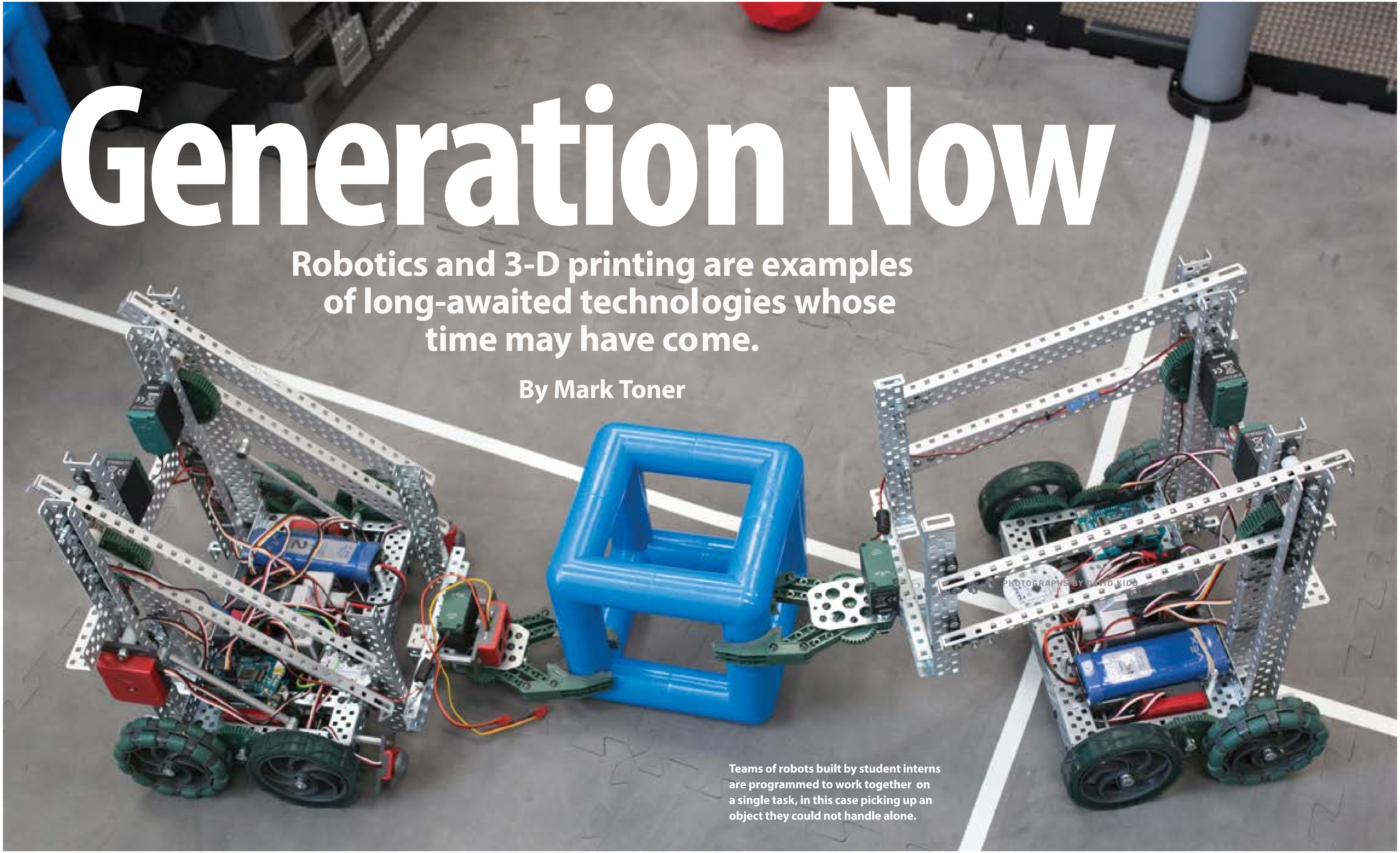
Generation Now

Robotics and 3-D printing are examples of long-awaited technologies whose time may have come.

