Innovation Quarterly

2017 February

The Data Plan

Artificial intelligence to decode the future

Cyber Defenses

Securing the air

Autonomous World

Unmanned controls for the sea and skies

A publication of The Boeing Company

Innovation Quarterly

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Boeing Chief Technology Officer

ASSOCIATE PUBLISHER
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Marna Kagele

LEGAL ADVISOR
Tom Donahue

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WEBSITE
boeing.com/IQ

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Ian Willson is a Boeing Technical Fellow who specializes in computational data analysis and software. He is based in Bellevue, Washington.

PHOTO ILLUSTRATION BY MARION LOCKHART

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Boeing is committed to preserve safe airspace operations, and this analysis explores 1090 MHz congestion margins at various locations in the continental United States where Boeing operates, including Seattle; St. Louis; Oklahoma City; and Charleston, South Carolina. Our intent is to provide results that can be used to quantify requests for testing systems efficiently without causing interference with operations in U.S. national airspace, navigation facilities and airports.

31 | On-Demand Waveform Design for Software-Defined Radio Applications

The exponential growth in demand for wireless communications, both for civilian and military use, has created an urgent need to use as much of the increasingly scarce available radio frequency bandwidth as possible. This paper describes a way to operate typical software-defined radio technology through on-demand custom design of modulation waveforms for communication on nearly any available spectrum under an unlimited set of operational conditions.

The more we know

Every day at Boeing, we generate an enormous amount of data.

We track and support thousands of airplanes around the world, each one producing massive amounts of data during flight. Additionally, we have nearly 160,000 employees working with a range of tools and systems each day to deliver the best-in-class products and services for our customers—which creates an ongoing stream of data and information. Now more than ever, data can help drive sound decision-making and create value in today's global marketplace.

For example, our aircraft are built with thousands of sensors that can tell us about everything from engine health to the ways in which weather patterns affect flight routes. In our factories, we rely on data and information to optimize and track millions of parts and tools. We also use data to keep our employees safe by examining safety patterns within and around our workplaces.

But simply adopting new tools to aggregate more data isn't enough. We need accurate, real-time data, and we need to be able to use it in the right way. When used correctly, data can help us address the global cybercrime landscape (see "Tom Bui talks cybersecurity and cyber threats" on page 14), or help us make strides with advanced artificial intelligence techniques (see "AI driven transformation" on page 6).

Data doesn't work in silos; it needs to breathe and interact with other information in order to tell the whole story, not just parts of it. At Boeing, we're working across our enterprise to let data and information drive our collective decision-making. With the right analytics tools, the right people, and the right processes to bring them together, we can harness the power of data and information to drive success in our second century. IQ

Ted

TED COLBERT
Chief Information Officer
Senior Vice President, Information & Analytics

Recognizing Advanced Developments and Research

Technology RADAR

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.

Spinach that Detects Explosives

LOCATION
Cambridge

PROJECT URL
mit.edu

MESSAGE
MIT engineers have created spinach plants that can detect explosives by sensing nitroaromatic chemical compounds via carbon nanotubes in the leaves. The plants also emit a signal indicating the presence of the explosives when detected.

DNA-Origami Nanocircuitry

LOCATION
Dresden

PROJECT URL
hzdr.de

MESSAGE
Self-organizing circuits created from gold-plated genetic material could lead to a breakthrough of computer chip miniaturization, according to physicists at the Helmholtz-Zentrum Dresden-Rossendorf research lab, who have developed a method that could make DNA-based electronic devices possible.

Cool Shoes

LOCATION
Moscow

PROJECT URL
misis.ru

MESSAGE
A second-year Master’s student at the National University of Science and Technology MISiS has created 3-D printed shoes with a built-in cooling system. The prototype sneakers have an integrated micro-fan to control the temperature inside the shoes, set via smartphone.

Wearable Displays

LOCATION
Daejeon

PROJECT URL
kaist.edu

MESSAGE
A research team at the Korea Advanced Institute of Science and Technology (KAIST) has fabricated an ultrathin, transparent, and flexible oxide thin-film transistor, using an inorganic-based laser lift-off process. The methodology overcomes some of the challenges to high-performance wearable displays.

Noise Reduction from Owl Feathers

LOCATION
Blacksburg

PROJECT URL
vtnews.vt.edu

MESSAGE
Studying owls’ silent flight has helped an international team of researchers led by Virginia Tech engineers to achieve “trailing edge” noise reduction in wind tunnel tests of wind turbine blades. As noise pollution is often cited as a barrier to wind farms, the research could advance sustainable energy availability.

Locked-In Communication

LOCATION
Utrecht

PROJECT URL
umcutrecht.nl

MESSAGE
A 58-year-old woman, paralyzed from amyotrophic lateral sclerosis (ALS), has become the first person to use a brain implant to communicate by thought in “day-to-day” life, including outdoors. Devices that translate brain activity to communication signals have in the past required frequent recalibration, prohibiting use at home without constant supervision by doctors or engineers.

In-Court Artificial Intelligence

LOCATION
Melbourne

PROJECT URL
doogueobrien.com.au

MESSAGE
An Australian law firm will be employing “robot lawyers” to help defendants representing themselves to prepare and present data and personal information to courts. According to the firm, the free service’s legal work will be largely transactional and restricted to a limited scope of case types.

HARISH RAO, SENIOR DIRECTOR OF ANALYTICS

AI driven transformation

Sensors generate vast data. When this data is used with artificial intelligence techniques, it creates a perfect recipe to drive the Fourth Industrial Revolution. That's exactly our plan.

Imagine you have to read 10 pages of handwritten notes, find symptoms, diagnose the problem, correlate the problems and suggest recommendations. This may sound easy enough to a data expert—but it can be time consuming.

Now imagine this same exercise for 500 million pages. The time, effort, accuracy and cost required would be overwhelming.

> At Boeing, we have successfully built and trained machine-learning algorithms that can identify patterns in data, and make recommendations accurately within just a few minutes.

Design

An engineer designing even a simple part faces immense complexity looking at related design, choice of suppliers, overall cost and quality, availability of similar parts, potential for 3D-printed parts, safety and past experience of work orders on the shop floor. This complexity and the non-linear combination of work factors could be handled instead through a digital virtual assistant, powered by artificial intelligence (AI), which leverages real-time data and makes recommendations to the engineer. This recommendation engine could complete tasks much quicker with higher first-time quality.

Further, simulating the design-to-build process through augmented reality, reinforced by predictive analytics, could expose a new way of implementing customer-driven design changes by understanding the quality, cost, supplier choices and available inventory implications before building the product.

Supply Chain

Accurate demand forecasting could drive significant improvement across the entire supply chain. Bringing together data across past forecasts, current demand, availability of raw materials, capacity and quality of suppliers, and by leveraging machine learning algorithms to change the forecast in a dynamic fashion, we can positively affect cost, productivity and quality.

As well, we could use data analytics to combine natural language processing in the contract, past performance of suppliers, and demand forecasting to deploy a dynamic recommended pricing model to the procurement specialists directly affecting our bottom line. This learning could also lead to redefining the right contract to ensure a win-win.

Inventory management is another aspect of supply chain that can be optimized by predictive analytics. To optimize inventory, determining the right threshold is the key. Inventory level has to be adjusted dynamically, similar to demand forecasting.

Smoothing out the inventory across factories and warehouses ensures inventory optimization. New data can further enrich the predictive models and improve the accuracy of inventory.

Factory

Many jobs within the factory require specialized training to complete safely. Automation of these difficult, repetitive tasks through the use of a combination of human and machine robotics could improve safety, productivity and quality.

Deep learning models, an advanced AI technique, address non-linear work interactions such as safety conditions, training, tool/parts availability and work priorities.

This is an area of huge opportunity for any company, including Boeing. Complex jobs can be automated to improve productivity, quality and safety while helping to meet delivery schedules.

To automate and leverage AI, data from sensors on machines can be connected with traditional data such as design, inventory and safety records, to optimize tasks. Instead of simply identifying a task to be automated, a deep learning model can analyze all the data, determine patterns and recommend the best task for automation.

Service

Our aircraft remain in service for several years after they are built. Detecting and preventing problems before they occur builds confidence and paves the way for higher customer satisfaction.

By deciphering usage patterns such as flight conditions, location, temperature, altitude, wind speed and direction, we could predict with confidence when a part needs maintenance, repair or replacement.

> By collating the data from sensors, we can deliver predictive solutions to help our customers better plan their operations and reduce total maintenance costs over the life of the aircraft they purchase from us.

Boeing is driving these innovations through data analytics to lead the fourth industrial revolution. IQ

Harish Rao is senior director of Analytics and Information Management Services, providing analytics services and data management solutions for Boeing's global enterprise.

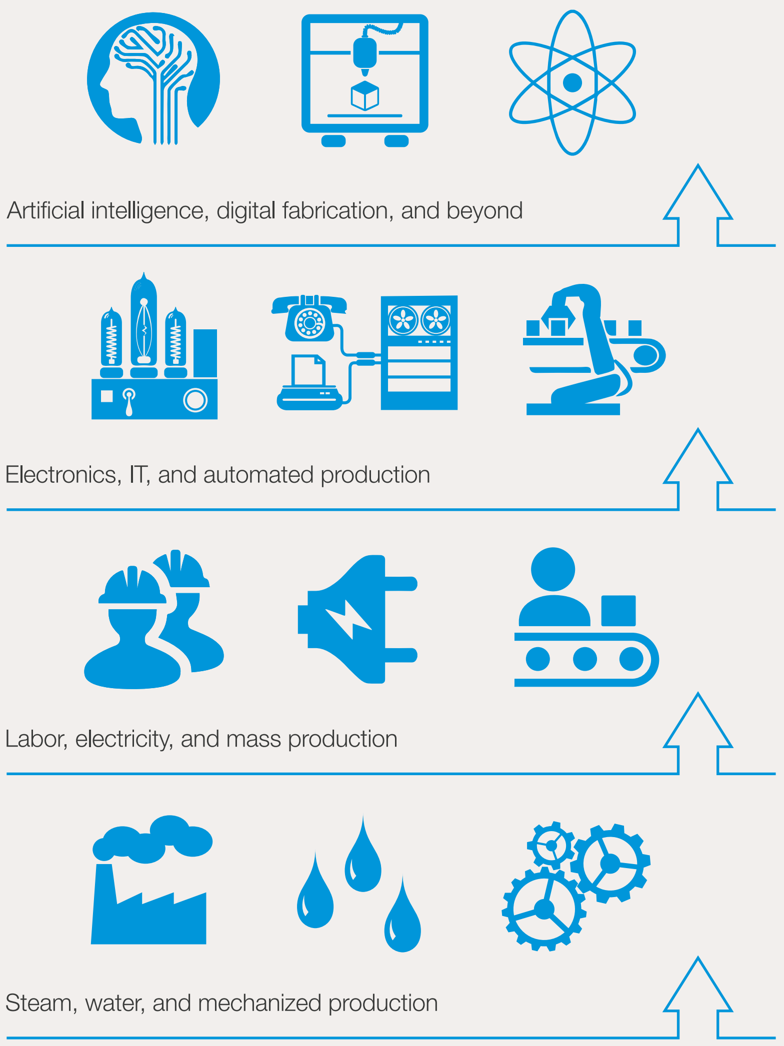
The Internet of Things

The Fourth Industrial Revolution is predicted to be a combination of cyber-physical systems—that is a blending of the physical, digital and biological worlds. The concept was popularized by Klaus Schwab, founder and executive chairman of the World Economic Forum, who published a book a year ago entitled "The Fourth Industrial Revolution."

The vision shows a future where intelligent, connected machines operate within a manufacturing system working independently based on objectives and understanding of the complete production chain. Unlike previous changes in industry over the last millennium, new technologies in this combination of systems would impact every aspect of life around the world.

To learn more, visit the World Economic Forum online at www.weforum.org.

