# Innovation Quarterly

2016 August

## The Next 100
To build a stronger, cleaner, faster future

## A Trailblazer
In the chemistry lab

## Sphere of Influence
Meet Boeing's new Senior Technical Fellows

A publication of The Boeing Company

**Innovation** Quarterly

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**ON THE COVER**
Jill Seebergh is Boeing's first Senior Technical Fellow assigned to the company's Environment and Safety technology domain.

## Featured



## Technical Papers



MARIAN LOCKHART PHOTO

# With sights set on tomorrow

Picture crafty inventors spinning startup after startup from new tech. Whole new industries are being created around breakthroughs in science. Moguls of wealth from earlier ventures shed their button-down Brooks Brothers business suits for a tinkerer's khakis.

In this new landscape, competition for dominance in the world of aerospace is fierce. Battles rage at the patent office, while American warfighters overseas are in need of newer defense capabilities. Discovery, knowledge, innovation, business savvy—and the courage to pursue all of those at once—eventually wins the day.

It sounds a lot like today's headlines. But what I'm describing is a Seattle of Bill Boeing's time a full century ago when he launched his startup company: Pacific Aero Products. His venture was a passion-driven stake on the future.

The same can be said of many legacy aerospace startups at the time—Douglas Aircraft, North American Aviation, McDonnell & Associates, Stearman Aircraft, Piasecki Helicopter, Jeppesen, Hughes.

The difference between then and today is the century of experience behind these companies we now call Boeing.

If it seems that we're going back to the future, it is because we are. Competition today in aerospace is as spirited as ever, with some familiar names and many new entrants taking their best shots toward the stars.

As so much has changed, this remains: Boeing is a 100-year-young technology startup, focused and committed to a successful future driven by innovation. This is what we hope to convey to the world via this new technically focused publication.

Innovation Quarterly is a publication by and about the most important element in this enterprise, the people who will make the future happen. In it, we will share peer-reviewed technical papers, thoughts from our technology leaders, our ideas, visions and dreams. At Boeing, we are committed to aerospace leadership—to expanding possibilities for human life in ways that haven't yet been imagined.

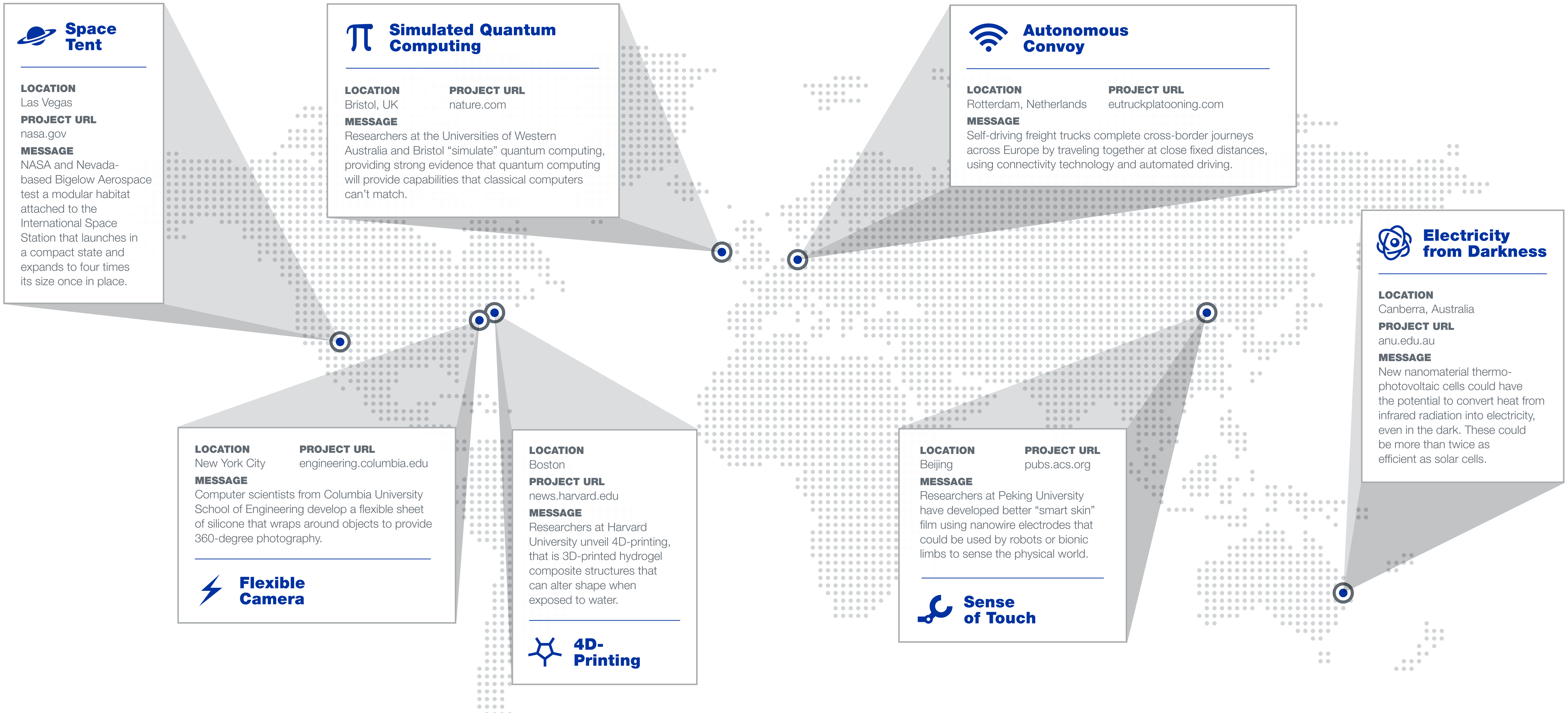
Don't get me wrong. We would be unwise to reveal the depth of all we know. But there is a healthy portion of experience we are happy to share. In the interest of shaping tomorrow, let's begin the discussion today. IQ

**GREG HYSLOP**
Boeing 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.



### Space Tent

**LOCATION**
Las Vegas

**PROJECT URL**
nasa.gov

**MESSAGE**
NASA and Nevada-based Bigelow Aerospace test a modular habitat attached to the International Space Station that launches in a compact state and expands to four times its size once in place.

### Simulated Quantum Computing

**LOCATION**
Bristol, UK

**PROJECT URL**
nature.com

**MESSAGE**
Researchers at the Universities of Western Australia and Bristol "simulate" quantum computing, providing strong evidence that quantum computing will provide capabilities that classical computers can't match.

### Autonomous Convoy

**LOCATION**
Rotterdam, Netherlands

**PROJECT URL**
eutruckplatooning.com

**MESSAGE**
Self-driving freight trucks complete cross-border journeys across Europe by traveling together at close fixed distances, using connectivity technology and automated driving.

### Electricity from Darkness

**LOCATION**
Canberra, Australia

**PROJECT URL**
anu.edu.au

**MESSAGE**
New nanomaterial thermo-photovoltaic cells could have the potential to convert heat from infrared radiation into electricity, even in the dark. These could be more than twice as efficient as solar cells.

### Flexible Camera

**LOCATION**
New York City

**PROJECT URL**
engineering.columbia.edu

**MESSAGE**
Computer scientists from Columbia University School of Engineering develop a flexible sheet of silicone that wraps around objects to provide 360-degree photography.

### 4D-Printing

**LOCATION**
Boston

**PROJECT URL**
news.harvard.edu

**MESSAGE**
Researchers at Harvard University unveil 4D-printing, that is 3D-printed hydrogel composite structures that can alter shape when exposed to water.

### Sense of Touch

**LOCATION**
Beijing

**PROJECT URL**
pubs.acs.org

**MESSAGE**
Researchers at Peking University have developed better "smart skin" film using nanowire electrodes that could be used by robots or bionic limbs to sense the physical world.

**HEAD IN THE GAME**
George Parker (above) runs basketball practice at Seattle Pacific University earlier this year.

# All about the chemistry

## From the ball court to the lab, George Parker practices a team sport

**BY DAN RALEY | PHOTOGRAPHY BY MARIAN LOCKHART**

George Parker's work day in Seattle begins at 4 a.m. While the rest of the city sleeps, the Boeing research chemist turns on his computer, works on reports, unlocks basement laboratories, pulls supplies from a freezer, and answers urgent phone calls.

There is nothing particularly magical about reporting to his job at such an early morning hour. Parker simply has a low need for sleep and a deep passion for problem-solving, all of which compels him to head to the office before the sun comes up and start digging for answers before anyone else.

"When you enjoy what you're doing, what is time?" he says.

Parker heads an eight-person research and technology team that performs investigative and failure analysis across the company. They look at defective parts, new materials, pollutants. They seek out environmentally responsible substitutes for chemicals of concern. They examine every aspect of an airplane.

Always on call, this group uses some of the company's most complex equipment—instruments that have been assembled by Parker and come with names such as thermal analysis (differential scanning calorimeter), mass spectrometry, X-ray spectroscopy and scanning transmission electron microscope. Intricate issues are solved with these sophisticated resources.

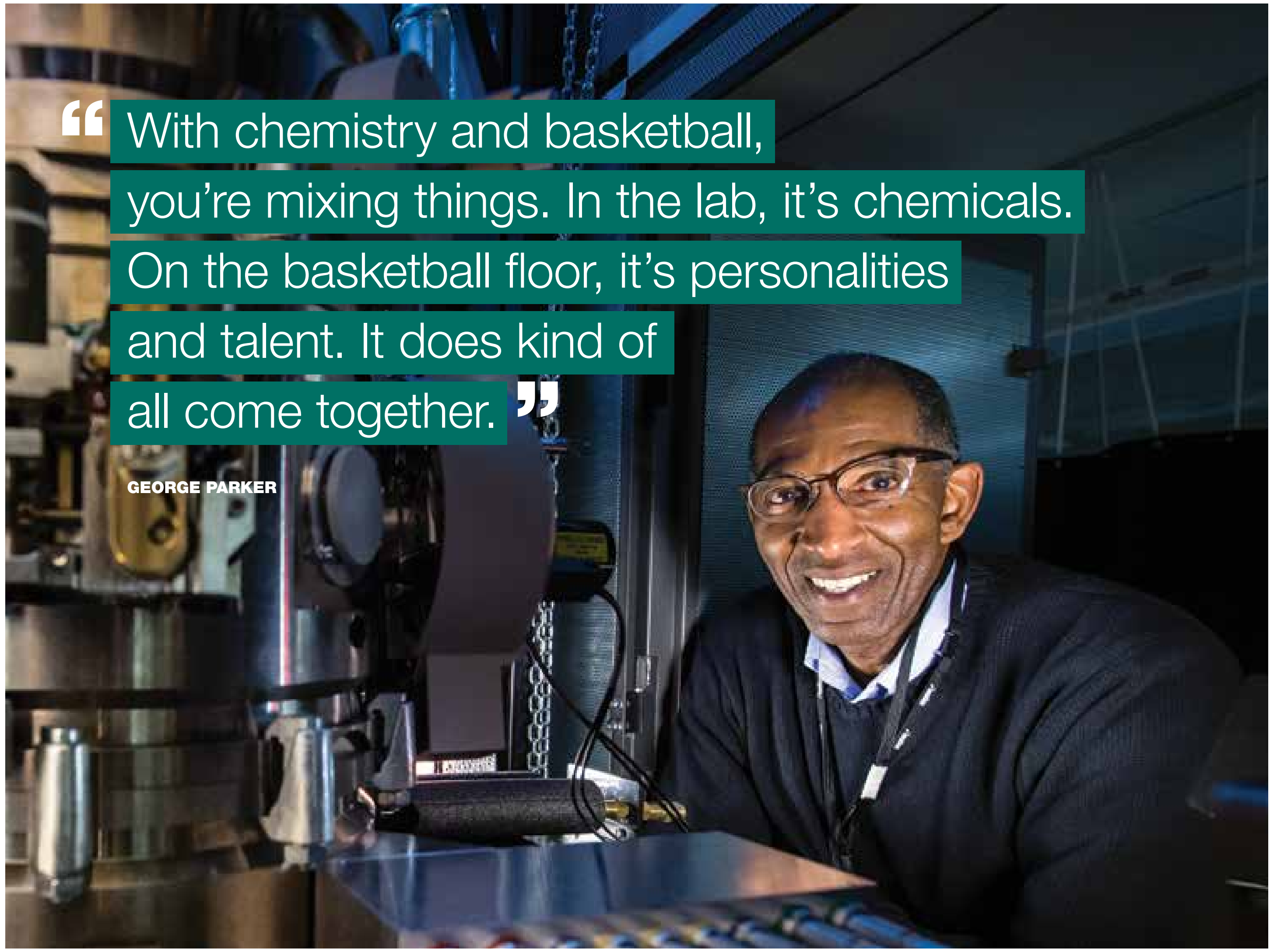
"We are like the FBI and CSI of Boeing," he explained.

