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ARMY AL&T

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SPECIAL EDITION AUGUST 2018

IT'S ALL ABOUT THE SCIENCE

Interview with DASA(R&T) Dr. Thomas P. Russell

INVESTING IN ARMY LABORATORY INNOVATION

A fresh look at how to get the best labs and best people for leading-edge S&T

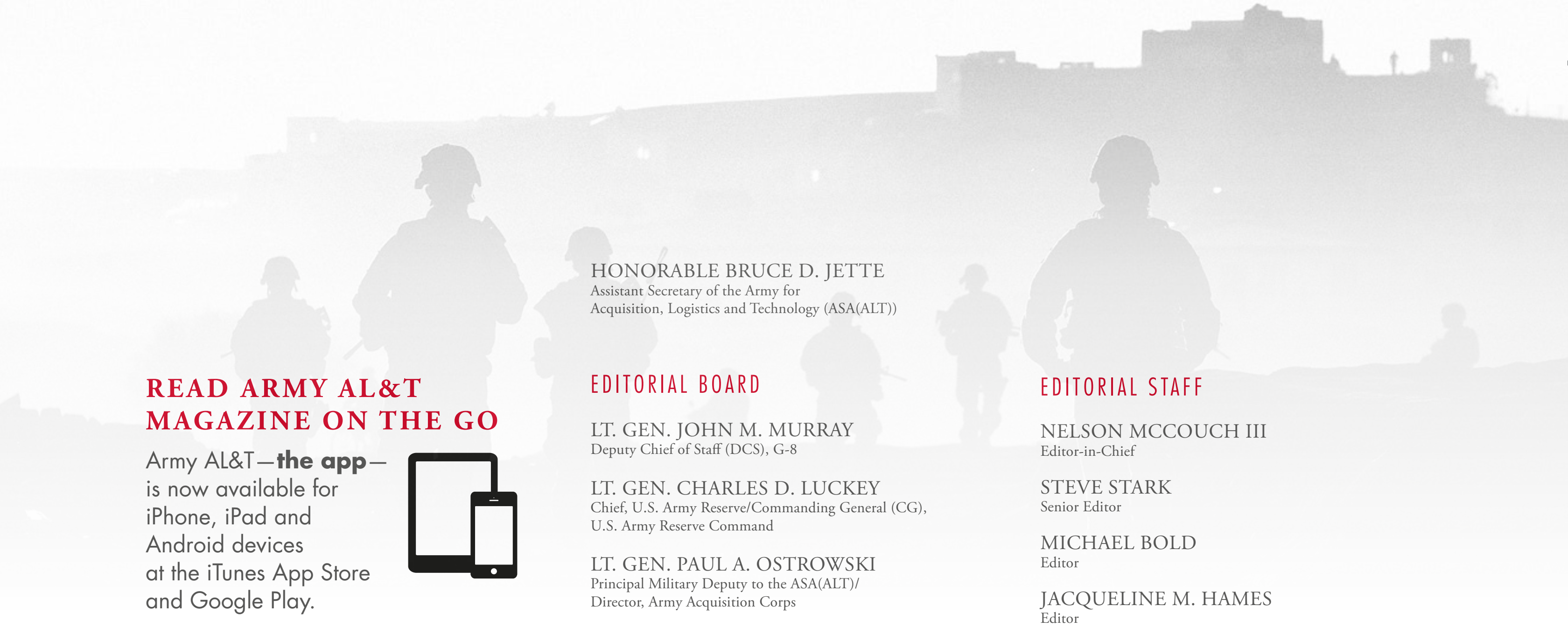
TILT THE FIELD

Building overmatch in long-range precision fires, air and missile defense

TECHNOLOGY MATURATION

Transitions bridge the gap between concept and acquisition

RESEARCH & TECHNOLOGY



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FEATURES

ON THE COVER

The people of Army S&T work in labs and offices across the country and around the globe, on projects both massive and nano, and in every scientific discipline, to put science and technology at the warfighter's service. This special edition is a compilation of S&T-focused articles first printed in the January-March 2018 issue.

DESIGN ▪ DEVELOP ▪ DELIVER ▪ DOMINATE

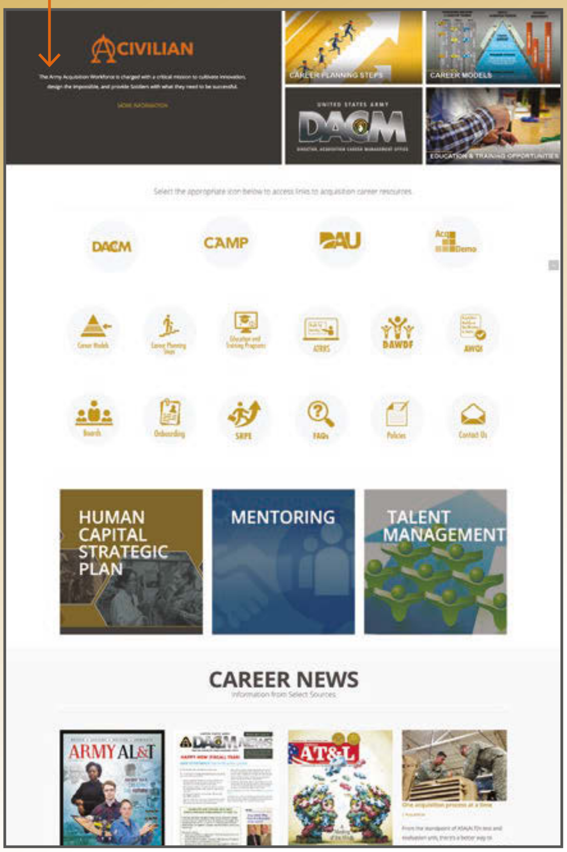
ARMY AL&T

SPECIAL EDITION AUGUST 2018

New look, same url: ASC.ARMY.MIL

The U.S. Army Acquisition Support Center (USAASC) website has been reorganized based on user feedback and most-viewed pages. On the homepage, you'll find career information, news and U.S. Army weapon systems data. Landing pages for civilians, officers and noncommissioned officers (NCOs) have been created to make it easier and faster to locate what you need. Now all of the career information relevant to you is available from a single starting point.

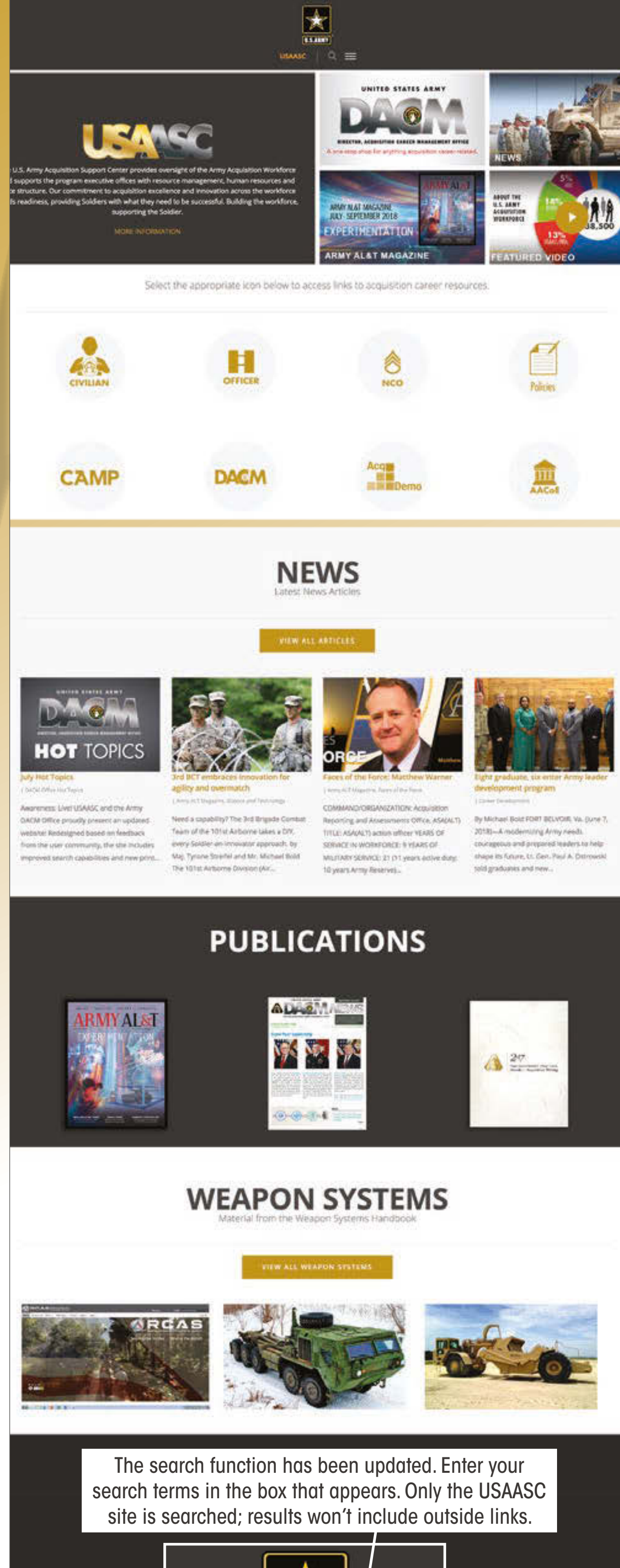
Simple navigation and user-centric career resources



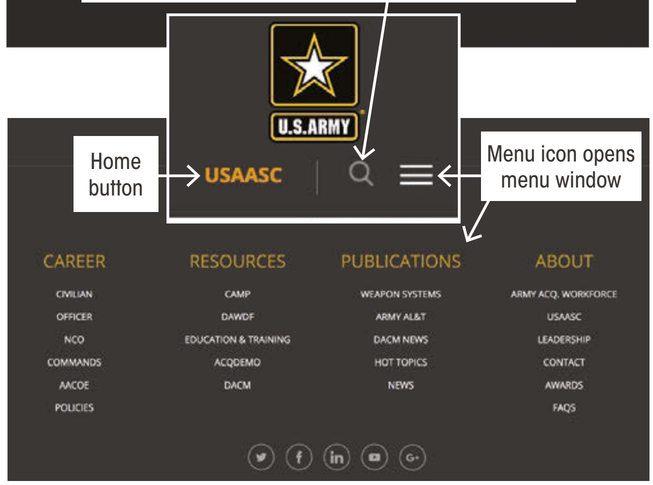
The tiles at the top of the civilian, officer and NCO webpages are images that go to the **main career** links. On each page, such as the civilian page on the left, are links to career steps, career models, career programs and opportunities, and the main Army DACM page. These tiles also include links to career announcements.

Links to all **career resources** are shown as an icon or an image.

Career news can also be found at the bottom of each main user page.



The search function has been updated. Enter your search terms in the box that appears. Only the USAASC site is searched; results won't include outside links.



About the Army Acquisition Workforce (AAW)

Under each civilian, officer and NCO main tile is a "MORE INFORMATION" link that will take you to a page that explains who's in the AAW and what the AAW does. This page is also accessible under the About header of the menu.

Policies and FAQs have their own search

The dedicated search function for these pages quickly directs users to policies and FAQs. Click on the headers underneath the search function to reorganize the information on the page.

Print pages

New policies, new blog articles and weapon systems have widgets like these that allow the page to be printed, saved as a PDF and emailed.

ROUGH TERRAIN
The Heavy Expanded Mobility Tactical Truck A4 is one of the vehicles that will be used to demonstrate the Tactical Vehicle Electrification Kit, which aims to improve vehicle operational energy, range and future electrical systems. The kit reflects the Army priority to deliver Next Generation Combat Vehicles with the most modern firepower, protection, mobility and power generation capabilities. (Photo courtesy of Oshkosh Defense)

FROM THE ARMY
ACQUISITION EXECUTIVE
DR. BRUCE D. JETTE

COLLABORATING ON INNOVATION

The Army is joining forces with industry to achieve land power dominance through science and technology

The future Army must be ready to deploy, fight and win decisively against any adversary, anytime and anywhere, as well as to operate in a joint, multidomain, high-intensity conflict, while simultaneously deterring others and maintaining agility to conduct irregular warfare. While the Army has been at war, the world witnessed the value and impact that technology brings to the battlefield and how capabilities, enabled by such technology innovations, are critical to the success of our Soldiers.

Similarly, our adversaries studied the Army's successes and challenges, then mimicked many of those successes and hence avoided many pitfalls in an attempt to bring themselves to near-peer status. However, they will not succeed in their efforts, because when it comes to creating and deploying cutting-edge technology, the keystone is research and development, empowered by the scientific workforce and how it views and solves problems.

Articles in this special edition highlight several Army modernization research activities designed for the Army to fight tomorrow's wars with the right equipment. The Army's science and technology (S&T) mission is to enable Soldiers to dominate the battlefield, both today and in the future. Research and development is a key part of the Army's modernization strategy. It focuses on maturing technology, reducing program risk, developing technology demonstrators and experimental prototypes to better define affordable and achievable requirements, and conducting experimentation with Soldiers to refine new operational concepts.

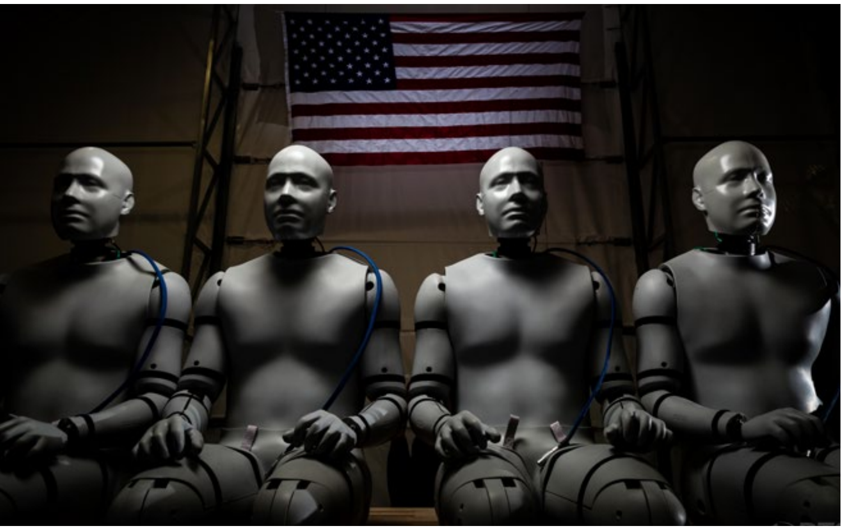
S&T is an investment in the Army's future, whereby we nurture innovation and drive toward new leap-ahead technologies with game-changing potential, evaluate technology and system vulnerabilities, and address issues such as affordability, sustainability, reliability and manufacturability early on during a system's design phase.

The Army's S&T enterprise comprises more than 25,000 scientists and engineers, including civilians and on-site contractors, who are essential to developing near-term fixes for our Soldiers' urgent needs. The Army's scientist and engineer network operationalized and delivered numerous capabilities to support Operation Iraqi Freedom and Operation Enduring Freedom during the better part of the last few decades. The understanding of Army operations forms the foundation of innovative mid- and far-term capabilities being developed for the Army of tomorrow.

A FOCUSED EFFORT

The S&T enterprise is dedicated to continuously meeting the needs of the Soldier, but we compete with the private sector and academia for critical technology and technical talent. We must execute faster and with higher impact to address current capability shortfalls, outpace anticipated threats and defeat technology solutions being adopted by our adversaries.

Technology is global, and the Army competes for the highest-caliber technology and talent. To retain overmatch in an open and pervasive technological environment, we must apply our resources thoughtfully to develop and employ the technologies that will provide the greatest military advantage.



MANNING UP
Researchers from the U.S. Army Research Laboratory and the U.S. Army Tank Automotive Research, Development and Engineering Center make use of innovations from industry partner Diversified Technical Systems Inc. (DTS), which developed these Gen 1 ATDs—anthropomorphic test devices. (Photo courtesy of DTS)

AIM HIGH
The Army's long-range precision fires priority seeks to restore Army dominance in range, lethality, mobility, precision and target acquisition. The Extended Range Cannon Artillery project at U.S. Army Yuma Proving Ground in Arizona includes the XM1113 projectile, which surpassed 60 kilometers in May, and the Hyper Velocity Projectile, which has exceeded Yuma's testing space. (U.S. Army photo)

The secretary of the Army and the chief of staff of the Army have identified six modernization priorities that address our most pressing operational needs to ensure overmatch against potential near-peer competitors. Army research and development programs and resourcing have been realigned to focus on developing the six priority areas:

- **Long-range precision fires**—Platforms, capabilities, munitions and formations that restore Army dominance in range, lethality, mobility, precision and target acquisition.

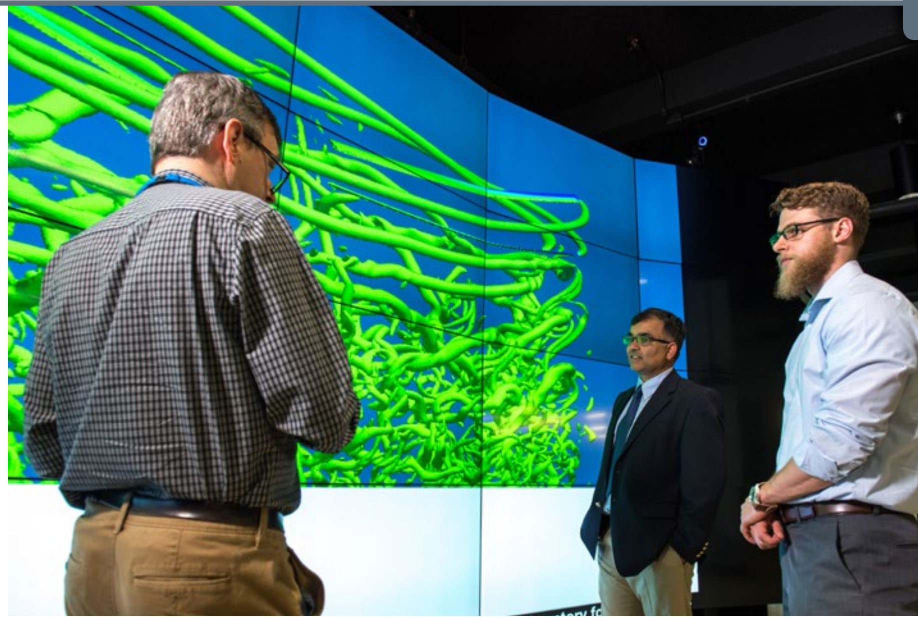
- **Next Generation Combat Vehicles**—Combat vehicles that integrate other close combat capabilities in manned, unmanned and optionally manned teaming. These vehicles will leverage semi-autonomous and autonomous platforms in conjunction with the most modern firepower, protection, mobility and power generation capabilities necessary for our future combat formations to fight and win against any foe in any environment.

- **Future Vertical Lift**—A set of manned, unmanned and optionally manned platforms that can execute attack, lift and reconnaissance missions on the modern and future battlefield at greater range, altitude, lethality and payload.

- **Network and command, control, communications and intelligence**—An integrated system of hardware, software and infrastructure that is sufficiently mobile, reliable, user-friendly, discreet in signature and expeditionary to enable Soldiers to fight effectively in any environment where the electromagnetic spectrum is denied or degraded.

- **Air and missile defense**—A series of mobile integrated platforms, capabilities, munitions and formations that ensure that our future combat formations are lethal while remaining protected from modern and advanced air- and missile-delivered fires, including drones.

- **Soldier lethality**—A holistic series of capabilities, equipment, training and enhancements that span all fundamentals of combat, including shooting, moving, communicating, protecting and sustaining, to make our Soldiers more lethal and less vulnerable on the modern battlefield. This will include not only next-generation individual and squad weapons but also improved body armor, sensors, radios and load-bearing exoskeletons in concert with optimized human performance and decision-making.



QUIET RIDE
Army researchers study the effects of moving rotors at the DOD Supercomputing Resource Center at Aberdeen Proving Ground, Maryland, as part of the Army's Future Vertical Lift priority. The U.S. Army Research Laboratory (ARL) is working with ride-sharing company Uber Technologies Inc. in research to produce quieter unmanned aircraft. (U.S. Army photo by David McNally, ARL)

IN SEARCH OF INNOVATION

Innovation is an important part of the Army's strategy to provide the right capability to the Soldier at the right time. The Army makes use of innovations from industry and other partners whenever possible, and we encourage industry to bring innovative technologies and solutions forward to explore the full ideation space and the art of the possible.

With approximately 23 million companies in the United States, the Army only does business with about 5,000 of them. Having recently come from industry and knowing the challenges associated with entering "the process" of defense acquisition, I submit that the Army must engage proactively and aggressively with all innovators to see what new ideas, concepts, systems and subsystem components they can demonstrate.

Private sector innovation, especially from nontraditional sources, is critical to the Army's future. I have embarked on a new strategy for soliciting innovative, paradigm-breaking technologies from the startup and nontraditional community to support the Army's modernization priorities. The first engagement within the new innovation strategy began in June 2018 with the launch of the Expeditionary Technology Search (xTechSearch). It serves as a catalyst for the Army to engage with the nontraditional business sector, driving American innovation to meet Army challenges and spurring economic growth.

Aimed at attracting game-changing innovation, xTechSearch will provide access and venues to pitch novel technology solutions directly to Army leadership. So far, xTechSearch has hosted several outreach events across the country to engage with American innovators and spark the development of leap-ahead technologies for the future Army. The Army will provide non-dilutive seed prizes—money that doesn't require giving up shares of their businesses—for companies to demonstrate proof of concept for their technology solutions.

Strategic land power dominance is critical to the Army for prompt, sustained and synchronized operations with a force customized to the mission and poised to win in all domains. For the imaginable future, the nation's land power dominance will continue to rely on significant S&T advances to ensure a competitive advantage.

We will look everywhere for opportunities to accelerate innovation and to deliver advanced technologies that enable our Soldiers to win decisively.

(Image by U.S. Army Acquisition Center/Nongkran_ch/iStock)

DEPUTY ASSISTANT SECRETARY OF THE ARMY
FOR RESEARCH AND TECHNOLOGY

Dr. Thomas P. Russell

It's all about the SCIENCE

...and the people who do it, and the problems they solve.

by Mr. Steve Stark

Winning in a complex world, the multidomain battlespace: These are extraordinarily complex concepts. How will the Army operate in an area that a peer or near-peer adversary has worked very diligently to make sure that the Army cannot operate in? How will the Army counter swarms of networked, unmanned systems?

For Dr. Thomas P. Russell, the deputy assistant secretary of the Army for research and technology (DASA(R&T)), envisioning and developing the capabilities and the technologies that the Army will need in five years or 30 years is not a job that includes crystal balls or tea leaves. It's science, and lots of it, done by scientists, and lots of them.

Science, he said in an Oct. 27 interview with Army AL&T, is a process of discovering and understanding the world we live in. "As we discover more and more about the world we live in, and we understand those fundamental principles, eventually we start thinking about how we can use that knowledge we've developed to start solving problems."

Right now, Army science and technology (S&T) is working to solve a lot of problems. "We're developing new capabilities or technologies that could serve to either help the military or help the commercial market space." Those capabilities, of course, are intended first for the military. And the problems to be solved are specific:

- Precision fires and air and missile defense.
- Next Generation Combat Vehicle.
- Future Vertical Lift (FVL).
- The network and command, control, communications and intelligence.
- Soldier lethality.

In addition, there are the people and the laboratories that make those things possible, which includes the Army's S&T laboratory enterprise network, S&T workforce development, Army collaboration with the other services, international partners and industry. Finally, there's the issue of transitioning technology, or getting needed capabilities into the hands of Soldiers.

GETTING SMARTER
A Patriot missile radar system set assigned to 1st Battalion, 1st Air Defense Artillery Regiment during the unit's table gunnery training exercise on Kadena Air Base in Japan, in October. Precision fires and air and missile defense are top priorities in Army S&T research, and newer versions likely will be smarter and more accurate. (U.S. Army photo by Capt. Adan Cazarez, 94th Army Air and Missile Defense Command)

A REBALANCING ACT

Russell earned his doctorate in chemistry in energetic materials, which are substances that contain lots of energy and release it rapidly to "do work," in the physics sense of the term—moving energy from one place or form to another. When he went to work for the U.S. military in 1990, Russell didn't think it would become his career. However, like a lot of those in the acquisition, logistics and technology fields, he found the research meaningful, a way to be a part of something greater than himself. Plus, he found the hard problems DOD was trying to solve to be deeply engaging.

He started his career with DOD working as a research scientist with the Navy, spent several years working with the Air Force and came to the Army in 2013 as the director of the U.S. Army Research Laboratory.

It was, in fact, Russell who suggested the science and technology theme of this edition of Army AL&T, and he backed up the suggestion with more than two dozen articles in this special section on rebalancing the Army's S&T portfolio.

Rebalancing the portfolio is a process, he said, of "looking at the potential threats in the future from our adversaries. What I mean by that is, we've been operating at war for probably a decade and a half or more. And our adversaries have been watching the way we operate. They've been building capabilities to offset or attempt to offset those strategic advantages we have today." And that presents the possibility that, in the future, those "threats may put us in a situation where we'll be overmatched by our adversaries. So rebalancing is about how we strategically align the S&T portfolio to address those emerging or evolving threats that our adversaries will present to us."

The emphasis is on the evolutionary nature of the threats. "That's not just now in the near term. … We're not focused on just where the puck is today, but where the puck will be in the future," he said, paraphrasing hockey great Wayne Gretzky.

Rebalancing, he continued, "is aligning ourselves to more effectively address the potential future threats and beginning to look at what technologies we need to create to evolve our capabilities. It's also about ensuring we have a more balanced investment portfolio for the future of the Army."

Modernization, Russell said, can and should encompass both the near and long term. "There are very specific things we're doing today in the Army to address near-term shortfalls, or to modernize our equipment to ensure that we have the capability that we need today. But there are also, in the S&T investments, things that we're doing that I would say would potentially modernize our force in 2030. It's all part of modernization." And all part of the same evolutionary process.

PRECISION FIRES, AIR AND MISSILE DEFENSE

Precision fires and air and missile defense are top priorities in Army S&T research. The former is about more accurate artillery and surface-to-surface missiles, which the Army calls kinetic capabilities. Those capabilities will be more accurate, smarter and with longer range. Or, the future could be artillery- or missile-like capabilities in an environment where artillery or missiles could not be used. Missile defense will include nonkinetic capabilities, such as directed-energy weapons.

The future—and the midterm—will include precision missiles with a 35-kilometer range that can loiter, provide operators with a full-motion video view-on-target on a linked tablet, and eliminate tanks or other high-value targets. The portfolio of capabilities also includes the ability to defeat collaborative or swarming threats. In the successful proof-of-principle phase, the goal was for a single operator to be able to fire and guide six missiles against four static and two moving targets.

For other means of air and missile defense, directed-energy weapons, specifically high-energy lasers, offer a lot of promise as part of a layered defense, said Russell. While they may not be the ultimate weapon, they will have a use on the battlefield of the future. "It's going to be a partnership between kinetic capabilities and directed-energy capabilities, including lasers, because lasers and directed-energy capabilities aren't going to be able to provide a single solution to every challenge we face from an air missile defense perspective." In the nearer term, Russell said, one of the benefits will be the lower overall cost of laser defenses.

An example of the utility of directed-energy weapons is defense against the increasing use of small unmanned aerial systems (UASs), either as intelligence, surveillance and reconnaissance platforms or as mules for explosives. "At least in the near term, its benefit is based on the cost equation," he said. While "it does cost quite a bit to build a laser system," after that initial outlay, lasers are a great deal cheaper to use. The real issue is "how much it costs me for the stored energy to be able to provide a laser pulse that will take down a target."

In the case of small UASs and "other lower-cost targets, you don't necessarily want to spend lots of money with missile systems to take out a counter-UAS," which would not only be expensive but could be far less accurate, like using a shotgun to take out a fly.

While lasers have been around since the 1960s and commercial lasers are everywhere, Russell noted that "we haven't really gotten to the point where we've been able to operationalize lasers at the cost-effective size, weight and power necessary to make them operationally relevant. I think we're on the verge of being able to do that. I think, in this evolving modernization process, you'll see laser systems coming online over the next 10 years that provide defensive capabilities for both mounted and unmounted units." Those capabilities will continue to evolve and will become another "tool in the toolbox. It won't be the only tool in the toolbox. … But it's very exciting."

THE PATH TO IMPROVEMENT

JLTVs perform demonstration runs around Marine Corps Base Quantico, Virginia, in June. Army S&T programs are exploring ways to improve vehicle platforms by leveraging developments in artificial intelligence and advanced sensors to improve vehicle autonomy. (U.S. Army photo by David Vergun, Defense Media Activity – Army)

ARMED FOR THE NEXT FIGHT

A Soldier assigned to the Mississippi Army National Guard's 155th Brigade Combat Team provides security during Decisive Action Rotation 17-07 at the National Training Center (NTC), Fort Irwin, California, in June. Decisive action rotations ensure that units remain responsive and consistently available for current and future contingencies—"not focused on just where the puck is today, but where the puck will be in the future," said Russell. (U.S. Army photo by Spc. Daniel Parrott, NTC Operations Group)

NEXT GENERATION COMBAT VEHICLE

When Russell talks of the Next Generation Combat Vehicle, it's about a host of possible concepts and platforms. So, while the Joint Light Tactical Vehicle (JLTV) "is where we're at today," it's a long way from what the Army may need in the future. For example, Russell said, autonomy, whether in the air or on the ground, is a big part of where the Army sees its vehicular strategy going. The S&T programs are looking at autonomy and teaming, meaning that both air and ground unmanned vehicles will be able to operate and navigate by themselves as part of a collaborative, man-unmanned team, without a pilot actively guiding the vehicle. The man-unmanned teaming approach launched in 2009 (See "Wingman Is First Step Toward Weaponized Robotics," Page 38), and has already shown great promise. The future, however, will see a great deal more collaboration between platforms.

S&T programs are looking to answer difficult questions about where vehicle autonomy can go, aided by artificial intelligence and advanced sensors. "Can we enhance the mobility, and can we increase the speed, the speed-to-contact, maneuver-to-contact?" Russell said. Or, how can a manned ground vehicle teamed with unmanned air or ground vehicles find, engage and defeat an adversary that's entrenched and well-protected, before the enemy detects a potential attack?

"If I look out 10 years from now, there may be other ground-vehicle capabilities that we need that would be the next generation. And again, it's not just JLTV we're talking [about]," Russell said. "Are we going to have Abrams [tanks] for the next 50 years, or are we going to develop something that would be different from a tank? Or do we really even need a tank? Could we develop a different concept of operations, based on new ground vehicle capabilities that emerge from technologies" the Army is developing or looking to develop now?

Part of that next generation vehicle strategy is the Robotic Wingman program. The potential there is huge, not just for applying more force, but also for using those vehicles for sensing, for scouting and providing highly accurate situational awareness. "When I say a Soldier is operating three wingmen, it could be one air vehicle and two ground vehicles," Russell said.

As to the probability that a potential future adversary could be working on similar technology, Russell said, it's not just about the machines, it's also about the people, and that's where he thinks the United States has the advantage. It's about "humans and how you train, and the rest of the DOTMLPF [doctrine, organization, training, materiel, leadership and education, personnel and facilities]," he said.

"In the end, I think one of the things that is to our strategic advantage over a lot of our adversaries is our DOTMLPF process. And that's how we integrate material and technological solutions and how we use them to our advantage based on the overall process."

FUTURE VERTICAL LIFT

The current Army fleet of rotary-wing aircraft are Cold War-era relics. They've been upgraded and enhanced over the years again and again, but, according to Russell, the basic platforms

> *"We have to start thinking about the different clock cycles of updating and modernization of the force. The software piece is going to probably occur at a much faster time scale than the hardware piece."*

have reached the limits of their potential. "The three major things we're trying to overcome today are speed, range and 'maneuverability at the X'," he said. The X is where the craft is going to land. "That's been a lot of the focus today. Right now, rotorcraft aircraft have limitations—what their speed is, which relates to range, and then of course there's maneuverability." So the issue with vertical lift is much like the issue with combat vehicles: It's all about mobility. That, Russell continued, is "part of this integrated multidomain battle problem."

Currently in S&T, Russell said, "we're looking to see if we can move beyond" the limits of available technology as it has been applied to current vehicles. "Are there ways that we can actually change that, or can we design different kinds of vehicles and structures that would take us to the next level of range, speed, maneuverability, which includes a lift-of-weight capability?"

TEAMING IN THE FIELD

Soldiers with 38th Cavalry Regiment, 1st Security Force Assistance Brigade build their communications system during a field training exercise in October at Fort Benning, Georgia. Today's networks are not nearly as mobile and self-contained as they will need to be in the future, Russell said. (U.S. Army photo by Sgt. Arjenis Nunez, 50th Public Affairs Detachment)

The Joint Multi-Role (JMR) demonstrator is the next step, he said. JMR is an ongoing technology demonstration process, which is a program of record to further FVL (see "Science and Technology Supporting Future Army Aviation" on Page 48). "JMR is a technology demonstrator. There are currently two companies [Sikorsky Aircraft with Boeing, and Bell Helicopter] that are technology demonstrators, one of which is rotary-wing capability [Sikorsky-Boeing], and the other one [Bell] is a tilt-rotor." Sikorsky-Boeing's prototype has counter-rotating rotors, which provide more stability than conventional single-rotor aircraft, plus greater efficiency and lift capacity.

FUTURE NETWORK

Another major focus of this rebalancing act is the network. "In the S&T world today, we're looking at a variety of different programs that will help us understand what the network of the future will look like. There's nothing wrong with the network that we're developing today. It's a good capability." Still, it's today's capability.

In the future, multidomain battle will "require something that's probably much more robust, much more interoperable. It may be highly heterogeneous, and what I mean by that is that a dismounted group may need a network that's different than a mounted group of Soldiers, but those networks need to be interoperable so that they can communicate," the way that cellphones move seamlessly between networks. There is also the coalition environment to consider, he said. "How do I do that exact same thing with my coalition partners? How do I know what information I can and can't share?"

And then there's mobility, which is a major thrust. "In the future, I don't want to have a network guy, I don't want to

EXPANDING SOLDIER CAPABILITIES

The Joint Tactical Autonomous Resupply System (JTARS) is designed to move materials from the rear of the battlefield to the front line, without requiring a manned convoy operation. Improving Soldier lethality involves more than just improving weapons: It also involves providing the kinds of technology, like JTARS, that will make Soldiers more resilient and responsive. (U.S. Army photo by C. Todd Lopez, Army News Service)

sit and wait for a bunch of signal Soldiers that are going to be setting up the network." That future network would come into whatever environment and it would "basically set up itself, sort of like what happens with your cellphone. I get off a plane in another country and it detects the network, and [based on my plan] it connects me to that network." Unlike with a cellular network, its infrastructure would follow it.

Today's networks are robust, but not nearly as mobile and self-contained as they will need to be in the future, Russell said. "When we talk about all these technologies, they become highly dependent upon our connectivity and having this robust, heterogeneous, highly dynamic network that is going to evolve as partners and as different capabilities come and go within that operational space." It's the military's own internet of things that "drives different technologies and capabilities that we, militarily, will need."

SOLDIER LETHALITY

Increasing a Soldier's capacity to be more lethal is only partly about weapons. It can also mean seeing the battlespace more clearly than the enemy, as well as gaining a better understanding of Soldiers to help them be more resilient and make decisions more quickly—and providing the kinds of technology that will enable that.

Continuously improving Soldiers' situational understanding is a major part of this. That means, Russell said, ensuring "that they get information that's required for them to execute the mission … without overloading them to the point that they're not able to execute." There could be a variety of new ways to keep the Soldier aware, using different mechanisms to help update information. That could include augmented reality that overlays information on the Soldier's field of view, haptic feedback (the most common haptic feedback mechanism is phone vibration) that tells the Soldier to duck, turn left or turn right, or even audio feedback.

"We're not there yet," Russell said, but there are "technologies currently—it's in some of the laboratories—where I can actually fuse [situational awareness] information through" a heads-up display so that "it's projecting the environment, the sensory environment, the information [networked sensors are getting] onto the Soldier's field of view." That technology is not a reality, yet, but "it's a major focus in Soldier lethality."

"It's really the integration of all these things to enhance situational awareness," Russell continued. "One of the things you have to be careful about is not overloading the human. That's why there's a focus on technologies that help to reduce the Soldier's cognitive load. On a future battlefield, the difference between us and them could come down to whose warfighters are less burdened by needless information.

"A real challenge to this is not the materiel piece," Russell said. "It's really understanding how the human can receive and process information so that we can actually optimize their ability to make those decisions with these decision aids."

ARTIFICIAL INTELLIGENCE

The future of autonomy, software-intensive weapon systems, advanced networking and lots of sensing technologies will not be possible without decision-support capabilities to help Soldiers not get instantly overloaded with information. That's where artificial intelligence (AI) comes in. While we encounter AI on a daily, even hourly basis, from personal assistance technologies like Amazon's Alexa and Apple's Siri to Microsoft Word's grammar-check function, there's a big difference between the home or office and the battlefield.

To make the best use of AI and all of the other software that the Army will employ, Russell said, the Army will have to code and update code much faster than it does today. The auto industry, he said, is doing interesting things with software updates and patches. The "vehicle itself actually updates on a regular basis. … They download software to update the algorithms."

That could make a big difference in the Army's next generation combat vehicles. If "I can update the algorithms for efficiencies in the engines, if I can put sensors on and change how the sensors actually behave and the way they detect and so on, based on software updates," Russell said, it increases the capabilities available to the Soldier. "We have to start thinking about the different clock cycles of updating and modernization of the force. The software piece is going to probably occur at a much faster time scale than the hardware piece."

The other part of that equation, Russell said, is that, with more recent weapon platforms being more software-based, "they have to be updated on a much faster timeline," and to do that "we need to do the science and engineering to look at how you validate software that's being developed. How do you ensure you have protected environments where, in a developmental process," the software doesn't inadvertently provide a way in for people who should not have access to the software? "There is a lot to do in a software-based" future, and that's why "you really need to move to more of an open architecture so that we can actually take advantage of this multiple time scale for modernization."

> *"We haven't really gotten to the point where we've been able to operationalize lasers at the cost-effective size, weight and power necessary to make them operationally relevant. I think we're on the verge of being able to do that."*

CONCLUSION

The United States has a lot of catching up to do after a decade and a half at war in Iraq and Afghanistan—a particular kind of war that global rivals and potential adversaries have observed intently. Russell has no doubt that the Army's capabilities will be up to the task if called upon to confront and defeat a near-peer adversary.

For Russell, the key to all of Army S&T is the S&T workforce. Indeed, he refers to the personnel of the Army S&T enterprise as "the crown jewel of the laboratory community." Maintaining that workforce is "about being able to recruit and retain the best and brightest people that are interested in solving challenging problems that have tremendous purpose, and that purpose is protecting Soldiers on a daily basis—and national security. And there are a lot of us that are more interested in serving in this way, than [in] money," he said.

"There's a significant portion of our population in the science and engineering field that are really interested in serving," he continued. Maybe that's not in uniform, but by contributing—as Russell himself has done—to national security, to what the Soldier needs every day. "The laboratory system actually provides that unique opportunity if you're coming out of graduate school and you want to be a scientist or engineer but you want to serve your country in a way that will protect its security," you can.

It's an attractive proposition, because for budding scientists and engineers, the Army has "a bunch of very interesting problems," Plus, he said, "There's a purpose to what we do. It's not just science for science's sake. It's not just engineering for engineering's sake. There's an outcome, and I think that's a tremendously satisfying experience as a scientist or engineer."

The biggest issue, Russell said, has been getting the word out to future Army scientists and engineers about "what happens in our laboratory systems so that they can decide whether they want to work in the commercial world or in the government world." That's changing, he said, because "we're now beginning to do a much broader outreach across the country in trying to get exposure of what we really work on in the laboratories." Internships are particularly effective because future workforce members think, " 'I just had no idea what you guys really did here. This is fabulous, how do I get a job?' At that point, it's no longer about could I make an extra $10,000-20,000 a year. It's about, 'These are really interesting problems.' "

That's not too different from how DOD snagged Russell. "Speaking for myself," he said, "coming to the government to work in the laboratory," he'd figured he would maybe work three to five years in a government lab. "Here I am, 28 years later, still serving as a civilian but serving at the Department of Defense as a scientist and engineer to ensure that we can maintain our principles as a nation."

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IN ALLIES' DEFENSE

Soldiers from the 7th Air Defense Artillery Regiment engage targets with Patriot missile systems at the NATO Missile Firing Installation in November at Chania, Greece, during Artemis Strike, a German-led multinational air defense exercise. Fires leaders and Soldiers will need to conduct both LRPF and air and missile defense tasks in a variety of settings—some more supported, some more austere—to support joint and multinational operations in the future battlespace. (U.S. Army photo by Sgt. 1st Class Jason Epperson, 10th Army Air and Missile Defense Command)

PRECISION FIRES TILT the FIELD

New technologies give the U.S. greater precision at greater range; stronger air and missile defense.

by Mr. Michael Holthe

Imagine a battlefield where U.S. forces do not enjoy freedom of maneuver, where supporting forces cannot guarantee dominance of the airspace above us or even the ability to communicate or track and locate threats. Imagine a battlefield where friendly forces are not only overmatched by range but where the enemy can employ myriad electromagnetic effects to deny or degrade our ability to locate targets. Such a scenario is not only fast approaching, but is in many cases already upon us.

These very real, very urgent challenges are what drive the Army science and technology (S&T) strategy for lethality, both now and in the future. Our lethality strategy is anchored in its goal to regain and ensure overmatch against any adversary, at any time and in any environment to enable decisive joint warfighting capability and ensure freedom of maneuver to close with and engage with our adversaries.

Among the critical modernization priorities, as identified by the secretary of the Army and chief of staff of the Army, that are key to U.S. forces seizing the initiative and owning the battlespace remain the ability to employ precision fires—that is, the ability to precisely place a mortar round, artillery shell, cruise missile, etc., exactly where it will be most damaging to the enemy, at greater range than our adversaries—and the ability to protect those fires assets as well as our maneuvering forces as they drive toward the objective.

As the Army develops future long-range precision fires (LRPF) capabilities for both missile and cannon artillery, its requirements for what that system can do must take into account multiple, complex and integrated threats across the range of military operations in anti-access and area denial (A2AD) environments. Future LRPF must enable the joint force to continue to deter adversaries and, when necessary, enable fires overmatch and freedom of maneuver through the destruction, neutralization or suppression of adversary capabilities.

LRPF units must be mobile, expeditionary and prepared for global threats—an important emphasis as adversaries are investing in technologies to obtain a differential advantage and undermine the United States' ability to achieve overmatch. Those threats include precision-guided rockets, artillery, mortars, aircraft, satellites, electronic warfare and ballistic and cruise missiles that challenge traditional U.S. dominance in land, air and maritime domains. Success in this future battlespace also will require the ability to adapt to multiple scenarios. To overcome these challenges, the Army S&T community is exploring the development of technologies that will restore LRPF overmatch and protect friendly forces from air and missile defense threats.

In multidomain battle, future Army LRPF forces must provide precise, responsive, effective and multifunctional fires to enable maneuver forces as they fight across complex A2AD environments that include cyber and PNT contested spaces, electronic warfare and dense urban environments, to maintain overmatch in seizing, retaining and exploiting the initiative. Multifunctional capabilities will provide the commander with sufficient scale and endurance to support joint combined arms operations with limited assets. This complementary relationship between fires and maneuver is the foundation of multidomain battle. In the future, the Army must be able to achieve increased standoff, expand fires across any domain of battle, converge multifunctional capabilities, enhance the link between battlefield sensors and the Soldiers operating fires weapon systems, and leverage joint, interorganizational and multinational capacity to ensure domain superiority.

Being precise means operating with accuracy to achieve desired effects only on desired targets. Future fires forces must have adequate range, precision and mass to offset threat capabilities and defeat threat forces throughout the depth of the battlefield in all domains. Future fires leaders and Soldiers must conduct both LRPF and air and missile defense tasks in a variety of conditions and missions to support multifunctional, joint combined arms operations. Future fires formations are envisioned as flexible, expeditionary and sustainable—mission-tailored organizations whose agile leaders and Soldiers will integrate and employ multirole and multimission weapon system capabilities, such as the Multi-Mission High Energy Laser system, which will provide short range air defense for the maneuvering force as well as enable counter-battery fire capabilities for the fires force, using a common mission command network and procedures.

To enable this future concept of operations, Army S&T is developing technologies in mutually supportive areas of precision fires as well as air and missile defense. The LRPF capabilities provide the land component of the joint force the ability to detect and engage enemy targets at extended ranges well beyond those of the adversary. They, in concert with air and missile defense capabilities, also enable freedom of maneuver and protection of friendly forces as they assemble to maneuver, close with and defeat enemy forces at both the operational and tactical levels.

Fires missions, particularly ballistic missile defense and counter-fire, place a premium on the ability to react rapidly to battlefield stimuli and are time-sensitive by nature, requiring rapid responses for success. LRPF units must detect adversary targets before U.S. and friendly units can be detected and rapidly deliver devastating fires and effects beyond the counter-battery fire range of the enemy. These long-range precision missiles and cannon artillery provide layered and overlapping ranges of indirect fires to regain operational advantage.

Air and missile defense capabilities provide improved protection for the joint force against enemy manned and unmanned aircraft, cruise missiles, rockets, conventional artillery and mortars. To increase survivability, units must operate with greater dispersion and range while improving the capability to concentrate fires and effects. To operate with greater dispersion, units are protected by layered air and missile defense countermeasures that provide protection at multiple distances and against diverse threats such as counter-unmanned aerial systems, as well as "shieldlike" protection from enemy observation, indirect fires, surface-to-surface weapons and air attack. The Army must be able to see and fight across wider areas to counter adversaries that have long-range and precise lethal capabilities.

LAYERED DEFENSE

A U.S. Air Force fighter jet flies overhead as two Soldiers raise a signal tower for a Patriot missile system during a training exercise in October at Kadena Air Base in Japan. Protecting fires assets requires layered air and missile defense countermeasures that provide protection at multiple distances and against diverse threats. (U.S. Army photo by Capt. Adan Cazarez, 94th Army Air and Missile Defense Command)

In support of Army modernization priorities and the Army S&T vision for LRPF and air and missile defense, the Army lethality strategy prioritizes investment in several key technology areas:

- **LRPF:** Projection of extended-range point target and area effects: Significantly increase ranges as well as the ability to identify and target threat systems with ground-based missile and cannon artillery systems at ranges beyond the firing distances of adversary systems. Deliver overwhelming lethality and massed-area effects to produce a resulting fires forces with overmatching fires capability at extended tactical and operational ranges.

- **Air and missile defense:** Protect maneuvering forces and provide cost-effective, 360-degree battlespace depth capability. Provide layers of lethal countermeasures for formations. Technologies in this area include lower-cost extended-range air defense missiles for countering cruise missiles and strategic unmanned aerial systems (UAS); high-energy lasers for countering rocket, artillery and mortar threats; and tactical UAS and gun-based air defense systems for tactical UAS. This layered approach ensures "shieldlike" protection for both the fires and maneuvering forces.