The four stages of the Industrial Revolution



The information opportunity

Immersed in a world of math and computation, the intrigue of artificial intelligence sparked an ongoing pursuit of better data analysis.

BY DAN RALEY, BOEING WRITER | PHOTOGRAPHY BY MARION LOCKHART

Ian Willson was a weary business traveler—well before leaving his house.

More than two decades ago, the then-data analytics software consultant typically couldn't find time to book his flights until Sunday night, after-hours for the airline reservationists and travel agents who might have helped him.

He scrambled to find the cheapest rates and best routes, printing out multiple computer screens of information from complex reservation systems to compare options. He spent far more time on this than he should have.

So, Willson created a solution.

He introduced Air Travel Manager in 1993, a consumer-friendly interface on top of an intelligent agent that removed all of the complicated command sequences of the airline reservation system. It made sense of all of the cryptic information. It turned into a thriving business.

Today, he makes things happen for Boeing in a similar fashion. Willson tackles complex data situations and not only provides solutions that have companywide implications, he delivers methods that influence industry standards.

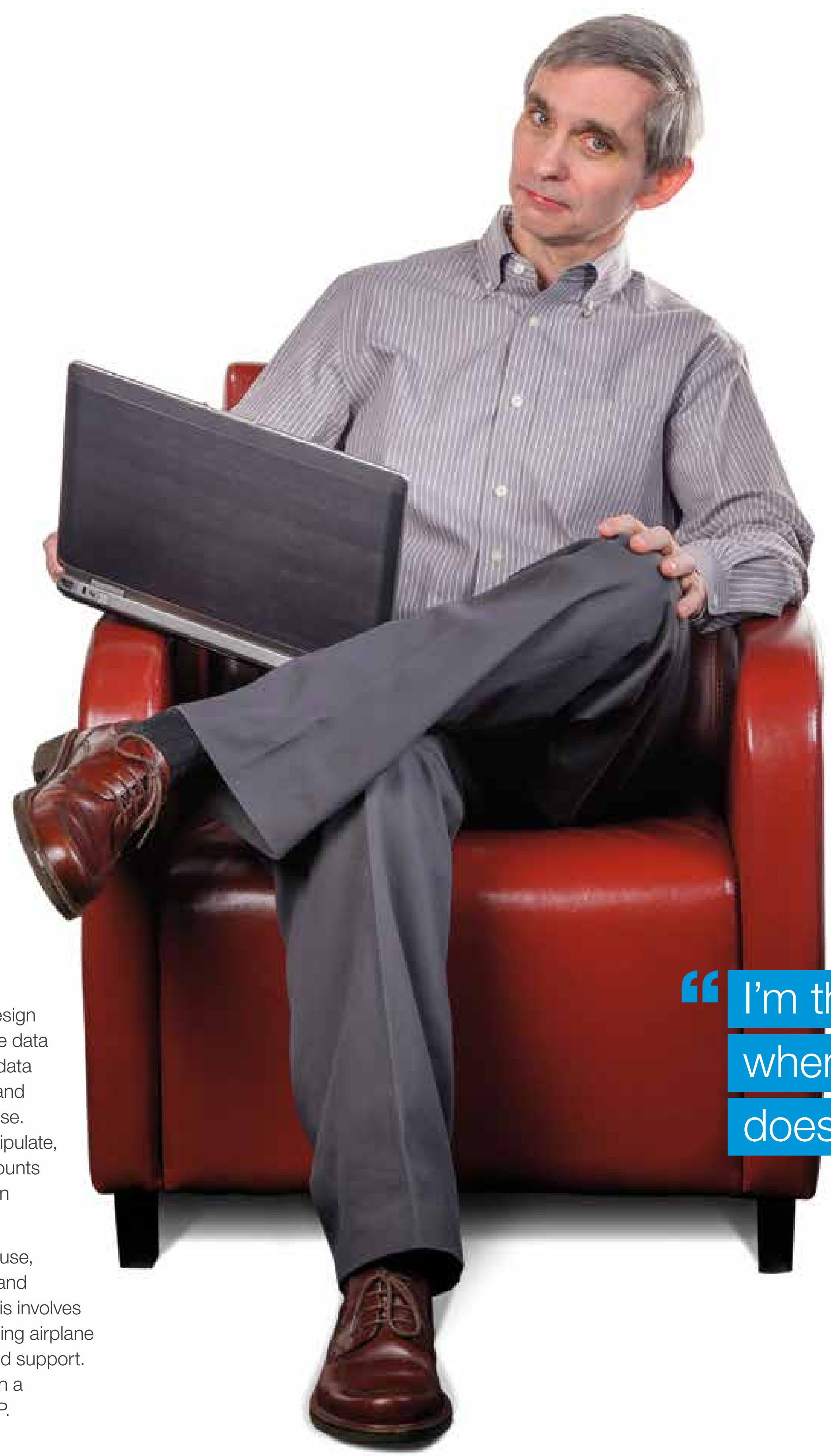
"I'm the person to go to when normal stuff doesn't work," he said.

Mehdi Ghods, Boeing Technical Fellow and senior mathematician, was at a data analytics conference in San Diego, speaking with an executive from another company about industry developments, when their conversation took a surprising turn.

"He says, 'There is a person at Boeing called Ian Willson who is incredibly unique,'" Ghods said. "That is so important to us."

In 1999, Willson was hired by Boeing to help design a Teradata system that would serve as an active data warehouse and an operational data store. Teradata remains a long-term provider of data software and platforms, and Willson was highly skilled in its use. Boeing needed someone to customize, or manipulate, software to deal with the rapidly increasing amounts of information generated by its products. Willson was that person.

After installing Boeing's first active data warehouse, Willson was tasked with integrating 50 internal and external systems into a single data platform. This involves all aspects of Boeing's data from new and existing airplane programs, from conception through delivery and support. This data analytics clearinghouse is centered on a Massively Parallel Processing database, or MPP.



"He has deep expertise in a very complex area of computer science, analytics and mathematics, all critical skills," Ghods said.

This active data warehouse—for the 787—evolved far beyond the original request. The Dreamliner program simply needed a way to run reports. But Willson took it several steps further, providing airplane web-based engineering and manufacturing information to thousands of customers worldwide. He also enabled time-based analytics to be run on the 787 factory floor. It was such a breakthrough in cost and efficiency that Willson received one of Boeing's 2013 Special Invention Awards. His work was also awarded two patents and helped set the industry standard in 2011 for time-based analytics in a relational database.

Willson further extended his time-based invention to the Internet of Things and has a patent pending for making interactive time-based analytics available for airline sensor data at a fleet level. Among a myriad uses is to use predictive analytics to prevent breakdowns. Willson came up with a time-based analytics system used to measure trillions of rows of fleet-level sensor data that is 3,453 times faster than Boeing's previous version.

"The broader question—to use your data in intelligent, thoughtful ways—is what I specialize in," Willson said.

Willson initially was pulled to the field by what is now an antiquated way of generating, storing and processing numbers and words. He was an air-traffic controller in training in Toronto when he became more interested in the computer resources surrounding him. The data retrieval process was primitive, involving cassette tapes and readout strips of paper punched full of holes.

"I'm the person to go to when normal stuff doesn't work."

IAN WILLSON

I was really captivated by all of the technology they had," Willson said.

He would leave the tower to study computer science and earn a doctorate in the relatively new field of artificial intelligence and predictive analytics at the University of Toronto. And then he taught what he learned. He wrote

CYBER SPACES
One might have easily been lost within a labyrinth of server racks, but Technical Fellow Ian Willson relishes building data infrastructure for Boeing.

his dissertation on a form of approximate math logic, known as fuzzy sets, which can provide answers based on incomplete information in situations (such as focusing a camera lens) where conventional methods fail.

Willson left the classroom to branch out and become an entrepreneur. He settled on the Seattle area to be near an influential technology community that might assist in his creative development or share in a possible business venture.

He operated Air Travel Manager from his home, using seven phone lines. He enlisted virtual employees to answer calls and mail out brochures. He used an algorithm to determine airline seat pricing and create the first self-booking practice for non-computer-savvy consumers—charging them a onetime $59 fee to operate the software, yet rebating them half of the airline booking commission. Best of all, he no longer had to fuss over his own travel.

AirTM was hailed as a pioneering development by USA Today. In a 1994 story bannered across the top of its front page, the newspaper declared that “booking airline tickets on your computer just got easier and cheaper.” A year later, Forbes magazine weighed in on the emergence and relative simplicity of the online service, stating: “High commissions give way to a software-smartened appliance as ubiquitous as a toaster.”

Willson’s consumer business thrived until airlines responded by eliminating all commissions for online bookings. In its wake, he was sought out to create software for the National Business Aviation Association. Travel$ense founder David Almy pursued Willson after personally using AirTM and reading glowing reviews about it. He urged Willson to develop software for his company.

Travel$ense provided business travel analytics (including real-time creation of a comparable airline trip) over the next decade, reaching more than 1,000 companies in 19 countries, until that technology changed. Users were informed whether private or commercial air travel was cheaper in different instances, taking many customizable factors into consideration.

Almy was so impressed that years later he recommended Willson for the Boeing Technical Fellowship.

“Willson’s accomplishments creating two pioneering software programs have been widely recognized in the software industry,” Almy wrote on his behalf. “Rarely is the first of a new breed of software successful … but Ian has achieved this distinction twice.”

Logic dictates that Willson now should be president and chief executive officer for some well-heeled, travel-minded company. Yet in spite of his personal business successes, the entrepreneurial Canadian American determined he needed to be more of an in-house problem-solver at a broader scale than online travel booking.

“The further intellectual challenges of air travel booking weren’t there at the time,” Willson said of his business ventures. “Computing capabilities had since solved many of the hard problems.”

At Boeing, Willson intends to create something that can answer all types of complex questions as easily as it does basic inquiries. This requires the inclusion of IBM’s Hadoop, computer software that specializes in the storage management and processing of varied data and the integration of advanced algorithms such as machine learning.

He envisioned and is deploying for Boeing a special-purpose hybrid data analytics platform fully parallelized across multiple types of massively parallel systems. For instance, ask a question, and up to 600 tasks will respond at once within the database cluster. This is done while interacting in parallel with IBM’s Hadoop using hundreds of processes to execute advanced algorithms. All of it working transparently to the end user and at interactive speeds on near-real-time data.

In the case of airplane sensor data, data comes off an airplane and is sent to Boeing, which initially stores it in Hadoop. Willson has invented a format for both Hadoop and Teradata that requires a lot less space to house these overarching quantities of information. The format maintains the accuracy of the data in an unfailing manner and drives analytics to respond faster.

He has invented a range of time-based analytics methods that helps determine how broad-based data analytics should best be applied. He recognizes that analytics innovation needs to be shared and used as an industry standard to be properly accepted. He is determined to get rid of the old, pre-conceived limitations of how data should be leveraged and analyzed.

“I want people’s mobile device or web browser view to be everything they need,” Willson said.

Willson moves in select analytics company. He meets privately with 14 other deep-thinkers who represent major companies in similar capacities. They brainstorm for two weeks each year at an information summit, sharing ideas in how to move their industry forward.

Willson’s ability to compress data in an efficient manner has changed the way the company does business in this arena, said Michel Claessens, an analytics specialist in Boeing Commercial Airplanes. Willson, having once been an entrepreneur, also is suited to sell his methods to business people.

“First, I think he’s really bright; second, he’s really knowledgeable in his field, and third, he’s really effective,” Claessens said. “He finds practical solutions that work. There’s no waiting around. There’s no misunderstanding. Ian is very straightforward and direct.”

When he first joined the company, Willson said there was no call to create a company-wide data analytics engine. He handles that responsibility now, with data evolving to the point that it’s now a foregone conclusion.

Willson, in a sense, has become Boeing’s air traffic controller regarding data. He directs it to the proper runway and makes sure it lands on time.