How Parker came to head this overly inquisitive collection of Boeing scientists and engineers is a matter of discovery itself. His background couldn't have been more diverse, his interests more varied, his drive to succeed more determined.

Parker grew up in poverty in New York City, on the lower east side and in Harlem, as someone intent on following his dreams.

Music was a big part of Parker's world as a youngster. He traveled the Eastern Seaboard as part of a drum-and-bugle corps. He played the tuba, percussion and bass trombone, and twice performed at Carnegie Hall with a borough-wide symphonic band.

Like many children from the inner city, he also was introduced to basketball. It was a way to express himself through team sport and a means to escape economic hardship. He made friends and shared the local outdoor courts with the likes of



> "With chemistry and basketball, you're mixing things. In the lab, it's chemicals. On the basketball floor, it's personalities and talent. It does kind of all come together."
>
> **GEORGE PARKER**

Kareem Abdul-Jabbar (then Lew Alcindor), Nate Archibald and Julius Erving, each of whom would become a legendary figure in the National Basketball Association.

Had things turned out a little differently, Parker would have counted himself as a pro basketball player, too. He was talented enough to earn a college scholarship and become an athletic hall of fame inductee at St. Martin's College in Lacey, Washington. He received several pro tryouts. Turns out that basketball, however, did not consume him to the point it was an all-or-nothing proposition.

As a teenager, Parker was also introduced to chemistry by a high school science teacher who was passionate about the subject. Similar to basketball, Parker found he had a proficiency in chemistry, eventually earning a college degree in it. His wide range of interests made sense to him.

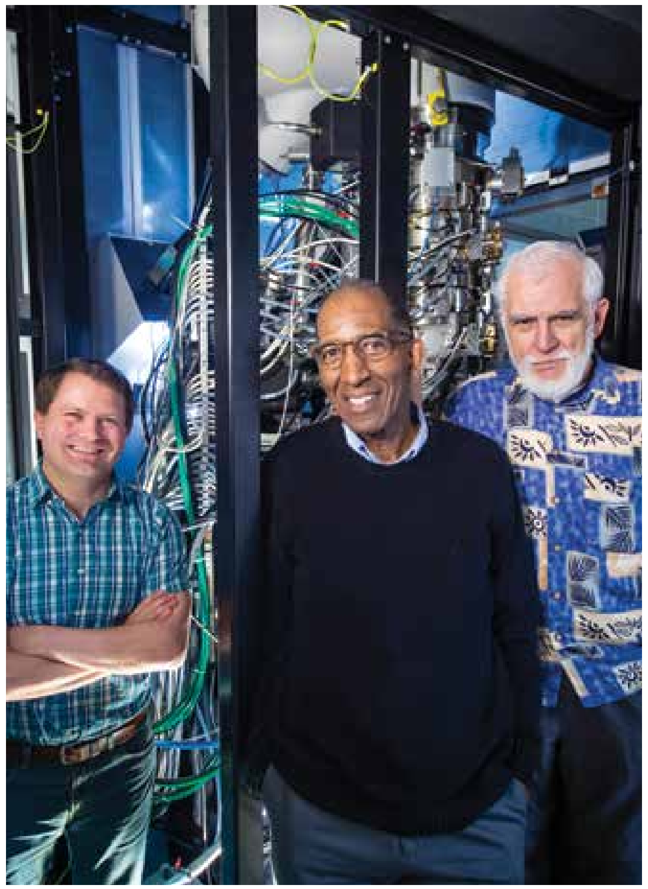
"With chemistry and basketball, you're mixing things," he said. "In the lab, it's chemicals. On the basketball floor, it's personalities and talent. It does kind of all come together."

In 1972, Parker's pro basketball pursuits were curtailed some, and his chemistry involvement accelerated when the U.S. Army drafted him while the Vietnam War raged on. He was sent as a scientist and an engineer to Maryland and the Edgewood Arsenal, which conducted classified chemical research. It was a place that significantly enhanced Parker's subject matter knowledge—though, as he acknowledged, "I was exposed to a lot of stuff that I still can't talk about.

His basketball career officially ended when the last pro team to give him a tryout—the Baltimore Claws of the American Basketball Association—folded before the 1975-76 season. He returned to the Edgewood Arsenal, this time working for

> “I talk to minorities, particularly kids of color. They see me and where I’ve come from and they say, There’s hope for me. If he did it, I can do it, too. I’ve always been a trailblazer.”

**GEORGE PARKER**



**IN THE LAB**
Scientist Chris Meyer, left, and technician Gene Ledbury, right, are part of George Parker’s team using high-powered microscopes and other equipment to find defects and pollutants.

the U.S. Department of Defense, before returning to school.

After receiving a master’s degree in chemistry from the University of Virginia, he moved to Seattle, his wife’s hometown. He mixed basketball and chemistry once more, becoming a volunteer assistant coach for Seattle Pacific University in 1986 and a failure analysis engineer for Boeing two years later, two positions he continues to hold today.

Out of curiosity, Parker poked his head in the door during practice at SPU a number of times before he was asked to stay and share his experiences. Since then, he has worked for five different coaches, retained each time there was a change in basketball leadership at the school, which makes him a pillar of the program unlike any other. He’s valued for his cerebral approach and studious analysis. He’s the one who quietly pulls players aside and offers insights and encouragement, but little about himself. His other job is somewhat of a mystery to them.

“I visited his lab and it was pretty cool,” said Grant Leep, the current SPU basketball coach. “You see a different side of him, the professional side. I saw a sign that said, ‘If there’s an emergency, call George Parker.’ I kid him about that.”

One of Parker’s project players is Joe Rasmussen, whose father, Blair, was an NBA player. Parker helps the younger Rasmussen with his shot and his confidence.

“Coach Parker has been around 25 years and knows his stuff,” Joe Rasmussen said. “He’s not the most vocal, but when he tells you something you have to listen. I don’t know much about what he does for work; I heard what he does is pretty important, though.”

At Boeing, Parker is entrusted with finding answers to problems that save the company millions of dollars. He oversees eight labs in two Seattle buildings. He helps set up Boeing labs in other cities. He purchases all of the test equipment that’s needed for this work across the enterprise. He keeps abreast of technology that, in some cases, is changing daily.

“He’s an interesting guy,” said Cynthia Wittman, a Boeing chemist and engineer, who has worked with Parker for more than a decade. “He’s good at bringing people together on projects and making sure they get a solution. I could tell right off the bat that he had a wide variety of experience.”

Typical of his job, Parker will examine transition in a composite material, one that acts like spaghetti when put in hot water, going from stiff and rigid to rubbery. He’ll insert another test sample into an oven-like container and smash it with a laser beam to see how it reacts. He’ll look at atoms. He’ll seek out contaminants.

Chris Meyer, a scientist on Parker’s team, noted that Parker’s emphasis is on problem-solving.

“He doesn’t focus on titles—he focuses on drive and passion,” Meyer said. “I’ve gotten to know him slowly. I didn’t know he was a basketball coach for the longest time. I didn’t know he was a Ph.D., for the longest time.”

Parker also molds the next generation of chemical test engineers by serving as a board member for multiple universities, teaching college classes and overseeing a mentoring program, hence the long but rewarding days.

He tells prospective Boeing candidates that no odds or obstacles are too great for someone pursuing a job in his field—and that he’s working proof of that. Similar to his basketball players, he tries to inspire young engineers by sharing the details of his journey.

“I talk to minorities, particularly kids of color,” Parker said. “They see me and where I’ve come from and they say, ‘There’s hope for me. If he did it, I can do it, too.’ I’ve always been a trailblazer.”

Today, Parker has yet another master’s degree in industrial/business management from the University of Washington/Lille and earned that aforementioned doctorate in management of technology in engineering from Skema Business School in Lille, France. He’s a Boeing Technical Fellow and considered an expert in multiple technical fields.

And he remains tireless.

He still sets his alarm clock so he can drive through nearly deserted streets and be at his desk by 4 a.m. He encounters many obstacles in his job, but sleep is not one of them. He has far too much to accomplish to keep his eyes closed long. He feels a sense of duty that knows no bounds.

“My job is simple,” Parker said. “I remove roadblocks.” IQ



**COACH AND MENTOR**
In addtion to mentoring aspiring engineers and scientists, George Parker has put his athletic expertise to use as an assistant basketball coach at Seattle Pacific University since 1986.

**TIM BRIDGES, DIRECTOR OF KNOWLEDGE MANAGEMENT**

# A thousand heads are better than one

## How Boeing makes the most out of sharing knowledge

One of our chief engineers recently faced a situation where a weld cracked in a special-material valve bracket during a test in a high-temperature, high-vibration environment. With more than two decades at Boeing, this chief engineer had an extensive personal network of friends and associates that he called on to help him solve the problem. But after a couple of months, his network was exhausted, and he was no closer to a solution.

With tens of thousands of engineers, scientists and technologists at Boeing, it should be easy for teammates to tap into the company's collective knowledge. Right?

Five years ago, people such as this chief engineer could rely only on personal networks to gain and share knowledge. But today, the entire community of our experts and their expertise is so much closer, thanks to new, internal, online business networks. Two of our approaches in particular—Boeing Designated Experts and sponsored Communities—have proven valuable for reliable knowledge-sharing and problem-solving. They capture the knowledge and skills of our 160,000 global employees, and make them readily available throughout the company.

Launched in 2011, the Boeing Designated Expert initiative provides visibility and access to proven and vetted experts across the enterprise. BDEs complement subject-matter experts by providing endorsement by Boeing functions that include engineering, operations, supplier management and finance, as well as specialties such as medical services and crane operations. SMEs, by contrast, are more often and traditionally self-declared.

Back to that chief engineer: After two months of working through his personal network, he tapped into the online Boeing network for a BDE on the material and welding process. He found one immediately. After a 30-minute phone conversation, he had a line on a solution, including a supplier near the plant. The next morning, he visited the supplier and solved the issue, and retired a large program risk.

Another example of our knowledge-management tools at work: Boeing's Communities network—specifically the Lighting, Displays, and Optics Community of Excellence—recently used its connections to shape a standard within the industry.

All flat-panel electronic displays in cars, airplanes, and even on our laptop computers, each have certain brightness, contrast, color and sharpness standards. These standards ensure, for example, that a pilot sees the same type of screen across different airplanes. Boeing and the aerospace industry are required to test the displays in our products to these standards—and testing can be expensive.

SAE International, the industry's standards body in this area, could have impacted us and our suppliers with new standards for these displays. But our Community experts got strategically involved to help shape the standard.

These kinds of knowledge networks have existed throughout human history. But historically at Boeing, as well as other companies, these networks and the passing of knowledge has happened organically. Our engineers considered themselves lucky to find a mentor or technical advisor to teach them and share information.