To achieve success in these two primary investment areas, several key subcomponent technologies are vital as well, such as:

- **Navigation, guidance and timing:** Provide navigation technology to enable precision guidance in GPS-degraded or -denied environments. Develop assured position, navigation and timing capabilities to prevent near-peer threat detection, denial and exploitation of GPS capabilities affecting weapon systems and geolocation of units.

- **Cooperative and collaborative engagement:** Provide the ability to perform coordinated precision strikes against both hard and soft targets and enable collaborative engagement of multiple targets simultaneously or sequentially to optimize the effectiveness of precision strikes.

PROTECT THE BASE

Air and missile defense capabilities, like this Terminal High Altitude Area Defense weapon system assigned to the 94th Army Air and Missile Defense Command at Andersen Air Force Base, Guam, will provide improved protection for the joint force against enemy manned and unmanned aircraft, cruise missiles, rockets, conventional artillery and mortars. (U.S. Army photo by Capt. Adan Cazarez, 94th Army Air and Missile Defense Command)

- **Weapons fire control, targeting and sensor fusion:** Provide fires, target identification, discrimination, deconfliction and fire control in land, air and maritime domains. Provide fused data from air, land, maritime, cyber and warfighter-borne sensors to achieve real-time integration and optimization of targeting data.

- **Advanced energetics, propulsion and warheads:** Provide advanced energetics and warhead technologies for maximum fragmentation radius, maximum blast, reduced collateral damage, and penetration against targets. Propulsion technologies for increased range and energy management.

- **Novel materials and structures:** Allow weapons to survive higher Mach speeds with increased lethality through the use of robust high-compression strength composites, advanced material technologies with superior thermal and structural properties, and insulation materials that reduce volume and weight.

- **Image processing and target tracking:** Increase performance in high-clutter, networked environments; provide capability for autonomous engagements and secure data links; and develop multipurpose sensors for LRPF that include anti-ship capabilities to enable freedom of maneuver.

- **Modeling and simulation:** Enable deeper understanding of warfighter needs and impacts of alternative designs through the use of models to characterize changing operational contexts; capabilities for data-driven trade space exploration; and analysis for multidimensional generation and evaluation of alternative designs.

CONCLUSION

As investments for the future, these technologies will enable the Army to emplace assets and to engage and destroy targets that are inaccessible with current ground-based fires capabilities, as well as increase its capability to support maneuver, defend against enemy air attack and counter enemy long-range systems. The following articles on high-energy lasers, the Single Multi-Mission Attack Missile and Missile Multiple Simultaneous Engagement Technologies, and research on distributed and cooperative engagements in contested environments examine key capabilities that Army S&T is investing in to inform future systems and not just level the battlefield, but tilt it in our favor.

For more information, contact the author at ***michael.j.holthe2.civ@mail.mil****.*

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The Army must be able to see and fight across wider areas to counter adversaries that have long-range and precise lethal capabilities.

WHEN BEAMS COMBINE

With high-energy lasers, the Army looks to optimize lethality and efficiency against multiple threats and targets.

by Dr. Kip R. Kendrick

LASERED OUT OF THE SKY

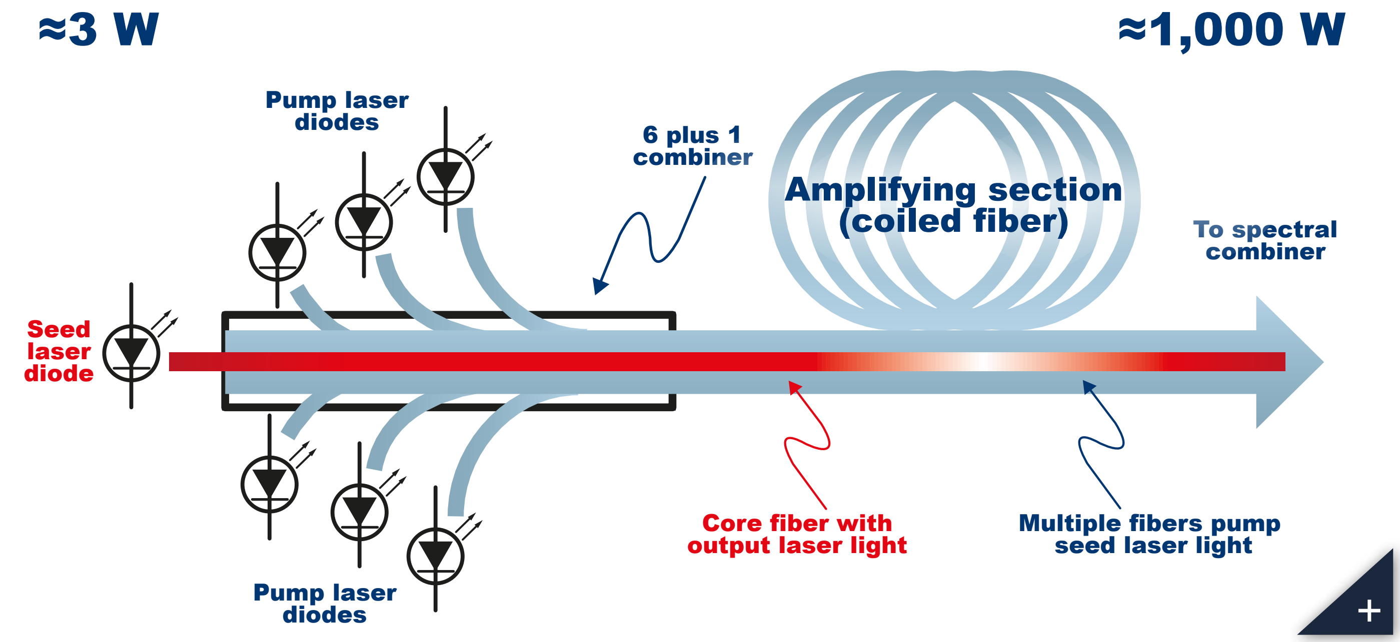
One of the drones shot down by a MEHEL-equipped Stryker in April at Fort Sill during MFIX-17. Lessons learned during MFIX-17 will make the MEHEL easier for Soldiers to operate. (U.S. Army photo)

Solid-state laser weapons offer warfighters unique capabilities for the battlefield: precision, controllability, predictability, repeatability and flexibility. These laser systems will enable Soldiers to defeat multiple threats and affect materiel targets. Each engagement, whether disabling an enemy's communications antenna or causing low-order detonation of an artillery round in flight, has an average cost of $30.

During the 1970s, the Army investigated carbon dioxide lasers. But there were issues with beam transmission through the atmosphere and difficulty focusing the beam to a small spot at the target. Both factors reduced the lasers' effectiveness. Chemical lasers provided improved performance, but the hazardous materials required to generate the laser beam posed significant risk to warfighters.

A safer, more efficient alternative to chemical lasers, solid-state lasers generate their beam by converting electricity into tightly focused laser light. There are two main types of solid-state high-energy lasers—greater than 1 kilowatt (kW)—in development today: thin-sheet and combined-fiber lasers. Of these two, combined-fiber lasers show the greatest promise for laser weapon systems on tactical and combat platforms because of their efficiency in converting electrical power to power on target. The Army, working with the High Energy Laser Joint Technology Office, initiated the Robust Electric Laser Initiative (RELI) effort in 2010. Four contracts were issued under RELI. The Army retained two of the contracts and later elected to scale a combined-fiber laser, designed by Lockheed Martin Corp., to a 50-kW class power level.

FIGURE 1



POWERING UP

Combined-fiber lasers show great potential for use in laser weapon systems on tactical and combat platforms because they convert electrical power efficiently to power on target. However, today's fiber laser modules are limited to a little over a kilowatt. So, to reach higher power levels, the individual fiber laser modules must be combined into one beam. This diagram shows how the combination process works. (SOURCE: SMDC/ARSTRAT)

FIBER LASER BASICS

A fiber laser module begins with pump laser diodes to create light energy from electrical energy. The light from the pump laser diodes is then fed into a special optical fiber where the power from a seed laser diode is amplified. (See Figure 1.)

Today's fiber laser modules are limited to a little over a kilowatt. To reach higher power levels, the individual fiber laser modules need to be combined into one beam. The Lockheed Martin design uses a spectral-beam-combining architecture whereby laser beams of different frequencies are transmitted to a grating and combined into a single beam that is transmitted out of the laser at many tens of kilowatts.

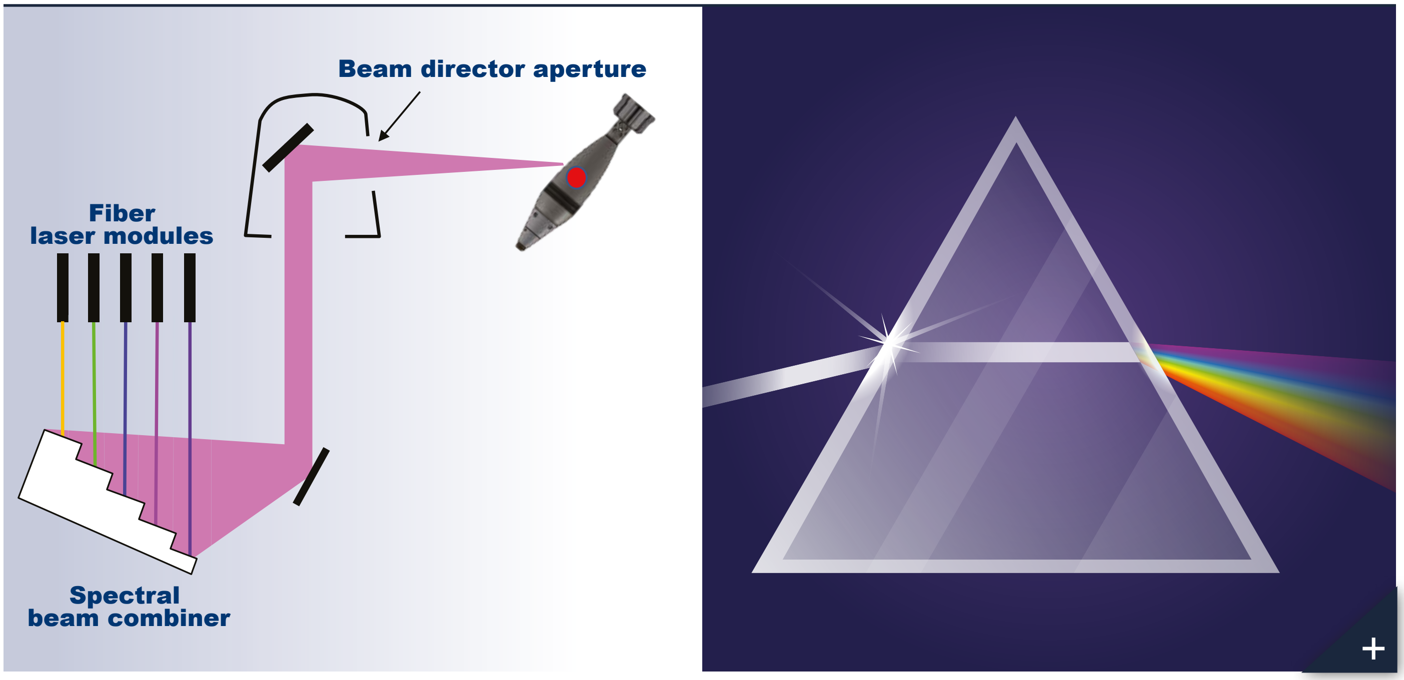
To understand the spectral-beam-combining process, imagine shining a beam of white light through a prism: The prism bends each of the frequencies differently, scattering the original beam of light into multiple beams of various colors. The spectral beam combiner does the opposite: It combines the different frequencies of each fiber laser module into a single beam. (See Figure 2.) Another beam-combining architecture, coherent-beam combining, is also being developed and matured within the high-energy laser science and technology community.

GETTING SOLUTIONS TO SOLDIERS

The Army's Indirect Fire Protection Capability, Increment 2 – Intercept (IFPC Inc 2-I) is an acquisition program designed to provide a materiel solution to protect troops from cruise missiles, unmanned aerial systems (UAS), and rockets, artillery and mortars (RAM). IFPC Inc 2-I has a Block 2 milestone decision in FY24 to add the counter-RAM capability to the program.

The U.S. Army Space and Missile Defense Command/Army Forces Strategic Command (SMDC/ARSTRAT) is developing the 100-kW High Energy Laser Tactical Vehicle Demonstrator (HEL TVD) to address the counter-RAM requirements for IFPC Inc 2-I, Block 2. The HEL TVD will be integrated on the 10-ton variant of the Family of Medium Tactical Vehicles. In FY22, the HEL TVD will demonstrate target acquisition, tracking, aimpoint selection and maintenance, to defeat selected rocket, artillery and mortar threats.

FIGURE 2



COMBINE, CONTRAST

A spectral beam combiner does the opposite of a prism. It combines the different frequencies of each fiber laser module into a single beam. By contrast, when a beam of white light shines into a prism, the prism bends each frequency of light contained within the beam, scattering the white light into multiple beams of various colors. (SOURCE: SMDC/ARSTRAT and Oceloti/iStock)

Multiple subsystems are under development for integration into the weapon system. They include laser, beam control, electrical power, thermal management and fire control. The goal of the FY22 demonstration is to confirm that a pre-prototype laser system can defeat RAM threats in an environment similar to the battlefield.

To reduce risk and provide information for HEL TVD development, the Army is using its High Energy Laser Mobile Test Truck (HELMTT). The HELMTT has demonstrated laser lethality against small-caliber mortars and Group 1-2 (hobby-size) UAS using a slightly modified 10-kW commercial off-the-shelf fiber laser.

In FY14, this system underwent several proof-of-concept demonstrations, defeating small-caliber mortars and UAS. In FY16, the HELMTT was part of the Maneuver Fires Integrated Experiment (MFIX) 2016 at Fort Sill, Oklahoma, exposing the warfighter to the military utility of laser weapons. HELMTT also was used in the Joint Improvised-Threat Defeat Organization's UAS Hard-Kill Challenge in FY17. In addition to these demonstrations, the HELMTT has collected laser propagation data in a variety of environments, from coasts to high deserts. These data helped anchor models used to predict laser effectiveness on the battlefield.

The 10-kW laser subsystem has been removed from the HELMTT to modify the platform for integration of the Lockheed Martin RELI 50-kW-class laser. The Army will test the 50-kW HELMTT against a variety of RAM and UAS targets in late FY18. This demonstration is designed to verify laser lethality against RAM threats for the HEL TVD effort.

To ensure that laser weapons will be lethal against assigned threats, the Army is developing vulnerability modules for RAM and UAS. The Solid State Laser Testbed on the High Energy Laser Systems Test Facility at White Sands Missile Range, New Mexico, collects lethality data for these targets. Engineers there analyze each threat to determine the best aimpoints, as well as the total laser energy required to defeat the threats. The results are threat-specific vulnerability modules in a format common across the DOD laser community. Laser lethality is one of a number of areas in HEL technology development where the services and agencies work together and share data.

ARMED AND DANGEROUS

A MEHEL-equipped Stryker shot small fixed- and rotary-wing UAS out of the sky using a 5-kW fiber laser in April during MFIX-17 at Fort Sill, a first for the Army. (U.S. Army photo by C. Todd Lopez, Army News Service)

FINDING THE RIGHT PLATFORM

The Army has been working with industry on a concept for a high-energy laser combat platform to be used in warfighter experimentation. Integration of existing laser subsystems began in January 2016; within four months the Mobile Expeditionary High Energy Laser (MEHEL) participated in MFIX-16 at Fort Sill.

A 2-kW fiber laser system, integrated on a Stryker platform, was the first high-energy fiber laser on a combat vehicle. The MEHEL defeated hobby-size quadcopters and some ground targets during MFIX-16. While defeating targets shows the potential for lasers on the battlefield, the main objective of the MEHEL is to support the development of tactics, techniques and procedures and concept of operations for future laser weapons. Late in FY16, the 2-kW laser was replaced with a 5-kW fiber laser. The Army designated this new 5-kW configuration MEHEL 2.0.

In preparation for MFIX-17, contractors trained Soldiers to operate the MEHEL 2.0. During the integrated experiment, these Soldiers shot down small fixed- and rotary-wing UAS—a first for the Army. The Army is using lessons learned from MFIX-17 to make the MEHEL easier for Soldiers to operate. MEHEL 2.0 will also be part of MFIX-18.

MULTI-MISSION HIGH ENERGY LASER

The Multi-Mission High Energy Laser (MMHEL) is a technology maturation initiative starting in FY18. Technology maturation initiatives facilitate the transition of key technologies to acquisition programs. The MMHEL will be a 50-kW laser system on a Stryker, designed to reduce risk and inform requirements for the Maneuver-Short Range Air Defense objective capability. The MMHEL will undergo an operational demonstration in FY21 to validate the laser system's counter-RAM, counter-UAS, counter-battery targeting and counter-materiel capabilities.

In addition to the HEL systems developed for data collections and demonstration, the Army is conducting basic and applied research in HELs. The basic research is focused on developing technologies for next generation high-energy lasers, tracking systems and control algorithms. The Mobile Beam Control System Integration Laboratory will be built to investigate, mature and verify the performance of next generation beam control technologies. This trailer-mounted laboratory will provide the ability to collect performance data on beam control components in a variety of atmospheric environments.

CONCLUSION

The Army recognizes the many advantages that HEL weapon systems may provide the warfighter and is developing HEL technologies to satisfy requirements for programs of record. High-energy laser weapons simplify logistical support, requiring only diesel fuel, which is easily converted into electricity to power the laser. High-energy laser weapons also have the flexibility to defeat or affect many different types of threats, making the laser a potential air-defense solution for maneuvering forces and forward bases. These characteristics, coupled with a low cost per shot, will provide a battlefield advantage for U.S. forces.

For more information, contact the SMDC/ARSTRAT Public Affairs Office at 256-955-3887 or 719-554-1982, or at P.O. Box 1500, Huntsville, AL 35807; or go to ***www.youtube.com/armysmdc****.*

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SURVIVE and PROJECT INDIRECT FIRES

AMRDEC pursues two missile technology solutions to strengthen the Army's hand in close combat.

by Mr. Spencer Hudson and Mr. Shannon Haataja

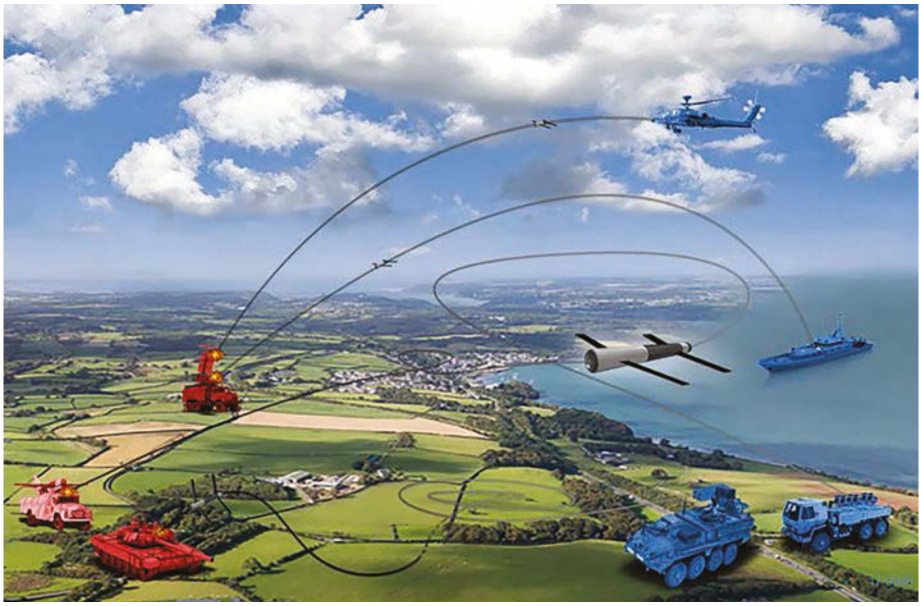
One of the top U.S. Army modernization priorities is increased precision and effects at extended range in all operational environments. This is part of a broader strategy to make warfighting units more lethal to regain overmatch against peer and emerging threats. In response, the deputy assistant secretary of the Army for research and technology's lethality portfolio is investing in a layered, extended-range precision fires solution across operational levels to shape deep and close fights. The lethality portfolio represents science and technology (S&T) investments at the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) and other contributing elements of the Army S&T enterprise.

The close fight, or close combat, is the final engagement phase, wherein U.S. ground forces maneuver to seize and control key terrain and destroy enemy forces. This fundamental building block of operational success may be challenged by highly capable peer threats, particularly in anti-access and area denial threat environments where U.S. forces may lack traditional close air support, and where U.S. anti-tank guided missiles may be outnumbered.

To address this gap, two midterm S&T investments in close combat missiles are focused on giving small expeditionary units increased standalone precision and lethal effects at extended ranges to enable freedom of maneuver to decisively defeat the enemy.

The Single Multi-Mission Attack Missile (SMAM) is an emerging precision loitering missile capable of engaging enemy tanks and other high-value targets out to 35 kilometers or farther. Loitering refers to a missile's ability, when commanded by the operator, to fly a specified flight path to a known target location, circle in a holding pattern once in the target area, and engage or wave off and

FIGURE 1



COVERING ALL THE OPTIONS
SMAM is capable of precisely targeting and defeating hard and soft targets at extended ranges and can be integrated on a range of Army ground vehicle and aviation platforms as well as maritime platforms. (Images courtesy of the authors)

then re-engage the same or a different target of interest.

Soldiers operate the SMAM with a commercial tablet-based controller. The system's two-way data link provides full-motion video for positive target identification. The operator selects the target using a track box once it comes into the field of view. Image processing software then automatically locks on to and guides the missile to terminal engagement with no operator intervention required. The operator has the ability to wave off and redirect the missile to another target, making it extremely effective in urban terrain and helping to avoid collateral damage. (See Figure 1.)

SMAM includes a self-contained launch tube and a portable mast-mounted antenna. With a total weight, including the missile, of 50 to 70 pounds, the system is easily transportable and can be readily mounted on a range of Army ground vehicle or aviation platforms.

AMRDEC and partnering organizations have been developing this emerging capability for several years. The organizations achieved a major milestone in June 2015 with a successful proof-of-principle, live-fire range demonstration that resulted in direct hits on a 12-man mannequin array and a sport utility vehicle, both located 25 kilometers from the launch point.

The AMRDEC Enhanced SMAM S&T program, getting underway in FY18, will focus on precision navigation and targeting at extended ranges in contested, GPS-denied and electronic-jamming environments, as well as optimizing warhead technology to defeat main battle tanks.

AMRDEC is also working on another system: Missile Multiple Simultaneous Engagement Technologies (MSET) is a suite of technologies providing the capability to rapidly defeat swarming and dispersed threats, providing simultaneous multiple launch, control and supervised autonomous terminal engagement of multiple missiles against various targets.

MSET is configured as a kit that could be hosted on a variety of manned and future unmanned Army ground vehicles and aviation platforms. (See Figure 2.) This allows it to leverage existing organic intelligence, surveillance and reconnaissance targeting sensors such as small unmanned aircraft systems, day and night cameras and forward-deployed radars. Both SMAM and MSET are designed to directly accept precise target location coordinates transmitted over the tactical network from external targeting sensors.

Two midterm close combat missile S&T investments are focused on giving small expeditionary units increased stand-alone precision and lethal effects at extended ranges.

AMRDEC initiated a rapid prototyping effort for MSET in 2016 that involved modifying and integrating existing technologies to demonstrate concept feasibility. The goal was for a single operator to be able to fire and control six loitering precision missiles against four static targets and two moving targets, using an Android application to simultaneously control the surrogate missiles and then sequentially perform the terminal engagements.

Targeting data was provided by a surrogate radar feed. AMRDEC successfully conducted extensive hardware-in-the-loop integration and testing, coupled with six risk-reduction flight test events over a nine-month period. This culminated in a proof-of-principle range flight demonstration conducted by AMRDEC in November at Dugway Proving Ground, Utah.

Future AMRDEC S&T efforts on MSET will focus on developing image-processing algorithms to enable supervised autonomous terminal engagement, i.e., moving from "man-in-the-loop" to "man-on-the-loop," where the operator can still observe an engagement while retaining the ability to abort the mission once the target has been positively identified by the operator. AMRDEC's future efforts also will focus on developing key operator fire control and data link technologies that will scale the system up from six simultaneous engagements to as many as 20.

CONCLUSION

S&T programs for SMAM and MSET will demonstrate key technologies to enable U.S. Army multidomain battle and the manned-unmanned teaming operating concepts of decentralized, expeditionary maneuver in contested environments. Once fielded, those technologies will provide brigade combat teams with precision strike capability at extended ranges against hard armor and high-value targets in scenarios that demand increased autonomy while providing increased Soldier survivability. These close combat investments are part of the lethality portfolio's integrated strategy to achieve the Army's precision fires modernization priorities.

For more information on MSET, refer to Sources Sought W31P4Q-17-R-0132, released June 22, 2017.

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FIGURE 2

KEY **MAFIA C2:** Maneuver Aviation Fires Integrated Application Command and Control **DDL:** Digital datalink **EO/IR:** Electro-optical/infrared **FCU:** Fire control unit

OBJECTIVE: OVERMATCH

MSET works by relaying sensor target inputs to a vehicle-mounted command-and-control and fire-control system. That system determines grid coordinates, generates flight paths and launches the appropriate number of missiles. Those missiles are guided via real-time waypoint updates to the target location, and image processors on the missile provide positive identification, target lock-on and track to terminal.

ON TARGET

Experts at ARL are looking deep into the science of the future battlespace and trying to answer questions that have no simple answers, such as how to deliver the power of a tank without a tank.

by Dr. Frank Fresconi, Dr. Scott Schoenfeld and Dan Rusin, Lt. Col., USA (Ret.)

The notion of winning in a complex world requires envisioning a battlefield that is so complex and multidimensional that, more often than not, it's referred to as a battlespace. With good reason: The kind of warfare that the Army must prepare for, and for which experts at the U.S. Army Research Laboratory (ARL) at Aberdeen Proving Ground, Maryland, are developing new technologies, would include everything from the most conventional kinds of warfare, to electronic warfare, to warfare that employs technologies not yet invented.

To understand the difficulty of the questions that the Distributed and Cooperative Engagements in Contested Environments program is trying to answer, imagine a foreign city under siege. The city is in a NATO country that adjoins a hostile power. That hostile power invaded and took over the city months ago, and now it's the Army's job to help our NATO ally dislodge enemy forces and take back the city. The adversary has had plenty of time to dig in and fortify its positions. In addition, it has deep influence on both the electric and electronic infrastructures.

This is a city in a friendly nation, so the Army wants to damage enemy capabilities without devastating the city, which is important to the global economy. Soldiers need to be smart for this to work, and so does nearly every bit of their equipment.

BIGGER IMPACT, SMALLER FOOTPRINT

Future collaborative weapons will be so precise that they will challenge the age-old concept of mass. These interconnected weapons will have shared sensing, computing and navigating capabilities that deliver the desired battlefield effect with fewer, more precise and smarter warheads. (SOURCE: Shutterstock)

Yes, smart equipment.

If Soldiers are denied global positioning systems, they will have to navigate under pressure. Tanks might not fit within the infrastructure of this environment. So, if the force requires a tank's capabilities, they'll have to come from something other than a tank.

If Soldiers require artillery, but conventional artillery conflicts with civilians in close proximity, they will have to find something that can provide the effects of artillery without artillery.

ARL is developing the technologies to fit a set of tools that will be smarter, more aware, connected and autonomously collaborative. These interconnected weapons will operate along the lines of shared sensing, computing and navigating, with the goal of delivering the battlefield effect by actually using fewer but more precise, smarter, warheads.

A NEW VOCABULARY

To understand the new battlespace, it helps to understand some of the concepts, both old and new, that ARL is working with, because in the future we may look to provide new ways to deliver existing weapons to oust an enemy. Soldiers may be effective in one case by using one weapon directed at a single target, and, in other cases, by delivering artillery shells that loiter over an area and mass until needed. Position, navigation and timing will be key in overcoming challenges. The outcomes, or effects of future warfare, will need to be both kinetic and nonkinetic. Use of a precision missile would deliver the kind of physical damage that is common in warfare—a kinetic effect. A less traditional, nonkinetic effect would be knocking out an enemy's communication system.

Kinetic and nonkinetic assets of the future will be networked and able to collaborate at scale. The landscape of battle that we expect will expand beyond the mounted and dismounted Soldiers to which we have grown accustomed, and will include robots of different shapes and sizes. The interesting, complex and, as yet, nonexistent nonkinetic effects that will have a major impact could include electronic warfare assets dispersed in the battlespace by Soldiers, small unmanned aerial vehicles or munitions with varieties of electronic payloads.

Military leaders have indicated that future fights could be waged with weapons that will take orders from unit commanders and then, after launch, would have to "talk" to each other on the fly, figure out

Words of Future War

Kinetic: Traditional explosive weapons that physically damage things.
Nonkinetic: Novel effects that stop electronics, disturb sensors or influence people.
Distributed: Multiple sensors, multiple warheads of various types, at several locations.
Collaborative: Cooperative computing, distributed computing, sharing information.
Contested: Enemy actions to retaliate, such as jamming or anti-aircraft/anti-artillery.
Effect: The physical or behavioral state of a system that results from an action.

Even these words are novel and in development. Many are not even included in the DOD Dictionary of Military and Associated Terms at http://www.dtic.mil/doctrine/new_pubs/dictionary.pdf.

Sometimes what's needed is a really big bomb.

what to do, and make course corrections according to the changing position of the enemy or intelligence. These are just some of the difficult scenarios that ARL grapples with. Another issue is adapting to a common operating picture.

HARD QUESTIONS

The U.S. intends to defeat near-peer adversaries who have had time to establish themselves in a foreign city. Scientists prepare by taking a hard look at how to deliver firepower to difficult targets in places that are farther away. Can we deliver artillerylike effects without an artillery cannon? What else can we put in the weapon round to make it infallible? Can weapons talk to each other on the fly? Can these collective communications be made to resist misinformation?

To address these questions without clear answers, we have to think in terms of the outcomes that will best serve combatant commanders. For instance, scientists are taking steps to design approaches to disable enemy equipment that is fixed, hiding, moving or attacking at a high rate of fire and volume.

The U.S. must recapture overmatch and avoid technological surprise by empowering Soldiers with the capabilities of a main battle tank, empowering squads with the full flexibility of combined arms and empowering armored brigades with full freedom of maneuver in the most challenging environments.

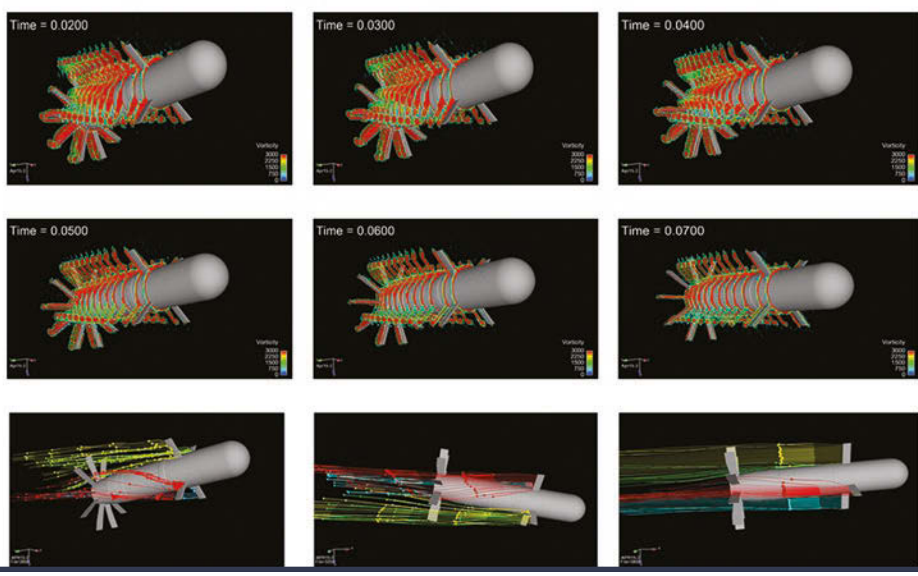
Our intention is to develop the science to enable battlefield assets to be effective in dispersed positions. This requires weapon systems that communicate with one another, make autonomous decisions and maneuver to provide desired effects. By combining various weapons over the distributed battlespace, working together to provide the right lethal or nonlethal effects on target, Soldiers will deliver fewer high-explosive rounds that are more precise.

THE HURDLES WE FACE

Technical gaps exist between the desired and current states of U.S. land forces' capability to implement distributed and cooperative engagement in contested environments. ARL improves the odds of technological success by identifying technology gaps and conducting basic research from the earliest stages of the technology life cycle.

Here are four known barriers to realizing the capability:

Navigation: Navigation is the fundamental feedback required to deliver weapons on the battlefield. Advances in weapon navigation are hindered by technical limitations associated with algorithms, sensing on dynamic vehicles, real-time processing, cost and extreme weapon dynamics. Some weapons are subject to accelerations 100,000 times the acceleration of gravity from being launched to speeds four times the speed of sound. Other weapons are spun thousands of times per second to maintain flight stability—to fly accurately



A COMPLEX FUTURE

ARL uses defense high-performance computing, advanced computational fluid dynamics and other techniques to model aerodynamic interactions. Future engagements will likely employ weapons that incorporate advances in propellants and aerodynamics to allow them to maneuver and change course based on a commander's guidance. (SOURCE: ARL)

SETTING THE SCENE

To achieve the upper hand on a battlefield that's expected to be complex and multidimensional, ARL is developing interconnected weapons that will incorporate advances in shared sensing, computing and navigating. (Image by Evan Jensen, ARL)

on a line to the target and not tumble over. ARL predicts that future technologies will face challenges against threats such as jamming, spoofing, camouflage and decoys, radar or laser warning receivers and active protection. The performance degradations that come with counterattack will be amplified if the enemy has numerical superiority in troops, platforms and weapons.

The strategy of this research is to use multiagent collaboration to address these threats and technical gaps. Multiple dispersed entities equipped with varied, low-cost components can gather the navigation information required to deliver the weapons in a contested environment where a single, high-cost weapon may fail. For instance, six or 12 smaller lethal agents packed into a transport carrier may be less expensive than a $1 million missile. One approach is to use many "dumb" weapons that would take orders from a "sophisticated" parent that would in turn communicate back to the warfighter and the network of sensors.

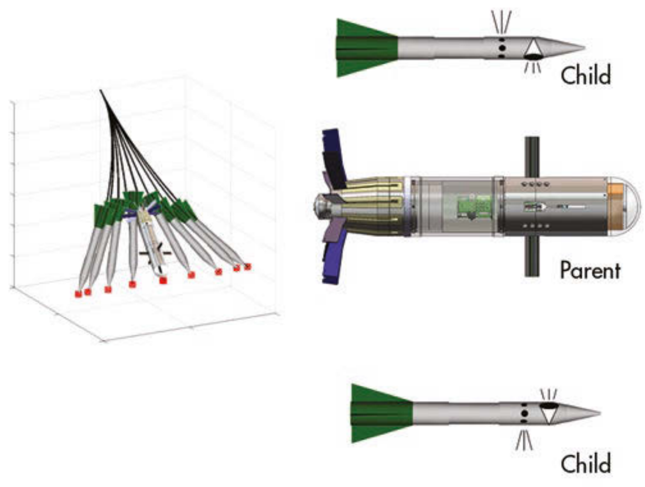
The focus of navigation research is on strong, robust software algorithms. New software algorithms that are able to perform in uncertainty, and despite denial, deception and misinformation, will be able to share appropriate information for group action. Several approaches are being developed and implemented on real-time processors with associated components for concept demonstrations that overcome these technical barriers, including:

- Image processing algorithms to identify friend from foe. In the past, these algorithms used rigid models. However, recent advances in machine learning techniques may enable these algorithms to detect and classify complex targets more powerfully.

- Communication between weapons and networked assets to rapidly share information and coordinate massed effects in the battlespace. Scientific insights must be gained into communications to overcome limitations in the amount of information that can be shared and to protect information from adversarial intent.

- Algorithms to fuse sensor data (e.g., images from a camera and inertial measurement tools such as those used in cellphones) from different weapons and determine the critical information for autonomous group decisions within a short timeline as a weapon is flying toward the target. The current state of the art relies heavily on linear models for a single weapon, but research will improve performance by focusing on incorporating nonlinear behaviors of the threat and extending the techniques to multiple weapons.

In the same way that many eyes looking out of many windows from many vantage points can give a total composite picture, we can combine the sight-picture of several weapons as they approach the target to provide a better solution. ARL is leveraging the ongoing revolution in the microelectronics industry that aims to



PARENTAL AUTHORITY

The concept of "parent" and "child" weapons uses distributed computing and communications to achieve the desired effects. Child weapons take orders from a parent—which has more onboard computing capability for communications and processing—that would, in turn, communicate back to the warfighter and the network of sensors. (SOURCE: ARL)

reduce size and cost and improve the performance of real-time processing and sensors in the weapons environment.

Each of these complicated weapons comes with its own additional challenges, such as the need for power. As new sophisticated electronic components are developed, they must be made rugged for flight or ballistic delivery. They also must use tiny amounts of power. Further, while all these weapons will demand much less power than today, some of the "parent" weapons will have to have more computing capability on board for communications and processing.

Maneuverability: We want to develop one weapon that flies like an airplane most of the way and then performs like a precision bomb at the last second. This may mean turning very quickly and actually changing the shape of the aerodynamic parts while flying. Maneuverability enables extended-range engagements by using glide aerodynamics, the interception of moving targets, the evasion of defensive suites and favorable shaping of the terminal approach. This would allow new U.S. warheads to strike dug-in targets, effectively hitting targets on the far side of obstacles from multiple directions. We will be able to hit the back of enemy fortifications or fly the weapon into doors or tunnels. Hardening for the weapons environment and reducing the size and cost of technology for maneuverability to allow more precision engagement means less ammunition will be fired. Increased battlefield effectiveness will come from smaller, more precise weapons that talk to one another. For the warfighter, having maneuverable weapons means that their truckload of ammunition will last longer, do more and require resupply less often.

For larger, fast-moving artillery or missiles, knowledge gaps inhibit our ability to predict and characterize controlled flight for maximal maneuverability. Additionally, we lack the technology to outmaneuver threats while subjected to the extreme environment. Research is specifically designed to find weapons that fly farther, faster, with more precision and maneuver control to penetrate an enemy's increasingly complex network.

ARL is solving several problems of very fast flight. For instance, when very fast bodies fly near each other, the air vortex can sometimes cause individual rounds to remain very close or impact each other. This is undesirable, to say the least. The science that ARL will develop will include optimal flight vehicle design using an understanding of close-maneuvering aerodynamics.

This understanding will be demonstrated using small weapons carrying launch-hardened components, flying from subsonic to supersonic speeds with the ability to drastically change shape in adapting to emerging conditions. This morphing weapon will have to make its own last-second decisions based on complex rules governed by a simple interface that the warfighter controls.

Modular and scalable lethality: Cooperative weapons will require efficiencies and mechanisms for concepts that execute cumulative lethality. We envision that individual munitions in the flight group may not carry similar payloads; these payloads may be significantly reduced when compared with conventional payloads with strikes that are sequenced for multiple impacts. As such, we need to carefully understand the variety of lethal mechanisms and the sequencing of impacts to provide effects against dismounts, protective structures, aircraft, tactical vehicles, hardened combat platforms and even adversarial inbound munitions.

Sometimes what's needed is a really big bomb. But more often, a more precise approach with smaller explosions is preferred. ARL's computing expertise and its interaction with other DOD laboratories are very important here. The ARL team is fully linked with other groups of DOD scientists to develop the models, simulations and computational codes required for success.

Protection: Weapons need protection against an enemy who will be fighting back. Kinetic, directed electromagnetic and electronic mitigation of a peer adversary is part of the solution. To fight in the future battlespace requires the assessment of an unpredictable enemy, but one who has similar peer technology. Our systems must be able also to attack and defeat their systems, which are also increasingly electronically complex, highly maneuverable and guided by autonomous programs.

As our weapons head to the target, the enemy will be fighting back. Our weapons will have to perform very fast evasive maneuvers and generate their own force field or "cloaking-device," because the enemy will be defending its site with anti-aircraft or anti-artillery-type defenses. These are all extremely hard science problems.

Crippling blows of the future will rely on a small number of dispersed entities to deliver overwhelming kinetic and non-kinetic effects by combining omni-speed, radical maneuverability and navigation in contested environments and efficient payload-kill mechanisms. Omni-speed and radical maneuverability depend on long-range advances in propellants and aerodynamics so that a weapon can maneuver and change course based on a commander's guidance. Navigation of teams of projectiles will require each round to be able to communicate with the collaborative munitions on the team while on the path to the target.

CONCLUSION

Through the fundamental research program at ARL, scientists dig into problems and move beyond the least likely approaches, in search of the one or two solutions that advance the technology through the Army's research and development engineering centers.

The benefit of the Distributed and Cooperative Engagements in Contested Environments research is effects that can be deployed either mounted on a vehicle or carried by dismounted Soldiers—consistent value regardless of what munitions it takes to deliver a desired outcome. Such future engagements will involve cooperation among munitions on the attack path and communication with warfighters, who will continue to retain ultimate control. These highly intelligent weapons will combine effects and mechanisms, maneuver and make high-speed robust decisions.

All these efforts underway in ARL's research program combine electronics, energetics, propulsion, navigation and other technologies to cooperate in the battlefield of the future, and provide technology to the warfighter on the line and on time.

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ARL is developing the technologies to fit a set of tools that will be smarter, more aware, connected and autonomously collaborative.

FUTURE TREADS
To develop and field the next generation of combat vehicles, the Army needs to overcome the current problem: Adding new capabilities and systems is complicated by the weight-bearing and power-generation constraints of the original platforms. (Images courtesy of DASA(R&T))

THE NEXT GROUND COMBAT VEHICLES

The next generation of Army combat vehicles will need to include manned, unmanned and optionally manned variants that include the most advanced protection, mobility, lethality and power generation capabilities to ensure that our Soldiers can survive first contact and defeat any adversary.

by Mr. Andy Steel

The modern battlefield has combined the air, land, sea, space, cyber and information battlespace into blended domains as simultaneous operations must be conducted over a dispersed battlefield. This requires the Army to design, equip and train forces capable of defeating adversaries with advanced capabilities to prevail in complex and multidomain environments. While the Army's current fleet of ground vehicles maintains a tactical overmatch or close parity with our adversaries, additional upgrades are proving challenging to these platforms given their current size, weight and power limitations. The ability to add evolving technologies to existing ground vehicles is rapidly diminishing as the weight-bearing capability, power generation and available footprint to support these technologies has exceeded the original design.

Our adversaries have paid careful attention to the last decade and a half of combat operations conducted by U.S. forces and modified their tactics, techniques and procedures to hide from our strengths and exploit our vulnerabilities. When U.S. forces deploy, the enemy usually is operating from a "home field" advantage or is at least in position and prepared for conflict. Adversaries are well aware of the disadvantages of giving U.S. forces the time to deploy, position and amass firepower in an uncontested environment before any potential engagement. They understand that letting U.S. forces

LASER FOCUSED

The Army is looking to leverage investments in high-energy laser applications to develop vehicle platforms with improved operational capabilities at significantly smaller sizes, offering defense capabilities against unmanned aerial vehicles, rockets, artillery and mortars.

A SMALLER FOOTPRINT

The Army is focusing vehicle technology investments on vehicles that are smaller, lighter, intelligently interconnected, safer and more lethal than current combat platforms.

gain superiority in any domain can raise their likelihood of failure immensely.

Survivability in the future battlespace will be challenging. Our near-peer adversaries have combined enhanced long-range sensors with the effects from long-range precision fires. This is forcing a careful review of the requirements for future combat vehicles. Army leadership recognizes that the Army must develop the critical enabling technologies to support the next generation of combat vehicles. Increased capabilities, including advanced mobility, lethality and power generation, are required to operate smartly in the current operational environment.

Additionally, vehicle survivability can be greatly increased with intelligent sensors that are integrated with the hardware, software and effectors to create an overarching, layered system of passive and active self-defense measures. Examples include protective systems that could prevent an adversary weapon system from engaging a U.S. platform or identify an incoming threat and electronically render it ineffective or physically engage to defeat its lethal mechanisms. These overlapping and multiaspect methodologies would sequentially complement each other to defeat adversarial capabilities and protect friendly forces.

To expand its combat capability, the Army is exploring the use of unmanned vehicles teamed with manned control vehicles to support a yet-to-be defined role in multidomain operations. Surviving first contact and dominating in the dispersed battlespace will require the integration of a range of ground and air systems: semiautonomous, fully autonomous, optionally manned, tethered and untethered. Autonomous unmanned systems will have the maneuverability to travel over complex terrain and environments with greater capabilities than their manned counterparts. These systems will extend the reach of U.S. forces and will allow them to initiate contact with their adversaries under the most favorable conditions. These platforms will extend the maneuver force's understanding of the combat environment, increase survivability and extend lethality. Autonomous systems also will perform some of the dangerous, physically demanding and mundane tasks required of Soldiers.

Areas of specific focus supporting the Army's next generation ground vehicles include:

- **Sensors.** Improved sensors will provide increased capability to detect, recognize, identify and locate entities rapidly and precisely, at extended distances and with greater image resolution.

- **Directed energy and energetics.** The Army is investing to leverage the effects of directed energy in lethal, nonlethal and protection applications that can lead to reduced logistics and vehicle platforms that have significantly improved operational capabilities at significantly smaller sizes. For example, Army investments in high-energy laser applications are leading to effective defense capabilities against airborne threats, including unmanned aerial vehicles, rockets, artillery and mortars.

- **Power generation and management.** The Army is investing in vehicle platforms that require less fuel yet have greater operational range and generate more power, improving mobility, survivability and lethality.

- **Advanced armor materiel solutions.** Army science and technology is investing in lighter and more capable armors that can, when augmented with other

PUTTING THE PIECES TOGETHER

Surviving first contact in the dispersed battlespace of the future will require a range of ground and air systems to extend the maneuver force's situational awareness, increase survivability and enhance Soldiers' lethality.

layers of defense capabilities discussed in this article, improve survivability while enhancing operational combat effective range.

- **Vehicle protection suites.** The Army is making investments in active and passive protection systems that allow for reduced armor requirements (weight), enable pre-shot understanding of the threat and post-shot protection from incoming threats. Vehicle protection applications that optimize passive armor and active protection systems allow for a decrease in vehicle size, thus improving deployability, mobility and protection.

- **Maneuver robotics and autonomous systems.** Investments in semiautonomous, fully autonomous, optionally manned, tethered and untethered ground and air systems will expand the next generation ground vehicle's understanding of the operational environment, increase survivability and potentially extend lethality.

