Innovation Quarterly

2017 August
Volume 1, Issue 5

On Her Orbit
Women give rise to technical strength

Way Out There
Opportunities in space

Launching Innovation
Advancing humanity’s greatest adventure

A publication of The Boeing Company

Innovation
Quarterly

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Julie Perkins is an Associate Technical Fellow in satellite systems based in El Segundo, California.

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To simulate the acoustic environment generated at liftoff by four main engines and two solid rocket boosters, engineers set up towers of subwoofers and amplifiers to create 142 decibels of sound, testing the structure of the Space Launch System.

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More than 1,600 flights have been operated using blends of biofuels and conventional kerosene, demonstrating that alternative fuels are safe and technically sound, and can reduce overall carbon footprint by an average of 60-80 percent over its full lifecycle, depending on the pathway and feedstock used. The aviation industry will continue to pursue a range of opportunities in new technology, such as new aircraft design and biofuels to meet emission reduction targets.

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The ability to move information quickly and cheaply on a global scale is a multi-trillion-dollar market and has become a competitive discriminator in many industries. This affects international aerospace markets in ways that would not have been anticipated a generation ago, as communications systems increasingly rely on higher bandwidth communications in all segments of the electromagnetic spectrum.

Explore space to change the world

I'm sure you know that the opening voiceover of "Star Trek" describes space as "the final frontier." To me, though, space isn't the final frontier; it's the new frontier.

There is so much about space that we don't know. For example, Proxima b, a possibly habitable planet rotating around the star Proxima Centauri, was identified in August 2016.

Those of us at Boeing share an irrepressible curiosity to discover and learn about a universe of topics—whether it's the molecular structure of new materials that could make our airplanes even more capable or the celestial bodies that lie light years beyond Earth. That's why we're active in space, which is the focus of this edition of Innovation Quarterly. The work we do in space aligns with Boeing's overall vision, which states that we aim to "connect, protect, explore and inspire the world through aerospace innovation."

Right now we're working on the CST-100 Starliner space capsule, a part of the next new spacecraft for low-Earth orbit missions such as flying to the International Space Station—for which Boeing is NASA's prime contractor. We're also building NASA's Space Launch System, the world's most powerful rocket; and Phantom Express, a vehicle to demonstrate technologies for rapid, aircraft-like access to space. What's more, we build satellites, such as the GPS SiriusXM constellations. We also launch satellites with all-electric propulsion, which can be up to 1,000 times more efficient than satellites using chemical propellant.

In addition, we're investigating developments for new vehicles of future generations. These include products powered by hypersonics, as well as those that can reduce the cost of space access by orders of magnitude.

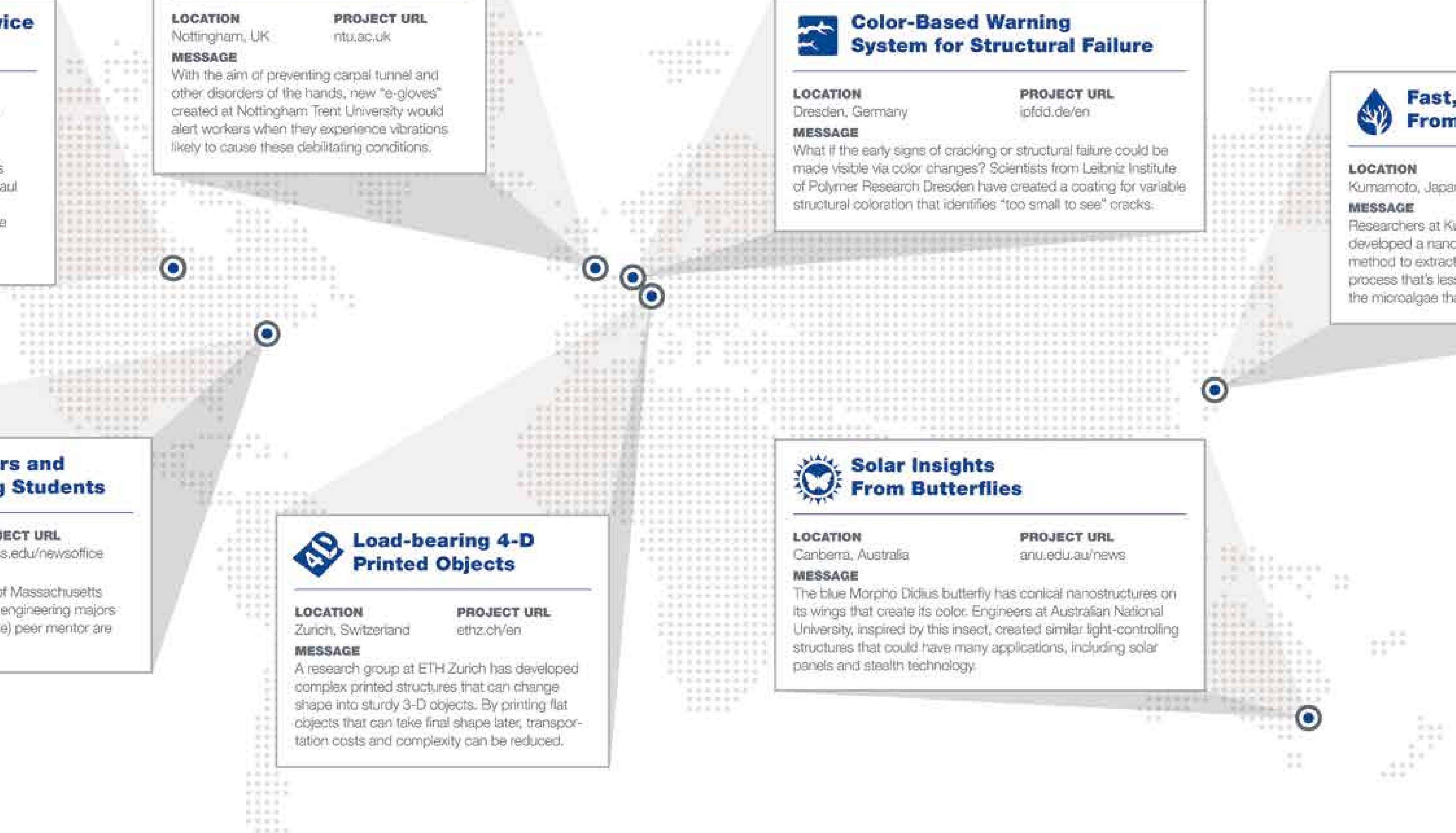
The chance to be a part of programs like these is what makes a career at Boeing exciting and meaningful. Our people are changing the world.

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

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.



Biometric Self-Service Luggage Check-ins

LOCATION Saint Paul, Minnesota

PROJECT URL news.delta.com

MESSAGE
Delta Air Lines is testing facial recognition technology, which matches customer faces with passport photos, at Minneapolis-St. Paul International Airport self-service luggage drops. The airline will gauge how much time fliers save by this process and see what customers think about it.

Vibration-Sensitive Safety Gloves

LOCATION Nottingham, UK

PROJECT URL ntu.ac.uk

MESSAGE
With the aim of preventing carpal tunnel and other disorders of the hands, new "e-gloves" created at Nottingham Trent University would alert workers when they experience vibrations likely to cause these debilitating conditions.

Color-Based Warning System for Structural Failure

LOCATION Dresden, Germany

PROJECT URL ipfdd.de/en

MESSAGE
What if the early signs of cracking or structural failure could be made visible via color changes? Scientists from Leibniz Institute of Polymer Research Dresden have created a coating for variable structural coloration that identifies "too small to see" cracks.

Fast, Low-Cost Biofuel From Microalgae

LOCATION Kumamoto, Japan

PROJECT URL kumamoto-u.ac.jp/en

MESSAGE
Researchers at Kumamoto University have developed a nanosecond pulsed electric field method to extract biofuels from microalgae—a process that's less costly and less destructive to the microalgae than traditional drying methods.

Female Peer Mentors and Women Engineering Students

LOCATION Amherst, Massachusetts

PROJECT URL umass.edu/newsoffice

MESSAGE
A study by psychologists at the University of Massachusetts concluded that first-year women in college engineering majors who were paired with a female (but not male) peer mentor are more likely to continue within the major.

Load-bearing 4-D Printed Objects

LOCATION Zurich, Switzerland

PROJECT URL ethz.ch/en

MESSAGE
A research group at ETH Zurich has developed complex printed structures that can change shape into sturdy 3-D objects. By printing flat objects that can take final shape later, transportation costs and complexity can be reduced.

Solar Insights From Butterflies

LOCATION Canberra, Australia

PROJECT URL anu.edu.au/news

MESSAGE
The blue Morpho Didius butterfly has conical nanostructures on its wings that create its color. Engineers at Australian National University, inspired by this insect, created similar light-controlling structures that could have many applications, including solar panels and stealth technology.

**MICHAEL WOOD,
SPACE LAUNCH
SYSTEM CHIEF
ENGINEER**

The Space Launch System

Building the future of a new space economy.

The stakes are high—at least four lives are on the line—and you only have one chance. Do you play it safe, or do you innovate? How much added risk to cost, schedule and human safety is acceptable to attain the future?

That's engineering in the human spaceflight business every day. Everything is on the line for that one big event—launch—when engines, fueled by giant tanks and controlled by millions of lines of software, ignite to push tons of mass against Earth's gravitational pull.

NASA encourages innovation across all their directorates, even as they demand the highest possible safety standards for new capabilities that make up America's human spaceflight infrastructure and enable the next great adventure.

Again and again, we face the question of how—and where—to innovate safely, as we design, develop, test and manufacture propulsion systems and avionics for the world's most powerful rocket, NASA's Space Launch System. To keep flying in a challenging economic environment, we absolutely have to cut costs from the production and launch of big rocket systems.

We also need to fly sooner, rather than later, in order to maintain our launch pace and keep our supply chain engaged for future systems.

So we're using a phased approach to manage the risks of innovation. Our first flight, in 2019, uses proven capabilities from our 60 years of human spaceflight experience, while introducing innovations in manufacturing and engineering. SLS is designed to be a family of rockets, allowing us to onboard new technologies in each consecutive configuration as both NASA and Boeing, along with our partners, test new spaceflight materials, capabilities and systems. Incorporating them as they become available, they move us ever forward on our journey back to deep space. We're working with new technologies such as advanced composites and insulation, propulsion control systems, digital development solutions, determinate assembly, and so much more.

Leading through change

Our technical lead engineers (TLE) are the key to managing the changes in design, development, test and production of this adaptive rocket design, so we're innovating how we work together. By placing TLEs at important crossroads across the program, we're better able to manage ongoing and incoming design and engineering changes of the integrated rocket. Additionally they leverage their extensive network of experienced engineers from across the company every day to ensure technical challenges are met.

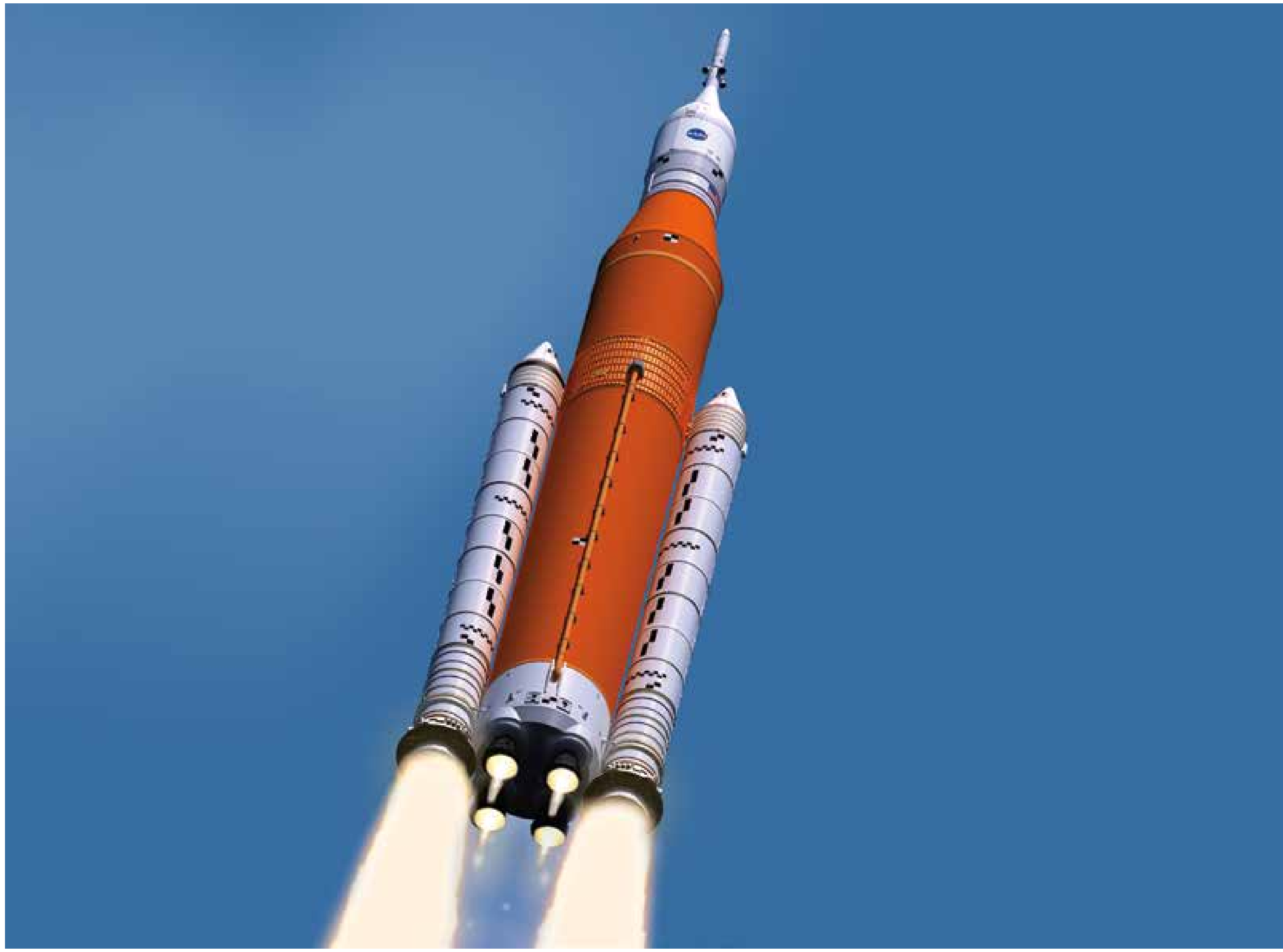
Our technical review board makes decisions about one segment of the rocket, but all of the disciplines are in the room, contributing their broad expertise, so we capture impacts to the system as a whole. These very senior engineers bring expertise from across Boeing, so the diversity of thought is extraordinary. The same principle is applied to how we're working with NASA and their independent review boards.