While there have always been thousands informal groups and subject-matter experts within the company, Boeing Designated Experts and the Communities programs have created an intentional structure for them, so that their expertise and skills can be tapped by anyone in need, anywhere in Boeing. Today, with more than 200 formal technical Communities spanning eight technology fields, and nearly 4,000 designated experts, Boeing no longer leaves this practice to chance. IQ

# From cyberspace to outer space

## A lot of smart people working on a lot of tough problems

BY CANDACE BARRON | PHOTOGRAPHY BY PAUL PINNER

Tom Barrera doesn't have all the answers. No one working lithium-ion technology does.

But in the pursuit of innovation, Barrera, a Technical Fellow in El Segundo, California, will gladly share what he knows about safety requirements, new designs and testing protocols for Li-ion batteries with fellow Boeing engineers in hopes that someone might have new ideas.

Same goes for Nathan Packard, who can demonstrate his group's latest active flow control actuators to encourage dialogue about how this new technology can help meet the complex aerodynamic requirements of Boeing products.

And who would have thought that a breakthrough in aerospace technology might come from flora found deep within the Amazon rainforest? Or that Boeing engineers in Europe have been churning out inventions in everything from materials technologies to guidance, navigation and control?

Welcome to the Boeing Technical Excellence Conference—the company's largest gathering of its technical workforce. It's an annual breeding-ground for innovation.

Known better by its acronym, BTEC, the conference draws technologists from all geographic regions of the company, and from all business units, programs and subsidiaries.

"When you come to BTEC, you really see firsthand the breadth of what we do here," said Senior Technical Fellow

**DIRECTED DISCUSSION**
Greg Hylsop, Boeing's chief engineering leader, moderates a panel of prime customers from the defense and commercial sectors at BTEC in 2015.

Brian Tillotson, who coordinates the development of all platform systems and subsystems technology across Boeing worldwide. "We could fill a baseball stadium with just Boeing scientists and engineers. That's a lot of smart people working on a lot of tough problems."

The program for BTEC 2016, held in Bellevue, Washington in July, includes presentations on detailed technical issues, as well as broad ideas in a range of technology covering everything from underground and underwater into outer space, and even through cyberspace.

The dealings here are proprietary, and only Boeing personnel may attend. But the fact that the company can


> "For others, it created an opportunity for us to discuss potential solutions to problems they have been dealing with for some time."
>
> NATHAN PACKARD

have a meeting of such wide-ranging interests and technical disciplines year-to-year illustrates the magnitude of Boeing's technical ecosystem, said Senior Technical Fellow Anne Kao, chairwoman of BTEC 2016.

After presenting a paper on titanium alloys with improved high-temperature performance at BTEC two years ago, mechanical-metallurgical engineer Catherine Parrish, from Huntington Beach, California, caught the attention of leaders from Boeing Research & Technology who were opening a new center in Brazil, their own eyes set on developing a focus on high-temperature alloys.

"Long story short, we asked Catherine to lead the advanced materials program in Brazil, with both high temperature alloys

**PRESENTING IMPROVEMENTS**
Megan Thompson, a propulsion engineer from Boeing South Carolina, talks with colleagues after her presentation on Improved Thermal Analysis of a Metalllic Acoustic Panel at BTEC in 2015.

**COME TOGETHER**
Andrew Owen, director of research and development for Boeing Defence UK, shares his team's capabilities and achievements with the broader Boeing technical community at BTEC in 2015.

and sustainable materials portfolios," said Antonini Puppin-Macedo, director of the Brazil center, where there is promise of several breakthroughs in aerospace materials.

"We've already identified many opportunities for advancing our research," Parrish said. "After working in California for 12 years, to then have an opportunity to further my experience and research in another hemisphere, where else can that happen but a company like Boeing?"

The annual conference started in 2000 as an internal grassroots meeting by a few Technical Fellows who thought it would be beneficial to gather peers from the different heritage companies that make up today's Boeing.

As with industry technical organizations that organize their own conferences, the competition for the right to present a paper or other material at BTEC is high.

More than 700 abstracts, which are applications to present, were submitted for this year's convention. Only 260 were accepted.

"With that kind of knowledge and experience base from all around the world, you can't help but expect to see new ideas and solutions come out of this meeting," Kao said.

Most technologists agree: innovation often happens at the cross-current of technical disciplines, where detailed first-hand knowledge of customer needs meets the latest technology developments in different areas. To find a better solution, problems must be viewed from multiple angles. Those angles come by seeking diverse perspectives from many different people with different training, scientific backgrounds, expertise and experiences.

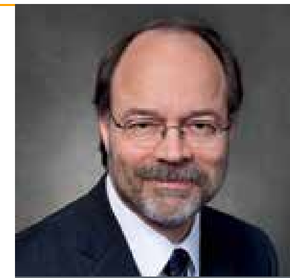
For example, while steeped in the technical discipline of fluid mechanics, Packard's active flow control technology has the potential to completely change the way aircraft are designed today, which then affects aerodynamics, payload, environmental performance, and overall affordability.

"For some it was their first encounter with (active flow control) technology and they gained a basic understanding," said Packard, whose actuator demonstration won the People's Choice Award at the conference in El Segundo last year. "For others, it created an opportunity for us to discuss potential solutions to problems they have been dealing with for some time."

And Barrera's Li-ion technology is already shaping the face of electrical power subsystems in everything, everywhere.

"Boeing is leading the aerospace industry in transitioning from heritage battery power systems to lithium-ion battery alternatives," Barrera said. "Because we have multiple, smart people working in this technology in defense and space, as well as commercial applications, there is great promise for developing valuable solutions together." IQ





**BRIAN TILLOTSON, SENIOR TECHNICAL FELLOW**

# What will the world be like in 2116?

## Will an average person live for centuries? Will travelers cross the world in two hours? Will energy be cheap—even free?

No one can see the future. But with a little foresight on technical possibilities, a bit of research, and some smart people in the room, we can make good guesses. Recently, dozens of Boeing engineers and scientists, along with a few university research partners and potential industry collaborators gathered to imagine what the future could bring—and how Boeing could shape that future.

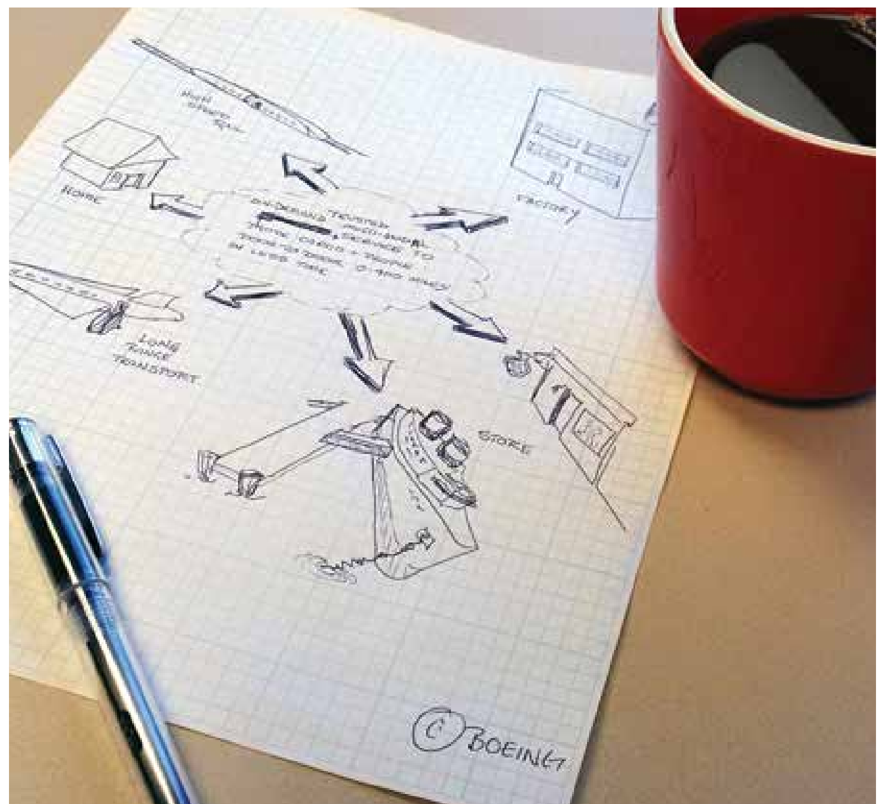
Teams peered into the future in six areas: long- and short-range transportation, manufacturing, exploration, defense, and even business models. In some subjects, like hypersonic flight, Boeing is the clear leader setting the pace for tomorrow. In others, the competition changes as fast as the technology: new companies offer personal air vehicles, and deep-pocketed internet firms aim to fill the sky with drones and small satellites.

In manufacturing, changes like 3D printing—where Boeing is active today—may presage a world where bio-engineered airplane structures grow in vats. In the far future, barely within the careers of today's youngest employees, lie even bigger changes.

When space travel matures from exploration to development, will Boeing build factories on asteroids to make new kinds of spacecraft? When buildings are 10,000 feet tall, will the upper floors be pressurized and have environmental control systems designed by Boeing? Will defense products be huge platforms bristling with laser weapons, or will they be autonomous swarms of small, cooperating vehicles?

We can't give solid answers to these questions, but we can figure out what to watch for and what steps Boeing might take. After all, the future is something we do, not just something that happens to us.

As we celebrate our centennial in 2016, we don't just marvel at the last 100 years—we aim to create the next 100. IQ




**WHERE ARE WE HEADED?**
Automous vehicles will play a vital role in tomorrow's transportation systems.

Illustration by Daniel Newman, Senior Techncial Fellow.

# Jill Seebergh
## talks innovation for the health of people and the planet

**When it comes to the future of the planet, environment technologies are one of Boeing's strategic domains.**

BY WILL WILSON | PHOTOGRAPHY BY GAIL HANUSA

**Q&A** with Boeing's first Senior Technical Fellow for Environment and Safety

**Q Why are environment and safety technologies important to Boeing?**

**A** In the simplest terms, maintaining the health of our planet and of our teammates and the people who use our products is critical to maintaining the health of Boeing as a profitable corporation in our second century. Boeing has defined strategies that drive the mission and investment in environment and safety technologies.

**Q What is the Environment and Safety technology domain?**

**A** Boeing's Enterprise Technology Strategy comprises eight technology domains. The Environment and Safety domain covers technologies related to workplace safety, chemical materials and processes, cabin and crew environment, and emissions and environmental footprint reduction. We work with programs and functions across Boeing's different businesses to develop and align strategies and maximize the value of the company's R&D investment in these areas.

**Q How have innovation and new technology been the drivers in Boeing's strategy to advance the environmental and safety performance of its products and operations?**

**A** The advances in the field of materials science over Boeing's last century have provided engineers with an amazing suite of environmentally progressive technologies that we now use to design, build and operate our products. Strong, lightweight metal alloys and composite materials for fuel-efficient structures; sustainable aviation fuels, solar cells and batteries to power vehicles; and coatings, sealants and adhesives that are free of heavy metals and volatile organic compounds are just some examples from a long list.

Many of these technologies also bring safety benefits. For example, sol-gel surface treatments, which were invented by Boeing engineers, reduce worker exposure to toxic chemicals while also creating strong, durable bonds; and paint reactivation coatings (also invented by Boeing engineers) benefit worker ergonomics while improving interlayer adhesion of coating systems.

Boeing's innovation has led the industry in these and other technology areas, and we don't have to look any further than the 787 to see how we've integrated state-of-the art materials into a product that reduces the environmental footprint and pleases our customers.