“Being a plane guy, there are so many great problems you can solve here and so many more to come,” he said. IQ

“I want people’s mobile device or web browser view to be everything they need.”

IAN WILLSON

Fly like a pro: UAVs with Boeing tech

Boeing subsidiary Insitu develops commercial software designed for professional, safe and effective commercial UAV operations.

BY GREER CARPER, PRODUCT MANAGER
INSITU

PROFESSIONAL TOOLS FOR SAFER SKIES
Boeing subsidiary Insitu launched its INEXA Control commercial ground control station software package last August on the day new Federal Aviation Administration rules governing commercial unmanned aerial vehicle (UAV) operations went into effect. The software gives UAV operators professional aviation tools to control UAVs while staying compliant with FAA regulations.

INSITU PHOTO

The U.S. Federal Aviation Administration last August released its Part 107 rules governing small unmanned aircraft operations. The rules, which went into effect August 29, will allow an estimated 600,000 UAVs to take to the sky in 2017.

Because pilots of commercial off-the-shelf UAVs spend the majority of their time physically controlling the aircraft and payload instead of focusing on the mission, we saw the opportunity to translate Insitu's expertise in command and control into a commercial product that can provide a professional, safe and effective way to control unmanned systems being used for a variety of missions—from aiding first responders to monitoring utility poles.

The result is INEXA Control, a commercial ground control station software package based on Insitu's Common Open-mission Management Command and Control (ICOMC2) software used in defense applications. INEXA Control gives operators professional aviation tools to control UAVs while staying compliant with Part 107 regulations.

Operators can control UAV platforms and payloads with a simple drag-and-drop interface combined with a familiar set of aviation gauges and air tapes. The system can integrate and visualize data such as weather information and airspace data—as well as terrain data and satellite imagery for better situational awareness while flying. It also includes a mission planning function with a built-in simulator to create payload and platform actions around waypoints, set operational limits and identify no-fly zones for safe flights.

"Commercial UAV technologies are skyrocketing and will continue to do so—not just because they're cool, but because of the data and information they provide," said Kory Mathews, vice president of Boeing's autonomous systems organization.

The use of augmented and mixed reality technologies with INEXA Control provides new ways to visualize and interact with data to make better decisions.

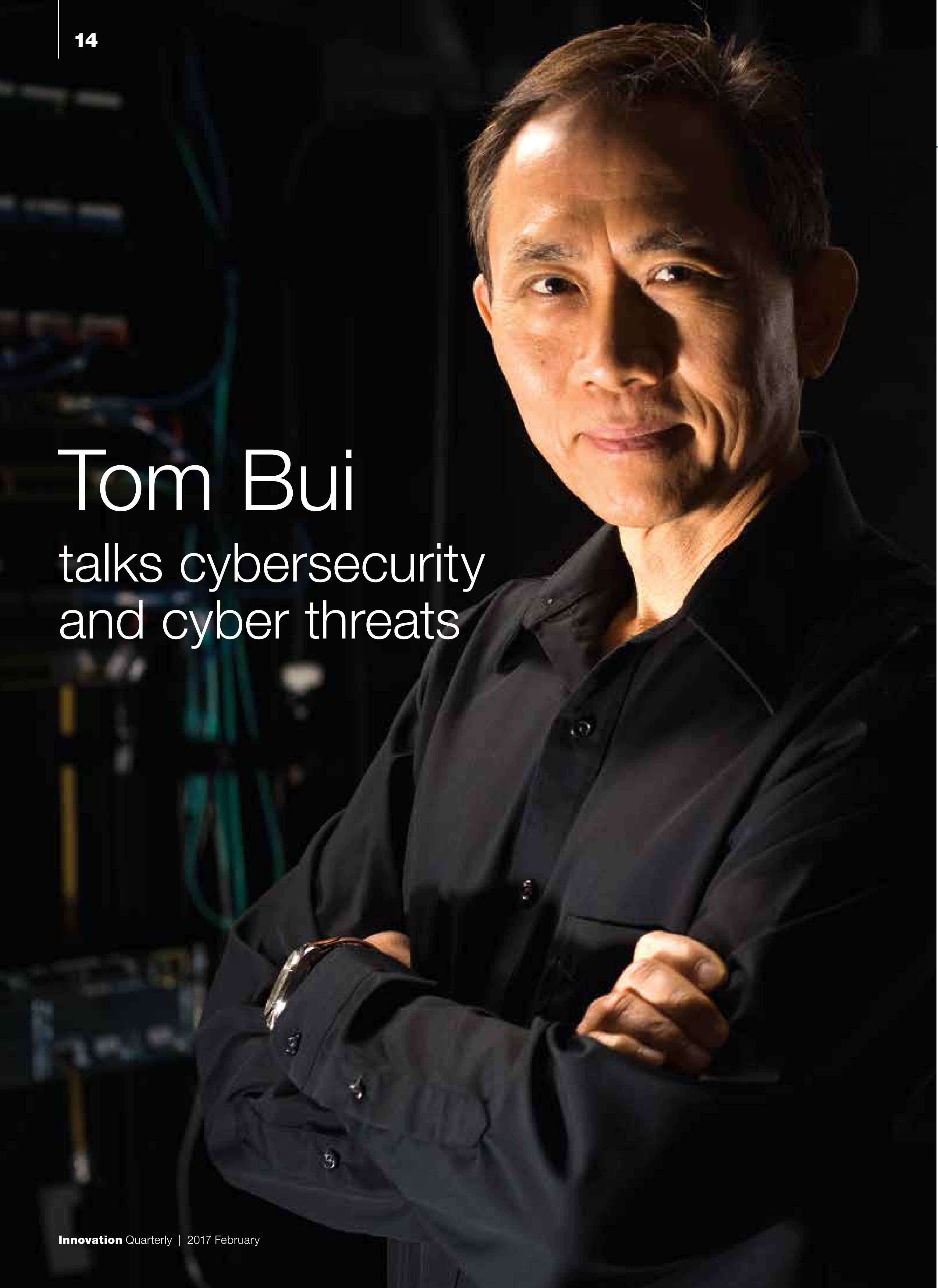
"Success in the commercial marketplace will depend on safe and secure integration of unmanned systems into airspace, as well as the ability to capture real-time, high-quality, actionable data for customers," Mathews said.

In addition to targeting commercial users, Insitu is also working with colleges and universities to bring this technology to aviation and aerospace students. Last May, the University of Nevada, Reno, College of Engineering chose the software as a tool for teaching command and control in its newly established UAS Flight Coordinator course. Embry-Riddle Aeronautical University and San Diego Christian College have both since added INEXA Control to their classrooms. IQ

> "Commercial UAV technologies are skyrocketing and will continue to do so..."
>
> KORY MATHEWS, VICE PRESIDENT, AUTONOMOUS SYSTEMS

The growing commercial market for unmanned aircraft systems

- In July, government leaders in Queensland, Australia, announced a new partnership with Boeing and Insitu Pacific Limited to develop an advanced system that safely and securely integrates UAS into airspace. This is in addition to developing data analytics tools that can help process and analyze important monitoring and inspection data from UAS operations. The collaboration is a significant step forward in creating the infrastructure that allows for greater commercial use of unmanned aircraft. Gas and mining industries have shown interest in more services performed by unmanned aircraft.
- In the United States, Insitu is part of the U.S. Federal Aviation Administration's Pathfinders program, an initiative to develop UAS regulations in collaboration with industry to work toward safe and secure commercial operations. As part of the program, Insitu used the ScanEagle to conduct the first beyond-visual line-of-sight UAS flights in the contiguous United States with BNSF railroad in 2015.
- The ScanEagle also has been used in civil and commercial efforts such as monitoring fires in Australia and Olympic National Park in Washington state—demonstrating search and rescue efforts in the Arctic with the U.S. Coast Guard, providing disaster response intelligence following a tropical cyclone and aiding agronomists in crop monitoring.



Tom Bui

talks cybersecurity and cyber threats

Protecting the company's platforms and services, and securing the Boeing global enterprise are high priorities.

BY WILL WILSON, BOEING WRITER | PHOTOGRAPHY BY PAUL PINNER

Q&A with a Senior Technical Fellow who develops the strategy for R&D investments made in cyber technology systems, software and architecture at Boeing

VIGILANCE BY DESIGN
Senior Technical Fellow Tom Bui.

Q **Hacking and cybercrime are dominating the news these days. How has the global cybersecurity landscape changed?**

A The benefits of digital systems—notably scalability, programmability and ubiquity—are increasingly leveraged in the design of new network systems. For example, a vast majority of vital functions in our military and commercial airplanes are performed by networked digital systems versus roughly 30 percent just two decades ago.

As one would expect, the number of vulnerabilities in the system that could be exploited for nefarious intent grows as technology progresses, providing a number of ways an attacker might compromise the information or system. Attackers, organized or not, have access to hacking tools and financial resources. In addition, there is no or little penalty for attackers, while their rewards are generally significant.

Q **What can the cybersecurity community do about it?**

A Cybersecurity threats are dynamic and unpredictable. The traditional approach to cybersecurity has been more like a bolt-on implementation after functional features were designed, instead of the preferred baked-in-from-the-start approach that we now undertake. We're shifting from a reactive architecture to a proactive one where we anticipate an attack by knowing our attack surfaces and understanding the attackers' strategies and tactics. So, our response is quick and effective.

To counter the increasing speed of successful attacks and the wide range of attack vectors—and to improve on the often long delay between the launch and discovery of attacks—cyber defense systems need to collaborate in near real-time. They can do this through sharing and learning via trusted

> “We do have the technology and systems in place to mitigate cyber risks, but the weak link is arguably still with the users.”

TOM BUI, SENIOR TECHNICAL FELLOW

communities and working toward a cyber-ecosystem where risk decisions are automated by machines with human oversight. Advances in machine learning, large scale data analytics, and standards like the Trusted Automated eXchange of Indicator Information (TAXII) and Structured Threat Information eXpression (STIX) play a role toward this capability.

Q What are the opportunities for Boeing?

A Boeing has unique opportunities to address these challenges on many fronts. Our research and technology arm is advancing technology beyond a proactive architecture to a resilient cybersecurity where our systems adapt to new threats. We invest heavily in advanced technologies and products to protect our airplanes from current and anticipated future threats.

One example of this is Boeing's collaboration with others in industry and academia on DARPA's High Assurance Cyber Military Systems (HACMS) with the aim of creating cyber-physical systems that are functionally correct and meet appropriate safety and security properties. Such systems are less vulnerable to remote attacks.

As Boeing's products span frontiers from undersea to air to space, we have also developed unique cybersecurity capabilities such as the key management security protocol and architecture for Delay/Disruption Tolerant Networking (DTN) for NASA's interplanetary missions and submitted for standardization with the Internet Engineering Task Force.

Q What are the unique challenges for Boeing?

A The short turnaround time between discovering a vulnerability and mounting an attack necessitates frequent patching of in-service products. This poses a challenge to the longer update cycle for our commercial products (due to the certification process).

On top of that, governments are introducing legislation and issuing guidance for compliance at the product and corporate levels, and extending our responsibility beyond our traditional enterprise boundary to include our suppliers.

Q What's a misconception people might have about cybersecurity?