TLEs have delivered innovations for existing program challenges, and for onboarding new technologies as we design elements of the larger, even more powerful and capable rockets. And they carry lessons learned from one project to the next, because understanding how a problem occurred is equally as important as fixing it.

We want wisdom and continuous improvement, not just technical expertise and quick fixes. SLS will be transporting crew and cargo to deep space for decades to come, so development isn't just about creating a single rocket; it's about developing an evolvable, reliable, cost-effective system that will be capable of meeting new mission needs as they develop. To do that, we need wisdom that spans generations and geography, old and new, innovative and proven.

Together, we can do anything. And everything. And we are. IQ

BOEING PHOTO



"To do that, we need wisdom that spans generations and geography, old and new, innovative and proven."

MICHAEL WOOD

Michael Wood is the Chief Engineer for the Space Launch System based in Huntsville, Alabama. He has 30 years of technical experience in developing military, commercial and human spaceflight systems.

Sound check: 3, 2, **1, LIFTOFF**

Intense acoustics rock a rocket launch vibration test.

BY STEPHEN MORGAN, ASSOCIATE TECHNICAL FELLOW AND TECHNICAL LEAD ENGINEER
BOEING TEST & EVALUATION

Boeing test engineers recently made a lot of noise and shook the rafters at NASA's Michoud Assembly Facility in New Orleans. During a development test simulating the effect of the external acoustic environment generated during a Space Launch System liftoff, it was loud.

One hundred and forty-two decibels.

That is like being within 45 meters of a jet aircraft, and is above the threshold of pain for humans.

The exploration upper stage (EUS) to be used on the second configuration of the SLS will be exposed to an intense acoustic environment during launch that will generate vibrations that could potentially damage the launch vehicle structure.

One potential means to mitigate the impact is to install acoustic blankets inside the launch vehicle to absorb the acoustic energy. But, the application of acoustic blankets is a weight penalty to the EUS. It diminishes payload, which means accurate mathematical modeling validated by test data is essential.

To simulate the acoustic environment generated at liftoff by four main engines and the two solid rocket boosters producing a net 39 million newtons of thrust, test engineers brought in Maryland Sound International—known for its rock concert sound systems—to set up 14 speaker stands with 140 subwoofers and 168 amplifiers. Standing at 6 meters tall, the speakers were placed around a simulated EUS barrel section.

The development test collected data with and without acoustic blankets deployed on the inner surface of the interstage simulator to determine the achievable reduction in the internal acoustic environment. The type of testing is called a direct field acoustic test (DFAT), a method that minimizes cost and schedule because the test could be conducted in situ.

The speaker array produced an overall sound pressure level (OASPL) of 142 dB. The actual flight environment for the exploration upper stage has an OASPL of approximately 155 dB, but the direct field acoustic test level of 142 dB was adequate to fully exercise the mathematical modeling. This test was the first DFAT performed by Boeing for a NASA program and was the largest diameter DFAT ever executed.

The greatest challenge to the DFAT was dealing with the logistical issues associated with executing the test inside the Michoud Assembly Facility at the same time manufacturing was proceeding for the Core Stage of the first launch vehicle. The test required 2,000 square feet of space near an external wall of the building, so the power lines could be brought in from the diesel generator parked just outside the building.

BOEING PHOTO

The power required to run the sound system at max levels was 300-400 kVA.

Michoud personnel had to cut a hole in the wall next to the test setup to allow the power lines to be brought in from the generator. (The hole was patched after the test completed.)

The DFAT was executed over a weekend to minimize the number of people in the building. During test execution, the entire building near the test shook, and the vibrations could be felt through the floor and the walls. The DFAT has been a significant success and generated the required data to meet test objectives and will provide improved performance and efficiency for all SLS systems over the life of the program.

BOEING PHOTO

THESE GO TO ELEVEN
Engineers arranged an array of amplifiers and subwoofers to simulate the acoustic power of a rocket at liftoff.

Defying Gravity

Powering a highly competitive technical career takes perseverance for anyone, more so for women in engineering.

BY JILL HULINGS, BOEING WRITER | PHOTOGRAPHY BY PAUL PINNER

“So, as a kid, I played with Barbie dolls, but I knew how to fix a car, too.”

JULIE PERKINS

When Julie Perkins brought her daughter Kiley to work a few years ago, something unexpected happened.

Perkins, a chief engineer and Boeing Associate Technical Fellow, wanted to inspire her young daughter to follow in her footsteps and, perhaps, pursue a career in aerospace engineering. But, as the child stood in the Southern California factory, gazing at a 702HP satellite, the very one her mother helped design as then-chief engineer for quality, she matter-of-factly asked, “But what about the light? Aren’t you going to turn it on? You know, for the ‘satell-light?’”

Perkins still gets a kick out of sharing this memory.

“It sort of sums up her enthusiasm for what I do,” she said, with a smile. “She is smart, but definitely prefers the arts. All the stuff I hated in school, she’s already so much better than I ever was.”

Rocket scientist smart

Some people know from a young age what they aspire to become as an adult—a doctor, a firefighter, an engineer. Perkins wasn’t quite sure where her future would lead. Her parents, neither of whom attended college, were loving and supportive of both her and her older brother.

“He loves to tell people, ‘There’s my sister, the rocket scientist,’” Perkins said about her brother, who became a dentist.

As a child, Perkins excelled at math and science, and her father instilled within her an early love for engineering. Dad owned a small silk screen business, and he loved to tinker with cars in the family’s garage. It’s how the two spent their quality time, Perkins recalled.

“He would tell me from a young age, ‘You are not going to be a damsel in distress,’” she said. “So, as a kid, I played with Barbie dolls, but I knew how to fix a car, too.”

Perkins became more interested in engineering after taking a high school career placement exam. The test revealed that she should pursue engineering or mathematics, so she set her sights on becoming a jet fighter pilot like in the movie “Top Gun.” Unfortunately, vision issues dashed her dream of becoming a pilot, so she decided to design the airplanes instead.

In the early 1990s, Perkins was a newfound undergraduate student studying mechanical engineering at the University of California, Irvine. She was also one of two women in the entire engineering program.

“By the end, I was the only woman in their graduating class,” she said. “My peers and professors thought it was so cool that I was there with them. They were incredibly supportive.”

But just like many college graduates before her, Perkins found the real world sobering.

What an engineer looks like

“My daughter doesn’t really ‘get’ what I do,” Perkins explained with air quotes. The same can be said for many people she encounters. Upon meeting someone new, Perkins describes her role as an aerospace engineer and the type of highly technical work she performs.

“People don’t believe I’m an engineer,” she said. “I dress normal. I don’t go to ComiCons. I don’t fit that stereotype of an engineer.” Being a woman is also not representative of the stereotypical engineer in the minds of most people—or in the reality of most technology companies.

Over the past decade or so, the push to encourage more women to pursue STEM fields has begun to normalize the idea of women engineers. This drive has begun to open access into many fields for women scientists and technologists. But, it seems that access comes with setbacks.

In 2016, the Society of Women Engineers (SWE) released its Climate Control study, which explored specific gender and racial bias within the engineering profession. The study revealed three distinct patterns of prejudice that persist against women engineers versus their white, male counterparts.

“While we are making strides and engineering programs are growing, the percentage of women in engineering has

> “By the end, I was the only woman in their graduating class. My peers and professors thought it was so cool that I was there with them. They were incredibly supportive.”

JULIE PERKINS

DIMENSIONS OF AN ENGINEER
Perkins works to achieve the family balance many professionals seek.

remained relatively constant for almost two decades,” said Karen Horting, CEO and executive director of the Society of Women Engineers.

According to the SWE study, nearly 61 percent of women versus 35 percent of white men reported that they have to prove themselves repeatedly to get the same levels of respect and recognition as their colleagues. A separate study published in 2010 in the Journal of the Association of American Medical Colleges showed that women post-docs needed to be twice as productive to receive the same competency rating as their male counterparts.

Women engineers often find themselves needing to walk a tightrope, navigating both pressures to behave in feminine ways and pushback for behavior seen as “too masculine.” This resulted in 67 percent of women engineers avoiding assertive behavior, according to SWE. Additionally, one-third of women were more likely than white men to report pressures to let others take the lead. Others reported that they were more likely than their white, male counterparts to perform administrative tasks, such as scheduling meetings, taking notes or planning office parties (55 percent of women versus 26 percent of white men).

A separate study, conducted by Cornell University researchers in 2007, found that among women, mothers were dramatically less likely to be hired and promoted, offered sharply lower salaries, and held to higher performance and punctuality standards than equally qualified women without children. The only difference in their resumes: listing membership in a parent teacher association.

“To instill real change and truly diversify, we need to change the perception of what an engineer looks like,” Horting said. “We need to make engineering appear as a normal career path for women, as it is now viewed for men, and we need to provide support and resources for women in engineering to make sure we keep them there and help them reach their fullest potential.”

Challenging the norm

At the first engineering company Perkins joined in the early 1990s, she was the only woman among a group of colleagues who were all decades older. Although she was accustomed to being the only woman among male engineers, as was the case in college, the experience at work was vastly different from the supportive environment she left upon graduation.

“It was doing work that wasn’t challenging or motivating,” she said. Her situation became worse when she felt that she had experienced sexual harassment by some of her colleagues. “That’s when I left for Hughes Space and Communications,” which was acquired by Boeing in 2000.

Perkins said her teams at Boeing have been among the most gender-diverse of any of her previous employers. The 702SP satellite team (affectionately nicknamed “GirlSat” because every lead on the program was a woman) was one of Perkins’ favorites.

“It was one of the most efficient programs I’ve ever worked on,” she recalled. “I remember when we launched our first 702SP. Seeing videos of our product in space was amazing.”

“It was the most unique team and program I’ve ever worked on,” said Jeanne Morris, customer training lead in the Customer Operations Support Center in El Segundo, California—and member of GirlSat.

From the beginning, the team set out to disrupt the market and challenge the norm. They pushed back. They challenged expectations. The new satellite became a market-moving innovation for Boeing, featuring all-electric propulsion, next-generation avionics architecture, and additional mission flexibility for its operators and broader services to users.

“We had to be extremely communicative with customers and with each other,” Morris said. “We were all technically smart, but we all had really strong soft skills, too.”

As the 702SP program evolved, the team focused on technical execution and growth of its team members, and Perkins stood out as one of the team’s strongest leaders, Morris said.

“She’s wonderful,” Morris said. “She’s smart technically, and she was so supportive of every person on the program, taking time to explain the methodology behind her decisions.”

The women of GirlSat banded together and bonded so well because there aren’t many of them, Morris said.

“Those were among the best years of my career because it felt so empowering,” she said. “This team was truly focused on mentorship, growth and elevating all team members.”

Lessons learned

As her 4th-grade daughter gets older, Perkins reflects on her roles as an engineer and a single mother; she admits it’s often challenging to balance the two. Throughout her career, she was keenly aware of differences in gender roles; parenting can heighten those expectations.

“As mothers, we often have to do most of the balancing, and I’ll be the first to admit that it’s hard,” she said. “I have to drop my daughter off at school and daycare, then try to

make quality time for her in the evenings. And keep a clean house. And try to fit some workouts in between. It's tricky trying to make it all fit in 24 hours."

Perkins considers herself lucky to have a strong network of family and friends nearby who can help care for her daughter when work demands pick up or when business travel, sometimes internationally, is required. What's most important to Perkins is ensuring her daughter is nurtured and supported in her passions—just like she was growing up.

> "I'm very independent; I never wanted my daughter to grow up thinking she was dependent on anyone," Perkins said. "It's OK to depend on people, but don't be dependent."

Perkins says in her career, the biggest challenge she's learned to overcome was feeling comfortable and confident in her own skin.

"I had to learn how to get over feeling uncomfortable with the eyes on me in the room," she said. "For a long time, I tried to act like something I wasn't because I thought it was expected of me. It took me a long time to learn how to get my voice heard."

The best piece of advice she bestows on her mentees—both young women and men—is to be yourself.

"People are quick to pick up on you when you're not genuine, and then you lose their trust," she explained. "With me, what you see is what you get. People are either going to accept it or they're not. When I stopped trying to be what was expected of me, that's when I began to feel most confident." IQ

TAKE YOUR DAUGHTER TO WORK DAY
Perkins and her daugher, Kiley, walk the halls of Boeing's main satellite manufacturing facility in El Segundo, California, earlier this year.

Space Style

Ride in comfort on the CST-100 Starliner.

