

Physics at Boeing runs the gamut from lightning strikes to neuromorphic processors, with a dash of metamaterials

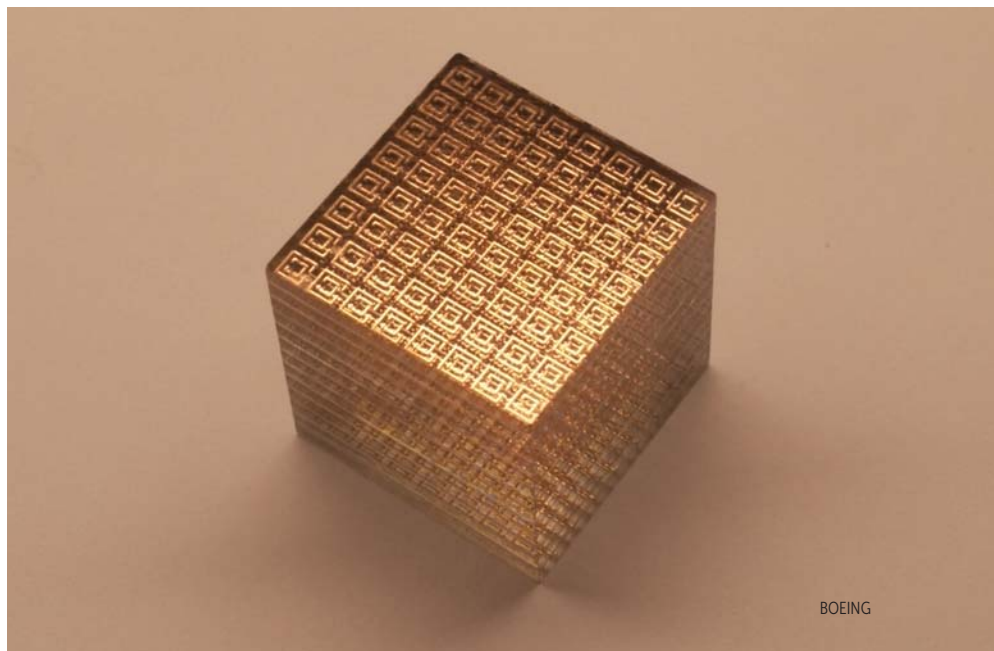
Physicists are uniquely qualified to solve problems that require an understanding of the bigger picture.

Every hour during an airliner flight, dozens of sensors monitoring thousands of parameters produce around 1.5 terabytes of information. As more sensors are added in next-generation aircraft to detect maintenance issues before they become a problem, the volume of data is expected to increase 10-fold, and more than a petabyte of information could be generated during a 10-hour flight.

Jay Lowell is a Boeing senior technical fellow and one of more than 90 physicists who work at Boeing Research & Technology, the aerospace giant's central R&D organization. He and his team will have to cope with that growing data avalanche. He believes neuromorphic processors—chips configured like neural networks—can help address the onboard data-processing crunch and flag abnormal situations. “They are exceedingly efficient for machine learning and artificial intelligence applications,” he says.

But running machine learning and artificial intelligence programs with current processor technology would require tens or hundreds of kilowatts of power, compared with the 50 watts typically used by today's planes to process maintenance data. There will never be enough bandwidth to transfer all that data from a fleet of aircraft to the cloud for processing, Lowell adds, noting that around 10,000 Boeing 737s alone are currently in service.

The data problem is one of the challenges Boeing physicists are working on under the rubric of the company's initiative on disruptive computing and networks. A second thrust seeks to advance high-performance computing architectures by pairing central processing units with coprocessors such as graphics processing units. GPUs are “exceedingly more efficient” than CPUs at performing a smaller number of specific



THIS 2.5 CM METAMATERIAL CUBE was fabricated by researchers at Boeing and the University of California, San Diego, and other universities under a 2004 Defense Advanced Research Projects Agency contract. The object demonstrated that scientists could engineer a material with specific properties in a format that resembles a real material.

tasks, Lowell says. Boeing is looking at architectures that use a wider variety of coprocessors than today's top-performing supercomputers do. Looking further out, Boeing sees a future in quantum sensing and computing to address such problems as optimization in manufacturing.

Besides computing, Boeing physicists tackle problems that range from handling aircraft lightning strikes to protecting factory workers from static shocks. But they don't dwell on one problem or topical area indefinitely. Whether they work on a problem for two months or two years, once they hand off solutions for implementation by engineers, their next assignment is likely to bear little resemblance to the last. “Our job is to work ourselves out of a job,” says Lowell.

One of Lowell's first assignments at Boeing in 2016 was to improve the functionality of a robotics system on the factory floor. “What they needed was somebody who could approach the problem like a physicist and understand the fun-

damental principles involved.” It turned out, says Lowell, that he needed to apply the principles of metrology to understand how the robots were making measurements and to use classical mechanics to help identify and characterize the robots' limitations in performing their tasks. Physics also helped him capture data and build a picture to provide insight into the processes that were occurring. “You then had to perform analysis on the data you captured to model the entirety of the system at the scale of the factory,” he says. In the end, his suggestions for changes and fixes made the factory floor much more efficient.