A Thinking that technology will solve all cybersecurity problems. We do have the technology and systems in place to mitigate cyber risks, but the weak link is arguably still with the users—phishing attacks via email messages being the quintessential example. Cybersecurity awareness and cyber hygiene can help avoid many attacks. A robust cybersecurity culture is an essential component of a successful cybersecurity strategy. IQ

Securing an increasingly connected world

- The U.S. Department of Homeland Security recently released “Strategic Principles for Securing the Internet of Things (IoT), Version 1.0.” The principles cover areas such as incorporating security in the design phase and prioritizing security measures according to potential impact. As part of the DHS mission to work with the private sector to drive cybersecurity, the principles target IoT developers, IoT manufacturers, service providers and industrial and business consumers, including governments and infrastructure owners. The principles can be found at **dhs.gov/securingtheIoT.**
- The U.S. National Institute of Standards and Technology (NIST) is requesting public comment until April 10 on its draft Cybersecurity Framework Version 1.1, released on Jan. 10. The draft and instructions for submitting comment can be viewed at **nist.gov/cyberframework**.
- The United States Commission on Enhancing National Cybersecurity's “Report on Securing and Growing the Digital Economy” focuses on the need for international cooperation and public- and private-sector partnering. The report is available online at **nist.gov/cybercommission**.
- The Association of Southeast Asian Nations held its first Ministerial Conference on Cybersecurity in Singapore. As part of the conference, a new ASEAN Cyber Capacity Program was established, with the aim of funding training, expertise and resources for the region's nations to defend against cyber threats.

Echo Voyager

Powered by a hybrid combination of battery technology and marine diesel generators. The Echo Voyager vehicle can also accommodate a modular payload of up to 34 feet in length and approximately 19,004 cubic-feet in volume, as well as payloads extending outside of its envelope.

- Weight: 50 tons (45,360 kg)
- Length (no payload section): 51 ft (15.5 m)
- Maximum depth: 11,000 ft (3,000 m)
- Maximum speed: 8 kts (14.8 km/hr)
- Endurance: At least 3 months

Check out the newest member of the Echo family on the Boeing YouTube channel.

BOEING ILLUSTRATION

Under and across the oceans

The next generation of unmanned undersea vehicles is autonomous, extra-large and long-range.

BY DAN RALEY, BOEING WRITER

Echo Voyager, with its oblong shape and predominantly gray exterior, resembles a giant whale.

Yet Boeing's extra-large unmanned undersea vehicle (XLUUV) has a mast instead of a spout, a propeller for a tail. It doesn't breathe.

That, in itself, is the advantage of introducing Echo Voyager to a world becoming more and more autonomous, said Lance Towers, director of Sea & Land for Boeing's Phantom Works division.

The mini-submarine was designed to "offload the dull, dangerous and dirty missions where you don't want humans involved," Towers explained.

Echo Voyager, which rolled out early last year and is headed for ocean testing off the California coast, is expected to be able to spend up to six months at sea. It was designed to travel 7,500 nautical miles (13,800 kilometers) on lithium-ion batteries and a full tank of diesel fuel.

In other words, Voyager could go unimpeded from San Francisco to as far as Hong Kong—all without a surface support ship, relying instead on a lone operator stationed several time zones away.

Echo Voyager is the newest and most versatile member of Boeing's UUV trilogy. It is the extra-large version and builds on the experience and capability offered previously by smaller Echo platforms. Echo Ranger, which is 18 feet (5.4 meters) long, was first unveiled in 2001 and now performs ocean surveys and payload experimentation. Echo Seeker, which is 32 feet (9.7 meters) long, has been in service since 2015.

Boeing has designed and operated manned and unmanned deep sea systems since the 1960s.

It is expected that some day unmanned vessels will provide an undersea security force that patrols the largest American harbors and waterways, plus demonstrate the ability to perform surveillance missions in potentially hostile waters, according to Boeing leaders.

Echo Voyager could be used to inspect infrastructure below the surface, create ocean-floor mapping and detect environmental hazards in open waters, program engineers say. It can launch and be recovered from virtually any port, again negating the need for a support ship. Navies, salvage crews, researchers and fossil fuel companies are logical entities that would use the XLUUV at a fraction of what a full-scale manned submarine would cost.

"We were interested in trying to help our customers break the cost curve," Towers said at a demonstration in Arlington, Virginia.

The vehicle uses encrypted Inmarsat IV, Iridium, Wi-Fi, and/or freewave-enabled communications on the

UNDERWATER ENDURANCE
Echo Voyager is expected to be able to cross the Pacific Ocean nonstop on a full tank of diesel fuel and a powered-up bank of lithium ion batteries.
BOEING PHOTO

> "We were interested in trying to help our customers break the cost curve."

LANCE TOWERS, DIRECTOR OF SEA & LAND FOR BOEING'S PHANTOM WORKS DIVISION

surface, and acoustic communications for command, control and status messages during submerged operations.

To insure its seafaring independence, the vehicle comes equipped with redundancy and backup systems, necessary to withstand the rigors of the highly pressurized underwater world.

What separates Echo Voyager from other unmanned vessels is a hybrid rechargeable power system. Once its batteries run low, the submarine will surface, raise its mast and turn on diesel-powered generators to charge the batteries. Once recharged, it will submerge, lower its mast and be on its way.

There is much to be done under the ocean's surface.

"Oceans offer a look into our past and our future," said Steve Deinstadt, who works for Boeing in Huntington Beach, California, and was a senior field engineer for Boeing's Echo Seeker. "Let's seek it out." IQ

Autonomy expanded with SHARCs

Boeing has taken another step toward growing its position in the autonomous systems marketplace by acquiring Liquid Robotics.

Liquid Robotics is a market leader in autonomous maritime systems and is the developer of the Wave Glider autonomous ocean surface robot.

"With Liquid Robotics' innovative technology and Boeing's leading intelligence, surveillance and reconnaissance solutions, we are helping our customers address maritime challenges in ways that make existing platforms smarter, missions safer and operations more efficient," said Leanne Caret, president and CEO of Boeing Defense, Space & Security.

Liquid Robotics, with operations in Sunnyvale, California, and Kamuela, Hawaii, is now a subsidiary of Boeing's Autonomous Systems organization, a business that includes unmanned aircraft systems subsidiary Insitu, Inc.

In September 2014, Boeing and Liquid Robotics entered into a teaming agreement that resulted in extensive integration on the Sensor Hosting Autonomous Remote Craft (SHARC), a version of the Wave Glider. The SHARC, integrated with Boeing's advanced sensors, connects intelligence, surveillance and reconnaissance capabilities ranging from satellites to manned and unmanned aircraft to subsurface vehicles.

Liquid Robotics has designed and manufactured the Wave Glider, the first wave- and solar-powered autonomous ocean robot, since its founding in 2007. With more than 1 million nautical miles (1,852,000 kilometers) traveled, the craft's capabilities address the challenges facing defense, commercial and science customers by making ocean data collection and communication easier, safer and immediate.

-Ashlee Erwin, Boeing Writer

ANN KAO, SENIOR TECNICAL FELLOW

The discipline of Big Data

Machine learning and artificial intelligence drive the data movement.

Data analytics is a not just a new term for the relatively old discipline called statistics.

Data analytics methods are often statistically based, but the goal of data analytics is typically not to prove or disprove a hypothesis, but rather to use machine learning and heuristics to discover a model of the data in order to characterize and predict new data.

The success of a data analytics application depends on the following:

- The quality of the data;
- Preparation of the data;
- Understanding of the data and the associated business rules and business problem to be solved, in conjunction with the method or algorithm used;
- How well the results are presented; and
- The business value it can bring.

What distinguishes modern day data analytics from the data mining of 20 years ago is that the former focuses on analysis of data from multiple sources and often in multiple formats and with different business or coding rules.

For a better understanding of manufacturing defects, for example, we have to know how information is coded in the system. If there are 10 holes drilled incorrectly in one part, is that 10 defects or one? If it affects multiple planes how is that recorded? How do changes of processes and coding over time affect the analysis?

Big data is not all about volume. "Big data" also refers to the variety, variability, veracity, velocity and the value it brings—collectively, the six V's.

Data scientists may spend 70-90 percent of their time transforming and preparing the data for analysis.

> There is no single analytics method that is good for everything. Some approaches are more robust. Some algorithms are accurate but uninterpretable.

If I could tell you that a particular program will have more mechanical issues but not tell you what types of failures or what activities correlate strongly with those failures, there would not be much value in that knowledge—even if I'm very accurate. Interpretability makes for actionable results.

Early artificial intelligence research in the 1980s failed in the early 1990s, not because of lack of computing power, but because the amount of knowledge required was massive and hard to manage.

Machine learning efforts in the late 1990s swung to the other side, relying on heuristics and statistically based methods to learn from sample data. But it still takes time to obtain sample data, and this "blind" way of learning can involve lots of trial and error—and cannot handle complex problems in a timely manner.

Many in the data mining community now promote a best-of-both-worlds approach: dividing large problems into more easily intelligible chunks by mixing smaller, simpler models; complementing machine learning with interactive science; and drawing on users' own domain knowledge to interpret complex results.

The recent renewed hope for artificial intelligence has to be based on the right mix of machine learning and domain knowledge. This is a necessary foundation for the future of data analytics, as well as other areas such as autonomous systems (self-driving cars and the like). IQ

Anne Kao is Boeing's Senior Technical Fellow for data analytics and an internationally recognized expert working at the intersection of language philosophy, computation and machine learning.

Unique requirements for safeguarding aircraft

Cyber-physical systems are ones that integrate physical components through computation and networking, and they present unique challenges and opportunities for cyber defense.

**BY DOUGLAS STUART, CYBERSECURITY NETWORK TECHNOLOGY ENGINEER
BOEING RESEARCH & TECHNOLOGY**

BOEING PHOTO

HACK RESISTANT Boeing rotorcraft test pilot Roger Hehr (left), reviews security features following a successful High-Assurance Cyber Military Systems flight test on the Unmanned Little Bird helicopter. (Douglas Stuart, background center.)

Wherever there are computers, there is the potential for adversaries to attempt to subvert them for their own purposes.

First the challenge: cyber-physical systems like aircraft are typically more resource constrained—including in connectivity—than desktop and enterprise systems (and even mobile systems). This means that desktop and enterprise security solutions relying on spare computing power, storage and always-on high-bandwidth networking, generally cannot be used on cyber-physical systems. This complicates the problem for cyber defense.

But here's the opportunity: cyber-physical systems are generally designed for a specific purpose and to interact with the physical world. In other words, their behaviors tend to be designed to achieve a physical result.

This simplifies the problem for the defense; if we know what our systems are supposed to be doing, it can be easier to recognize attacks. Additionally, cyber-physical systems typically have significant safety requirements, and so benefit from more extensive verification and validation than desktop systems.

Cybersecurity research leverages these constraints to develop new approaches. One angle of recent research uses mathematical techniques to guarantee that the software in cyber-physical systems is free from the sort of implementation defects that attackers can use to subvert systems.

These techniques have been used in the past to ensure safety, and we are looking to extend these formal methods to enhance cybersecurity. If we can mathematically prove that the software in our cyber-physical systems is free of a particular kind of defect, then we have a complete defense against those types of attacks.

Another approach uses the designed regularity of our systems' behavior to detect signs of attacks. Such anomaly detectors have a mixed heritage in desktop and enterprise systems, in part because it is difficult to predict what the user of such a system might legitimately do. For example, is visiting a new website evidence of an attack, or did the user just need to research a new vendor? Exploiting the constrained behavior of our systems (e.g., the aileron actuator should not be talking to the cabin lighting) allows us to significantly reduce these kinds of false alarms.

Cyber threats evolve rapidly, and defenses that work can quickly become obsolete. So, there is a need for the defenses to be able to adapt to threats. We are adapting emerging paradigms, such as software-defined networks and software diversity that provide the ability for cyber-physical networks to quickly adapt to changing environments and defeat emerging threats.

Finally, communications also affects cybersecurity, as a system cannot rely on being able to "phone home" to make sure that the signature on a message hasn't been forged or a credential stolen.

Emerging Delay/Disruption Tolerant Networking (DTN) protocols specialized for space and aircraft applications where network connectivity is intermittent could also be leveraged for security.

Boeing has also been involved in developing standards for Delay Tolerant Networking (DTN). Originally intended to enable space applications to compensate for the large transmission delays and intermittent connectivity of the interplanetary internet, DTN can help earth-bound platform systems deal with limited and slow connections to aircraft in flight or submarines under water.