BY TERENCE WILLIAMS, BOEING WRITER

Picture this: Your vehicle is fully fueled and ready to go. An instrument panel digitally reads all of the carefully monitored indicators of your ride. Awaiting the exciting journey, your gloved hands grip the controllers as your body settles into the comfortable seat. The climate control is just right. You look around and notice your interior sports the latest innovations in features. It's a feeling of luxury, not unlike the excitement of a sports car speeding down a highway.

Only this is not a sports car. It's Boeing's CST-100 Starliner spacecraft, ready to safely propel you into space atop a United Launch Alliance Atlas V rocket… and in the latest scientific style.

Creating a spacecraft involves more than running complex equations and meeting safety requirements. There also is room for Boeing to add its unique flair through innovation, art and design. Adding to the accomplishment of being the first commercial space capsule of its kind, Boeing employees are making use of creative ideas, high-fidelity mock-ups, trainers and simulators to ensure the Starliner incorporates safe and effective design innovations. These efforts reflect the commitment of the company's people to support space exploration, one of mankind's most inspirational achievements.

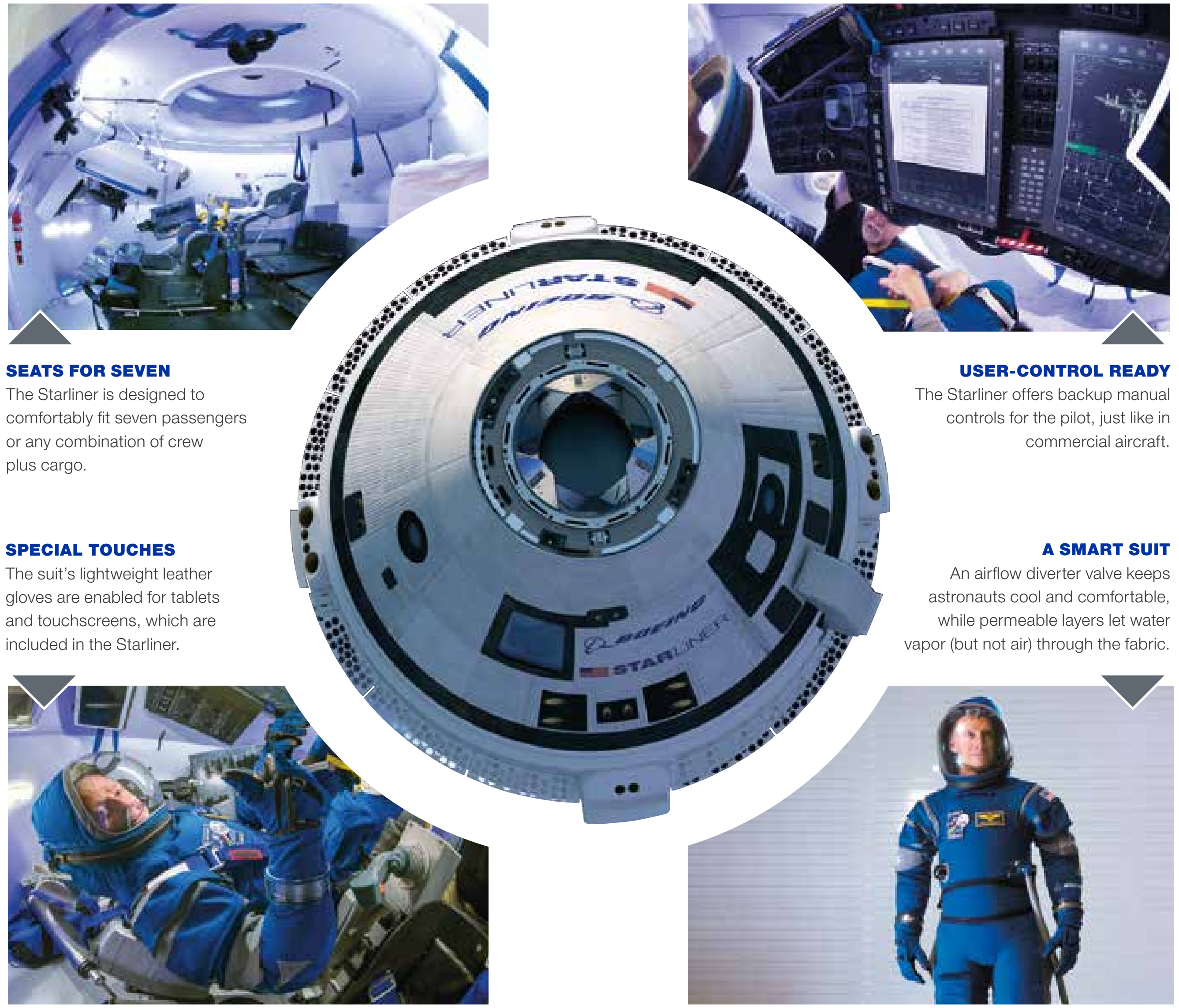
Melanie Weber, a design engineer for Boeing's Commercial Crew Program, knows firsthand about the influence of art and design in the development of a spacecraft, having been involved with the program from the blueprint to implementation phase.

> "It started off with us imagining everything we possibly could, pulling inspiration from science fiction movies to best practices of Boeing's Commercial Airplanes business," Weber said.

"As we worked hard to align luxury and aesthetics with requirements unique to human spaceflight, we found ourselves thrust into an evolution that took into account a variety of factors for the crewmembers."

What started off as a seemingly simple chance for the people on Weber's team to put their own mark on a historic spacecraft became a design and technical challenge, as the team constantly had to balance customer requirements, safety and design ideas. Choices in leather were nixed due to toxicity concerns. Kevlar and flame-retardant cloth were preferred over nylon and polyester. But, that didn't mean the team wasn't able to put its own touch on the Starliner. Turns out that spacecraft luxury can have a different feeling.

Like many luxury cars on the market today, the Starliner



SEATS FOR SEVEN
The Starliner is designed to comfortably fit seven passengers or any combination of crew plus cargo.

USER-CONTROL READY
The Starliner offers backup manual controls for the pilot, just like in commercial aircraft.

SPECIAL TOUCHES
The suit's lightweight leather gloves are enabled for tablets and touchscreens, which are included in the Starliner.

A SMART SUIT
An airflow diverter valve keeps astronauts cool and comfortable, while permeable layers let water vapor (but not air) through the fabric.

offers innovations that provide simplicity, comfort and style, by combining elegance and technology. Touchscreen displays replace thousands of switches and dials, leaving those only for critical phases of the spacecraft's journey. Bulky paper-based pilot flight logs have been supplanted by sleek tablets that enable real-time communication with ground support teams and even provide in-flight entertainment. The vehicle's soothing color pallette and LED lighting are based on years of experience with Boeing's commercial passenger jets. Custom contour seats and even a tailored Boeing blue spacesuit complete the package. The spacecraft development team also strives for the Starliner to become a top safety pick, putting every element into extreme environmental, shock and loads testing with simulated humans.

One of the primary means of testing new interior designs is through the use of mock-ups, trainers and simulators.

Astronauts can operate two Boeing-built trainers and a fully immersive mission simulator installed at NASA's Johnson Space Center in Houston. The devices enable astronauts and flight controllers to gain familiarity with Starliner simulations and crew interfaces, including designs for ergonomics and ease of movement.

Through use of the trainers, astronauts and flight controllers learn how to operate switches and touchscreen pilot manuals, understand onboard displays, train for planned activities and react quickly to unusual events that could arise in the harsh environment of space. These movements also give users the opportunity to give feedback on interior designs and other human factors that otherwise may not appear on paper designs.

> “At the end of the day, the final product will speak for itself—that we mastered safety and comfort.”

MELANIE WEBER, DESIGN ENGINEER
Pictured here with veteran astronaut Chris Ferguson, Boeing director of crew and mission operations.

“Think of the trainer as our training wheels,” said Eric Boe, one of four NASA astronauts training for a commercial crew flight to the International Space Station. “As we get more familiar, the training wheels will come off, and we will start advancing to the next systems.”

Included in training is an immersive, high-fidelity simulator, with interiors that faithfully mimic and encapsulate all mission scenarios.

This flight-like simulator, built to resemble the Starliner, isolates astronauts from outside distractions as they learn from full out-the-window visuals, audio and vibration cues, as well as onboard personnel and ground controllers.

The simulator, just like the trainers, offers unique opportunities for Weber's team to gauge the reactions of the items' users. Design engineers find out how factors like cabin color schemes may help astronauts orient themselves in space. For example, white tones make spaces appear larger than dark colors. The team also can get crucial feedback on seat comfort—important when trying to break the bonds of gravity at launch.

“Being in the cockpit and learning the muscle memory of where your hands are and how to manage the routine and emergency functions is really important,” said NASA astronaut Suni Williams. “It takes us to that final stage of getting ready and acclimated for the real spacecraft. It is really exciting to be working with the other aspects of the whole mission, which is the control team, and this is where that comes into play.”

Some changes came with a single observation, and could mean the difference in a joyful ride and an uncomfortable one. During one evaluation, the team noticed that astronauts had difficulty maneuvering over a particular area of the Starliner engineering mock-up in Florida. As they maneuvered over the area, the lack of handholds made it difficult to climb into the pilot seat. They decided that a small climbing gear clip would be used for the crewmembers to navigate into their seats.

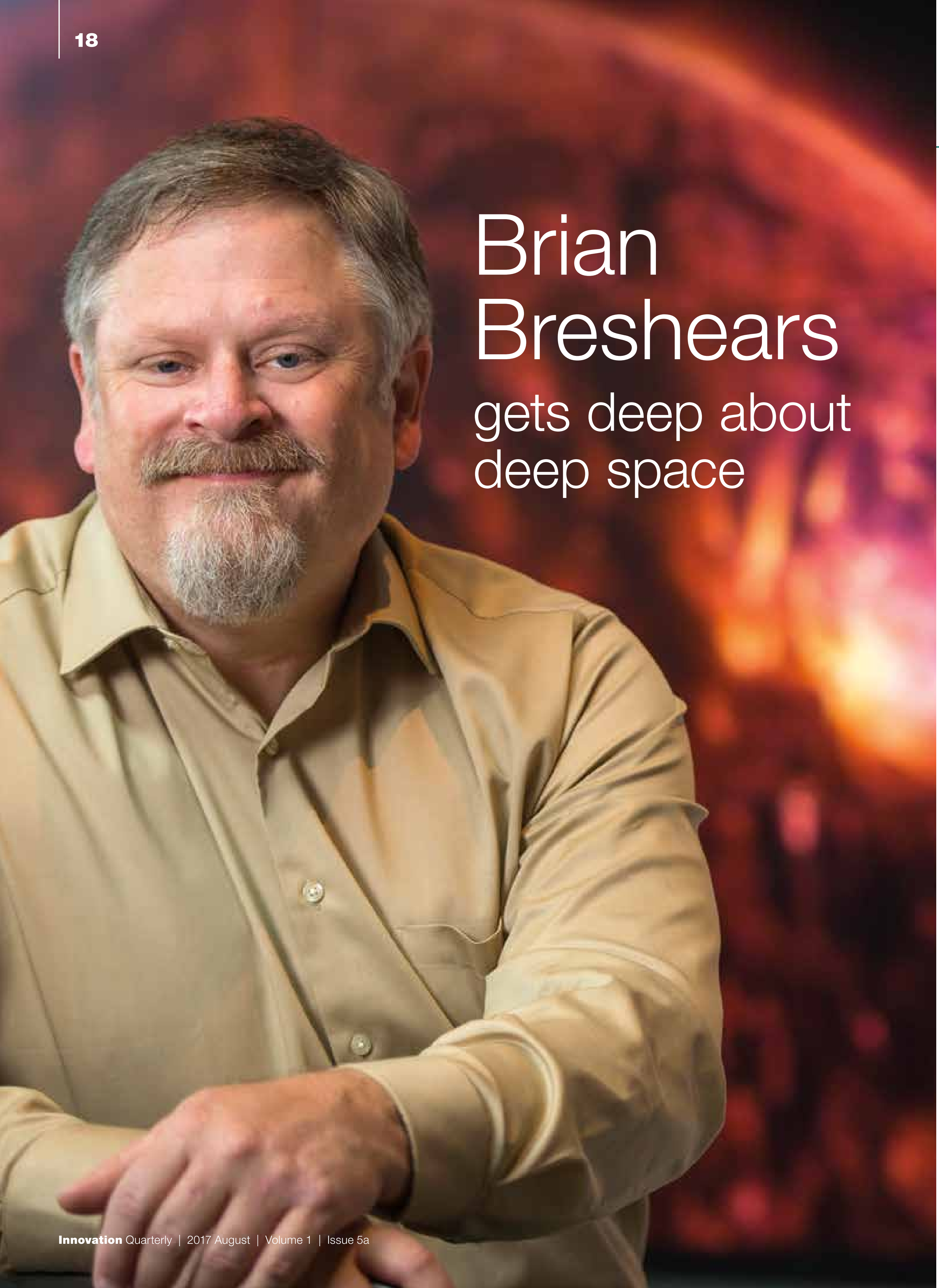
“Even though it was a small change, we still had to take a lot of measurements and even agree on the color of the clips,” said Weber. “But really, it only helped us to be more creative and flexible in finding new ways to get the crew safely into the vehicle.”

As lessons learned from trainers, simulators and mock-ups eventually make their way to the actual spacecraft, crew members can be confident that the finished product will incorporate some of the comforts they enjoy right here on Earth. The Starliner's first crew flight test to the space station is targeted for 2018. It will be Boeing's first commercial flight transporting humans to that destination.

