrISUm set out to build a car that one could use in their everyday life. Our vehicle displays state of the art technology with a touch screen infotainment system, integrated JBL audio, electronic paper displays, and wireless charging for your cellphone."

Boeing's efforts included getting the packing crate for the car from its manufacturer to Iowa State, then getting the crated car to O'Hare International Airport in Chicago for a flight to Australia, and reversing the process at the end. The team also made sure the shipments had all the needed clearances from export and customs officials in both countries.

A particular challenge was handling the car's lithium-ion battery modules, which required special handing and shipping approvals.

"It just felt great to be able to support this amazing group of students who had put their hearts into building the solar car," said J.J. Iwasaki, a senior manager of supply chain logistics.

The ISU team was thankful for the Boeing assist, which helped make Team PrISUm the only solar car program to receive its vehicle on time to test and prepare.

"Through the process, they taught us so much valuable information in such a short time," said Dylan Neal, who led the team at the time. "The best part is we will be able to pass on that knowledge for years to come." IQ

2017 Bridgestone World Solar Challenge Results

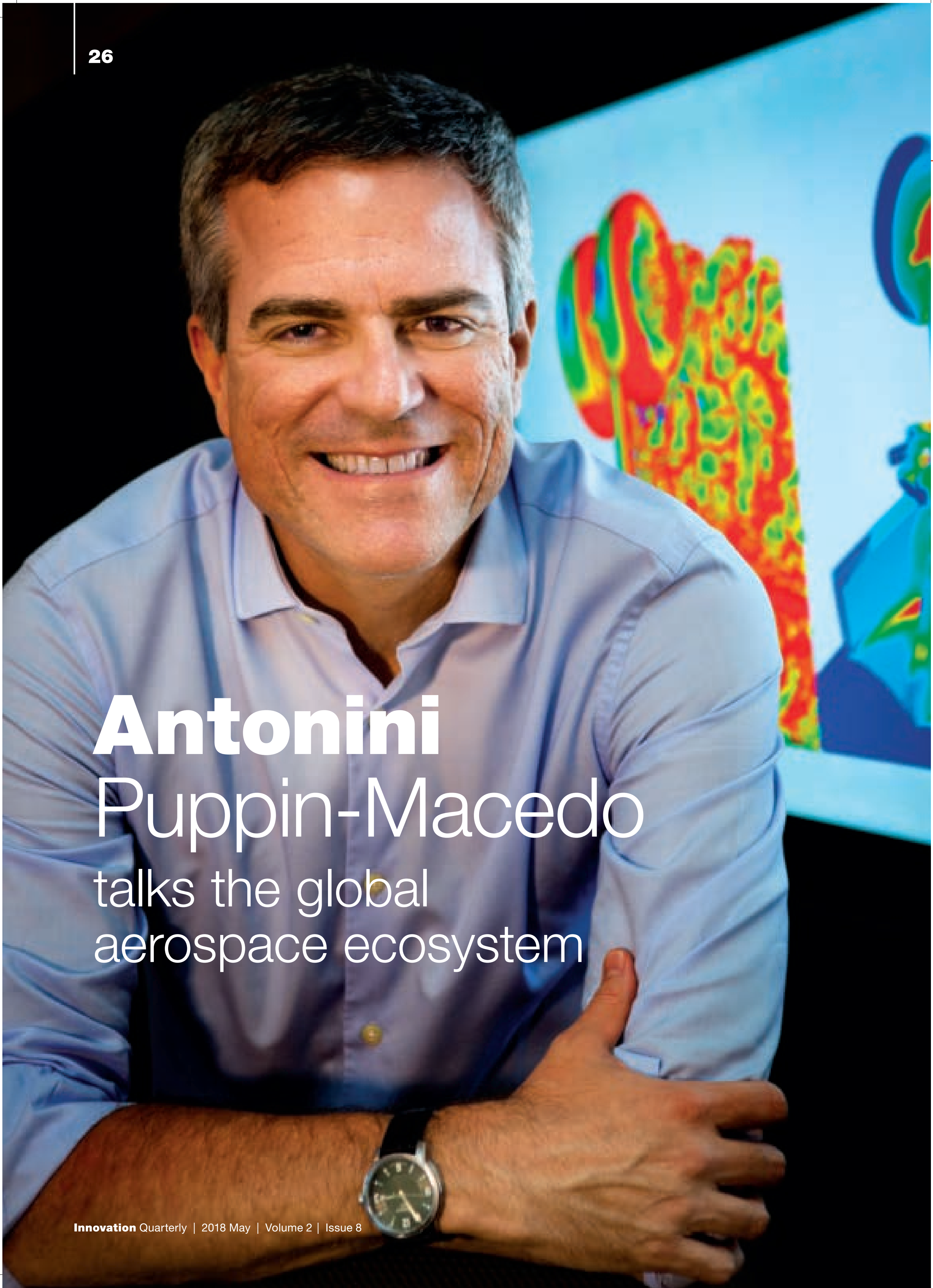
Challenger Class

1. Nuon Solar Team—the Netherlands
2. University of Michigan Solar Team—USA
3. Punch Powertrain Solar Team—Belgium

Cruiser Class

1. Solar Team Eindhoven—the Netherlands
2. HS Bochum—Germany
3. Clenergy TeamArrow—Australia

COMPLETE RESULTS POSTED AT
www.worldsolarchallenge.org



Antonini Puppin-Macedo talks the global aerospace ecosystem

The innovation landscape in Brazil is but one strong example of how Boeing's research partnerships nurture a global industry ecosystem of aerospace technology.

BY WILL WILSON, BOEING WRITER | PHOTOGRAPHY BY MICHELE MIFANO, SPICAT INTERNATIONAL

Q&A with the director of Boeing technology in São José dos Campos (São Paulo state), a hub of Brazil's aerospace companies, R&D organizations and academia.

Q Why does Boeing have a research center in Brazil?

A Boeing invests in R&D internationally for three main reasons: to access world-class technologies and talent, helping us to improve performance and affordability; to co-invest with partners to do more together faster than we would be able to do separately—accelerating and increasing productivity via collaboration; and to strengthen our understanding of and presence in local markets, that is, to generate value-added opportunities for local communities and Boeing.

All of this applies in Brazil. We are focused on strengthening our R&D portfolio through local partnerships, and delivering technologies of value to Boeing and to Brazil. In our experience here, we have been able to develop strong relationships with leading R&D and academic organizations, in an environment that values capturing and protecting intellectual property. We also have been able to develop relationships with the Brazilian government R&D supporting organizations, become immersed in the innovation support ecosystem, and develop funding opportunities to increase the effect of world-class technology development projects for Brazil.

Q What are the strengths of the Brazilian innovation ecosystem?

A Brazilian engineering culture is very practical and holistic—that is, innovation drives toward real-world applications that result in applied technologies.

Let me give you an example of what I mean. A paper by three folks in our Boeing Brazil team received an award for best paper at Boeing's signature internal technical conference last year. The paper focused on an automated cruise climb solution to be implemented in future Boeing flight management systems. In less than a year, the technology was developed, patented, implemented and transitioned to commercial application within Boeing. In our market environment, that ability to transition ideas into customer-oriented solutions is crucial.

It's important to note, as well, that we have found great support at the Ministry of Science Technology, Innovation and Communications, the Ministry of Development, Industry and Commerce and their investment support agency APEX. We are discussing with EMBRAPII (Brazilian Agency for Industrial Research and Innovation) and FAPESP (São Paulo State Research Foundation) funding opportunities to leverage our investments in our local partners, as well as bringing U.S. academic partners to this collaborative scenario.

And there's still lots of opportunity to shape innovation in Brazil. We are developing a strategy project with the MIT Industrial Performance Center, as a strategic university partner, to take a deeper look into how Boeing and Brazil can better work together and bring more mutual benefits, impact and speed in technology.

We also have Georgia Tech MBA students working with our researchers in Brazil to tap into the business value of our R&D. In fact we just had a very nice visit by the Georgia Tech teams to our research center and partners to present their initial business assessments.