**Q What do you think will be the most important areas of innovation in Environment and Safety in the next 25 years? What will be the biggest challenges?**

**A** From a safety perspective, it is critical that we innovate around designing products that can be built efficiently without risk of injury to our teammates. Everything will need to be on the table—materials, assembly processes, production systems, laboratory, office and factory architecture. Automation will play an increasingly larger role in manufacturing processes, and that will lead to one of the biggest safety challenges, which is to manage the integration of humans and automation systems in shared spaces, especially in older factories that were not designed with automation in mind.

Another critical area for innovation is environmentally responsible replacements for chemicals subject to restrictions or bans around the world. We are working to develop and implement replacements while collaborating with suppliers, customers, industry associations and regulatory agencies to ensure that safety is not compromised and we retain access to chemicals necessary in production, maintenance and throughout the life cycle of Boeing products.

**Q What would you consider success in your new role as Environment and Safety Senior Technical Fellow?**

**A** The entire Boeing technical community embraces environment and safety as key drivers for *all* of the work we do. IQ

> "Boeing's innovation has led the industry in these and other technology areas."
>
> **JILL SEEBERGH**



TECHNICAL FELLOWSHIP

# Meet the experts

## Boeing names 12 new Senior Technical Fellows

**BY WILL WILSON**

Among the more than 60,000 engineers, scientists, and technical professionals working for Boeing worldwide, the Technical Fellowship represents the best of an already formidable technical team.

This year, Boeing advanced 12 of the company's top technical leaders to Senior Technical Fellow for their commitment to personal and professional excellence. These men and women are major contributors at an industry level and are recognized as authorities on the national and international stage.

Their ability to overcome technical barriers is proven through their work and sphere of influence. And their continuing dedication to innovate drives Boeing's leadership in aerospace. »

# Rich Aston

Structures and Satellites

—

## Engineered from birth

Growing up in Detroit, the son of an engineer, Richard Aston could see his life laid out ahead of him. After he graduated from the University of Michigan, he had myriad interviews with car makers and one interview with Douglas Aircraft.

“Being a Detroiter, our lives revolved around the automotive industry,” he said “They were very compartmentalized. I was going to work on a windshield wiper or something.”

As someone who tries to find unique solutions to problems, that pre-fab future wasn't inspiring.

Thanks to his decision to become an aerospace engineer at Boeing, Aston is instead working on 3D printing, satellites and missile airfoils. And that's just a typical week out of his life as a Senior Technical Fellow.

Aston became an STF by following the same passion for innovation that led him away from cars and into aerospace in the first place.

“I never thought or worried about advancement,” he said. “I've varied my position within mechanical engineering, moving from designer to stress analysis, even production engineering. I built up my knowledge base by following my interests. For a person who never worried about advancement, I somehow magically advanced.”

SALLY ARISTEI PHOTO


BOB FERGUSON PHOTO

# Kay Blohowiak

Chemical Engineering

## Pursuing a legacy

Kay Blohowiak doesn't necessarily think that it's what you do for a living that really matters. “What matters is what you do on a day-to-day basis to make the world a better place. Growing those things creates your legacy,” she explained.

Blohowiak's legacy includes developing alternative airplane coatings that have reduced paint hangar hazardous waste by more than 400,000 gallons annually. That's just some of her innovations that have improved safety and environmental performance, a small part of the reason she is a Senior Technical Fellow today.

When Blohowiak started at Boeing, there were few chemists in the company. “As a chemist, I come to the table at an aerospace company thinking about things in a different way.”

Early on, that different way of thinking helped change the culture of materials engineering to look beyond traditional technology boundaries for integrated solutions. This initiative has changed how the company solves adhesion, chemical processing, composite manufacturing and other issues, with industry-wide benefits across a product's lifetime, from ergonomics in manufacturing to durability in service repairs.

As Blohowiak sees it, engineering doesn't have to look the same to everyone. Her advice to teams is to understand the total system well enough to always think of how things can be improved: “Consider engineering as an adventurous journey that can always benefit from innovation.”

# Gregg Bogucki

Composites

—

## Learning by doing

Gregg Bogucki wanted to be an architect. So much so, that in high school he redesigned his high school's parking lot.

So how did he become a Senior Technical Fellow in the area of composites? It helps to cut your teeth by working on historically seminal airplane composite projects.

Right out of college, he started working at Cessna. As Bogucki tells it, a “let-the-new-kid-handle-it” opportunity in the budding field of composites led to his career. That was in the late 1970s, just as composites were becoming the next big thing in airplane production.

A few years later, he met and researched with some of the founding fathers of composite laminated theory at NASA Langley Research Center in Hampton, Virginia, and his expertise in the subject really took off.

By the early 1980s, he was at McDonnell Douglas, where there were three airplanes in production with major composite components. “When you are faced with making deliveries, you get good at it—you have to or you aren't going to be delivering them for very long,” Bogucki said.

Now, as a Boeing Senior Technical Fellow of composites, he's relishing the chance to teach and inspire young engineers—to give them the same good fortune he had. “I want to give all the engineers an opportunity to increase their knowledge, to go beyond what is out there now.”

STEWART GOLDSTEIN PHOTO

# Paul Dodd

Cybersecurity

—

## Protecting what matters

Boeing is one of the leading creators of intellectual property and a major defense contractor for several governments. “That makes it a target of people who want to steal our information,” said Paul Dodd.

As Boeing’s first Senior Technical Fellow in information security, Dodd is the person whose job it is to protect all that information. He has been a leader in keeping Boeing at the forefront of information security for the company and in its partnerships with customers and suppliers.

Dodd realized in college that he loved working at the unknown intersection of well-known fields. In those days, it was the intersection of network communications and computers. That led to his interest and work in network security, and eventually to the information security architecture and logical modeling he does today.

He has followed these threads to Boeing, in part, because Boeing offered the opportunity for advancement on a technical path, as opposed to climbing the management ladder.

“I was a manager once, then I healed and got better,” Dodd joked. “Being a manager just wasn’t for me.”

So, from the day he started with Boeing in 2001, he set a goal to become a Senior Technical Fellow. He relished the challenge of prioritizing and balancing information security and usability throughout Boeing’s many businesses.

“The road to STF is much more than technical achievements,” he said. “It’s not just that I know technology. I know technology that matters to Boeing and the business.”

BOB FERGUSON PHOTO


# Philip Freeman

Robotics and Automation

—

## Teaming for solutions

The way Philip Freeman puts it, learning how to *not* solve problems has led to his greatest career growth.

“So many things have happened in my career because something looked like an interesting challenge that I thought I could solve,” he said.

But early in his career at Boeing, one of Freeman’s mentors asked him, “Do you want to solve this problem yourself? Or become the person who can help lots of other people solve this problem?”

That conversation helped Freeman become a more strategic problem-solving engineer and a mentor to others.

“You can’t solve every problem yourself,” he explained. “You have to look after the skills of the team you work with.”

Freeman still solves challenging technical problems, but now his work focuses on developing the team he leads at the Boeing Research & Technology Center in South Carolina, and getting everyone focused on important problems where Boeing can make a difference.

He sees now how Boeing can capitalize on its advantages by learning from the rest of the research world. “What are problems that other people are solving and how are they solving them?”

ALAN MARTS PHOTO

# Gary Georgeson

Non-Destructive Evaluation

—

## Inspired to invent

Around Boeing, Gary Georgeson is considered "The Inventor."

As of this publication, he has more than 140 U.S. patents to his name, the most of any Boeing employee. He also has nearly 100 foreign patents. Neither are easy to do at a company that holds most of its intellectual property in trade secrets.

Georgeson is a proselytizer for innovation and technology, and has helped many other engineers achieve success on the path to invention. But what not many of his teammates know is that he also holds a master's degree in theology and has been a pastor for the last 25 years.

That doesn't mean he leads separate lives. "My life at Boeing has made me a better pastor," he explained. "And my caring for people as a pastor has helped me become a better co-worker, team lead and Senior Technical Fellow."

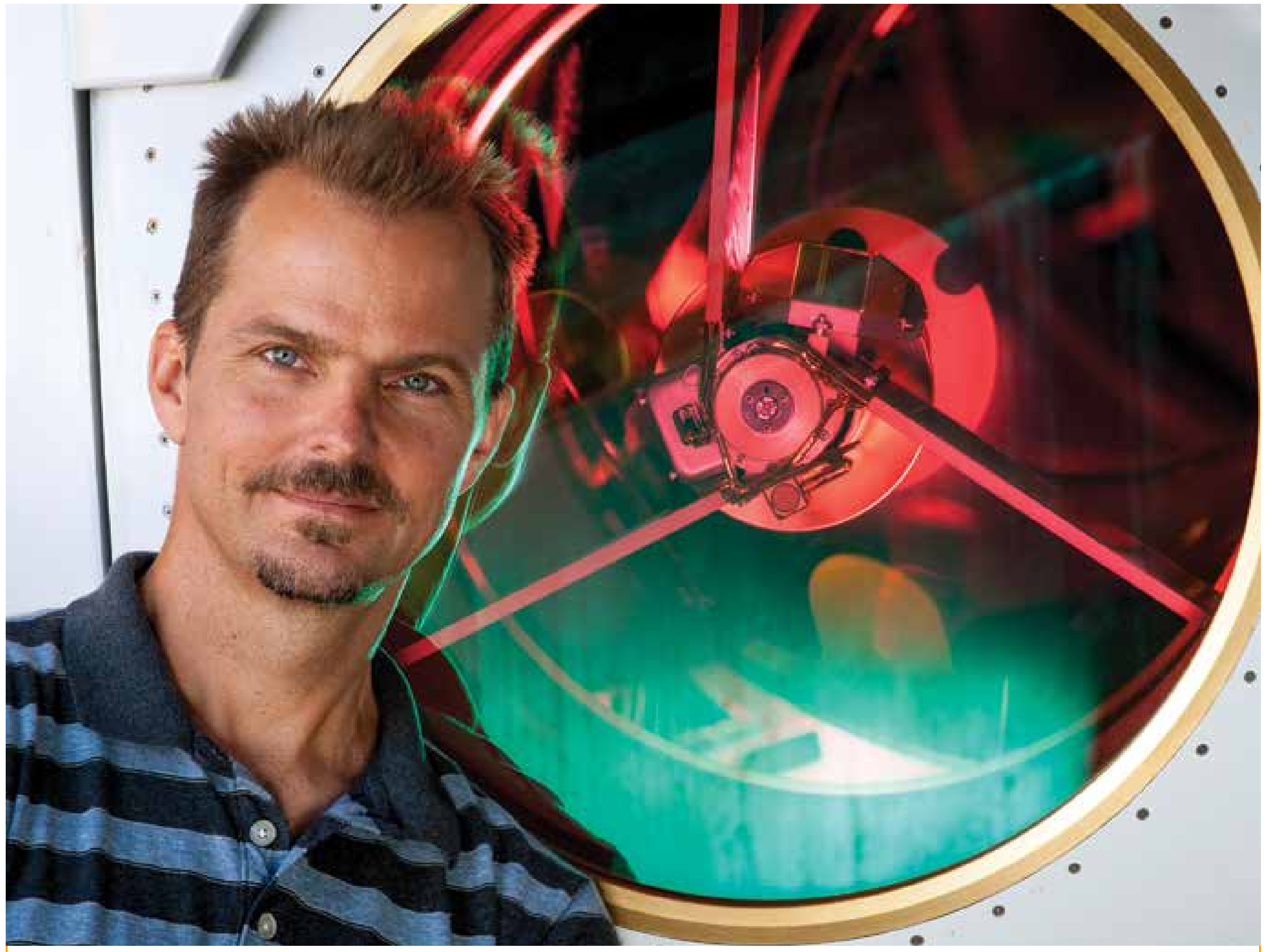
Georgeson's inventive creativity started early.