Army leadership faces profound challenges in developing its next-generation combat vehicle to protect Soldiers on the modern multidomain battlefield. Soldiers need the capability and skill to deploy rapidly, close with and destroy adversaries throughout the battlespace. The Army's goal is to focus its vehicle technology investments to develop a generation of vehicles that are not only more lethal and survivable than current combat platforms but much smaller, lighter, more fuel-efficient and intelligently interconnected for shared battlespace awareness. The following two articles on the Army's development of Robotic Wingman, its first armed and unmanned ground vehicle, and the potential applications of artificial intelligence illustrate the critical enabling technologies the Army is pursuing to increase Soldiers' operational capabilities and survivability. Army leadership is fully engaged to provide Soldiers with the best possible capabilities for future combat operations.

For more information, contact the author at ***carl.a.steel.civ@mail.mil****.*

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WINGMAN is first step toward WEAPONIZED ROBOTICS

The Army's first armed and unmanned ground vehicle is in the works.

by Mr. Thomas B. Udvare

In 2014, the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and the U.S. Army Armaments Research, Development and Engineering Center (ARDEC) teamed up to integrate a remote weapon system on a robotic vehicle to see if that system could become certified on a Scout Gunnery Table VI course, the same course used to train and qualify ground combat vehicle crews.

The vehicle was a High Mobility Multipurpose Wheeled Vehicle (HMMWV), and its "brain" was the TARDEC-developed Robotic Technology Kernel. ARDEC contributed the prototype wireless system known as the Picatinny Lightweight Remote Weapon System, which it had developed. The command-and-control HMMWV consists of the Warfighter Machine Interface, developed in-house at TARDEC, which controls and operates the robot and weapon system. Collectively, this Wingman capability allows Soldiers in a command-and-control vehicle to remotely operate an unmanned ground vehicle weapon system.

Initial experiments have met with limited success, but the Wingman program has ignited further investigation into weaponized robotics and how keeping the Soldier-in-the-loop could mitigate many of the gaps seen in today's autonomous systems.

WINGMEN

From left, the Wingman command-and-control vehicle and the unmanned Wingman. The command-and-control vehicle is mounted with a Long Range Advanced Scout Surveillance System providing target designation and handoff capability. Equipped with unmanned mobility, automated target tracking and a remotely operated weapon system, the robotic Wingman vehicle permits engagement of targets from covered positions. (U.S. Army photos by Keith Briggs, TARDEC Ground Vehicle Robotics)

In 2016, the U.S. Naval Surface Warfare Center Dahlgren Division (NSWCDD) joined the Wingman team with its target acquisition and tracking system, the Autonomous Remote Engagement System. With the addition of the NSWCDD, the Wingman program received three years of funding to demonstrate the technology. The program will culminate in a military utility assessment at an Army national training center or equivalent between 2019 and 2020. TARDEC engineers say Wingman is the research and development (R&D) community's first step toward weaponized robotics.

TACTICAL ADVANTAGE

"The Wingman technology developed today will be foundational for tomorrow's advanced fighting vehicles," said Dr. Robert Sadowski, TARDEC chief roboticist. "The Wingman technology will extend the warfighters' reach and direct-fire engagement range, allowing our Soldiers to dominate more terrain while keeping them out of harm's way."

TARDEC is leading the Wingman development effort with technical partners ARDEC, NSWCDD and the U.S. Army Research Laboratory (ARL), which provides the analysis necessary to assess the Wingman technology from a Soldier's perspective for operational and training purposes.

Military ground elements in first contact with the enemy often uncover obstacles, suffer the highest casualties and become decisively engaged, limiting friendly freedom of maneuver. Capable autonomous systems could provide a tactical advantage for these operators. However, aggressive state and nonstate actors are also pursuing the development of armed lethal robotics. As the level of autonomous capability increases, automation will spiral into weaponized systems. Unmanned systems deployed by our adversaries could impact the advantage our current reconnaissance forces have in the fight for information and increase the already high mortality rates of these units.

The Wingman technology demonstration program will investigate how to use unmanned assets to project lethality and move effectively with a mounted formation and engage ahead of or along with manned platforms without increasing manpower requirements. The team believes that unmanned assets can reduce casualties by extending the reach of the warfighter through unmatched advanced situational awareness, platform autonomy and targeting in a weaponized unmanned ground vehicle (UGV).

Wingman will begin to develop the concept of operations and tactics, techniques and procedures to integrate weaponized, unmanned systems into the current force and increase operational standoff.

Initiating contact with UGVs gives commanders flexibility and maneuver space to effectively respond to enemy threats, and eliminates some of the risks of casualty extraction. The Wingman technology will allow friendly commanders the ability to disperse manned systems without creating exploitable gaps and seams in their own formation.

TECHNICAL ADVANTAGE

In 1997, a computer named Deep Blue beat world chess champion Gary Kasparov. By 2005, two amateur chess players using three personal computers won a chess tournament against supercomputers and grand masters. Teaming amateurs with computers produced a significant advantage over the computers or the grand masters.

Current autonomy technologies aren't as capable at their tasks as Deep Blue was at its in 1997. Most have gaps in the perception and cognition areas. The use case for lethal robotic ground systems requires a Soldier-in-the-loop in order to pull the trigger. Wingman seeks to combine the perception and judgment of the Soldier with the speed, power and precision of the machine to produce an effective unmanned ground weapon system.

Currently fielded autonomous ground systems require a high degree of Soldier oversight and tend to be limited to a specific mission. They often fail to meet warfighter expectations because of limitations in the autonomy or robustness of the integrated hardware and software systems. These constraints make it difficult to field an effective weaponized robotic platform. The Wingman technology demonstrator will address some of these limitations with today's autonomous technology by developing manned-unmanned teaming behaviors to iteratively define and decrease the gap between autonomous vehicle control and the required level of human interaction.

"Unlike other autonomous systems that seek to eliminate the operators, weaponized autonomous systems will leverage the Soldier-in-the-loop to automate operations and enhance the Soldier's reach," said Keith Briggs, TARDEC's technical manager of the Wingman program.

ON ITS OWN

The Robotic Wingman vehicle maneuvers semiautonomously through a Scout Gunnery Table VI course at Fort Benning, Georgia, in late 2017. This is the same course manned combat vehicles and their crews must pass before moving on to live fire training; there is thus plenty of data about how manned vehicles handle the course, which the unmanned Wingman's performance can be measured against.

The prototype system complies with DOD Directive 3000.09, "Autonomy in Weapon Systems," and will be used as a surrogate to inform the development of future unmanned weapon systems.

ROBOTIC VEHICLE SUBSYSTEMS

The Wingman Weaponized Robotic Vehicle is an M1097 HMMWV and contains three primary subsystems:

- First is the TARDEC-developed Robotic Technology Kernel (RTK), the autonomy system for planning and controlling the vehicle's mobility. RTK contains driving cameras for remote operation, LIDAR sensors (light detection and ranging) for object classification, stereo cameras for terrain classification, computers for computation, radios for communication, and all the essential hardware, cables and mounts. The system can be manually driven through teleoperation or autonomously driven through waypoint navigation.

- The second subsystem is lethality, which uses the Picatinny Lightweight Remote Weapon System. That system can use an M134 Gatling-style minigun or an M240B machine gun. Wingman is currently investigating changing the M240B for an ARDEC-developed Advanced Remote Armament System. This will provide additional capabilities, such as an externally powered, purpose-built weapon to improve reliability and accuracy, the ability to load and clear the weapon remotely and an increased stowed ammunition load without decreasing aim or stabilization.

- The Autonomous Remote Engagement System (ARES) is the third subsystem. It provides automated engagement capabilities to decrease target acquisition time with vision-based automatic target detection and user-specified target selection. This system will decrease engagement time and overcome wireless control latency through video tracking, user assisted fire-control and control of the weapon.

COMMAND-AND-CONTROL VEHICLE

The Wingman Joint Capability Technology Demonstration (JCTD) is currently using an M1151 HMMWV as its command-and-control (C2) vehicle. The C2 vehicle contains the Soldier-machine interface that the Soldier uses to remotely operate the weaponized robotic vehicle. Five Soldiers currently man Wingman's C2 vehicle. In front sit a driver and a vehicle commander. In the rear seats are a wireless remote weapon system

AIM HIGH

The ARES optical system, developed by the NSWCDD, is mounted on ARDEC's Picatinny Lightweight Remote Weapon System and coupled with an M240B crew-served weapon. These are two of three subsystems that make up the Wingman.

operator, the robotic vehicle operator and a manned machine gun operator through the hatch. The Soldier in the hatch also uses a Long Range Advanced Scout Surveillance System to designate targets and send the coordinates to the robotic vehicle for engagement.

The C2 vehicle contains the TARDEC-developed Warfighter Machine Interface, which provides customized interactive displays for the vehicle commander, robotic vehicle driver and remote weapon system operator. These interfaces will be expanded to accept voice commands to naturally communicate with the robot and provide real-world data on the surrounding environment.

ASSESSMENT AND CERTIFICATION

The Wingman program will assess the performance and feasibility of the technology against a Scout Gunnery Table VI course, which the Army uses to train and certify crews for Army combat vehicles. The course also evaluates the vehicle's ability to move, shoot and communicate. Generally, a crew and its vehicle must pass the Table VI course—during which they engage both moving and stationary targets—annually, before participating in live fire training or deploying. Putting a robotic vehicle through the Table VI course will allow the team to quantify the tactical performance of an armed UGV and directly compare this to how manned platforms perform.

During a Table VI, the vehicle crew conducts 10 engagements on 16 targets. Target ranges vary depending on the weapon system, and target types vary from infantry silhouettes to armored vehicle silhouettes. To pass, the crew must obtain 700 out of 1,000 possible points. The Wingman program plans to field the first robotic vehicle to obtain a certification on this course.

MODELING AND SIMULATION

Along with hardware and software, TARDEC, NSWCDD and ARL are standing up a modeling and simulation capability through the development of a Wingman System Integration Laboratory (SIL), which will be used to develop and verify software before conducting expensive live testing. The lab also will make it easier to conduct Soldier virtual experiments to inform and develop future capabilities and train Soldiers before they use the system in live experiments on the range. The SIL integrates the real-world vehicle software within a simulated environment for rapid prototyping, software development and early assessment of interactions between the manned vehicle team and the vehicle.

CONCLUSION

Current autonomous systems face many issues in the areas of perception, cognition, classification and communications—which prevent fielding effective unmanned weapon systems, especially in hostile environments—Wingman will address these issues by exploring new ways to use the situational awareness of the Soldier-in-the-loop to supplement these capabilities and mitigate gaps in critical areas. As the R&D community's first step toward weaponized robotics, Wingman aims to reduce casualties and increase standoff for Soldiers, especially those units in first contact.

For more information, go to ***https://www.army.mil/tardec****.*

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The ARTIFICIAL Becomes REAL

A back-and-forth interplay of government and commercial funding and research has brought AI to the edge of a breakthrough.

by Dr. Alexander Kott

Few fields of technology are as paradoxical as artificial intelligence (AI). For one thing, since its official inception in the mid-1950s, AI has experienced multiple cycles of boom and bust. Time and again, AI would be proclaimed a miracle technology; an intense hype would build up and last for a decade or so, only to be followed by an equally intense disappointment and sense of abandonment. Similarly, human emotions around AI seem to run to extremes.

Back in the 1950s, many a life was changed by fascinating visions of the future depicted in the robot stories of Isaac Asimov. Sixty years later, science and technology experts, including astrophysicist Stephen Hawking, Microsoft's Bill Gates, Apple co-founder Steve Wozniak and Tesla's Elon Musk, have warned that humankind could be extinguished by AI. It is hard to imagine more passionate attitudes toward what is, after all, merely software.

This brings to mind yet another paradox: As soon as a research topic in AI achieves practical maturity, it is invariably demoted to "just a computer program." Thirty years ago, finding an efficient route on a complex, realistic map while taking into account traffic conditions and road closures was considered a major topic of AI research. Today, it is merely a GPS app on your smartphone, and nobody calls it AI anymore.

While no definition of AI seems quite adequate for such an unconventional field of endeavors, one way to describe AI is the ability of computer-enabled agents (e.g., robots) to perceive the world, reason and learn about it, and propose actions that meet the agent's goals. Equipped with AI, agents—whether purely computer-resident, like a highly sophisticated version of Amazon's Alexa, or physical robots—become capable of autonomy. Autonomy means the ability of a system to perform highly variable tasks with limited human supervision (e.g., dealing with unpredicted obstacles and threats). Another often-heard term, machine learning, is a subfield of AI; it refers to improving machine knowledge and performance via interactions with the environment, data, people, etc.

The last few years have seen dramatic yet uneven advances in AI in application to both physical

GAME OF DRONES

Scientists gather information about unmanned aerial vehicles in August through an Army alliance of government, academic and commercial partners known as the Micro-Autonomous Systems and Technology Collaborative Technology Alliance. The Army's long-term focus includes collaboration among highly dissimilar entities—teams of large and small air and ground robots and Soldiers—spread over large contested environments. (U.S. Army photo by Jhi Scott, ARL)

robots and software-only intelligent agents. Some capabilities, like answering questions (IBM's Watson), "deep learning" (Google's TensorFlow machine learning) and self-driving cars, have achieved significant breakthroughs. But others see ongoing exploration without any dramatic advances—yet. Almost all initial breakthroughs (all of those named above) came, to a large extent, from government's pioneering research funding. Only later, when the research efforts showed commercial potential, were they picked up by industry, which then invested much more in these technologies than the initial government funding.

Considering the recent, enormous growth of interest in AI shown by both the public and industry, the interplay between government and commercial investments is interesting and complex. Published estimates of global commercial investment in AI (including autonomy) vary widely, between $20 billion and $50 billion per year. The major commercial markets include retail, telecommunications, financial, automotive and industrial assembly robots. In comparison, the Army's science and technology (S&T) investment in AI and autonomy is two to three orders of magnitude lower. If so, why should the Army bother? Why not let industry take the lead and wait until its enormous investments produce the AI technologies the Army wants?

First, the Army S&T community is well aware of the industry efforts and products; it uses these products extensively in Army-focused research, often tailoring them as needed. In their autonomy research, for example, Army scientists and engineers use industrial or industry-supported robotic platforms, such as iRobot's widely used small unmanned ground vehicle PackBot and the popular Robotic Operating System (ROS)—open-source middleware supported by a number of corporations. Computers and processors also come from industry: NVIDIA Corp.'s graphic processing unit, which helps accelerate deep learning, is one example, as is IBM's TrueNorth chip, which emulates

MAP TO THE FUTURE
Just 30 years ago, finding an efficient route on a complex map with current traffic conditions and road closures was considered cutting-edge AI research. Today, it's commonplace—just one more app on your smartphone. (Photo by NEstudio/Shutterstock)

brain neurons for power-efficient computations. For machine learning, Army S&T uses well-developed software tools such as TensorFlow.

At the same time, the focus of the Army S&T community is on problems that are quite distinct and are not going to be addressed by commercial applications. For example, much of Army research and development (R&D) investments in autonomy are focused mainly on autonomous convoys traveling in adversarial environments on terrain other than conventional roads; on robotics for manned-unmanned teams for reconnaissance, surveillance and target acquisition and breaching; and on AI for military intelligence data analysis. These are not yet areas of significant interest to commercial developers, who focus on lucrative consumer markets.

Furthermore, there are deep, foundational differences in the scientific and technical challenges that Army-specific AI problems present, and which are not typical—or at least not a high priority—compared with the problems targeted by commercial investments. For example, AI and machine learning for self-driving cars, although initially spurred by the Defense Advanced Research Projects Agency's Grand Challenge competitions, are currently being developed by industry and optimized for relatively orderly, stable, rule-driven, predictable environments, such as the highways and streets of modern cities. Nothing could be further from the environments where the Army-specific AI will have to operate—unstructured, unstable, chaotic, rubble-filled urban combat.

As another example, the recent explosion of successes in machine learning has been connected with availability of very large, accurate, well-labeled data sets, which can be used for training and validating machine learning algorithms and, given lengthy periods of time, for the learning process. But Army-relevant machine learning must work with data sets that are dramatically different: often observed and learned in real time, under extreme time constraints, with only a few observations (e.g., of the enemy techniques or materiel); potentially erroneous, of uncertain accuracy and meaning; or even intentionally misleading and deceptive. In other words, some of the very foundations of commercial AI algorithms diverge strongly from what the Army needs.

MANNED-UNMANNED TEAMING

Human-agent teams—Soldiers teamed with robots and other intelligent systems operating with varying degrees of autonomy—will be ubiquitous on the future battlefield. These systems will selectively collect and process information, help Soldiers make sense of the environment they're in, and—with appropriate human oversight—undertake coordinated offensive and defensive actions.

Many will resemble more compact, mobile and capable versions of current systems such as unattended ground sensors, unmanned aerial vehicles (drones) and fire-and-forget missiles. Such systems could carry out individual actions, either autonomously or under human control, collectively provide persistent and complete battlefield coverage as a defensive shield or sensing field, or function as a swarm or "wolf pack" to unleash a powerful coordinated attack.

In this vision of future ground warfare, a key challenge is to enable autonomous systems and Soldiers to interact effectively and naturally across a broad range of warfighting functions. Human-agent collaboration is an active research area that addresses calibrated trust and transparency, common understanding of shared perceptions, and human-agent dialogue and collaboration. Army S&T is focused on the fundamental understanding and methods to design and develop future Army autonomous systems that will interact seamlessly with Soldiers.

One function with technology that has relied on a foundation of government research is question answering—the system's ability to respond with relevant, correct information to a clearly stated question. The recent question-answering successes of commercial technologies like IBM Watson and Apple's Siri are based on several decades of government leadership in related research fields.

They work well for very large, stable and fairly accurate volumes of data, like encyclopedias. But such tools don't work for rapidly changing battlefield data, which can be distorted by adversaries' concealment and deception. Commercial question-answering systems cannot support continuous, meaningful dialogue in which both Soldiers and artificially intelligent agents develop shared situational awareness and intent understanding. The Army is performing research to develop human-robotic dialogue technology for warfighting tasks, using natural voice, which is critical for reliable battlefield teaming.

FROM CHAOS, ORDER

Army AI and machine learning involve unique challenges for Soldiers, including operations in unstructured, unstable, rapidly changing, chaotic and adversarial environments where gathering information is difficult, and the information gathered may be potentially erroneous, misleading and deceptive. (Image courtesy of ARL)

Also critical is the self-organization of robotic team members. By leveraging available commercial technologies like the Robotic Operating System and commercial robotic platforms, Army scientists are performing research to address Soldier-robotic teaming on complex ground terrain. For example, the Army recently demonstrated leader-follower driving of resupply trucks in which several unmanned vehicles autonomously follow a human-driven truck, on narrow forest roads with tree canopy, at tactically appropriate speed and with long gaps between the trucks.

When a team includes multiple artificial agents, or when multiple teams must work together, new challenges arise: decentralized mission-level task allocation; self-organization, adaptation, and collaboration; space management operations; and joint sensing and perception. Commercial efforts to date have largely been limited to single platforms in benign settings. Within the Army, some programs like the U.S. Army Research Laboratory's (ARL's) Micro Autonomous Systems and Technology Collaborative Technology Alliance (MAST CTA) have been developing collaborative behaviors for unmanned aerial vehicles. Ground vehicle collaboration is challenging and is largely still at the basic research level. The Army's long-term focus is on enabling collaboration among large numbers of highly dissimilar entities, such as large and small teams of air and ground robots, as well as human Soldiers, distributed over a large contested environment. To

IN THE AI LOOP

Thanks to advances in AI, human-agent teaming and machine learning, Soldiers will provide commanders with real-time information about the enemy gathered from a variety of different sources, including possible courses of action, which will help them to make better decisions in battle. (Image courtesy of ARL)

address such challenges, ARL has started Distributed and Collaborative Intelligent Systems and Technology, a collaborative research alliance between academic scientists and ARL government scientists.

MACHINE LEARNING

Machine learning is a key precondition for human-agent teaming on a battlefield, because agents will be neither intelligent nor useful unless they are capable of learning from experiences and adapt what they know while acting on the battlefield. For example, ARL has been working on learning algorithms for small ground robots that are able to learn the conditions of the ground (wet, slippery, sandy, etc.) and learn the appropriate modifications that control the turns and the speeds of their tracks. In another example, academic scientists collaborating with ARL in the framework of the recently completed MAST CTA developed a small rotorcraft that can execute aggressive maneuvers while flying through unfamiliar, highly cluttered indoor environments. The rotorcraft does so by continually learning the probability of collision directly from an onboard video camera. It recognizes new scenes and continually updates its knowledge.

Machine learning, although not yet capable of addressing the complexities of battle, has seen dramatic advances using "deep learning" computer algorithms known as deep neural networks. To deal with the unique nature of Army-specific machine learning, ARL is researching specialized extensions to commercial algorithms such as the TensorFlow software toolkit.

Yet another challenge that is uniquely exacerbated by battlefield conditions is constraints on the available electric power. Commercial AI relies on vast computing and electrical power resources, including cloud computing reachback when necessary. Battlefield AI, on the other hand, must operate within the constraints of edge devices: Computer processors must be relatively light and small and as frugal as possible in the use of electrical power. Additionally, the enemy's inevitable interference with friendly networks will limit opportunities for using reachback computational resources.

TIP OF THE RESEARCH SPEAR
Popular technologies that are sold commercially, such as intelligent personal assistants on mobile devices and driverless cars, began with government research funding and were matured later through industry. (Image by posteriori/Shutterstock)

HUMAN LEARNING

Human learning and training for the complex battlefield of the future needs AI for building realistic, intelligent entities in immersive simulations. The Army principle of "train as you fight" places high importance on training experiences with the realism to match operational demands. Immersive training simulations must have physical and sociocultural interactions with the fidelity to meet the training demands of strategic and operational planning and execution. Modeling and simulation capabilities must also match the complexity of the operational environment so that simulated interactions enable effective transfer of skills and knowledge to the operational environment.

Game-based training provides cost-effective development of immersive training experiences. Still, game-based training is not a silver bullet. Mismatches between the gaming environment and the real world may cause unintended effects, such as giving users an unrealistic framework for combat. Army training simulations need to include realistic sociocultural interactions between trainees and simulated intelligent agents. The actions of human actors teaming with robots and other intelligent agents will be pervasive in the complex operational environments of the future.

Army training simulations build on advances in commercial game engines like Unreal, which powers the game "Kingdom Hearts III," and adapt that kind of action role-playing to meet the unique needs of the Army in programs like the $50 million Games for Training, overseen by the Program Executive Office for Simulation, Training and Instrumentation.

ARL is also at the cutting edge in computer generation of realistic virtual characters that are needed to enable realistic sociocultural interactions in future Army training applications. More than once, Hollywood studios have sought technologies from the ARL-sponsored Institute for Creative Technologies at the University of Southern California to create realistic avatars of actors. These technologies enable film creators to digitally insert an actor into scenes, even if that actor is unavailable, much older or younger, or deceased. That's how actor Paul Walker was able to appear in "Furious 7," even though he had died partway into filming.

CONCLUSION

That is a glimpse of perhaps the greatest paradox of AI: its looming power to erase the divide between the real and the imaginary, the natural and created. To defy, indeed, the very notion of artificial.

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SUNSET ON THE APACHE

Army aviation S&T is investing in a portfolio of enabling technologies as a precursor to fielding a replacement for the AH-64 Apache helicopter, including these from the North Carolina Army National Guard's 1st Battalion, 130th Aviation Regiment, positioned in the Mojave Desert in May at the National Training Center, Fort Irwin, California. (Mississippi National Guard photo illustration by Staff Sgt. Tim Morgan, 102nd Public Affairs Detachment)

Science and Technology *Supporting* FUTURE ARMY AVIATION

Research in several areas will mature new capabilities to make Future Vertical Lift possible.

by Mr. Todd Turner and Mr. Matthew Simone

In the future, Army aviation systems will need to operate in an anti-access and area denial (A2AD) contested airspace against adversaries that have advanced capabilities that constrain freedom of maneuver. To be effective in these environments, future aviation systems will need extended range, increased situational awareness and higher speed to maneuver into positions of advantage, survive and engage the adversary. There also will be a need for increased use of unmanned systems to penetrate this contested airspace.

The investments in the air systems science and technology (S&T) portfolio are dedicated to discovery, innovation and transition of products to enable U.S. technical superiority and combat overmatch for current and Future Vertical Lift (FVL) systems. The portfolio is invested in five broad areas of research:

- Platform design and structures to focus on extending the range and speed of vertical lift systems.
- Investments in power to ensure that systems can achieve higher speeds and improved efficiency to achieve extended ranges.
- Mission systems technologies to ensure that once the platform is in the operational environment, it can provide the desired lethality and survivability.
- Unmanned aircraft autonomy and teaming to extend reach and lethal effect while also providing the ability to penetrate A2AD environments.
- Investments in maintainability and sustainability to ensure that platforms are capable of high operations tempo while reducing logistics demand.

PLATFORM DESIGN AND STRUCTURES

Ultimately, the desired effect on the battlefield for aviation systems, whether assault, attack, lift, reconnaissance or medical evacuation, is provided by the platform. That platform may be manned, optionally manned or unmanned, depending on mission and environment. The focus of S&T in platform design is to support FVL. S&T in this area encompasses concept development and design analysis through system development and demonstration.

This includes current efforts such as the Joint Multi-Role Technology Demonstrator (JMR-TD) and future efforts such as Next Generation Tactical Unmanned Aircraft Systems (NGTUAS). The JMR-TD is demonstrating platform and mission systems technologies in support of FVL. NGTUAS is focused on the development and demonstration of technologically feasible and affordable unmanned air vehicle technologies and capabilities that provide improvements in flight performance, survivability and reliability. Long-term efforts are focused on vertical lift technologies that enable both high speed and efficient hover.

POWER

One of the most important areas of technology needed to dominate the future operational environment is aircraft power systems. This area includes technologies that advance the capabilities of turbine engines and drivetrains. Current vertical lift turbine engines and drivetrains are designed to operate at a fixed speed and lift; forward movement is produced by adjusting the pitch of the helicopter rotor blades. These turbine engines and drivetrains are optimized for this fixed speed but are at their limit of efficiency and power.

To meet the requirements for range and speed with maximum efficiency, technologies like variable-speed turbine engines and multispeed transmissions are being developed. To build these future power systems, new turbine designs, materials and components will need to be developed through innovative manufacturing capabilities like additive manufacturing. Additionally, engine designs will need to be highly reliable to meet the demands of the future operating environment, which will be fast-paced and require much longer operation between maintenance sessions than today's aircraft. Leap-ahead technologies like hybrid-electric power systems are also being investigated and developed. These technologies combine the efficiency of electric motors and optimized engines, not unlike current hybrid-electric cars. Combining all of these new technologies and capabilities will be required in order to enable the FVL aircraft to meet all of its future requirements.

MISSION SYSTEMS

The goal of the mission systems area is to mature and validate man-machine mission equipment software and hardware technologies to enable overmatch and survivability in the future operating environment. If the airframe, engines, transmission and rotors are the body of FVL, then the mission systems can be thought of as the eyes, ears and brains. To allow for a holistic approach to mission system development and employment, open systems architectures will be required to allow Soldiers to "plug and play" future reconnaissance, survivability and lethality systems.

Current sensors and payloads are federated, meaning they don't interoperate much. In order to install updated payload equipment, an aircraft upgrade would likely need to be developed, which would increase cost and aircraft downtime. The Army's air systems S&T portfolio is conducting research in

A BIRD IN THE HAND

Spc. Derek Opthof of the 3rd Brigade Combat Team, 82nd Airborne Division winds up to throw an RQ-11 Raven unmanned aerial vehicle to scan the field where Soldiers had just jumped from an aircraft during a deployment readiness exercise at Fort Bragg, North Carolina, in July. This kind of teaming between unmanned systems, Soldiers and manned systems is an important area of investment and research for Army aviation. (U.S. Air Force photo by Staff Sgt. Andrew Lee)

ONE POSSIBILITY

The JMR-TD is demonstrating platform and mission systems technologies to help the Army make decisions about FVL capabilities, which could look like this hypothetical rendering. The demonstrator effort is managed jointly by a team led by the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC). (U.S. Army graphic by AMRDEC VizLab)

multifunctional sensors so as not to overload the size, weight and power of the aircraft. An example of this type of sensor would be one that has a combination of situational awareness and targeting capabilities.

The mission systems also need to be designed so that the FVL aircraft can operate anywhere, anytime and in any weather condition. This calls for systems that increase situational awareness and survivability but also reduce the cognitive burden on pilots that can come with data overload from these advanced sensors. New types of algorithms for artificial intelligence are being researched and developed to create this new pilot modality, called "supervised autonomy," whereby pilots oversee instead of execute lower-level flight functions. Speaking at an aviation forum held Sept. 7, 2017, by the Association of the United States Army, Maj. Gen. Bill Gayler, commander of the U.S. Army Aviation Center of Excellence at Fort Rucker, Alabama, said supervised autonomy would "aid a human in the loop and augment the pilot rather than replacing the pilot." All of these new advanced capabilities will transform the way FVL is operated and will enable survivability in the fast-paced, dynamic future operating environment.

AUTONOMY AND TEAMING

In the future, unmanned aircraft systems (UAS) may be used to extend the reach of manned systems while removing the Soldier from dangerous conditions. Potential applications include reconnaissance, attack, resupply and casualty evacuation. Research in this area is focused on technologies for the next generation of UAS to support manned-unmanned teaming in combined arms operations. This includes a wide spectrum of research, from control interfaces to advancing autonomous behaviors.

Research in these areas needs to be conducted in parallel to realize the potential of unmanned systems. Common human-machine interface efforts are focused on human-system interface

UP AND AWAY

Chief Warrant Officer Natalie Miller, assigned to Company B, 2-238th General Support Aviation Battalion, leaves Greenville, South Carolina, in February 2017 aboard a CH-47F Chinook heavy-lift cargo helicopter, bound for a weeklong training mission focused on high-altitude flight operations. FVL platforms will need to operate at extended ranges and endure difficult conditions longer and with less-frequent maintenance. (U.S. Army photo by Staff Sgt. Roberto Di Giovine)

designs to improve mission effectiveness in airborne operations. Areas of investigation include cockpit designs with advanced cueing, controls and displays. In autonomous teaming, the focus is on the development of autonomous algorithms to allow one pilot to control UAS, and cognitive decision aids to reduce the time a Soldier has to spend in direct control of a UAS. The long-term goal is to extend UAS capability beyond remote control or teleoperation to truly autonomous capability, to allow combined manned-unmanned platform teaming in contested environments, through the realization of systems that adapt to changing battlefield conditions.

MAINTAINABILITY AND SUSTAINABILITY

Maintainability and sustainability focus on the development of technologies and methodologies to enable more reliable designs, the ability to forecast component failure, and technologies to reduce maintenance and the logistics burden, one of the biggest cost drivers for Army aviation. Specific areas of research include integrated health management, efficient component design for optimized reliability, material failure modes, and the effects of thermomechanical and electromagnetic loading. The iterative goals are to move from maintenance based on time-on-aircraft to condition-based maintenance and, ultimately, to predictive maintenance.

CONCLUSION

The S&T investment in air systems is positioned to deliver the next wave of capabilities that will ensure that our vertical lift and UAS are capable of providing close air support and maintain U.S. dominance on the battlefield. The following articles discuss in more detail some specifics of the FVL S&T portfolio: architecture specification, collaborative air systems and aircraft survivability.

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Strength in ARCHITECTURE

Development of a government-led architecture specification promises to transform Army aviation mission systems.

by Mr. Scott Wigginton and Mr. William "Bill" Jacobs

Mission systems provide crucial elements of our warfighting capabilities—in the case of aviation mission systems, components integrated directly onto an air vehicle and encompassing traditional avionics (communications, navigations and displays, for example) as well as specific warfighting capabilities (weapons and sensors).

Current methods of acquiring these systems, however, lead to duplication of effort and a multiplicity of requirements for different contractors providing essentially the same capability. The Aviation Development Directorate (ADD) of the U.S. Army Aviation and Missile Research, Development and Engineering Command (AMRDEC) is researching new methods of acquiring aviation mission systems through a government-led architecture specification. This specification will describe the desired system characteristics, or "-ilities," such as reusability, portability and interoperability, and document enforceable requirements for these characteristics. This approach will foster competition and reuse across systems, and reduce timelines for managing obsolescence and acquiring new capabilities.

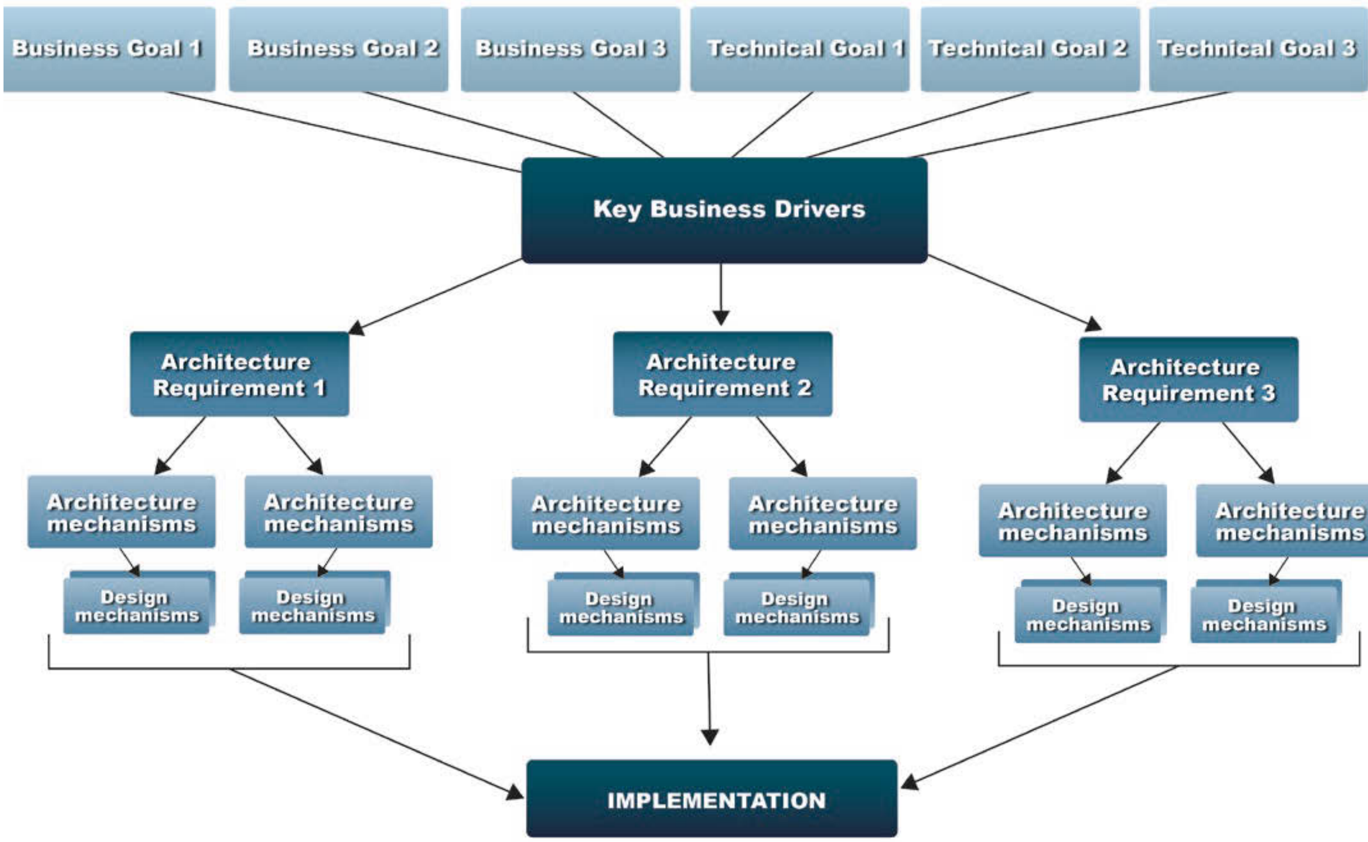
A NEW APPROACH NEEDED

Military services develop aviation mission systems from a program-centric perspective. In other words, each program is singularly responsible for satisfying its system performance requirements. This approach makes sense from the program manager's perspective, as they are able to manage cost, schedule and performance. The disadvantage, however, is that contractor-unique solutions are likely to preclude any component reuse across programs.

Often, the Army acquires the same basic capability multiple times through independent procurements, each with unique sets of requirements implemented by different contractors. Additionally, any modifications or modernization almost certainly will have to come from the initial contractor, impeding a program's long-term supportability by limiting competition.

Throughout the life cycle of a system, many common functions need upgrading, with repeated development, integration, testing and qualification. Using a program-centric approach may reduce initial development cost and schedule, but it sacrifices long-term affordability and

FIGURE 1



SENSIBLE REQUIREMENTS

The JCAS takes a multitiered approach to provide enforceable, traceable requirements for future procurements to conform to explicitly stated standards, processes or practices. The strategy is designed to lead to systems that are implemented in a specific, consistent manner. (SOURCE: AMRDEC)

supportability by making it impossible to share the upgraded capabilities across programs. Additionally, nonfunctional requirements such as openness, interoperability, upgradability and maintainability become secondary to system performance requirements and are often compromised in favor of near-term program performance.

Overall, this program-centric perspective results in a loss of competition and innovation and increases long-term costs.

DOD acquisition processes focus on what performance is required and not how it should be implemented, providing limited insight and understanding of the reasons behind the "how." When the government procures a capability this way, it inherits the business objectives of the contractor, which may not align with those of the government. The organization's business and technical goals influence the architecture of that system, substantially affecting its life cycle. The government needs a systematic method to convey a system's characteristics accurately from a broader, enterprise perspective. This method would drive architecture decisions for the system and lay the groundwork for development and sustainment decisions.

DOD has tried to tackle these challenges through an open systems architecture (OSA) approach that combines business and technical objectives that yield systems with severable modules that are subject to competition. But program-centric attempts and broad mandates to implement an OSA have yet to adequately improve life cycle affordability, enable competition or shorten fielding timelines in the aviation community. This is because achieving and assessing many life cycle characteristics such as openness are subjective and are pursued without coordination between the program offices and other stakeholders. To achieve the potential benefits of an OSA, the Army needs to apply a comprehensive, systematic approach across the aviation enterprise.

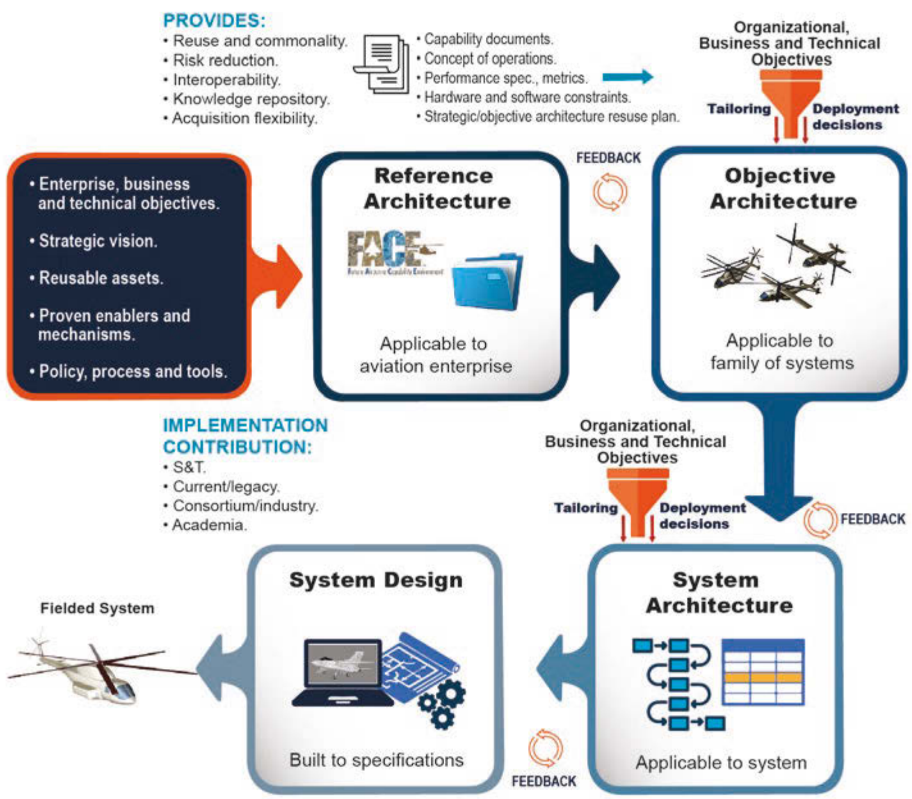
SHIFTING PERSPECTIVES

ADD is investigating an approach to prioritize the government's business and technical objectives as part of the Joint Multi-Role Technology Demonstrator (JMR-TD), a science and technology program to demonstrate transformational vertical lift capabilities to prepare DOD for decisions regarding the replacement of the current vertical lift fleet. The JMR Comprehensive Architecture Strategy (JCAS) supports efficient development and sustainment of open and interoperable aviation mission systems.

The JCAS is based on analyzing, documenting and tracing the government's business and technical goals, including key business drivers (for example, affordability, time to field, tactical overmatch, etc.), policy and processes. This analysis and documentation result in enforceable architecture requirements for aviation mission systems.

The JCAS provides a layered architectural management approach to inform and constrain subsequent development activities. It also provides enforceable, traceable requirements for future procurements to conform to explicitly stated standards, processes or practices. (See Figure 1.) It specifies a measure or verification method to prove desired characteristics or attributes. By providing traceability

FIGURE 2



THE ARCHITECTURE OF DEVELOPMENT

The three-level JCAS system was developed by AMRDEC's ADD as a way to eliminate shortcomings in the current method of acquiring avionics systems and improve cost and interoperability. JMR-TD's capstone event, planned to begin this year, will provide proof of concept. (SOURCE: AMRDEC)

of the desired attributes and the means for achieving them, the strategy will lead to systems that are designed and implemented in a specific, consistent manner to achieve enterprise goals.

The JCAS proposes three levels of architectural management: reference architecture, objective architecture and system architecture. Throughout these levels, methods exist to enable identified improvements or changes as the JCAS matures. (See Figure 2.)

The **reference architecture**, the highest level of architecture in the JCAS, is intended to guide and constrain the development of subsequent levels of architectures. The reference architecture represents strategic-level interests by combining stakeholder concerns reflecting both business and technical perspectives. Its requirements are independent of a specific solution but still support desired stakeholder objectives, such as affordability and interoperability, in a common, consistent manner.

TAKING CHARGE

A UH-60M Black Hawk helicopter, right, and a CH-47 Chinook helicopter, both from the 2nd General Support Aviation Battalion, 149th Aviation Regiment Task Force Rough Riders, land in August before inserting paratroopers from 2nd Brigade Combat Team, 82nd Airborne Division, during an aerial response force exercise at Camp Taji Military Complex in Iraq. It is in the government's best interest to develop an aviation mission systems architecture that will encourage shared capabilities. (U.S. Army photo by Capt. Stephen James, 29th Combat Aviation Battalion)

A reference architecture provides common language and terminology, guides the application of technology, supports traceability of requirements to validate future architectures and provides a method to adhere to common standards and patterns. It facilitates the development of cross-platform capabilities by constraining the ability to develop unique architectural approaches. Options within the reference architecture apply to all programs within the organization's influence and include elements such as purpose, principles and standards.

The **objective architecture** derives from the reference architecture and represents a way to identify opportunities for commonality across related programs, such as in a family of systems. Whereas the reference architecture is an overarching set of options, the objective architecture represents the selections that meet the desired technical and business decisions for the family of systems. The objective architecture documents the tailoring and refinement by an organization to meet the missions of the related programs, as well as documentation of the methods to meet the requirements defined in the reference architecture.

At the lowest level of architectural specification is the **system architecture**, which the procuring organization develops by further refining and tailoring the objective architecture to satisfy the performance requirements of a specific system. The system architecture further guides and constrains the architectural principles and methods that the system developers may use while still adhering to the higher-level organizational objectives. Because the system architecture is focused on architectural principles, it does not prescribe the system design and implementation decisions, leaving flexibility for many potential designs.

CONCLUSION

The JMR-TD is pursuing a series of demonstrations to mature various concepts of open systems. The final event, the capstone demonstration, begins with anticipated awards in June 2018 and runs through the end of 2020. It will help mature and validate the JCAS concept by determining if multiple related programs can use the same systematic approach to architecture to achieve desired characteristics. In the long term, the requirements to achieve these characteristics, which may provide the basis for a new generation of mission systems, will be encapsulated in a best-of-breed specification that leverages the observations and learning gained through the JMR demonstrations.

Military services develop aviation mission systems from a program-centric perspective. In other words, each program is singularly responsible for satisfying its system performance requirements.

BETTER SUPPORT FOR MULTIPLE AVIATION SYSTEMS

Rows of U.S. Army 1st Air Cavalry Brigade, 1st Cavalry Division helicopters—UH-60 Black Hawks, CH-47 Chinooks, AH-64 Apaches and HH-60 Medevac Black Hawks—leave Chièvres Air Base, Belgium, for Germany, Latvia, Romania and Poland in October in support of Operation Atlantic Resolve. Aviation mission systems developed from a program-centric perspectives make component reuse across programs difficult or impossible. (U.S. Army photo by Visual Information Specialist Pierre-Etienne Courtejoie, Training Support Activity Europe)

To achieve the desired life cycle characteristics for air vehicles, the government must take a leading role in describing and specifying the architecture of its aviation mission systems. Ultimately, the JCAS is intended to be a basis for future procurements of aviation mission system capabilities, reducing the likelihood that individual programs will develop unique and difficult-to-support solutions. Such an approach will be needed to achieve and maintain capability overmatch in a rapidly changing world with ever-evolving threats.

For more information, email ***usarmy.redstone.rdecom-amrdec.mbx.amrdec-add@mail.mil*** *with the subject line "AL&T Article: Strength in Architecture."*

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SMART AIRCRAFT

A drone directed by one or more Soldiers through uncontested skies is a thing of the past. Army aviation is developing collaborative and intelligent systems for manned and unmanned fleets in contested airspace.

by Mr. Kevin Kee

Future warfare will present challenges to Army aviation assets not seen since the contested airspace of World War II. Communication, navigation and command-and-control systems will be degraded and jammed, and aircraft will encounter air defense threats with new capabilities. While sobering, these challenges offer an opportunity to leverage autonomy and teaming in both manned and unmanned aircraft.

Army aviation uses a manned-unmanned teaming (MUM-T) capability first fielded in 2009. This capability provides full-motion video in an AH-64E Apache cockpit from an RQ-7 Shadow or MQ-1C Gray Eagle unmanned aircraft system (UAS). It also offers multiple levels of control of the UAS, from the ability to view and control the electro-optic payload and laser designator to remotely controlling the vehicle's flight. These systems allow the MUM-T operator to identify and fix the laser designator at targets, allowing HELLFIRE and other smart missiles to guide to and destroy the target. MUM-T is enabled by the Mini-Tactical Common Data Link, which transmits UAS or aircraft sensor video to a ground or airborne One System Remote Video Terminal. With this capability, UAS can provide reconnaissance, targeting and security to an Army brigade.