Q What are some areas of specific research interest in Brazil?

A We are always looking to create a technology leap forward with real-world application possibilities. We've found several opportunities in Brazil where we can work with partners to rapidly advance world-class technical solutions and research—and to do so on topics and research areas that are especially salient in Brazil.

A good example is an aerodynamics project (focused on aeroacoustics) in which we are

BRAZIL TEAM
Boeing's core São Paulo research team: from left, Italo Romani, Onofre Andrade, Antonini Puppin-Machedo, Jose Fregnani, Marcelo Villar and Catherine Parrish (not pictured, Glaucia Balvedi).

In less than a year, the technology was developed, patented, implemented and transitioned to commercial application within Boeing.

bringing together the University of São Paulo and the state University of Campinas—two of the top universities in Latin America and sources of world class talent—as well as Stanford University, a strategic university partner of ours in the U.S. In the last two years, we have performed wind tunnel campaigns and complex CFD (computational fluid dynamics) simulations in benchmark cases and Boeing applications, using Boeing's proprietary code in Brazil.

Another great example is the work on sustainable materials and additive manufacturing we are developing in partnership with Embraer. A recycled titanium technology—a technology that was developed by Boeing in Russia—is now flying in our 2018 ecoDemonstrator program, integrated in collaboration with Embraer. Our work is crucial to explore the potential for this new technology, bridging from invention to application, which is what matters when it comes to real innovation.

Here in Brazil, we are also developing applications in recycled titanium powder for additive manufacturing, with environmental and cost benefits to the industry. Environmental sustainability is of great importance in Brazil, and has been a key area of our efforts here.

In flight performance and efficiency, in addition to the cruise climb technology we mentioned before, we are just starting a project with GOL airlines for "big data in the skies" for their fleet and to use software in tablets to provide real-time guidance to the pilots and airplane, to save fuel or improve performance. We will fine tune the technologies in a joint tech project with GOL—the fifth-largest 737 operator—to help them be more efficient as a competitive differentiator with the 737.

Q Boeing's relationship with Embraer has been in the news recently. What are your thoughts?

A We have had a research partnership with Embraer for many years, including establishing a Joint Research Center for Sustainable Aviation Biofuels in 2015 and our joint work on our ecoDemonstrator program. The first time Boeing's ecoDemonstrator program had flown in a non-Boeing platform was in 2016, and it was an Embraer E170.

Our joint efforts on biofuels exemplify our mutual value as partners. We not only continue to work with Embraer on biofuel research, but we are jointly leading advocacy and policymaking to enable the sustainable aviation biofuels industry in Brazil. Recently we were invited to provide our vision, together with Embraer, to the Brazilian Senate commission on the subject. This is a model for how industry partners can work together to accomplish something that will have large and long-lasting positive influence on the world. IQ

PESQUISA E TECNOLOGIA
Antonini Puppin-Machedo heads a core group of researchers and engineers at Boeing's technology facility in São Paulo.

Environmental sustainability is of great importance in Brazil, and has been a key area of our efforts here.

Selections from the Boeing Technical Journal

The Boeing Technical Journal is a peer-reviewed periodical for Boeing subject matter experts to capture and share 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

METHODS FOR ESTIMATING A PROBABILITY OF RARE ACCIDENTS IN COMPLEX NON-STATIONARY SYSTEMS

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GLOBAL COGNIZANCE OF CHEMICAL RESTRICTIONS DRIVES FUTURE BUSINESS

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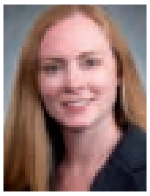
ADVANCING ENVIRONMENTAL TECHNOLOGY WITH THE IAEG AND OUR COMPETITORS



Jennifer Branton is a Technical Lead Engineer in the chemical technology division of Boeing's advanced research organization. She is one of Boeing's representatives to the IAEG.

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.

Methods for Estimating a Probability of Rare Accidents in Complex Non-Stationary Systems

Summary

BY ÍTALO ROMANI DE OLIVEIRA | JEFFERY MUSIAK

Despite increasing levels of automation, aerospace systems are often inserted in heterogeneous organizations having both technical infrastructure (hardware and software) and human beings with certain roles and responsibilities.

Estimating a probability of failures or accidents with aerospace systems is often necessary when new concepts or designs are introduced, mainly because such events may pose threats to human life or property. In highly sophisticated systems, such as these "socio-technical" systems featuring people interacting with technical systems, accident cases are not obvious and may be the result of complex combinations of events, thus adequate analysis techniques should be employed.

The traditional method of analyzing safety in aerospace systems is the elaboration of a Safety Case, which is a structured argument, supported by evidence, intended to justify that a system is acceptably safe for a specific application in a specific operating environment. Safety cases are used as acceptable means of compliance when a regulatory authority does not have a repeatable and prescribed process for compliance assurance or certificate issuance, or when the system under scrutiny is sui generis and no existing standard pertains, situations often encountered in innovative designs.

The limitation is that traditional Safety Cases do not guarantee full consistency among the several safety case sections and individual elements, thus non-obvious failure paths may be grossly ignored.

These challenges grow with the system complexity that has accompanied technological advances. Thanks in large part to these advances, accident rates in aviation have consistently dropped over the last few decades, while cost and energy efficiency improved markedly. A corresponding evolution in safety analysis methods is needed.

One of the emerging alternatives to Safety Cases is called System-

> The basic principle of Theoretic Accident Model and Processes (STAMP) is to identify leading indicators for risk management based on the assumptions underlying our safety engineering practices and on the vulnerability of those assumptions rather than on likelihood of loss events.

Theoretic Accident Model and Processes (STAMP). Its basic principle is to identify leading indicators for risk management based on the assumptions underlying our safety engineering practices and on the vulnerability of those assumptions rather than on likelihood of loss events.

STAMP is a qualitative and comprehensive accident model to analyze accidents in complex systems. STAMP assists in recognizing scenarios, non-functional interactions and the incorrect models and processes that will be used in the development of a safer system. However, its main limitation is that, by itself, it does not calculate any probability of accident, thus requiring complementary modeling techniques able to do so.

Another analysis technique, Multi- agent dynamic risk models (MA-DRMs), has been proven successful for quantifying the safety properties of complex socio-technical systems. Such models estimate failure and accident rates during early design stages, particularly for the systems whose failure could result in catastrophic consequences. These rates need to be under certain target levels of safety (TLS) as set by governing regulations.

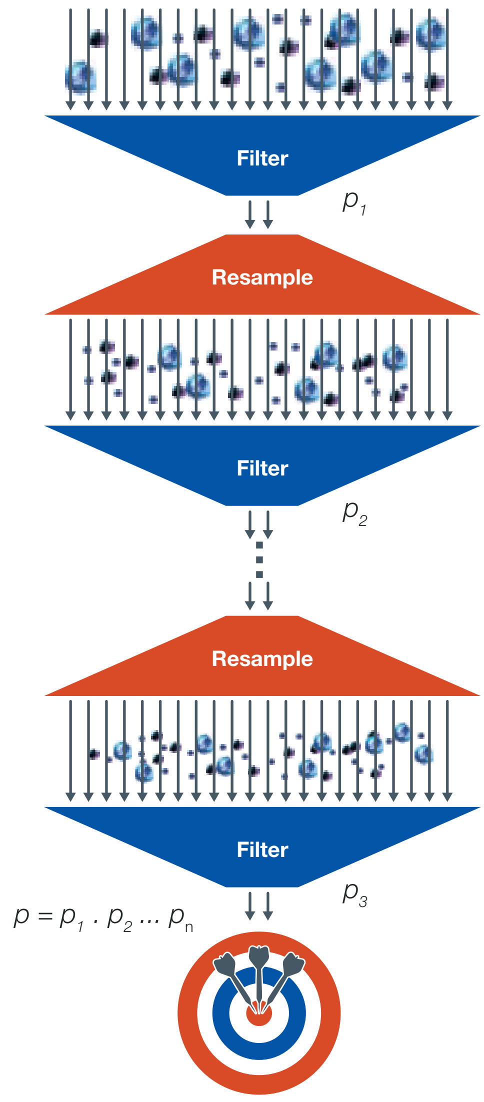
One of the difficulties in this estimation is that the TLS, expressed as a probability of occurrence of an undesired event per unit of time, is often on the order of 10-9 or less—and such rare occurrences are difficult to verify analytically using realistic models.