“It all comes down to doing what we can, with what we have, and what can be allowed,” Weber said. “At the end of the day, the final product will speak for itself—that we mastered safety and comfort.” IQ

Brian Breshears

gets deep about deep space



DEEP SPACE THINKER
Technical Fellow Brian Breshears.

When it comes to outer space, there's no shortage of dreamers. But with real science, technical rigor and informed imagination, possibilities for humankind can be unlocked.

BY CANDACE BARRON, BOEING WRITER | PHOTOGRAPHY BY MARIAN LOCKHART

Q&A with a Technical Fellow who is investigating opportunities for technical advancements in deep space and has developed future concepts for what to do there

Q **What is concept development?**

A Concept development is both an art and a science. A basic understanding of how the world works mixed with common sense will go a long way. Add to that innovative thinking, and you have the first vestiges of a good concept. It is a skill that is difficult to learn because it requires more than engineering, more than analysis, and more than management of a project; it requires the ability to develop, refine and communicate a vision.

Q **You recently completed an internal concept study on automated manufacturing on asteroids. What is the opportunity there?**

A Asteroids are unique and accessible. For asteroids less than a kilometer long, gravity is almost nonexistent; navigation in and around them can be easily managed without a lot of energy expenditure.

Small asteroids are like piles of dirt clods clinging to a larger core rock. These may be the very best opportunities for mining we can find. Why? Because it is much easier to mine a pile of dirt than it is a big solid rock. The first step in a mining operation on Earth is to make big rocks into small rocks. This usually involves high energy expenditure (like TNT) and a rock crusher of some sort. If you can mine an undisturbed rock pile instead, then you've eliminated a significant step in the process and can focus more on building with less spent on demolition.

Q Are we talking about mining asteroids for use on Earth?

A Not necessarily. We should primarily mine the asteroids for use in space. Building infrastructure for more mining or eventually for habitats that could support human operations. Both are options.

That said, there are some things in the asteroids that might make a case for themselves being sent back to Earth, like materials that are still quite rare on Earth. Itokawa, a typical LL chondrite asteroid, was landed upon by an unmanned Japanese explorer in 2005, and samples it took made it back to Earth in 2010. The materials they found on Itokawa included many precious minerals, some in surprising abundance. So as a mining operation is developed, there will always be the possibility that there are enough materials discovered to justify the cost of a ride home to Earth.

EXPLORING THE POSSIBILITIES
“Concept development requires the ability to develop, refine and communicate a vision.”—Brian Breshears.

Q Many people and companies seem to be focused on Mars. Why?

A The Red Planet fires the imagination. From the 1877 discoveries of so-called canals on Mars by astronomer Giovanni Schiaparelli, to Edgar Rice Burroughs’ 1911 story of John Carter, Mars has held human fascination. The wholly unexpected success of the Opportunity rover—an unmanned explorer meant to last 90 days, but still alive and exploring after 13 years—gives hope that manned exploration will be equally successful.

To answer in a more technology-focused manner, there are a number of factors from the standpoint of business and simple human-scale perception. Mars is like Earth. It has gravity and atmosphere and sky, and it LOOKS like Earth—at least what Earth might look like without water.

It remains to be seen if Mars is exploitable, though.

Q What is the benefit of achieving human exploration of Mars or deep space?

A Deep space holds so many mysteries and so much potential for human advancement, it is impossible to capture. The past has taught us that we are not limited by what we see around us today or even what we imagine for tomorrow. In 1975, the makers of the first Cray supercomputer could not have imagined that within 40 years, we would carry around a device smaller than a pack of cards with a thousand times more computing power.

People need to think more about the long term—the long, long term. Sometimes there’s no near term return on investment; you just have to continue to play the long game.

Exploration of Mars will actually be the best way to answer this question. Right now, we can only imagine the benefits of exploring Mars. And NASA’s role in space exploration will only carry the missions so far.

> “Deep space holds so many mysteries and so much potential for human advancement, it is impossible to capture.”
>
> **BRIAN BRESHEARS**

Q What has to happen between now and the time we actually get to Mars or to an asteroid?

A We must first develop the technology that allows us to achieve our goals once there. There is still a lot of value in unmanned systems for exploring space. The use of space manufacturing to build a self-replicating capability is one such idea. That capability at its most fundimental requires significant development in both mechanical systems, as well as software to drive it. Once you have that first self-manufacturing capability, the process becomes evolutionary rather than revolutionary.

It doesn’t take processing capabilities that are too far beyond the capabilities we have in autonomy today. The biggest investment any company can make towards the goal of autonomous deep space systems is in the people who understand and do autonomy.

More difficult are the manufacturing challenges that are not part of our history. Such as making raw materials in the form of rock and dust into useable materials for producing objects. Making the basic issues even more difficult is the absence of gravity and atmosphere. Most of our processes for refining materials currently require gravity, and almost all require products drawn from the atmosphere, like oxygen for heat for energy production.

Perhaps most difficult will be automation. While telepresence has come a long way and will continue to develop, it cannot overcome light-speed limits and distances that will induce minutes of latency. Therefore, independent command-and-control at the site will be required. To address this, likely the best approach is to develop piecemeal technology that contributes to this operation as a long-term goal while also solving near-term needs.

Q What is the serious likelihood of all this, and how far in the future are we talking about?

A All of this can indeed be done. It is not impossible that this exploration could incite another gold rush.

The key term is “possible.” Let’s face it, the landing of a probe on asteroids is not a simple task. If a gold rush does result, and a self-replicating system has been in place for some time, whomever has put that system in place, whomever had that vision, will certainly have the upper hand on claiming a large part of the available resource.

With the right investment, a self-replicating capability could be seen in a couple decades with profitability in another decade. But that will require a significant commitment to see it through.

KEVIN BOWCUTT, SENIOR TECHNICAL FELLOW

Breaking gravity—and the cost curve

Space dreams depend on new approaches to rocketry.

We find ourselves in a new-age race to space, with many newcomers entering the field—if not to build spacecraft, then to brave far-flung space adventures to the moon or Mars.

Not to be outdone by NASA, billionaires are investing their personal fortunes in new approaches to rocketry and space travel. These hopes and dreams hinge upon a critical enabler—reducing the cost of space access by a factor of 100. But how could this be possible?

There are two keys to such dramatic cost reductions: reusable launch vehicles; and aircraft-like operation of launch vehicles, which provide safety, reliability, maintainability, operational flow and flight rate.

While some of these newcomers have developed reusable rockets, Boeing's recently announced collaboration with DARPA will design, build and fly a space plane—Phantom Express—that will be both reusable and have aircraft-like operability.

The primary differentiator is our approach to operability. Whereas other space-race players are demonstrating vertical landing (VL) under rocket power, Boeing will employ horizontal landing (HL) using wings, similar to the X-37 and the Space Shuttle before it, to capture decades of experience in rapid turn of winged vehicles.

Starting from scratch, developing the expertise to do VL is technologically easier than doing HL. For the most part, a VL system is a traditional rocket with the addition of a wider-range aerodynamic control system, a deep-throttle rocket engine, and landing system hardware. This VL capability was first demonstrated by McDonnell Douglas 24 years ago.

BOEING ILLUSTRATION

Developing an HL system demands development of structures, aerodynamics, guidance and thermal protection that can operate across the broad spectrum of flight regimes from hypersonic to subsonic. Based on experience in developing and operating vehicles in these flight regimes, Boeing is not starting from scratch, and we can apply many lessons learned from years of investment in research, development and operations.

Because all rockets are essentially wrapped around an engine, system reliability of the engine is of paramount importance. Horizontal landing requires a single engine start per mission, and energy management to touch down is accomplished aerodynamically. Vertical landing requires multiple engine starts and throttling to achieve landing. Engine life is determined by several factors, among them the number of engine starts that generate transient loads. All things being equal, VL will consume engines at a higher rate than HL. Moreover, an engine failure in flight for a vertical landing is catastrophic, whereas a horizontal-landing vehicle may be recovered via aerodynamic flight.

Boeing has the world's most extensive knowledge base in autonomous entry and landing capability for the disciplines of aerodynamics, structures, avionics and controls. Designing a reusable HL vehicle is not much different from what we have already done.

This allows us to develop a system with the aircraft-like functionality needed to achieve affordable space launch.

If one intends to develop the capability to land in barren locations such as Mars, then VL must be perfected. There is insufficient atmosphere on Mars to support HL and certainly no runways.

Boeing is aimed at reducing the cost of trucking payloads to space, therefore using existing runway infrastructure is valid. Phantom Express can also be used for other valuable missions such as boosting a hypersonic test bed to speed and altitude to conduct flight experiments or boosting a hypersonic UAV to scramjet operating conditions.

Our design also has the ability to become a reusable upper stage in a larger system, allowing Boeing to leverage its investment for future growth without having to design a completely new reusable upper stage. A launch system comprising two reusable stages, both having aircraft-like operability, can achieve the ultimate goal of 100-fold reduction in launch cost and help realize the space dreams of a generation. **IQ**

BOEING PHOTO

VERTICAL LANDING
The DC-X, called the Delta Clipper, was an experimental recoverable spacecraft developed by Boeing heritage company McDonnell Douglas. The program ran from 1993–1996 with many successful landings.

Kevin Bowcutt is a Boeing Senior Technical Fellow and chief scientist of hypersonics. He is a member of the National Academy of Engineering, and a fellow of the American Institute of Aeronautics and Astronautics and the Royal Aeronautical Society.

How sweet the future of aviation

An informal brainstorm turns into potential climate-saving flight technologies.

BY MARTY BRADLEY, TECHNICAL FELLOW
BOEING COMMERCIAL AIRPLANES

BOEING PHOTO

BOEING SUGAR FREEZE

Normally, your average sugar rush doesn't last a decade. But the last nine years for Boeing's partnership with NASA on Subsonic Ultra Green Aircraft Research (SUGAR) has brought about promising developments for the future of aviation.

The original SUGAR project began with a brainstorming session in December 2006.

I pondered what Boeing could do to make our aircraft more environmentally friendly. So, I assembled some colleagues, and we generated a list of ideas that included alternative fuels, electric aircraft, and improved aerodynamics, propulsion and sustainable materials. We also came up with the name SUGAR. In this original form SUGAR stood for Sustainable Ultra Green Aircraft Research. After narrowing the list of ideas, the team worked on quick tools to assess the ideas and quantify the possible benefits.

Then along came a NASA request for proposals on subsonic aviation concepts and technologies that could help meet these goals in the 2030-2040 timeframe:

- A 71-decibel reduction below current Federal Aviation Administration noise standards.
- A greater than 75 percent reduction on the International Civil Aviation Organization's Committee on Aviation Environmental Protection Sixth Meeting, or CAEP/6, standard for nitrogen oxide emissions.
- A greater than 70 percent reduction in fuel burn.

At the beginning, none of us thought we could reach those levels. Because of the work we had just done in the brainstorming activity, we were able to respond quickly with lots of green ideas and add quantitative results. Combining many ideas, and adding a healthy dose of improved air traffic management as well, we were able to show it was possible to get close to these goals.

After winning the contract, deemed Phase I, three additional phases were awarded. The original goals were adjusted between each phase, but NASA always tried to keep the goals just ahead of what the team thought could be achieved.

SUGAR had great teammates from other companies, including Georgia Tech, Virginia Tech, General Electric, and NextGen Aeronautics.

From SUGAR has come ideas for multiple concepts and technologies:

SUGAR High—a high span, high aspect ratio, high lift-to-drag truss braced wind concept that has been tested in aeroelastic and high speed wind tunnels and is preparing for a low speed wind tunnel test. It is currently estimated to deliver an 8 percent reduction in fuel burn compared to a conventional cantilever (non-strut-braced) wing. Additionally, the high wing allows easier more efficient integration of large diameter fans and open rotor propulsion systems for additional fuel burn benefits.

SUGAR Volt—the first concept for a hybrid electric commercial airliner. This played a major role in electrifying the current interest in small and large electric aircraft at companies, government labs and universities around the world. Much like a hybrid car, the SUGAR Volt is able to decrease fuel use and substitute electrical energy, which if from a renewable grid source (wind, solar, etc.), can significantly reduce the life cycle greenhouse gas emission of a conventional airliner.

SUGAR Freeze—uses liquefied natural gas, fuel cells, cryogenically cooled electric motors, advanced battery energy storage, and aft fuselage boundary layer ingestion propulsion for even more potential benefits. (This is farther on the technology horizon.)

Recently, Boeing was awarded a new contract to continue studying the SUGAR Volt and a NASA hybrid electric concept called the STARC-ABL (single-aisle turbo-electric aircraft with an aft boundary layer propulsor). Boeing is interested in developing environmentally progressive vehicles, but it's too soon to say whether any of the concepts that have been studied under this contract will be incorporated into Boeing aircraft. Except for Boeing proprietary technology, the knowledge NASA gained in collaboration with Boeing from this research is publicly available.

SUGAR sweetens the deal with Phase 3 results, Phase 4 underway

In 2016, the Subsonic Ultra Green Aircraft Research (SUGAR) program reduced drag by 6 percent without affecting weight relative to previous analysis of the Transonic Truss-Braced Wing. The total benefit of this technology has the potential to provide 8 to 10 percent fuel consumption reduction relative to an equivalently configured conventional baseline at Mach 0.75.

Phase 4 of the program, which kicked off in January, focuses on the next hurdles: increasing the high-speed design to a more conventional Mach 0.8 cruise speed and investigating the low speed characteristics of the high aspect ratio wing with truss-bracing. With every phase of the program, strides are made to mature the concept with a long term goal of a flight test under the NASA UEST demonstrator program.