By Mark Toner



PHOTOGRAPHS BY DAVID KIDD

Teams of robots built by student interns are programmed to work together on a single task, in this case picking up an object they could not handle alone.

To hear Wayne Stilwell tell it, the next chapter in robotics may have its roots in an overgrown field in the Virginia Piedmont.

At a test site near U.S. 29 in Brandy Station, a team of computerized commercial mowers will soon go into action, communicating electronically with each other to mow in unison, each tackling a specific part of a field. If one breaks down, the others will determine how best to take on its chunk of the field—all under the watchful eye of a human operator, but while making these decisions and communicating with each other without direct intervention.

It's a test of software developed by Manassas-based Stilwell Technology and Robotics to coordinate the activity of a wide range of machinery. With many future workplaces, from farms and hospitals to warships and army units, likely to staff fewer people and more machines, a key challenge is getting different types of equipment to work together—and with humans.

"We want the 'Star Wars' bar scene of robots," Stilwell says. "If you've got five or six different robots on a farm, for example, you want them to do something together. A lot of people are thinking this way. We actually have working software."

Robotics is not new—nor are its real-world uses. But with advances in both hardware and software, it's on the cusp of leaving the factory floor and other controlled environments and becoming a part of everyday work and life. In a similar fashion, 3D printing has been a longstanding area of interest for product developers and, more recently, hobbyists. Now, it's moving from prototyping to manufacturing, making it possible to fashion replacement parts in the field—whether that field is a farm, a factory floor, or a battlefield.

Experts in both sectors say that the technology is rapidly catching up to the vision—and now it's the vision that needs expanding. "3D printers are where personal computers were in the '80s," says David Sheffler, a longtime aerospace industry designer who now teaches at the University of Virginia's mechanical and aerospace engineering department. "If you asked then what the Internet would be like, no one would know because they hadn't envisioned it yet. I think 3D printing is like that now."

Lockheed Martin Vice President of Engineering Jeff Wilcox agrees. "We will wind up with new and fundamentally different structures we can't imagine today," he says, pointing to how 3D printing and other advanced manufacturing technologies are closing the loop between design and production. "The creative thinking required to imagine the art of the possible is critical to this feedback loop."

When you picture a robot, chances are you think of a smallish, wheeled contraption—the kind of machine high school robotics teams build to compete in flat arenas or the kind your early-adopter neighbor might have vacuuming his home.

Unfortunately, the real world is rarely so level. And a warship such as a destroyer, which rolls with the ocean and is divided into compartments with high door sills to prevent flooding, is essentially impassible to a Roomba-like contraption. But it's also an ideal place for robots, which can be put into service doing jobs that are both dangerous, like damage control and firefighting, and tedious, like watch duties that ensure that equipment is operating as it should.

In 2010, Virginia Tech's mechanical engineering department took the lead on a research program sponsored by the Office of Naval Research and the Naval Research Laboratory. The goal? To create a robot that could help sailors in both routine and emergency situations.

"More and more, there are reduced manning initiatives on ships," explains Brian Lattimer, an associate professor in Virginia Tech's mechanical engineering department. "Starting to have robots on board to support the sailors seemed like a thing that would be good for the future of the Navy."

Wayne Stilwell's SquadLeader software focuses on making robots work in self-organizing teams.

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As they worked to develop the Shipboard Autonomous Firefighting Robot (SAFFiR), students at Virginia Tech quickly settled on a human-shaped robot, given the need to navigate through compartments and ultimately up and down ladders. The problem with humanoid robots is that they, like us, are top-heavy and prone to stumbling. Humans have inner ears that help us keep our footing, but for a humanoid robot, a whole set of systems need to be developed to maintain balance.