"My dad was an industrial arts teacher," he said. "When I was a child, he brought an amphibious duck home, and we built it into a camper. We would sit in the dark and we would collaborate on ideas. 'Where should we put the windows? How should we put down floorboards?'"

That experience helped make Georgeson a collaborative innovator.

"I really enjoy getting people into a room together and asking, 'How are we going to address this problem?' You get so many more perspectives. It magnifies the creativity," he said. "I have been the beneficiary of working with so many thoughtful people."

BOB FERGUSON PHOTO



BOB FERGUSON PHOTO

# Steve Griffin

Structural Dynamics and Vibration

—

## Science and sensibility

Steven Griffin took a different path to engineering.

"I'm not one of those people who was hooked on science in high school," Griffin said.

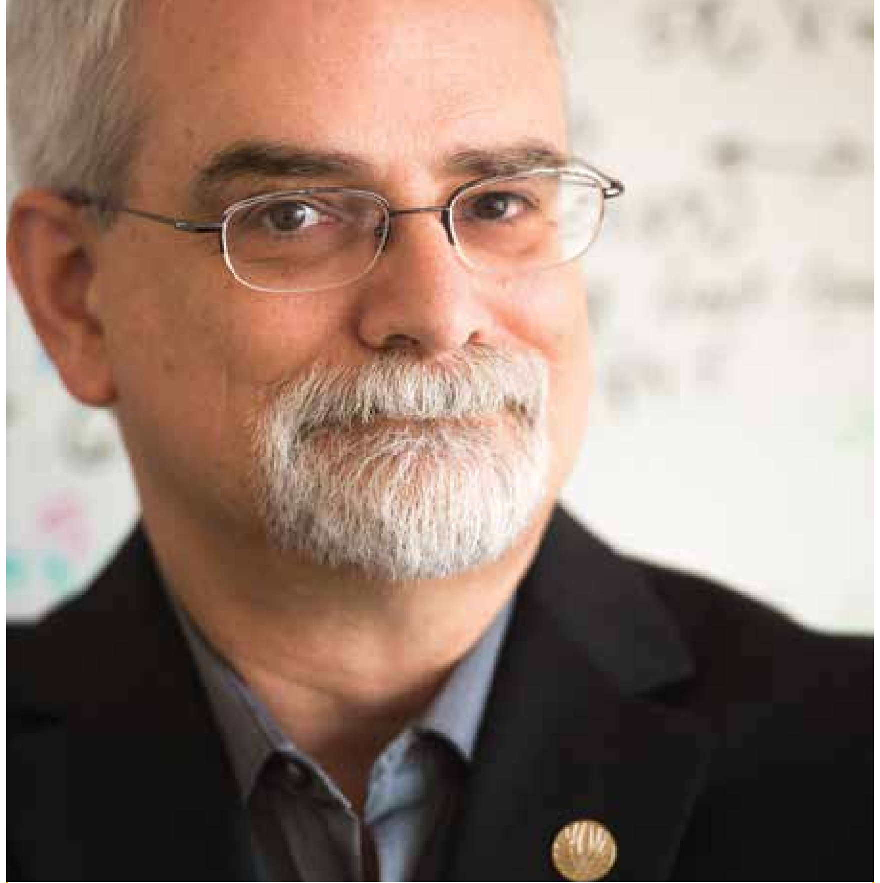
Like anyone who would someday become a Boeing Senior Technical Fellow, he liked to create gadgets, but mostly out of curiosity. "It wasn't a career direction thing," he said.

In fact, Griffin's first passion was books. Among his favorites are Charles Dickens, P.G. Wodehouse and Jane Austen. "I like complexity in language. The way authors like Austen fold subtexts into what they are saying."

But as he started college, it became clear that science and technology came easier to Griffin than a career in literature. An Air Force ROTC scholarship gave an extra push in the technical direction, as well.

His love of science and research grew from there. "The implementation is what I like best," he explained. "Seeing hardware work, testing it, and seeing that it did what it was supposed to do. Or figuring out what assumptions are not quite right."

He still loves words. To this day, he reads or listens to two or three books per week—and serves as a journal editor. He likes putting on conferences and enjoys the challenge of teaching in a way that is meaningful.



BOB FERGUSON PHOTO

# Jack Hagelin

Loads and Dynamics

—

## Art of probabilities

Jack Hagelin loves thinking through specific uncertainty risks in a systematic and probabilistic way. That's part of the reason he prefers backgammon to chess.

"There is an element out of your control," he says of backgammon, which involves a roll of the dice. "You have to play in a way that accounts as best you can for all the possibilities out there. Chess is not as realistic; there is no element of chance."

As Senior Technical Fellow, Hagelin applies that passion for probabilities to understanding structural impacts to an airplane of everything that nature and physics will throw at it.

Consider landing: landing gear are understandably designed to tolerate touchdown forces. "But landing also sends a ripple of forces up through the airframe, affecting the airplane design from nose to tail," Hagelin said.

"Modeling the whole airplane for each of the forces that will act on it becomes a very complicated process," he said. "It is a holistic view of the airplane, combining the aspects of structural dynamics, aerodynamic forces, flight control systems, weight and balance limitations, flight envelope, propulsion systems, and regulatory requirements."

But Hagelin relishes that challenge and the benefits it provides. "My job is directly responsible for the safety of the flying public as well as affecting Boeing's profitability. If that doesn't get you motivated, I don't know what would."

# Leonard Hebert

Propulsion Aerodynamics

## Minding the competition

Leonard Hebert appreciates every facet of his job.

He loves the discovery. "Mother Nature hangs on to her secrets very tightly. She's not just going to show you," he explained regarding his work as Senior Technical Fellow for aerodynamic propulsion performance and technology. "I'm the first describer of some of these physics. That is energizing."

He also loves the competitive aspect. He's a self-described pit bull with a passion for hard fights—and winning them.

"I don't want us to share the market, I want us to dominate the market," he said, adding that his shorthand job responsibility is "making Boeing's aircraft better than the competition."

But more than anything, Hebert said he loves the feeling of shaping the future.

Since his first job with the company, researching propfan propulsion in response to high oil prices, he's enjoyed seeing the direction engine technology has been going and making best use of it for Boeing aircraft.

He's always been a bit ahead in the flight game. When Hebert was 16, he and some friends built a working airplane from scratch, with the help of a mentor who worked for the FAA. "I learned a ton from him, and about a lot more than just aviation."

BOB FERGUSON PHOTO

BOB FERGUSON PHOTO

# Jim Kinder

Fuels

—

## Fuel for innovation

When Jim Kinder was in high school, a friend with a pilot's license took him up in a private airplane. Since that day, Kinder has been hooked on flying.

Nowadays, it's not an exaggeration to say that Kinder can make jet fuel out of things found in your kitchen or garden. As the technical lead of Boeing's efforts to develop renewable biofuels, Kinder and his team have developed biofuels that perform as well as or better than existing petroleum-based fuels.

"The key is to do it right," he said. "The right fuel must not compete with food sources, must be able to replace current jet fuel without changing plane engines or distribution systems, and it has to be economical."

Kinder said he relishes his work at Boeing, in large part because the company sees challenges in the future and is doing something about it now. To that end, Kinder also plays a significant role as a member of aviation fuel specifications committees in the United States and internationally, working to ensure that future flights can be powered by numerous sustainable fuel alternatives.

"We need an economically efficient option for fuel, and we need to reduce our environmental impact," he said. "We have to start this now, before we run out of petroleum."

## Jeff Miller

Production Systems

—

### Producing a passion

For someone fascinated with space exploration since childhood, it was the opportunity of a lifetime when Jeff Miller got a tour of McDonnell Douglas' Huntington Beach production facility years ago.

"I had the most fantastic interview," Miller said of the visit. "This was where SkyLab was actually built!"

Miller grew up next to Bell Labs in Murray Hill, New Jersey, where his father worked as a chemist. Sometimes he'd join his father for lunch. From a young age, Miller saw the operating cadences and work flows at one of the world's major research centers.

Little surprise that Miller's passion—and his expertise as a Senior Technical Fellow—is production engineering. In fact, the job offer he received from McDonnell Douglas was to become the first employee in a new production engineer job classification.

"Productivity motivates me," he said, regarding his work on large, complex projects that integrate structures, processes, equipment and facilities. "How do we provide the most value for our customers so that we can globally compete and grow?"

Having grown up in a technical setting, Miller now enjoys taking his two sons on factory tours and to Boeing Family Day events to provide them with an appreciation of science and engineering. "They are both technically inclined, and they get a big kick out of it," he added.

BOB FERGUSON PHOTO

BOB FERGUSON PHOTO

## Jill Seebergh

Coatings and Chemical Technology

—

### Expertise that sticks

Jill Seebergh had been working as a chemical engineer for 3M when she toured Renton's 737 assembly line. "It's hard not to be impressed by the difference in scale between Post-It Notes and airplanes," she said.

It wasn't just the size of the airplanes that drew her to Boeing. "Boeing identified a need for people with my expertise (coatings, adhesion, and colloid science) and gave us the freedom to apply it to solve problems in an independent way," she explained.

That freedom has allowed Seebergh to advance aerospace coating technology, developing and implementing new materials and processes that improve safety, reduce manufacturing flow time, improve performance, and reduce environmental impact.

As a Senior Technical Fellow, she looks forward to new challenges and to mentoring up-and-coming engineers, the same way she was mentored in her own career, and even as a young student. After all, much of her own success is owed to a high school teacher who convinced her to join the chemistry team.

"I had a teacher who persuaded me to be on the least popular team in the entire high school," she joked. "But I loved the challenge of learning science and testing my knowledge. That's how I convinced myself that I had the talent to pursue what has become my career." IQ





# Selections from the Boeing Technical Journal

**The Boeing Technical Journal (BTJ) is a peer-reviewed periodical for Boeing subject-matter-experts to capture and leverage knowledge.**

Patterned after similar external society publications, each BTJ paper is deep in innovative work, tackling challenges and publishing results in a competitively safe, proprietary environment. Research coverage includes all manner of commercial and defense product development, as well as products and services spanning land and sea, to air and space, and through cyberspace.

As a confirmation of Boeing's open culture, the BTJ is operated by Boeing technical experts. Often, an experienced mentor will team with newer recruits or a protégé to produce co-authored papers, which are then critically peer-reviewed by other company experts. This process spreads knowledge vertically and horizontally throughout our businesses. Papers are distributed in the Boeing library, and collaboration websites are established for ongoing discussion.

While the expansive BTJ archive remains exclusive to Boeing employees, we look forward to sharing a selection through this publication. Papers offered in Innovation Quarterly have been edited to remove truly competition-sensitive material, but remain valuable for technical discussion.

As the BTJ Chairman, I extend my personal welcome to you, and hope that you will sense the passion by which Boeing manages knowledge, and the fervor in which employees move that knowledge forward. IQ

**KENNETH R. HARDMAN**
Associate Technical Fellow
Boeing Technical Journal Chairman

## Contributing Authors

**JOINT SUPPLY COST MODELING**
Andrew Parker is in the Boeing Commercial Aviation Services division as a data scientist performing analytical work on spares inventory optimization.

Steve Stranghoener is the Boeing-wide Partnering for Success Team lead for procurement financial analysis.

Jesse Womack works in the area of core estimating within Boeing Commercial Airplanes, collecting and archiving cost and non-cost data for major development programs

**VISUALIZING PRODUCTION STATUS IN TIME**
Michael Callaghan, a manufacturing operations analyst, consults the 777X production system integration team responsible for establishing the support cell infrastructure, compliance and daily management system for the program.

**POLYMERIC ADDITIVE MANUFACTURING**
Antonio Paesano is a manufacturing engineer, supporting research and development on V-22, H-47, 787, 737, EMARSS, ecoDemonstrator, and LIFT! programs, as well as Boeing Research & Technology Europe.