In the previous SUGAR phases, engineers worked with NASA to focus on the structural aspects of the Transonic Truss-Braced Wing. After a year of design work on the concept, NASA and Boeing engineers tested a 7.5-foot wingspan model at the NASA Ames Transonic Wind Tunnel in Mountain View, California, producing successful results and valuable data.

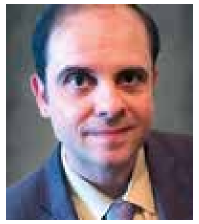
**—CHRISTOPHER DRONEY,
SUGAR PROGRAM MANAGER
BOEING RESEARCH & TECHNOLOGY**

Selections from the Boeing Technical Journal

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

Contributing Authors

AVIATION INITIATIVES AND THE RELATIVE IMPACT OF ELECTRIC ROAD VEHICLES ON CO2 EMISSIONS



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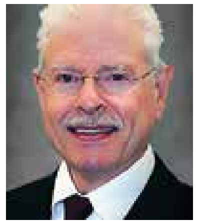
TELESUPERVISED CO-ROBOTIC SYSTEMS FOR REMOTE CONFINED/HAZARDOUS SPACE OPERATIONS



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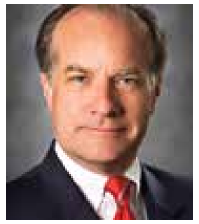
ULTRA-LOW LIGHT LEVEL PHOTORESPONSE IN THERMOELECTRIC NANOWIRE ARRAYS



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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.

Aviation Initiatives and the Relative Impact of Electric Road Vehicles on CO2 Emissions

Summary

JOSE ALEXANDRE FREGNANI | ONOFRE ANDRADE

The aviation industry has made great efforts to lower aviation-related emissions such as the use of alternative fuels, improved airplane designs, new aircraft concepts and fuel-saving operational procedures. At the United Nations Climate Conference in Copenhagen in 2009, the aviation industry (airlines, manufacturers, airports and air navigation service providers) announced its commitment to a global approach to mitigating aviation greenhouse gas emissions, setting the following objectives:

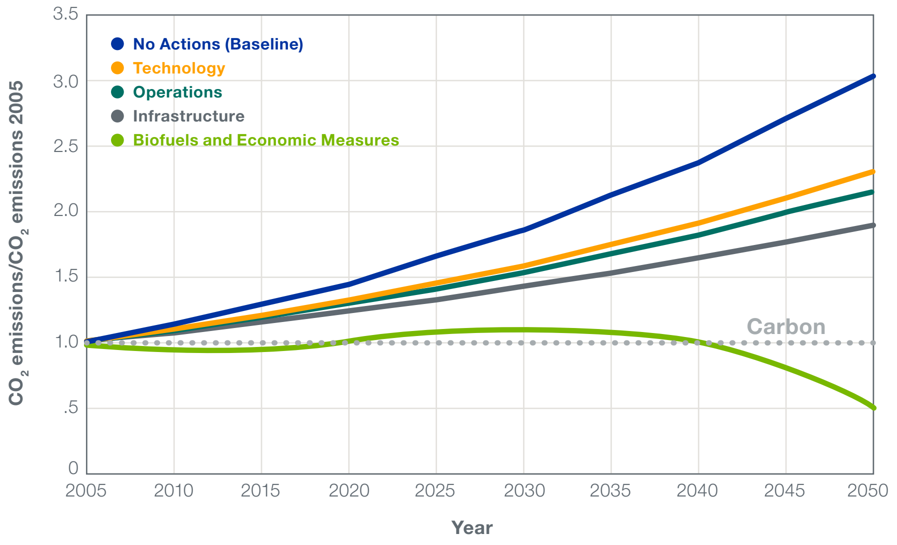
1. Improvement in fuel efficiency of 1.5 percent per year from 2009 to 2020 (measures that industry can control, linked to operational procedures and basic infrastructure improvements).
2. Carbon-neutral growth at 2020 (Fuel CO2 emissions are neutralized).
3. Reduction in CO2 emissions to 50 percent of 2005 levels by 2050.

This is an ambitious roadmap where the aviation industry would invest heavily and continuously on new technologies. Focus on fuel efficiency, therefore, is driven not only by fuel prices, but also by environmental impact. Opportunities continue to exist for addressing aviation emissions through further air traffic management and operational measures, but are not realistically sufficient to push the ambitious 50 percent reduction by 2050. Therefore, the aviation industry will continue to pursue a range of opportunities in new technology, such as new aircraft design and biofuels as to meet these emission reduction targets. (See Figure 5.)

Historically, the development of aviation has always been driven by fuel efficiency (fuel burn per seat). And over the last 50 years, the fuel burn (and associated carbon emissions) per passenger kilometer has been reduced by more than 70 percent. Fuel is the most important single cost element for airline operators, and the strongly volatile oil prices of the last few decades have increased their need for more fuel-efficient aircraft. The development of new operational procedures and techniques are relevant, but limited to the current technological limitations.

FIGURE 5.
Emissions Reduction Roadmap

SOURCE: BOEING



The ISEAS Map and Functions

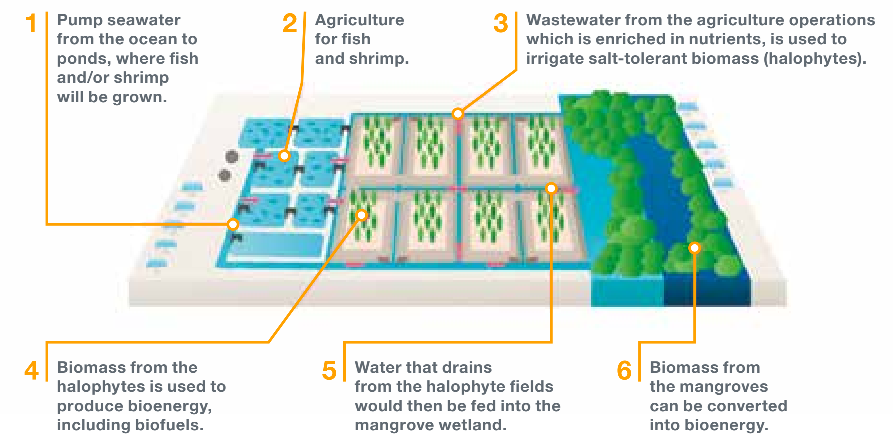


FIGURE 3.
Integrated seawater, energy and agriculture.

SOURCE: MASDAR INSTITUTE

Sustainable aviation fuel

One of the most important developments for the aviation industry was the introduction of aviation fuels, starting with a number of test flights in 2008 until the certification of production pathways (ASTM certified).

- **FT-SPK (Fischer-Tropsch Synthetic Paraffinic Kerosene)** in 2009. Converts syngas into jet fuel and was approved by ASTM (D7566) and UK MOD DefStan (91-91). Can be blended up to 50 percent with fossil jet fuel.
- **HEFA (Hydroprocessed Fatty Acid Esters and Free Fatty Acid)** pathway was approved in 2011 to be blended at 50 percent rate with jet fuel. Converts natural oils from lipids to hydrocarbons by treating the oil with hydrogen to remove oxygen and other molecules.
- **HFS-SIP**, approved in 2014 up to a 10 percent blend, entails the fermentation of sugars into a hydrocarbon molecule using modified yeasts. The existing approved process produces a C15 hydrocarbon molecule called farnesene.
- **FT-SPK/A**, approved in 2015 up to 50 percent blend, uses the FT synthesis process plus the alkylation of light aromatics (primarily benzene) to create a hydrocarbon blend that includes aromatic compounds.
- **ATJ-SPK**, approved in 2016 up to 30 percent blend, a yeast biocatalyst converts sugars (carbohydrates) to isobutanol.

As of today, more than 1,600 flights have been operated using blends of biofuels and conventional kerosene. These flights have demonstrated that alternative fuels are safe and technically sound, and can reduce overall carbon footprint by an average 60-80 percent over its full lifecycle, depending on the pathway and feedstock used. Aviation drop-in biofuels are blended directly with petroleum jet fuel and are expected to meet or exceed performance standards of fossil fuels with no change to airplanes, engines and fueling infrastructure. The aviation industry sees the importance of sustainable biofuels as the key long-term technology for decarbonizing aviation.

Technological breakthroughs in biological improvements, chemistry and the development of systematic approaches for the production of aviation biofuels have driven costs down, according to market estimates, from around $30 per gallon in 2009 to $3 per gallon in 2015, without direct incentives from governments.

One of the best examples of a systematic approach to the production of aviation biofuels is the initiative led by Boeing, Masdar Institute and Etihad Airways (Sustainable Bioenergy Research Consortium—SBRC—that also includes Takreer, Safran and General Electric) to produce both aviation biofuels and food using halophytes irrigated with seawater. (See Figure 3.)

These “super plants” could lead to a breakthrough in biofuels as seawater and sand once considered a weakness could become, in fact, the strength of the project. According to Masdar Institute, the salicornia plant (the “super plant”) is a salt-tolerant halophyte, with a unique internal mechanism that allows it to grow in seawater. Its seeds contain plant oils that can be turned into jet fuel.

The consortium recently began construction of its integrated seawater, energy and agriculture facility at Masdar City, United Arab Emirates, the world’s first bioenergy pilot project to use desert land, irrigated by seawater, to produce both aviation biofuels and food. The 20,000 square-meter

The aviation industry sees the importance of sustainable aviation fuel as the key long-term technology for decarbonizing aviation.

The Group on International Aviation and Climate Change (GIACC), formed at the ICAO 36th assembly, has recommended the following potential areas of development and investments to contracting states as follows:

1. INVESTMENT IN NEW TECHNOLOGIES

Measures in this category may include purchase of new aircraft, retrofitting and upgrade improvements on existing aircraft, new designs in aircraft/engines, fuel efficiency standards and alternative fuels.

2. DEVELOPMENT OF EFFICIENT OPERATIONS

These measures include minimizing weight, improving load factors, reducing speed, optimizing maintenance schedules, and tailoring aircraft selection to use on particular routes or services.

3. INVESTMENT ON EFFECTIVE INFRASTRUCTURE

These measures mean more efficient air traffic management planning, ground operations, terminal operations (departure and arrivals), en-route operations, airspace design and usage, and air navigation capabilities. These measures have the potential for relatively short to medium-term gains, although the scale of potential gains is low to medium. In addition, more efficient planning and use of airport capacities, construction of additional runways and enhanced terminal facilities, and clean fuel operated ground support equipment could be implemented in the short to medium term.

4. POSITIVE ECONOMIC MEASURES

These measures include voluntary carbon offsetting, emissions trading schemes (CORSIA, Market Based Measures), emissions charges and positive economic incentives.

5. REGULATORY AND OTHERS

Measures that include regulatory enforcements on carbon emissions reduction (i.e. aircraft movement caps/slot management) and other initiatives such as enhanced weather forecasting, transparent carbon reporting and education/training programs.

bioenergy pilot facility will include saltwater aquaculture ponds where fish and shrimp will be grown. Water from the ponds, including nutrient-rich waste produced by these fish, will be used to irrigate and fertilize salt-tolerant halophyte plants that will then be harvested and turned into aviation biofuel and other products.

Electric road vehicles

Despite such efforts, the aviation industry could see its share of overall global emissions change significantly if electric road vehicles gain more widespread use. Electrical vehicles have gained steady acceptance among the public and are being supported by some government policies worldwide.

According to InsideEVs.com, total sales of EVs in the United States rose 23 percent annually in 2014. If in coming decades the sales of electric vehicles soar, considerably replacing internal combustion vehicles, the noise and emission percentage caused by road vehicles will drop significantly. In this scenario, aviation's relative contribution to CO2 emissions and noise levels will be significantly higher.

How will the public, government, industry and academia handle this upcoming reality?

The International Energy Agency (IEA) has worked with the world Business Council for Sustainable Development (WBCSD) in its Sustainable Mobility Project (SMP) to develop a global transport model that can serve both organizations in conducting projections and policy analysis. Table 2 displays the SMP projection of CO2 emissions up to year 2050.

Considering the presented data the aviation biofuels reduction of CO2 emissions was concluded to be effective from 2020, according to IEA. For example, by 2050, if 100 percent of road vehicles are electrical ones, the relative aviation contribution would be increased by 27.3 percent if no biofuels are used (Biofuels are expected to achieve an average of 60 percent of greenhouse gas reductions in the time frame considered).

Year	Road	Aviation	Maritime	Road Total	Aviation Total	Maritime Total
2000	4.10	0.70	0.50	77.4%	13.2%	9.4%
2005	4.30	0.80	0.60	75.4%	14.0%	10.5%
2010	4.80	0.90	0.60	76.2%	14.3%	9.5%
2015	5.20	1.00	0.80	74.3%	14.3%	11.4%
2020	5.70	1.10	0.80	75.0%	14.5%	10.5%
2025	6.10	1.30	0.80	74.4%	15.9%	9.8%
2030	6.50	1.50	0.80	73.9%	17.0%	9.1%
2035	7.00	1.60	0.80	74.5%	17.0%	8.5%
2040	7.45	1.85	0.90	73.0%	18.1%	8.8%
2045	8.00	2.00	1.00	72.7%	18.2%	9.1%
2050	8.60	2.30	0.90	72.9%	19.5%	7.6%

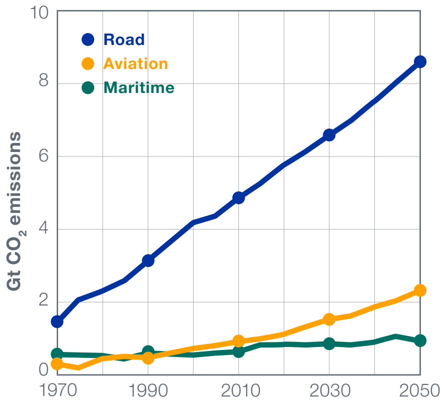


TABLE 2A AND 2B.