Through three iterations, SAFFiR (pronounced "safer") gained force control actuators, then whole body momentum control systems that optimize the position of each joint in its body to ensure the robot wouldn't fall on uneven or shifting surfaces. Given its mission to fight fires in smoke- and steam-filled compartments, students at Virginia Tech, along with research collaborators at the University of Pennsylvania and University of California Los Angeles, developed multiple perception systems, including laser rangefinders and stereoscopic thermal imaging along with traditional cameras. Together, these systems "provide depth and visual information even with zero-visibility smoke surrounding the robot," Lattimer says.

SAFFiR was put to the test last fall, when it walked across warped planks in a hallway aboard the decommissioned USS Shadwell. It carried a hose, turned, located a burning fire, and blasted it with water. The robot also used its systems to search for leaks and overheating equipment during its shipboard trials. As part of a second three-year contract with the Navy, work will continue on refining SAFFiR's ability to navigate stairs and ladders and tight passages filled with equipment.

Ultimately, Lattimer envisions the robot being used as part of a hybrid team—SAFFiR, human operators and firefighters, and a small drone that can fly into dangerous spaces and beam back information to its human and non-human teammates. "We want them to work as a team to share information," he says.

"If a hazardous condition happens, maybe an aerial vehicle goes in and identifies the leak—but it can't do anything about it, so it sends that information back to the human and the humanoid, and the human has the humanoid go in there and shut off a valve."

SAFFiR uses what Lattimer calls "sliding autonomy"—an operator identifies where the robot needs to go, and then it calculates a footstep plan to figure out how to get there. Finding ways to give robots more autonomy remains a significant challenge, both in terms of software development and the implications of self-guided robots—challenges that are just now beginning to be addressed.

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A graduate of The Entrepreneur Center @ NVTC's FastTrac® TechVenture™ program, Stilwell launched Stilwell Technology and Robotics in May 2014 after retiring from a military career that focused largely on simulation—which, in turn, focused largely on getting disparate systems to talk to each other in real time. "I wanted to use the interoperability from simulation to make machines work together," he says.

Along with working with NATO on simulation and training solutions, Stilwell's startup has focused initially on the software side of the robotics equation. The result, its SquadLeader software, focuses on making robots work in self-organizing teams.

To date, Stilwell's software has largely been tested on teams of simple wheeled robots built by student interns from several local universities, who have also contributed to coding and software engineering. (The company's first patent credits two George Mason University interns and one from Northern Virginia Community College along with Stilwell.) But that soon will change. The company's 220-acre demonstration site in Brandy Station is intended to show what happens when the software drives working commercial machinery instead of wheeled "toys," as Stilwell calls them. Agricultural settings are a particularly good test for machine teams, Stilwell says, because modern farming operations already feature large numbers of machines overseen by comparatively few people. Stilwell's goal is to partner with a major company in each of a broad range of fields—agriculture, security, medicine, among others—to adapt its core software to each sector's needs.

While technology continues to accelerate and robots become more adept at communicating with each other, the next step involves refining how they communicate with people. That's going to become all the more important as both commercial and military models for the workplace continue to evolve.

"If you are a U.S. Army unit, you will probably have fewer people and more machines," Stilwell says. "What do the people do and the machines do? No one's really thought through it at all… Beyond getting machines to work, we need to build a command and control system that's appropriate and can make a lot of fast decisions that can stand in court."

Lattimer believes that robots will ultimately complement, not compete with, human workers. "The exciting thing about cyber-physical systems is now you have the opportunity to, instead of replacing people, put systems into place that may help people keep their job," he says. Given the aging workforce, Lattimer adds, robotics can help "do some of the more strenuous things they can't do without losing the expertise you don't want to lose."

To see where 3D printing technology is headed, visit another field off U.S. 29 in Central Virginia, where University of Virginia students have been flying what may be the first aircraft to be printed, not put together using traditional means.