# Joint Supply Cost Modeling

## Summary

BY ANDREW PARKER | STEVE STRANGHOENER, JR. | JESSE WOMACK

In today's competitive airplane market, Boeing is motivated to reduce costs to become increasingly more competitive. A majority of the cost of building a Boeing airplane is sourced from external suppliers. Consequently, true cost savings can't come solely from reducing Boeing internal costs; opportunities must be sought in the supply chain, as well.

The Boeing Supplier Management initiative known as "Partnering for Success" aims to do exactly that: implement improvements in the supply chain so that suppliers can reduce their costs allowing both Boeing and the supplier to benefit. Under the umbrella of Partnering for Success, a team was created to understand Boeing's current supplier market and develop mathematical cost models required to identify cost drivers to analyze these supplier costs. The initiative is called Joint Supply Cost Models. Cost modeling is a standard practice in many Boeing finance groups, a direct result of the desire to achieve data-driven, comprehensive estimating methods.

In a broad sense, the goal of the JSCM team is to identify where Boeing could potentially be paying too much for a purchased part in comparison to a "market" average. The analysis spans categories of parts across numerous ATA chapters, from large major structures and systems down to small sheet metal parts. This method involves creating data-driven, statistically-based cost models for various categories of parts mentioned above. For example, Boeing buys landing gear for many commercial and defense airplanes. Is there a way to predict the cost of landing gear based on the technical complexity of the assembly and other contractual requirements?

The JSCM team has assembled a diverse set of analysts comprising members of multiple Boeing business units including Boeing Commercial Airplanes, Boeing Defense, Space & Security, and Shared Services Group. The team also leverages Boeing's vast technical, engineering and manufacturing skill base, procurement expertise and finance.

In a nutshell, the product of the JSCM team is envisioned to be a linear or multiple linear regression using ordinary least-squares (OLS) regression utilizing cost data as the dependent variable and various technical and contractual parameters as the independent variables. Examples of parameters used to explain cost could be "length of the part" or "quantity purchased per year." A best-fit line is fit to the observed data with the goal being to explain as much variation in cost as possible. See notional visual representation above in Figure 1.

To derive the above result, a lean process is employed to ensure data is collected in a standardized manner, and this data is analyzed using robust statistical methods. The process is started by gathering technical experts and communicating the end-goal. With everyone up-to-speed on the benefits of the tools, individuals are motivated to offer valuable time and resources to the project to provide expertise and collect data. Data is collected from a wide variety of Boeing databases ranging from pricing systems to engineering drawing release systems.

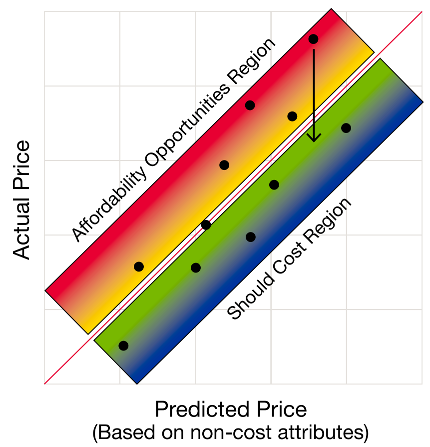



**FIGURE 1.**
JSCM product: actual vs. predicted graph.

Following data collection and verification of data integrity, the process of looking for trends with statistical analysis can begin. Analysis includes, but is not limited to, univariate analysis, clustering techniques and OLS regression. Modern computing power allows the team to use stepwise analysis, an extension of OLS regression, to allow dynamic consideration of the impact of adding any variable to the model given any other number of variables currently included in the model. An ideal model should meet many statistical criteria in order to be considered robust and viable to use in analysis of supplier proposals. Some criteria to judge the model are r-squared of the model, significant estimated parameters with p-values $< 0.05$, sufficient number of observations, number of explanatory variables, Cook's distance and multi-collinearity.

When the analyst deems that an appropriate cost model has been developed, the product undergoes a peer-review process and brings forth strengths and weaknesses of the model. Not every model is perfect. Open and honest communication allows the process to flow smoothly and provide the best possible model to be achieved with available data.

After model approval and release, there are several uses the models have in analysis (when analysis is not subject to the U.S. Truth in Negotiations Act or TINA). The tools can be used for estimation and risk analysis of newly developed parts, not yet in production. The prediction equation outputs a Boeing market-average price and forecasted error around this estimate to provide a range of possible outcomes of supplier cost for the part under observation.

Another use case is plotting a supplier's opening position price overlaid on the existing best fit line. At a high level, this allows the analyst to visualize if the proposed pricing is above or below market average and can potentially aid in negotiation. Additionally, after a model is complete, the results can be used to find a "best-in-class" supplier for a category of parts. This works best with large datasets that include several suppliers. Boeing's supplier rating (quality and performance) data can also be integrated to add more dimensions to help visualize the value of a supplier relative to other suppliers providing similar parts.

Not every model is perfect. Open and honest communication allows the process to flow smoothly and provide the best possible model to be achieved with available data.

These data-driven models have the potential to fundamentally change the way Boeing conducts business with its sub-tier supply base by identifying where Boeing is potentially paying too much, supporting supplier negotiations by comparing a supplier to the market average, and provides insight for Boeing engineers into technical cost drivers.

The JSCM process bridges the communication gaps between disciplines internally by producing validated, defensible, data-driven cost models integrating technical and financial information.

Since its inception, the JSCM team has set in motion the procedures to reshape the marketplace by giving tangibility to the idea of what a commodity should cost, or an objective view of the market. In doing so, the team's intent is to give credence to the idea that there is a better way of doing business.

Ultimately, with successful cost-reduction efforts, the value stream from production to Boeing's customer airlines will benefit as they struggle in a razor-thin margin operating environment, ensuring competitively priced Boeing products produces a more stable business model for the future. IQ

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

"Joint Supply Cost Models"

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

# Visualizing Production Status in Time

## Summary

BY MICHAEL L. CALLAGHAN

**Takt Time = Available Time / Daily Demand (units)**

Typical manufacturing companies benchmark their Lean production systems against car manufacturers or other production systems that have made the transition to Lean production. The question is, can you measure airplane production the same way you would measure automotive production?

We might consider doing so, but unfortunately we cannot tell whether our production system is balanced without some sort of visual control. If we were to measure airplane production like cars, we would not be able to visualize how our production system is performing.

It is imperative that we not only understand whether our production system is balanced, but also how to respond and keep balance throughout the day. An example of balance would be the charbroiler at a quick service restaurant where the top of the unit is producing burgers, and the bottom is toasting buns. If too many are loaded over the other, there is imbalance, thus causing the potential for waste.

Providing critical real-time production status in a graphic format enables manufacturing personnel to make timely decisions that can increase production rates and reduce errors.

The Pulse suite of tools provides schedule, production rates and forecasts, in-process inspection rates, and Takt Time that can be quickly assimilated to produce a uniquely powerful view into the state of the production environment.

Manufacturing personnel have always had access to some form of production data. However, it is not typically available or seen on the same day it is generated.

Consequently, late or hard-to-assimilate data inhibits management from understanding key production factors that can be altered to improve production. Additionally, lack of access to much-needed data leads to creating a workforce that requires years of airplane production experience in order to develop the depth of knowledge necessary to effectively manage production.

Visualizing real-time airplane production status is critical for making manufacturing decisions rapidly. This system provides this data in a format that can be quickly assimilated to produce a powerful view into the state-of-the-production environment. It also provides users with particular insight into which changes will improve manufacturing and quality inspection processes, and could help change approaches to production system balance.

Founded on the five "S" Lean Methodologies, this Lean-based implementation system focuses on the relationship of real-time data. It uses the following Lean tactics:

- **Balance the Line**
  Balance the entire production system by doing more than aligning work packages with equal numbers of employees on shifts. For a balanced solution, scope must include: work schedule, assembler and support. In a perfect environment, an equal amount of work should be completed hour-by-hour across balanced shifts. To model and achieve balance requires detailed production knowledge.
- **Visuals in Place**
  Provides information at-a-glance in the form of simple numbers or complex interactive real-time graphics to present the audience with a clear understanding of data relationships as they relate to production environment. An effective visual easily and clearly conveys the health of any segment of the production environment.
- **Point of Use**
  Information on demand at the time, place and in the format where it is to be used. For example, a text-only, non-conformance alert may be sent to a shop leader's smart phone, or that same information can also be available on an internal webpage as a graphic display.
- **Pulse Line**
  This is the Takt Time model. Takt Time is a Lean manufacturing term that defines the desired production rate based on the available time per day, divided by the required number of units to produce per day. This is referred to as daily demand. We view Pulse Line in the context of a moving production line, and use it to measure production efficiency.

Airplane production relies on key elements to insure the continuous balance of production. The Pulse project resolves these situations. We can identify bottlenecks in our production system and address them to continually improve our performance.

Boeing developed a suite of web-based visualization tools that display all levels of production data (an example shown in Figure 1). These displays consist of several specific views:

- Pulse view provides schedule, production rates and forecasts. It allows for discrete time analysis and a concise summary view of the production system relative to balance. Comparisons between production and load balance Takt Time are included.
- Quality view displays process inspection rates.
- Manufacturing Rollup view aggregates production rates and allows drill-down to lower levels.
- Shop Detail view provides an example of a graphic format, real time production status, which in turn provides specific features that support the production decision management process.
- Takt Time view displays the current Takt Time. This dashboard displays a comparison between production and Takt Time balance views.
- The Production (i.e. Pulse) view contains production schedules and rates, inspection (in-process and completion) rates and the Takt Time view. Here, it displays jobs per hour and contrasts this data against a theoretical model for a balanced line.

This methodology uses the production and Takt Time views to provide a better diagnosis of production problems. It provides "at-a-glance" health metric views in critical production areas to facilitate rapid decisions for production and inspection. Ultimately, this results in increasing production rates and reducing errors.

The benefit of this approach is that management gains immediate visibility as to where the actual production levels should be. In turn, this enables the quick identification and adjustment of resourcing and technical support to balance the production system. IQ

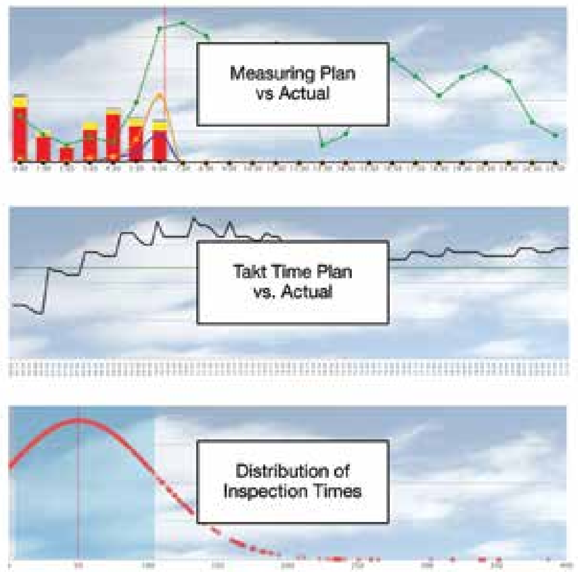



**FIGURE 1.**
An example of real-time visualization.

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

"Visualizing Production Status in Time"

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

# Polymeric Additive Manufacturing: Present Status and Future Trends of Materials and Processes

## Summary

BY ANTONIO PAESANO

Additive manufacturing technology, also known as 3D printing, has been predicted to bring about a new revolution in industrial manufacturing. Because of this potential, the capacity for innovating and developing materials with better performance and broader range of applications is a growth driver across many industries.

AM uses a wide array of materials including, synthetic polymers, metals (Figure 1), ceramics, concrete, chocolate, and even biomaterials. Each material is designed to meet specific form, fit and functional needs.