The Boeing physicists who spoke with PHYSICS TODAY declined to discuss their role in returning the 737 MAX airliner to service, saying only that employees with many backgrounds are working on the problem. In March the aircraft was grounded by governmental authorities after two crashes that killed all 346

passengers and crew aboard. The accidents have been attributed to faults with the onboard Maneuvering Characteristics Augmentation System, which repeatedly caused the planes to turn their noses down.

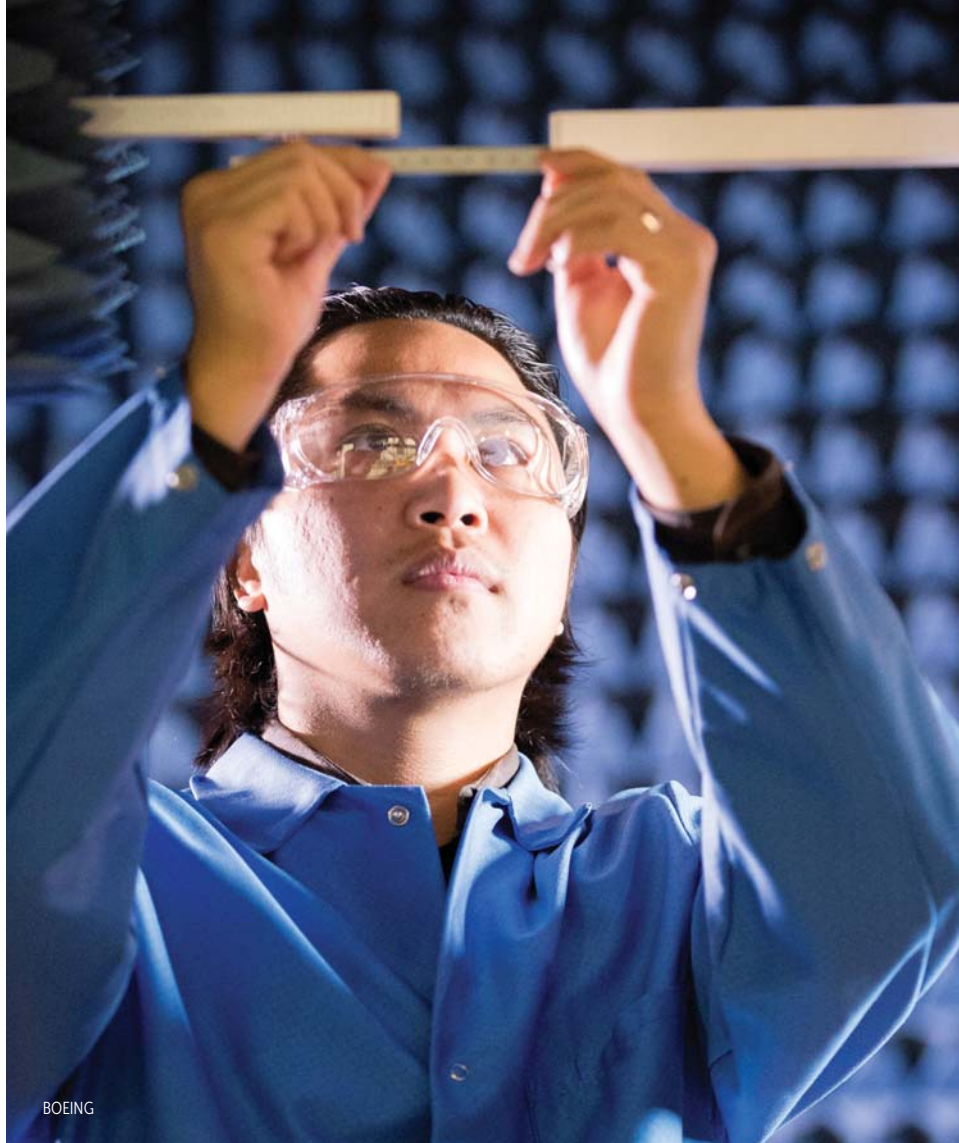
Problem solving

The real-world environment encountered by a Boeing physicist is unlike an academic setting, says Lowell, who previously worked as a US Air Force Academy instructor and as a program manager at the Defense Advanced Research Projects Agency (DARPA). For one, university scientists tend to be focused on a narrower range of research. Moreover, says Lowell, "we get to apply physics research to a problem that's concrete enough that we don't have to make a lot of assumptions. We don't have to toy the problem down to the point where it's trivial."

Compared with most academic research, Boeing's requirements are greater both in scale and in the level of detail. Modeling the fluid dynamics of a wing, for example, must take into account the winglet, gaps, and flaps, says Dejan Nikic, a physicist who joined the company in 2006. Simulating the flutter and elasticity of a wing as it flexes during flight adds to modeling complexity.