"No one had printed and flown an aircraft," says U.Va.'s Sheffler, who led a three-year project to develop the unmanned aerial vehicle (UAV). "We really needed to step back and ask if you could make anything strong enough and lightweight enough to get off the ground."

Working with The MITRE Corporation, students and professors ultimately developed the Razor, a UAV with roughly the wingspan of a large bird that is completely printed on one of the university's refrigerator-sized 3D printers. "I literally push a button on the computer, and 35 hours later, I have an airplane," Sheffler says.

Powered by an Android cellphone and a few batteries, the Razor can cruise at 35-40 miles per hour and has a similar range to the Army's RQ-11 Raven UAV, which Sheffler used as a benchmark.

There's a reason why a printed plane is especially intriguing. Most aircraft, including UAVs, are now manufactured using carbon fiber—a strong lightweight material that's ideal for airframes, but requires highly specialized, labor-intensive manufacturing processes that can't be replicated anywhere but in tightly controlled settings. But with a 3D printed UAV, "if I crash it, I could have a machine standing in the desert to make a replacement part, not in a controlled facility that works with carbon fiber," Sheffler says. "I could make a functioning state-of-the-art UAV with no skills at all."

That's surprising, but perhaps the biggest surprise about 3D printing is that the technology is more than three decades old, with the first patent dating back to 1980. Before the end of that decade, it was already being used for rapid prototyping and product development in a variety of fields. The concept has largely remained the same—using a computer-generated file of 3D information to print a solid object, one layer at a time. (Picture a much more sophisticated variation of the Play-Doh spaghetti factory we played with as children.)

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Razor's development reflects the technology's rapid prototyping roots. Initial flights had to be launched from the sunroof of Sheffler's moving car. Video of subsequent attempts at hand launches show a lot of crashes—and a lot of retooling of the aircraft to make it more airworthy. Unlike the Raven, which looks more like a traditional aircraft, the Razor has a flying wing design with no tail and fuselage, eliminating the need for fasteners or support materials. Printed in two pieces, it literally snaps together.

In recent years, there's been a significant shift from prototyping to production, as new printing materials and technology have resulted in stronger, more durable products rolling off 3D printers. Now often called "additive manufacturing," 3D printing is being used in a broad range of applications, particularly in the aerospace sector. As part of its broader advanced manufacturing initiative, Lockheed Martin is using an end-to-end manufacturing process it calls its "digital tapestry" to design and print satellite parts out of titanium. Company officials say the technology could someday be used to build entire satellites.

"If you're working in aerospace, you're always at the edge of the envelope," says Lockheed Martin's Wilcox, pointing to the technology's ability to produce lighter, stronger materials much more quickly. "We're realizing 50 to 80 percent savings in time for production. Time is money, but time also lets you tighten the loop on the innovation-feedback cycle. It lets you try stuff—that's always been the secret sauce of engineering."

The military also has used 3D printing to help prototype and then build replacement parts for some of its aging planes. The Navy even has tested 3D printers on board some of its ships, including a 2014 test which saw sailors aboard an amphibious assault ship print caps for holding tanks and other small parts.

Northrop Grumman began using 3D printing for rapid prototyping as early as 1990, according to Skylar Cobb, a manufacturing technology development engineer with the company. Its first flyaway metallic part, fabricated in 2008, was used in its demonstration X-47B unmanned combat aircraft. Today, additive parts made from Nylon 12 are used in several Northrop Grumman UAVs, and additional ones crafted from a titanium alloy are expected to be qualified for satellite applications later this year.

"Thousands of parts are flying across several of our programs," Cobb says.

Manufacturing also is moving beyond the skunkworks of the largest companies. Companies like Microsoft and Autodesk are working to make 3D printing available to even small companies, integrating modeling engines with printers to create end-to-end solutions. "We're going to move from modeling to manufacturing in the near future," Steve Guggenheimer, Microsoft's chief evangelist, said during the Microsoft Build Developer Conference earlier this spring.