Because of the competition- sensitive nature of this new technology, we cannot discuss specifics regarding Boeing's strategy and development in additive manufacturing. This paper, however, will address many of the technical aspects of the materials and process, and general advancements that have been made. This paper also focuses on polymeric AM for engineering applications, particularly on current and future polymers for AM

Plastic printed parts made by Boeing have been in flight operation for many years. Examples of Boeing aircraft featuring parts are F/A-18 Hornet and 787 Dreamliner for the defense and commercial side respectively.

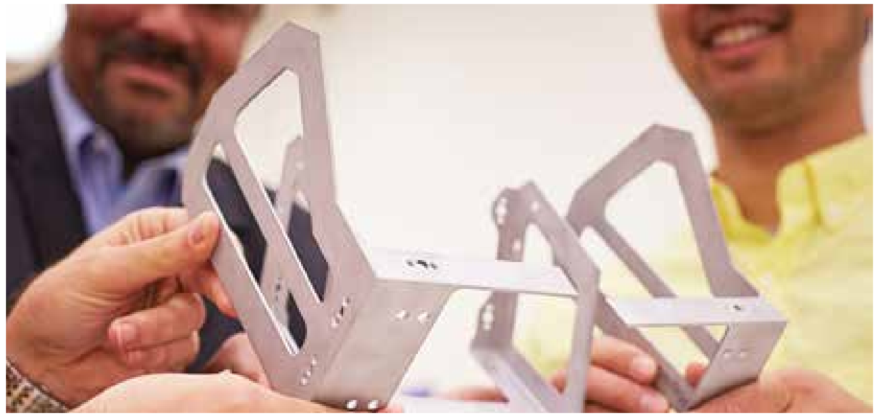


**FIGURE 1.**
Metal part made using an additive manufacturing process.

The AM applications are countless. David Leigh, co-founder of Harvest Technologies (Belton, TX), a leading manufacturer of AM parts, predicts that aerospace, automotive and medical applications will be the most likely future application areas for AM. Further, he says that the most likely future components made of AM polymers will be prosthetics (cranial and maxillofacial), aerospace cabin and cockpit, engineered low-pressure ducting systems for automotive and aerospace, automotive dash and trim (including under hood and headlight/tail light) pieces, testing and production jigs/fixtures.

AM has grown over the last 25 years at a remarkable average rate of about 25 percent per year. In 2020 the AM industry is expected to sell $21.2 billion in products and services, according to Tim Caffrey, in the 2015 Wohlers Associates report. But knowledge about AM has long left the specialized circles and is now discussed widely in the mainstream media.

ASTM International defines additive manufacturing as "a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies." Other common terms for this process include additive fabrication, additive layer manufacturing and 3D printing.

| AM PROCESS | MATERIALS | EXAMPLE COMPANIES |
|---|---|---|
| Binder jetting | Polymers, metals, foundry sand | 3D Systems, ExOne, Voxelijet |
| Directed energy deposition | Metals | PM, Optomec |
| Material extrusion | Polymers | Stratasys, Maker Gear |
| Material jetting | Polymers, waxes | 3D Systems, Solidscape, Objet, Arburg |
| Powder bed fusion | Polymers, metals | EOS, 3D Systems, Arcam |
| Sheet lamination | Paper, metals | Fabrisonic, Mcor, Solidica |
| Vat photo-polymerization | Photopolymers | 3D Systems, Envisiontec |

**TABLE 1.**
Materials and examples of companies involved in additive manufacturing processes.

**ASTM International has also categorized the AM processes into the following seven areas:**

- Binder jetting: a liquid bonding agent is selectively deposited to join powder materials.
- Directed energy deposition: focused thermal energy provided by sources like laser, electron beam, or plasma arc, is used to melt the feedstock within a small area. This process is currently used for metal parts exclusively.
- Material extrusion (commonly known as fused deposition modeling): process in which material is selectively dispensed through a nozzle or orifice.
- Material jetting: droplets of build material are selectively deposited. Example materials include photopolymer and wax.
- Powder bed fusion: thermal energy selectively fuses regions of a powder bed.
- Sheet lamination: process in which sheets of material are bonded to form an object.
- Vat photopolymerization (commonly known as stereo-lithography): a liquid photopolymer in a vat is selectively cured by light-activated polymerization.

Additive manufacturing was officially born in the United States in 1986, when Charles Hull received a patent for an "apparatus for production of three-dimensional objects by stereolithography" (U.S. patent 4,575,330). In 1986, Hull founded the first company to generalize and commercialize this procedure, 3D Systems Inc., making models that, while highly complex, were mostly limited to prototype parts because of the durability of the resins at that time. But because specialized tool path programming was not required, parts could be made much faster. This is how the term "rapid prototype" became the primary name used to describe all types of 3D printing in those early years. It was only after the printed parts became on a par with injection-molding for quality and cost (at least for small batches) that the term "additive manufacturing" came into existence.

Boeing has been using AM since the 1990s, when Douglas Aircraft operated an SLA machine from 3D Systems. Along with other large aerospace companies, AM process has been adopted on a large number of military, and commercial aircrafts, as well as many unmanned aerial vehicles.

There are two distinct markets for printed parts: a) the industrial/production market, which includes medical, dental, aerospace, automotive and power generation; and b) the consumer market, comprising home accessories, fashion and entertainment.

The process is currently used for: prototypes; models for form, fit and function; presentation models; non-load bearing products; and increasingly for the fabrication of end-use products. The share of money spent on printing final products instead of prototypes was 28 percent in 2012. As long as the AM technology maintains its pace in increasing the maximum volume of printable parts and the printable rate of single parts, final parts printing could grow to more than 80 percent by 2020, exceeding $21 billion in sales of products and services by 2020, according to industry experts.

**The benefits associated with AM are the following**:

- Virtually unlimited design freedom at no additional cost, being a method that is not constrained by design complexity, and allows for structurally efficient shapes similar to structures found in nature, e.g. bones, and plants.
- Unparalleled degree of design complexity at no added cost and without the need for complex multi-axis machining vs. no complexity
- Minimized or eliminated need for assembly, allowing for more highly integrated designs where part features can be fabricated as one piece rather than as a multi-part assembly
- High speed from a shorter overall process in case of limited quantities and applicable designs (no tooling such as a mold or die); significantly reducing production ramp-up time, cost and lead time; and simplifying the supply chains (lower inventories, etc.)
- Relative affordability through small production batches—even one item—that are feasible and economical
- Convenience—AM can be done in-house, on your schedule. Furthermore, many service agencies are also available to build parts with a much broader selection of processes and materials. In most cases, instantaneous job bidding is available and parts are made in just a day or two.
- Reduced waste because there is no material removal like with machining
- A hedge against obsolescence. In aerospace, it is very expensive to qualify a new product, and often a sole source is available. Many parts are needed infrequently and in relatively small quantities. Therefore, it is challenging to find suppliers that can provide the same parts, affordably over time.

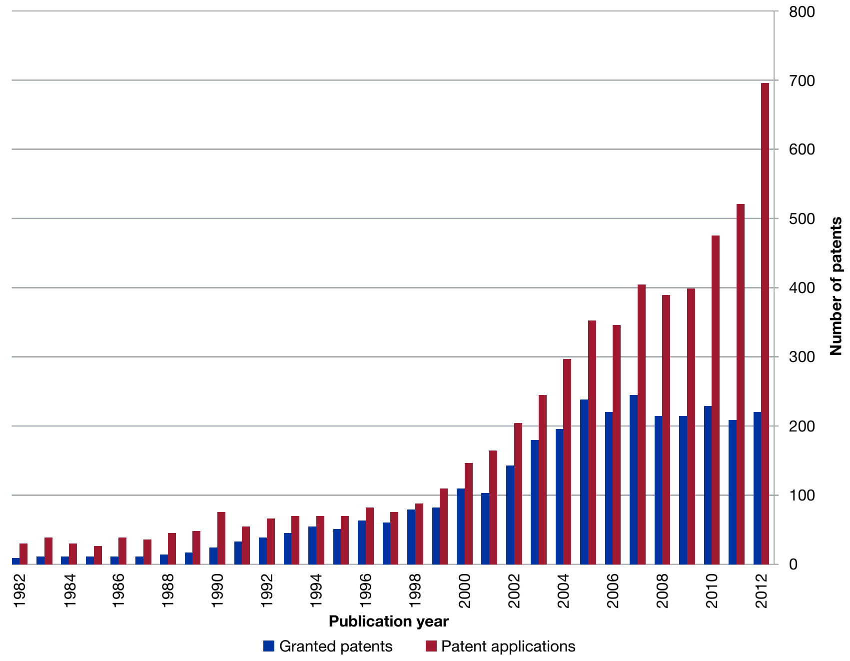



**FIGURE 2.**
AM patent applications (red) and patents granted (blue) from 1982 to 2012.

SOURCE: INTELLECTUAL PROPERTY OFFICE OF THE UNITED KINGDOM.

Different AM processes are commercially available, proving the intense and constant efforts to come up with new patents and, therefore, the growing vitality of this type of technology.

In fact, the graph in Figure 2 displays an example of AM-related patent applications (higher column in each year) and granted patents (lower column in each year) in the period 1982-2012, and illustrates how the number of patent applications linked to AM has jumped in recent years, with patents concentrated particularly for healthcare applications, such as dental implants, medical devices and bone implants. However, the number of granted patents has stabilized in most recent years.

Predicting future polymers for AM is difficult, and can be most successful only in the short term, because new materials appear at extraordinarily fast pace, and companies are understandingly secretive about the materials they have in their pipeline.





Plastic printed parts made by Boeing have been in flight operation for many years. Examples of Boeing aircraft featuring parts are F/A-18 Hornet and 787 Dreamliner for the defense and commercial side respectively.

One limiting feature of the AM processes is that the surface of current polymeric printed parts is less smooth than cut or molded plastic parts, often requiring post-processing operations.

One way this shortcoming is being addressed is to develop techniques to predict the surface roughness of printed parts using different techniques and models.

Understanding the material properties of AM materials after they have been processed to print the part is regarded by some as the most important aspect of any future improvement.

**Future AM processes will have to meet the following technology-specific requirements:**

- Higher build-up rates, higher dimensional accuracy and better surface quality
- Lower maintenance costs
- Lower machine acquisition costs
- Larger build-chamber volumes
- High process stability
- Quality control process after job completion, and even better, on-line quality control processes, that can be crucial for a broad application of AM in the future
- Continuous certification for aircraft, automotive, and electronics manufacturing equipment
- Controlling the composition of the material of the printed part at the nano level. For example, using multi-material AM processes, we can print in the same part hard and soft materials resulting in a component with peculiar new structural behavior.

A current advanced development is complementing AM with subtractive and molding processes.

One accomplishment, that if completed would multiply AM applications, is making databases of the physical-mechanical properties and allowables of the AM materials available to designers and users. Unfortunately, comprehensive versions of such databases are costly and lengthy; therefore collaborations among industry, academia and government will be beneficial in order to reach this goal faster.

Predicting future polymers for AM is difficult, and can be most successful only in the short term, because new materials appear at extraordinarily fast pace, and companies are understandingly secretive about the materials they have in their pipeline. Caffrey, of Wohlers Associates, agrees: "With 3D printing, we don't necessarily know where it's going."

Fortunately, some valuable indications to anticipate future AM materials have come from some reports prepared by AM experts from industry and academia that point out what topics should be addressed by future material research in order to meet additional requirements. IQ

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

"Polymeric Additive Manufacturing: Present Status and Future Trends of Materials and Processes"

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

# India Innovation at Horizon 3

## Advanced materials and manufacturing research in Bangalore

BY OM PRAKASH, BOEING ENGINEERING & TECHNOLOGY CENTER–INDIA

Creative, breakthrough ideas must create value for the organization or society to be considered innovation. In practical terms, integrating invention and business outcomes together enable innovation.