One way to proceed with this estimation is to use sequential Monte Carlo methods, among which one of the best known is referred to as "multilevel" or "importance splitting." Additionally, in order to improve computational efficiency, sequential Monte Carlo solutions are expressed in the form of a particle filter, as is the case of the Interacting Particle System (IPS), illustrated in Figure 1.

However, developing and tuning a proper particle filter to deal with rare events is challenging because of the degeneracy that results from the lack of diversity after successive resampling steps, which in turn results in high variance or, often, in not calculating any occurrences of target events.

Another way to perform rare event sampling is to employ optimization techniques such as the Cross-Entropy method, in order to find alternative probability distributions, with higher occurrence of the desired event, which then can be used in importance sampling to allow the estimation of the base rate of occurrence of the rare event. However, such a technique forces fitting of predetermined distribution shapes and this may result in large errors.

FIGURE 1.
Illustration of the principle of particle filtering.



Many other methods exist for rare event probability estimation, among which the family of methods named Markov-Chain Monte Carlo (MCMC) has achieved a prominent success in failure analysis of complex systems. However, such methods require the system under analysis to have states with stationary probability distribution, which is hardly true for socio-technical systems that depend on human agents and do not run on a continuous basis.

Despite these difficulties, our research work shows that there are ways to produce statistically significant results involving rare accidents with non-stationary MA-DRM models of complex systems. The approach that produced the best results so far is based on smart partitioning of the probability search space. We developed an algorithm that, given a MA-DRM model of the system, explores the event probability space and partitions it in a way that allows computation time to be focused in the partitions with higher probability of accidents. So far, we applied it in case studies involving simulated scenarios of highly automated manned aircraft and it showed capable of producing statistically significant results for accidents of very low probability. We also compared it with the standard Interacting Particle System (IPS) and the latter failed to achieve statistically significant results, as it can be seen on Figure 2.

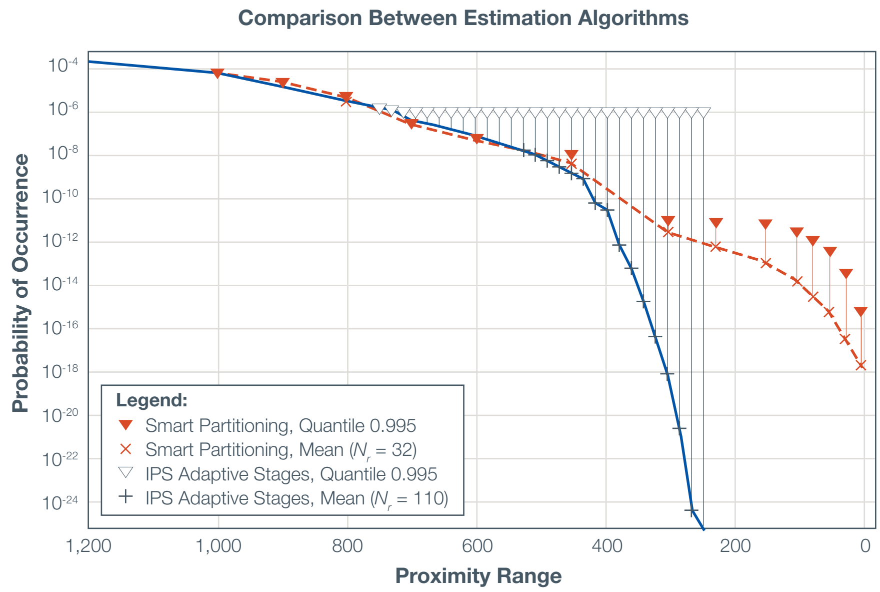


FIGURE 2.
Comparison of probabilities of reaching filtering distances, according to different algorithms.

In this figure, one can see that only the smart partitioning algorithm reaches the collision event (proximity range equals zero), while IPS does not, rapidly diverging, with mean values going extremely low but with very high upper limits, which show lack of statistical significance. Also, the smart partitioning algorithm took one-fifth of the time taken by IPS to compute, using about the same amount of memory.

It is worth noting that our bibliographic search did not find an example of probability estimation below 1E-10 for models of complexity similar to ours, and here we have reliable results below 1E-17. Our models allow use of Stochastic Differential Equations (SDE) which, by definition, introduce an infinite number of random variables and contribute to the model complexity, which, on the other hand, is managed by efficient sampling and careful implementation of the model.

We believe that our approach can greatly help the development of innovative aerospace products and operational concepts by diagnosing system safety early in the design phase. IQ

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

"Methods for Estimating a Probability of Rare Accidents in Complex Non-Stationary Systems"

Please visit **boeing.com/IQ.**

Global Cognizance of Chemical Restrictions Drives Future Business

Summary

BY STEPHANIE R. LABOO | LINDA M. THOMAS

Global chemical regulations have entered a new era requiring more transparency and greater data from not only manufacturers and importers but also downstream users for both civil and defense operations.

Most product sectors do not have sufficient information systems in place to retrieve and store chemical data that is needed to meet current and future regulatory requirements and customer inquiries. To continue transitioning from a reactive regulatory strategy to a proactive strategy will require significant investment in securing agreements with the supply chain, investment in capital for the proper information technology infrastructure, investment in documenting proper configuration management protocols (drawing callouts), and investment in documenting processes that ensure targeted chemicals are not introduced into new products.

Adopting a proactive strategy can create long-term value for Boeing.

In this paper, we are focusing on global environmental legislative agencies, for example the U.S. Environmental Protection Agency (EPA), whose mission is to “protect human health and the environment” through developing and enforcing environmental regulations, and helping its stakeholders understand these requirements. Another important regulatory agency of interest to Boeing is the European Chemical Agency (ECHA), whose mission is to implement the European Union’s chemicals legislation, which “helps companies to comply with the legislation, advances the safe use of chemicals, provides information on chemicals, and addresses chemicals of concern.”

Over the last decade, these regulatory agencies, along with agencies in many other countries, are passing legislation and regulations requiring companies to know the chemical composition of their products that are supplied in commerce.

Of the hundreds of environmental regulations being adopted throughout the world, new rules on chemicals, substances and materials are the most abundant. Although most of these regulations typically target the uses for everyday household consumer goods, aerospace manufacturing, including supplier operations and also in service fleet operations, could be impacted. Simply stating that supply chain complexities, unawareness to materials purchased by buyers and cost burdens is no longer being accepted by regulatory agencies as a reason for exemptions.

Figure 3 illustrates several proposed and released chemical regulations dating back to 2004 that have had an impact on the manufacture, operations and maintenance of aerospace products.

As an example, the Canadian EPA, U.S. EPA, and the Stockholm Convention have proposed regulations phasing out the manufacturing, import and use of specific brominated flame retardants (for example decabromodiphenyl ether or decaBDE). These flame retardants have been used in plastics, sidewall panels, carpets, curtains and other textiles in the interior of the airplane, as well as in electrical connectors and components.

The Boeing Company spent significant amounts of money in labor hours searching for all of the uses of these chemicals in Boeing-designed parts, communicating with the supply chain to ensure they know their uses must be phased out, conducting research and development to find alternative products, certifying these new products, preparing specification updates, and at times creating

Over the last decade, these regulatory agencies, along with agencies in many other countries, are passing legislation and regulations requiring companies to know the chemical composition of their products that are supplied in commerce.