The computational resources needed for wing modeling, however, pale when compared with what's needed for figuring out how aircraft components, engines, and airflow around the aircraft combine to propagate noise to the ground. Those problems can take months for the most powerful supercomputers to solve, Lowell says. The benefits to airlines from cutting noise levels in half would be enormous; many airports could ease or eliminate bans on overnight takeoffs and landings.

Unlike their academic counterparts, Boeing scientists rarely publish their research, most often because it's proprietary. Publishing also has the potential to provoke changes to regulations, notes Nikic, whose interests include the electro-



DENNIS DUGAY, an electrophysics engineer at Boeing, is in an anechoic chamber at the company's laboratory in Huntington Beach, California. Dugay develops and tests RF and microwave components for airplane communications systems.

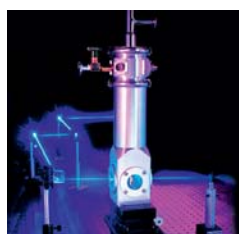
magnetics of plasma physics and pulsed power. He's worked on such topics as laser weapons and lightning strikes.

On average, airliners are struck by lightning once or twice a year, says Lowell. As manufacturers have begun incorporating more composite materials for weight savings, building a Faraday cage to safely dissipate lightning and keep it out of the cabin has become more complex. For metal airplanes, that's easy, says Lowell. "The lightning follows the metal skin of the plane. It doesn't penetrate to the interior of the plane, or maybe a few hundred amps do. Com-

posites are not nearly as conductive, and thousands of amps could flow through the interior."

Physicists are well-equipped to understand how the current will flow between structural members, down to the microscopic details of the fasteners that hold them together. Says Nikic, "We've done things like understanding the plasma density and temperature when lightning hits a surface, what that plume contains, how far the lightning penetrates a given material, and the erosion rate. That is all basic physics."

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plane is to boost the skin surface conductivity by incorporating a layer of metal foil in the composite stack. Doing so reduces the amount of current that transfers into the airplane substructure, which itself is designed to handle any transferred current. Boeing adds other proprietary features to provide a redundant layer of protection.

More mundanely, Nikic was called in to address complaints from factory workers who routinely received harmless but annoying static shocks when peeling sheets of plastic off of wing panels after they are cured in autoclaves. The solution entailed altering how panels were unbagged, changing what workers wore, and other steps. "Every other person who tried to approach this wasn't able to make headway," Lowell says.

A different model

Minas Tanielian is a somewhat atypical Boeing physicist; throughout his 30-plus years at the company, he has specialized in organizing consortia with universities, DARPA, and other federal agencies. He's also worked on wireless systems, microsystems, autonomous systems, quantum devices, and laser-powered systems, among other areas. He holds 65 patents and has published more than 60 scientific articles. Currently he's working under contract with the Air Force Office of Scientific Research on a university-industry collaborative program on power beaming.

Nearly 20 years ago, after reading a news story in *PHYSICS TODAY* (May 2000, page 17) about left-handed materials—now called metamaterials—Tanielian contacted the researchers at the University of California, San Diego. "I put a team of university researchers together and we started the metamaterials program at DARPA," he says. "Initially, the concept of metamaterials was somewhat controversial among the engineering community, but within six months we conducted an experiment which verified that they were real and published the results. The program eventually went to a second phase at DARPA called negative-index materials, where we focused on applications." Tanielian subsequently identified an application for the technology in Boeing's defense business, which he says he can't discuss for proprietary reasons.

Some of the modeling tools devel-

oped for the DARPA program were later used in developing electrically small antennas for cell phones. Lowell says that's an example of how basic physics often transitions by "bank shot" from basic physics to application: "It's not that what you do always goes directly to a place you might think but somewhere that's one step removed."

The reductionist approach physicists employ is ideal for troubleshooting, the Boeing scientists say. "When you get called in, the physicist approaches the problem by asking, How do I reduce the system down to its bare core physics and build the complexity up?" Lowell notes. "The engineer starts with the complexity and looks at the system at that level and sometimes struggles to simplify things enough to see what's going on."

Physicists also help bridge knowledge gaps that occur among different types of engineers and other scientists working on multidisciplinary programs, says Tanielian. Just as an electrical engineer may not understand the mechanical-engineering, thermal, or other aspects of a program, a mechanical engineer likely has trouble with electronics, he explains. "Physicists are not as expert in terms of how to do some specialized things, but we understand the core of how things happen or interact with each other, especially in a multidisciplinary environment."

Getting the word out

Boeing wants people with experimental backgrounds and those with theoretical backgrounds, people with analytical skills and people with numerical skills, says Lowell. "The breadth of problems in a company our size is large, so the breadth of skills we need is broad and deep."

Lowell expects that the company's disruptive computing and network organization alone will require at least a dozen new physicists over the next two years. Quantum physicists—those who have worked in supercomputing and those with modeling experience—are in particular demand. High-energy physicists who deal with large amounts of data and codes that take advantage of different kinds of processors are also needed.

"We have a problem in trying to recruit young physicists to industry and specifically to Boeing, which is essentially an engineering company," says Tanielian.

David Kramer **PT**