For startup Asius Technologies, which competed in the NVTC Destination Innovation 2015 event, the rapidly changing technology is allowing the company to insource 3D printing from outside manufacturers. A developer of an ear lens that mimics the behavior of the eardrum to improve sound reception for users of hearing aids, headsets and earbuds, Asius expects the change to improve supply chain control and reduce the need to manufacture large batches at once, says CEO Steve Lebischak.

"We have to change our mental model," he says. "We're used to designing something and sending it out and having to wait for it to come back. We're not used to making an adjustment and instantly seeing how it responds."

Lebischak predicts that more companies will gain expertise

Virginia Tech students' fire-fighting robot located and extinguished a shipboard fire as part of a recent test.

LOGAN WALLACE

with 3D printing as the market grows. "As the community grows, there will be more sharing [among] innovative companies trying to find best practices and share them," he says. The National Additive Manufacturing Innovation Institute, the first of a series of public-private research institutes in the federally supported National Network for Manufacturing Innovation, has played a significant role in advancing the technology, according to Wilcox.

The technology continues to proliferate. The 3D print industry grew by 21 percent worldwide in 2014, according to a study by the Wohlers Report. Much as color copying became a staple of office technology stores in the 1990s, UPS has now expanded a pilot of its 3D printing services to nearly 100 UPS Store locations, including one in downtown D.C., allowing customers to email 3D design files and have them printed there. (U.Va. offers a similar service in its 3D printing lab to customers worldwide.)

University of Virginia students and professors have been flying what may be the first printed aircraft.

UNIVERSITY OF VIRGINIA

Challenges remain for both technologies. 3D printing continues to be limited by the materials used in printers, whose properties aren't as defined and developed as others used in traditional manufacturing. "It's tough finding a resin that matches the printer," says Asius' Lebischak. Government and industry best practices also need to be formalized to encourage production, according to Northrop Grumman's Cobb. "This is a key enabler for more widespread adoption of additive manufacturing fabricated products," he says.

In a similar fashion, robots remain maddeningly complex systems, expensive and difficult to repair in the field. "As we develop new approaches on the software side, then we revisit the hardware side to make it better, lighter, less maintenance, and cheaper," Virginia Tech's Lattimer says. "How can we get the costs down and make [robots] that are easily maintained so you can start to put these systems in disaster response applications?"

But the technology continues to evolve rapidly. Additive manufacturing materials and the machines that use them continue to improve, Cobb says. "Materials specifically tailored for additive manufacturing 'producibility' is an area of industry growth, as well as gradient and more complex composite materials," he says. "Capabilities are expanding to larger scales enabling bigger and more integrated parts, and conversely to smaller and more detailed intricacies at micro and even nanoscales."

U.Va.'s Sheffler agrees. "Once that comes together, it can truly revolutionize manufacturing," he says. "There's no reason you can't make jet engine parts. And there's no reason you can't make parts of internal combustion engines." (In fact, his students already use 3D printing to build working models of both.)

The tools used to design products for 3D printing also continue to evolve, says Lockheed Martin's Wilcox. "I used to think of additive [manufacturing] as making the same part a different way, but [the technology] gives you the ability to think about functionality," he says. "The tools engineers use for conventional subtractive processes have been around for a long time. We're just now getting to the point where we have design tools for additive."

With 3D printers beginning to appear in elementary school labs, Wilcox believes that a new generation of engineers will advance the field in ways currently difficult to imagine. That kind of transformation "will require a blend of art and science and manufacturing know-how," he says.

If you're wondering where robotics and 3D printing will ultimately come together, look no further than the next-generation Razor that Sheffler and his students are working on at U.Va. Along with adding the ability to take off vertically like a helicopter, Sheffler envisions a UAV with fully autonomous flight capability. "We have a completely hands-off manufacturing process, and now we're working on a completely hands-off operational capability," he says. "You set it on the ground, push a button, and it flies away." **nvtc**

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