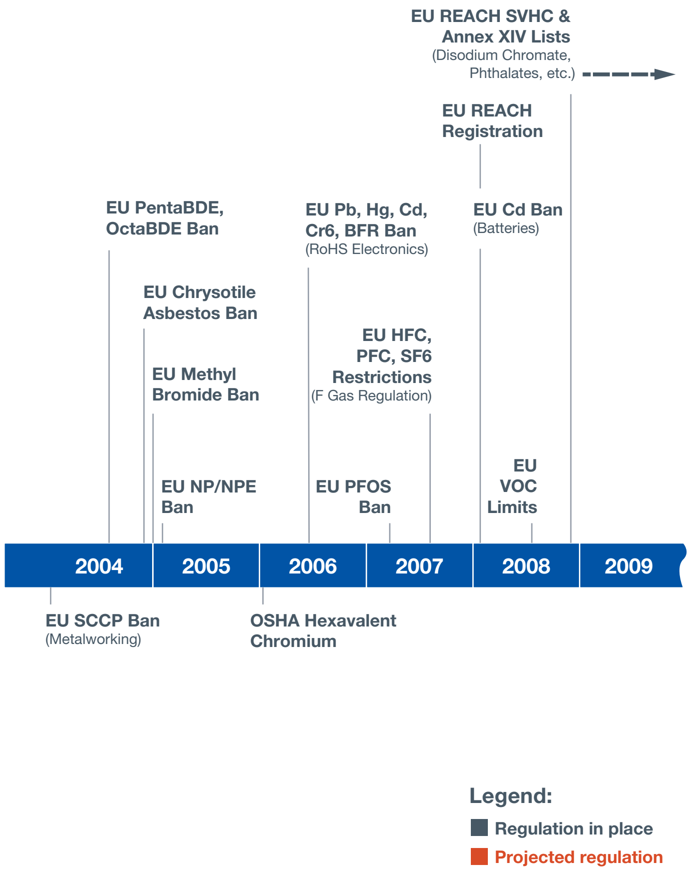


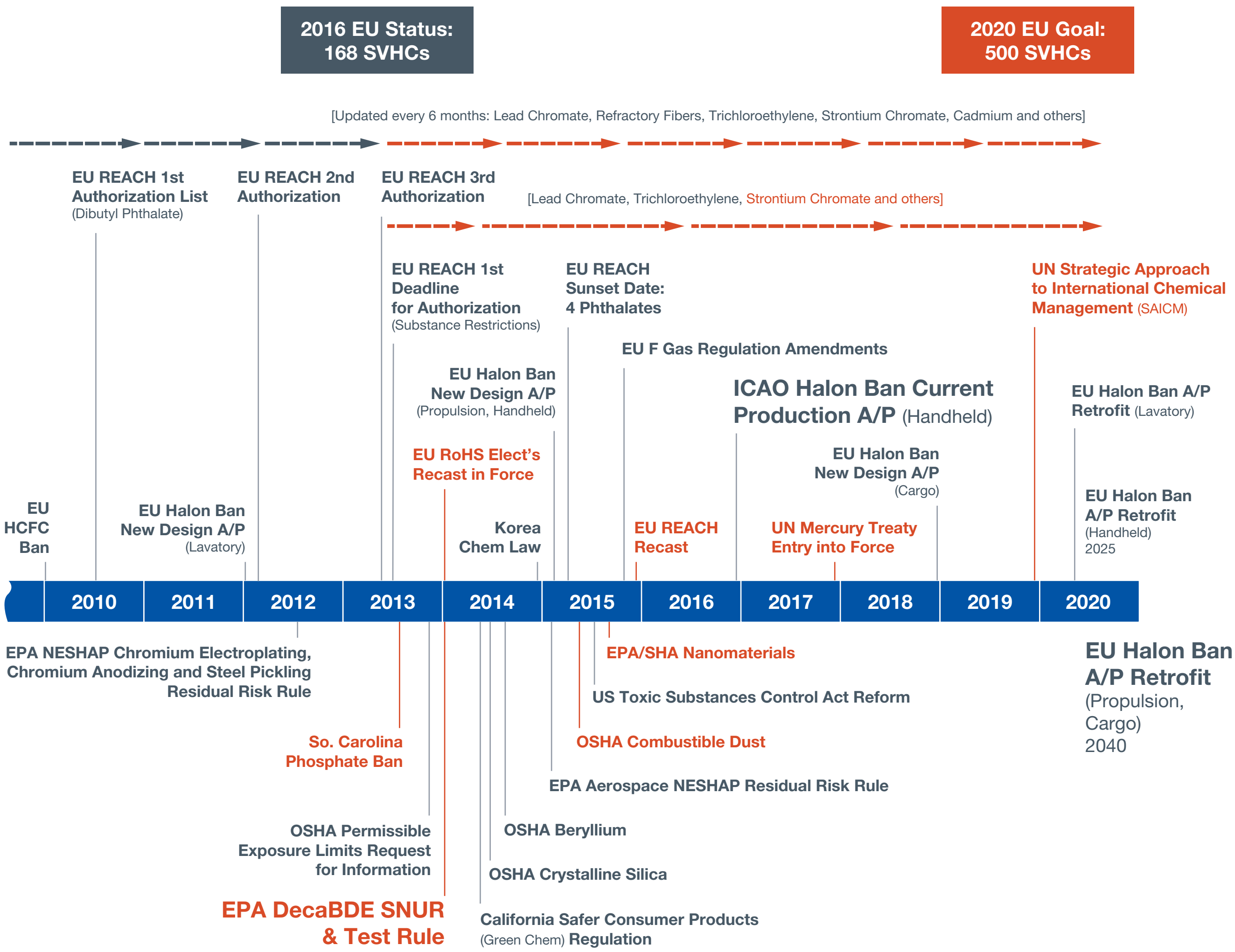
FIGURE 3.
Chemical regulations dating back to 2004.

part number updates to enable configuration control of modified parts and assemblies.

For Boeing to contain the costs of mitigating chemical and material obsolescence, the engineering community must be more strategic about selecting materials and products when designing aircraft products. In addition, the company must become more aware of the chemical constituents used in Boeing-designed and supplier-designed components. And so, we explore ideas to make more progressive material choices to alleviate downstream regulatory burdens.

Using materials and processes already qualified and certified for airworthiness and also being quite familiar with their properties helps the company reduce costs and increases quality. Using familiar processes also allows for better information to be used to predict maintenance cycles for customers and determine reparability. Although these are all benefits, many of these familiar products utilize compounds that are being phased out by environmental agencies all around the world. Many of these processes do have an alternatives process that has been qualified for years, yet old technologies are called out in designs or allowed as options. Examples of this are shown in Table 1.

Environmental trends tend to show that once one country or region starts to ban or restrict a compound, many countries follow suit with similar or identical regulations. Quickly removing the use of targeted materials from current designs will alleviate the need to spend money on regulatory mitigation in the future when additional countries and regions follow suit and enact similar regulations.



To effectively mitigate chemical risks, chemical compounds are identified in the materials and processes specifications that are used on Boeing-designed parts. These processes and products are then searched in a database to find out which programs and functions have drawings that are impacted if the compound is taken out of commerce or restricted in any way.

However, material and process specification searches can be challenging because of nonstandard data input methods. Even more difficult are direct product callouts.

TABLE 1.
Targeted chemicals versus alternative technology.

Technology with Targeted Chemicals	Alternative Technology
Cadmium plating	Zinc-nickel plating
Chromic acid anodize	Boric-sulfuric acid anodize, sulfuric acid anodize
Chromated paints and primer	Nonchromated paints and primers
Mercury-containing fluorescent lighting	LEDs

Companies can no longer be unaware of the manufacturing processes of upstream suppliers and must be actively knowledgeable of product compositions that come in contact with the general public. This information goes beyond high-level chemical safety data found in safety data sheets.

Companies continually buy out or merge with other companies and change the name of products, or products are no longer manufactured for various reasons and need to be replaced. Finding every drawing using a specific product is imperative to ensure the right callouts are established and production is not disrupted.