The Boeing research center in Bangalore was established in April 2009, with a handful of employees, a clean slate, and a mandate to build relationships and Horizon 3 research—that is research with the potential for profitable growth in the future. Decisions had to be taken to develop and pursue the right strategies, R&D focus areas, research partners and specific project goals.

Materials and manufacturing research is one of the focus areas for Boeing in India. The example shown below illustrates how we have pursued ideas, discovery, invention and creativity in conjunction with business requirements to create value.

The initial set of projects were all with various partners in academia and government research labs. Educating our partners on concepts relating to technology readiness progression has been useful; it opens their eyes to help drive sharper focus. Inviting them to our facilities inspires them to look beyond academic content in their projects.

One academic project we observed at the research college, the Indian Institute of Technology Kanpur, dealt with using a pointed stylus to produce controlled change in the shape of a metal blank. Looking through the filter of "value creation," it was easy to imagine a scaled-up process with tools on both sides of the blank as a way to produce sheet-metal formed components with aerospace-type features. This approach would allow for making a few parts without a die, and with quick turn-around time.

The project has progressed from developing predictive mechanics model to establish process capabilities, followed by lab-scale experimental demonstration and validation of various requirements relating to part accuracy and quality. Development of algorithms to deal with a wide range of geometrical complexities in an automated manner, so that the process design for a part being considered can be handled by non-experts, was the next step.

Our current effort is focused on retiring the risks associated with scaling up from lab scale to production scale through the development of a machine that can handle large parts, and evaluating the process further. The scaled-up machine was installed at the Indian Institute of Technology Hyderabad a few weeks back, and the initial trials have been successful (picture left).

**SCALING UP**
Doctoral student Rakesh Lingam, working on a Boeing project, displays the first sample part fabricated on die-less forming machine. The machine can handle part geometries 1.2m x 1.2m. The machine was installed in Hyderabad.

BOEING PHOTO

### Where are we today?

To date, the materials and manufacturing research at the Engineering & Technology Center-India has contributed to about 14 inventions, five patents filed, a number of technology transitions and many more in the pipeline.

Current research activity in the areas of electromagnetic effects shielding, nanocomposites, high-temperature polymers, additive manufacturing, material development for electromagnetic shielding, and predictive models and material architecture for lightning-strike protection are all shaping up nicely with exciting innovative solutions on the horizon. IQ

# Global Scale

No matter where they are, Boeing and its partners are at work to accelerate growth, productivity, research and innovation. Here is a snapshot of a few of the technical projects in work with dozens of joint research centers and consortia worldwide.

### Boeing and Embraer partner to develop biofuel solutions

The Boeing and Embraer joint research center for sustainable aviation biofuels in Sao Jose dos Campos in Brazil will have the opportunity to test a new formula soon. The companies are developing research in areas they have collaboratively identified as technology gaps between industry, government and academia, such as feedstock production and biofuel-processing, thus contributing to establish an aviation biofuels industry in Brazil. This year both companies will fly sugarcane-based, Brazilian-produced biofuel on a joint sponsored ecoDemonstrator using an Embraer airplane. Suppliers, airlines, government agencies and other organizations have partnered with Boeing on the ecoDemonstrator program since it began in 2011.

### Making wastewater reusable to conserve the natural resource

Wastewater is a valuable resource, especially in arid regions. Boeing researchers at the King Abdullah University Water Desalination and Reuse Center in Saudi Arabia are developing a membrane to process industrial wastewater and remove contaminants to enable wastewater reuse in agricultural and manufacturing processes.

The research team has ultra-filtered this re-usable "synthetic wastewater" and is now preparing to test it in a trial factory setting.

**wdrc.kaust.edu.sa**

### Assembly Optimization at Factory 2050

You've seen reconfigurable homes. Check out Factory 2050: A glass-walled reconfigurable factory for data-driven manufacturing and assembly technologies at the Advanced Manufacturing Research Centre, at the University of Sheffield, England, one of Boeing's GlobalNet group of industrially focused research centers.

The AMRC Integrated Manufacturing Group has developed intelligent assembly systems that self-optimize, using data analyzed from sensors on each machine. This innovative system integrates advanced technologies, such as robotics and augmented reality, to ensure perfect assembly of complex products.

**amrc.co.uk**

# Patent Spotlight

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

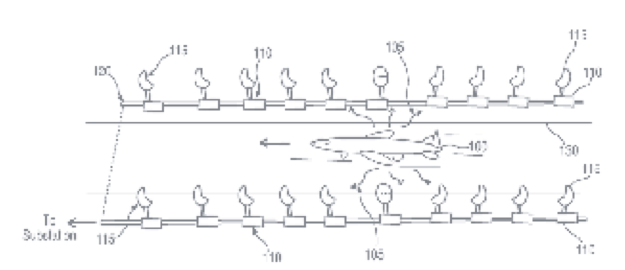


FIG. 1

## Method and system for producing electricity from airport acoustical energy

**U.S. PATENT: 9,359,997**
**INVENTOR: CHIN TOH**

News flash: airports are noisy. But researchers believe that the acoustic energy associated with all that noise could possibly be harvested to generate electricity.

Boeing was recently granted a patent on a system where acoustic wave collectors could be configured along a runway to collect that noise energy.

The system also includes an acoustic converter assembly positioned to receive the acoustic energy from the acoustic wave collectors and convert the received acoustic energy into an output air flow. The output air flow is what would be directed toward a turbine, in turn connected to a generator, which then would generate electricity that is sent to a substation for distribution.

> "As many of you know, one of the biggest advantages that we've got in this global economy is that we innovate, we come up with new services, new goods, new products, new technologies."

**PRESIDENT BARACK OBAMA**
May 11, 2016, upon signing a new law to boost federal trade secret protections

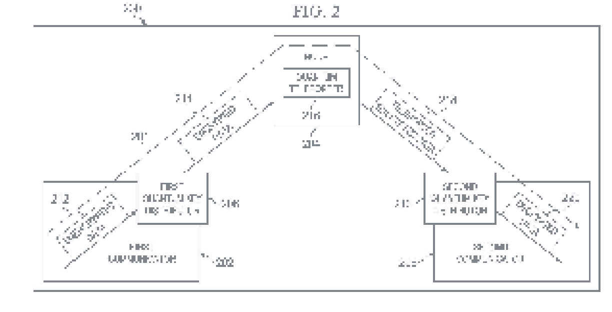


FIG. 2

## Quantum Communication Using Quantum Teleportation

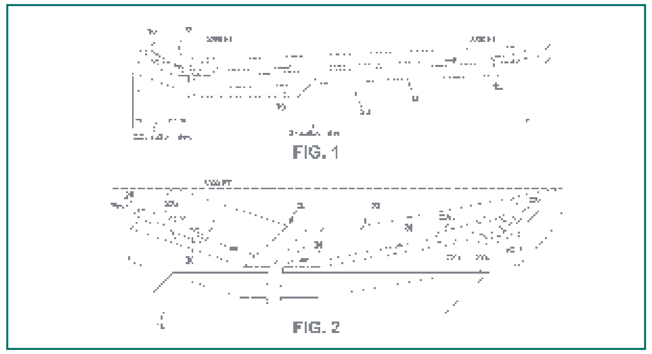
**U.S. PATENT: 9,264,225**
**INVENTORS: JEFFREY HUNT, WAYNE HOWE**

Quantum cryptography is a use of quantum mechanics in cybersecurity, a critical and growing communications discipline. The quantum mechanical property of Entanglement is used to create so-called quantum bits, or qubits. Communications based on qubits (instead of classical bits) can be used to build a new generation of completely secure communication networks that are impossible to hack and include the ability to detect eavesdroppers.

One present technical limitation is that quantum bits cannot be transmitted for long distances, and standard (classical) repeaters would disentangle the quantum bits, thus enabling them to be hacked and preventing the detection of eavesdroppers.

Boeing was recently granted a patent that describes the creation of a quantum teleporter to be used at nodes along a communication system, such as a server, network switch or router. The quantum teleporter simultaneously transfers the exact qubit state of the incoming entangled photons to outgoing entangled photons without the effect of disentangling the photons (thus quantum teleportation).

This invention enables quantum encryption keys and encrypted data to be transmitted for extremely long distances without losing the quantum entanglement effect that prevents decryption and enables the detection of eavesdroppers. In this way, quantum cryptography qubits can be teleported over very long distances with complete end-to-end uncrackable quantum encryption security and detection of eavesdropping.




## Aircraft Bird Strike Prevention

**U.S. PATENT: 9,227,726**
**INVENTOR: KELLY BOREN**

Bird-aircraft collisions are bad news, and not just for the bird. Airplanes can suffer damage that is costly to repair. There's also the lost revenue when an airplane is out of service. Previous techniques to shoo birds from shared airspace have been less than effective.

Enter this invention, which suggests that a manmade, fragrant cloud around the runway corridor might do the trick. The patent provides for a persistent vapor of non-toxic bird repellent, such as methyl anthranilate, to be dispersed by airplanes during both takeoff and approach.

Methyl anthranilate, which is an environmentally responsible food-grade compound found in flowers, stimulates the trigeminal nerves in the bird's beak, eyes and throat, but otherwise smells like grapes to humans and other animals.

The aircraft discharging the vapor does not necessarily protect itself against bird strikes in the runway corridor, but subsequent aircraft in the runway corridor would receive the protection.

**Patents Granted** Domestic

YTD **455**

**Patents Granted** International

YTD **503**

# Boeing IP News

## American trade secret laws reinforced with civil action

Congress recently passed, and President Obama signed, the Defend Trade Secrets Act of 2016, a new law that allows intellectual property owners to sue over the theft of trade secrets in federal court.

Previously, IP owners had to bring most civil trade secret lawsuits in state courts under laws that vary state-by-state. The Defend Trade Secrets Act is the biggest change in U.S. IP law since the 2011 America Invents Act, and shows lawmakers' growing attention to IP in the modern knowledge economy.

While stealing IP continues to be a major crime, the FBI's resources to investigate and prosecute trade secret theft have been limited. According to a 2013 report by the Commission on the Theft of American Intellectual Property, trade secret theft costs the economy more than $300 billion a year.

Boeing was one of many large companies pushing for the legislation, including testimony before a U.S. Senate subcommittee in 2014.

## Boeing licenses non-destructive inspection technology

Boeing recently licensed exclusive non-destructive inspection technology to FemtoMetrix, a manufacturer of optical inspection machines for the integrated circuit industry.

Undetected defects in semiconductor starting materials cause device failure and are a critical problem for fabricators. FemtoMetrix inspection systems help manufacturers improve yield by detecting defects such as surface and buried metallic and organic contamination that cannot be seen by other in-line tools.

FemtoMetrix, based in Santa Ana, California, will use the Boeing technology to provide greater fidelity to the inspection process used during microchip, semiconductor and solar materials fabrication.

As part of a greater intellectual property strategy, Boeing has been engaging in license agreements with companies outside of the core aerospace sector who might benefit from Boeing's extensive technology portfolio. IQ


# Geeking out. Making apps.

Boeing is tapping into the mobile technology of smart phones and tablets to bring real-time data to pilots in flight. With applications such as Boeing's Flight Deck Fuel Advisor, pilots can receive up-to-the-minute fuel data that helps them fly more efficiently.

"There's a fundamental performance relationship between weight and the fuel efficiency of the aircraft," says Ian Britchford, director of fuel efficiency for Jeppesen. "Through proprietary algorithms, we can actually calculate what the actual weight is, and then provide more information to the flight crew in terms of how to operate the aircraft efficiently."

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


BOEING
TOP 100
GLOBAL INNOVATOR
For five years running, Boeing is one of the
Top 100 Global Innovators by Thomson Reuters.