Projected CO2 emissions share by modes until 2050.

SOURCE: IEA AND WBCSD

In 2050 under the most "pessimistic scenario" for aviation, when 100 percent of the road vehicles would be electrical (with maximum efficiency 80 percent) and no biofuels are used, the participation of aviation on transport CO2 emissions would be 46.7 percent, 3.3 times greater than 2005 levels (considering that no EVs and no biofuels are present). Under the most "optimistic" scenario for aviation, if 100 percent of the road vehicles present only 20 percent efficiency (technology has not evolved so far) and aviation biofuel is used on 43 percent of the flights, the participation of aviation on transport CO2 would be 17.1 percent, approximately 1.2 times greater than 2005 levels (considering no EVs and no biofuels are present).

The evident conclusion is that even introducing biofuels on aviation operations, the increasing demand for electrical road vehicles would lead aviation to a scaling increase of its share of transportation emissions throughout the year 2050, despite the overall emissions reduction. In other words, there is significant evidence that aviation will be increasingly on the hook throughout the years regarding the greenhouse gas emissions. This fact obviously reinforces the necessity of improvements of aircraft/engine design, alternative engines, other sources of energy to power aircraft systems, and improvements in operational efficiencies.

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

"Aviation Initiatives and the Relative Impact of Electric Road Vehicles on CO2 Emissions"

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

Telesupervised Co-Robotic Systems for Remote Confined/Hazardous Space Operations

Summary

MARK A. STUART

The assembly of major aircraft components involves ergonomically-challenging tasks in confined spaces. Tasks include: gauging, fastening, sealing, cleaning, coating and inspection inside of the wings and fuel tanks, and fuselage. Boeing is addressing these tasks with co-robot technologies—that is human capabilities augmented by robotic technologies, aimed at producing substantial increases in productivity and worker safety.

Telerobotic technologies deploy human technicians remotely into confined or otherwise hazardous spaces by bringing the human technicians' skills to tasks but not to the dangers. This will result in the elimination of musculoskeletal disorders; removal from exposure to harmful atmospheres; and reduced cognitive workload. Additional benefits include higher productivity and quality; and allowing experienced technicians to continue to use their skills over a longer period and retain healthier outcomes.

This paper describes a co-robotics telesupervision architecture, high-fidelity immersive telepresence, co-robotic telesupervision workstation, and intelligent assisting agents. We also describe an experimental system to be built on these principles for remote operation inside the confines of a wing bay, and the formal testing methods to be used to validate this system.

Of the many forms that humans working with robots may take, we focus on a systemic approach to augment human capabilities. This includes extending human senses and reach physically; modifying human senses in scale both geometrically and spectrally; and expanding human cognition.

Recognizing the limits of autonomy that preclude direct leaps from the majority of human-accomplished tasks to fully-automated tasks, we take a tractable approach to selectively integrate augmentation of human sensory and cognitive capabilities. Within our open architecture of human/autonomous cooperation, we support multiple layers: from direct human teleoperation; to augmented human operations; to high-level human supervision of autonomous actions.

The open telesupervision architecture, developed by Gregg Podnar (and first author of the full Boeing Technical Journal article referenced below), has supported research for planetary exploration using semi-autonomous rovers for NASA's Exploration Systems Mission Directorate; and research for harmful algal bloom detection by semi-autonomous ocean vessels for NASA's Earth Science Technology Office. The architecture provides a framework within which co-robotic assembly and inspection systems can be continuously improved as intelligent autonomous agents are developed, proven robust and integrated.

The primary elements of our co-robotic telesupervision architecture used for remote confined space operation are: the distal robotic sensory and manipulation tools; the proximal immersive telepresence and manipulation controls of the telesupervisor's workstation; and the interposed intelligent assisting agents. (See Figure 1.)

Our design principles for a co-robotic system for internal wing bay assembly and inspection, and our testing methodology, are based on fundamental requirements:

- Deployed robotic equipment must be physically capable of accomplishing the domain-specific tasks;
- Deployed sensing capability must provide situation awareness with sufficient fidelity; and
- Workstation must provide the most natural interfaces practical.

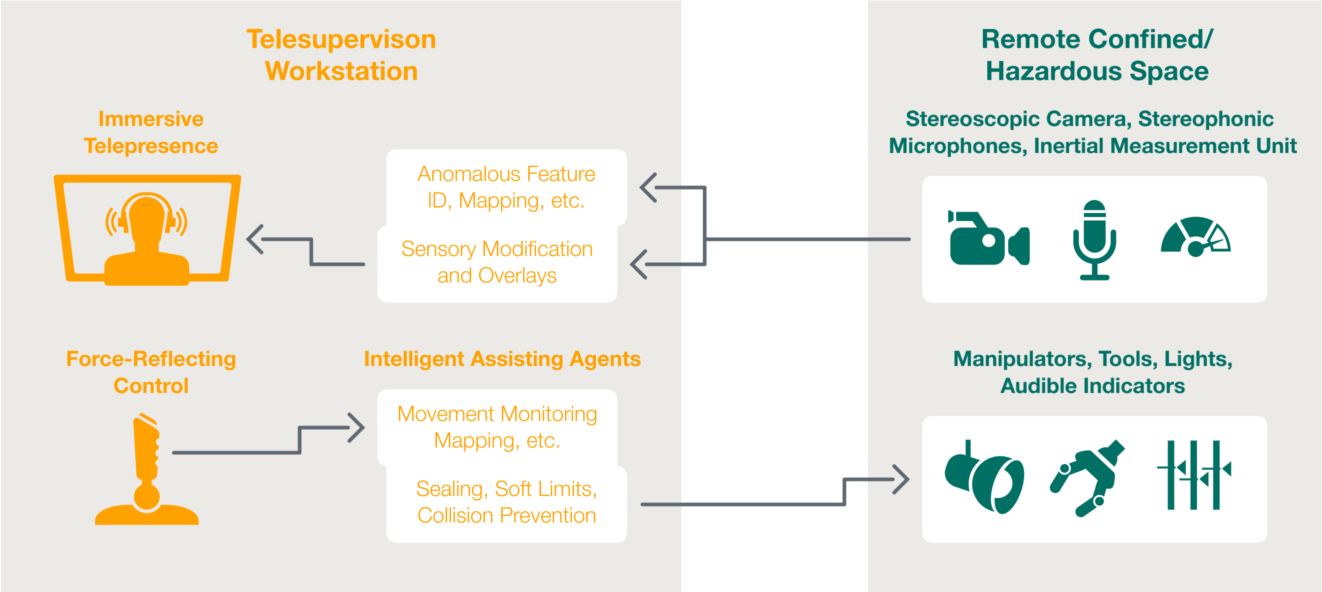
Performance experiments of the co-robotic system for wing bay assembly and inspection tasks will prove the effectiveness of integrated telepresence, teleoperation and human augmentation technologies. This formal approach is appropriate to validate every task-specific, co-robotic system developed within our telesupervision architecture.

We recognize that while workers are remote from the confined space environment, they will be working through an interface that may itself pose ergonomic issues. Therefore the co-robotic telesupervision workstation developed for this testing will first be assessed using a musculoskeletal disorder risk factor checklist. Interface devices and features of the co-robotic workstation include:

- Immersive human interfaces to remote sensory systems.

FIGURE 1.
Co-robotic telesu rchitecture with autonomous agents for human augmentation.

SOURCE: BOEING



Distal Robotic Systems

Sensory and manipulation systems are deployed into confined/hazardous spaces and include teleperception sensors for binocular stereoscopic vision, binaural stereophonic audition, proprioception, and force-reflecting haptic manipulators. These are deployed using robotic vehicles or arms adapted to the tasks, spaces and access.

High-Fidelity Immersive Telepresence

Situation awareness and the sense of presence requires high-fidelity acquisition and presentation of sensory and sensorimotor data. Telepresence presentation to the telesupervisor includes geometrically-correct binocular stereoscopic viewing systems and high-fidelity stereophonic audio reproduction. Force-reflecting manipulation allows the teleoperator to feel into the environment.

Co-Robotic Telesupervision Workstation

By integrating high-fidelity operator interface components for mobility, manipulation and telesensing, the co-robotic telesupervision workstation becomes the hub of planning and control.

Intelligent Assisting Agents

The immersive telepresence and teleoperation data are communicated between the distal robotic systems and the telesupervision workstation and thus are available to the intelligent assisting agents that can autonomously monitor, interpret, indicate, automate and limit. Some high-level robotic autonomy is relatively mature, such as robot path planning and navigation. Others such as automatic task-specific operations, and system health monitoring are less robust or must be developed per application.

Distant Human Expert Telecollaboration

A further expansion of the concept of the “intelligent assisting agent” that is supported by our architecture is the facility to provide a subset of the telepresence data to a distant human expert who has more specific domain knowledge than the telesupervisor operating through the co-robotic system. This is especially useful when an unforeseen condition is experienced for which additional expertise is required.

- Intuitive human controls for telerobotic actuation.
- Geometrically-correct binocular remote vision system.
- Binaural stereophonic remote audition system.
- Autonomous vision agent to detect features-of-interest.
- 3-D visual overlay with mode selections.
- Height-adjustable, positionable chair or sit/stand stool.

We will utilize measures of task performance, usability testing and workload assessment. Objective measures include task completion times, frequency and type of errors, and quality acceptance ratios (e.g., in an inspection task, how many incomplete fasteners were correctly identified).

Usability evaluations using formal testing methods will take advantage of our research in usability testing with teleoperated robots supported by NSF (IIS-0636173) and Army Research Laboratory (ARO 103526, W911NF-06-2-0041). We use a set of measures that are especially suited to remote robot operations that provide indirect indication of the quality of interface design including task completion time, the number of objectives accomplished within a time, and subjective surveys.

Workload will be measured using the NASA TLX (Task Load Index) method. Users provide subjective assessments along scales in six dimensions: mental demands (how much thinking, looking, calculating, remembering, searching), physical demands (how much pushing, pulling, turning, activating), temporal demands (how much time pressure), performance (how well did the user think they performed the task), effort (how hard did the user have to work), and frustration (how irritated, discouraged, stressed or annoyed was the user).

Situation awareness is a critical component of robot teleoperations. We will evaluate the interface conditions in terms of their contribution to enhanced operator SA using coding schemes modified from previous research, wherein operators spent much of their time trying to determine the state of the robot (its location, configuration, mode).

We will also perform musculoskeletal disorder risk factor assessments while operators perform tasks manually and while using the co-robotic system. Musculoskeletal disorder risk data provide quantitative information to help determine if there are differences between manual and co-robotic system risk.

Parametric statistical procedures such a balanced multifactor repeated measures analysis of variance (ANOVA) will be used to analyze ratio-scale data collected—task performance times, for example. Nonparametric statistical procedures will be administered to ordinal and interval-scale data, such as numerical questionnaire data. Simple descriptive analyses will also be completed on each study group separately. Variables of interest include typical demographic characteristics.

The results gathered from this research will increase knowledge of task performance outcomes with new teleoperation techniques and technologies; identify the types of feedback most effective in assisting operators; and understand the ergonomic improvement associated with new ways of performing confined space manufacturing operations.

The ability to scale the human worker through co-robotic systems allows the expansion of the design space—supporting design of significantly higher-performance systems or systems in significantly challenging environments that would otherwise be nearly impossible to achieve by conventional means.

> The open telesupervision architecture has supported research for planetary exploration using semi-autonomous rovers for NASA’s Exploration Systems Mission Directorate; and research for harmful algal bloom detection by semi-autonomous ocean vessels for NASA’s Earth Science Technology Office.

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

“Telesupervised Co-Robotic Systems for Remote Confined/ Hazardous Space Operations”

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

Ultra-Low Light Level Photoresponse in Thermoelectric Nanowire Arrays

Summary

JEFFREY H. HUNT

The international telecommunications market is now a $4 trillion-per-year industry. This is not an accident, as the ability to move information quickly and cheaply on a global scale is one of the things that separates profitable companies from those relegated to the trash heap of yesterday's businesses.

This fact affects international aerospace markets in ways that would not have been anticipated a generation ago. Specific to Boeing, our communications systems increasingly rely on higher bandwidth communications in all segments of the electromagnetic spectrum. As a result, systems involving high speed communications, sensing and imaging require ever more sensitive detection systems coupled with the ability to operate in a trans-spectral architecture. This is increasingly true in the opto-electronic regime, in which rapid conversion of electro-magnetic radiation (including rf, microwave and optical signals) to electrical signals—and the inverse—must occur at high bandwidth to avoid communications and informational bottlenecks.

Detectors in the optical regime historically employ detectors based on bulk absorption in semiconductor media. For general semiconductor devices, photocurrent is generated by the separation of excited electron-hole pairs by a built-in electric field or photovoltaic effect (PV). In other words, the excitation of electrons from valence to conduction band generates an internal field. For semiconductor-based optoelectronic devices, such as silicon solar cells, photon absorption leads to the transfer of charge between different electronic bands, resulting in a photocurrent (PC).

However, there are other physical mechanisms in condensed matter than can be exploited to make a detector. For example, there is a class of materials which exhibit a so-called thermo-electric response. In this case, a temperature gradient is generated by light absorption between two surfaces, a potential difference is created via the thermoelectric (TE) Seebeck effect. Recent work in two dimensional graphene demonstrated a hot carrier thermoelectric (TE) photoresponse, in which an electrical response was generated by the thermal heating caused by light absorption at the nanoscale.

REFERENCE 1.