As one example, Henkel AG & Company, a manufacturer of numerous adhesives, sealants and chemical finishes, has acquired product lines or entire companies such as Loctite (1997) and the adhesives and electronic materials businesses from AkzoNobel (2008). Starting in 2012, Henkel launched a rebranding initiative to consolidate the names of all the products they acquired. Although product compositions or formulations did not change, callouts and specifications on drawings that utilize these materials needed to be searched and updated to reflect the new product name.

Traditionally, Boeing has relied on upstream suppliers of parts and materials to be compliant with government environmental regulations. The assumption when parts and materials are received is they are environmentally compliant with local regulations and are installed on Boeing products. A slight shift in this approach has occurred within the last five to six years because of regulations such as European Union's Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), legislated through the European Chemical Agency, where countries want to know the final chemical composition of products entering their country.

Companies can no longer be unaware of the manufacturing processes of upstream suppliers and must be actively knowledgeable of product compositions that come in contact with the general public. This information goes beyond high-level chemical safety data found in safety data sheets. Some suppliers are either reluctant to provide this information or at times simply do not have the information because of the depth of their own supply chain.

How can additional chemical information be obtained and retained effectively without compromising confident business information? How can we achieve transparency in the supply chain? Currently, teams throughout the company are working with an outside consortium to help answer this question.

The International Aerospace Environmental Group is a trade association formed by major aerospace companies around the globe that focuses on global environmental laws and regulations impacting the civil and defense industry. In collaboration, the group developed the list of 2,000 chemicals used by the industry that are targeted for phase-outs or bans by environmental agencies all over the world. This list is periodically updated in an effort to stay ahead of developing regulations and legislations.

Because it is a targeted list, it can be used to negotiate transparency with the supply chain to disclose specific chemical constituents without requesting full disclosure. In addition to supply chain usage, the list can be used to ensure alternative technologies are not being researched and developed with chemicals targeted for ban or phase-out in the future. IQ

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

"Global Cognizance of Chemical Restrictions Drives Future Business"

Please visit **boeing.com/IQ.**

Advancing Environmental Technology with the IAEG and Our Competitors

Summary

BY JENNIFER BRANTON

The International Aerospace Environmental Group (IAEG), established in 2011, is an international organization that focuses on environmental issues and regulations within aerospace. Boeing is one of the founding members of this organization along with 11 other industry leaders.

With the ever-increasing number of regulations adopted globally, there was a large need to have an organization representing our industry while focusing on the myriad laws and regulations impacting health and the environment.

This group seeks to drive continual improvement in the processes used by the aerospace industry, thereby delivering consistently high-quality products and regulatory compliance with reduced environmental impacts.

Chemical regulations can originate from any number of countries that are implementing new policies. However, many of the regulations that impact the aerospace industry's use of certain substances are initially brought forth by the European Chemicals Agency (ECHA) or the U.S. Environmental Protection Agency (EPA).

One of the European Union regulations administered by ECHA is REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals). Companies that manufacture or import certain substances into Europe are required to register with ECHA, and collect and report information on substances imported or used above one metric ton per year.

ECHA evaluates the information that is submitted by companies and assesses the risk to human health and the environment. A substance may be identified as a substance of very high concern (SVHC) if it is carcinogenic, mutagenic, toxic for reproduction, or persistent or bioaccumulative and toxic. Materials that are labeled as SVHC may become subject to authorization under the REACH regulation for continued use in Europe. When a substance is placed on the authorization list it is assigned two dates: a last application date to apply for authorization and a sunset date, which is the date when the substance can no longer be used within Europe without having been granted approval to continue use through an authorization application.

REACH regulations do not only affect Boeing. They also have an impact on the operations of Boeing's suppliers, some approved processors and maintenance repair operations that service Boeing aircraft.

IAEG currently has about 50 member companies representing more than half of the aerospace industry with a combined annual turnover of more than $400 billion. There are several working groups that have a variety of focuses, ranging from monitoring and surveillance to reporting and replacement technologies. In particular, Working Group 2 (WG2) focuses on replacement technologies and has more than 40 participants representing more than 26 member companies.

In late 2015, the IAEG executive committee approved a change in the IAEG charter to allow collaborative work between member companies under a collaborative agreement. This was followed by a revision to the WG2 charter to define how these collaborative activities could proceed. The years of 2016 and 2017 were dedicated to developing the process flow for new replacement technology efforts and establishing the initial projects' statements of work and collaboration agreements.

Five replacement technology projects were initiated in 2017 and are described in the sidebar.

PHOTO: BOEING

IAEG Working Group 2 collaborative chemical replacement projects

Hard chrome plating

Chromic acid is used in the hard chrome plating process to produce a thick hard chrome plating to be applied to steel or other metal alloys. Hard chrome plating is applied directly to a base metal by electrodeposition of a solution containing chromic acid or potassium dichromate.

The electrodeposition process makes it possible to apply hard chrome plating to parts with complex geometries. It is a cost-effective coating resistant to corrosion and to wear from sliding, fretting and environmental conditions.

Although several alternatives have been developed for hard chrome plating, none are direct drop-in replacements. Thus, process modifications and design changes will be required.

The goal includes exchanging information to identify alternatives for hard chrome plating on standard parts and original equipment manufacturer designs.

Chromate conversion coatings

The second replacement project is focusing on conversion coatings that provide corrosion protection and electrical conductivity to aluminum substrates. The proposed solutions will be hexavalent chromium-free.

The goal of this technology exchange is to review the proposed environmentally compliant alternatives to chromate conversion coatings and summarize performance data provided by the participants and major suppliers. The team will then propose next steps.

Bond primer

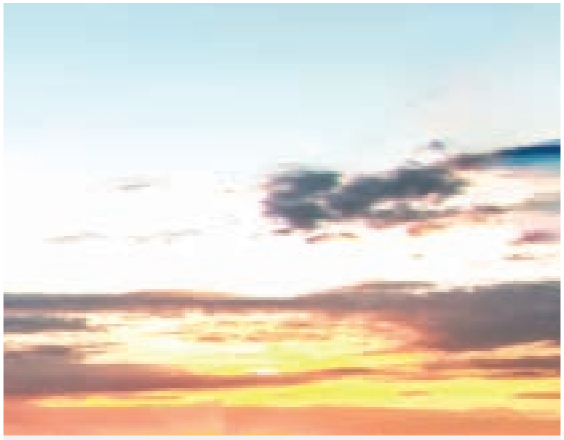
Bond primers are used for a variety of applications and often contain strontium chromate, which has a sunset date of January 2019. In addition to corrosion resistance, bond primers enhance wetting capability for film adhesive contact and improve adhesion between the substrate and adhesive. These properties result in widespread use over many different applications.

This technology exchange will include replacement efforts to identify applications and the functional requirements, exchange technical information regarding past replacement efforts, and identify potential alternatives to current bond primer systems.

Cadmium plating on industry-standard parts

Cadmium functions as a sacrificial coating when it is plated onto copper, aluminum or steel substrates. A sacrificial coating corrodes before the substrate metal, thereby protecting it. Although some alternatives exist to cadmium plating, industry-standard parts provide an additional challenge to replacement. Cadmium-plated fasteners and cadmium plated electrical connectors are used extensively in the aerospace industry.

The design and manufacture of industry-standard parts are conducted per industry specifications. These parts may be manufactured by many suppliers across different countries and subsequently used by many different customers. The output of this work will include a list of industry -standard parts that are within the scope of this project; a set of the technical, commercial and environmental requirements of alternatives; and the resulting data produced from the requirements testing of these alternatives.



The IAEG, established in 2011, is an international organization that focuses on environmental issues and regulations within aerospace. Boeing is one of the founding members of this organization along with 11 other industry leaders.

Corrosion-inhibiting epoxy primers

Corrosion-inhibiting epoxy primers are used to protect metals against oxidation. Oxidation occurs over time when metals are exposed to fluids, humidity or dissimilar metals. Like bond primers, epoxy primers also contain strontium chromate. This corrosion inhibitor had a sunset date of September 2017, set by ECHA and thus needs to be replaced with an alternative.