These approaches and others help bridge the gap between the capabilities offered by the overall computer security industry and the unique requirements of cyber-physical systems. IQ

Cyber threats evolve rapidly, and defenses that work can quickly become obsolete.

Customer-centered data analytics in Vancouver, Canada

Harvesting data is only the beginning of integrated operational problem-solving for complex organizations.

JRÉ DE KLERK, PRODUCT MANAGER AND STRATEGIST
BOEING VANCOUVER LABS

In the era of increasing data, countless hours are spent parsing vast amounts of information, turning data into knowledge and deriving actionable data-driven insights that help customers save money, improve efficiency and minimize disruptions.

Airline operations involve a network of airports, a fleet of aircraft and a team of employees separated by long distances. When a disruption hits, critical and immediate decisions are required. Make the wrong decision, and schedules get off track. Passengers become frustrated. Brand loyalty is on the line.

Getting back to schedule as soon as possible requires complex coordination with various departments across the airline. When a disruptive event occurs, airlines typically go through a decision-making process that includes identifying the issue, gathering the impacts, developing, comparing and choosing a recovery solution. Finally, the chosen solution is executed.

One of the biggest challenges faced by airlines today is the ability to view all disruptive events in one place at one time. Airlines and their operational stakeholders must constantly monitor many disparate systems in order to gain an understanding of the current operational situation, a very time consuming task. And during day-of-operations, time is one of the most valuable resources.

What makes understanding the severity of a disruption—and how a delay will propagate downline—even more challenging is that not all delays are created equal. For example, a 180-minute delay that only affects a single flight may not be as important to mitigate as a 30-minute delay that affects several flights downline. Connecting passengers and cargo onboard also plays a big part in saving a particular flight or mitigating a specific issue.

Boeing Vancouver Labs, which opened in September 2016, applies data analytics, rapid product development and agile software approaches to a variety of complex problems facing the aviation industry today. The intent is to deliver tangible insights and results—challenges like prognostic maintenance, fuel optimization and integrated disruption management.

Our goal is to develop customer-centered data-analytics software solutions that are customizable, scalable and modular, so that airlines may implement them incrementally within existing complex systems, enabling a future with no surprises.

This includes exposing and quantifying the most significant systemic sources of disruptions in an airline's operation with root cause delay tracing, delay cost calculation and airline delay benchmarking to help airlines anonymously understand how their operation lines up against other similar airlines.

Boeing Vancouver Labs works with Boeing's global team, including other Boeing subsidiaries such as Jeppesen, to focus on solutions for the entire airline life cycle that are powered by analytics. This involves planning to day-of-operations to post-operations analysis, in order to help customers improve their processes, boost resource utilization and increase overall situational awareness across their entire operation. IQ

Boeing Vancouver

Formerly a subsidiary known as AeroInfo, the Boeing Analytics Group opened a new downtown laboratory focused on data analytics-driven software solutions in September 2016. The Vancouver Labs complement the company's facilities in Richmond, B.C., Canada, which today employ more than 200 highly skilled software engineers and data scientists.

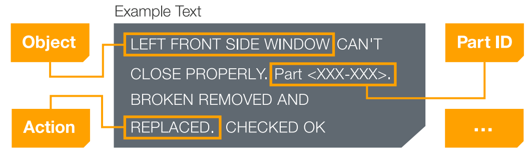
Introduction

Textual data is one of the richest data sources for fleet health and maintenance analytics.

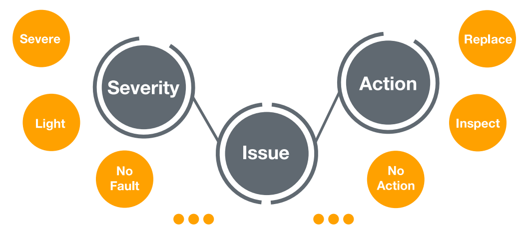
Taking advantage of this information plays a key role in optimizing an airline's and Boeing's business.

Maintenance text can provide rich information such as root cause and action performed about each issue detected. Due to its large volume and highly unstructured nature however, industry lacks mature analysis capability and often relies on manual processing.

The Advanced Analytics team identified opportunities to produce more robust solutions leveraging text analytics and have provided solutions in the areas of reliability, airline maintenance program and customer support.



"Which components and locations are having more issues? What are the root causes and how should I fix it?"



Benefits

Text mining techniques lead to various benefits.

- Improve operations by supporting analysis in a large scale on critical events such as flight delay.
- Save costs by eliminating unnecessary manual work by engineers.
- Enable new innovative ideas.

Global scale

The plane for Antarctica

In November, then Secretary of State John Kerry became the highest ranking U.S. official ever to visit Antarctica, when he arrived aboard a C-17 Globemaster III to meet with scientists and researchers. For the past 17 years, the U.S. Air Force has relied on C-17s as part of Operation Deep Freeze, which supports National Science Foundation research studying Antarctic bodies of water, weather systems, glacial movements and marine life. The Globemaster III is well suited to the unique challenges of Antarctic air support because of its payload capabilities, extended range, and ability to operate in extreme environments, including small, semi-prepared runways. Boeing, which supports the entire C-17 fleet, has decreased cost-per-flying-hour by 16 percent over the past 12 years, while that cost for similar platforms during the same period increased.

Student satellites in the UAE

For the fifth consecutive year, Boeing will provide technical guidance and funding support for the capstone design project at Khalifa University's Aerospace Department. Five Emirates students will work as a team to design, build and fabricate a 2U CubeSat, a miniature satellite, to study the environmental effects of desalination in the Middle East. The students will learn different technical and professional skills related to flight dynamics, composite materials, 3D printing, control systems design, technical writing and public speaking.

Digital toolbox comes to China

Shanghai-based Yangtze River Express has become the first airline in China to use Boeing's Digital Toolbox Records. The automated record keeping system—and the underlying Secure Technical Records for Electronic Asset Management (STREAM) application from Boeing subsidiary AerData—reduces time and error associated with managing paper records. Combined, 50 aviation customers use Toolbox Records and STREAM on a daily basis to dynamically manage aircraft and engine technical records of more than 8,900 aircraft. This is done with indexed and searchable data, built-in data quality control workflow, and integration with in-house IT systems for secure web-based application with a graphical user interface.

Selections from the Boeing Technical Journal

A peer-reviewed periodical for Boeing subject-matter experts.

Research coverage includes all manner of commercial, defense and space technology development, and products and services. The following are selections from an exclusive internal publication by and for Boeing technical staff.

Contributing Authors

AIR TRAFFIC MANAGEMENT RADIO FREQUENCY RELATIVE MARGIN ANALYSIS

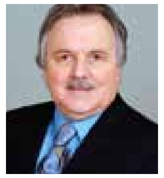
Guangyu Pei is an Associate Technical Fellow in Boeing Research & Technology and an IEEE certified wireless communication professional.

Arun Ayyagari is a Senior Technical Fellow in Boeing Commercial Airplanes focusing on information management, communications and networking, manufacturing and automation, and networked/embedded systems.

James Farricker was a Senior Technical Fellow and senior chief engineer for networks and communications in Boeing Defense, Space & Security.*

Sue-Lynn Yim is senior manager of the Boeing Technical Fellowship and a technical specialist in integrating avionics, communications and combat identification systems on the Airborne Warning and Control Systems (AWACS) platform.

ON-DEMAND WAVEFORM DESIGN FOR SOFTWARE-DEFINED RADIO APPLICATIONS



Gary Ray is a Technical Fellow in Boeing Research & Technology, with more than 30 years in the field of communications and signal processing, including experience at Hughes Aircraft and Westinghouse Hanford.

*This publication is dedicated to our late colleague, James T. Farricker, an engineering vice president, architect of Boeing's enterprise network and prolific Boeing inventor (1955-2016).

Air Traffic Management Radio Frequency Relative Margin Analysis

Summary

BY GUANGYU PEI | ARUN AYYAGARI | JAMES FARRICKER | SUE-LYNN YIM

With the introduction of civilian air traffic management technologies such as Mode S and Automatic Dependent Surveillance-Broadcast (ADS-B) in the continental United States, the U.S. Federal Aviation Administration (FAA) has unprecedented capability to track, identify and receive on-board information from transponder responses in the 1090 megahertz (MHz) frequency band. Additionally, transponder Traffic Collision Avoidance System (TCAS) communications at 1090 MHz provides real-time proximity warnings to avoid in-air collisions.

However, these capabilities are not without cost. Longer data messaging formats, coupled with the ever-increasing number of domestic flights, has raised concerns within the FAA regarding additional radio frequency (RF) interrogations at the 1030 MHz frequency band and replies (at 1090 MHz), especially those located near international airports.

Boeing is committed to preserve safe airspace operations, and this analysis explores 1090 MHz congestion margins at various locations in the continental United States where Boeing operates, including Seattle; St. Louis; Oklahoma City; and Charleston, South Carolina. In our studies, we propose novel stochastic relative margin analysis for analyzing 1030/1090 MHz congestion, using published reports and data generated by the Massachusetts Institute of Technology's Lincoln Laboratories in 2012 that are cited by the FAA. Our intent is to provide results that can be used to quantify requests for testing systems efficiently without causing interference with operations in U.S. national airspace, navigation facilities and airports. **Table 1** summarizes the key characteristics of MIT LL data matched in our studies.

Our relative margin analysis is based on the key observation that safe operations are currently being conducted in the dense northeast corridor of the United States (i.e., near John F. Kennedy, LaGuardia and Newark airports). Therefore, for any other airport that is in a less dense area, it should be able to increase its load on the 1030/1090 MHz channel safely as long as total number of aircraft within range is less than that of the dense northeast corridor.

While it seems intuitive that 1090 MHz transmissions are lower in Oklahoma City than at JFK, it requires vigorous statistical analysis to quantify the relative margin between locations such that we can evaluate the impact of additional hypothetical test flights at each test location. The methodology, analysis and corresponding results are presented in detail in the full paper, available online. The steps of this statistical analysis on the relative margin can be summarized as the following:

1. Compute hourly distribution of aircraft density within 30 nautical miles from any major airport of interest.
2. Select reference airport (for example, JFK). Compute the hourly distribution of aircraft within 30 NM from the reference airport. Since both Newark and LaGuardia are within 30 NM from JFK, the reference hourly distribution is the sum of JFK, Newark and LaGuardia.
3. Measure the reference airport 1030/1090 MHz channel occupancy and per aircraft 1030/1090 MHz message reception distribution.
4. Perform stochastic simulations to compute the channel occupancy using hourly distribution obtained in step 2. Compare the simulated channel occupancy with measured data from step 3 to scale parameters used in simulations such that the channel occupancy from simulations matches with measurement.
5. Use the same parameters obtained in step 4 for all other airports to compute their channel occupancies via stochastic simulations.
6. Compute the relative margin using the channel occupancies from step 5.

We focused on the average civilian aircraft traffic within 30 NM of major airports because this corresponds to an average transponder's detection threshold. Aircraft densities for airports of interest were plotted on histograms that showed the number of takeoffs and landings every hour each day for the entire 2014 calendar year.

A simple, statistical takeoff and landing model was developed by Monte Carlo simulation of 10,000 samples until the statistical results correlated to measured 1090 MHz transmissions in the JFK/LaGuardia/Newark corridor (as published in the 2012 MIT Lincoln Laboratories report) and the statistical model was adjusted for nominal air traffic density increases in 2014. Once this statistical model of the northeast U.S. corridor was verified, we applied similar per-aircraft transmission characteristics to other airports of interest based on publicly available flight-tracking data. Assuming we have safe national airspace operation in the JFK/LaGuardia/Newark corridor, we can compare our control JFK/LaGuardia/Newark scenario results to similarly modeled airports (such as Seattle, Charleston, St. Louis and Oklahoma City) and thereby infer relative capacity margins.