RAVEN VISION
Staff Sgt. Justin Higginbotham, a U.S. Army Reserve Soldier from the 346th Military Police Company, launches an RQ-11 Raven at Fort Riley, Kansas, in October. The Raven increases operational visibility in austere environments, helping Soldiers see the battlespace from above. (U.S. Army Reserve photo by 1st Lt. Kirk Westwood)

MANNED PLATFORMS

The MUM-T link, while providing great operational benefit, has also introduced new challenges to the manned aircraft fleet. In the AH-64E, both the pilot and the gunner must balance the needs and requirements of flying the aircraft with the operation and control of the UAS over the MUM-T link. Much like driving while talking on a cellphone, multitasking limits the effectiveness of the capability.

To address these shortcomings, the U.S. Army Research, Development and Engineering Command (RDECOM) is increasing investment in human machine interface (HMI) technologies to reduce MUM-T workload. A touch interface, voice commands, and a head-tracker that knows where the pilot or gunner is looking are promising technologies in this area.

RDECOM is expected to reach a major milestone in its Synergistic Manned Unmanned Intelligent Teaming program, which focuses on assessing new technologies in the areas of HMI, decision aiding and autonomy as well as new ways to employ those technologies. In 2019, RDECOM will demonstrate an air mission commander that uses one crew station to manage up to eight unmanned systems to execute scout, attack and air assault missions with less workload than is required to control one UAS today.

UNMANNED PLATFORMS

Current UAS platforms have served the Army well in counterinsurgency operations by offering a durable, relatively cost-effective platform with a sensor and, on the Gray Eagle, HELLFIRE missiles. In Iraq and Afghanistan, these unmanned platforms are able to circle high above the battlespace, providing continuous information to the commander. In the future, however, such uncontested environments are likely to be the exception. Current UAS platforms require a runway for operations, and their limited airspeed means that they must be operated from many locations to provide the coverage required, requiring many more platforms and infrastructure to support operations.

The rise of UAS platforms has also led countries all over the world, including the U.S., to develop counter-UAS systems. These systems vary but generally have the ability to jam or degrade data links and GPS signals, or to simply shoot down the UAS. Commercial UAS platforms have been hacked numerous times, degrading the platform, so this possibility must be considered for any existing or future Army UAS.

These factors are driving a need to develop new UAS platforms that balance endurance with greater speed and range. Most important is the ability for the UAS to operate independently of a runway, so that a division or brigade does not have to depend on a fixed air base. RDECOM is exploring these platform configurations and developing ways to increase survivability while driving down cost. The rapidly growing commercial industry offers new opportunities to team and leverage commercial advances.

CONTROLLING CONTROLS

Currently fielded teaming capability provides the crew of an AH-64E Apache with full-motion video and multiple levels for controlling a UAS while balancing the demands of flying the aircraft. (Image courtesy of AMRDEC)

A NEW DOG IN THE FIGHT

The combination of new UAS designs and HMI technologies enables the next level of MUM-T capability: true teamed operations. Current MUM-T missions involve many Soldiers, including the pilot, the MUM-T controller and ground control station operators. All of these Soldiers must coordinate and hand over control of individual UAS platforms while coordinating with other aircraft on the mission. But the Army could take a lesson from game hunters to streamline this manpower-intensive process. Every game hunter knows the value of using a hunting dog or a bird dog to find prey or retrieve game, and this relationship between hunter and dog provides a model for what true teaming should be.

The operational concept can be as simple as the pilot directing the UAS to provide reconnaissance of a particular area, so that the UAS—like the bird dog—would travel to the objective without continuous monitoring. A much more complicated MUM-T mission could involve multiple UAS platforms and manned platforms locating and tracking a target and then maneuvering to engage and destroy it.

This complex coordination of manned and unmanned platforms is enabled by RDECOM investment in airspace command-and-control systems that can translate a high-level group command—to scan an area, for example—into specific orders for each aircraft. Additionally, the system must have a self-healing capability to rapidly determine whether a UAS has to return to base or is destroyed and would, as a result, require a manned or unmanned platform to continue its task. These future MUM-T systems also would enable ground commanders to assign tasks directly to air platforms, demonstrating a new level of combined arms coordination.

AUTONOMOUS OPERATIONS

The ultimate goal of air systems is fully autonomous operation for all aviation mission sets. Already RDECOM has demonstrated an autonomous cargo delivery system called Autonomous Technologies for Unmanned Aerial Systems (ATUAS). In December 2011, it became the first aerial system to deliver cargo in theater, for the U.S. Marine Corps. Two aircraft deployed for a six-month demonstration period that was extended to 2 1/2 years. RDECOM is building upon this success to explore autonomous operations for other aviation missions.

Fully autonomous operations are less vulnerable to data-link jamming since an autonomous vehicle can act on its own, given initial commands from an operator, and does not require

MOVING IN THE RIGHT DIRECTION
Current large UAS platforms like this Gray Eagle provide important capabilities but need a runway to take off. These systems also have lower airspeeds and depend on data links and GPS signals. Future systems will need to be more independent to operate in a complex battlespace. (Image courtesy of AMRDEC)

constant updates. When fully realized as a swarm, this capability provides an operational benefit greater than what manned aviation could provide alone. These benefits come with the added challenge of platform complexity, however. Manned aircraft and human pilots have the ability to adapt to any condition on the battlefield, including system failures, changes in weather conditions and adjusting the mission based on new information. An autonomous or artificial intelligence pilot requires programming to exhibit these humanlike behaviors to provide the same flexibility. Additionally, starting in 2019, RDECOM will explore autonomous reconnaissance and target acquisition in complex environments where the enemy is hidden or camouflaged.

Any autonomous system has to interface with a Soldier at some point, and this is another technology focus. The automotive industry provides some examples and recommendations as it develops similar standards. Imagine, in the not-too-distant future, sitting in the driver's seat of an autonomous car watching a movie and not having to pay attention to the road. If you were fully engrossed in the movie, it would be very difficult to take control of the car if the auto-steering system suddenly disengaged. You would need even more notice if you were traveling on curvy roads during icy weather. And how would such a system operate if the car were struck by lightning? The Army needs to explore the same issues and develop systems that can degrade gracefully—slowing and landing an aircraft in a safe area, for example, as soon as the autopilot starts failing.

Current aircraft undergo block upgrades to modify hardware and software to improve performance and capability. The software of any weapon system is underpinned by system architectures, which are traditionally difficult to modify or upgrade. Much research is being done in this area, but for future air systems, what's needed is development of open system architectures that are designed to make adding, upgrading and swapping components easy. For an autonomous system, the use of machine learning, the continuing pace of commercial and government research, and upgrades to the autonomy system from operations are going to stress the traditional block upgrade scheme. Similar to smartphones,

In Iraq and Afghanistan, these unmanned platforms are able to circle high above the battlespace, providing continuous information to the commander. In the future, however, such uncontested environments are likely to be the exception.

PICKUP AND DELIVERY

AMRDEC's Aviation Development Directorate (ADD) conducts autonomous dual-lift operations with two RMAX UAS carrying a 20-pound payload through a set of hover and low-speed maneuvers at Moffett Federal Airfield, California, in September. The helicopters are an autonomous flight resource developed by ADD and have been used for numerous flight experiments since 2002. (U.S. Army photo)

the autonomous UAS of the future will require the ability to securely update and obtain the latest security patches and algorithm updates.

Last—but most important for any autonomous system—is trust. Global investment in autonomy and artificial intelligence is massive and growing every year, and new technologies appear frequently. The specific technologies required to demonstrate an autonomous system are not completely understood yet, but it is likely that the algorithms will exhibit learning behavior.

For a Soldier to fully trust an autonomous system requires a thorough understanding of the system design and its behavior at any point. The operational requirement for the system, however, will require more flexibility and more humanlike behavior to truly provide operational benefit. It is important to balance these two demands, both to ensure safety and to provide trust in the system.

CONCLUSION

Developing the future of collaborative and intelligent air systems involves continually balancing investment priorities in MUM-T and its enablers. Investment and innovation will occur throughout the joint community, industry and academia, and the Army must be ready to adjust investment in response to these external sources. Especially important is coordination in the DOD Autonomy and Air Platform Communities of Interest to leverage investments and share knowledge.

RDECOM has already had success in demonstrations of the ATUAS cargo delivery system and technologies that will lead to the fielding of MUM-T. Over the next decade, the organization will build upon this success to develop and demonstrate new UAS platforms, autonomy and teaming technologies. This will culminate in a series of demonstrations to highlight the capability and its benefit to the Army. Overall, RDECOM's focus in this area will ensure that the Army's manned and unmanned aircraft are ready to overmatch any potential adversary.

For more information about AMRDEC, part of the RDECOM, go to ***https://www.amrdec.army.mil/*** *or contact* ***usarmy.redstone.rdecom-amrdec.mbx.pao@mail.mil****.*

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KEEPING AIRCRAFT IN THE FIGHT

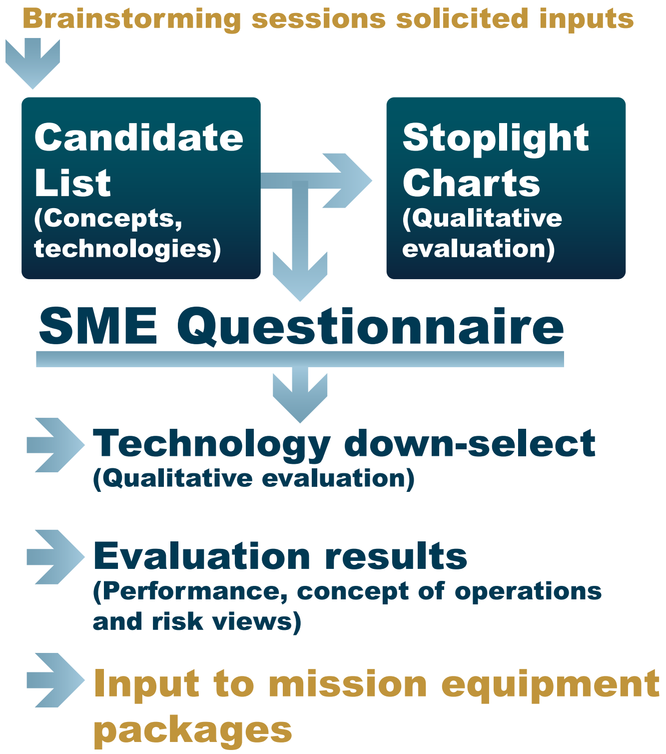
Working group identifies new suite of technologies to boost aircraft survivability.

by Mr. Mark Calafut

U.S. Army aviation faces a diverse threat environment, spanning broad categories of threats from ballistic munitions and guided missiles to directed energy and cyber weapons. It also spans generations of technology, ranging from constantly evolving sophisticated systems to widely proliferated legacy equipment. The modern threat environment presents both a technical challenge and a moving target to Army aviation. Historically, the science and technology (S&T) community has played an important role in developing advanced technologies to outpace the evolution of the threat. In an increasingly challenging threat environment, S&T is now even more critical.

This has driven the S&T community not only to begin developing nontraditional technologies for advanced protection, but also to establish new practices and processes to evaluate them. In May 2016, the U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) and the U.S. Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) jointly formed an advanced protection working group to answer key questions for Army aviation. In its first year, the goal of the advanced protection working group was to identify the best technologies to protect the future force. The working group began its analysis from the

FIGURE 1



PROCESS OF PROCESSES

The working group performed market research, conducted technology surveys and talked with SMEs before identifying 160 promising technologies. The list was narrowed to 70 unique technologies for formal evaluation after review. (SOURCE: CERDEC)

fundamental premise that there is no "silver bullet" technology capable of addressing all future threats and operational scenarios. Instead, the solution for future aircraft survivability would be a range of technologies to avoid, detect and defeat the emerging threat. This group would identify that solution.

CERDEC and AMRDEC structured the working group to include both breadth and depth of technical knowledge, as well as to engage with the intelligence, requirements and acquisition communities. The core team of the working group was responsible for performing technical analysis and developing the group's recommendations. The team was composed of technical experts from within CERDEC and AMRDEC, as well as from the U.S. Army Research Laboratory, the U.S. Army Armament Research, Development and Engineering Center, the Institute for Defense Analyses and Massachusetts Institute of Technology's Lincoln Laboratory. The core team also regularly consulted with subject matter experts (SMEs) from other government and academic organizations, such as the Defense Advanced Research Projects Agency and the Air Force Research Laboratory. To ensure that the technical analysis was performed in the broader context and to facilitate engagement with the stakeholder community, the group also included representatives from the intelligence, requirements and acquisition communities.

The advanced protection working group began by adapting proven system engineering processes that are measurable and repeatable into a standardized method to evaluate technology. The group used this method to determine the performance of technologies with respect to classes of threats rather than with respect to any individual threat. This approach was intentionally designed to identify technologies whose capabilities span multiple threats and provide broad protection.

To ensure that all technical options were considered, the working group performed market research, conducted technology surveys and initiated discussions with SMEs. The working group initially identified 160 technologies; after review, it narrowed this list to 70 unique technologies for formal evaluation. These technologies include advanced sensors, defensive electronic attack capabilities and signature reduction technologies. A quantitative methodology enabled the working group to perform sensitivity analysis and assess the specific benefits and risks associated with each potential technology (See Figure 1.).

DISPARATE TECHNOLOGIES

Technology evaluation was inherently challenging across this wide range of disparate technologies. The working group categorized the 70 technologies into several subareas, including topics

> *The agreement on a common road map also has driven participating organizations to alter their planned S&T investments and more closely coordinate development efforts into common programs.*

FIGURE 2

GETTING AT THE CORE OF THE PROBLEM

Technical experts from across an array of disciplines and research organizations make up the working group's core team. They work to generate solutions to challenging S&T problems. (SOURCE: CERDEC)

such as aircraft survivability equipment (ASE)—electronic systems to detect and defeat threats—and vulnerability reduction—technologies to reduce the damage a threat delivers to the aircraft and crew (See Figure 2.). To minimize subjectivity in the analysis, the working group established a process of processes, where each of these technology subareas was evaluated with a process appropriate for its characteristics and technical maturity. For example, in the area of ASE, there are experimental data and established modeling and simulation (M&S) tools available from across DOD. For many ASE technologies, including traditional electronic support sensors and electronic attack countermeasures, it was appropriate to use historical data or M&S tools to assess performance. In contrast, in the area of nontraditional susceptibility reduction (NTSR), the working group was specifically looking for unconventional concepts that had not been previously considered for the survivability application. The NTSR assessment included technology options ranging from wild ideas that push the limits of the possible to proven components adapted from different applications. In many cases, NTSR technologies did not have appropriate M&S tools to support an assessment similar to the one conducted for ASE. Therefore, a unique assessment was developed specifically for the NTSR subarea. This process included an initial technology assessment followed by a selection process performed through structured SME assessment. To maximize objectivity, each technology was assessed by experts from different backgrounds to obtain multiple data points and provide a full perspective.

Overall, the working group engaged more than 15 SMEs to assess the 70 technologies. The experts evaluated each technology according to the process for its technology area and assigned a numerical value to its performance. They also provided confidence representing the body of evidence behind the performance value. In the next step, stakeholders developed weights for each evaluation criterion based on priority, and the working group calculated a normalized composite score for each technology. This score represents a concise estimate of the relative performance of each technology.

After assessing the technologies individually, the working group determined the optimal suite of technologies. The working group envisioned a spectrum of technologies integrated into a layered survivability suite. When a threat is encountered, the survivability suite autonomously employs appropriate technologies throughout the tactical timeline to maximize survivability. This concept makes the most effective use of each technology available to defeat the threat given the unique parameters of an engagement. The working group systematically

SEEKING SURVIVABILITY

Infantrymen with 3rd Armored Brigade Combat Team ("Iron Brigade"), 4th Infantry Division (3-4 ABCT), conduct an air assault in August with 3rd General Support Aviation Battalion, 10th Combat Aviation Brigade during the U.S. Army Europe Combined Resolve IX exercise at Grafenwoehr Training Area, Germany. Army S&T is pursuing aircraft survivability technologies across a spectrum of technologies and areas of expertise. (U.S. Army photo by Capt. Scott Walters, 3-4 ABCT)

combined the highest-scoring technologies and considered technology dependencies to create candidate technology suites. The more threat characteristics that a technology suite addressed and the higher the priority of those characteristics, the greater the protection capability of the suite. Finally, the working group went beyond performance and considered the potential multifunctional applications of the suite and calculated the platform's size, weight and power requirements. The working group then agreed on a recommended technology suite for future survivability. The group will use these processes to refresh its technical solution and road map every three years, or more frequently if events drive a significant change in the threat picture or the state of technology.

10-YEAR ROAD MAP

The last step was the creation of a common 10-year technology development road map. The agreement on a common road map also has driven participating organizations to alter their planned S&T investments and more closely coordinate development efforts into common programs. This includes cross-cutting S&T areas that will require the joint attention of multiple laboratories, on topics such as M&S, power generation and storage, and common architectures that enable compatibility and data exchange. The road map was designed to include the development of enabling technologies with broad applicability, as well as more targeted efforts specifically designed to invest in identified S&T gaps.

To balance and manage risk, the road map includes critical decision points. Often, potential leap-ahead technologies are technically immature and high- risk. For these elements, the road map includes one or more critical decision points, where the result of technical analysis or a technology maturity assessment determines whether investment should continue. This allows the S&T community to contribute to Army aviation by providing new advanced technologies as well as by determining the practical viability of potential leap-ahead technology paths.

FACE THE THREAT

Helicopters from 1st Battalion, 3rd Aviation Regiment, 12th Combat Aviation Brigade (CAB), depart Katterbach Army Airfield, Germany, in June bound for Cincu Training Area, Romania, for Exercise Noble Jump 17. U.S. Army S&T plays a critical role in developing advanced technologies to help Army aviation take on diverse threats. (U.S. Army photo by Capt. Jaymon Bell, 12th CAB Public Affairs)

The working group completed its first phase of analysis in July and has established the common objectives and decision points for the S&T community. Over the coming months, the group will present its results and recommendations to Army leadership for review and concurrence.

CONCLUSION

The advanced protection working group already has led to several major benefits for the S&T community. Foremost among these is the repeatable process it has established to assess a broad portfolio of technologies together and in an objective manner. This facilitates the development of common S&T programs and demonstrations, improves targeting of investments and return on investment, and documents the contribution of each technology to the larger solution. Overall, the activities of the advanced protection working group demonstrate that S&T is about much more than technology: It's about creating and using balanced processes to help the Army identify cross-domain solutions to its most challenging problems.

*For more information or to contact the author, go to **www.cerdec.army.mil**.*

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> ***The working group categorized the 70 technologies into several subareas, including aircraft survivability equipment—electronic systems to detect and defeat threats—and vulnerability reduction—technologies to reduce the damage a threat delivers to the aircraft and crew.***

TOMORROW'S COMMAND POST

The Missouri Army National Guard's 35th Aviation Brigade sets up a command post under the Milky Way in May 2017 at the National Training Center (NTC), Fort Irwin, California, in support of the 155th Armored Brigade Combat Team's NTC rotation. Army S&T investments will support mobile, scalable, tailorable command posts through servers, infrastructure and vehicle and equipment packages. (Mississippi National Guard photo by Staff Sgt. Tim Morgan, 102nd Public Affairs Detachment)

NETWORK C3I

Targeted S&T supports new directions in network modernization by focusing on command, control, communications and intelligence capabilities for expeditionary operations featuring active electronic warfare.

by Ms. Nora Pasion

Army senior leaders have identified network command, control, communications and intelligence (C3I) as one of the Army's six modernization priorities. Consistent with guidance from the chief of staff of the Army (CSA), the Army will move away from the existing network modernization path that lacked survivability, effectiveness, interoperability and suitability, and toward an expeditionary network enabling the Army to fight and win in all environments and against all enemies. To support this way forward, the Mission Command Network Modernization Implementation Plan will drive the development of the future Army network through four lines of effort (LOEs):

1. Unified network.
2. Common Operating Environment.
3. Joint and coalition interoperability.
4. Survivability and mobility of command posts.

The Network Modernization Implementation Plan defines each LOE in support of the CSA's intent. LOE 1, unified network, will address unified transport and the supporting network enablers to provide assured network transport in a contested and congested environment. The second LOE, Common Operating Environment (COE), will focus on integrating the Joint Information Environment (JIE) and the associated applications that support commanders and leaders at echelon.

LOE 3 addresses interoperability in both JIE and mission partner environments, and supports the overall COE. Lastly, LOE 4 addresses the mobility and survivability of command posts (CPs), focusing on the capabilities that enable combat formations to conduct distributed mission command in an increasingly contested and congested environment against a peer adversary. This plan is grounded in the CSA's first principles of modernizing to achieve critical operational requirements.

To provide warfighters with the necessary equipment to support the CSA's modernization objectives, the Army is investing in science and technology (S&T) in the following network C3I and enabling areas: tactical communications and networking; assured positioning, navigation and timing (PNT); electronic warfare (EW); and cyber-electromagnetic activities (CEMA); mission command applications; persistent iintelligence, surveillance and reconnaissance (ISR); and command post.

Following this article are three articles addressing select S&T concepts and research that support the network C3I portfolio across the near term (through 2025), midterm (2026-2035) and far term (beyond 2035): sensing in complex and congested environments; future Army Networks; and novel distributed processing approaches.

TACTICAL COMMUNICATIONS AND NETWORKING

To ensure information dominance on the battlefield, the Army's tactical network must provide assured communications in contested, congested and degraded environments. This supports communications at the point of need and enables timely, decisive action. Army S&T investments are addressing these challenges through the research and development of automated and intelligent networks, anti-jam voice and data, autonomous platform communications, spectrum situational awareness (SA) and high-bandwidth commercial technologies.

ASSURED PNT

Unified land operations in multidomain environments require Army forces to access and integrate capabilities across space, cyber and EW domains to gain and maintain PNT superiority in support of joint operations. Transmission platforms that support unified land operations with unified action partners (or, "military forces, governmental and nongovernmental organizations, and elements of the private sector with whom U.S. Army forces plan, coordinate, synchronize, and integrate during the conduct of

WEEDING OUT DIFFERENCES

Sgt. Joshua Burnette of 1st Stryker Brigade Combat Team, 25th Infantry Division instructs a member of his squad during Exercise Orient Shield 2017 at Camp Fuji, Japan, in September. The exercise is designed in part to enhance U.S. and Japanese combat readiness and interoperability at the tactical level, which is also a focus of S&T efforts for C3I. (U.S. Navy photo by Mass Communication Specialist 2nd Class Christopher Lange)

WHAT'S ON THE HORIZON?
An Expeditionary CEMA Team member surveys the battlefield near the mock city of Razish at the NTC in May as part of a training rotation for the 2nd Armored Brigade Combat Team, 1st Infantry Division under the CEMA Support to Corps and Below Initiative. Led by the U.S. Army Cyber Command (ARCYBER), the initiative started as a pilot to explore cyberspace capabilities and doctrine, and grew to encompass the integration of cyber with warfighting disciplines such as EW, information operations, intelligence and network operations. (U.S. Army photo by Bill Roche, ARCYBER)

operations," according to Army Doctrine Reference Publication 3-0, "Unified Land Operations") must be assured and secure to deliver on-time situational awareness that allows operational units to act quickly and outmaneuver adversaries.

U.S. forces need the ability to prevent, degrade, eliminate and mitigate threats aimed at joint unified land operations while preserving friendly freedom of movement and action. S&T investments provide technologies that enable monitoring and control of the navigation warfare environment. Supported capabilities include electronic protection, support and attack; denying PNT capabilities to adversaries; and demonstrating quantum-based, GPS-independent, ultra-high precision PNT in any environment. Other research efforts include developing modular GPS-independent sensors, open architecture sensor fusion capability and leading DOD's PNT modeling and simulation collaborative initiative.

ELECTRONIC WARFARE

EW provides an advantage over the adversary by enabling forces in operational areas to conduct electronic attack (EA), EW support (ES) and electronic protection (EP), in combination with other tactics. Army S&T investments are providing EW technologies for the mid and far term to enable ES, EA and SA through the foreseeable future. Research efforts are also producing standards-based, multifunction platforms in support of the Army EW strategy for unified land operations in 2025 and beyond.

CYBER-ELECTROMAGNETIC ACTIVITIES

Technologies are needed that harden critical network and weapon systems and protect these vital assets from emerging cyber threats as well as those that exploit the electromagnetic spectrum. These S&T investments deliver technologies that enable the resilience to fight through an attack and to acquire SA by leveraging tactical assets. These investments are expected to provide rapid access and effects to gain an advantage over adversaries.

Research efforts are also developing system architectures that support a warfighting network platform in order to increase interoperability across operational domains, decrease the burden of training and enable the tactical delivery of cyber-electromagnetic effects.

MISSION COMMAND APPLICATIONS

Mission command applications must rapidly correlate and integrate data into useful information, enable rapid and accurate SA and reduce the number of Soldiers required for command post operations. Key capabilities include a common operating picture and awareness of cyberspace and the electromagnetic spectrum, which support commanders and leaders at all echelons and enable all warfighting functions.

Army S&T investments are delivering decision-support tools that implement standardized digital plans, model-based decision tools, automated sensor feed discovery, predictive visualization and machine learning to improve Soldier understanding, response time and accuracy, regardless of the tempo of operations.

DATA TRANSFER DUTY

Combat Cameraman Spc. Christopher Bellafant tests a data transmission system as part of tactical digital media training at Aberdeen Proving Ground, Maryland, in October. Army S&T investments in network modernization are focused on expeditionary, mobile and agile capabilities that increase combat effectiveness and improve decision-making and targeting. (U.S. Army photo by Dan Lafontaine, Program Executive Office for Command, Control and Communications – Tactical)

PERSISTENT ISR

To overcome range limitations and deliver accurate long-range precision and area fires, Army S&T provides capabilities that enable assured maneuverability through continuous battlespace SA. Enhanced SA reduces tactical surprise and prevents detection. Additionally, these assets increase the probability of target acquisition and deliberate operational engagement to defeat adversaries in an attack. S&T investments in this area include affordable, precision, standoff target identification and geolocation capabilities for mounted and dismounted Soldiers.

These programs are intended to assure speed and protection for ground forces. Complementary investments will include autonomous sensing of potential threats, sensor interoperability, multifunctional sensing, automatic target acquisition and data processing and synthesizing for Soldiers and units to employ for exploiting and disseminating information.

COMMAND POSTS

CPs enable commanders and their staff to visualize, comprehend, direct and synchronize operations continuously in all phases of unified land operations. CPs must enable units to conduct distributed operational mission command ranging from while en route to a crisis, during early entry to major combat operation and while rapidly integrating warfighting functions.

These CP capabilities are necessary to facilitate planning, collaboration and synchronized unified land operations with unified action partners, while reducing electronic and physical signatures to prevent hostile detection and targeting from enemy fires. Additionally, CP infrastructure must be deployable, mobile and survivable in a fast-paced, lethal fight. Army S&T investments will support a mobile, scalable and tailorable CP with improvements to CP infrastructure (including servers), power generation systems, vehicle and equipment packages, and other enabling technologies.

CONCLUSION

Focused network modernization is critical to achieve the Army's desire to fight and win in any environment against any foe. In support of the Army's top modernization priorities, Army S&T develops network C3I and enabling technologies in tactical communications and networking; assured PNT; EW; cyber-electromagnetic activities; mission command applications; persistent ISR; and CP technologies.

Collectively, these technologies enable expeditionary, mobile, agile, survivable, situationally aware and interoperable capabilities that increase combat effectiveness and improve decision-making and targeting in future conflicts. To enable the Army to execute the conduct of war and remain prepared for war, these efforts are critical to aligning modernization efforts with the Army's first principles.

For more information, go to ***https://www.army.mil/asaalt***.

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COMPLEX ENVIRONMENTS CALL FOR BETTER SENSORS

Or multiple sensors that work better together.

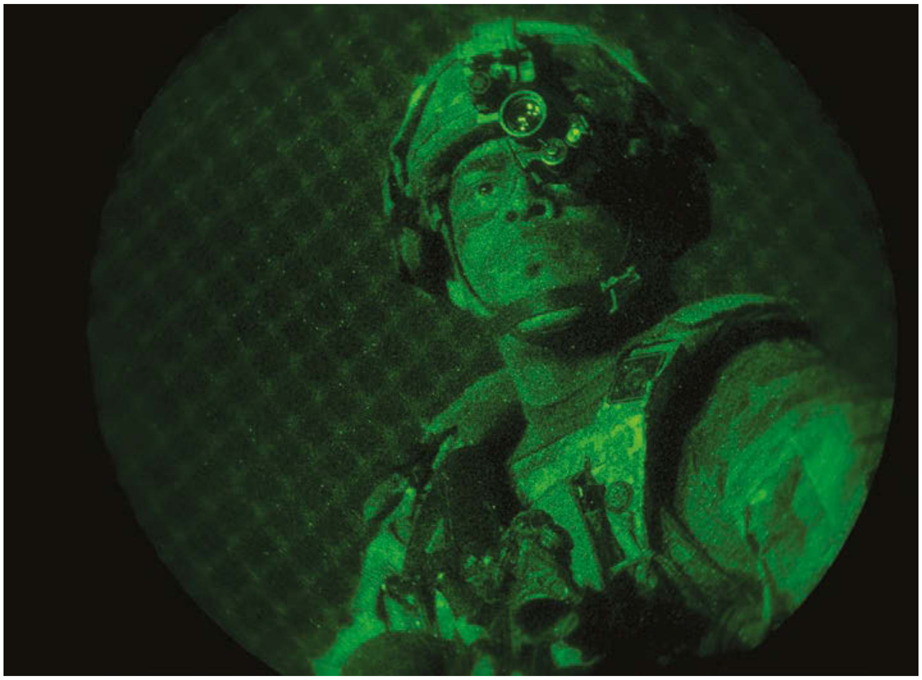
by Dr. Richard Nabors, Dr. Donald A. Reago Jr. and Mr. Nathan Burkholder

"War is the realm of uncertainty; three quarters of the factors on which action in war is based are wrapped in a fog of greater or lesser uncertainty," wrote Carl von Clausewitz in his 1832 treatise "On War." The dictum still holds for modern warfare. Confusion, chance, chaos and resistance are as much factors in modern warfare as they were in Napoleonic times. Weather and terrain, misunderstandings and inaccurate intelligence, a creative and adaptive enemy and a civilian population in the battleground are just a few of the contributors to the "fog of war" that have always challenged the warfighter.

However, modern warfare is becoming dramatically different from warfare in the past, with multiple, shifting players operating within complex, dynamic environments. At the Oct. 4, 2016, Association of the United States Army's annual Eisenhower Luncheon, Gen. Mark A. Milley, Army chief of staff, warned that "we are on the cusp of a fundamental change in the character of ground warfare. Land-based forces now are going to have to penetrate denied areas to facilitate air and naval forces," Milley said. "This is the exact opposite of what we have done for the last 70 years, where air and naval forces have enabled ground forces." The nature, location or duration of the next conflict cannot be predicted accurately. With continually changing coalitions, alliances, partnerships and actors, the operational environment has become extremely multifaceted and fluid. No longer a battlefield, the complex operational environment has become a battlespace—jungle, forest, city, desert, arctic and cyber—where the enemy is already entrenched and knows the operational environment.

EYES UP

Sgt. Luciano Batista, left, and Sgt. Michael Hughes react to a simulated attack at the 2017 U.S. Army Reserve Best Warrior Competition at Fort Bragg, North Carolina, in June. Several Army working groups are looking at ways to field better sensing technologies that will help Soldiers react faster and more accurately. (U.S. Army Reserve photo by Sgt. David Turner)



BEYOND NIGHT VISION

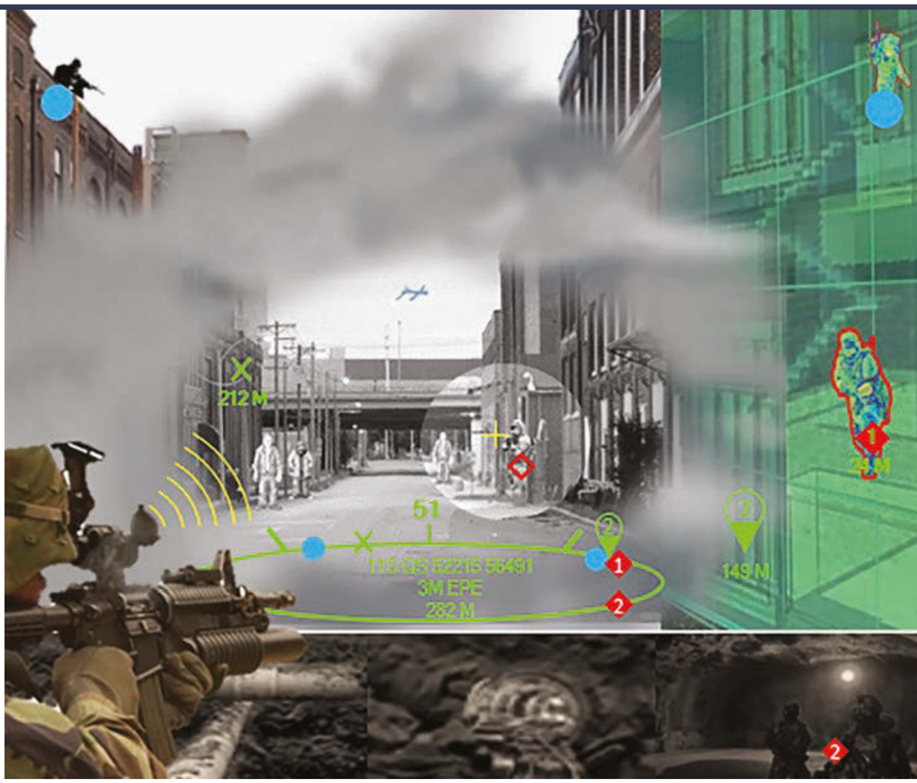
A Soldier assigned to the 3rd Brigade Combat Team, 82nd Airborne Division watches as troops move to cover while clearing buildings as part of a deployment readiness exercise, Panther Storm, at Fort Bragg, North Carolina, in August. Night vision and other advanced sensing technologies have given U.S. forces a strong advantage, but the complex, dense environment where future conflicts are likely to be fought reduces that advantage considerably. (U.S. Air Force photo by Staff Sgt. Andrew Lee)

NECESSARY UPGRADES, TECHNICAL CHALLENGES

Military technology combined with superior training and the unmatched excellence of our Soldiers has given the U.S. military significant means of reducing the fog of war, leading to decades of overmatch. For example, the U.S. military's ability to "own the night" through night-vision technologies has provided 40 years of military dominance over both near-peer and hybrid threats. The volatile and complex environments of tomorrow will require a move from owning the night to owning the environment. Improvements in sensing that extend beyond simple awareness of activities concealed by darkness is an imperative.

Complex and congested environments level the field between the United States and its adversaries by reducing standoff and line-of-sight advantages. Expected advances in Army sensing capabilities will directly address operational vulnerabilities in future environments, including intelligence, surveillance and reconnaissance (ISR) by a concealed enemy, and poor visibility and short lines of sight against positioned and moving threats in urban environments. These needed advances will buy back the field of view lost to clutter, and reinforce and expand small units' ability to sense the adversary across modalities (maneuver, surveillance, targeting, engagement, etc.). They also will provide the small unit with an understanding of the operational environment that the adversary lacks. These sensors will provide local ISR by collecting, sorting and fusing real-time data and sending it to the point of need, significantly reducing the fog of war.

These changes will restore the military advantages that the United States has had in employing the movement and maneuver functions necessary for successful



NEW ENVIRONMENT
Though the Army has fought in urban areas before, it's not just the density of a city that challenges scientists designing the sensor equipment to help Soldiers navigate future operating environments. The electromagnetic spectrum, where communications and navigation information flow, is also more crowded, and jamming, denial and disinformation campaigns will clog and obscure the battlespace. (U.S. Army graphic by Sonya Beckett, CERDEC NVESD)

land warfare. If the United States is going to maintain its historic advantages, then it will need continued, sustained investments to nurture the technology development required to maintain overmatch capabilities. Some of the technical challenges we will need to address to secure this future include:

- Fusion of disparate sensors into a combined capability.
- Tactical computing resources.
- Network connectivity and bandwidth.
- Sensor suitability for environmental observation.
- Reduced power requirements.
- Tailored, individual mechanisms through "sensored" Soldiers.
- Disguised unmanned systems to gather and communicate intelligence.

CONCLUSION

The Army has several groups working to identify and assess innovative concepts that could provide a significant advantage to U.S. forces and their partners in complex environments. Enhancing human vision beyond traditional night-vision technologies, integrating computers into sensing systems to detect and identify items of interest in real time, using augmented reality to overlay computer vision with human vision and fusing data together from multiple sensor sources to provide a comprehensive understanding, will allow Soldiers to make better, faster decisions while operating in complex environments against a resolute and adaptive enemy. Because network coverage in these future environments will be volatile and intermittent, it is important for these sensors to be able to work autonomously to support local operations as well as converge and diverge as needed.

Many science and technology (S&T) labs and centers within the Army, including the U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) and the U.S. Army Research Laboratory, are working on programs of significant impact in bringing needed sensing capabilities to our Soldiers. Army S&T is dedicated to investing heavily in technology areas that support our Soldiers' constant situational understanding of the battlespace.

"On the future battlefield, if you stay in one place longer than two or three hours, you will be dead," Gen. Milley said at the Eisenhower Luncheon. In the future, there will be no clear front line, no secure supply lines, no large bases. Small units will be on their own, far from friendly forces, in constant motion to avoid detection and targeting by enemy forces. The most valuable asset and advantage of the U.S. military, as Milley said, is that Americans are improvisers, innovators and problem-solvers with the initiative to act independently. Equipped with the best technology in sensing, weaponry and defense, Soldiers will be empowered to adapt to changes in real time in spite of a complex and congested operational environment. Continued technology improvements will ensure future success and overmatch.

The Army must be effective across the entire spectrum of conflict. To do so requires understanding the operational

THE FOG OF WAR

Soldiers assigned to 2nd Armored Brigade Combat Team, 1st Armored Division conduct sentry duty in August during Decisive Action Rotation 17-08 at the National Training Center, Fort Irwin, California. The battlespace where modern wars will be fought layers new sources of uncertainty and confusion on top of the factors that already produce the fog of war. (U.S. Army photo by Spc. Dedrick Johnson, Fort Irwin Operations Group)

No longer a battlefield, the complex operational environment has become a battlespace—jungle, forest, city, desert, arctic and cyber—where the enemy is already entrenched and knows the operational environment.

environment and how Soldiers and units accomplish missions. In complex environments, the gathering and fusion of information lead to greater understanding. Improved sensors, remote and near, manned and unmanned, can both save Soldiers' lives and make them more lethal.

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SENSOR OVERLOAD

An S&T objective looks to 'ExPED'ite and improve processing and exploitation of the avalanche of raw intelligence data.

by Mr. Michael Pellicano and Ms. Danielle Duff

At the tactical level, a commander depends on the depiction of accurate and timely battlefield situational understanding on the common operating picture (COP) to support the decision-making process. This picture is directly influenced by intelligence analysts using an institutionalized workflow called tasking, collection, processing, exploitation and dissemination, which turns raw intelligence data into actionable intelligence that is then fed into the COP.

Over the previous decade, driven by the demands of war and technological advances, significant enhancements in the capabilities of sensors and collection platforms have led to collection systems that generate extraordinarily large amounts of data, which has the potential to provide a rich and more accurate understanding of the battlefield. Unfortunately, the wealth of data overwhelms analysts' ability to turn it into actionable intelligence. To put this in perspective, William M. Arkin writes in his book "Unmanned: Drones, Data, and the Illusion of Perfect Warfare," that "the amount of visual data collected each day [is] five seasons' worth of every professional football game played—thousands upon thousands of hours."

But drones are just one of the many sensors on the battlefield. Arkin notes that "the next generation of wide-area motion imagery sensors will be capable of collecting 2.2 petabytes per day, bringing 450 percent more data into the network than all of Facebook adds on a typical day." As a result, data is left unprocessed, unexploited and unavailable for future analysis. This inefficiency leads to gaps in situational awareness and sometimes duplicative collections.

The Defense Science Board in February 2011 came to a similar conclusion, stating: "[T]he rapid increase of collected data will not be operationally useful without the ability to store, process, exploit, and disseminate this data. … Current collection generates data that greatly exceeds the ability to organize, store, and process it." There are not, and never will be, enough analysts to review the massive amount of raw intelligence collected on the battlefield.

GATHERING INTEL—THEN WHAT?

A Soldier with the Regimental Engineer Squadron, 2nd Cavalry Regiment assembles an RQ-11 Raven unmanned aerial vehicle during a surveillance mission in May during Saber Junction 17 at the Hohenfels Training Area, Germany. Saber Junction is designed to assess the readiness of the regiment, which is assigned to U.S. Army Europe (USAREUR), to conduct unified land operations, with an emphasis on operational and tactical decision-making, among other skills. The collection, analysis and dissemination of intelligence play an indispensable role in accurate, timely decision-making in combat. (U.S. Army photo by Spc. William Marlow, Viper Combat Camera Team, USAREUR)

To complicate this already difficult problem, the Army is consolidating analytic personnel, setting up centralized sites outside of conflict zones where specialized Soldiers can support operations by focusing on exploiting sensor data. However, legacy systems were not designed to move this amount of data across the network or support the collaborative analyst workflows needed to support decentralized processing, exploitation and dissemination (PED).

The Intelligence and Information Warfare Directorate of the U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC), a subordinate organization of U.S. Army Materiel Command's Research, Development and Engineering Command, initiated the Extensible Processing Exploitation and Dissemination (ExPED) Science and Technology Objective (STO) in October 2016 to improve the process of converting raw sensor data into usable situational understanding. A STO is a three- to five-year critical science and technology (S&T) project that has direct oversight from the Warfighter Technical Council, a one-star-level governing body that addresses strategic program topics, recommending and reviewing major new S&T investment efforts. The STO comprises several research focus areas combined under one program to work collaboratively on high-priority Army capability gaps, which for ExPED is "developing situational understanding."

The program title, ExPED or Extensible PED, refers to the desired capability to adapt Army PED operations based on mission needs and available resources such as sensors, computers and human analysts. Under optimal conditions, tactically deployed intelligence analysts will develop and refine the intelligence COP by combining data from multiple organic and strategic sensors with the help of advanced processing resources and subject matter experts who may be distributed around the world. The tools used to perform PED must support these distributed workflows and also adapt to more constrained conditions where networks or limited timelines don't allow for an enterprise solution.

The ExPED effort began with an intensive effort to analyze and study the PED process, by observing and interviewing analysts to determine what architectures, systems and sensors exist in the tactical environment and how these capabilities

ALL TOGETHER NOW

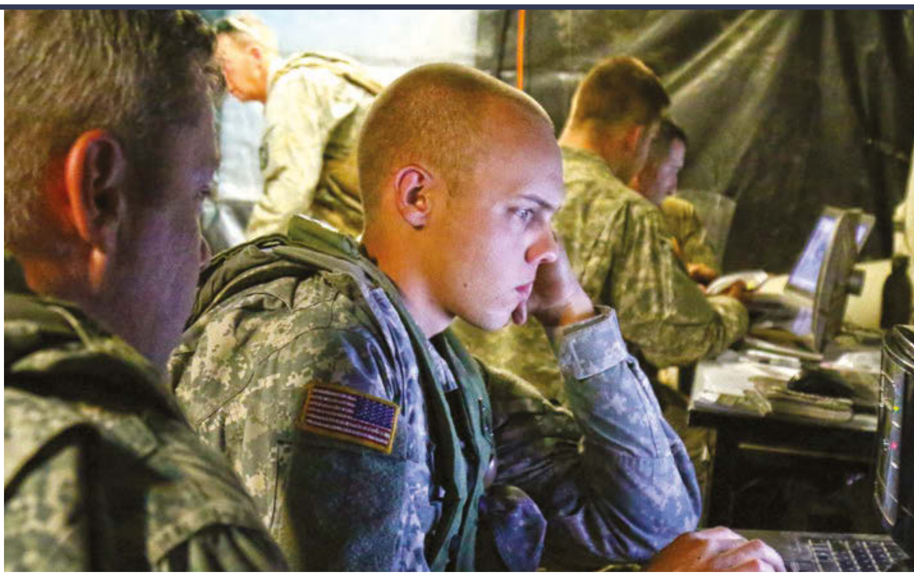
An AH-64 Apache attack helicopter provides security while CH-47 Chinooks drop off supplies to Soldiers with Task Force Iron at Bost Airfield, Afghanistan, in June 2017. The Soldiers' mission is to provide accurate fires capabilities in support of Task Force Southwest and Afghan national defense and security forces during current operations. One of the objectives of the ExPED STO is to identify sensor solutions with scalable open architectures that will adapt to the echelon in which they will operate in a tactical environment, thus facilitating integration with other ISR systems and the sharing of valuable information using the proper security boundaries. (U.S. Marine Corps photo by Sgt. Justin T. Updegraff, Resolute Support Headquarters)

are used to create intelligence products. The program then created a PED model and ran it through different scenarios to see where breakdowns might occur. Along the way, this effort identified the following top-level problems: the lack of automated processes to support multiple sensor and multiple intelligence (multi-INT) data; the high probability of missing significant events as data volume increases; and the lack of awareness of sensor collection plans.

With these findings, the ExPED team started an extensive system engineering process that identified basic PED use cases and then developed sequence diagrams to define how current PED processes functioned and to identify areas where applying S&T resources could have high payoff in PED workflows. The program designated three focus areas: PED architectures; data processing and analytics; and collaboration and visualization.

OPEN ARCHITECTURES IMPROVE INTEROPERABILITY

Recent combat operations necessitated focusing intently on immediate PED needs—narrowly targeted, evolutionary improvements, without appreciation for broader capability alignments; integration into the intelligence, surveillance and reconnaissance (ISR) enterprise; or life cycle cost. For the sake of speed, new sensor systems were developed and fielded as stovepiped systems, each with a dedicated processing system and dedicated analyst. This allowed for faster design, development and testing, whereby the engineers controlled all aspects of the system. In addition, sensors and PED systems are stovepiped within security boundaries because of classification of the systems or the data they collect. However, valuable information could be shared across security boundaries if the proper processes were in place.



GETTING THE BIG PICTURE

Spc. Clayton P. McInnis, a human intelligence analyst with 1st Battalion, 155th Infantry Regiment of the Mississippi Army National Guard, reviews reports in the unit's tactical operations center in June, at the National Training Center, Fort Irwin, California. The ExPED STO is designed to improve the conversion of large amounts of raw sensor data into usable situational understanding. (Mississippi National Guard photo by Staff Sgt. Shane Hamann, 102nd Public Affairs Detachment)

These stovepipes hinder the ability to conduct multi-INT analysis, to hand off targets between sensors (cross-cue) or to share data with other systems. Stovepiped systems also present unscalable and unsustainable costs for the doctrine, organization, training, material, leadership and education, personnel and facilities aspects of maintaining the ISR enterprise.

Instead, sensor solutions need to use industry standards, be scalable—capable of handling a growing amount of work—and built on open architectures designed to support rapid integration of new capabilities by making it easy to add, upgrade and swap components. These architectures should adapt to the echelon in which they will operate, provide a framework for distributed PED and facilitate integration with other systems.