This project team will exchange information on test methods that have been used by the various team members for critical test requirements and establish a list of fundamental key requirements for the aerospace industry. The project team will create a list of available primer candidates that have the potential to meet the requirements. The scope could then be expanded to establish a test plan and begin testing potential candidates. IQ

As part of the REACH regulation it is necessary for all businesses in the aerospace industry that conduct business in Europe to find replacements for the regulated hazardous chemicals. Many of these materials pose a great challenge to finding an alternative that performs well enough to pass the performance requirements.

Collaborative efforts among these companies shows that there is an industrywide effort to find alternatives to hazardous materials and to be more environmentally conscientious. Additionally, the cost savings can be significant for the participating companies; the collaboration allows each of these companies to contribute a portion of the project financing rather than each individual company funding the entire effort independently.

Collaborative research among competitors can be difficult and requires a careful balance of strategic sharing of proprietary information to advance the technology and protection of proprietary information for competitive advantage. Individual companies are responsible to use their unilateral business discretion to decide if and how to utilize results of the collaborative research and efforts.

We hope these initial collaborative projects will be the beginning of a great resource for the aerospace industry to overcome technical challenges and find solutions together for hazardous chemical replacements. IQ

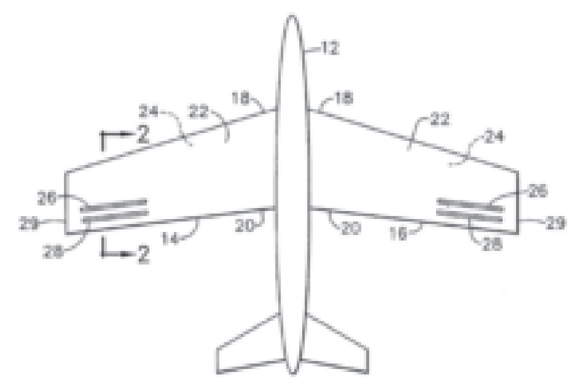
To read and download the complete Boeing Technical Journal paper titled:

“Advancing Environmental Technology with the IAEG and our Competitors”

Please visit **boeing.com/IQ.**

Patent **spotlight**

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



Active Flow Control for Transonic Flight

U.S. PATENT 9,908,617
INVENTORS: AHMED A. HASSAN, CASEY L. MADSEN, GARRETT M. BILLMAN

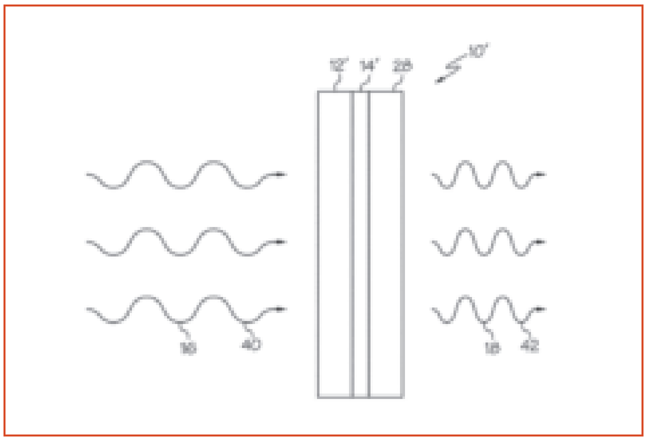
Attitude of air vehicles is typically controlled by flight control surfaces (e.g. flaps, rudders, and fins), which require substantial infrastructure that increases cost, weight, and vehicle complexity, while decreasing vehicle performance.

This recently issued Boeing patent describes an air vehicle that has an active flow control system that controls air vehicle motion during transonic flight by controlling airflow through orifices in the airfoil to alter the strength and location of shock waves.

Such a system mitigates the need for typical hinged control surfaces, the use of heavy hydraulic/pneumatic actuators and the associated under-surface plumbing, thus resulting in a reduction of wing/vehicle weight and mechanical complexity.

> "Now, more and more, innovation is the engine behind economic growth, and our patent system is the crown jewel that provides both the incentives and protections necessary to enable that innovation."

ANDREI IANCU, UNDER SECRETARY OF COMMERCE FOR INTELLECTUAL PROPERTY AND DIRECTOR OF THE USPTO



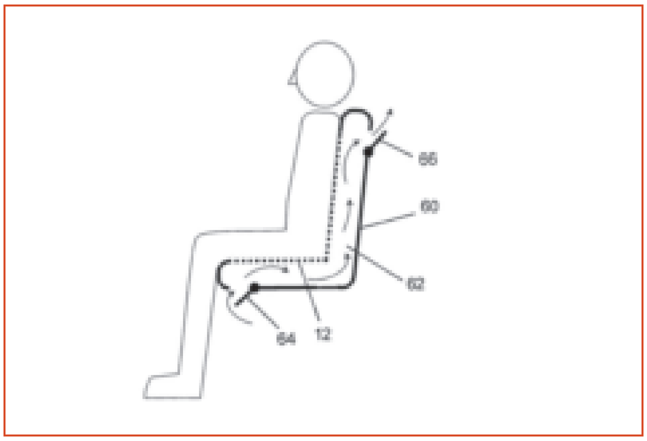
Electromagnetic Radiation Shielding Assembly

U.S. PATENT 9,939,131
INVENTORS: DALLAS S. SCHOLES, ERIC P. OMAN, JASON D. HABEDANK, DAVID J. MEYER

A laser pointer can generate a focused, high power laser beam that when directed at the glass of a flying airplane can distract the pilot. The easy availability of commercial laser pointers makes this a risk to aircraft safety. Specialized sunglasses or tinted windows may alleviate the impact of a directed laser beam, but also could restrict the pilot's vision.

This newly granted Boeing patent proposes a method for making a shielding assembly that describes how to manipulate the coating on the surface of an object to create unique specialized coatings that absorb a specific frequency—such as the frequencies currently used by commercial laser pointers—and then emanates that energy at another frequency.

The shielding assembly may include a transparent substrate layer and transparent active layers positioned with respect to the substrate. The active layers are configured to absorb electromagnetic radiation having a first wavelength and to emit electromagnetic radiation having a second wavelength—one that is in the near infrared spectrum, which is invisible to the naked eye. Thus, the shielding assembly could transform light energy that may interfere with visibility into light energy that does not interfere with visibility.



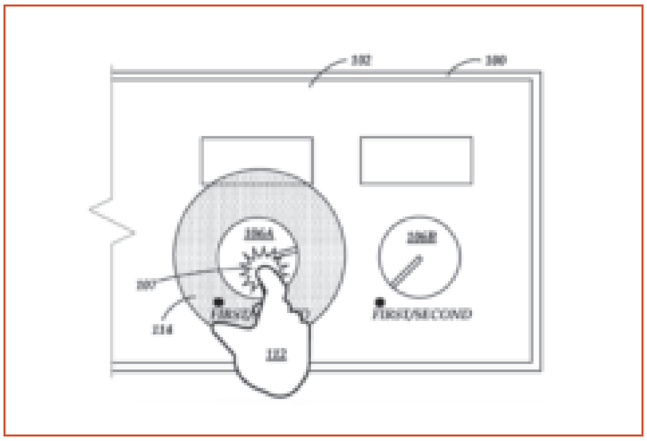
Variable Thermal Resistance Device for Vehicular Seats

U.S. PATENT 9,914,540
INVENTORS: TREVOR M. LAIB, ANTHONY R. PARKINGTON, SHAWN A. CLAFLIN, HENRY V. R. FLETCHER III

Nobody likes sitting in a hot airplane while waiting at the gate. Personal air outlets help cool off the parts of the body exposed to air but cannot reach the parts of the passenger resting on the seat.

A new generation of lightweight passenger seats uses a mesh fabric material or webbing instead of solid cushions. If the pores of this mesh material are left open, a welcome ventilation results that provides a cooler sensation along a passenger's back and thighs. However, such ventilation can become uncomfortably cold once the plane is at altitude. As such, the current practice is to cover the seat face with leather, which makes for a more comfortable ride at altitude but eliminates the advantage the uncovered mesh seat has for hot-day ground conditions.