Normalizing to Seattle peak-hour aircraft densities (and consequent transponder occupancy and reception rates) to 1.0, relative transponder occupancies for other locations are shown in **Table 2**. (See page 30.) The detailed per hour distributions are given in **Figure 9** and **Figure 10** for various locations of interest within the continental United States. The shaded area represents the variation from the data and simulation.

The sensitivity of transponder occupancy to additional flights also was modeled statistically as illustrated in **Figure 11**. (See page 30.) In this scenario, 5, 10 and 20 test flights per hour are added to the baseline number of flights around the Seattle area for

MIT LL Data	Match requirements
Signal-in-space @-74 dBm	Proper equivalent range to count aircraft and the other airports.
Hourly aircraft counts	Need to have same granularity for all the other airports.
Omni-directional reception rate and occupancy	All at system macro level, not per aircraft.
Per-aircraft transmission rate statistics	It can be used as upper bound directly when fewer airlanes than that of JFK present.

TABLE 1.
MIT LL Data Characteristics

SOURCE: Massachusetts Institute of Technology

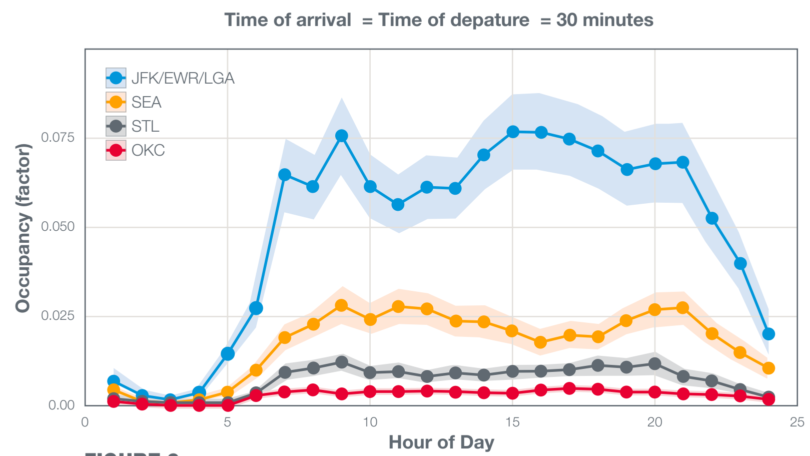


FIGURE 9.
SEA, STL and OKC vs JFK/EWR/LGA: Timeline Occupancy

SOURCE: BOEING

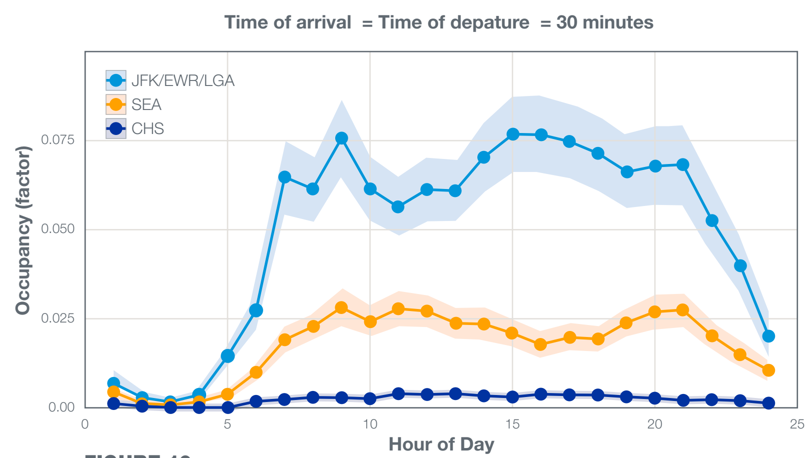


FIGURE 10.
SEA and CHS vs JFK/EWR/LGA: Timeline Occupancy

SOURCE: BOEING

Therefore, for any other airport that is in a less dense area, it should be able to increase its load on the 1030/1090 MHz channel safely as long as total number of aircraft within range is less than that of the dense northeast corridor.

each hour between 7 a.m. and 7 p.m. That corresponds to 60, 120 and 240 total test flights added during a day. The effect of adding 20 more flights per hour to the Seattle corridor is still roughly less than half what is currently experienced in the JFK/LaGuardia/Newark area, as can be noted in **Table 2**.

It can be safely inferred that less dense air traffic corridors can safely accommodate 1090 MHz transmissions from airborne and ground testing if we can model the equivalent impact of additional flights. For example, to estimate the effect of military interrogator systems, we would identify the number of transponders "painted" in the airspace of interest (based on flight density and interrogator altitude and antenna beamwidth), and approximate an equivalency to additional commercial flights.

By judiciously managing temporal differences in flight density and interrogator directionality (e.g., away from air corridors of interest) effective and safe test objectives can be completed while maintaining the integrity of operations in the national airspace. IQ

Airports	Normalized to Seattle peak hour occupancies
JFK/LGA/EWR	2.7
SEA	1
STL	0.43
OKC	0.16
CHS	0.14

TABLE 2.
Normalized occupancies based on SEA peak hour occupancy

SOURCE: BOEING

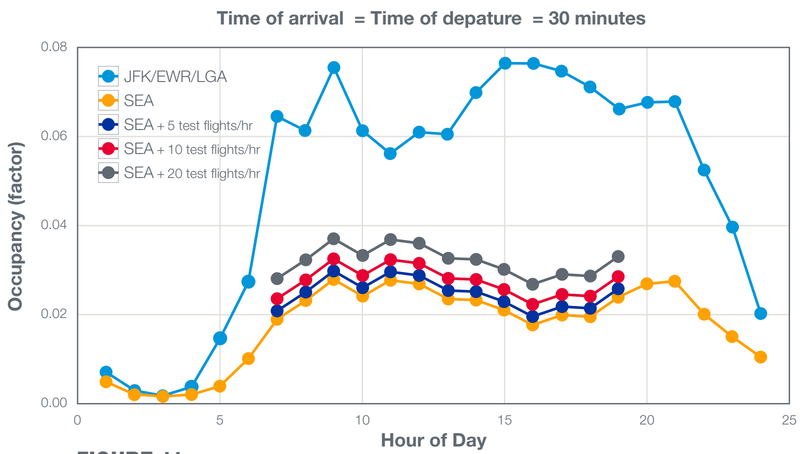


FIGURE 11.
SEA, STL and OKC vs JFK/EWR/LGA: Timeline Occupancy

SOURCE: BOEING

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

"Air Traffic Management Radio Frequency Relative Margin Analysis"

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

On-Demand Waveform Design for Software-Defined Radio Applications

Summary

BY GARY RAY

The exponential growth in demand for wireless communications, both for civilian and military use, has created an urgent need to use as much of the increasingly scarce available radio frequency (RF) bandwidth as possible. This remaining available bandwidth is usually non-contiguous, time-varying and non-uniform in propagation characteristics.

The ideal would be to have a single physical radio that implements all existing communication signals and protocols (one radio that does it all), as well as one that adapts to new conditions to effectively use as many communications resources as possible, while still meeting applicable Federal Communications Commission and World Radio Conference requirements.

Software-defined radio (SDR) technology brings these benefits of flexibility and cost efficiency to end users. An SDR typically includes a collection of hardware and software technologies where some or all of the radio's operating functions are implemented through modifiable software or firmware running on devices including field programmable gate arrays (FPGA), digital signal processors (DSP), general purpose processors (GPP), programmable System on Chip (SoC) and other application specific programmable processors. This allows new wireless features and capabilities to be added to existing SDR systems without requiring new hardware.

Software-defined radios typically use a set of fixed modulation waveforms for a fixed set of channel band-widths and choose among them to meet their operational goals. For example, when a set of non-contiguous channels become available, the SDR chooses one signal from this fixed set for each empty channel that matches that particular channel's conditions (maximum energy, bandwidth, noise, channel characteristics, etc.). There are drawbacks to this method.

First, the fixed modulation waveforms do not exactly match each channel and so must be chosen conservatively so that all channel conditions are met (especially conditions that define the maximum signal leakage into adjacent channels). This mismatch leads to lower performance.

Second, coding is typically done only within each channel, rather than across channels. This leads to worse performance for certain channels when they are affected by worsening channel impairment over time.

Third, each channel must do its own synchronization (symbol, bit and frame, for example) because each is handled independently. This increases the complexity of the receiver because of the requirement for separate independent real-time parallel signal processing.

This paper describes a way to operate typical SDR systems through the on-demand custom design of modulation waveforms for communication on nearly any available spectrum under an unlimited set of operational conditions.

In summary, the technical paper

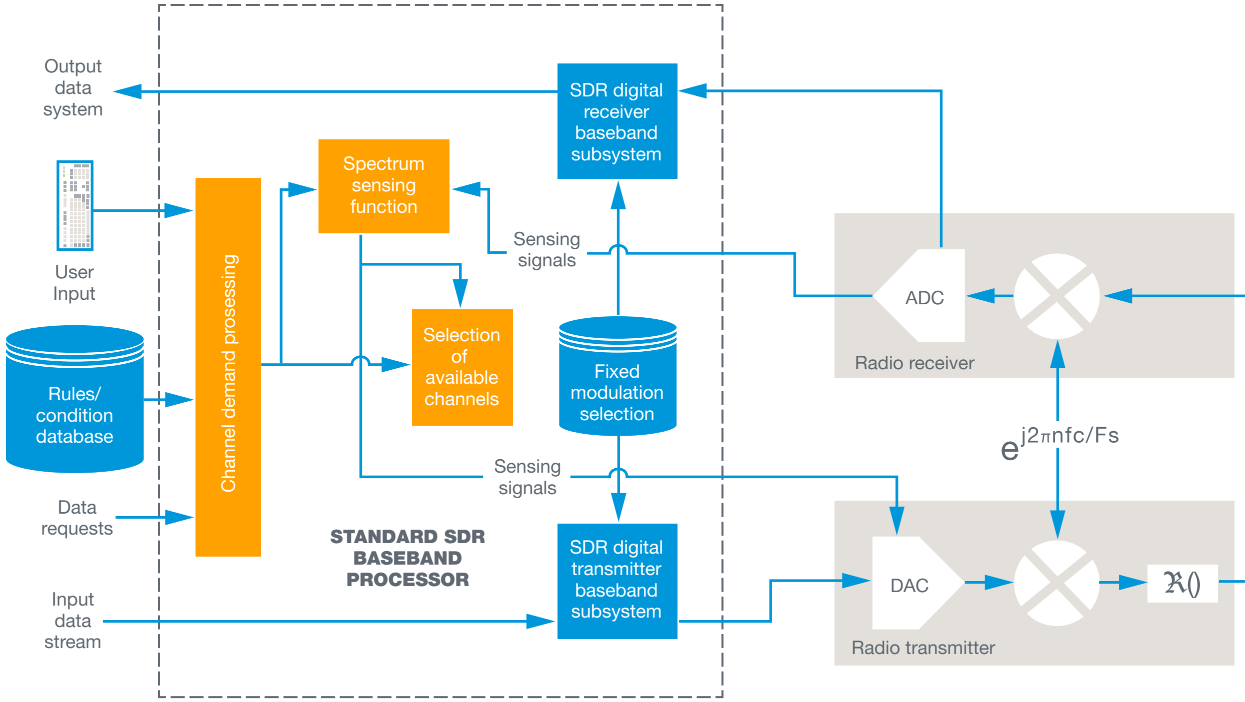


FIGURE 1.
Software-defined radio

There are several other terms with slightly different meanings under the category of software-defined radio.

Adaptive radio is radio in which communications systems have a means of monitoring only their own performance and modifying their operating parameters to improve performance. This capability enables greater degrees of freedom in adaptation to changing conditions and to achieve higher levels of performance and better robustness for a communications link.

Cognitive radio is radio in which communication systems are aware of both their internal state and the communications environment. Therefore they can make decisions about their operation by mapping that information against predefined objectives such as the most efficient usage of available frequency spectrum.