SOURCE: BOEING

The efficiency of TE power conversion is characterized by a figure of merit Z, defined by $Z=\alpha^2\sigma/(T\kappa)$ where α is the thermopower, σ is the electrical conductivity, κ is the thermal conductivity, and T is the absolute temperature.

Boeing has on-going experimentation at strategic universities in the various areas of nanotechnology. One of these nanotechnologies has to do with thermoelectric optical detection. From this, we report on the first demonstration of thermoelectric optical detection in bismuth nanowire arrays (NWA).

NWA devices are composed of thermoelectric bismuth nanowire arrays that are capped with a transparent indium tin oxide electrode. The incident surface features very low optical reflectivity and enhanced light trapping. The unique attributes of the thermoelectric arrays are the combination of a strong temporal and optical wavelength dependence of the photoresponse.

We have shown that, under infrared illumination, the photoresponse can be completely described by thermoelectric effects. At low frequency, quasi-equilibrium is achieved and the signal is f-independent. At high frequencies, the absorbed heat is not dissipated in the back electrode during the illumination cycle, and the signal can rise proportionately with $f^{1/2}$ to much higher values because the energy is delivered to a thin layer on the front of the sample where the junctions are located.

The TE effect that completely describes the infrared-only illumination appears to be complimented by PV and hot-carrier processes under visible illumination. The TE signal can be fast, with a response time much shorter than the array thermalization time, only limited by optical penetration. The resulting detection arrays may find future optoelectronic application as fast nanoscale thermopiles.

Through this paper, we report the first demonstration of TE response in an array of junctions of nanowires. We discuss the nanoscale optical and TE properties that give rise to the effect. We also find that under illumination there is a photoresponse in both near infrared (NIR) and visible spectral regimes.

Under infrared illumination, the photoresponse is simply governed by heat diffusion and can be uniquely attributed to TE effects. However, under visible illumination, the photo response is a combination of TE and PV effects.

TE effects are caused by the difference in the broadening of the energy distribution in the electronic bands caused by a temperature gradient. (See Reference 1.) Some traditional TE materials, such as bismuth, have unusually high thermopower values and large, leading to exceptionally large

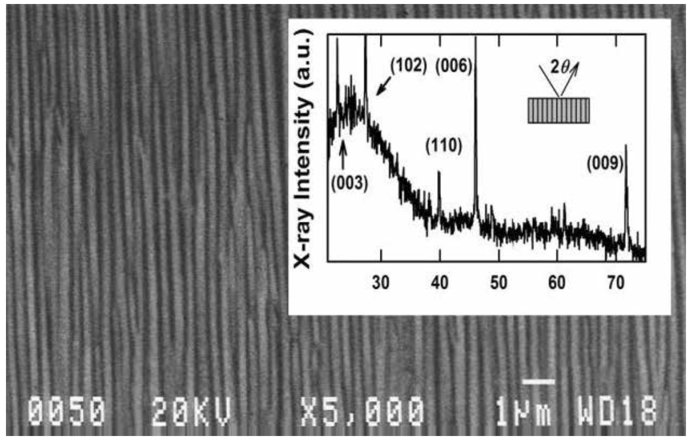


FIGURE 3.
Scanning electron microscope side image of NWA. Inset: X-ray diffraction spectra showing presence of crystal grains oriented with the c-axis parallel to wire.

SOURCE: BOEING

> Through this paper, we report the first demonstration of TE response in an array of junctions of nanowires. We discuss the nanoscale optical and TE properties that give rise to the effect.

Z values and high efficiency. However, although it is almost counter-intuitive, bulk TE crystals are not good candidates as TE photoresponse detectors because the same properties that create high Z values cause the material to have high thermal conductivity.

As a result, the energy dissipates quickly in these systems. We chose to address this problem by working in a nanowire geometry. We anticipated that this geometry would show enhanced thermoelectric performance because κ is less in nanowires than in the bulk. In addition, bulk thermoelectric materials have large refractive indices relative to air. This causes large Fresnel reflection at the incident surface of bulk thermoelectrics, which is not conducive for efficient conversion. In fact, in a variety of bulk systems, including bulk crystalline semiconductors and Bi, light induced thermoelectric responses are so weak that they have only been observed under pulsed illumination.

In investigations of PV in solar cells, researchers have discovered that the nanostructuring of bulk materials into wires or sharp points aligned along the optical incident direction results in reduced optical reflection and induced light trapping. There are many mechanisms that may play a role in this effect. The optical reflection of a nanowire array is greatly reduced relative to the well-ordered surface because the electromagnetic field penetrates deep in the material. This property has been attributed to dipole effects because the wires point parallel to the light wave vector, and the photon electric field is perpendicular to the wire length. Nanowire array optical properties have also been discussed in the context of optical meta-materials.

The array electronic properties were determined in separate experiments. X–ray diffraction spectra show that the crystal grains were larger than the wire diameter and were oriented with the c-axis along the wire length. (See Figure 3.) Electron and hole band parameters were determined via magneto-resistance experiments. As with bulk bismuth, the bismuth in the nanowires was determined to be a semimetal. Thermopower measurements show that the thermopower of the nanowires was diffusive in nature and negative. (Nanowires, as well as bulk, are n-type because electrons have greater mobility than holes.) This value of approximately –90 mV/K did not differ significantly from that attained for single-crystal bulk bismuth along the diagonal orientation.

We also characterized the nanowire arrays under optical light illumination. The optical properties of the array were significantly different from those of bulk single crystal bismuth with its highly reflective front surface. In addition, the 50-μm thick alumina template, prior to processing, was translucent/transparent in the visible and infrared. By contrast, we found that the optical absorption by our nanowire arrays was very high, broadband and anisotropic. The array surface was black and dull without the reflective surface characteristic of single crystal bismuth. This finding is consistent with arrays of many diverse materials (e.g. silicon nanowire arrays) and denotes low reflectivity caused by high levels of light trapping.

We also observed that light reached deep inside the array. Under oblique illumination—that is to say, with the incident light propagation vector non-parallel to the nanowire orientation—the reflected visible light is highly polarized.

Interpretation of this data can draw upon prior TE theoretical work. The physical interpretation of our observations is outlined in the full paper. From these observations, the signal is interpreted as a pure TE response.

The assignment of the signal to TE effects is appropriate in the case of infrared-only illumination. Under infrared illumination, which includes visible light, the inflection point is barely noticeable, and the signal strength is nearly independent of frequency. This behavior strongly suggests that part of the signal is not strictly thermal, indicating the presence of PV or hot electron component in this case.

Semiconductors used in solar cells cannot convert the infrared part of the solar spectrum, which represents approximately half of the total solar energy output, because in PV processes the absorption of a photon with energies below the bandgap energy cannot readily produce electron-hole pairs.

Devices based on TE nanowires can convert the infrared radiation part of the spectrum into usable electrical power, which suggests that their integration in solar cells may increase overall solar energy harvesting efficiency.

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

“Ultra-Low Light Level Photoresponse in Thermoelectric Nanowire Arrays”

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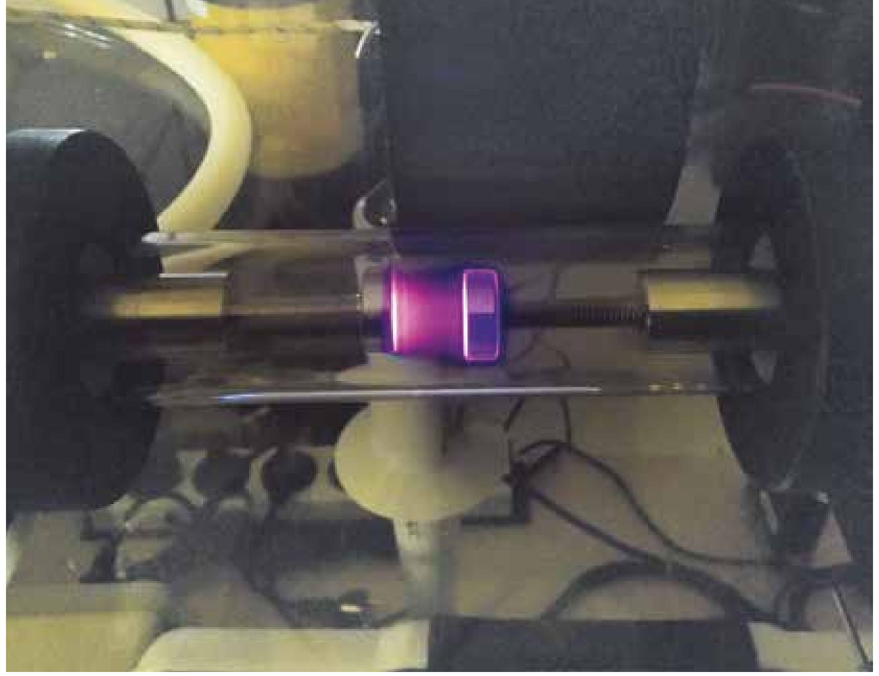


GLOW WITH THE FLOW
By changing the electrode or aircraft material properties, energy discharge can be manipulated toward a "glow discharge" (the purple glow in this image) with diffuse and low-energy density, as opposed to a high-density voltage arc discharge.

SOURCE: S KRISHNA, D LACOSTE, J DAMAZO, E KWON, W ROBERTS

Lightning protection research partnership

Performance and productivity improvements from Europe

BY EDDIE KWON | JASON DAMAZO
BOEING RESEARCH & TECHNOLOGY

Advanced materials have increased the capabilities of aircraft relative to aluminum—the status quo material used on commercial airplanes. The 787 was the first commercial airplane to have a structure chiefly constructed of a composite material; the carbon fiber reinforced polymer structure provided the strength of an aluminum airplane with less weight and thereby enabled the 787 to fly farther and more efficiently.

However, this new capability came with a technological challenge: Aluminum, being an isotropic material, is uniformly electrically conductive in all directions. Conversely, CFRP has good electrical conductivity along the length of the fibers, but may have poor conductivity in other directions.

Because airplane wings double as fuel tanks, the wings must protect the potentially flammable environment from be ignited by external threats like lightning.

The 787 design accounted for these conductivity characteristics by layering protection schemes on top of structural elements. However, solutions like this are still confined by the history of applying designs that originated in aluminum aircraft to aircraft manufactured from composite materials.

For future aircraft, advancing our technological understanding will better allow us to take full advantage of advanced materials and methods.

> Research being performed in a partnership between Boeing and the King Abdullah University of Science and Technology (KAUST), in Saudi Arabia, aims to provide lightning protection in a fundamentally different way from previous designs.

This research is proceeding along two paths that, at first, may seem at odds.

First, we are investigating the physical mechanisms that result in the quenching of deflagration waves. Second, we are investigating minimum electrical current conditions that could result in ignition. Understanding these phenomena is a particularly complex science that requires simultaneous investigation of chemistry, fluid mechanics, thermodynamics and electrodynamics in physical scales that have previously been impossible to measure.

The unique aggregation of multi-disciplinary expertise and state-of-the-art diagnostics makes KAUST an ideal partner for these works.

"These projects develop and apply cutting edge diagnostics in novel facilities to gain fundamental insight into the very real technical issues of flame quenching and ignition phenomena," describes William Roberts, director of the Clean Combustion Research Center at KAUST and professor of mechanical engineering.

Our collaborations have resulted in new data that provide insight into the physical processes that govern combustion behavior to enable tailoring electrical and other properties of carbon fiber reinforced polymer to complement the structural advantages in airplanes and other products. Future aircraft will be designed using a much more holistic approach where the structural elements will either double as protection features or manipulated to retain the same high level of safety. IQ

Global Scale

Satellites that deliver value with production and payload

Flexible digital payloads help future-proof satellites for commercial and military communications. Digital payload technology gives customers the ability to adapt to changing business plans with capabilities that include reconfiguring the satellite to provide bandwidth in real-time to meet demand where and when it is needed.

Launched on July 5 from Cape Canaveral, Florida, an Intelsat 35e satellite will use Boeing's advanced digital payload technology to offer flexible internet (fixed broadband), media (broadcast) and mobile broadband (air, sea, and land) coverage over Intelsat's global satellite network.

Boeing satellites like the WGS-9 (Wideband Global SATCOM), which launched on March 18 from Cape Canaveral, provide that same digital payload to support military satellite communications that connect U.S. and allied warfighters around the globe.

In addition to delivering the digital payload, which increases value to customers over the life of the satellite, Boeing designs apply advanced manufacturing practices, such as additive manufacturing (3-D printing), that simplify production, translating to cost-savings and timely delivery of satellites to customers. For example, the SES-15—a Boeing 702 all-electric small platform satellite that launched on May 18 from French Guiana—had more than 50 metallic 3-D printed parts in its main structure.

Brisbane engineers battle for communications solutions

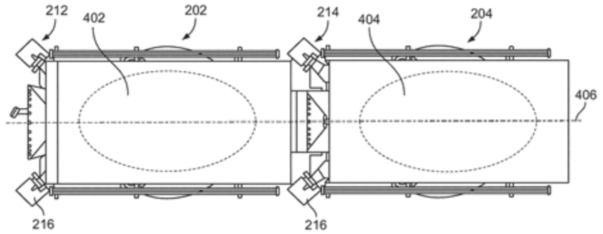
Currently in field testing, Boeing's Battlespace Communications System will provide secure wideband voice, data and video services over wireless and wired infrastructure between deployed forces and headquarters for land-based Australian Defence Force personnel deployed around the world.

Designed by Boeing engineers in Brisbane, the core computer and mission system module incorporates passive cooling and flexible components—currently unavailable in the market—that enable capabilities to be added into the system, including medium SATCOM, external network access, troposcatter, high-capacity line-of-sight, long haul fiber, radios and field voice.