This Boeing patent describes a seat that adjusts to provide thermal comfort in hot and cold conditions as needed. The seat contains at least one device (placed, for instance, under the seat and/or behind the seat) that can be actuated to open and close the ventilation depending on the needs of the passenger.



Adjustment Mechanisms for Virtual Knobs on a Touchscreen Interface

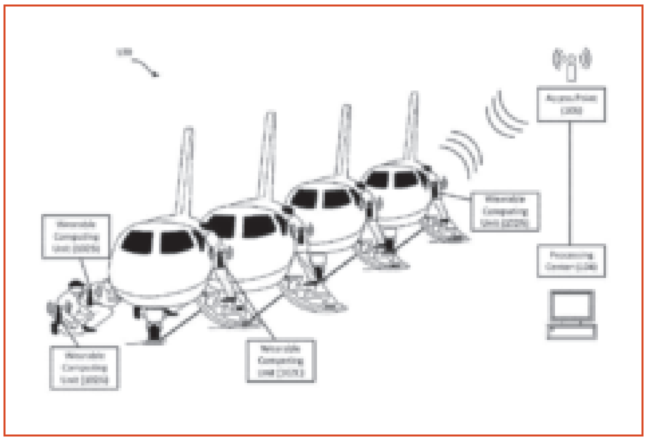
U.S. PATENT 9,916,074
INVENTOR: PENG ZENG

Touchscreen interfaces are becoming very popular in many areas. For instance, instrument panels in aircraft cockpits may be simulated on a tablet computer or a flat-screen panel that utilizes a touchscreen interface that provides an accurate depiction of the location of buttons and knobs on the instrument panel.

However, touchscreen interfaces do not adequately simulate the act of adjusting a physical knob. Many aircraft instruments and other devices utilize three-dimensional control knobs that the operator twists or rotates to provide control input. Because of the two-dimensional depiction of a three-dimensional knob, the operator is unable to adjust a virtual knob in the same manner as an actual physical knob.

Current practices, such as sliding a finger linearly along a two-dimensional touchscreen surface, do not accurately simulate the physical rotation of a three-dimensional knob. Additionally, the location of the slider may not be the same location as the virtual knob and may divert the attention of the operator who may need to look down to locate the slider after selecting the virtual knob on the touchscreen.

Boeing recently received a patent that describes a method for an operator of a touchscreen to turn a virtual knob in a more realistic and accurate way. When the operator taps the virtual knob, a touch-sensitive ring appears around, and acts as an extension of, the virtual knob. This extended ring allows the operator to rotate a finger around the ring and to adjust the knob's "position," thus more accurately simulating turning of a three-dimensional knob.



Ergonomic Data Collection and Analysis

U.S. PATENT 9,936,902
INVENTOR: ANANT BHUSHAN

Implementing ergonomic solutions to improve employee comfort, productivity, health and safety requires analysis of the most current and complete data related to a specific task or environment. This is particularly true for those jobs that require physical movement, including repetitive tasks that could lead to physical discomfort and impairment for the employee. Traditional methods for gathering data related to ergonomics has been time-consuming and reliant on historical, and sometimes subjective, information.

This new Boeing patent describes a method for using wearable computing units that gather acceleration data in real time, or at periodic intervals. The wearable unit would be attached to a person to monitor and collect data associated with movements of a person's joints (e.g. wrist, elbow, knee), and then to transmit the collected data to the processing center. The data analysis can determine a pattern of task-related movements indicative of ergonomically undesirable conditions for that particular movement or task, thus identifying an ergonomic "hot spot" that can be proactively addressed in real time.

This data analysis can be used by the ergonomist to develop a customizable solution for an individual subject. Additionally, the processing center can compile and analyze aggregate data received from a plurality of subjects, resulting in solutions that may improve the health of a group of people or the overall safety of a particular environment.

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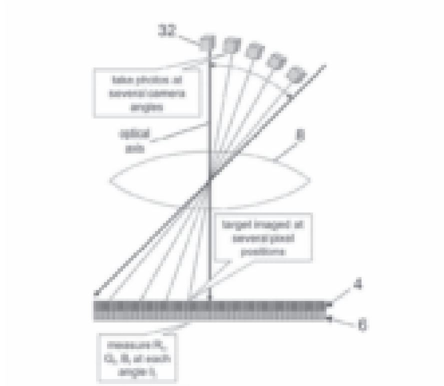
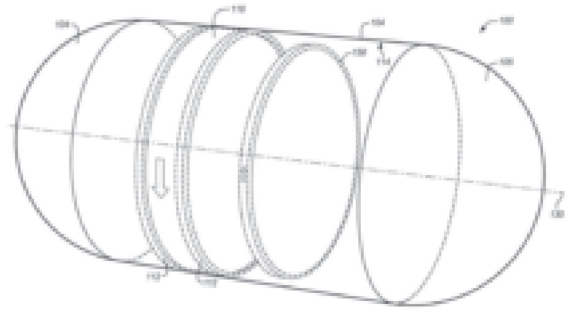




Hyperspectral Resolution Using Three-Color Camera

U.S. PATENT 9,918,050
INVENTOR: BRIAN TILLOTSON

In the color images used in common computer systems and cameras, each element has three scalar values of intensity: one each for red, green, and blue wavelengths. In a hyperspectral image, each element has more than three values, sometimes many more. Hyperspectral images provide fine-grained spectral data that can be useful in quality control, agriculture, oceanography, prospecting, pollution tracking, medical diagnostics, and military surveillance.

Hyperspectral images, however, typically require hyperspectral cameras. A hyperspectral camera uses dozens of filter colors, or it uses a diffraction grating at each image location to scatter light of different colors onto dozens of separate charge-coupled device elements. Hyperspectral cameras are therefore heavy, bulky and expensive.

This recently granted Boeing patent describes a method for capturing images with hyperspectral color resolution with a conventional color camera. The camera (or platform) communicates with a computer, which directs the camera to take multiple images of the same target, orienting the camera to put the target off-center by a different angle for each image. At greater angles, light travels farther through the red, green, or blue filter over each pixel, changing the relative weights of various wavelength bins that contribute to the output of the pixel. The camera sends the image data to the computer, where software inverts a matrix of relative weights to resolve fine-grained spectral bins at selected locations in the scene.

Gravity Chamber that Rotates on Support Bearings Mounted on an Inner Surface of a Hull of a Habitation Module

U.S. PATENT 9,908,644
INVENTORS: RAJU DHARMARAJ, PATRICK A. SWARTZELL, JAMES MICHAEL ENGLE, KARL DAVID HEIMAN

This patent, granted to Boeing in March, describes an improvement to artificial gravity environments for space habitats. Extended exposure to a zero-gravity environment is detrimental to humans, which is why artificial gravity environments could be beneficial in habitats like space stations.

The patent describes multiple embodiments of a habitation module composed of a hull and a gravity chamber with an outer cylindrical wall and opposing side walls. The gravity chamber attaches to an inner surface of the hull of the habitation module via support bearings. Artificial gravity would be created within the gravity chamber when a drive mechanism rotates the chamber on the support bearings about an axis to create centrifugal force within the chamber. Attaching the gravity chamber to the hull via support bearings increases the smoothness of rotation.

Previous artificial gravity environments required rotation of the entire habitation module, which could be problematic for structural design, load transfer, up-mass and evelopment cost. Rotating the gravity chamber within the module offers potential improvements to crew health. Other improvements include reconfigurations of resting areas where crew may sleep in a horizontal position or sit in a natural posture while working.