Data services, an essential architectural component, must provide data management and delivery to the right user; this includes enabling access to joint, interagency, multinational, NATO, allied and national operations. Some currently fielded sensor architectures provide sensor data and status. However, these architectures are not tailored for tactical environments with limited communications, cannot be easily reconfigured during missions and are not designed to support multi-INT fusion—the process of comparing and correlating data from multiple sources and disparate types, including human inputs, collected signals, measurements and imagery, and then generating more useful observations.

The ExPED program is investigating and developing sensor architecture prototypes that will dynamically tie together PED resources (sensors, analytics and analysts) across the tactical space. This will provide the ability to reconfigure resources in changing conditions and make better use of constrained tactical bandwidth, thus increasing awareness and discovery of significant events.

REDUCING ANALYST WORKLOADS

The Army continues to add sensors that are capable of collecting greater volumes of data, but we can't afford to move all of the data around our networks, and we don't have enough analysts to look at all of it. Analytics provide process automation, smart logic, computation and threat trending that expose nuggets of relevant information to the analysts.

Taskable automated and semiautomated multi-INT analytics and processing—whereby the user (or multiple users simultaneously) can seek and detect particular features for a particular mission or at a specific time, for example, a red truck or people with white shirts—are needed closer to the sensor to increase the Army's ability to manage and exploit the breadth and scale of collected data. Distributed data processing—using multiple computers across different locations to divide the processing load—can help reduce the amount of network traffic by filtering and compressing data as it moves through the network, increasing system performance in bandwidth-limited environments. These capabilities will create opportunities to leverage remotely stored data to glean new insights.

ExPED is investing in the development of prediction, fusion, correlation and alerting capabilities that are critical to managing the big data challenge and are necessary to reduce an analyst's workload. ExPED is working with Army and industry stakeholders to define standards for analytic interoperability so that more sophisticated mission-specific solutions can be built from existing analytic toolsets.

To validate these standards, the ExPED program is developing multi-INT analytics to merge radar tracks, full-motion video and electronic signals to provide greater confidence in the data and lessen the time for alerts to significant events. The analytics also need to be scalable and extensible so that the user can execute them wherever it makes sense across the tactical space. For example, an analytic can run on a multisensor platform, ground station or sanctuary, depending on the mission's concept of operations and communications links.

COLLABORATION AND VISUALIZATION

As the Army moves more toward centralized PED sites, collaboration is going to be all the more important. The Army has been realigning how it organizes and employs its human analysts as part of the PED process. One idea is setting up centralized sites outside of conflict zones where specialized Soldiers can focus on exploiting sensor data and feeding situational awareness back to theater. However, bandwidth constraints will limit scalability of this solution. Additionally, analysts who are not on the ground lack the mission context to fully exploit the data.

Reliance on the current system of countless chat windows to collaborate is inefficient and not scalable. Therefore, the Army requires a solution that allows for PED operations to move seamlessly between tactical and remote PED analysts.

Usability and software interface design are critical for handling, filtering and understanding the data and analytics, as well as providing an environment for analysis and user collaboration. Development and integration of techniques for big data visualization, collaboration and workflow management are essential for common understanding. These tools will enable management of tasks across echelons, provide mission context to facilitate situational understanding and reduce cognitive burden on analysts.

The ExPED program is developing a sensor COP to support all parts of the PED process, from tasking sensors to exploiting data to use of the intelligence. This includes developing an interface that is tailorable to all users in the PED process, including mission managers, exploitation analysts and analysts at every echelon. The ExPED sensor COP is a shared collaborative environment where all parties can interact and conduct their respective tasks and workflows—in real time, if communications allow.

The ExPED sensor COP is extensible, allowing applications to be built into it. This will allow data to move from one phase to the next with collaboration along the way, and will task and automate processes effectively to reduce analyst workload.

CONCLUSION

Current Army PED operations are not extracting the maximum amount of intelligence from existing sensors. The Army can get additional value by better leveraging the opportunity for multi-INT processing and exploitation, cross-cueing between sensors, forensic analysis and increased awareness and use of available resources.

The S&T community has the opportunity and imperative to work outside the narrow bounds of acquisition programs of record in order to design and demonstrate standards-based interoperable systems. By implementing a common framework of interoperable PED components, such as those being developed and demonstrated under the ExPED STO, Army PED operations will realize improvements in efficiency and capability such as:

- Moving processing closer to sensors to improve the timeliness of actionable intelligence and reduce the bandwidth necessary to transmit raw data.
- Automated or semiautomated cross-cueing of sensors for faster target acquisition and tracking.
- Use of advanced analytics to increase the speed and effectiveness of extracting intelligence from high-volume and high-speed sensor feeds.
- Better leveraging of distributed sensors, processing systems and analysts to execute ISR missions.

Commanders rely on situational understanding to make timely decisions, but more data does not equal situational understanding. Understanding will be accomplished only by providing analysts with the tools to process, exploit and disseminate the extensive amount of sensor data collected across the battlefield.

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PROCESSOR SWARM

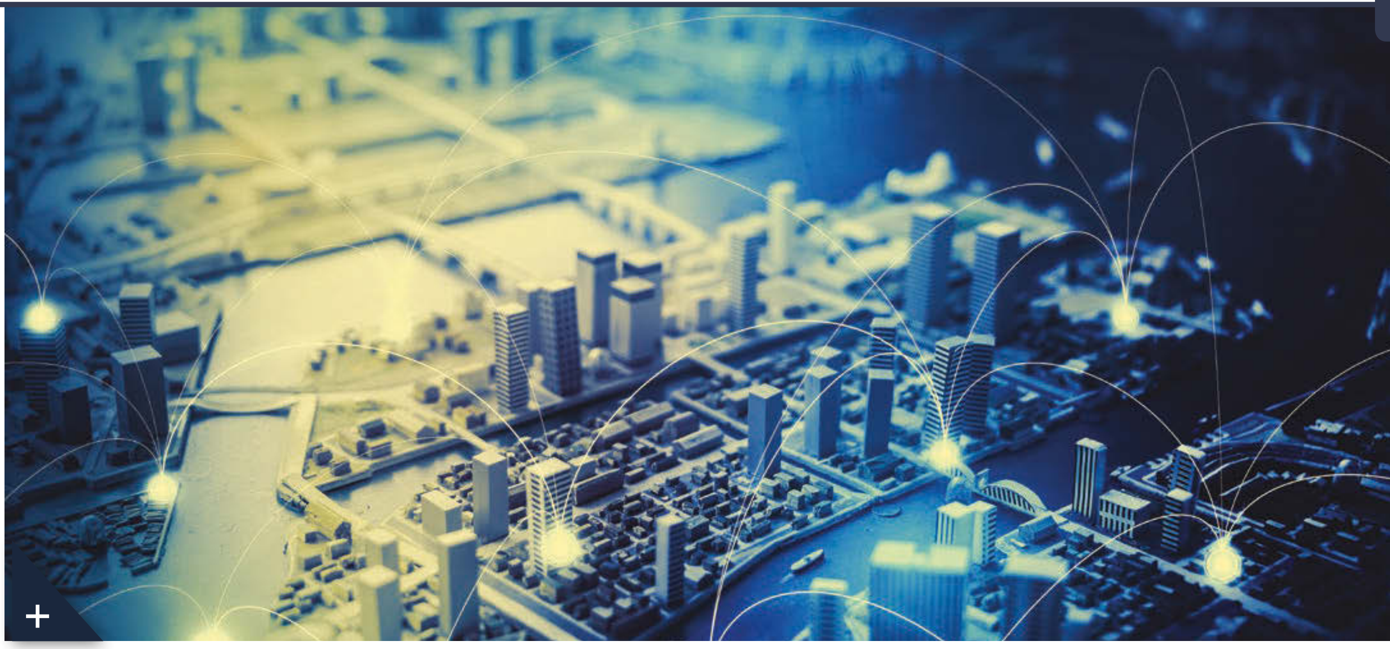
Inherent in the coming internet of battlefield things are challenges that commercial products don't face. But those products might have solutions to the Army's problems, which is why ARL and its partners are exploring novel distributed processing approaches, a domain the Army practically invented.

by Dr. Raju Namburu and Dr. Michael Barton

Distributed processing—using multiple computers to run an application—is not a new idea. But as technology advances, opportunities arise for new and novel distributed processing approaches that take advantage of nascent network-based communication, computing systems, innovations in algorithms, and software.

First realized around 1983 at Aberdeen Proving Ground (APG), Maryland, distributed processing has evolved over several decades as information technology has expanded exponentially. It will be a key technology for future Army operations, especially complex Soldier situational awareness.

As computer and network capabilities grew, distributed processing also grew to mean multiple, interconnected processors or computers working together to perform a common calculation or to solve a common problem. The Ballistic Research Laboratory, predecessor to the U.S. Army Research Laboratory (ARL), implemented network communication protocols—now known as internet communication protocols—for communication among four processors.



INTERNET OF THINGS

Novel distributed processing is essential to leverage the knowledge from many connected devices in time to quickly affect outcomes. (Image by Shutterstock/chombosan)

With each generation of distributed processing, more capable processors are pushed further out into organizations and society with more functionality, greater interaction and improved communication among different tiers of processing with greater integration among them, culminating in the internet of things: the proliferation of processors, mobile devices and sensors that are embedded in the physical objects—appliances, vehicles, buildings and other items—that surround us in our daily lives.

SITUATIONAL AWARENESS COOKIES

Today, a primary motivator for novel distributed processing is recognition of the enormous potential that resides in both the unused and dedicated processing power of many connected devices and the need to know more, sooner, and to leverage that knowledge to affect immediate future events. In the same way that every webpage you visit serves up advertisements based on browsing habits, the Army needs to be able to do something similar with intelligence, surveillance and reconnaissance systems so that Soldiers get served up what they need for superior situational awareness.

The Army faces directly analogous technical challenges—Soldiers need to know more and sooner (situational awareness) to allow rapid, decisive action. Now, and even more so in the future, the battlespace is characterized by highly distributed processing, heterogeneous and mobile assets with limited battery life, communications-dominated but restricted network capacity, and operating with time-critical needs in a rapidly changing hostile environment. Capabilities to be developed for the Army for enhancing situational awareness in contested battlefield environments are different from traditional commercial applications, which are targeted at exploiting the consumer. Essentially, the Army needs to be Facebook in reverse—exploiting the data for the use of the consumer, not exploiting the consumer for the use of data.

Distributed processing is one of the essential technologies for maintaining overmatch in the land domain in various operational and contested environments, including cyber and artificial intelligence. Some examples of future operational environments where innovative distributed processing approaches are essential include:

- Real-time situational awareness.
- Distributed machine learning and relearning.
- Distributed intelligence.
- Human-machine teaming.
- Delivery of big data analytics at the right place in a timely manner.
- Operations in megacities.
- Cooperative and collaborative engagements.
- Cyber and electromagnetic engagements.
- Accelerated learning.
- Augmented reality.

INFORMATION FOR ACTION

Soldiers need to know more and sooner—without being overwhelmed with information—to allow rapid, decisive action. (U.S. Army illustration)

The Army needs to be Facebook in reverse—exploiting the data for the use of the consumer, not exploiting the consumer for the use of data.

HOW WE GOT HERE

Large, expensive computers with interconnected processors were available to a small number of expert users in the 1980s. By the 1990s, the industry had moved away from custom processors to commodity chips, co-processors and shared software. The concurrent growth and proliferation of internet-enabled distributed processing, most notably in applications like SETI@home (the University of California, Berkeley-based Search for Extraterrestrial Intelligence, with 5 million internet-connected devices) and in processors like Rosetta@home (molecular biology, with 1.6 million internet-connected devices or processors). For these applications, algorithmic innovations took advantage of unused computer time donated by people worldwide.

They also benefited from the asynchronous nature of applications, in which every calculation is independent of every other calculation. These projects showcased more than a billion operations per second to achieve exascale computing. Exascale computing is not achievable by any single supercomputer that exists today.

By the 2000s, the internet brought about service-oriented architectures with seamless web access. Later, hardware virtualization allowed software to emulate an entire computer infrastructure, which culminated in the popularity of hosting pictures and other personal data in the cloud. We refer to the cloud as distributed processing, since it literally is distributed all over the world. But its purpose is to centralize computing infrastructure. It relieves the end-user organizations of having to invest individually. DOD's Distributed Common Ground System is an excellent example of cloud computing at the edge.

As opposed to cloud-computing, emerging technologies in ad hoc networked mobile devices, the internet of battlefield things, special purpose robotics, unmanned vehicles and social networks will produce enormous amounts of data. It is critical for Army scientists to explore novel distributed processing approaches for Army-specific applications, especially those distributed approaches that have potential to enhance the speed of decision-making.

THREE EVOLVING NOVEL APPROACHES

Distributed processing "at the edge" is a new paradigm in which we see convergence of computer processing with low-power processing, intelligent networking, algorithms and analytics as one entity, as opposed to stovepiped technologies. Distributed processing at the edge—referred to as edge computing, fog nodes, cloudlets, micro data centers and micro-clouds—is simply localized, trusted, resource-rich computers that are connected.

Edge computing requires a lightweight solution using containers for distributed processing. Instead of a physical canister that stores things, these containers optimize computer data by processing it near the source of data. The draw is that containers can be tailored to single solutions, such as a machine-learning container or a video-processing container. Army scientists want to figure out how to harness the benefits of edge computing with containers while navigating the challenges of doing it with mobility, such as intermittent bandwidth, ad hoc networking and policy-based environments.

Emergent computing is another evolving form of distributed processing. Information processing and control emerge through the local interaction of many simple units that exhibit complex behavior when combined. Intelligent software agents are in this arena: sophisticated computer programs that act on behalf of their users to find trends and patterns.

There are also multiagent systems that are loosely coupled networks of intelligent agents that interact to solve problems outside of what any one agent would accomplish.

Neural-inspired computing is fast becoming an option for low-power novel distributed processing. Neural-inspired computing mimics the neurons and synapses of a biological brain. Another characteristic is that communication processing in neurons and synapses uses efficient digital or analog techniques such as two-dimensional (2-D) atom-layered nanotechnologies. An example of 2-D is a crystalline material that has a single layer of atoms with unusual

THE SHAPE OF NEXT-GEN PROCESSING

ARL has internal programs aimed at the capabilities of the next generation of distributed processing, and is working with partners at academic institutions and in industry. (U.S. Army graphic by Peggy Frierson, Defense Media Activity) semiconductor and neuromorphic characteristics at the nanoscale.

In addition to continuous innovations in scalable algorithms and software, future computing architectures like quantum networks, data flow computing, and cyber- and electromagnetic-secured heterogeneous processors are going to play a role in overcoming distributed processing shortcomings that surface in military scenarios.

DISTRIBUTED PROJECTS FOR DISTRIBUTED RESEARCH

ARL is working toward the capabilities of the next generation of distributed processing, in collaborative projects with academic institutions and industry and in internal programs.

External collaborative programs that address challenges with distributed processing from algorithms and theory include the international technology alliance with the United Kingdom Ministry of Defense, the internet of battlefield things, distributed and collaborative intelligent systems and technology, the U.S. Army High Performance Computing Research Center, the Center for Distributed Quantum Information and ARL's Single-Investigator Program, executed through the Army Research Office.

There are also internal projects that lay some of the foundation. For example, we work with IBM, Purdue University and the Lawrence Livermore National Laboratory in understanding the programming and use of neuromorphic processors—brain-inspired computing. These neuromorphic processors have proven quite adept at machine-learning tasks, yet consume 1,000 times less power than conventional processors.

CONCLUSION

The Army has been at the forefront of computing and distributed processing and continues to make investments in related research to shape how the future Army will fight and win. The complexities of distributed processing become more clear as the way in which humans will engage with distributed artificially intelligent systems becomes more defined.

The reliance of intelligent systems on wireless communication and networked processes makes them vulnerable to cyber, physical and electronic attacks. Thus, it is necessary to develop technologies that mitigate those risks and keep systems functional in the face of such attacks. In the current and future world, this requires innovations in distributed processing and computation on and off the battlefield.

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First realized around 1983 at Aberdeen Proving Ground, distributed processing has evolved over the last several decades as information technology has expanded exponentially.

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Path of GREATEST RESILIENCE

Facing an enemy intent on creating a highly contested electromagnetic environment, S&T investments in Army networks focus on mobility, redundancy, ease of use and detection avoidance.

by Mr. Seth Spoenlein, Mr. James Snodgrass, Mr. Michael Breckenridge and Dr. Brian Rivera

The expeditionary nature of the future force will require mobile, secure communication networks that are dynamic—able to survive in active electronic warfare environments and available in all environments to ensure continuous mission command. However, obtaining and sustaining the higher ground in a network context will not come easily in the future battlespace.

The enemy will have advanced technologies designed specifically to create a highly contested electromagnetic (EM) environment, disrupting our ability to communicate, degrading our performance and injecting uncertainty into our decision cycle. To address these challenges and provide robust EM defense of information exchange, we need to develop mobile communication networks that can make optimal use of the EM spectrum, enhance EM security and reduce the probability of detection or intercept.

In addition, the network must be resilient to attacks in both the cyber and land domains by responding and adapting much more rapidly than today's networks. It must have low EM signatures and operate on-the-move. The entire network setup, from spectrum allocation to subnet configuration and security monitoring, must be automated to simplify network operation. Today's tactical Army networks are reliant on conventional radio-frequency (RF) technologies, which limits our ability to maintain communications in a contested environment.

Therefore, Army science and technology (S&T) is investing in innovative mobile communication platforms that employ advances in RF and nontraditional portions of the EM spectrum; highly directed adaptive anti-jam antennas to mitigate effects of multipath interference; and new algorithms and software to predict network performance, enhance cybersecurity and provide network self-configuring and self-healing capabilities.

Maintaining persistent connectivity, or network resilience, amid the noncontiguous and disrupted communication links

GRID SEARCH

Sgt. Rogelio Hercules, the network operations noncommissioned officer in charge assigned to the 44th Expeditionary Signal Battalion, 2nd Theater Signal Brigade (TSB), configures equipment during Saber Guardian 17, a U.S. Army Europe-led, multinational exercise held in Bulgaria, Hungary and Romania in July. The future force is expected to be more expeditionary, and as a result will require dynamic communication networks capable of operating in active electronic warfare environments. (U.S. Army photo by Staff Sgt. Brian Cline, 2nd TSB)

To achieve spectrum awareness, we will leverage every receiver on the battlefield as a spectrum sensor to yield relevant data for signals intelligence, electronic warfare and radio frequency communications.

in a tactical environment will require an automated intelligence system. Automation and intelligent network switching capabilities will simplify Soldier operation and guarantee the ability to quickly adjust based upon the mission needs and the enemy's action, in order to establish, adapt and maintain communication in a complex, contested environment.

To accomplish this network resilience and agility, Army S&T is looking to the use of multiple redundant network links, a diverse selection of alternate networks, and efforts to decrease the likelihood of disruption by an enemy. Network diversity will require separate physical connections to the tactical internet, the "final-furlong" squad area networks and long-haul networks. Effective network and spectrum diversity allows Army units to communicate regardless of what happens to the physical infrastructure over which those communications are transmitted.

CHOICES MAKE THE DIFFERENCE

Commercial technology has implemented automated processes in mobile devices (smartphones, tablets, etc.) to autonomously transition media among differing network connections without user selection or decision-making about which network to use. For example, automated network selection occurs when someone walks inside their home with a cellular device; that phone is programmed to autonomously switch to a home Wi-Fi network that has higher throughput and better signal strength; the device also uses Bluetooth to automatically discover a smart high-definition TV to telecast video or a speaker system to stream audio. In this commercial implementation, the source and destination devices are linked over a network infrastructure with redundant, highly reliable communication links.

The same cannot be said for current tactical Army networks where users may be located in physically and logically separated subnetworks and where the reliability of communication links can be intermittent, especially in contested spectrum environments. Army units need the flexibility to discover and leverage all viable network options, allowing multiple pathways to critical networks and data sources.

For ease of interaction with the network, an automated network selection system must maintain awareness of all available network connections, the status of each link and the source and destination of data to traverse the network. This system automates the planning methodology practiced by units to designate the primary, alternate, contingency and emergency (PACE) means of communication used to build a mission-based communication plan.

In tactical Army networks, different communication solutions are available to provide connectivity between users across varied environments. These solutions vary widely by technology, protocol, throughput and other factors that must be evaluated for priority in a PACE plan. Most Soldiers are not specialists in establishing or maintaining the network. We must reduce the need for a Soldier to be an expert for every configuration interface of every network radio. An automated PACE system will ease Soldier interaction with data traversing the network without concern for how the data flows from source to destination. The automated network selection system can automatically, intelligently and seamlessly route data over the available network connections as the PACE plan executes.

Another major element of network resilience is the need to decrease the probability of detection, as well as jamming and other types of interference. Future systems will minimize, or at least control, the spectrum signature a unit produces during normal operations, in order to defeat detection and eventual disruption. The automated PACE system is also a means to mitigate spectrum interference. When an enemy is successful with interference, the automated PACE system can maintain user-to-user connectivity during primary link disruption, and allow continued communications for units to accomplish mission objectives. Development of solutions for use at-the-halt or near the tactical edge will include technologies from unconventional regions of the spectrum that are difficult to detect or jam, such as terahertz and ultraviolet radiation.

An increased understanding of the spectrum environment amid interference and congestion will enhance situational understanding by helping to pinpoint sources of interference and their targets, and this will enable persistent network connectivity. To achieve spectrum awareness, we will leverage every receiver on the battlefield as a spectrum sensor to yield relevant data for signals intelligence, electronic warfare and radio frequency communications. Often, the same dataset can be used to support related mission needs, such as those of electronic warfare or offensive cyber operations. The spectrum data not only feeds

SHRINKING SIGNATURES

Army communication systems of the future will minimize a unit's spectrum signature to thwart detection and disruption. To that end, Army S&T is developing technologies that use nontraditional portions of the EM spectrum. (U.S. Army photo by CERDEC)

HYBRID NETWORK

Soldiers assigned to the 44th Expeditionary Signal Battalion, 2nd TSB assemble a dedicated antenna to support the command post of the Georgia National Guard's 648th Maneuver Enhancement Brigade during Saber Guardian 17 in July. The Army is developing technologies to operate in multiple bands, from low VHF to millimeter wave band and optical band, enabling a hybrid network that can adapt autonomously to attacks, connectivity problems or congestion. (U.S. Army photo by Staff Sgt. Brian Cline, 2nd TSB)

Army units need the flexibility to discover and leverage all viable network options, allowing multiple pathways to critical networks and data sources.

the network automation, but is also consumed by purpose-built systems that will effectively visualize this data and provide wide-scale situational understanding.

In addition, the Army will need to protect the network from adversaries attempting to geolocate our EM emissions and target them with long-range fires, making it critical to identify capabilities that lower the probability of detection and interception to increase network survivability. Future systems will minimize, or at least control, a unit's spectrum signature in order to defeat detection and eventual disruption.

Successful operations will require the ability to use nontraditional portions of the EM spectrum and to make it harder for the adversary to deny spectrum use to the force. Army S&T is developing technologies to operate in multiple bands from low VHF to millimeter wave band and optical band. Each of these bands has different performance constraints and capabilities, but together they will enable a hybrid network that can adapt autonomously to electronic warfare attacks, connectivity problems or congestion, thereby increasing the resilience of Army networks.

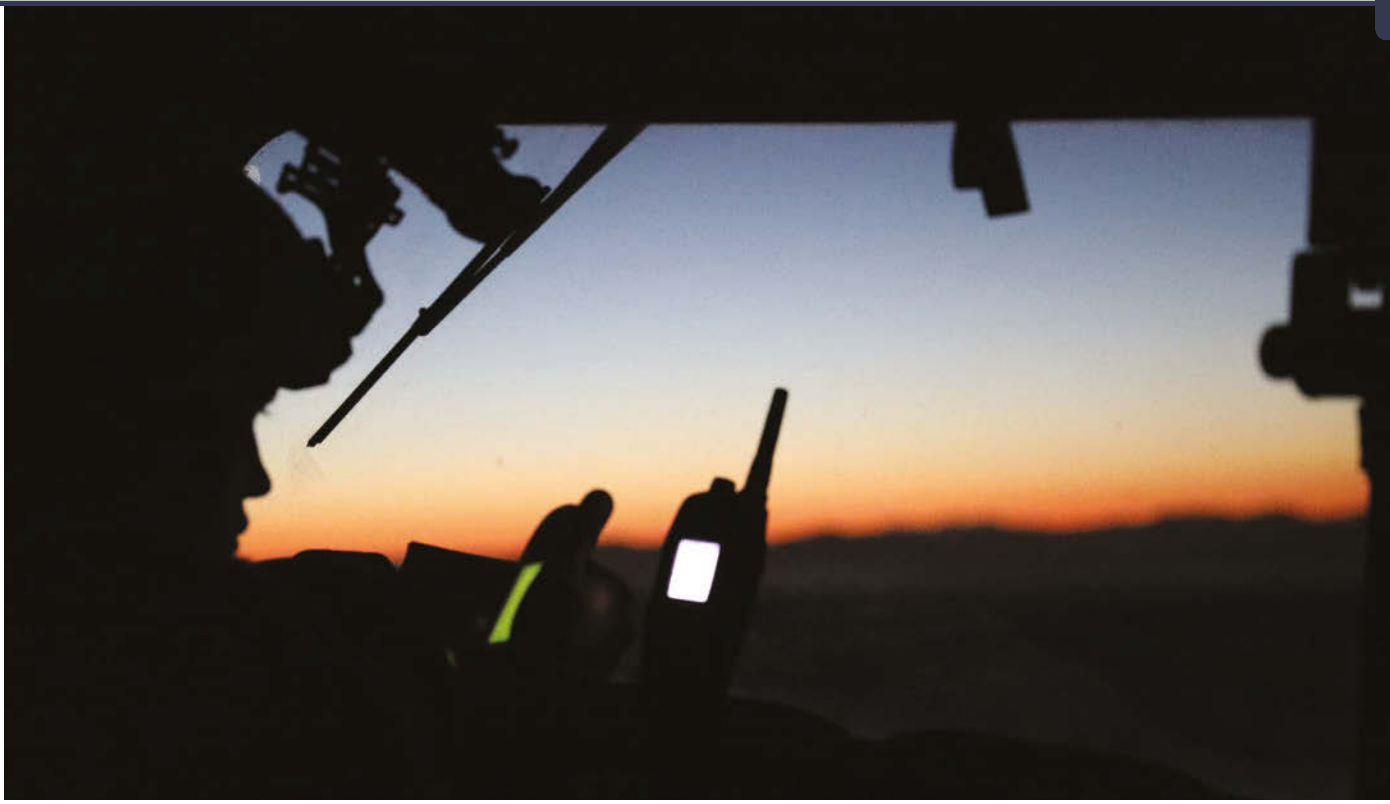
Key to this is spectrum awareness. To achieve this, we are developing approaches to leverage every receiver on the battlefield as a spectrum sensor to yield relevant data for signals intelligence, electronic warfare and RF communications.

Longer-term, we are developing technologies to enable combined RF and cyber effects that increase the uncertainty of friendly forces' locations in both the physical (RF) and cyber environments, as well as the use of quantum encryption methods to enhance network security.

CONCLUSION

The future Army network will possess intelligent automation, network resilience and situational understanding to enable automatic execution of PACE plans. The network will provide fast and reliable communications in anti-access and area denial environments. Simultaneously, flexible and tunable communication platforms will be less susceptible to detection and jamming.

Built-in network resilience is a foundational element of network EM security and reliability of operations. Implementation of components that enable spectrum diversity with failover capabilities—the ability to switch to backup systems after the initial system fails—will achieve more resilient network performance. By coupling varied mission needs with available



BOUNCING BACK

A Soldier prepares to copy a grid coordinate during Decisive Action Rotation 18-01, conducted in October at the National Training Center (NTC), Fort Irwin, California. To ensure that Soldiers have a network that's both resilient and agile, Army S&T is looking to the use of multiple redundant network links, a diverse selection of alternate networks and efforts to decrease the likelihood of enemy disruption. (U.S. Army photo by Spc. Audrey Ward, NTC Operations Group)

spectrum data, limiting the need for Soldiers to interact with configuration interfaces and automating PACE transition across a diverse network, we can enable units to meet multiple mission aspects with optimal bandwidth use, fast reconfiguration time and effective self-healing.

For more information, go to ***www.cerdec.army.mil*** *or* ***www.arl.army.mil****.*

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AUGMENTED TRAINING

Sgt. 1st Class Taikeila Dale uses the Mk-19 simulator with augmented reality head-mounted display while visiting the Army Research Laboratory – Orlando, Florida, in August. Researchers at ARL-Orlando developed the trainer, which enables training in smaller spaces and has a shorter reset time to provide more opportunities to refine necessary skills. (U.S. Army photo by C. Todd Lopez)

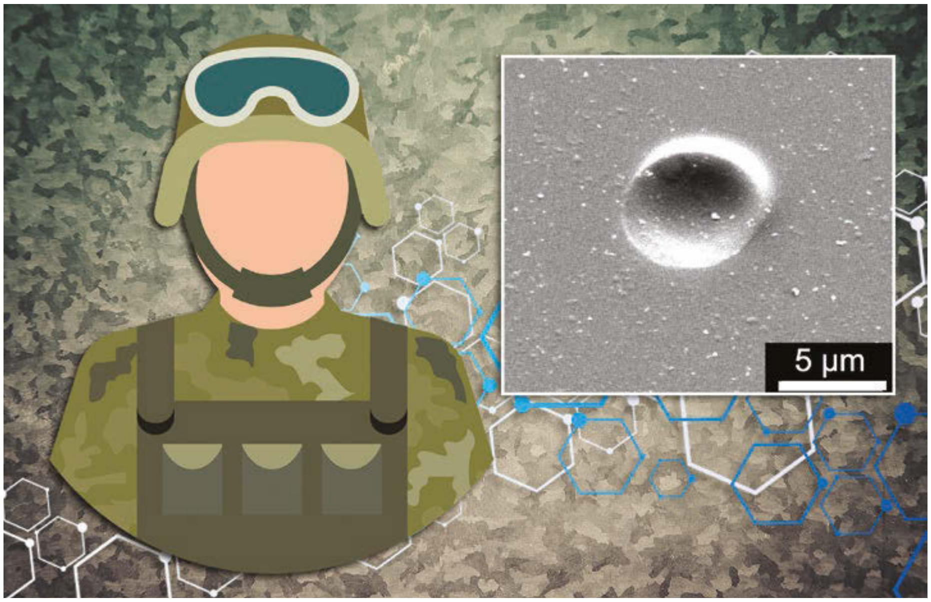
The CHANGING FACE of SOLDIER LETHALITY

From the tangible to the cognitive, squad weapons to casualty care to performance-enhancing training, Army S&T is exploring and finding materials, technologies and methods in six focus areas to provide land forces the capabilities they'll need for overmatch.

by Ms. Karen M. Burke and Lt. Col. Eric J. Wagar

Twenty years from now, Soldiers and small units will operate very differently than they did during the last two decades in Iraq and Afghanistan. As the Multi-Domain Battle Operating Concept emerges in the next 10 years, Soldiers will fight in multidomain environments characterized by dispersed, high-tempo operations that require small units to act independently in denied and austere regions.

Soldiers will operate with shorter lines of sight and a reduced standoff advantage in their intelligence, surveillance and reconnaissance and long-range strike capabilities. Dense electromagnetic environments will make it difficult to establish and maintain persistent, trusted communication links. Soldiers will also face large, culturally diverse populations of noncombatants with whom they will need to communicate and who they will have to monitor for threats and protect from engagements, particularly in increasingly crowded urban regions such as coastal cities.



UHM, WHAT?

The Army's Enhanced Combat Helmet uses composite fibers developed from UHMWPE—high-performance, ultrahigh molecular weight polyethylene. The inset image, obtained using scanning electron microscopy, reveals a permanent indent from a test bullet on the surface of polycarbonate material, in contrast with polyurethane urea elastomer materials, where no damage was observed after impact. (U.S. Army illustration)

Mitigating the impacts of these emerging challenges calls for Army science and technology (S&T) investments in Soldier lethality that account for the world's complexity—operational, technological, societal and cultural. The three articles that follow highlight examples of capability investments in innovative, technologically advanced, potentially game-changing solutions focusing on 3-D enriched urban terrain visualization, improved performance and resilience, and augmented and mixed reality.

DIMENSIONS OF LETHALITY

What makes a Soldier and a small unit lethal? The Army's S&T investment strategy addresses this question in both tangible and intangible ways.

Tangible materiel elements of lethality include Soldier and squad weapons, communications, situational awareness and protection systems that allow Soldiers to shoot, communicate, maneuver and survive in varied terrain and phases of conflict. Capabilities that support a Soldier's lethality include foundational training in executing missions and individual tasks, prolonged field medical care to treat injuries and sustain optimal performance, and physical and cognitive augmentation solutions such as wearable powered devices and nutrient delivery methods that increase strength and endurance. These will help direct Soldiers and squads and provide the speed of information that is becoming the cornerstone of overmatch.

Equally important are the less tangible lethality capabilities that contribute to total Soldier and small unit performance, such as cognitive aids, conditioning, leadership and resilience training. These intangible enabling technologies work in concert with Soldiers and their equipment to create a professional, well-equipped force.

To maintain the Army's strategic, operational and tactical advantages, Army S&T is exploring and identifying materiel and nonmateriel solutions in six key areas of Soldier lethality that leverage technology advances to offer land forces the vital capabilities they will need in the mid- to far term. These six areas are Soldier and squad weapons; Soldier protection and equipment; situational awareness; physical and cognitive performance, along with Soldier-optimized performance; prolonged field medical care; and training.

SOLDIER AND SQUAD WEAPONS

Small units require weapon systems that enhance lethality, accuracy and mobility to achieve and maintain overmatch against current and emerging adversaries' technologies and operating tactics. Just as our adversaries invest in improving their weapons technology, Army S&T has the responsibility to modernize our legacy weapons ammunition and accessories.

S&T support for next-generation weapon investments includes research into lighter-weight materials, improved ammunition design and penetration, modular component designs and integrated enabling technologies such as fire controls, optics and powered rails. The Army's improved weapons and munitions need to be able to defeat adversaries who are using partial and full defilade to protect their positions and equipment, limiting the effects of our direct-fire small arms and indirect fire systems. In response, Army S&T seeks to reduce the precision, size and weight of counter-defilade capabilities for small units, putting counter-defilade in the hands of Soldiers and small units in combination with more lethal weapons and enablers, to keep pace with and overmatch the capabilities of adversaries.

SOLDIER PROTECTION AND EQUIPMENT

Army S&T seeks a balance of protection, mobility and the impact of such enhancements on lethality. It boils down to a weight race, as the Army adds equipment to the Soldier kit faster than it can reduce weight through materials research, miniaturizing components and integrating capabilities into ergonomically designed systems and components.

Research continues on lower-weight protection options for increased mobility and lethality as emerging directed-energy and ballistic threats proliferate. We also seek to reduce battery-related Soldier load with research on power harvesting, battery chemistries and energy management—all with the goal to extend dismounted Soldier operations for a 72-hour mission using adaptive systems that supply continuous power generation for up to six days.

Army S&T is exploring bio-enabled and protective materials that combine protection against multiple environmental, detection and ballistic threats for clothing and individual equipment. It is also looking at signature management technologies to decrease the probability of a Soldier being seen and heard because of the thermal, electromagnetic or visual characteristics of the gear they wear and carry. Midterm body armor research focuses on vital torso protection against ballistic and blast threats, adding to earlier research on technologies that reduce Soldier-generated electromagnetic and auditory signatures.

A related research area is developing mechanisms to understand human response and injury in blast, ballistic and directed-energy trauma. Army S&T also seeks to create injury-based performance criteria to support readiness determinations and product design.

SITUATIONAL AWARENESS

Information overmatch, by allowing Soldiers to surprise the enemy, increases the chance of mission success. Army S&T is developing strategic technologies to enhance our ability to outthink and outmaneuver an adversary with Soldier-wearable technologies. Small units must have situational understanding and a common operating picture to operate in close contact with the enemy and to conduct continuous security operations.

To achieve state-of-the-art situational awareness, Army S&T is investing in three areas:

- **Advanced sensors and displays for dismounts**—Our focus is on low-cost Soldier-borne sensors, combat optical weapon sights and imaging and non-imaging sensors for individual and crew-served applications. These sensors will provide day-or-night capabilities enabling precision targeting and pointing, target marking and designation and obtaining accurate target locations at extended ranges.

- **Soldier system interfaces and integration**—These tactical system interfaces and decision aids reduce the cognitive overload caused by too much visual information, and support the 3-D visualization of mission command

HELPING HANDS

Lt. Col. Tyler Harris, M.D., an orthopedic surgeon at Womack Army Medical Center (WAMC), Fort Bragg, North Carolina, works remotely with a physician assistant during a surgical procedure in May. The surgical scenario explored the feasibility of training physician assistants to perform lifesaving measures when there isn't time or capability to get service members injured in theater to a surgeon. Future operational threats like anti-access and area denial could make it difficult to evacuate Soldiers to surgical treatment. (U.S. Army photo by Eve Meinhardt, WAMC) and sensor data to enhance tactical decision-making during dismounted operations.

- **Soldier data management**—We are developing Soldier-borne data management and distribution technologies whereby Soldiers can assess and maintain situational awareness and understanding, to enable real-time decision-making during dismounted operations. Hardware and software development address Soldier-centric integration and analysis of wired and wireless data management technologies, including Intra Soldier Wireless technologies and architectures, low-power sensor networks and Soldier-borne information assurance solutions.

Emerging wearable technologies provide an unprecedented ability to collect high-resolution data continuously over significantly longer periods compared to the handheld and head-borne display systems in use today. Sensor data, combined with advanced modeling techniques and machine learning, have the potential to enhance cognitive performance and provide state-of-the-art situational awareness.

Army S&T is exploring bio-enabled and protective materials that combine protection against multiple environmental, detection and ballistic threats for clothing and individual equipment.

SOLDIER PERFORMANCE

Soldier load, a combination of cognitive and physical stressors, has increased as battlefield scenarios become more complex and Soldiers' gear increases with the proliferation of capabilities and technological advances. Army S&T addresses physical and cognitive performance through our medical and human system integration (HSI) communities. Current operating concepts assume that Soldiers can comprehend large amounts of dynamic, complex data arising from dense, urban, technology-laden terrain, and make efficient and effective decisions.

Our research focuses on predicting the range of Soldier comprehension given varying quantities of information and tasks, in varying environments. Army S&T aims to enable Soldiers and small units to maneuver rapidly and engage adversaries in all environments, from dense urban areas to deserts, rolling terrain, mountains and jungle, and to operate in distributed small units as well as larger formation missions. S&T investments in medical and nonmedical augmentation technologies look to improve Soldier performance while reducing the physical, perceptual and cognitive workload and enabling units to operate at a sustained high tempo.

Applying HSI principles and practices before designing equipment is a key to achieving physical overmatch in a dynamic operating environment and improving Soldier and team performance. HSI applications include man-machine interface, brain-computer interaction and joint human-intelligent agent decision-making, with a focus on early integration of humans and systems. Common human-machine interfaces ensure that Soldiers have flexible, tailorable analytic tools for laboratory-grade, high-resolution assessment of dismount-robot interactions in complex environments.

The S&T medical community is the major contributor to research on optimizing Soldier performance, through its individualized regimens of nutrition, "nutraceuticals," pharmaceuticals and synthetic biology to prevent disease, speed recovery and augment human performance. Some of the major goals are to manage fatigue effectively, optimize nutrition and maximize physical and cognitive performance in dynamic operating environments. The field of Soldier-optimized performance delivers technologies that combine physical, metabolic and cognitive sensors to enable Army leaders to make decisions faster and to sustain resilience, protection and mobility.

PROLONGED FIELD MEDICAL CARE

The Army's last 16 years of contingency operations have demonstrated that surgical intervention within 60 minutes of injury—the "golden hour"—significantly increases the chances of casualty survival. Because operational threats such as anti-access and area denial challenge the Army's ability to evacuate Soldiers to surgical treatment within that hour, Army S&T is researching medical materiel and knowledge solutions to accelerate delivery of lifesaving medical care. Our two major programmatic efforts are prolonged field care and autonomous evacuation.

Prolonged field care will enable medical personnel, such as combat medics and battalion surgeons, to stabilize wounded personnel for extended periods of time until evacuation is feasible. The capability initially will consist of advanced medical devices to control bleeding from wounds for which tourniquets are

TOMORROW'S PATROL

By 2025, the Army sees ground troops conducting foot patrols in urban terrain with robots—called Squad Multipurpose Equipment Transport vehicles—that carry rucksacks and other equipment. Unmanned aircraft could serve as spotters, according to the Army's new strategy for robotic and autonomous systems. They could also deliver cargo, reducing reliance on rotary-wing support and facilitating sustainment. (U.S. Army image)

not effective, and a closed-loop, extracorporeal (that is, outside the body) life support system to provide lung and kidney function to patients who need it.

When medical evacuation is not feasible, the Army will use autonomous ground or air platforms, in conjunction with autonomous life support equipment, to move casualties to surgical care facilities. These platforms also will be useful for resupplying medical personnel during sustained operations. Army S&T investments in autonomous systems and advanced medical devices will provide tomorrow's force the dramatic increase in survival rates that the Army's first aeromedical evacuation brought to wounded Soldiers in Korea.

NEW NEEDS FOR TRAINING

Increasingly complex equipment, the rise in speed of conflict and increasing demands for diverse skills, such as cyber and languages, are driving Army S&T to research state-of-the-art methodologies and tools to support learning and training. These tools must outpace the learning demands arising from complex environments and provide Soldiers the expertise and confidence to synthesize information, rapidly make decisions and act upon those decisions to outmaneuver adversaries.

New training technologies and environments will allow Soldiers to train and rehearse warfighting skills such as faster decision-making to gain the advantage of speed over adversaries, with integrated capabilities such as intelligent agents that challenge the Soldier to improve individual and team performance and develop agile, adaptive leaders. As Army training missions increase, S&T has the challenge of replicating sufficient knowledge and time for every small unit on dispersed and varied battlefields. Investments in training tools such as simulations and synthetic training environments will increase retention, enhance situational awareness for cognitive overmatch, and improve Soldier and team performance while reducing training time and cost.

CONCLUSION

The future vision of land warfare is being shaped by today's S&T investments across many mature and emerging disciplines. The capabilities described in this article will start to bear fruit in three to 10 years in rapidly advancing information technology and physical and cognitive augmentation technologies, with solutions expected in 10 years or beyond in such areas as biomaterials and artificial intelligence.

The Soldier lethality S&T portfolio is shaped by a diverse community of scientists, innovators, end users, technology and global forecasters, and intelligence experts who identify and define the challenges and threats of the future. It employs an iterative analytical process to continually refine its investments and priorities so that future Soldiers maintain the lethality advantage on the future battlefields that are being conceived today.

For more information on Soldier lethality investments, go to ***https://www.army.mil/asaalt****.*

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A 'MAP' *for the* MULTIDOMAIN MEGACITY

Army scientists pursue advances in situational awareness, 3-D modeling and real-time data updating to help units make better decisions faster in urban combat.

by Dr. Robert E. Davis, Dr. Kevin R. Slocum, Dr. Tad T. Brunye and Dr. Aaron L. Gardony

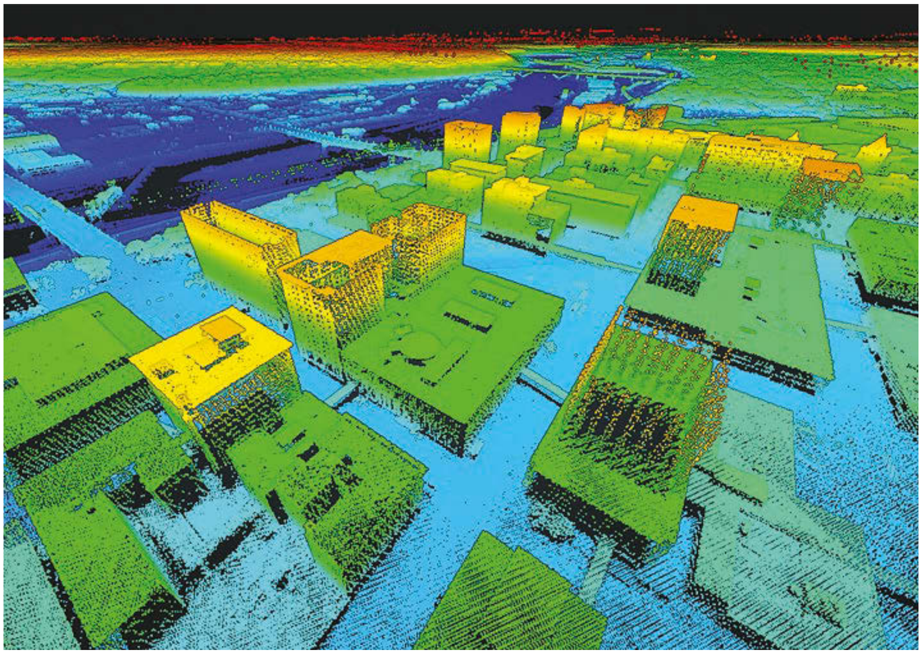
Today's Army leaders consider it inevitable that U.S. ground forces will engage in combat in dense urban environments, including building interiors and subterranean spaces. These settings eliminate or severely degrade many of the technological advantages that U.S. forces and their global (near-) peers have developed over several decades, and they also may provide sanctuary to friend or foe. Dense urban environments also heighten broader risks of unintended consequences in combat.

A broad spectrum of existing and emerging research topic areas has shown the potential to develop significant capability for providing small disaggregated mounted and dismounted teams the ability to act independently, to outthink and to outmaneuver the enemy in close combat despite limited and intermittent access to higher-echelon command and control. Most of the promising science and technology (S&T) development focuses on major advances in situational awareness in urban settings and how they can lead to better decisions faster, presenting dilemmas to an adversary.

The Army S&T community has adopted the premise that urban combat, considered as a flowing series of tactical unit decisions and actions, will greatly benefit from rich and intuitive space and event and trend context. Accordingly, near-term and emerging research areas at the U.S. Army Engineer Research and Development Center (ERDC), the U.S. Army Research Laboratory (ARL) and the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) include investigations into the design and formulation of new urban terrain data models, frameworks and cognitive display approaches. The goal is to identify solutions compact enough that many Soldiers and every vehicle can carry them along for sharing and analysis, while meeting a variety of needs for display

A LABOR-INTENSIVE PICTURE

This information architecture represents a high-density point cloud, viewed obliquely. A point cloud is a set of points on a coordinate plane; in this case, the data points are the edges of buildings and other structures in this dense urban area. Taken together, they create a 3-D visualization of a space. ARL is looking for a way to collect this kind of data about an urban environment from multiple sources and craft it into a usable map, without the many human analysts currently required to do so. (Images courtesy of the authors)



on different equipment. Research interest across the ERDC and the U.S. Army Research, Development and Engineering Command also has focused on characterizing, moving and communicating within the confined space of building interiors and subterranean infrastructure.