Patent Spotlight

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

> “Innovation can help transform the current economic upswing into longer-term growth.”
>
> **FRANCIS GURRY, DIRECTOR GENERAL FOR THE WORLD INTELLECTUAL PROPERTY ORGANIZATION, IN RESPONSE TO THE 2017 GLOBAL INNOVATION INDEX.**



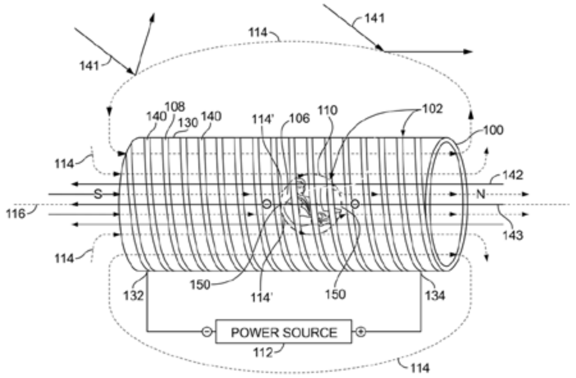
Methods and Apparatus for Performing Propulsion Operations Using Electric Propulsion Systems

U.S. PATENT: 9,643,739
INVENTORS: JAMES PETERKA, GLENN CAPLIN, RICHARD ASTON

Spacecraft, such as satellites, need to perform many types of propulsion operations following launch. Some satellites use cold gas propulsion systems, chemical systems, electric propulsion systems, or various combinations to control their movement. Propulsion operations include deployment, orbit transfer and station keeping. This patent, granted to Boeing in May, describes a fully electric propulsion system.

Some existing satellites use chemical propellants that are costly, highly reactive, weighty and burdensome. Use of electric propulsion systems is not hazardous, does not require onerous handling tools or equipment at the launch site, and is extremely safe to manufacture and operate.

By using an ion propulsion or other electric propulsion system, the mass of the satellite at launch may be reduced by hundreds of kilograms, the mission life may be extended, and the processing, production and launch costs could decrease. The total cost of a launch vehicle can also be cut as a result of a decrease in the size and weight of the satellite. Additionally, using an electric propulsion system enables the satellite to be repositioned into different orbits or orbital slots using substantially less propellant than a chemical or hybrid propulsion system.



Systems and Methods for Shielding Structures from Radiation and Magnetic Field Exposure

U.S. PATENT PENDING
INVENTORS: JIAN DONG, NAVEED HUSSAIN

Radiation in outer space typically consists of high energy, charged particles like gamma rays, protons and neutrons. This type of radiation damages human tissues and cells, as well as instrument and communication systems on board space vehicles and stations. The sun occasionally releases significant amounts of ionizing radiation known as coronal mass ejectas (CMEs). Even though CMEs are relatively uncommon, the radiation they potentially inflict upon a crew and equipment of a spacecraft requires shielding.

A need exists for radiation shielding that deflects ion particles in all directions, protects all areas of an internal chamber, is effective over long periods of time, and protects against long term exposure to magnetic fields. Active shielding, like the Earth's magnetosphere, can deflect radiation particles by creating enough flux density to change the trajectory of radiation particles, thereby diverting the radiation away from the Earth.

This recently published Boeing patent application describes such a system using an active inner shield and active outer shield to protect an interior chamber of a spacecraft. The outer shield generates a magnetic field through and around an outer wall of the spacecraft, and the inner shield deflects radiation away from the interior chamber while redirecting portions of the magnetic field around the interior chamber.

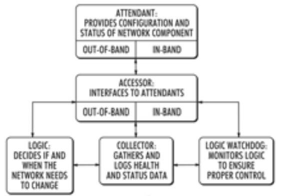


FIG.1

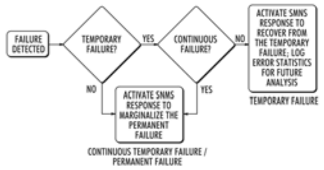


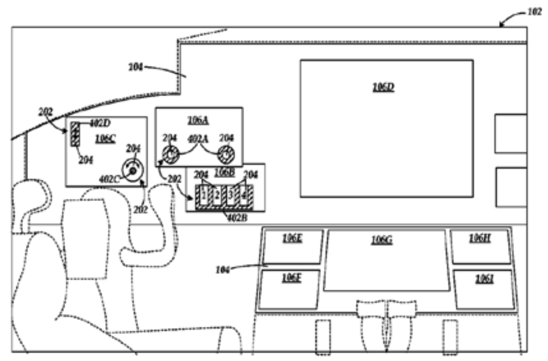
FIG.2

Spacecraft Network Management System and Method

U.S. PATENT PENDING
INVENTORS: BRIAN THOMPSON, ANDREW RIHA

There are unique features of a terrestrial network management system (NMS) that limit the usefulness of the terrestrial NMS to a system in space. Specifically, a space-based NMS, being isolated, must maintain a high level of reliability and availability, notwithstanding the increased environmental impacts encountered in space. In addition, the space-based NMS must recover quickly and autonomously.

The spacecraft network management system (SNMS) described in this recently published Boeing patent application is a distributed architecture organized in tiers. A multi-tiered SNMS has several levels of primary management entities, each with the capabilities and responsibilities required for that level plus a watchdog function presiding over all of the primary management entities. The entities contain common elements that manage communications with the software components and are connected with elements in other entities via a dual-band communication approach. The entities collect network management data by polling for it when it is needed and push it whenever network management data has changed. Each entity has a different function, but together they represent all the major functions of any spacecraft network management system.

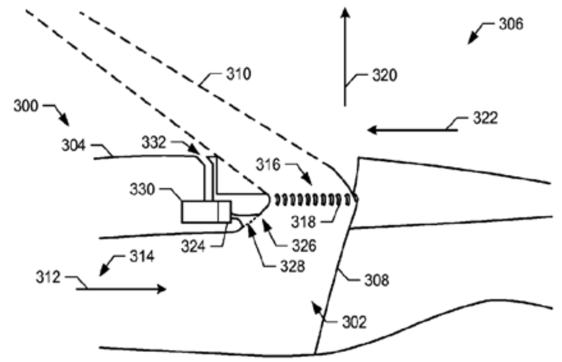


Tactile Feedback Devices for Configurable Touchscreen Interfaces

U.S. PATENT: 9,671,954
INVENTORS: JOHN M. JAUGILAS, CINDY DORFMANN

Modern aircraft cockpits are becoming increasingly advanced with respect to avionics displays. Customizable touchscreen displays provide pilots with extensive flexibility to process vast quantities of information. However, touchscreens may require increased pilot visual attention as compared to the manipulation of conventional cockpit controls such as buttons, switches or knobs, which provide pilot and crew with tactile reference points for using them with less visual attention.

This Boeing patent describes a tactile feedback device for touchscreen interfaces to provide a user with haptic feedback that increases the accuracy of input to the virtual control of the device. The invention allow for input to a virtual control adjacent to the tactile feedback device or via the tactile feedback device itself.



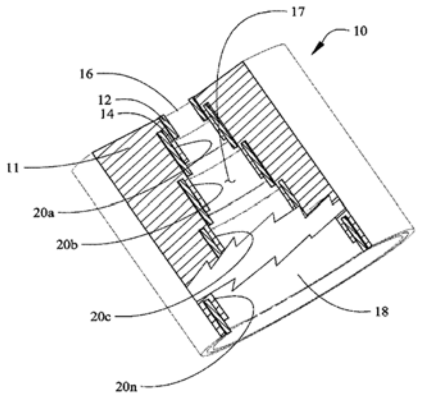
Thrust Reversers and Methods to Provide Reverse Thrust

U.S. PATENT: 9,670,875
INVENTORS: KURT ERIK ACHESON, CHEN CHUCK

Aircraft engines are often provided with thrust reversal mechanisms to slow the aircraft when landing. Known thrust reverser designs can add substantial weight to the engine and reduce the performance of the aircraft, the efficiency of the aircraft, and/or the load that can be borne by the aircraft.

During thrust reversal, instead of being ejected from the rear of the engine to generate forward thrust, the airflow is blocked by a blocking door and directed outward from the nacelle in a generally forward direction via a cascade to generate reverse thrust. As the airflow is directed through the cascade, the airflow flows over a diverter fairing portion of the nacelle.

This patent granted to Boeing provides more efficient thrust reversal. An air extractor extracts at least a portion of air from a volume adjacent the diverter fairing to increase the effectiveness of the cascade vanes, thereby enabling a reduction in the length of the cascade and, thus, a reduction in the weight of the engine. Example thrust reversers disclosed in the patent increase the performance of a multi-door type thrust reverser. As a result, the diverter door may be made smaller without sacrificing performance.



Plasma Actuating Propulsion System for Aerial Vehicles

U.S. PATENT 9,670,913
INVENTORS: VYACHESLAV KHOZIKOV, SHENGYI LIU

In certain cases for small or micro-/nano-unmanned aerial vehicles (uAV/nAV), the operating envelope includes efficient performance at low or extremely low altitudes (sub-meter to several meters). Functional specifications typically require a propulsion system that efficiently operates in a quiet and hardly detectable manner.

Traditional and advanced means of providing power for uAV/nAV applications include turboprops and flapping wings. Such systems can be mechanically complex and require power transformation using several stages. Plasma propulsion systems consisting of a single dielectric-barrier discharge unit have been employed, but have resulted in poor efficiency and insufficient power.

This patent specifies a plasma discharge device for accelerating air flow to propel a vehicle that incorporates a nozzle having upstream and downstream ends and a plurality of substantially cylindrical electrodes separated by dielectric spacers.

In a vehicle with this plasma propulsion nozzle, air is introduced through the nozzle inlet. A periodic voltage signal is applied, creating and expelling plasma clusters, introducing momentum change into the air along the interior chamber for exit through the nozzle outlet, and producing thrust. Thrust is controlled by varying the frequency, wave shape, and amplitude of the periodic voltage signal.

Global indicators

Switzerland, Sweden, the Netherlands, United States and United Kingdom remain the top five innovative countries despite an overall global weakening in research and development investment, according to co-authors of the annual Global Innovation Index.

Now in its 10th edition, the Global Innovation Index evaluates 130 economies using metrics such as patent filings, education spending, R&D expenditures from private, public and academic sectors, and scientific publications.

The 2017 report, released in May by Cornell University, INSEAD and the World Intellectual Property Organization, showed the continued gap in innovative capacity between developed and developing nations—high-income economies taking 24 of the top 25 spots.

The report notes that continued strengths in the United States, however, include the presence of high-quality universities and firms conducting global R&D, quality of scientific publications, software spending, and the state of U.S. innovation clusters.

TO READ THE FULL REPORT VISIT: WWW.GLOBALINNOVATIONINDEX.ORG.

PHOTO: CASIS

PHOTO: VIDEO ARCHIVE POSTED BY FIRST

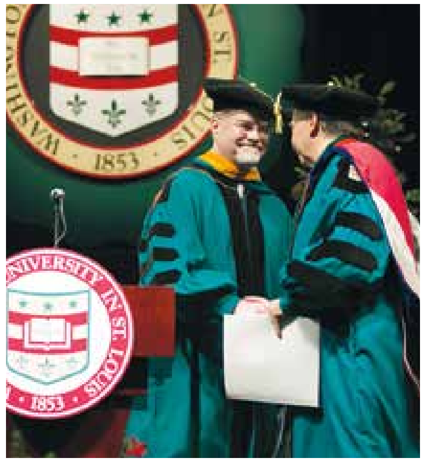


PHOTO: WASHINGTON UNIVERSITY IN ST. LOUIS

PHOTO: PETRUS COMMUNICATIONS

From the top, left to right:

2017 GENES IN SPACE COMPETITION

Winners Sophia Chen, 14, from Seattle, and Elizabeth Reizis, 14, from New York City, will have their DNA experiments performed aboard the International Space Station using technology from miniPCR. They are pictured here in July with astronauts Kate Rubins, Samantha Cristoforetti and Soichi Noguchi, as well as Mark Mulqueen, Boeing's ISS program manager. Boeing was a co-sponsor of the high school student competition.

INSPIRING A NEW GENERATION OF INVENTORS

In June, Brian Tillotson, a Boeing senior technical fellow and inventor, told elementary and middle school participants in the FIRST LEGO League Global Innovation Awards in Washington, D.C., to embrace the difficult challenges and help make life better for humankind.

WORDS OF WISDOM AND ENCOURAGEMENT

Greg Hyslop (left), Boeing chief technology officer, is congratulated by Aaron Bobick, dean of the School of Engineering & Applied Science at Washington University in St. Louis, after delivering the keynote address at the school's graduation ceremony in May.

THE POWER OF COLLABORATION

Lynne Hopper (far right), vice president of engineering for Boeing Global Services, took part in the first Global Engineering Dean's Council Industry Forum, held in Fontainebleau, France, in June. WIth her are (from left) Kirsten Williamson, of conference organizer Petrus Communications; Natasha DePaola, dean of the Armour College of Engineering at the Illinois Institute of Technology; and Peter Kilpatrick, dean of the College of Engineering at the University of Notre Dame.

From the Innovation Video Playlist

ISS: A Step Closer to Deep Space

The International Space Station is the largest, most complex international scientific project in history and humanity's largest adventure into space to date. Rotating 220 miles above Earth, the laboratory explores our universe, and Boeing provides astronauts with a safe environment to perform over 200 experiments at a given time. Designated a National Lab in 2005, the station is a test bed for future technologies and a research laboratory for new, advanced industrial materials, communications technology, medical research and much more.

Join the adventure at **boeing.com/space.**