Dynamic Ocean

A virtual environment for the Boeing maritime family of systems

BY ANDREW MCMAHON AND CRAIG PEPPER, ASSOCIATE TECHNICAL FELLOWS AND BRIAN BOUSMAN, SYSTEMS ENGINEER

Boeing has designed and operated manned and unmanned deep sea systems since the 1960s. The maritime air, surface and subsurface domains remain important markets for the company. Key examples include:

- The P-8A Poseidon—a derivative of the Next-Generation 737-800 aircraft designed for long-range anti-submarine warfare; anti-surface warfare; and intelligence, surveillance and reconnaissance missions—combines performance and reliability that ensures maximum interoperability in the future battle space.
- The Wave Glider unmanned surface vehicle (USV) by Liquid Robotics is powered by wave and solar energy. The Wave Glider autonomously operates individually or in fleets delivering real-time data for up to a year with no fuel.
- The unmanned undersea vehicle (UUV), Echo Voyager, can operate autonomously for months at a time thanks to a hybrid rechargeable power system and modular payload bay. The 51-foot-long vehicle is the latest addition to Boeing's UUV family, joining the 32-foot Echo Seeker and the 18-foot Echo Ranger.

But it is not only the individual systems that are key to future protection and exploration of the maritime environment. It is the ability to network these systems across operational domains—from seabed to space—in order to achieve a sustainable, resilient and integrated force that will provide the advantage.

"Digital-twin" technologies are being used across Boeing as enablers to support development of next-generation autonomous air systems.

> Digital-twin technologies blur the distinctions between the real operational world and the simulated or virtual world, enabling rapid development of new prototypes for platforms and systems with increased return on investment compared to traditional methods.

A similar capability for the maritime domain was needed in order to provide a low-cost alternative to sea trials, as well as a capability to help model how these different domains interact at a system-of-systems level.

Enter the "Dynamic Ocean," an advanced modeling and simulation environment for maritime operations, applicable across the Boeing maritime family of system development programs. Dynamic Ocean allows for exploration of how such systems interact, including with other domains (e.g. interoperability with airborne assets), with sufficient modeling fidelity to address real-world operational challenges.

Dynamic Ocean is built on top of a modeling and simulation software platform called Alliance, newly developed by and for a diverse set of technologists from Boeing's commercial airplanes, services and defense businesses. Alliance is designed as a hierarchical "mission level" simulation, visualization and data analysis software framework. It manages the different levels of fidelity and abstraction needed in order to create complex, networked seabed-to-space scenarios involving air, surface and subsurface units such as P-8A, Wave Glider and Echo Voyager.

Alliance is currently in use across Boeing's global business units and innovation centers across Australia, India, Saudi Arabia, South Korea and the United Kingdom. It supports engagement and prototyping activities in Boeing's traditional defense markets, but also in nontraditional sectors such as mining, energy and agriculture.

Alliance Dynamic Ocean allows the user to tackle complex underwater acoustic sensing and communication scenarios with confidence. It integrates a real-time, physics-based underwater acoustic effects service, developed by Boeing in Huntsville, Alabama. The service incorporates:

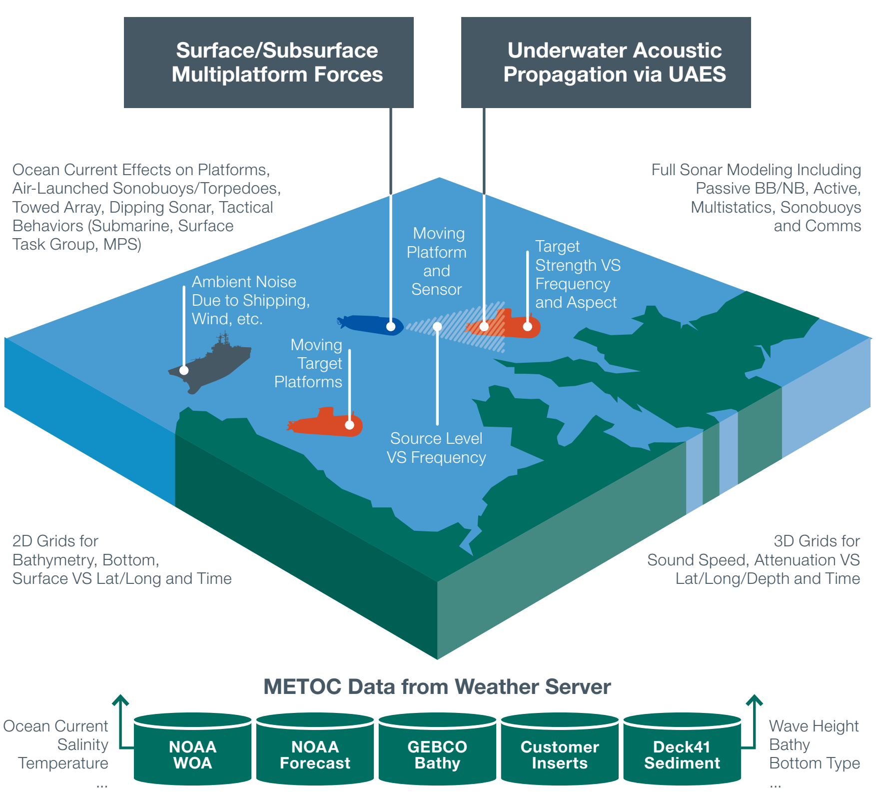
- The open-source Wavefront Queue 3D model, which computes acoustic transmission loss in the ocean using hybrid Gaussian beams in spherical/time coordinates. The WaveQ3D model is open-source technology funded as part of the U.S. Navy Office of Naval Research High-Fidelity Active Sonar Training program.
- A full suite of physics-based sonar models including passive, active and multistatic active sonar, and subsurface communications, all linked to the weather service.

Given constantly changing oceanographic conditions, and the dominant effect it has on underwater acoustic sensing, a high-fidelity representation of ocean weather is required to address real-world problems. Dynamic Ocean integrates an innovative virtual weather service, developed by Boeing in Australia, which can be used to create realistic and consistent weather environments. The weather service provides:

- Ability to replicate historical or current forecast weather conditions and events, or simply provide dynamically changing conditions over a basic standard atmosphere model.
- Correlated atmospheric, ground and ocean conditions with global coverage over long timeframes to many simultaneous end users using industry-standard web protocols, an application programming interface or a simple web service.
- Oceanographic and meteorological data, which are in turn used to provide ocean weather effects to drive physics-based dynamic and sensor models. Other pertinent geospatial data, such as bathymetry and sediment layer descriptions, are provided as layers via industry-standard terrain streaming technologies.
- Modeling of ocean current drift effects to both surface and subsurface platform dynamic models.

Led by a team in the United Kingdom, Dynamic Ocean has integrated technologies from the U.K., Australia and the United States, including the Alliance mission-level, LVC (live, virtual and constructive) simulation software platform in order to provide the necessary tools to enable Boeing technologists to analyze seabed-to-space operational scenarios in a virtual environment. IQ

ILLUSTRATION: BOEING



DYNAMIC OCEAN

This digital environment, developed by Boeing's Phantom Works International, enables a full suite of engagement and experimentation options for new capability development in the maritime domain.

Inspiring the world through our passion for innovation

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PHOTO: BOEING

PHOTO: BOEING

PHOTO: BOEING

From the top, left to right:

TEAM DAEDALUS FROM MISSISSIPPI STATE
cheers the Boeing Flight Competition held at the National Society of Black Engineers conference in Pittsburgh, Pennsylvania, in March.

SPACE LAUNCH SYSTEM ENGINEER TIERA FLETCHER
celebrates the American Girl of the Year 2018 doll, who has dreams of landing on Mars. The celebration drew hundreds of other dreamers and next-generation innovators to the U.S. Space & Rocket Center in Huntsville, Alabama.

BOEING AUSTRALIA'S MARTIN SZARSKI AND CHIEF TECHNOLOGY OFFICER GREG HYSLOP
pose with a co-bot at Melbourne's Fisherman's Bend in March. Co-bots are a new class of lightweight robotic arms that differ from traditional industrial robots because they are force-limited and designed to work alongside people.

JENETTE RAMOS, SVP OF SUPPLY CHAIN & OPERATIONS, AND CHIEF INFORMATION OFFICER TED COLBERT
discuss digital advancements and technical innovation with hundreds of suppliers at the Boeing Global Supplier Conference in Portland, Oregon, in April.