Results of this research will shape design and development of techniques for much more rapid data generation, tailored dissemination, change analyses and visualization. In other words, Soldiers will learn as they go, and retain this spatial knowledge. This new direction, in most cases, markedly departs from the commonplace use of flat maps, in perspectives that may include 3-D features and immersive training environments.

The Army geospatial enterprise uses a concept called standard sharable geospatial foundation (data models and information architecture), which will allow for horizontal and vertical interoperability and sharing of geospatial information from the national level to the tactical edge. Built on this concept and the need for high-resolution 3-D topography of urban spaces, and working across Army platforms and applications, Army research efforts face technology-limited challenges from the near term to the far term. In the mid to far term, these include investigations of methods to introduce a user to semantically and digitally enriched information that is key to combat activities, from training through rehearsal to combat operations. Semantic markup may include street names, for example, or symbols referring to unit positions, while digital markup can refer to coordinates used in routing or targeting.

A critical line of research on visualization in a mobile context involves developing automated and rapid georegistration without delays during motion, which can distract attention or exacerbate motion distress. Some symbols and features added to displays, such as the user's location, range to objects in the distance, etc., stay in the same position regardless of changing viewpoint. Other augmenting features, such as building outlines, need to remain fixed in the real 3-D world even when the user's perspective moves.

We can expect improved and more diverse techniques to produce accurate, updatable geometries of urban infrastructure, including relevant materials and functions. The need to support decision-making and faster action also shapes research on what makes terrain visualization intuitive, cognitively low-cost, measurable by operators and interactive when needed. The following sections describe Army S&T research on the military-unique aspects of high-resolution 3-D enriched terrain data while leveraging commercial and academic innovation.

THE 3-D URBAN 'MAP'

The goal of Army geospatial research is to design, develop and test a new, multidimensional 3-D "map" of urban infrastructure geometries, materials and functions. This capability would provide the context and baseline for a variety of Army operations. Current research efforts focus on some key attributes that such a map—really an information architecture—would include:

- Available on demand to Soldiers and their applications, particularly in its small units.
- Measurable and supporting a variety of automated analyses.
- Updatable as conditions change.
- Intuitive displays for more rapid decision-making.

Let's consider a requirement for 3-D urban terrain data available to the Soldier before deployment. First, by the time Soldiers deploy, the standard urban geospatial load may not have the most up-to-date geometries and other relatively static conditions in the area of operations. Second, units may need to know what has changed during the course of combat operations. Accordingly, we must consider the need for an organic capability to rapidly generate new 3-D data to upgrade gaps or other uncertainties in the standard geospatial load. This same function also becomes a change detection capability when comparing new data with existing information.

These two key considerations support sequential, in-stride rehearsal, movement and maneuver, targeting and battle damage assessment: Navigation, targeting and other sensing systems can "see" the real urban environment and compare that, in real time, with urban information on board to move, learn and assess. Think of three tiers in an open modular architecture for 3-D enriched urban terrain information, two of which involve inspecting the operational environment, while the third deals with improving support for decision-making and execution by analyzing data in hand.

At the highest level, we consider the creation of a 3-D, high-resolution geospatial foundation focused on complex and built-up areas. Currently, dedicated and analyst-intensive technologies exist to acquire, store, process, manage and distribute imagery and point clouds, a set of ranging data points that represent the surface of an object as obtained from either active or passive collection modes, from overhead or from ground-based sensing systems. From point clouds, mature exploitation technologies can identify shapes, edges and corners to model the urban objects, and can classify and label objects in the data space. The products have a variety of formats, nearly all requiring significant analyst involvement to make, large volumes to store, considerable cost to analyze, and substantial time delays related to access and visualization.

In the context of training environments, high-level mission planning and other activities, the main near-term research objectives involve designing and integrating a variety of tools for visualizing diverse data sets—such as point clouds, imagery, semantic descriptors and so forth—from diverse collectors. In the farther term, emphasis shifts to consolidating standard analyses and products into a common set of highly compact and manipulable formats.

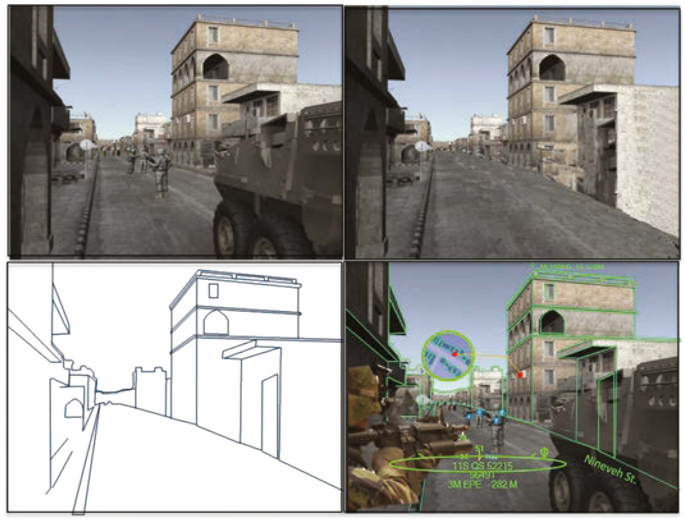
For training purposes and tactical uses, the gross geometries of urban infrastructure, for example, should have a high level of precision, so that the buildings and other objects look right and building models overlay the real buildings in their actual locations. Important research investigates how to automate the functions of representing infrastructure as compact formats. Another area of research attacks the problem of automatically assigning functions (e.g., residential, commercial, industrial, transportation,

PLAN FROM ALL PERSPECTIVES

Data-rich 3-D maps would let Soldiers spend time viewing terrain from a variety of perspectives to gain an intuitive sense of the battlespace before operations begin. That basic understanding of the physical environment and how to navigate it improves spatial memory.

etc.) and functional attribution of infrastructure objects and features in military and civilian context. For example, the interior complexity of a building and the building's use are major factors in the efficiency of precision targeting or clearing.

Other near-term to midterm research seeks to dramatically reduce collection time, particularly since the U.S. cannot forecast with certainty where conflict will require our forces. Other areas of effort, also spanning the near term and midterm, investigate techniques to automatically filter and remove ephemeral features and objects—such as vehicles, people and urban clutter—to produce a time-stable foundation that contains only the horizontal and vertical infrastructure. Researchers also are designing and testing compact and common frameworks for adding back currently observed or projected ephemera, whether natural (e.g., ice, snow, water) or man-induced, like traffic on our day-to-day personal navigation applications.



THREE DIMENSIONS, FOUR WAYS

These are some of the views possible with an enriched, 3-D visualization of a given area: Clockwise from upper left, a high-resolution representation; a version that filters out ephemeral objects such as passing cars; augmented reality view with edges and corners georegistered and attributed; and extracted edges and corners.

CAPABILITY AT BRIGADE AND BELOW

When it comes to the next tier of 3-D, high-resolution terrain data generation, management and dissemination, the Army S&T community is exploring the need for tactical capability at brigade and below. In the 2030 to 2040 time frame, the brigade combat team will have a variety of laser, LIDAR and imaging systems for characterizing urban infrastructure. This expectation necessitates an organic capability to improve gaps in a standard geospatial load, to perform change analysis and to collect and overlay real-time information. Urban operations also may need purpose-designed kits for exploration of interior and subterranean spaces by Soldiers or robots.

To deal with all of this effectively and efficiently, the tactical user will need an operational data environment where generation, processing and dissemination of 3-D urban data can remain local for some period, avoiding the delays currently experienced in vetting and validating authoritative data.

As a third and directly actionable tier of a future capability, we can consider the examples of derived information layers and terrain reasoning related to METT-TC, the military acronym for mission, enemy, terrain and weather, troops and support available, time available and civil considerations. Many mature derived-information products have become standards, such as line-of-sight analysis, trafficability (the ability of a vehicle to traverse a specified terrain) and mobility analyses and the identification of helicopter landing zones. For near-real-time information to serve tactical operations, a capability would require accurate georegistration to the foundation data, despite GPS degradation or denial, and precision sufficient to automatically identify movement of people and platforms and an update rate of a few seconds. Movement assessment would require a latency of less than about 10 seconds and an update rate of only a few seconds.

Critical research objectives at the ERDC, ARL and elsewhere in the near term to midterm include developing algorithms and techniques for robust and fully automated collection, buffering, processing and tailored direct distribution, all in a communications-challenged environment. Near-term research seeks to integrate on-demand and automated processing of products such as these with near-real-time updating, using data derived from battlespace sensing.

FORM, FIT AND FUNCTION

The prospect of 3-D enriched, high-resolution urban terrain with near-real-time updated tactical overlays does not necessarily constitute operational improvement and leap-ahead advantage. We can observe in the world every day the distraction and operational slowing caused by visual displays, personal and otherwise, as well as our dependence on them. To integrate and distill sufficient situational context—METT-TC—so that leaders of small units can make better decisions faster, a relatively new body of research is looking into the form, fit and function of visualization to catalyze a strengthening of intuitive understanding. From training to rehearsal to operational use, visualization requirements differ. With immersive training and research toward a fully synthetic training environment, and with mission planning at brigade and above, research challenges—near-term and enduring—appear well-defined.

For close-quarter combat in complex and especially dense urban environments, questions about what, when and how to visualize the data products described above become paramount. For example, the ability to move at will in dense urban environments and simultaneously force dilemmas on an adversary, as well as to manage risk, may depend on very short-lived multisensory (i.e., audio, visual, tactile) cues that bolster the retrieval and application of spatial memory. Can we train, rehearse and cue a Soldier to navigate in the city as effectively as the native city dweller?

Recent Army research at NSRDEC has demonstrated important trade-offs among the timing and type of information conveyed to a user, the attentional demands of the information and outcomes for individual and small unit performance. If, during mission planning and preparation, Soldiers visualize the intended operating area in 3-D from multiple perspectives and orientations, their spatial memory can improve; this increases their ability to move effectively through complex environments with constantly changing situations and demands on their attention.

NOT A SILVER BULLET

Army research has demonstrated that during combat operations, standard navigational displays can induce complacency, divide attention and disengage navigators from their environment. This can impair the development of flexible spatial memories Soldiers must rely on during times of heightened stress. These and other research outcomes present a challenging focal point for developing next-generation visualization technologies, such as chest-, helmet-, eyewear- and torso-mounted information systems that provide timely and relevant information without compromising the ability to think and act quickly and effectively. The Army's geospatial, training and Soldier S&T communities are working collaboratively on this challenge, including developing scenario-based virtual test beds to predict and quantify performance outcomes of future systems, the development and application of which span from the near to the far term.

CONCLUSION

With our current technology and doctrine, we can level the playing field in complex and congested environments—including dense urban and megacity domains—by degrading standoff and other advantages. Integrating capabilities like next-generation autonomous networked sensor platforms, heads-up situational awareness for small units and enhanced fusion and targeting has the potential to restore U.S. tactical advantage. Providing rich, detailed and actionable place and event context through analysis and visualization has great promise to give options to tactical commanders among integrated and available capabilities to make our adversaries' intentions unattainable.

For more information, go to ***https://www.nsrdec.army.mil/*** *or* ***http://www.erdc.usace.army.mil/****.*

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FIT, NOURISHED *and* RESILIENT

Human performance optimization aims to take Soldiers to higher and higher peaks of physical and mental fitness.

by Dr. Stephen Muza and Ms. Mallory Roussel

Let's flash back to the U.S. military in 2006.

The U.S. had been engaged in Operation Enduring Freedom and Operation Iraqi Freedom for five and three years, respectively. In a post-9/11 environment with a higher operations tempo and longer and more frequent deployments, the U.S. military had an ongoing need to enhance mental and physical resilience and decrease injuries among deployed service members.

In June of that same year, the Uniformed Services University of the Health Sciences hosted a conference titled "Human Performance Optimization in the Department of Defense: Charting a Course for the Future," with the goal of developing a strategic plan for human performance optimization (HPO). That conference marked DOD's acknowledgment of the importance of promoting warrior wellness and modernizing, training and structuring the force by leveraging cutting-edge science and technology (S&T) that would optimize the performance of servicemen and women in all stages of their careers. Such an approach would set the conditions for a more lethal force by ensuring that warfighters would be ready to respond to present and future threats. The conference was when the HPO effort officially emerged.

Flash forward to 2017, when knowledge and technologies to enhance and sustain warfighters' health, well-being and performance as part of the HPO effort continued to evolve. DOD now considers HPO fundamental to accomplishing the military's mission. For the U.S. Army Research Institute of Environmental Medicine (USARIEM), HPO is a newer, shorter term to describe the research that the small Army medical lab in Natick, Massachusetts, has been doing for more than 50 years.

CONTINUOUS OPTIMIZATION

The USARIEM team prioritizes Army readiness by engaging in essential medical research focused on optimizing

WEARABLE INFORMATION

A Soldier puts on an Equivital chest harness, which incorporates USARIEM's ECTemp algorithm to record heart rate changes over time. The heart rate indicates how much blood flows to muscles and the skin, from which researchers can extrapolate how much heat is being generated and lost by the body. Medics and leaders looking to prevent heat illness in Solders can monitor Soldiers' body temperatures if the ECTemp technology is included in a wearable monitor like the chest harness. (U.S. Army photo by David Kamm, RDECOM)

servicemen and women's health and performance during training and on the battlefield. "USARIEM partners with DOD, other federal entities, universities, nonprofits and industry stakeholders extensively to answer military-relevant questions and optimize Soldiers' health, resilience and performance," said Col. Raymond Phua, commander of USARIEM.

USARIEM's location at Natick Soldier Systems Center, a 30-minute drive west of Boston, puts the lab in close proximity to the extensive academic, federal and commercial knowledge and research assets of the Northeast corridor, giving researchers access to top potential collaborators. USARIEM is one of the very few labs in the world where all aspects of HPO come together.

While the lab looks at HPO through a biomedical or a bioengineering lens, USARIEM's holistic approach to attaining an "optimized performance state," as Dr. Karl Friedl, USARIEM's senior research scientist for performance physiology described it, sets the lab apart. Friedl also explained that the unique and critical research capabilities that USARIEM provides to the DA, DOD and the nation are the synergy of subject matter expertise on performance, nutrition, environmental stressors and biomedical modeling from civilian researchers and Soldier scientists.

"The Army will always have Soldiers holding terrains in parts of the world that have extreme environments, and as long as we continue to encounter threats near and far, warfighters will always encounter risks," Friedl said. "This makes an optimized performance state sound like an elusive goal. While we cannot eliminate these risks, we can mitigate them.

"USARIEM is the only lab that has looked at all aspects of Soldiers' physical and cognitive performance, in terms of health, occupation and the environments they work in. We aim to sustain the health and fighting ability of warfighters by developing military medical doctrine and technology that will give warfighters the ability to meet the physical and cognitive demands of any combat or duty position, accomplish the mission and continue to win present and future fights."

USARIEM's internationally recognized research leaders are executing and supporting key products and strategic doctrine shifts, which include the U.S. Army Training and Doctrine Command (TRADOC) project to examine the knowledge, skills, abilities and other attributes associated with military occupational specialties (MOSs), as well as the Army surgeon general's 2020 strategy of shifting to a system of health through the areas of performance and nutrition, with the goal of attaining high-quality, longer lives free of preventable disease, disability, injury and premature death.

Here are some of the emerging USARIEM technologies, medical doctrine and future research efforts to optimize warfighter health and performance in a variety of occupational environments and situations.

EMERGING USARIEM TECHNOLOGIES

The Estimated Core Temperature (ECTemp) algorithm accurately estimates a Soldier's core body temperature simply by analyzing heart rate changes over time. Physiologically, heart rate reflects both the blood flow to the muscles and the rate of blood flow to the skin, containing information about both heat production and heat loss from the body. ECTemp can be incorporated into wearable technology, such as a chest harness with a physiological status monitor, which mission leaders and medics can monitor with a phone to detect if one or more Soldiers are at increased risk of heat illness. USARIEM developed ECTemp based on years of physiological data collected from multiple studies. By providing accurate core temperature information, the ECTemp can help military leaders make timely, critical training and mission decisions in hot, humid and unpredictable environments. The ECTemp has opened the door to future monitoring apps and wearable technology for the military.

Unit leaders can use the Altitude Readiness Management System (ARMS), an Android-based app, to plan missions with appropriate expectations. By using data from more than 25 years of USARIEM's altitude studies, ARMS predicts how likely Soldiers are to experience acute mountain sickness during a mission, and how severely. ARMS also calculates how much time Soldiers need to complete missions and acclimate to a variety of altitudes. Unit leaders can use this easily accessible information to alter high-altitude missions before deployment in order to prevent hypoxic events. The app is now fielded on the Nett Warrior platform and is being fielded through the TRADOC online app store this year.

The Soldier Water Estimation Tool (SWET) is an Android-based smartphone app and mission planning tool that can predict average water needs for groups of Soldiers for defined periods of time. The app uses a validated, updated sweat prediction equation based on five decades of USARIEM's research on sweat loss and hydration. A unit leader can plug in the temperature, humidity, cloud cover, type of clothing worn and Soldiers' workload. The app does the rest of the work. SWET supports the use of real-world planning in military settings in a variety of outdoor conditions. The app is now fielded on the Nett Warrior platform and, along with ARMS, is also being made available on the TRADOC app store this year.

The Performance Readiness Bar (PRB) is a calcium- and vitamin D-fortified snack bar developed to optimize bone health in basic trainees. The snack bar was distributed at Fort Benning, Georgia, in the summer of 2017 and will be distributed at all four Army basic training locations in 2018. Calcium and vitamin D have already been proven to be necessary nutrients to improve bone health. However, USARIEM researchers' findings indicated that basic trainees needed higher-than-average amounts of calcium and vitamin D to support bone health during initial military training.

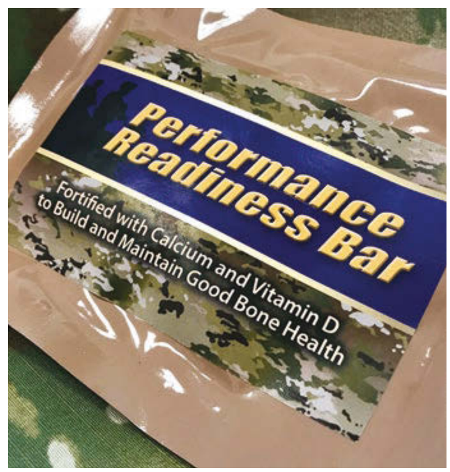
According to the Military Health System, recruits often arrive at basic training with poor calcium and vitamin D status, making their bones more vulnerable to stress fractures and other injuries. PRB is one solution to this problem that will reduce attrition and personnel costs associated with initial military training, increasing Army readiness.

The Occupational Physical Assessment Test (OPAT) was part of the TRADOC Soldier 2020 initiative, which would help set the standards necessary for Soldiers—male and female—to perform in combat MOSs. USARIEM researchers broke down those specialties into essential physical capabilities that a Soldier needs to be trainable for a given specialty.

Throughout 2016, USARIEM researchers conducted more than 27 field studies in initial military training settings at Fort

SWET THE DETAILS

Operations in extreme heat or cold, or at high altitude, can be unpredictable. Decades of USARIEM research informs the SWET app, left, and the ARMS app, which give unit leaders objective information to adjust deployments and prevent disastrous casualties. (U.S. Army photo by Mallory Roussel, USARIEM)



EDIBLE READINESS

The Performance Readiness Bar, a calcium- and vitamin D-fortified snack bar developed under the research guidance of USARIEM's Military Nutrition Division, will soon be available Armywide. The new snack was prompted by military health researchers' realization that basic trainees are doubly vulnerable to bone injury. (U.S. Army photo by Mallory Roussel, USARIEM)

Benning, Georgia, Fort Leonard Wood, Missouri, and Fort Sill, Oklahoma, administering a robust battery of physical performance tasks and questionnaires before and after training. This effort resulted in the OPAT, which contains a battery of four tests: a standing long jump, a medicine ball throw, an incremental squat lift and an interval aerobic run. During this project, the USARIEM team validated the predictive ability of the OPAT to accurately place Soldiers into seven combat specialties.

As a result of their efforts, the OPAT was fully implemented starting in 2017; it is now required for all Army candidates seeking to enter active, reserve or National Guard duty. The USARIEM team now is conducting a longitudinal study in which it is following volunteers for the next two years of their service to assess how successful they are in their assigned specialties after receiving their OPAT results. This data will provide the Army information on injury and dropout rates in basic training, showing how much time and money used to rehabilitate and recycle Soldiers could be saved.

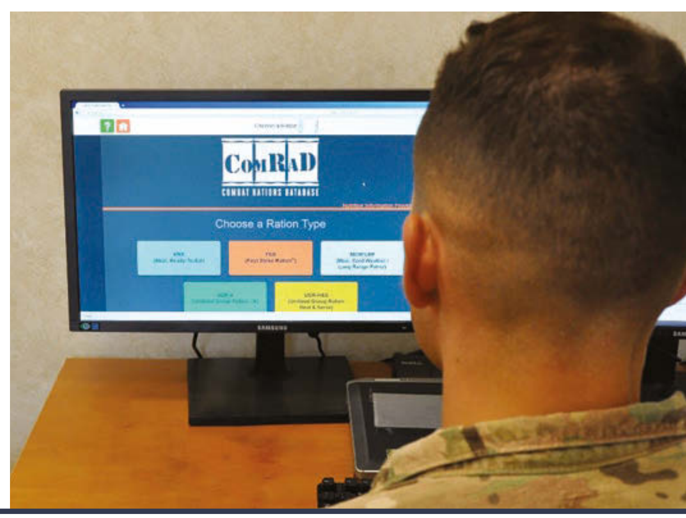
The Combat Rations Database (COMRAD) is an interactive, educational website that provides warfighters and military dietitians with information about military rations and the potential for affecting warfighters' diets and mission readiness. With COMRAD, warfighters and dietitians can view nutrition information for entire menus and even specific food components, like drinks and side dishes, in three types of rations: Meals, Ready to Eat; First Strike Ration; and Meal, Cold Weather/Long Range Patrol. COMRAD is based on a nutritional database created in collaboration with USARIEM's Military Nutrition Division. All nutritional information is accurate, and all menu components have been chemically analyzed, making COMRAD the go-to application for precise, easily accessible nutrition information on individual items, menus and daily food intake.

FUTURE RESEARCH TO OPTIMIZE THE WARFIGHTER

Warfighters engage in combat in all kinds of environments, including cold weather, such as in the Arctic. The question is: Are they prepared? USARIEM is conducting multiple research efforts, called Cold Weather Dexterity in Arctic Warfare, related to cold weather fighting protection. One of the biggest problems Soldiers can face is the loss of hand function and manual dexterity in the cold. This can happen when Soldiers do not wear gloves, causing the blood flow to the hands and fingers to decrease. Yet Soldiers can also experience reduced touch sensation and fine-motor dexterity by wearing gloves.

Either scenario could prevent warfighters from using their weapons or other sophisticated equipment that is required for the mission. USARIEM is collaborating with U.S. Army Alaska and the U.S. Army Mountain Warfare School to research and develop technologies to increase warmth and blood flow to the fingers and face. This effort could optimize performance in Arctic missions while preventing frostbite and other cold weather injuries.

Because of the unique multistressor environment of Army basic combat training, musculoskeletal injuries are common in recruits. The ARIEM Reduction in Musculoskeletal Injuries (ARMI) Study is a four-year research collaboration between USARIEM and the U.S. Army Public Health Center to develop evidence-based, actionable recommendations to Army leadership for strategies to reduce musculoskeletal injuries in basic combat training without reducing training standards.



FUEL FOR THE BODY

A Soldier uses COMRAD, an online resource that gives troops, military dietitians and food service officers the opportunity to learn about the nutritional value of the food they eat. The database is the result of a collaborative effort between NSRDEC, USARIEM and DOD's Human Performance Resource Center. (U.S. Army photo by Mallory Roussel, USARIEM)

WHAT ARE WE LOOKING FOR?

Marilyn Sharp, right, the USARIEM principal investigator in the OPAT research effort, consults with a drill sergeant before gathering physiological data that helped set physical standards for about 100,000 recruits and thousands of cadets training for various military occupational specialties. OPAT sought to identify the key physical capabilities Army recruits needed to succeed in one of the seven combat specialties. (U.S. Army photo by David Kamm, RDECOM)

USARIEM researchers will be tracking 4,000 recruits throughout and for two years after basic combat training to identify risk factors and evaluate the effectiveness of ongoing musculoskeletal injury prevention and related initiatives.

Bullets and rockets are not the only things servicemen and women contend with when they deploy. Often, gastrointestinal illnesses, like travelers' diarrhea, can decrease Soldiers' performance, prompting USARIEM's Nutrition Interventions. For the last few years, researchers from USARIEM and the Combat Feeding Directorate of the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC), an element of the U.S. Army Research, Development and Engineering Command (RDECOM), have been working together to understand the complex relationship between our health and the tens of trillions of microorganisms—including at least 1,000 known species of bacteria—living in our intestines. USARIEM researchers have conducted a series of field studies, from Natick to Pikes Peak in Colorado to Norway to characterize how different military stressors affect the gut microbiome and impact warfighter health. Some of these studies have shown that high altitudes, high physical stress and diet affect Soldiers' gut health. USARIEM researchers plan to start testing for dietary interventions based on the findings of these and future gut health studies.

CONCLUSION

In the perpetually changing world of U.S. military S&T, HPO is one of the newer terms and efforts. Yet USARIEM has been doing research on HPO for decades and will continue to do so. By tapping into civilian and military expertise in performance, nutrition, environmental stressors and modeling, as well as additional local and international partnerships with academic, federal and commercial knowledge and research assets, USARIEM has been able to generate knowledge, products and technologies that optimize the performance of servicemen and women throughout their careers.

For more information, go to ***www.usariem.army.mil****.*

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MS. MALLORY ROUSSEL is a science writer for the Science Strategic Management Office of USARIEM and a research fellow in the Oak Ridge Institute of Science and Education program. She holds a B.A. in English from Boston University. She has written about diverse subjects, from anatomic avatars to mission planning technology and military nutrition interventions.

A BETTER 'REALITY'

Technologies to enhance what Soldiers 'see' in complex, congested environments promise to improve the information available to make decisions quickly.

by Dr. Richard Nabors, Dr. Robert E. Davis and Dr. Michael Grove

Information overload! How many people have suffered from the feeling? A 2009 study, published by the University of California, San Diego, stated that an average American in 2008 consumed an average of 34 gigabytes of information every day from more than 20 different sources. And this was before the smartphone became ubiquitous. Such a deluge of information could overload even a powerful computer, let alone the average American.

As information technology has become more available to the military, it presents Soldiers in complex operational situations with significantly more information than in the past, and in a broader variety. Just as the average American can be overwhelmed by data, Soldiers receiving information from multiple sources in addition to their own senses can suffer from information overload, decision gridlock and mental exhaustion.

On the battlefield, Soldiers cannot afford to be mentally or physically fatigued. They do not have the leisure to sort through every bit of information, or the time to judge the value of the information received. Yet Soldiers must do these things, and they must do them quickly and decisively, constantly adapting to the changing situation. At the same time, information is often clouded by the "fog of war," limiting the Soldier's ability to make reality-based decisions on which their lives and others' depend.

To allow maximum latitude to exercise individual and small-unit initiative and to think and act flexibly, Soldiers must receive as much relevant information as possible, as quickly as possible. Sensor technologies can provide situational awareness by collecting and sorting real-time data and sending a fusion of information to the point of need, but they must be operationally effective. Augmented reality (AR) and mixed reality (MR) are the solutions to this challenge. AR and MR

NEW TACTICAL REALITY

In augmented reality, computer-generated or real-world sensory content is placed on top of a Soldier's view of the real-world environment. (U.S. Army photo)

technologies have shown that they make sensor systems operationally effective.

DIGITAL, REAL WORLDS UNITE

AR digitally places computer-generated or real-world sensory content on top of a Soldier's view of the physical, real-world environment. In MR, the scanned information about the user's physical environment becomes interactive and digitally manipulable. AR and MR function in real time, bringing the elements of the digital world into a person's perceived real world and thus enhancing their current perception of reality. Examples of AR and MR familiar to any National Football League fan are the blue and yellow overlays that appear on the television screen showing the line of scrimmage and the first down line, respectively. This overlay is intuitive and designed not to distract from the game, requiring no training and significantly enhancing the fan's experience.

On a Soldier's display, AR can render useful battlefield data in the form of camera imaging and virtual maps, aiding a Soldier's navigation and battlefield perspective. Special indicators can mark people and various objects to warn of potential dangers. Soldier-borne, palm-size reconnaissance copters with sensors and video can be directed and tasked instantaneously on the battlefield at the lowest military echelon. Information can be gathered by multimodal (visual, acoustic, LIDAR or seismic) unattended ground sensors and transmitted to a command center, with AR and MR serving as a networked communication system between military leaders and the individual Soldier.

When used appropriately, AR and MR should not distract Soldiers but will give pertinent information immediately, so that a Soldier's decision will be optimal and subsequent actions relevant and timely. AR and MR allow for the overlay of information and sensor data into the physical space in a way that is intuitive, serves the point of need and requires minimal training to interpret. Thus both information overload and the fog of war are diminished.

INFORMATION IS POWER

On the future battlefield, increased use of sensors and precision weapons by U.S. adversaries, as well as by the U.S., will threaten the effectiveness of traditional 20th century methods of engagement. Detection will be more difficult to avoid, and deployed forces will have to be flexible, using multiple capabilities and surviving by reacting faster than the adversary.

As networks of sensors integrate with greater numbers of autonomous systems, the need for faster decision-making will increase dramatically. With autonomous systems becoming more prevalent on the battlefield, adversaries who do not have the same human-in-the-loop rules of engagement may be quicker than the U.S. to effectuate lethal responses. Because speed in decision-making at the lowest military echelon is critical, accelerating human decision-making to the fastest rates possible is necessary to maximize the U.S. military's advantage.

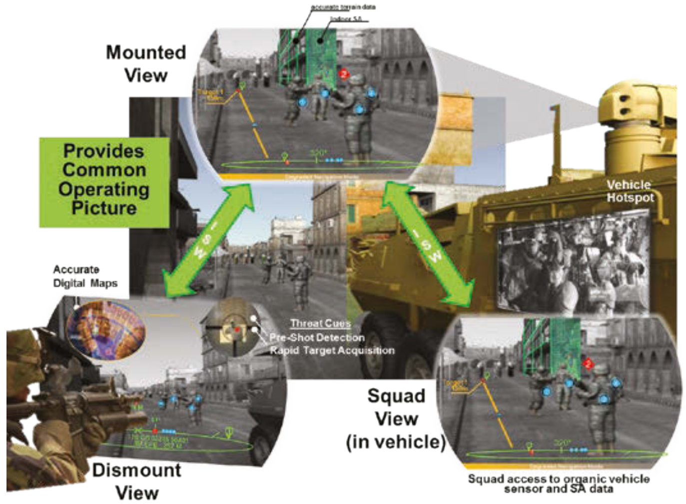
AR and MR are the underpinning technologies that will enable the U.S. military to survive in complex environments by decentralizing decision-making from mission command and placing substantial capabilities in Soldiers' hands in a manner that does not overwhelm them with information. As such, the Army has identified AR and MR as innovative solutions at its disposal as it seeks to increase Soldier safety and lethality as a priority of its modernization strategy.

MEETING THE CHALLENGES

The challenge for AR and MR is to identify and overcome the technical barriers limiting their operational effectiveness to the Soldier. For example, as Soldiers' operational information needs become more location-specific, the need for AR and MR to provide real-time, immediate georegistration will be increasingly important. To prevail in this near-term technical challenge and several others like it, the Army research and development (R&D) community is investing in the following technology areas:

- Technologies for reliable, ubiquitous, wide-area position tracking that provide accurate self-calibration of head orientation for head-worn sensors.
- Ultralight, ultrabright, ultra-transparent display eyewear with wide field of view.
- Three-dimensional viewers to provide the Soldier with battlefield terrain visualization, incorporating real-time data from unmanned aerial vehicles and the like.

Just as the average American can be overwhelmed by data, Soldiers receiving information from multiple sources in addition to their own senses can suffer from information overload, decision gridlock and mental exhaustion.



NETWORKED COMMUNICATION
A vision of the Army's future augmented reality capabilities. Augmented reality and mixed reality will provide a networked communication system between military leaders and the individual Soldier in the field. Information will be gathered by a variety of unattended ground sensors and transmitted to the command center. (U.S. Army graphic)

In the mid term, R&D activities are focusing on:

- Manned vehicles developed with sensors and processing capabilities for moving autonomously, tasked for Soldier protection.
- Robotic assets, teleoperated, semi-autonomous or autonomous and imbued with intelligence, with limbs that can keep pace with Soldiers and act as teammates.
- Robotic systems that contain multiple sensors that respond to environmental factors affecting the mission, or have self-deploying camouflage capabilities that stay deployed while executing maneuvers.
- Enhanced reconnaissance through deep-penetration mapping of building layouts, cyber activity and subterranean infrastructure.

In the far term, the R&D community can make a dent in key technological challenges once AR and MR prototypes and systems have seen widespread use. Research on Soldier systems will help narrow the set of choices, explore the options and reveal available actions and resources to facilitate mission success. This research will focus on automation that could track and react to a Soldier's changing situation by tailoring the augmentation the Soldier receives and by coordinating across the unit.

IMAGE IDENTIFIED

As a result of improvments in AR and MR, real-time sensor data from unmanned aerial vehicles will allow Soldiers to better visualize battlefield terrain, providing geographic awareness of buildings, roads and other structures before a mission. (Image courtesy of U.S. Army Communications-Electronics Research, Development and Engineering Center)

In more long-term development, sensors on Soldiers and vehicles will provide real-time status and updates, optimizing individually tailored performance levels. Sensors will provide adaptive camouflage for the individual Soldier or platform in addition to reactive self-healing armor. The Army will be able to monitor the health of each Soldier in real time and deploy portable autonomous medical treatment centers using sensor-equipped robots to treat injuries. Sensors will enhance detection through air-dispersible microsensors, as well as microdrones with image-processing capabilities.

In addition to all of the aforementioned capabilities, AR and MR will revolutionize training. Used as a tactical trainer, AR and MR will empower Soldiers to train as they fight. For example, Soldiers soon will be able to use real-time sensor data from unmanned aerial vehicles to visualize battlefield terrain, providing geographic awareness of roads, buildings and other structures before conducting their missions. They will be able to rehearse courses of action and analyze them before execution to improve situational awareness. AR and MR are increasingly valuable aids to tactical training in preparation for combat in complex and congested environments.

CONCLUSION

Currently, several Army laboratories and centers are working on cutting-edge research in the areas of AR and MR with significant success. The work at the U.S. Army Research, Development and Engineering Command and the U.S. Army Engineer Research and Development Center (ERDC) is having a significant impact in empowering Soldiers on the ground to benefit from data supplied by locally networked sensors.

AR and MR are the critical elements required for integrated sensor systems to become truly operational and support Soldiers' needs in complex environments. It is imperative that both technologies mature sufficiently to enable Soldiers to digest real-time sensor information for decision-making. Solving the challenge of how and where to use augmented reality and mixed reality will enable the military to get full value from its investments in complex sensor systems.

For more information or to contact the authors, go to ***www.cerdec.army.mil****.*

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DR. MICHAEL GROVE is principal deputy for technology and countermine at NVESD. He holds a doctor of science in electrical engineering and an M.S. in electrical engineering from the University of Florida, and a B.S. in general engineering from the United States Military Academy at West Point. He is Level III certified in engineering and in program management.

LOOK FURTHER

Despite challenges, Army STRLs are making significant strides—including work by the U.S. Army Space and Strategic Defense Command/Army Forces Strategic Command to advance high-energy laser weapons, like this one. They have the potential to be a low-cost, effective complement to kinetic energy to address threats from rockets, artillery and mortars, as well as from cruise missiles and unmanned aerial systems. (Images courtesy of DASA(R&T))

INVESTING IN ARMY LABORATORY INNOVATION

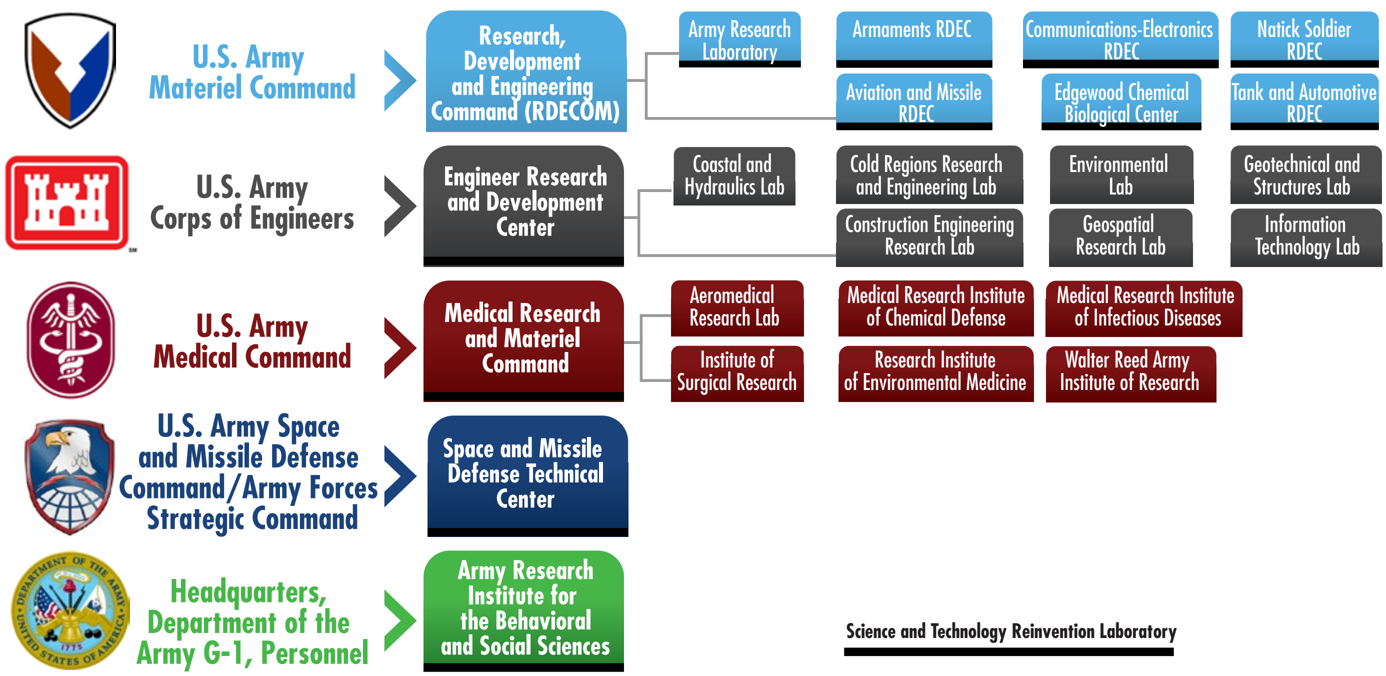
You need good labs and smart people to turn out good science and technology. If the Army wants innovative solutions backed by solid R&D, it needs to pay for them.

by Dr. Matt Willis

Army laboratories work diligently and collaboratively to deliver technology-enabled solutions for current conflicts and to develop technologies to prepare the Army for multiple futures by enhancing the force's ability to prevent, shape and win future conflicts. The Army labs are national assets, ensuring Army dominance in an asymmetric and complex warfighting future. The underpinnings of a robust Army laboratory network include strategic and focused workforce and infrastructure policies; collaborations with traditional and nontraditional defense partners; mechanisms for dynamic technology transfer to internal and external partners; and a science, technology, engineering and mathematics (STEM) ecosystem that promulgates a highly skilled, technically competent and diverse cadre of scientists and engineers at the Army laboratories. The assistant secretary of the Army for acquisition, logistics and technology (ASA(AL&T)) provides a strategic focus and policy framework to instill these organizations with the means and capabilities to develop critical Army technologies for the current and future force.

To stay at the cutting edge and provide continued dominance to our Soldiers, Army labs need the right facilities, equipment and workforce. It's a challenge to get them, however. Nationally, the number of U.S. students pursuing STEM degrees has declined for several years, and the Army faces stiff competition from the private sector for the limited talent pool once students graduate. The Army must continue to invest in STEM education to ensure a continuing supply of domestic scientists and engineers who can get security clearances in a timely manner, and who consider the Army for a long-term rewarding STEM career. Furthermore, Army labs have an average facility age of more than 50 years. Modern buildings, equipment and adequate resourcing are vital to developing cutting-edge technology and to recruit and retain the most talented scientific personnel. Minimizing the impact of aging infrastructure and maintaining world-class research facilities will require

FIGURE 1



RESEARCH BRANCHES OUT

Army STRLs encompass a wide-ranging and diverse but complementary network of 11 distinct laboratory organizations operating specialized labs, research institutes and research, development and engineering centers (RDECs) in more than 80 locations, 32 states and 15 countries.

strategic planning from the Army science and technology (S&T) community.

Congress has recognized the unique challenges that Army and other government-owned and government-operated laboratories face to remain competitive. The National Defense Authorization Act for Fiscal Year 1995 designated several Army laboratories as Science and Technology Reinvention Laboratories (STRLs) and delegated unique workforce and infrastructure authorities to these organizations. There are several criteria for an organization to be designated an STRL:

1. The laboratory must meet the definition of a research and development laboratory, as defined in paragraph 3.2 of "DOD Instruction 3201.4, In-House Laboratory Independent Research Program," whose scientific and engineering workforce is principally involved in performing exploratory development, research work or a combination of both.

2. A significant portion of the laboratory's staff should be scientists or engineers who spend a substantial amount of time personally performing exploratory development or research work.

3. Research and development efforts are preferably in at least two well-defined specialty areas.

4. The facility should have a significant portion of its programmatic effort in tech-based activities, as defined in DOD's Financial Management Regulation, Volume 2B, Chapter 5. The regulation organizes research, development, test and evaluation (RDT&E) appropriation into seven basic areas: basic research; applied research; advanced technology development; advanced component development and prototypes; engineering and manufacturing development; RDT&E management support; and operational system development.

5. A significant portion of research and development activities should be conducted in-house, so as to require and ensure continued development of in-house expertise.

6. At least one segment of the mission effort should be unique to that facility, at least within its own service.

7. Professional recruitment activity should include at least one critical hard-to-hire, high-demand occupation or area where there is considerable competition for trained personnel.

The list of government laboratories designated as STRLs has evolved numerous times since 1995; all Army laboratories executing S&T are now designated STRLs, with the associated workforce and infrastructure authorities. The Army STRLs are distributed among the U.S. Army Materiel Command, U.S. Army Medical Command, U.S. Army Corps of Engineers, U.S. Army Space and Missile Defense Command and HQDA G-1. The STRLs consist of 11 distinct laboratory organizations distributed across more than 80 locations, 32 states and 15 countries, each with distinct but complementary mission sectors and core competencies. (See Figure 1.)

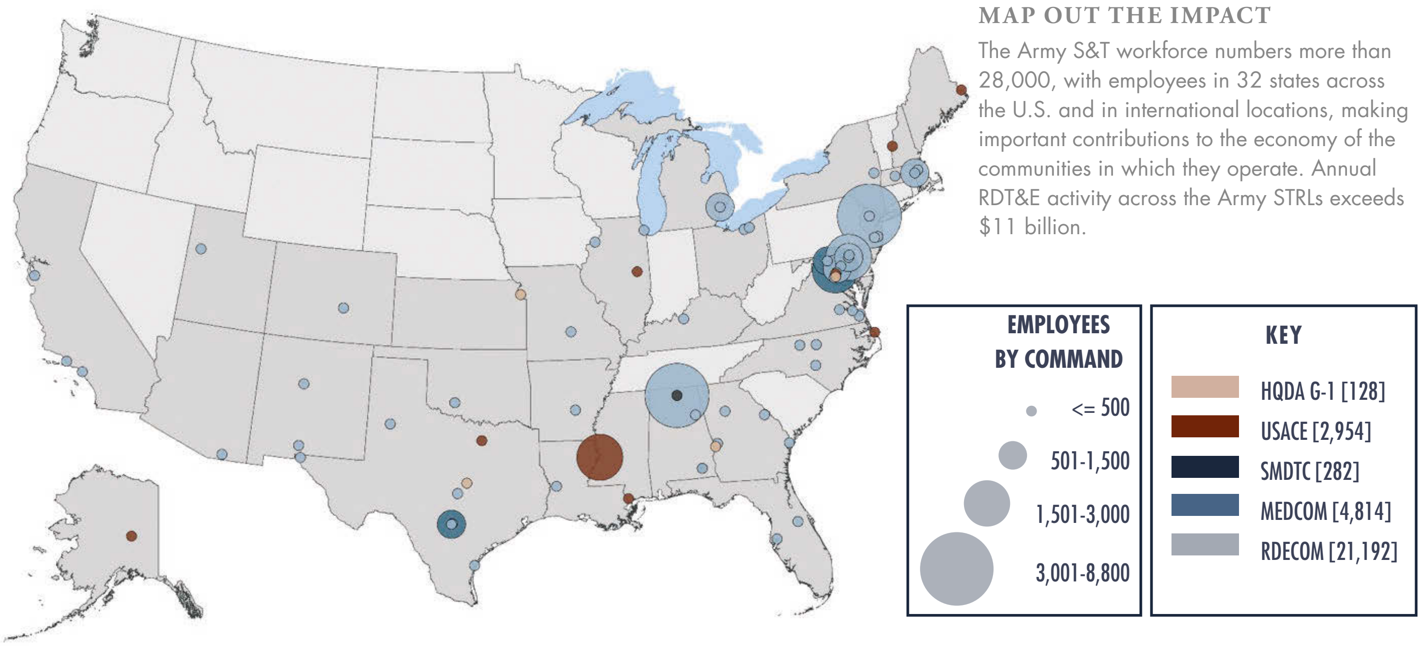
The organic Army S&T workforce includes approximately 28,350 employees around the world, at over 80 sites in 32 states across the U.S. and in 14 additional countries. The economic impact that the labs have on their local communities should not be understated. Figure 2 depicts a density plot of Army scientists and engineers across the U.S. for each S&T command; the size of the circle is proportional to the number of civilian, military and contractor personnel at each site. Annual RDT&E activity across the Army STRLs is greater than $11 billion.

Army labs have had great technological successes, including providing novel armor solutions for vehicles and Soldier protection; adaptive Soldier protection capabilities; lower-cost air defense

CHECKING FOR BRAIN INJURY

The work of STRLs includes research into warfighter health. As the incidence of traumatic brain injury rises, developing a tool to quickly and correctly diagnose head injuries is vitally important. These I-Portal PAS goggles, funded in part by U.S. Army Medical Research and Materiel Command's Combat Casualty Care Research Program, use virtual reality technology to assess possible brain injuries. The device has received financial support from DOD and the National Football League and is being evaluated in clinical trials at several military medical facilities.