Intelligent radio is cognitive radio that is capable of artificial intelligence, i.e., it is capable of automatically improving operation in the face of changes in environment and end user desires. All these concepts are typically implemented using SDR technology.

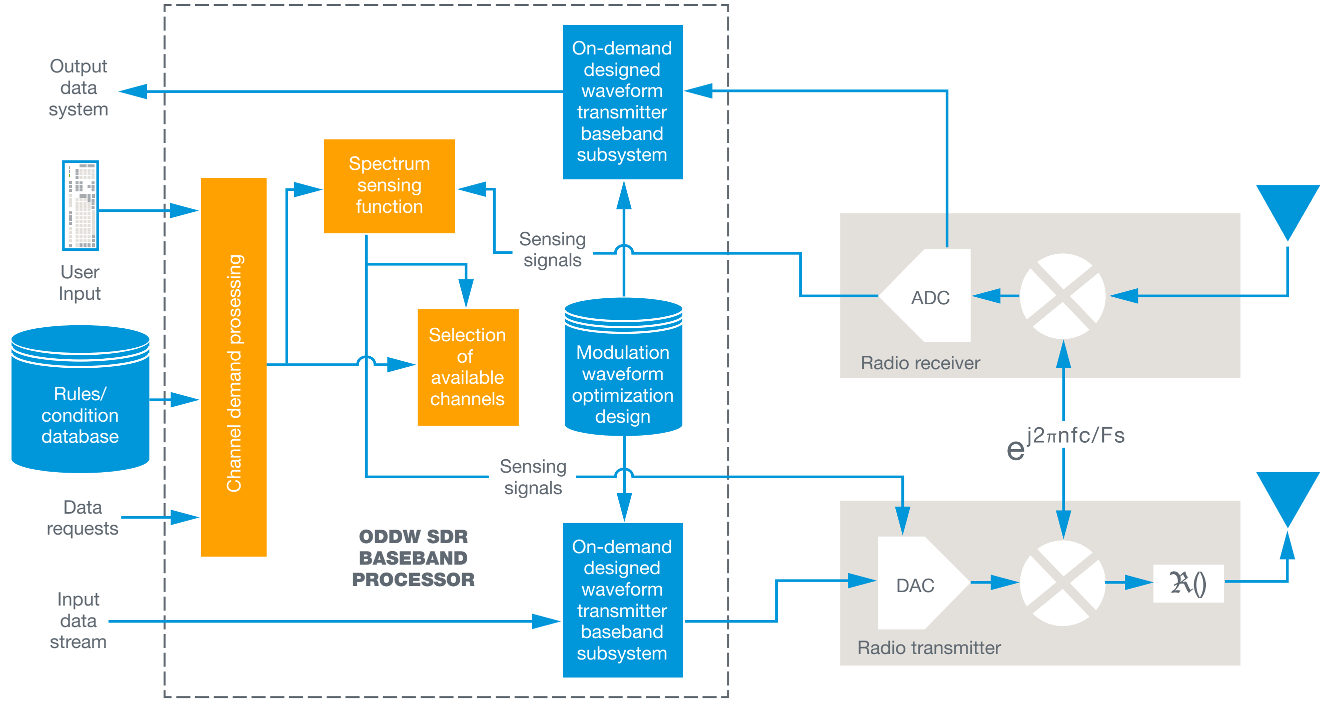


FIGURE 2.
On-demand designed waveform

U.S. Patent number 9,325,545, granted to Boeing in 2016, describes a system and method for generating an on-demand modulation waveform for use in communications between radios.

describes the concept of on-demand designed waveform generation and an approach to implement this concept in both standard and specialized software-defined radio architectures.

Specifically:

1. An optimization method is described to design modulation waveforms for SDR applications which enhances, among other things, both synchronization and bandwidth usage compared to traditional modulation methods. In particular, our approach allows:

- Longer range and lower power communications under comparable conditions.
- Communications allowing more efficient spectrum usage.
- Spreading of synchronization and coding functions across multiple channels and disjoint spectral regions.

2. A numerically controlled waveform generator is described which allows hardware/firmware to create a sampled version of the designed modulation waveform at any particular frequency for modulation by the symbol sequence of a transmitter or conversely by correlating in the receiver. This waveform can be further tailored to reduce storage requirements through judicious interpolation and various symmetries can be imposed within the optimization to reduce storage as well.

3. An on-demand architecture is described that allows creation and utilization of a designed modulation function within a typical software-defined radio architecture. A method of operation is also described that would allow on-demand waveform design to function within an existing SDR system.

Figure 1 shows a standard SDR system while **Figure 2** shows the corresponding on-demand designed waveform architecture introduced by this paper. The three main differences are the replacement of a fixed set of modulation waveforms with a processing unit that solves an optimization problem to design a new modulation waveform particular to the measured channel conditions and required data rates, together with modified baseband processing using these new modulation waveforms. Implementation of on-demand waveform design with SDR requires four items:

- A method of mapping communications channel conditions into a mathematical description that can be used via standard optimization processes to generate the desired waveforms.
- A transmitter and receiver architecture that implements on-demand designed waveform communication using the numerically controlled waveform generator.
- On-demand waveform SDR operation implemented within the larger software-defined network operation.

These four items are described in sections III-VI within the full Boeing Technical Journal paper available online. Specifically, section III covers the mathematical description of the design process for modulation waveform generation; section IV covers the numerically controlled waveform generator; and section V describes the on-demand designed waveform transmitter and receiver

Because of its designed structure, this modulation waveform can increase the bit-error rate performance and/or range of almost any existing wideband SDR, while increasing robust performance under varying channel conditions.

architecture, amplifying what was shown in **Figures 1 and 2.**

The approach described was tested on several design problems and the results are further described in the full paper. Finally, this architecture was implemented using the Universal Software Radio Peripheral (USRP) platform (GNU radio hardware) from National Instruments/Ettus Research at Boeing's 7-107 laboratory complex. This implementation and testing are described in the full paper.

This waveform method creates a single modulation function across the likely non-contiguous available spectrum with near-optimal synchronization and correlation properties and with near-optimal bandwidth efficiency. Because of its designed structure, this modulation waveform can increase the bit-error rate performance and/or range of almost any existing wideband SDR, while increasing robust performance under varying channel conditions. In addition, an SDR designed using the new hardware architecture described in this paper has a simpler structure than a traditional set of parallel digital modems, thus simplifying its design.

Many applications of our approach are possible for both the military and commercial communications.

In the commercial arena, possible application areas include:

- Better spectrum usage for public channels such as ISM.
- Operation within White Space (IEEE 802.22), such as within newly available UHF channels (formerly allocated to television).
- Ad hoc wireless system and emergency service providers.
- Mobile satellite and wireless systems.
- Increasing manufacturing network capacity while operating heritage communications networks.

Future work is planned to address real-world performance metrics to compare on-demand waveform design with traditional modulation approaches in given SDR scenarios. This work could also compare competing approaches, such as orthogonal frequency-division multiplexing, to design waveforms for specific tasks such as spanning non-contiguous transmission bands. We also plan to address the computational requirements and latency in more detail, especially for embedded applications such as mobile radios, as well as coordination among radios using the proposed on-demand protocol. IQ

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

"On-Demand Waveform Design for Software-Defined Radio Applications"

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.

Patents Granted Domestic

2016 **1,067**

Patents Granted International

2016 **1,865**

2016 Boeing patents

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

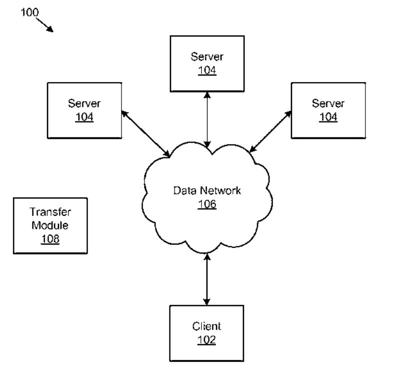


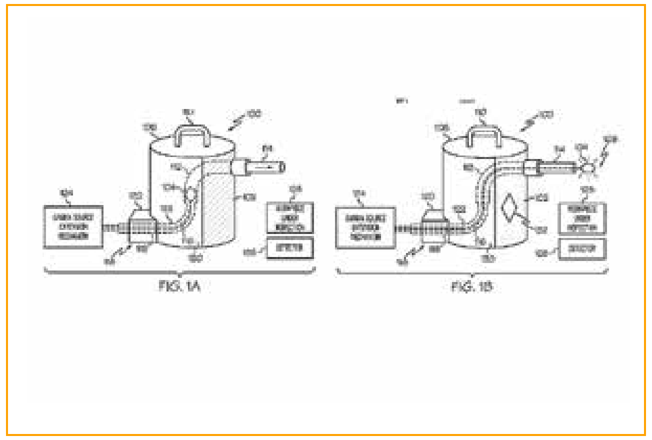
FIG. 1

Transferring files between different operating systems

U.S. PATENT: 9,524,301
INVENTORS: OMID B. NAKHJAVANI, MICAH D. DRUCKMAN

Automating data-processing tasks can be an effective way to achieve efficient and accurate data analysis results. But when you're using multiple computing devices that have incompatible operating systems or applications, you might have to manually transfer files, run analysis programs or format data, which is less efficient and may introduce errors into the data analysis process. This issue has not been fully solved by currently available systems.

Boeing received a patent granted in December 2016 for a method to automatically process data files between computing devices having incompatible operating systems. To illustrate, consider the example of just two computers with incompatible operating systems. In the patented system, data files are sent from the first computing device to the second computing device. One or more applications executing within the operating system on the second computing device process the data files. The results of the data processing are received by the first computing device. The first device determines whether the results of the data processing satisfy a predetermined threshold, and then modifies the data of one or more files based on the results of the data processing that does not satisfy the predetermined threshold. The modified files are resent to the second computing device.



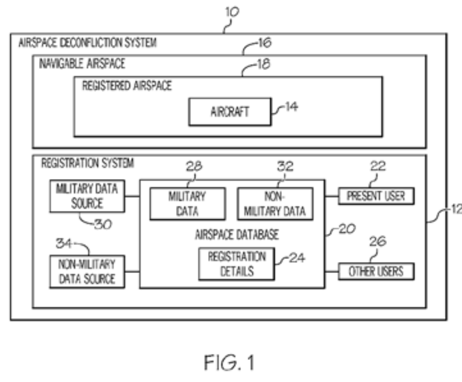
Visual indicator of an exposed gamma source

U.S. PATENT: 9,500,606 B2
INVENTOR: GARY E. GEORGESON

X-rays or gamma rays from a radioactive source or gamma radiation source have valuable uses in industry and medicine. However, exposure to X-rays or gamma rays, or prolonged or repeated exposure at even low intensity, may be harmful. X-rays are invisible to the human eye, so users of this equipment wear sensors or monitors to indicate that X-rays are on, or they wear film badges to show radiation exposure.

There might be circumstances, however, that warning devices may be inoperable for whatever reason. And film badges only identify exposure after the fact. So, there is a need for a mechanism that provides an instantaneous visual indication that an X-ray source or gamma source is exposed or unshielded—a method that is not subject to the disadvantages of electrical devices or the need for other mechanisms (like a switch).

This patent granted to Boeing in November 2016 makes X-rays and gamma rays plainly visible through the use of quantum dots. The quantum dots would be exposed onto a surface of the material used to operate or activate the X-ray or gamma ray exposure, or shield the radiation. The quantum dots fluoresce in response to being exposed to X-rays or gamma rays, providing an immediate color change on the exposed structure that will be a visible warning to anyone in the area.