FIGURE 2



MAP OUT THE IMPACT

The Army S&T workforce numbers more than 28,000, with employees in 32 states across the U.S. and in international locations, making important contributions to the economy of the communities in which they operate. Annual RDT&E activity across the Army STRLs exceeds $11 billion.

systems; and optimized Soldier-system integration and training technologies. Army leadership should invest in the current and future organic Army S&T workforce and facilities to foster overmatch for a complex and uncertain future, ensuring a deliberate investment in incremental and disruptive innovation.

The following articles explore some of the contributions Army labs have made, and highlight ways to keep those labs staffed with talented, dedicated people to continue the legacy of achievement.

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ARMY LABORATORIES

The U.S. Army Materiel Command's Research, Development and Engineering Command provides innovative research, development and engineering to support the joint warfighter and the nation. The U.S. Army Research Laboratory explores the art of the possible, while the research, development and engineering centers mature product development within armaments, aviation and missiles, communications and electronics, chemical and biological defense, Soldier systems, and tank and automotive systems.

The U.S. Army Corps of Engineers' Engineer Research and Development Center solves the nation's most challenging problems in civil and military engineering, geospatial sciences, water resources and environmental sciences for the Army, DOD, civilian agencies and our nation's public good.

The U.S. Army Medical Command's Medical Research and Materiel Command (MRMC) is the Army's medical materiel developer, with responsibility for medical research, development and acquisition and medical logistics management. The MRMC's expertise in these critical areas helps establish and maintain the capabilities the Army needs to fight and win on the battlefield.

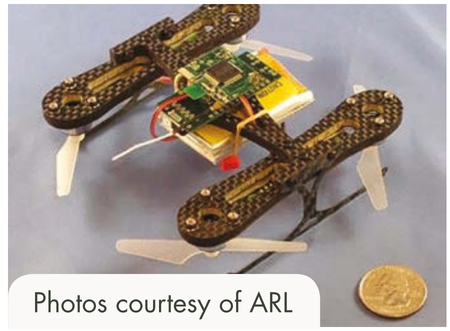
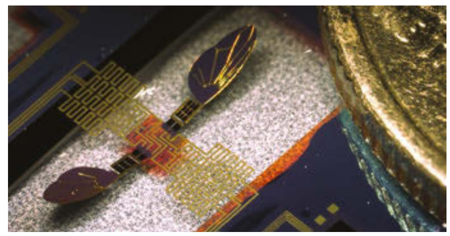
The U.S. Army Space and Missile Defense Command Technical Center (SMDTC) is part of a single, synchronized team charged to provide dominant Army space, missile defense and high-altitude capabilities to the Army, joint force, allies and partners. SMDTC manages S&T and R&D and conducts test programs for space, integrated air and missile defense, directed energy, hypersonics and related technologies.

The U.S. Army Research Institute for the Behavioral and Social Sciences provides the Army with scientific research concerning cognitive and noncognitive personnel testing and performance measurement, individual skills training and learning, leadership and leader development, recruiting and retention of the force, and strategic organizational issues.

ANSWERING HARD QUESTIONS

Army labs are invaluable assets in ensuring Army dominance in the complex battles of the future. However, new approaches for strategic planning and investment are needed as facilities age and competition for a shrinking pool of qualified candidates grows more difficult.

TECHNICAL ACHIEVEMENTS


Photos courtesy of ARL

U.S. ARMY RESEARCH LABORATORY (ARL)

Micro-Autonomous Systems and Technology Collaborative Technology Alliance (MAST CTA)

MAST CTA, a basic research program that ran from FY08 to FY17, was designed to enhance the tactical situational awareness of the dismounted Soldier in urban and complex terrain by enabling the autonomous operation of a collaborative ensemble of micro-autonomous systems. Since its inception, the program has advanced technology to reduce the size, weight and power of autonomous systems; increase operational speed in complex environments; develop obstacle detection, perception and mapping capabilities; and provide new understanding in bio-inspired agility and maneuverability. Several research efforts are ongoing and have advanced expertise within the Army to continue improving autonomous systems. Current research areas include:

- Development of bio-inspired sensors and controls, including sensor integration, human-in-the-loop controls and position, navigation and timing.
- Aeromechanics, soft materials, fluid and flight dynamics.
- Manipulation and mobility, e.g., self-righting and grasping.
- Collaboration behaviors, network-aware communications and GPS-denied navigation.

Photo courtesy of CERDEC

U.S. ARMY COMMUNICATIONS-ELECTRONICS RESEARCH, DEVELOPMENT AND ENGINEERING CENTER (CERDEC)

Vital Infrared Sensor Technology Acceleration (VISTA)

The VISTA program was a multiyear Army-led initiative that also involved the Navy and Air Force. The effort began in 2011 and aimed to maintain U.S. military superiority in infrared sensor capabilities. Products delivered from VISTA will enable the next generation of sensors to perform at the levels necessary to maintain overmatch and allow for multiple functions, including search, identification and tracking; wide area persistent surveillance; and operations in degraded visual environments. VISTA focused on III-V antimony-based infrared focal plane arrays, which use an entirely new class of materials that improve affordability, manufacturability and performance, while also offering size, weight and power advantages for advanced infrared systems. The technology developed in this program is already available in some defense products and will be transitioned to multiple programs of record. Ultimately it will facilitate warfighter overmatch in any environment. Over its five years of effort, VISTA created an entire new industry base for producing III-V antimony-based infrared focal plane arrays. Its use of domestic commercial compound semiconductor foundries, which sell products like cellphone chips and are not reliant on DOD for their survival, provide flexibility, producibility and affordability.

U.S. ARMY AVIATION AND MISSILE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER (AMRDEC)

Javelin Lightweight Command Launch Unit (CLU)

The technology behind the Javelin Lightweight CLU reduces the weight of the system by 50 percent and decreases the overall size by 35 percent while providing equal or greater detection, recognition and identification performance than the current Javelin CLU. AMRDEC's investments in critical technologies provide the capabilities to reduce Soldier load, greater force protection to ensure survivability, and persistent surveillance and acquisition to enable battlefield dominance. A smaller infrared target acquisition sensor provides increased detection, recognition and identification performance, and advanced composite and foam materials used in the CLU housing improve strength, thermal management and shock absorption. Production is planned for FY20.

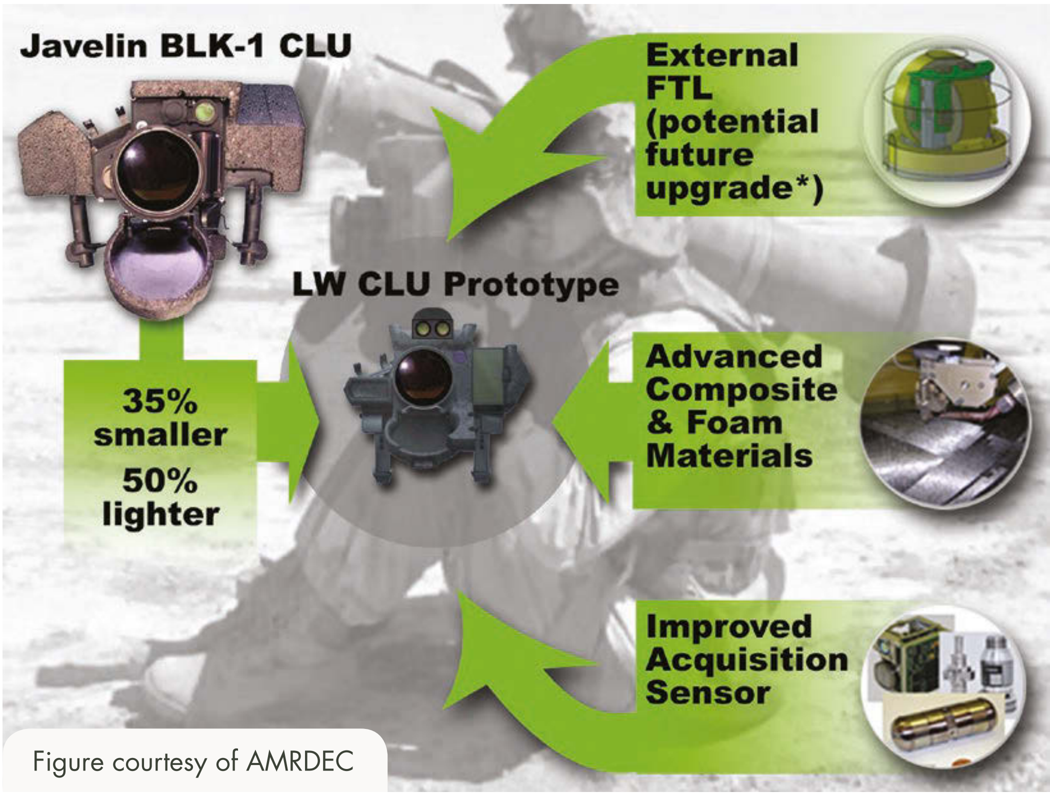


Figure courtesy of AMRDEC

U.S. ARMY SPACE AND MISSILE DEFENSE COMMAND/ARMY FORCES STRATEGIC COMMAND TECHNICAL CENTER (SMDTC)

Kestrel Eye

The Kestrel Eye is a small, low-cost, visible-imagery satellite prototype designed to provide near-real-time images to the tactical-level ground Soldier. Kestrel Eye was launched to the International Space Station (ISS) as a payload aboard the SpaceX Falcon 9 from Kennedy Space Center in Florida on Aug. 14, 2017, as part of the ISS cargo resupply mission. The system was subsequently deployed into space and activated on Oct. 24. "Kestrel Eye is a technology demonstrator, but it holds the promise of providing tactical imagery to the Soldier on the ground, and to do it responsively, persistently and reliably," said John R. London III, chief engineer for the Space and Missile Defense Command's Space and Strategic Systems Directorate. "For the first time, commanders in the field will be able to control the entire imagery process from end to end, from the tasking of the satellite all the way through to the dissemination of the data to the Soldiers who need it."

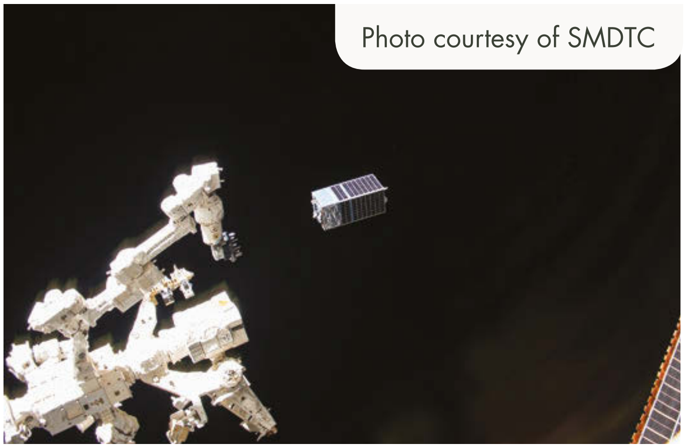


Photo courtesy of SMDTC

U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES (ARI)

Tailored Adaptive Personality Assessment System (TAPAS)

Army recruits complete a series of screenings to be deemed eligible to join. Most notable is the Armed Services Vocational Aptitude Battery (ASVAB), a cognitive ability measure required for entry and job placement. The U.S. Army Research Institute for the Behavioral and Social Sciences developed TAPAS to supplement the ASVAB and predict success in the Army, the first major change to Army accession testing since the 1990s. TAPAS is a computer-adaptive personality assessment tool, based on personality theory, psychometrics and advanced testing technology, that assesses 26 personality attributes, including achievement, leadership, adjustment, tolerance and team orientation. Preliminary results indicate that TAPAS facilitates prediction of technical performance, is a strong predictor of motivational outcomes and attrition, and is a useful tool to improve in-service assignment selection. The Walter Reed Army Institute of Research (WRAIR) found strong relationships between those who score lower on TAPAS and mental health diagnosis and medical attrition. Expanded screening, including noncognitive assessments like TAPAS, can reduce attrition and behavioral health risks, and improve readiness and performance.

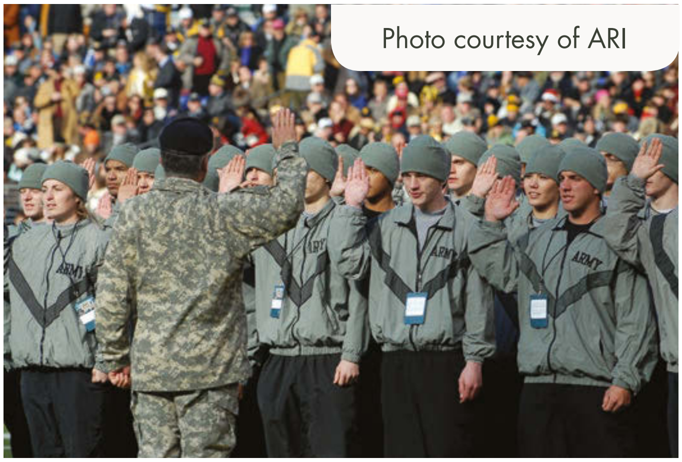


Photo courtesy of ARI


Photo courtesy of USAMRMC

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND (USAMRMC)

Occupational Physical Assessment Test (OPAT)

OPAT is a battery of four physical performance tests that the Army has administered since 2017 to all candidates seeking to enter active, Reserve or National Guard duty, to identify who is most likely to succeed in combat military occupational specialties (MOSs). The U.S. Army Research Institute of Environmental Medicine (USARIEM), a subordinate command of MRMC, began conducting field studies in 2016, in initial military training settings at Fort Benning, Georgia; Fort Leonard Wood, Missouri; and Fort Sill, Oklahoma. The effort resulted in the four OPAT tests—a standing long jump, a medicine ball throw, an incremental squat lift and an interval aerobic run—and validated the predictive ability of the OPAT to place Soldiers into seven combat MOSs. USARIEM is now in the first year of a two-year longitudinal study to assess how successful Soldiers are in their assigned MOSs after receiving their OPAT results. According to an Army Times article, Army statistics from late October 2017 indicate that since administering the OPAT, injuries in basic combat training have dropped by 17 percent, and on-time graduation rates have jumped from 85 percent to 93 percent.

U.S. ARMY MEDICAL RESEARCH AND MATERIEL COMMAND (USAMRMC)

Zika virus vaccine

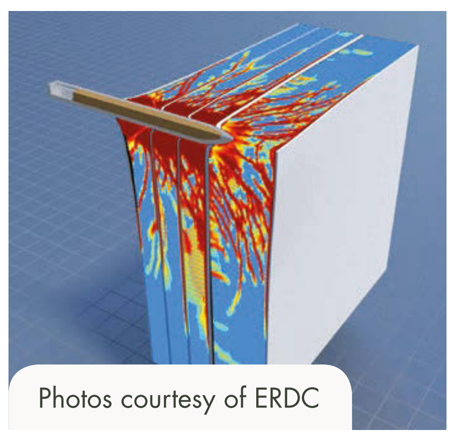
The Zika virus, which originated in the Zika forest in Uganda, has now infected humans around the world, causing fevers and rashes along with more serious nervous system complications such as Guillain-Barre syndrome and microcephaly. U.S. service members and their families are at higher risk for Zika virus infection than the general U.S. population as they often deploy to areas with active transmission of Zika. In an unprecedented 180 days, USAMRMC and WRAIR developed a Zika purified inactivated virus (ZPIV) vaccine candidate and published preclinical findings in Nature and Science. Three initial ZPIV human trials began in 2016, each addressing a unique question about background immunity, vaccine dose or vaccination schedule. The results of these trials, published in November 2017, showed that the vaccine induced a robust immune response and was safe and well-tolerated in healthy adults. A fourth ZPIV trial is still underway in Puerto Rico, where the population has natural exposure to other viruses in the same family as Zika, such as dengue.

Figure courtesy of USAMRMC

U.S. ARMY ENGINEER RESEARCH AND DEVELOPMENT CENTER (ERDC)

Countering anti-access and area denial (A2AD)

ERDC collaborates with the U.S. Army, Air Force, Navy, Marine Corps and others to solve significant projection and protection challenges facing Soldiers in A2AD environments. ERDC's force projection research is focused on developing and demonstrating technologies for planning and conducting forcible entry operations with nonexistent, damaged or destroyed infrastructure to ensure that the joint force can operate in any environment, at any time, regardless of terrain. Recent successes include demonstration of rapid airport and seaport repair solutions; terrain surfacing kits for unmanned aircraft landing strips, helicopter landing zones, and logistics over shore operations; and remote monitoring technologies and decision support tools for assessing critical infrastructure and littoral zones. To protect facilities that allow the U.S. to project force into denied areas, ERDC is exploring advanced materials and unique structural components that are incorporated into structural hardening solutions, as well as decision support tools that aid vulnerability assessments of critical facilities and mission impact.



Photos courtesy of ERDC

BROAD ROOTS GROW STRONG STEMS

Army Educational Outreach Program aims to engage, inspire and attract the next generation of science, technology, engineering and mathematics talent.

BUILDING BLOCKS

AEOP and its participants develop and implement programs for students and teachers that aim to attract the next generation of STEM talent and tell them about DOD STEM careers. Almost 2,000 Army scientists and engineers participated in the programs in the 2016-17 academic year, and students and teachers have worked in 22 laboratories and 118 universities across the country. (SOURCE: The author)

by Dr. Matt Willis

The United States' science, technology, engineering and mathematics (STEM) capabilities are critical to the nation's innovation, economic competitiveness and national security. Protecting and equipping our most critical asset, the U.S. Soldier, depends on thoughtful solutions that can thrive only if we are constantly ahead of our adversaries in science and technology innovation and manufacturing. Globally, STEM fields will drive the solutions to our most critical challenges in health, safety and the environment.

Recent studies illustrate a clear and alarming erosion in the United States' STEM capabilities, evident in both the skills gap plaguing our major industries and our students' lagging achievement in mathematics and science compared with peers worldwide. Since the National Academies' seminal report, "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future," brought this issue to the forefront a decade ago, partners across just about every sector have answered the call for a coordinated federal effort to reposition the U.S. as a leader in STEM.

To date, this coordinated federal effort has had mixed results in improving STEM throughout the school-to-career pipeline. Thanks to strong bipartisan support, STEM education has become a highly visible and widely championed issue in the business, education and STEM communities.

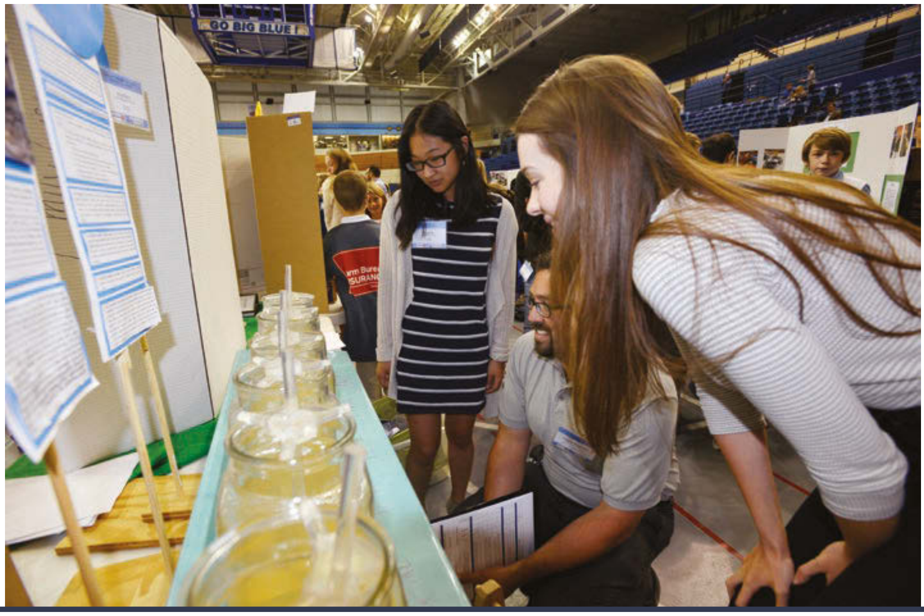
However, U.S. students still rank only 35th in mathematics and 18th in science in the most recent Program for International Student Assessment, and economic data show that roughly 1 million additional highly qualified STEM graduates will be needed over the next decade. Though student proficiency is beginning to increase in these subjects, the U.S. has a long way to go before its students have the knowledge and skills they'll need to succeed in tomorrow's jobs.

ARMY EDUCATIONAL OUTREACH PROGRAM

To address the challenge of attracting students to STEM careers in support of both DOD and the nation, the Army has curated a portfolio of STEM-rich programs for students and teachers that engage and inspire the next generation of STEM talent and provide exposure to DOD STEM careers. The Army Educational Outreach Program (AEOP) provides students and teachers from elementary school through college access to collaborative, high-quality STEM programs that encourage a STEM-literate citizenry, STEM-savvy educators and future STEM leaders nationwide. AEOP engages scientists and engineers from across the network of Army laboratories as mentors and guides, bringing young people directly into our laboratories and research assets for hands-on STEM challenges with real-world applications. The Army strives to build a diverse, well-prepared, STEM-literate workforce in support of the defense sector and the broader national STEM challenge. By leveraging the Army's strengths and leaning on the strengths of partners, the Army is addressing the STEM crisis on multiple fronts, with promising results.

The Army provides strategic direction and oversight for AEOP. The program is executed through a cooperative agreement managed by Battelle, a global research and development organization based in Columbus, Ohio, that also coordinates STEMx, a platform to share and disseminate STEM educational tools across the country. Additional partners for the cooperative agreement include the Purdue University College of Education; Widmeyer Communications, a Finn Partners Company; MetriKs Amérique LLC; Tennessee Technological University's Millard Oakley STEM Center; the National Science Teachers Association (NSTA); the Technology Student Association (TSA); the Academy of Applied Science; the Mathematical Association of America; and the National Inventors Hall of Fame.

Each partner plays an important role, from recruiting volunteers to supporting communications and administering programs. AEOP partners provide the STEM education component to maximize the benefits and use of Army research assets. Additionally, they help reach a much broader network of STEM educators through networks such as STEMx and through NSTA and TSA, with a combined active membership of over 300,000 students, educators and business professionals.

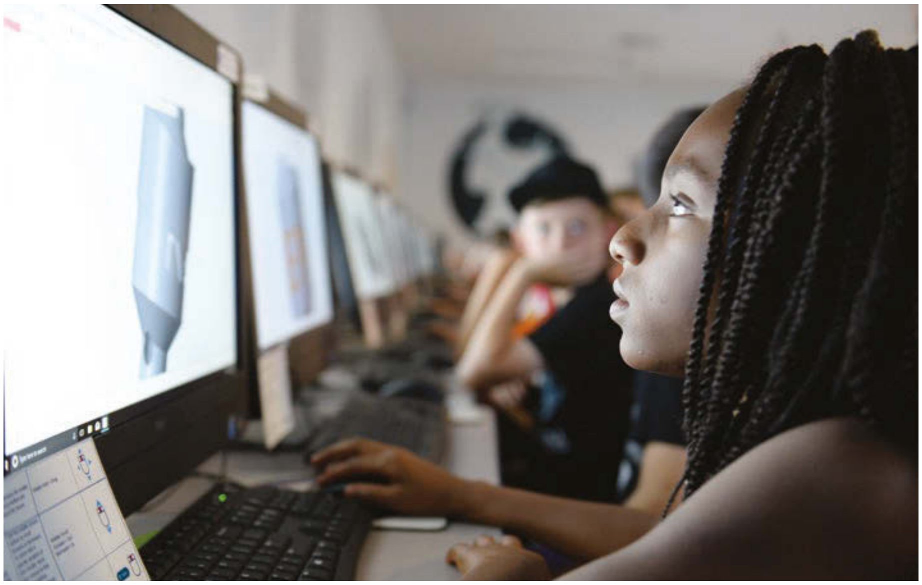


TAKE A CLOSER LOOK

David Bogema, a civil engineer with the U.S. Army Corps of Engineers (USACE) Nashville District, talks with students from the Central Magnet School in Murfreesboro, Tennessee, during the STEM Expo at Tennessee State University in April 2017. Student proficiency in STEM fields is on the rise, in part because of events like this one, but more progress is needed to keep the U.S. competitive and secure. (Photo by Mark Rankin, USACE Nashville District)

EXPLORE THE OPTIONS

Children learn to use computer-aided design and drafting software at STARBASE Summer Camp at Camp Mabry, Texas, in August 2017. Funded by DOD and now in its fifth year, STARBASE encourages children in areas that are historically underrepresented in STEM—inner cities or rural locations, for example, or those that are socioeconomically disadvantaged—to get involved in STEM disciplines through hands-on challenges and networking with positive role models. (U.S. Army National Guard photo by Sgt. Michael Giles)



AEOP is investigating new and innovative ways to forge mutually beneficial relationships with organizations and technical associations that have similar STEM goals, specifically serving students from underserved populations and military dependents. In collaboration with our strategic STEM partners, AEOP is empowered to leverage their partners' robust and established STEM networks, build on and synergize with existing relationships and promote its portfolio of enriching STEM opportunities for educators and students. The intent of the AEOP Strategic Outreach Initiatives, started in April 2016, is to broaden student participation in the AEOP portfolio to better reflect the nation's demographics. AEOP selected partners specifically for their leadership in STEM learning and outreach to African-American, Hispanic, female and military-connected students. Current partners include the Society of Women Engineers, the Tiger Woods Foundation, Harmony Public Schools, DC STEM Network, Carnegie Academy for Science Education and the EduCare Foundation, among many others. Through these strategic partners, AEOP is able to broaden its network far beyond the Army laboratories and our university partners.

The AEOP strategy has also significantly improved the Army's ability to capture measures of success, to identify STEM program gaps, to maximize resources, and to create, train and defend a sustainable STEM infrastructure. These investments center on a measurable and defensible value stream that affects an expanding workforce, including Americans in rural and urban settings, as well as other underrepresented groups in STEM fields. The program tracks improvements in these areas and analyzes the effectiveness of each AEOP STEM effort.

> *Recent studies illustrate a clear and alarming erosion in the United States' STEM capabilities, evident in both the skills gap plaguing our major industries and our students' lagging achievement in mathematics and science compared with peers worldwide.*

HEIGHTENED INTEREST IN STEM

Most important of all, the AEOP programs work. Students have reported a deeper interest in STEM after completing just one of the AEOP enrichment programs, competitions or apprenticeships. Program impact has been captured through survey data. Furthermore, AEOP alumni attest to how the AEOP experience dramatically improved their understanding of STEM careers in DOD and beyond and set them on a path to pursuing a STEM-related career. A recent initiative evaluated the impact of AEOP activities on the 21st Century

Skills Framework, representing the skills and knowledge students need to succeed in work, life and citizenship. Preliminary results suggest a statistically significant improvement in skills such as creativity and innovation, critical thinking and problem-solving, as well as productivity, accountability, leadership and responsibility. Teachers who participate in AEOP programs are better able to engage students in hands-on STEM learning in the classroom. Results also indicate that even Army civilian mentors gain valuable skills and insight through their work to inspire a new generation of STEM talent.

Across the country, the programs are showing significant progress. In the 2016-17 academic year, AEOP received 39,715 online applications and placed 32,792 students in programs, representing a 15 percent increase in both applications and participants from 2012. Additionally, 2,568 teachers had authentic laboratory experiences—a threefold increase in four years. Nearly 2,000 Army scientists and engineers participated in the programs, and students and teachers worked in 22 participating laboratories and 118 participating universities across the country. This success is a helpful case study for other programs and stakeholders looking to make a real impact on students from all communities.

LET'S TRY THIS

1st Lt. Robert Leisinger, executive officer for the 3rd Battalion, 15th Infantry Regiment, 2nd Infantry Brigade Combat Team, 3rd Infantry Division (2-3 IBCT), helps students assemble a robotic car at Snelson-Golden Middle School in Hinesville, Georgia, near Fort Stewart, in November 2016. The students were participants in Z Space, the school's STEM program. Encouraging kids to consider careers in STEM fields early in their education is important: Roughly 1 million additional highly qualified STEM graduates will be needed over the next decade. (U.S. Army photo by Spc. Efren Rodriguez, 2-3 IBCT Public Affairs)

CONCLUSION

It is an exciting time in the U.S. for STEM, and the momentum continues to grow. However, this momentum will not spur dramatic improvements in students' preparedness for tomorrow's STEM-driven careers if stakeholders fail to partner and work together toward measurable outcomes. We also won't get far if African-American, Hispanic, female and military-connected students continue to lack access to the quality STEM exploration and courses of study they need to thrive. The STEM workforce will continue to grow, not just in importance, but also in size and complexity. U.S. competitiveness—and our children's future—is at stake. Together, we must ensure the next landmark STEM report tells a different, triumphant story.

*For more information, go to **www.usaeop.com**.*

DR. MATT WILLIS is the director for laboratory management in the Office of the Deputy Assistant Secretary of the Army for Research and Technology. As such, he shapes policies that impact the workforce, infrastructure, technology transfer and STEM educational outreach posture at the Army science and technology research laboratories. He holds a Ph.D. and an M.S. in chemical engineering from the University of Illinois at Urbana-Champaign and a B.S. in chemical engineering from Cornell University. He is Level II certified in S&T management and is a member of the Army Acquisition Corps.

BENCH-BUILDING at ARMY LABS

Attracting an elite cadre of scientists and engineers is essential for the Army mission; Army labs need to be able to offer better pay and shorter hiring timelines to do so.

by Dr. Matt Willis

A core enabler for technology superiority in a constantly evolving and asymmetric threat landscape is technological excellence at the Army laboratory enterprise, empowered by a strategically shaped and highly competent technical workforce. Attracting, recruiting and retaining an elite cadre of Army scientists and engineers is essential for success in the science and technology (S&T) domain that is critical to the Army's mission. Army scientists, technicians, engineers and mathematicians—among other technical specialists—make fundamental S&T contributions to national security and to the nation as a whole. The Army must instill an open laboratory culture—steeped in innovation and collaboration, and a systems thinking approach—that is accommodating to creative, free minds and a stimulating atmosphere to break through the bureaucracy and attract future technical experts.

The Army, as an S&T incubator, competes with the private sector and academia for high-demand science, technology, engineering and mathematics (STEM) professionals. Army S&T success—and by proxy, dominance in the future fight—depends on tenets such as:

- The dynamic recruiting of high-caliber, future-focused STEM professionals, with timely initial hiring and flexible compensation.
- The responsibility, authority and flexibility for Army laboratories to manage workforce strength, structure, positions and compensation unencumbered by limitations on appointments, positions or funding.
- Talent management policies and strategies that fuel growth, innovation and

FIGURE 1

S&T COMMAND	TYPE	AUTHORIZED	USED	% USED
U.S. Army Corps of Engineers Engineer Research and Development Center	BACHELOR	69	48	70%
	ADVANCED	58	45	78%
	VETERANS	39	14	36%
U.S. Army Medical Research and Materiel Command	BACHELOR	36	12	33%
	ADVANCED	61	36	59%
	VETERANS	12	7	58%
U.S. Army Materiel Command Research, Development and Engineering Command	BACHELOR	557	286	51%
	ADVANCED	501	161	32%
	VETERANS	265	38	14%
ALL	BACHELOR	662	346	52%
	ADVANCED	620	242	39%
	VETERANS	316	59	19%
	TOTAL	1,598	647	40%

HOW DIRECT-HIRE IS USED

Direct-hire authority lets Army labs hire who they need without regard to regulations that slow down other federal hiring—but that authority is limited. This shows the Army laboratory use of the direct-hire authority in 2016. The number of direct-hire actions per calendar year is limited to a given percentage of the total number of scientists and engineers at the STRL in the previous fiscal year. For potential hires with an advanced degree, a lab can use direct-hire authority to bring on board 5 percent of the previous year's workforce level; for those with a bachelor's degree, it's 6 percent; veterans, 3 percent; and students, 10 percent. (SOURCE: The author)

market advantage with an agile and flexible operational structure designed to accomplish evolving S&T priorities.

- A robust group of senior STEM leaders to enable effective and efficient execution of S&T programs, with support from a balanced blend of administrative, technical and professional staff.

ARMY STEM WORKFORCE

The Army must instill innovative workforce management practices to empower the Science and Technology Reinvention Laboratories (STRLs) to be an attractive venue for technical careers.

The Army STRLs—all Army labs that execute joint S&T funds are designated as such, which confers additional authorities in how they're run—represent a unique segment of the broader Army workforce, including a highly educated, highly technical and highly recruited population. Recruiting and hiring into specialized positions within the Army STRL enterprise is often inhibited by the traditionally tepid hiring timeline and smaller compensation packages as compared with the private sector or academia. An innovative S&T enterprise requires

Case Study – USAMRMC

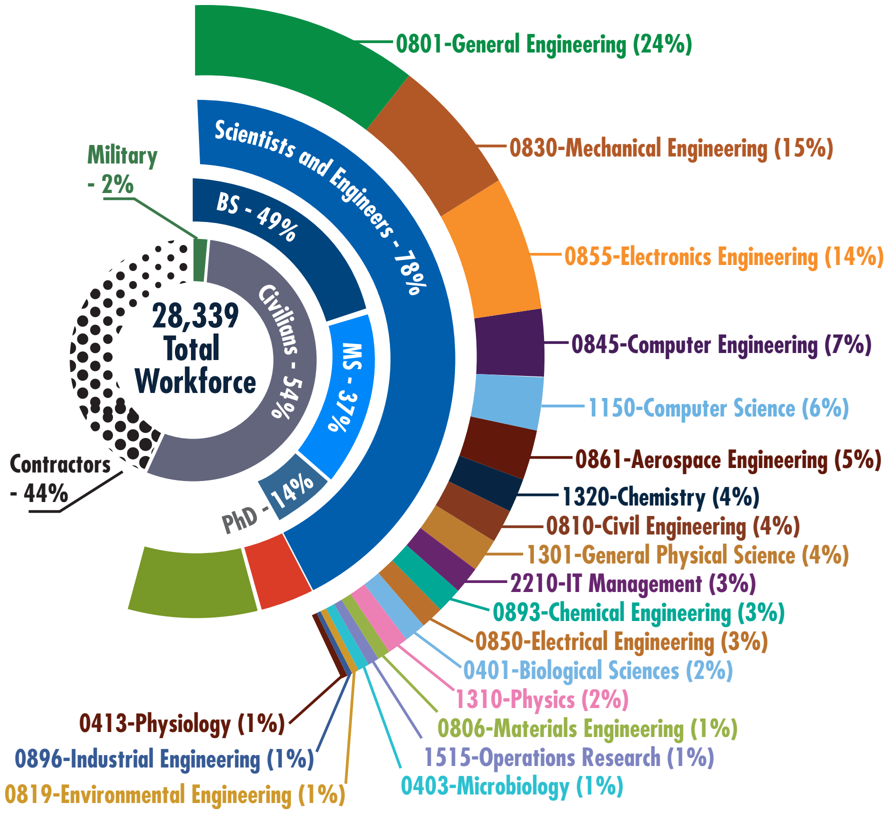
The U.S. Army Medical Research and Materiel Command (USAMRMC) has had challenges recruiting certain key technical personnel as civilian employees because of the inability to provide salaries competitive with what the pharmaceutical and biotech industries can offer. The national median salary for a senior-level life scientist is $244,000 a year; the maximum salary for civilian employees under the USAMRMC Laboratory Demonstration Project is $172,000 per year. Based on special authorities provided to the U.S. Department of Health and Human Services, top-level life scientists at the National Institutes of Health have salaries ranging from $194,000 to $240,000 a year.

One USAMRMC laboratory required an expert in the use of imaging technologies to evaluate disease states in animal models. This individual worked for a major pharmaceutical company at a higher salary than could be provided to a civilian employee. The only way this person could be attracted to work in the USAMRMC was to be hired through a contracting company. This incurred a significantly greater cost to the government and deprived USAMRMC of technical personnel who can manage employees and programs and make decisions on behalf of the government.

By being able to provide competitive salaries, USAMRMC would be better equipped to recruit top-performing medical researchers to its laboratories.

—DR. MATT WILLIS

FIGURE 2



WHO'S WHO

Seventy-eight percent of Army civilians are specialized scientists and engineers, sorted into 42 U.S. Office of Personnel Management occupational codes, ranging from microbiology (0403) to aerospace engineering (0861) to physiology (0413) and chemistry (1320). More than half of the Army S&T workforce hold an advanced degree, with 14 percent holding a doctorate. (SOURCE: The author)

an agile policy posture and hiring construct to attract, recruit and retain the current and future Army STEM leaders.

STRL WORKFORCE AUTHORITIES

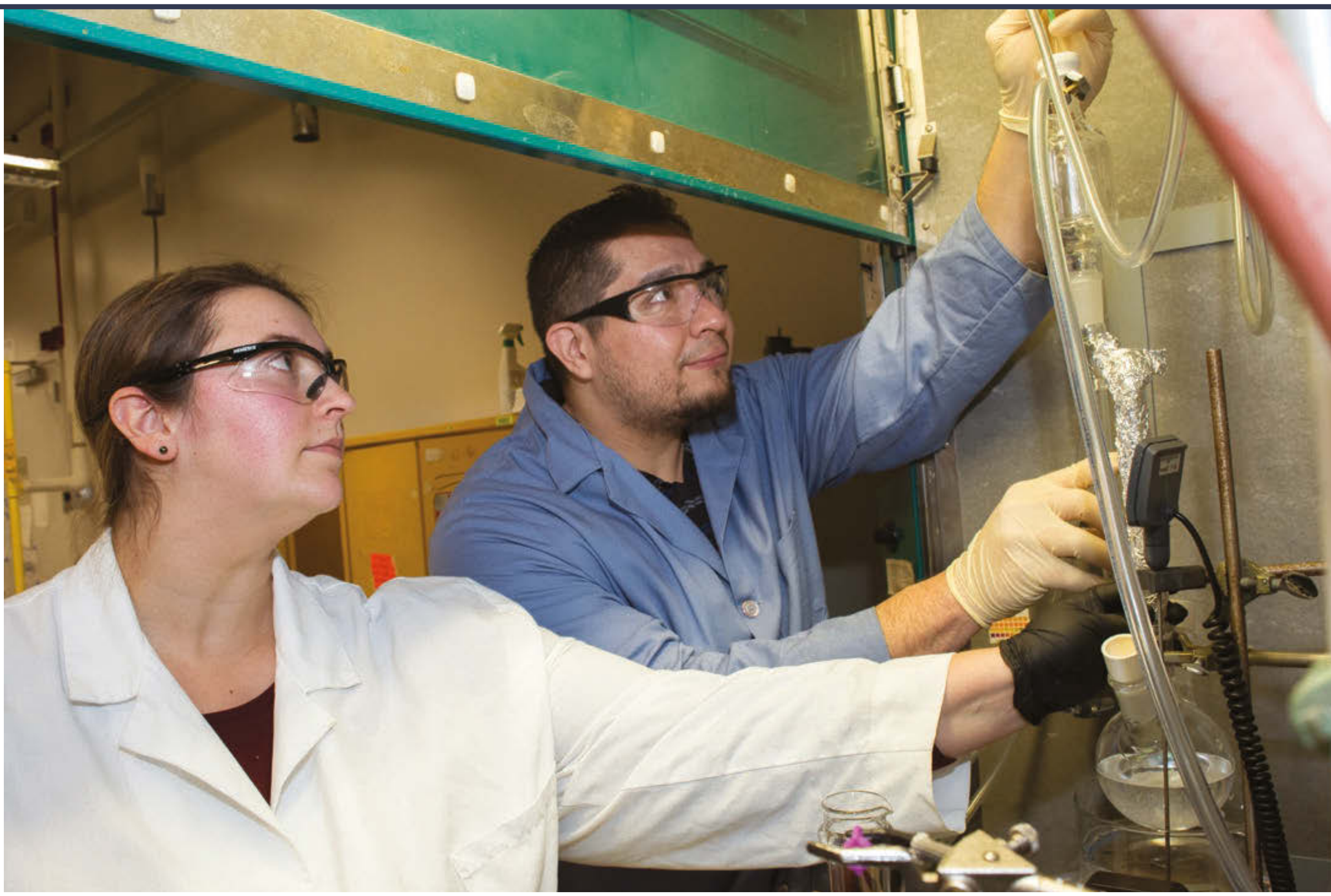
Unique personnel and operational authorities are required for the labs to develop the S&T that is critical to success in the future asymmetric multidomain battle. In recognition, Congress established Section 342(b) of the National Defense Authorization Act (NDAA) for Fiscal Year 1995, which authorizes the secretary of defense to conduct personnel demonstration projects at DOD STRLs. The personnel management authorities granted in the original provision have evolved into a permanent, continuing program to give all Army labs the freedom to build the necessary S&T workforce without the constraints that govern most federal hiring.

The STRL personnel management demonstration projects involve broadbanded pay systems and simplified classification; compensation linked to performance; recruitment and staffing changes; and enhanced training and development, including critical skills training, distinguished scholastic achievement authorities, modified term appointments, voluntary emeritus appointments, an entrepreneurial leave program and sabbaticals.

The purpose of the STRL personnel management demonstration project is to demonstrate the efficacy of specified management changes in improving the productivity and effectiveness of basic and applied research and exploratory development at the STRLs, while attracting high-impact STEM leaders. Further, the laboratory demonstration project provides a suite of dynamic tools that allow STRL directors to shape the mix of technical skills and expertise in the workforce to achieve one or more of the following strategic goals:

- To meet organizational and DOD-designated missions in the most cost-effective and efficient manner.
- To upgrade and enhance the scientific quality of the workforces of such laboratories. (See Figure 2.)
- To shape such workforces to better respond to such missions.
- To reduce the average unit cost of such workforces.

Title 10 of the U.S. Code (USC), Section 2358a permanently codifies additional authorities for directors of the STRLs. The directors manage each STRL's workforce strength, structure, positions and compensation without regard to any limitation on appointments, positions or funding and in accordance with the budget available to the facility. The directors are further authorized to implement a direct-hire authority, which expedites hiring by eliminating procedures such as competitive rating and ranking, and veterans' preference. (See Figure 1.) All laboratories are under



NEW HIRES BREAK NEW GROUND

Dr. Leah A. Wingard and Dr. Pablo E. Guzmán, researchers with the U.S. Army Research Laboratory (ARL), work on safer chemical and synthetic materials for products like explosives and propellants. Wingard has a background in inorganic chemistry, and Guzmán—who was hired after completing postdoctoral study under a Nobel laureate—has a background in synthetic chemistry. Relaxing hiring restrictions at Army research facilities could help the Army attract talented S&T professionals who often opt for similar work in the private sector. (Photo by David McNally, ARL)

command-imposed hiring restrictions that inhibited full use of the direct-hire authority. Direct-hire authority has reduced the elapsed time between the close of the job application and the conditional offer to the candidate from more than 90 days to often less than 20 days. The Laboratory Personnel Management Demonstrations Project has allowed Army labs to remain agile and competitive with the private sector, providing job offers in a matter of weeks versus months, with the option to offer more competitive compensation.

Congress has further embraced a future-focused STEM-oriented workforce and innovative laboratory enterprise by initiating a pilot program for operational streamlining of DOD laboratories. Section 233 of the NDAA for Fiscal Year 2017 challenges STRL directors to instill innovation in their organizations by streamlining management operations, rapid deployment of warfighter capabilities, experimentation, prototyping and partnership with universities and private-sector entities to generate greater returns on research and development activities. The Section 233 pilot program is a tailorable solution that will enable efficient and effective customization of activities such as facility management, construction and repair; business operations; personnel management policies and practices; and intramural and public outreach. The pilot program is authorized through the end of FY22.

CONCLUSION

Structured organizations like the Army are constrained in their ability to evolve toward a flexible, cross-organizational STEM workforce. Cross-organizational workforce utilization

SAMPLES FROM SPACE

Bintu Sowe, an associate scientist at the U.S. Army Center for Environmental Health Research at Fort Detrick, Maryland, processes samples in June 2017 from a bone healing experiment conducted aboard the International Space Station. Sowe's lab is part of the U.S. Army Medical Research and Development Command (USAMRMC), which historically has struggled to recruit experts when they can make twice the amount of money that the government can offer by working for the pharmaceutical or biotech industry. (U.S. Army photo by Crystal Maynard, USAMRMC)

I'M WORKING ON TUNNELS. YOU?

Jen Picucci, a research mathematician at the U.S. Army Engineer Research and Development Center's Structural Engineering Branch, explains tunnel detection equipment at the Pentagon's lab day in May 2017. Smart, technical specialists seek the stimulation and creativity of an "open lab" where scientists interact across disciplines and organizations. (Photo by David Vergun, ARL)

allows the Army to broaden capacity for critical focus areas while increasing efficiency within each organization. Congressional leadership has recognized the unique personnel recruitment challenges at Army STRLs and has given unique hiring and retention authorities to the laboratories, via mechanisms such as the direct-hire authority, 10 USC §2358a and the Section 233 pilot program.

However, challenges remain. Many STRLs remain subject to command-imposed hiring restrictions, inhibiting the laboratories' ability to reshape the workforce and keep pace with the rapid change of technology. Every echelon of Army leadership must embrace a paradigm shift to a flexible Army operational structure, ensuring clear goals and personnel accountability while fostering a systematic approach that prioritizes success but does not punish failure.

*For more information, contact the author at **matthew.p.willis.civ@mail.mil**.*

DR. MATT WILLIS is the director for laboratory management in the Office of the Deputy Assistant Secretary of the Army for Research and Technology. As such, he shapes policies that impact the workforce, infrastructure, technology transfer and STEM educational outreach posture at the Army STRLs. He holds a Ph.D. and an M.S. in chemical engineering from the University of Illinois at Urbana-Champaign and a B.S. in chemical engineering from Cornell University. He is Level II certified in S&T management and is a member of the Army Acquisition Corps.

FROM *MINDS* *TO* MARKETS

TechLink public-private intermediary helps small businesses access Army inventions, benefiting the U.S. military and the national economy.

by Mr. Thomas Mulkern and Mr. Troy Carter

Putting Army research and technology in the hands of capable partners in industry is crucial for fielding decisive Army capabilities. To be successful, technology transfer requires dedication, commitment and trust.

Since 1999, Army research labs have trusted TechLink, DOD's national partnership for technology transfer, to help bring innovative technology advances to the marketplace and the warfighter, supporting the U.S. military and the national economy and proving the value of the Army laboratory enterprise.

The Army conducts large amounts of scientific research that leads to cutting-edge inventions in virtually all technology fields, with the primary goal of maintaining our battlefield dominance. From 2014 to 2016, for example, the U.S. Patent and Trademark Office granted the Army an average of 151 patents per year on new inventions.

TechLink, based in Bozeman, Montana, is an outreach center at Montana State University with 38 full-time employees that is wholly funded by DOD through a partnership intermediary agreement. TechLink helps the DOD lab system transfer its patented technologies to businesses nationwide, primarily by marketing DOD inventions and helping establish license agreements for them. TechLink is involved in about 60 percent of DOD's license agreements across the U.S.

MARKETING TECHLINK

Tim Giles pilots a drone during the ThunderDrone Tech Expo at SOFWERX in September in Tampa, Florida. Before the development of TechLink, DOD labs relied on their own websites and trade shows like ThunderDrone to showcase their marketable technologies. (U.S. Air Force photo by Master Sgt. Barry Loo)

MISSED CONNECTIONS

Until recently, DOD had trouble connecting with small, entrepreneurial companies, which are eager adopters of new technology, willing to serve small specialized markets and able to develop new products rapidly for those markets.