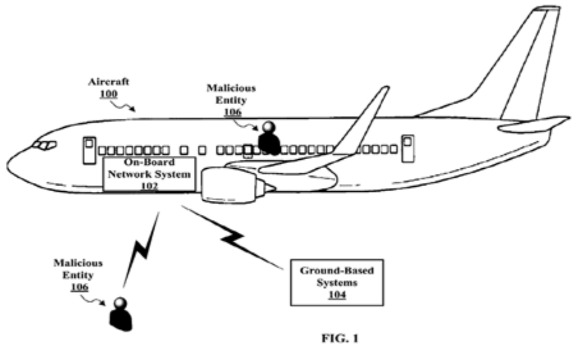
Airspace deconfliction system and method

U.S. PATENT: 9,495,877 B2
INVENTORS: MICHAEL J. DUFFY, JOHN J. MATTERO

Various aircraft, including both civilian aircraft and military aircraft, share the navigable airspace. To avoid mid-air collisions, a portion of the navigable airspace, typically referred to as “controlled airspace,” is controlled by ground-based air traffic control. Air traffic control communicates with aircraft pilots to effect an orderly flow of air traffic and to avoid both mid-air and on-the-ground collisions. Outside of controlled airspace, aircraft pilots avoid collisions by relying on their sight and sophisticated sense-and-avoid equipment, such as a traffic collision avoidance system and an automatic dependent surveillance-broadcast.

The introduction into the navigable airspace of unmanned aircraft (UAVs or drones), presents concerns of UAV-to-manned aircraft collisions, as well as UAV-to-UAV collisions. These concerns have become more acute with the proliferation of unmanned aircraft and the growing interest in using UAVs for commercial purposes.

This patent granted to Boeing in November 2016 describes systems and methods for providing safe flight of aircraft in navigable airspace. One part of the deconfliction system may include a registration system having an airspace database and an aircraft assigned to a registered airspace where the aircraft would have a guidance computer and an override unit. When the aircraft breaches the registered airspace, the override unit would take over.



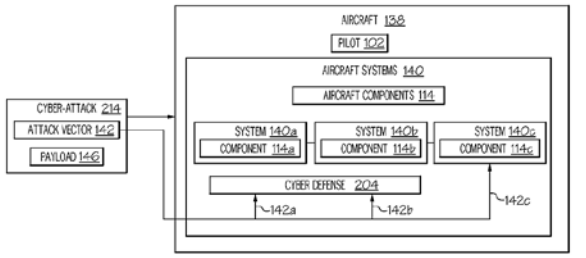
Systems and methods for detecting a security breach in an aircraft network

U.S. PATENT PENDING
INVENTORS: DAVID H. FLOYD, JASON W. SHELTON, JOHN E. BUSH

Modern aircraft typically include a networked system to allow the systems of the aircraft to communicate, provide services to the passengers, and communicate with off-board systems. The network, however, provides a conduit by which malicious entities (e.g., hackers) can attempt to gain unauthorized access to the aircraft. To prevent this, modern aircraft employ various security controls to prevent access to critical and sensitive systems.

The security controls, however, are not the complete answer. The disclosed systems and methods provide an effective and real-time means for detecting, analyzing and tracking attempted breaches. Conventional ground-based systems often include dedicated systems to detect and track breaches. The conventional ground-based systems that do this are designed to work on large scale networks and are not suitable for aircraft because of size and computational requirements.

This patent application describes a method to lure away a potential breach by malicious entities, in order to prevent a real breach. A “fake” target system simulates the systems of the aircraft in order to attract a potential breach of the data, file structure, communications, etc., of the systems of the aircraft. The target system may optionally include little, or no security or access controls in order to attract a potential breach and allow the malicious entity to gain access. Once a breach occurs, the target system can also be optionally configured to log, report or mitigate the potential breach without exposing the real systems of the aircraft to malicious entities.



System and method for developing a cyber-attack scenario

U.S. PATENT PENDING
INVENTORS: DANIEL NGUYEN, JASON W. SHELTON

Because the amount of digital information in operating and maintaining aircraft is increasing, the importance of protecting aircraft systems from cyber attacks is also increasing.

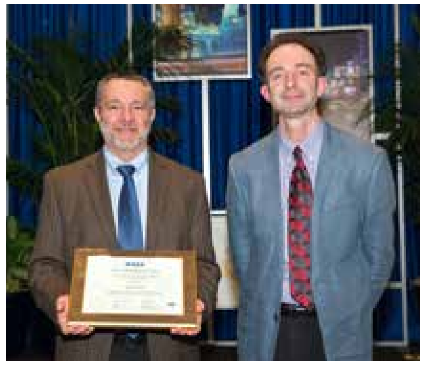
Traditional cybersecurity is aimed at preventing a cyber attack or mitigating the effects from a cyber attack on a computer system. Recently, development of responses to a cyber attack (also known as cyber defenses) includes simulating one or more cyber-attack scenarios on the computer system, analyzing the effects of the simulated cyber attack on the computer system and developing cyber defenses configured to respond to the effects of the simulated cyber attack. Unfortunately, such conventional cybersecurity standards are reactive and not proactive. In addition, the effects of the cyber attack on the pilot and/or any other non-hardware or non-software system related to the aircraft must be theorized.

This patent application describes a cyber-attack scenario simulation system and method that could be in the form of an aircraft simulator programmed to launch a cyber-attack scenario on the simulated aircraft. The system and method also allow for simulation and assessment while a pilot is in training. The method would include:

1. Generating an aircraft simulation;
2. Generating a cyber-attack simulation;
3. Generating a cyber-defense simulation;
4. Generating a cyber-attack scenario including the cyber-attack simulation and the cyber-defense simulation;
5. Launching the cyber-attack scenario against the aircraft simulation; and
6. Assessing an impact of the cyber-attack scenario on the aircraft simulation and, optionally the pilot’s response.

AIAA PHOTO

> "We recognize the importance of engineers to our world."
>
> GREG HYSLOP,
> BOEING CHIEF TECHNOLOGY OFFICER



IEEE PHOTO

AISES PHOTO

SHPE PHOTO

BOEING PHOTO

GMIS PHOTO

From the top, left to right:

THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS inducted new associate fellows from Boeing, which included (left to right) Greg Hyslop, Ed Whalen, Jeffrey Osterlund, Jeffrey Slotnick, Jason Hatakeyama and Jeffrey Crouch. The ceremony was held in Grapevine, Texas on Jan. 9.

BOEING SENIOR TECHNICAL FELLOWS Kevin Wise and Eugene Lavretsky at the IEEE Control Systems Awards in Las Vegas on Dec. 9, 2016. Wise holds his award for Technical Excellence in Aerospace Control. Lavretsky received an IEEE Fellows Award for contributions to adaptive and robust flight control technologies.

AMERICAN INDIAN SCIENCE AND ENGINEERING SOCIETY awarded Richard Johnson with the Executive Excellence Award at its national conference in Minneapolis on Nov. 12, 2016. Johnson is pictured with his wife and daughter.

BOEING TEAM MEMBERS attended the Society of Hispanic Professional Engineers national conference in Seattle on Nov. 5, 2016. David Davila (seated center), of Boeing subsidiary Spectrolab, received SHPE's Jaime Oaxaca Award.

CHICAGO'S MUSEUM OF SCIENCE AND INDUSTRY hosted the 2016 Boeing Innovation Awards in October, where 46 team members received Boeing's highest honor for technical achievement.

BOEING ENGINEERS AWARDED at the 2017 Great Minds in STEM conference in Anaheim, California, in October 2016. From left to right: Eduardo Lopez, Rosa Avalos Chumpitazi, Mona Simpson and Carlos Guzman.

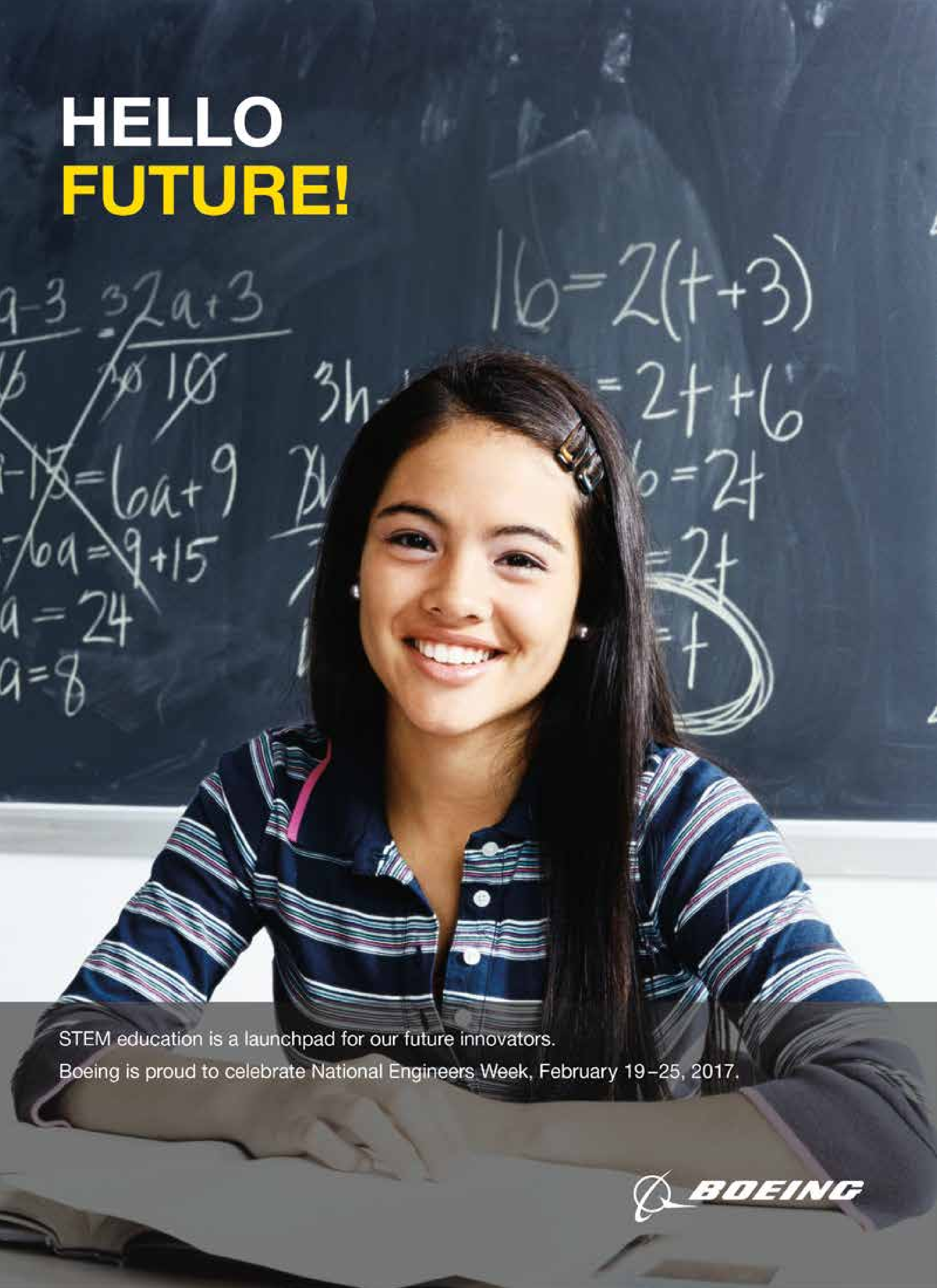
From the Innovation Video Playlist

The satellite that protects itself

Boeing is working to employ phased-array antennas to frustrate attempts to jam Wideband Global SATCOM (WGS) program satellite signals by enemies. By adjusting the power and timing for each of the antenna elements, Boeing engineers are able to create a shapable beam that avoids the jammer and allows warfighters to stay connected wherever they are located.

WGS is going through a fleetwide upgrade, uploading new software and modifying the ground segment to allow continuous communications that are resistant to jamming. It all allows for a more resilient system that the military can count on.

View this video and other Boeing Short Films on **boeing.com/innovation.**


HELLO
FUTURE!
STEM education is a launchpad for our future innovators.
Boeing is proud to celebrate National Engineers Week, February 19–25, 2017.
BOEING