The problem was one of DOD's approach to technology transfer. Traditionally, DOD labs posted their inventions on their websites and featured some of them at trade shows. However, most small companies and entrepreneurs were not aware that Army research and development (R&D) labs were generating patented inventions or that companies could acquire the rights to use those inventions to develop new products.

TechLink's traditional way of bridging the gap was to frequently review all new DOD inventions, assess their commercial potential and market the most commercially viable inventions to industry, using highly targeted website searches to identify companies that appeared to be good matches.

While successful in reaching well-established companies, this approach failed to identify smaller or newer companies that lacked a well-developed website but could be promising licensees.

EXPANDING THE UNIVERSE

In 2015, TechLink and the Leeds School of Business at the University of Colorado Boulder conducted an economic impact study of all DOD technology licensing from 2000 to 2014.

This study showed that the overwhelming majority of companies that licensed DOD technology were small businesses with fewer than 100 employees. In fact, most of those had fewer than nine employees.

The question TechLink then asked was: How can we market Army technology to small companies that might not even have a website? The answer was to let those small companies find TechLink.

In 2017, TechLink launched a new website that makes it easier to search for DOD technologies—by keyword, industry area and laboratory—and greatly expand DOD's connection to companies and entrepreneurs nationwide.

"We paired this new website with a robust digital marketing strategy that can leverage the power of the internet and social media to greatly expand our outreach," said Austin Leach, senior technology manager at TechLink. "This allows us to move beyond the traditional marketing approach that reaches hundreds of companies per year to a potential reach in the tens of thousands."

NEXT STEP: EXPRESS LICENSING

The online presence of Army technology began to expand in 2016, when the U.S. Army Research Laboratory (ARL) moved to improve technology transfer by increasing public access to its patents through a novel process called express licensing.

"This was a team effort utilizing two of ARL's existing partners in the technology transfer arena, TechLink and Leidos," a private, for-profit defense solutions company based in Reston, Virginia, said Jason Craley, the ARL technology transfer specialist who led the project.

The team began in January 2016 by identifying 40 patents believed to be good candidates for express licensing, notably those approaching their second maintenance fees at 7½ years. (Maintenance fees are required by the Patent and Trademark Office to maintain a valid patent.) Army policy is to not pay second maintenance fees on patents for technologies that are not being used or have not garnered outside interest.

The team selected half of the 40 patented technologies, conducted detailed interviews with inventors and gathered marketing materials. TechLink posted the inventions on ARL's Intellectual Property (IP) Store, which is hosted by TechLink's website and is also accessible through ARL's home page.

ARL's IP Store currently features 433 patented technologies, of which 30 are available via express licensing. Companies or entrepreneurs can browse these technologies, select a specific opportunity, download the patent and published papers, then apply for a license to make, use and sell the technology—all online.

"A few of our patents were sunsetting before the marketplace was ready or before we could adequately advertise them," said Craley. "Our hope is that by placing ARL's technologies in the online store and making them conveniently accessible through express licensing, we'll boost their exposure and reduce transaction costs to licensing. This is part of our push to reduce obstacles for small business," he said.

A BOOST FROM NATICK LABS

In June 2017, the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) began publicly offering express licensing on the TechLink website, which currently features a total of 112 NSRDEC technologies available for licensing.

Entrepreneurs and businesses can shop those patented technologies online, including the Insulated Container for Cold Beverages, a high-tech ice chest that keeps water bottles cool for 56 hours in 100-plus-degree weather—far longer than existing ice chests—resulting in less waste, better hydration and improved Soldier morale.

The Army's patented invention is constructed with Modular Lightweight Load-carrying Equipment webbing for secure storage, addressing concerns about traditional ice chests becoming projectiles

TECHNOLOGY LAUNCH

Sgt. Justin Carrington, unmanned aircraft system repairer with 2nd Infantry Brigade Combat Team, 3rd Infantry Division (2-3 IBCT), prepares an RQ-7 Shadow unmanned aerial vehicle for flight at Evans Army Airfield near Fort Stewart, Georgia, last January. TechLink's website makes it easier to search for Army technologies that are available for license—by keyword, industry area and laboratory. A search for "UAV," for example, brings up an Army system for collisionless flying. (U.S. Army photo by Spc. Efren Rodriguez)

Technology Transfer: The Economic Impacts

- $20.4 billion in total sales of new products and services.
- $3.4 billion in sales of new products to the U.S. military.
- $48.8 billion in total economic output nationwide.
- $1.6 billion in new tax revenues (federal, state and local).
- 182,985 full-time jobs created or retained.
- 12,199 full-time jobs per year with an average salary of $71,337.

(SOURCE: "National Economic Impacts from DoD License Agreements with U.S. Industry, 2000-2014," https://techlinkcenter.org/wp-content/uploads/2017/01/2016-DoD-Licensing-Study-E-Publication.pdf) inside vehicles hit by explosions. The U.S. Army Tank Automotive Research, Development and Engineering Center has slated the improved cooler for use in future Army ground vehicles, and several small businesses are pursuing licensing the design for production.

"The express licensing portal enhances the visibility of technologies that are valuable to the warfighter but may have significant commercial applications as well," said Sheri Mennillo, technology transfer manager at NSRDEC. "The simplified online process featuring standardized terms reduces the uncertainty of the negotiation process, which may be particularly attractive to small business and entrepreneurs."

The TechLink website provides a summary of each available technology. For technologies eligible for express licensing, it also gives standardized, prenegotiated financial terms for the types of licenses being offered. The types include exclusive, partially exclusive (limited to a particular field) and nonexclusive. Items that have the "express license" designation are eligible for the faster automated process.

"Express licensing provides transparency to industry, lowers barriers for everyone involved and reduces transaction costs," said Dan Swanson, TechLink's licensing lead. Above all, express licensing accelerates the process of getting cutting-edge Army inventions into production, where they can support the U.S. defense mission, help save lives and boost the nation's economy.

The Army's technology transfer partners—mostly small and midsize companies—also build surge capacity into the defense supply chain. This is especially true with dual-use inventions like improved batteries and pest control devices. By licensing these inventions, the Army develops a reliable supply chain of companies that are manufacturing dual-use products on an ongoing basis for their commercial customers. This increases the likelihood of timely supply when the product is needed.

The economic impacts are impressive. A 2015 survey by TechLink and the University of Colorado showed that DOD technology license agreements between 2000 and 2014 led to more than $20 billion in sales of new products and services, including $3.4 billion in sales back to the military. The 602 companies in the survey generated a total of $48.8 billion in economic output from those licenses, along with the direct support of 182,985 full-time jobs with an average annual salary of more than $71,000.

IMPLEMENTING INNOVATION

U.S. Army Spc. Victor Ramirez, 3678th Combat Sustainment Support Battalion, 191st Regional Support Group, replaces a reverse osmosis water purification unit filter in November 2017 in Quebradillas, Puerto Rico. The Army's scientific research leads to cutting-edge inventions in virtually all technology fields. Licensing those inventions pays numerous dividends for the Army as well as private industry. (U.S. Army photo by Sgt. Avery Cunningham)

IMPORTANCE OF PATENTING

Years of working with Army laboratories has convinced TechLink Executive Director Will Swearingen that without intellectual property protection, private firms rarely make the investment needed to bring new technology to the market.

"Without patent protection, other companies can simply copy the product, making it difficult for the company that developed the product to recoup its investment and make a profit," Swearingen said. "That's why we encourage labs to patent their inventions. It's essential to technology transfer and convincing a company to invest its resources in converting a lab invention into a commercial product the DOD can procure."

Patents also recognize the effort that scientists and engineers have made, conferring prestige that encourages continued excellence in the field. Last but hardly least, they provide a quantifiable measure of lab productivity. Some Army researchers are extremely productive. Herbert A. Leupold, a recently retired ARL physicist whose discoveries advanced radar, satellite communications and electronic warfare systems, received

116 patents assigned to the secretary of the Army dating back to the 1970s—the record for an Army employee, according to the Patent and Trademark Office database.

COST BENEFITS FOR DOD

"Typically, the DOD's investment in a new defense-related product, licensed from a DOD lab, is only around 15 percent of the total investment necessary," said Swanson. "By licensing to industry, DOD can offload the large expense of converting an early-state prototype into a final product. It's a very cost-effective way to acqure cutting-edge technology."

Many products derived from Army inventions have both military and civilian applications. In those cases, the Army frequently saves money on procurement because it benefits from manufacturing economies of scale. Where there is a sizable commercial market for a dual-use product, the Army will need to spend far less on acquiring that product than if it contracted with the defense industry to develop it. For example, rate-actuated tethers invented at ARL, which stretch and relax easily at normal stress but provide dramatically increased resistance force when pulled quickly, are being explored by small businesses for health care and sports applications. (See "Per Vivo Labs warms to tech transfer," Page 135.)

"Contracting with a prime supplier for a custom design and production of a defense product is usually far more expensive," Swanson said. "By patenting its inventions, the Army also protects itself from defense contractors and others laying claim to a technology," he added. "Without patent protection, the Army and other branches can end up paying twice for a product—once for the original R&D, and a second time by paying the contractor a premium price to use the patents that should belong to the DOD."

Finally, when licensing its inventions to industry for commercial use, the Army earns revenue and is no longer responsible for patent maintenance costs.

CONCLUSION

Partnerships between the private sector and the Army's science and technology community benefit the warfighter and the American taxpayer, and help grow the national economy. "Businesses provide upfront payments and ongoing royalties on the inventions they license. That enhances the return on the R&D investment while keeping the fighting force at a technological advantage," said Swanson. "And by bringing industry partners into the fold, TechLink helps the Army's science and technology community continue to innovate in ways that benefit the acquisition workforce."

*For more information, go to **http://techlinkcenter.org** or contact Will Swearingen at **wds@montana.edu**.*

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MR. TROY CARTER is the senior writer and editor at TechLink. He provides original reporting on technology transfer, visual media and marketing activity in support of the DOD laboratory system. He holds an M.A. in political science from American University of Beirut and a B.A. in political science from the American University in Cairo. He is a former infantry sergeant and combat veteran from the Army's 10th Mountain Division, serving in Afghanistan in 2003-04 and in Iraq in 2005-06.

COOL CUSTOMERS

This insulated container for cold beverages, a high-tech ice chest that keeps water bottles cool far longer than existing ice chests, is one of 112 technologies developed by NSRDEC that are available for licensing. (U.S. Army photo by David Kamm, NSRDEC)

PER VIVO LABS WARMS TO TECH TRANSFER

In 2005, Russ Hubbard went through boot camp like everyone in the Army, and he saw fresh-faced recruits overheat even while they chugged canteens of water and bawled: "Beat the heat, drill sergeant, beat the heat."

After several overseas deployments, Hubbard left the Army in 2012, transitioned back to civilian life in Kingsport, Tennessee, and founded Per Vivo Labs Inc. to address some of the problems plaguing Soldiers.

The startup's first product was called Polar Skin Ice Sheets, a highly portable lifesaving solution for on-site treatment of heat injuries. The company's first customer was the U.S. Army Cadet Command.

After the success of the ice sheets, Hubbard began exploring new mission-focused technologies for the U.S. military. And for that, he began looking within the DOD lab system, assisted by TechLink. "We're expanding," Hubbard said recently, "and TechLink has been helping us access the technology to do so."

Two technologies identified by TechLink caught his attention. The first was rate-actuated tethers, which contain a shear-thickening fluid first explored by the Army for body armor applications. Shear-thickening materials stiffen when exposed to high strain. The original ballistic application involved aramid fibers in a shear-thickening fluid pouch. It was envisioned that at low rates (walking or running), the armor would be flexible. When impacted by a bullet, the armor would stiffen at the point of impact and provide increased ballistic protection. The tethers exhibit the same behavior: Pull slowly and the tethers stretch. Pull quickly and the tethers resist. Hubbard envisioned physical therapy applications, such as braces and resistance bands.

The second technology was a Navy-developed training device for bomb-sniffing dogs. The mixed odor delivery device (MODD) enables safer, more effective K-9 training on homemade explosives without actually blending oxidizers and fuels.

Developing those products meant licensing patented DOD technology. While the rate-actuated tethers are still being developed, Hubbard began selling the MODD in October 2017, under the trademark Odor Trace, to military and law enforcement customers.

Per Vivo Labs is just one example of how the well-orchestrated transfer of DOD technology can reap benefits for industry and the economy. The same DOD technology can benefit multiple businesses simultaneously. As an example, Per Vivo Labs is now partnering with other small businesses to develop the rate-actuated tethers for applications including chin straps and ankle braces.

—MR. TROY CARTER

ALLIES IN SCIENCE

Dr. Mark Griep, third from left, a materials engineer working in the nano- and bio-nanomaterials field at ARL, recently returned from a one-year tour working at the Agency for Defense Development in Daejeon, Republic of Korea. The assignment was part of DOD's Engineer and Scientist Exchange Program, one of Army S&T's multiple avenues of international collaboration. (Photo courtesy of Dr. Mark Griep)

CRITICAL COLLABORATIONS

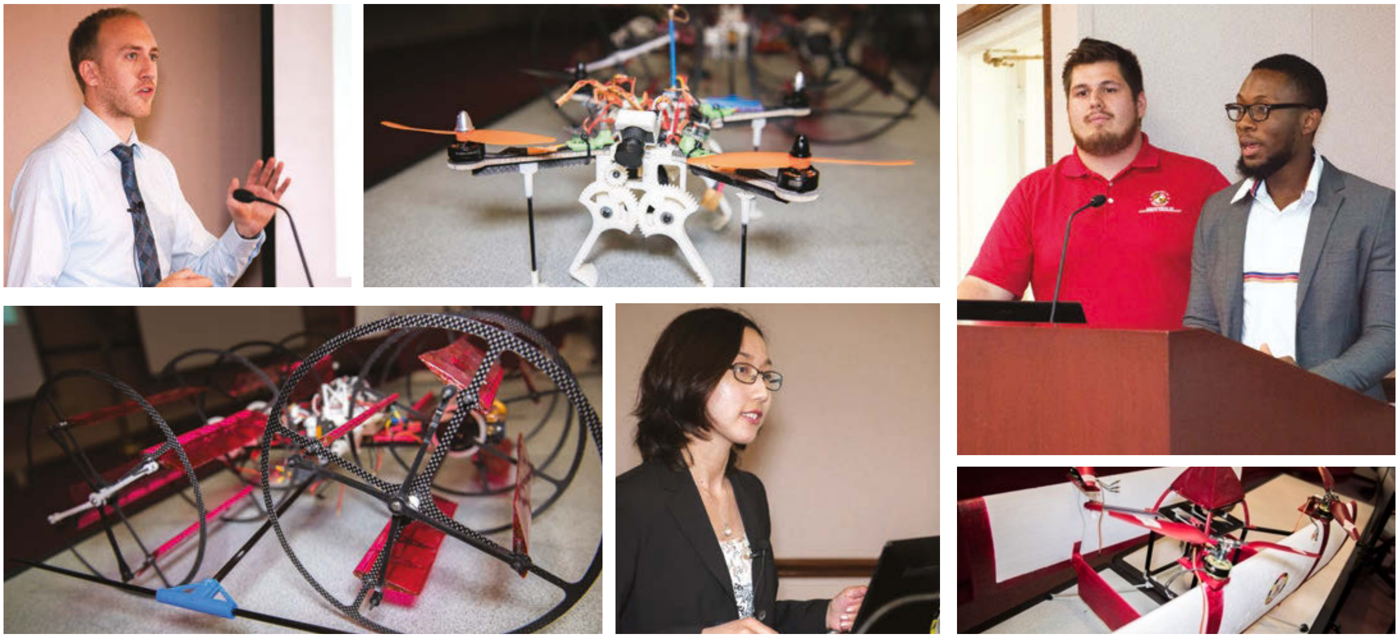
Bringing industry, academia, other government agencies, and international and nontraditional partners into the Army S&T enterprise.

by Dr. Matt Willis

The Army science and technology (S&T) program is critical to ensuring that the U.S. Army—America's principal land force—can continue to operate and dominate in complex environments characterized by adaptive adversaries employing conventional, unconventional and hybrid methods that are designed to challenge U.S. national security and vital interests. The future operational environment—2025 and beyond—for the Army and joint force will demand land power dominance through increased flexibility, adaptability and speed of response; mechanisms to mitigate or wholly eliminate tactical surprise; improved joint interoperability and compatibility; an ability to effectively accommodate evolving alliances and partnerships; and seamless Soldier proficiencies across myriad functional domains.

Such dominance will be critical to prompt, sustained and synchronized operations, as will a force that can adapt to mission demands and readily execute both combat and noncombat missions in air, ground, maritime, space and cyberspace. Excellence and overmatch in an extremely diverse spectrum of technical competencies are predicated on modernization—building greater capacity and capabilities in the longer term to prevail in future conflicts.

This section will explore Army S&T's growing engagement with international partners in cooperative S&T efforts, as well as the U.S. Army Research Laboratory (ARL) Open Campus, devised to cultivate a 21st-century research ecosystem that brings together government laboratories, academic institutions



AN OPEN DOOR TO ACADEMIA

Students from the University of Maryland and Penn State University deliver presentations and display their micro air vehicles for Army researchers during a visit in July 2017 to Aberdeen Proving Ground. The students designed and built small aerial vehicles that could fly autonomously around obstacles and identify targets for a May 2017 competition that caught the attention of ARL researchers. (Photo by David McNally, ARL)

and the private sector to address tough Army challenges. The potential partners within the federal sphere alone are numerous, including the other services, National Institutes of Health, U.S. Department of Energy, federally funded research, development and engineering centers and university-affiliated research centers.

The two follow-on articles explore in depth two approaches the Army S&T enterprise is taking to broaden collaboration in the United States and overseas: strategic international S&T engagement and ARL's open-door approach to innovation.

A MODERN S&T ECOSYSTEM

State-of-the-art technical facilities are essential to positioning the Army's S&T enterprise for discovery and maturation of technologies that are expected to be critical to Army and joint force operations well into the future. Because of myriad contributing factors, many technical facilities used by the S&T enterprise have become obsolete and require revitalization and recapitalization. Renovations and upgrades to existing facilities or construction of new ones will vastly improve safety, innovation and the Army's posture for exploring emerging scientific fields that would be difficult, if not impossible, to pursue using current facilities.

An enterprise-wide approach to modernizing this technical infrastructure will provide an integrated system of facilities accessible to technical personnel from across Army S&T, allowing the Army to execute its S&T strategy:

- Pursuing foundational technology developments for the future.
- Maturing technologies into innovative, affordable and sustainable solutions over the full system life cycle.
- Executing fundamental S&T initiatives that will ensure breakthroughs for affordable, decisive warfighter advantages.

The U.S. Army, however, cannot expect to be subject matter experts in all iterations of future S&T. Rather, it must promote critical cross-disciplinary research via mechanisms such as Open Campus; public-private partnerships and infrastructure investments; engaging nontraditional partners such as the entrepreneurial high-tech community and small businesses; and developing targeted and strategic international partnerships.

> *Many of these strategically targeted initiatives to connect diverse S&T partners have started to bear fruit.*

OPEN CAMPUS

ARL launched the Open Campus initiative in 2014 with the goal of integrating government laboratories, academic institutions and the private sector, including nontraditional partners, into a global collaborative network to address multiscale and multidomain Army S&T challenges. Open Campus lays the foundation for a global S&T ecosystem to pursue groundbreaking advances in basic and applied research areas of importance to long-term national security.

The model is based on three primary tenets:

- Modern government workforce and management.
- Sharing of facilities among government, academia and the private sector.
- Collaborative culture that fosters an entrepreneurial and innovative environment.

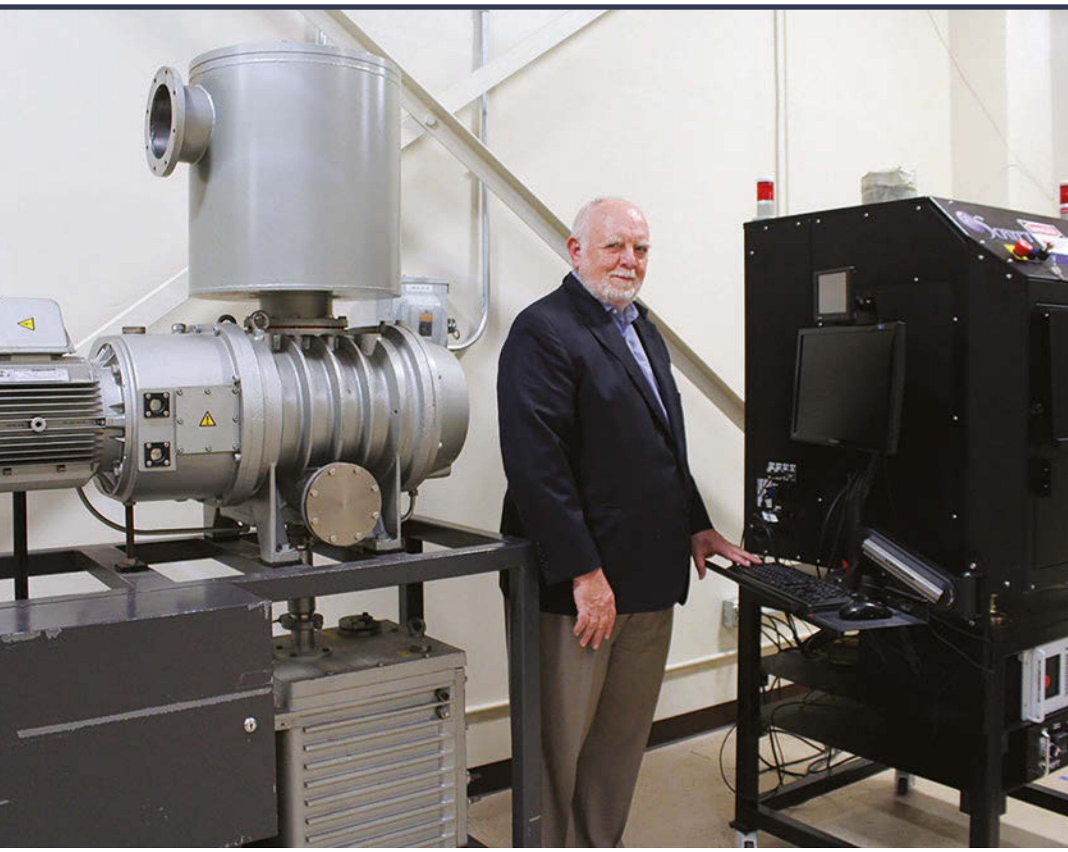
Since its inception, ARL has developed a diversified hub-and-spoke infrastructure to partner across the national and international S&T ecosystem. Active Open Campus sites are co-located with ARL labs in Adelphi and Aberdeen Proving Ground, Maryland. ARL has also established hubs in California, Texas and Illinois, is exploring a future hub in Massachusetts, and has expanded internationally, with a presence in Tokyo, London and Sao Paulo. Through the Open Campus framework, ARL scientists and engineers work side by side with visiting scientists in ARL facilities and as visiting researchers at collaborator institutions.

P4 COLLABORATIONS

Public-public and public-private (P4) collaborations represent an innovative strategy for infrastructure modernization and access, including voluntary relationships between federal and nonfederal entities (NFEs) through which the parties leverage each other's expertise, resources and incentives to address technical opportunities with greater speed, effectiveness, efficiency and residual benefit than they could achieve individually. P4 arrangements require no monetary transaction between parties. Collaborators may establish mutually useful, state-of-the-art technical infrastructure to pursue common goals. They have the flexibility to build

A NEW INFLATION MECHANISM

Army researcher Anthony J. Roberts, working in the lab in July 2017, inflates a balloon with hydrogen produced from a chemical reaction between water and an aluminum nanomaterial powder discovered at ARL at Aberdeen Proving Ground. ARL, through its Open Campus, has a leading role in fostering a 21st-century research ecosystem where government laboratories, academic institutions and the private sector can collaborate freely. (Photo by David McNally, ARL)



NETWORK OF EXPERTISE

Dr. Robert Hebner, director of the Center for Electromechanics at the University of Texas at Austin, stands in the collaborative ARL – University of Texas additive manufacturing laboratory. ARL South, part of the ARL Open Campus initiative, is an effort to co-locate Army research and development personnel in the southern and central U.S. to gain access to subject matter experts, technical centers and universities not well-represented on the East Coast. (Photo by Joyce Conant, ARL)

and configure facilities to support multiple public and private sector entities simultaneously.

Potential partners include a broad array of NFEs, including businesses, nongovernment organizations, foundations, academic and research institutes, state and local governments, community-based or other nonpublic organizations, and international entities. P4 collaborations instill and establish a flexible, cross-functional Army intellectual infrastructure with surge capacity for critical Army modernization priorities.

NONTRADITIONAL PARTNERSHIPS

The Army also embraces partnerships with organizations it has not traditionally worked with, such as startups, the venture capital-funded technology sector, the federally sponsored Manufacturing USA network of innovation institutes, and small businesses. The Small Business Innovation Research and Small Business Technology Transfer Research programs, as governed by 15 U.S. Code 638, provide a unique mechanism for aligning small businesses with critical Army modernization priorities and capability gaps.

In addition, the Army leverages mechanisms such as cooperative research and development agreements, other transaction authorities (e.g., the Consortium for Command, Control and Communications in Cyberspace), Defense Innovation Unit Experimental in the Office of the Secretary of Defense, and the Federal Laboratory Consortium for Technology Transfer to interface with nontraditional innovators.

INTERNATIONAL S&T COLLABORATION

U.S. Army hegemony on the future battlefield is intrinsically linked with the interoperability and compatibility of joint systems and the ability to accommodate evolving alliances and partnerships. The Army S&T enterprise focuses on research areas synergistic to allies' S&T portfolios, thereby leveraging allies' expertise versus investing in duplicative areas.

The Army also uses the Engineer and Scientist Exchange Program to promote

An enterprise-wide approach to modernizing this technical infrastructure will provide an integrated system of facilities accessible to technical personnel from across Army S&T.

international cooperation, in this case through the exchange of defense scientists and engineers among allied and friendly nations, including the United Kingdom, France, Israel, Chile, Germany, South Korea, the Netherlands and Australia. The program leverages defense S&T of U.S. allies and partners, while providing opportunities to identify and develop potential international cooperative research and development partnerships for the future.

CONCLUSION

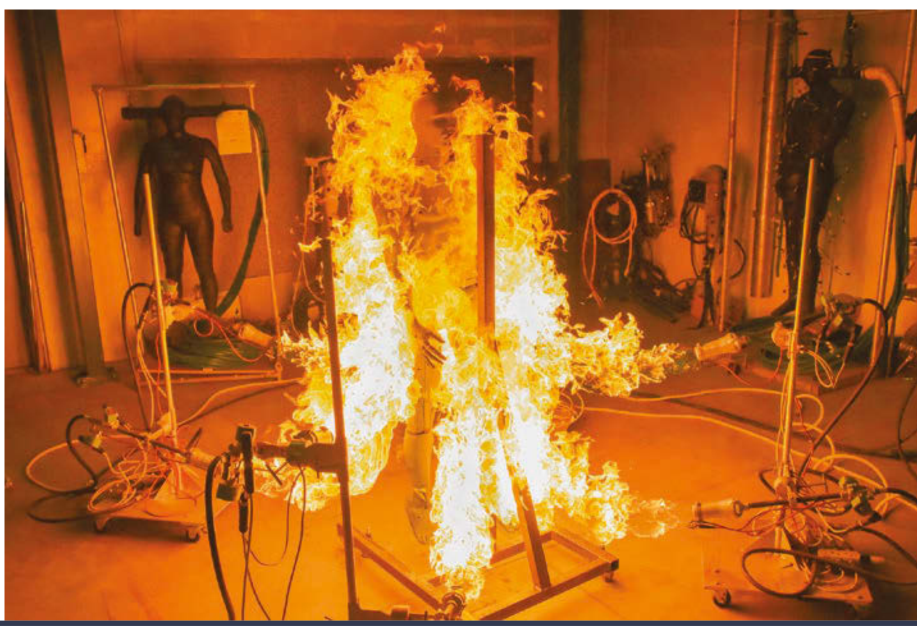
Many of these strategically targeted initiatives to connect diverse S&T partners have started to bear fruit. For instance, over 700 Open Campus participants have conducted research in ARL laboratories, including 80 international collaborators from 22 countries. Layered security mechanisms, commercial network access and the implementation of new security policies and procedures shield sensitive programs. These measures thus enable U.S. and international partners to pursue fundamental research collaborations on-site with ARL scientists and engineers.

Since establishing Open Campus, ARL has experienced, on average, a 40 percent year-over-year increase in the volume of collaborative research partnerships. Examples include multiple ARL collaborations in areas such as bioscience and additive manufacturing with the University of Texas system, and a NATO-aligned joint project involving ARL and Bulgarian and Ukrainian institutes to combat disinformation attacks in cyberspace.

Furthermore, within the last five years, the Army has entered into 180 different cooperative agreements with partnering countries. In 2017, the Army invested approximately $70 million in international collaborations through its international S&T portfolio. Army S&T is developing an integrated, country-specific road map to prioritize research efforts, efficiently allocate resources and ensure that cooperative agreements are integrated into overarching department-level engagement plans. Restructuring the Army's domestic and international S&T engagement strategy will allow for the development of leap-ahead technologies that will keep the U.S. Army ready for future conflicts.

For more information, contact the author at ***matthew.p.willis.civ@mail.mil****.*

DR. MATT WILLIS is the director for laboratory management in the Office of the Deputy Assistant Secretary of the Army for Research and Technology. As such, he shapes policies that impact the workforce, infrastructure, technology transfer and educational outreach in science, technology, engineering and mathematics at the Army Science and Technology Reinvention Laboratories. He holds a Ph.D. and an M.S. in chemical engineering from the University of Illinois at Urbana-Champaign and a B.S. in chemical engineering from Cornell University. He is Level II certified in S&T management and is a member of the Army Acquisition Corps.



HOT ITEM

A new, fully articulating thermal mannequin, developed under a U.S. Navy Small Business Innovation Research contract by the Navy Clothing and Textile Research Facility, undergoes a burn test inside the Ouellette Thermal Test Facility. Outellette, a joint Army-Navy facility, is managed by the U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) in Natick, Massachusetts. (Photo by Jeff Sisto, NSRDEC Public Affairs)

BORDER CROSSINGS

Modernization priorities spur the Army to take a more strategic approach to international engagement with S&T partners.

by Dr. Arthur J. Goff III

The future operational environment demands that the Army act now to increase flexibility and adaptability, improve interoperability and compatibility and effectively accommodate evolving alliances and partnerships. To meet these demands and maximize effectiveness for the warfighter, the Army is focusing its science and technology (S&T) investments on six modernization priorities: precision fires; Next Generation Combat Vehicle; Future Vertical Lift; network and command, control, communications and intelligence; air and missile defense; and Soldier lethality. Underpinning these modernization priorities are a series of cross-cutting topic areas and capability gaps: multidomain battle, manned-unmanned teaming, faster decision-making and asymmetric vision.

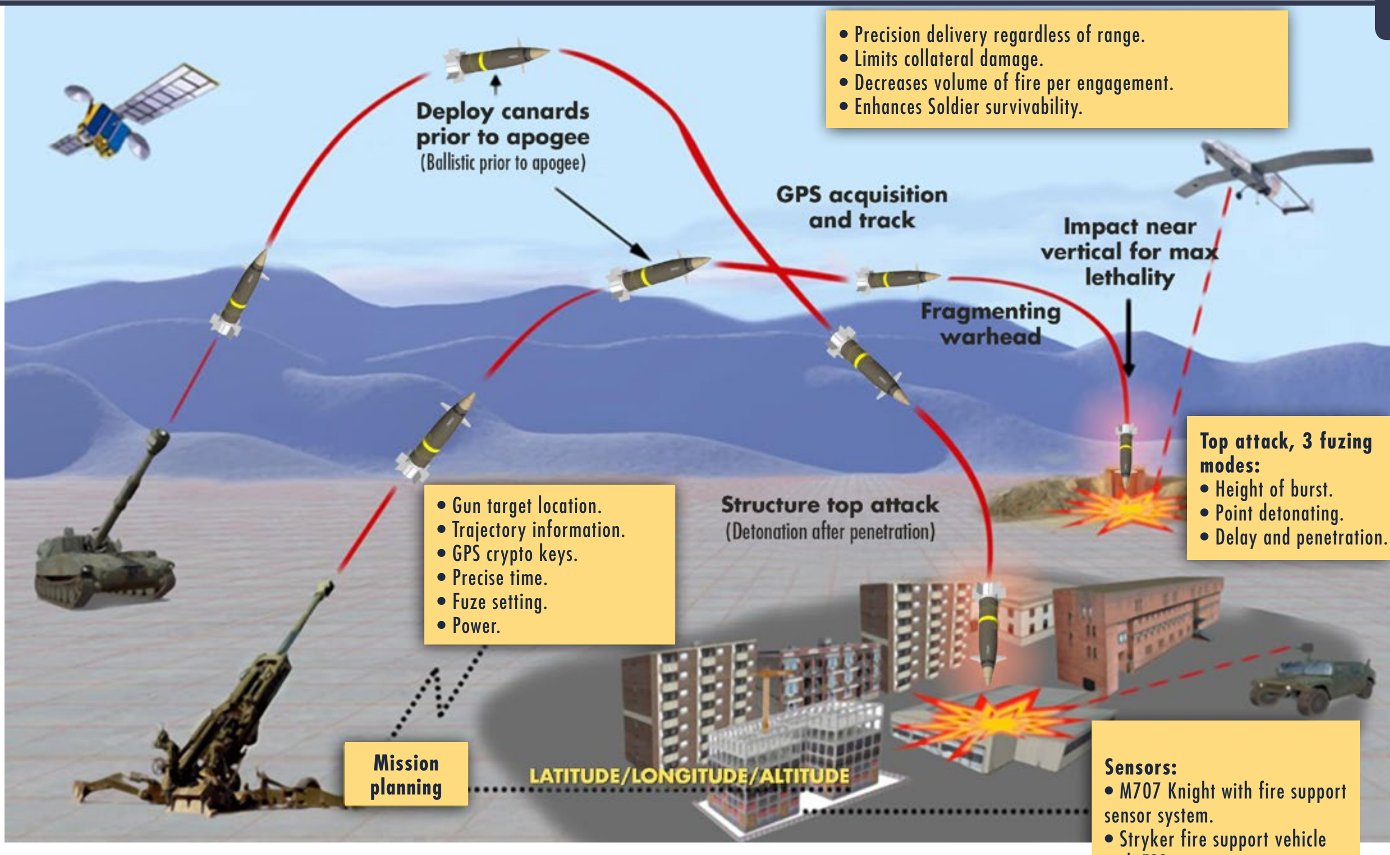
While we have great capability in U.S. Army laboratories to develop leading-edge technologies in support of these priorities and have some of the world's experts in many Army-unique areas, we also are looking to leverage S&T investments for leap-ahead capabilities wherever we can, especially with our international partners.

Engaging international partners is a vital part of the Army S&T program and is essential to keep the Army at the leading edge of technology development. International engagement allows us to expand the available pool of leading scientists and engineers to help us maintain technical superiority and avoid technological surprise. In addition to developing technologies to achieve overmatch, interoperability is key to accomplishing missions across the range of military operations. Consequently, it is a significant factor when choosing to develop particular technologies with partnering nations. The technical edge in a particular area is important, but it is not the sole driver of cooperative engagement.

MONEY BETTER SPENT

Over the last five years, the Army has entered into 150 different cooperative agreements with more than 20 partnering countries. In 2017, the Army invested approximately $70 million of its international S&T portfolio in international collaborations, typically at the principal investigator level. However, this approach does not meet Army requirements in the most effective and cost-efficient manner. The Army needs an integrated, country-specific S&T road map to prioritize research efforts, efficiently allocate resources and ensure that cooperative agreements are in sync with overarching strategic S&T engagement plans.

A vivid example of the importance of international cooperation is the development of Excalibur, a 155 mm, GPS-guided, extended-range artillery projectile, by the U.S. Army and the



EXCALIBUR AT WORK

The Excalibur, a GPS-guided, extended-range artillery projectile used by the U.S. Army in Operation Iraqi Freedom as a precision munition, was developed by the Army in partnership with the Swedish army. Developing relationships with international partners expands the pool of potential contributors developing solutions to future warfighting challenges, and is essential to keeping the Army at the leading edge of technology development. (SOURCE: DASA(R&T))

Swedish army, leveraging Sweden's advanced artillery projectile technologies. The U.S. Army used Excalibur as its next-generation cannon artillery precision munition in Operation Iraqi Freedom; it provided greatly improved fire support to the maneuver force commander, increased lethality and reduced collateral damage. Additionally, the munition represented a leap ahead in the ability to attack a target with precision from greater distances. Sweden contributed the projectile design work, interior and exterior ballistics, and gun-hardening technology.

Beginning in FY18, the Army will evaluate all established, developing and potential international agreements for their contribution to enabling the six modernization priorities. The Army is increasingly using data analytics to assess the technological edge that a cooperating nation may have, as well as its resource investment in a particular technology area. A review of data from the last five years will guide HQDA in deciding which nations we should partner with to develop technologies of strategic importance. In addition to technical capabilities, we will consider partnerships that offer strategic benefit geographically or logistically.

In one example of how the data analytics will be used, querying open literature sources provides information on how many publications a particular country has produced in a particular technical area. (See Figure 1, page 144.) The technical areas chosen for this search reflect cross-cutting topic areas related to the six modernization priorities. In this example, we searched the past five years and analyzed the output of 10 collaborating nations.

Based on this small data set, shown in Figure 1, Country E has produced the most publications (127) in the field of swarming unmanned vehicles. This demonstrates, at a minimum, that Country E has invested significant resources in this area and may have demonstrated leap-ahead technological capability. If this technical area were one that the U.S. Army had not invested in, it would make sense to partner with Country E. In contrast, if the Army needed to develop a capability in command, control, communications, computers, intelligence, surveillance and reconnaissance, then it

FIGURE 1

TOPIC AREA	A	B	C	D	E	F	G	H	I	J	TOPIC AREA TOTALS
Modeling and Simulation (Training)	102	116	200	117	193	54	181	103	28	29	1,123
Machine Learning	119	120	158	108	217	12	130	87	47	19	1,017
Position, Navigation and Timing	123	166	194	106	139	23	102	67	37	55	1,012
Human Performance Augmentation	100	81	164	101	204	10	136	69	30	25	920
Multispectral Sensing	70	76	219	156	136	31	106	85	11	25	915
Heads-Up Display	53	91	167	140	136	34	128	91	14	14	868
Swarming Unmanned Vehicles	53	54	90	63	127	7	78	91	12	10	585
Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance	70	113	89	11	109	11	75	26	21	40	565
Automatic Fires Control	32	47	101	57	99	12	68	49	10	33	508
Scalable Protection	18	22	77	68	48	3	33	44	6	11	330
COUNTRY TOTALS	740	866	1,459	927	1,406	197	1,037	712	216	261	

ANALYZING PARTNERS' INTERESTS

To determine the expertise of 10 collaborating nations in technical areas related to the Army's six modernization priorities, several open literature sources were studied to determine how many publications a particular country has produced in a particular technical area over the past five years. For operational security, the countries were coded A through J. (SOURCE: Virginia Tech Applied Research Corp.)

likely would not be beneficial to partner with Country F, which had only 11 publications in this topic area.

CONCLUSION

Today, the threat of near-peer and peer conflict is evident in the Pacific and Eastern Europe. The conflicts in which the U.S. Army has engaged over the last 15 years in the Middle East and Afghanistan have forced us to focus on incremental advances to maintain already fielded solutions. While we continue to maintain these fielded solutions for today's Soldier, we must refocus our attention and resources on maintaining and in some areas achieving the technological edge.

Our Army must modernize continually to increase our lethality against emerging regional and global near-peer adversaries and outpace their development to ensure our overmatch. Restructuring the Army's international S&T portfolio will allow for the development of leap-ahead technologies that will enable the U.S. Army to succeed in the operational environment of the future.

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Open-Door POLICY

ARL implements a new business model to pursue collaboration with academia and industry in a 21st century research culture.

by Ms. Wendy Leonard

The U.S. Army of 2040 and beyond will operate in rapidly changing domains with unparalleled complexity. Army leadership has long recognized the need to invest in science and technology (S&T) to empower the discovery and innovation needed to maintain technological overmatch and win future battles in an increasingly complex environment. In response, the U.S. Army Research Laboratory (ARL) has implemented a new business model, Open Campus, to pursue leading-edge basic and applied research in a truly collaborative fashion by enabling the continuous flow of people and ideas among government, academia and the private sector. This model creates a 21st-century research culture that could serve as a model to transform the entire U.S. defense laboratory enterprise into an agile, efficient and effective laboratory system capable of nimbly transitioning to address the complex problems of the future.

ACCELERATING INNOVATION AND DISCOVERY

ARL's Open Campus was launched in 2014 with the goal of bringing together government laboratories, academic institutions and the private sector to form a global collaborative network to address tough Army challenges. Open Campus lays the foundation for a global S&T ecosystem enabling long-term national security. Its model is based on three tenets:

1. Modern government workforce and management.
2. Shared facilities among government, academia and the private sector.
3. A collaborative culture that fosters an entrepreneurial and innovative environment.

To create the Open Campus ecosystem, ARL implemented policy and business practice changes to enhance the professional and technical development of its workforce, develop critical research facilities, and create interactions and engagements with public and private-sector entities with common technical interests. These changes require strategic investment in and leveraging of human capital, facilities and technical infrastructure across government, industry and academia, while increasing public involvement and understanding of defense science, technology and exploration.

Since 2014, ARL has developed a diversified, national hub-and-spoke infrastructure to more effectively partner across the national and international S&T ecosystem, tapping into technology centers across the country to gain access to regional talent that previously was underrepresented in Army labs and centers. ARL now has open campuses co-located with its laboratories in Adelphi and Aberdeen Proving Ground (APG), Maryland. Adding to the collaborative strength from the long-standing co-location with the University of Central Florida, ARL has established hubs in California (ARL West), Texas (ARL South) and Illinois (ARL Central), and is in the process of opening a hub in Massachusetts (ARL Northeast). ARL has also expanded internationally, with an Army Research Office presence in Tokyo, London and Sao Paulo.

The Open Campus initiative is also using enhanced use lease authority, a tool for using underused government property, to offer opportunities for public-private partnerships with a vision toward building research park environments on U.S. Army installations where ARL resides. ARL will anchor the Army Innovation Hub at APG, which serves as the epicenter for foundational research, engineering, test and evaluation, acquisition and sustainment in command, control, communications, computers, intelligence, surveillance and reconnaissance; chemical and biological defense; human performance; maneuver; materials; and protection sciences.

These environments will enable a broader range of collaboration, development of

A dramatic increase in newly signed patent license agreements realized since the start of Open Campus is projected to continue.

MORE THAN CAPABILITIES

Aurora Flight Sciences, an engineering firm in Manassas, Virginia, hosted ARL aerospace engineers in August 2017 to look at technologies to achieve high-speed, high-endurance and high-payload capabilities for vertical lift platforms. ARL's Open Campus model enables researchers to develop relationships with industry and academia, with the goal of creating a defense research environment that's more responsive to future national security challenges. (U.S. Army photo by David McNally, ARL)

SWITCHING PERSPECTIVES

Research partners prepare an autonomous unmanned aerial vehicle for flight during demonstrations at the capstone event for the Micro Autonomous Systems and Technology (MAST) program at APG in August 2017. ARL staff is encouraged to serve as researchers, professors or technologists at companies conducting joint research in ARL laboratories and the laboratories of their ecosystem partners. (U.S. Army photo by Jhi Scott, ARL)

co-located academic consortia to provide graduate education opportunities to ARL staff and residents of the local community, and strengthening of the international S&T network.

COLLABORATION TOOLS

ARL is working hard to create the policy framework necessary to support these new avenues of global collaboration to quicken the pace of future discovery and innovation. The primary mechanisms used to establish Open Campus collaborative partnerships are cooperative research and development agreements (CRADAs) and educational partnership agreements (EPAs).

CRADAs, governed by 10 U.S. Code §3710a and used in Army research for more than 25 years, remain critical to the success of Open Campus. CRADAs are formal agreements between one or more federal laboratories and one or more nonfederal parties (e.g., small business, industry or academic institutions) under which the government and the non-federal party jointly provide personnel, facilities, equipment or other resources to conduct specific research or development efforts that are consistent with the mission of the laboratory. The CRADA defines intellectual property protection for all parties and is appropriate when ideas, staff, materials and equipment are to be shared over a period of time for the purpose of collaboration or if an invention may result. Joint work statements, developed by the collaborating principal investigators, outline each collaborator's contributions and the research to be performed.

CRADA use has expanded dramatically with academic, corporate and small business institutions, and has been useful to protect the intellectual property of all partners while streamlining collaboration. ARL has 126 CRADA collaborators (56 from academia and 70 from industry or small business) and is currently in negotiations with an additional 106 potential collaborators.

Eight international CRADAs have also been established, and an additional five are in negotiation. Examples include multiple ARL collaborations in areas from bioscience to additive manufacturing, under an agreement with the University of Texas; new and expanded long-term relationships with historically black colleges and universities and minority institutions and their research staffs; 3D Systems, a company that has a reputation as an international leader in three-dimensional manufacturing; a NATO-aligned joint project with ARL and Bulgarian and Ukrainian institutes on the theoretical foundations of real-time analysis of cyber intrusion events; and a collaboration with General Motors Co. on the spray and combustion behavior of a novel, variable-area, high-pressure diesel injector at real engine conditions.

INNOVATION IMPLEMENTATION
The concept for the Army Innovation Hub is to accelerate Army innovation by using collaborative partnerships of government, industry and academia within a global network based at APG. (Image courtesy of ARL)

Since establishing Open Campus, ARL has realized an average annual growth rate of 40 percent in the volume of CRADA actions, and ARL's S&T funding has been matched by $51 million in-kind for projects that address Army-specific problems. (See Figure 1, Page 150.)

EPAs are established between ARL and academic institutions to encourage and enhance joint education and research opportunities with academia in science, technology, engineering and mathematics (STEM) disciplines relevant to ARL S&T programs. Under EPAs, visiting students and professors, including those with international citizenship, can access ARL's research facilities and collaborate with experts in their fields of interest.

Benefits to educational institutions include access to ARL's specialized research facilities, receipt of ARL's excess laboratory equipment, research experiences on Army projects, and the opportunity to enhance students' interest in STEM disciplines through collaboration and internships. EPAs also provide a mechanism for ARL researchers to serve as adjunct faculty, collaborating with educational institutions and helping to develop and implement cooperative education programs for undergraduate and graduate education.

RESEARCH CENTERS

As another means to advance collaborative fundamental research, ARL has initiated 14 research centers in strategic, enduring S&T areas of critical importance to the Army, including additive manufacturing, artificial intelligence and atmospheric sciences. The centers are being established across the country as a consortium of Open Campus partner organizations leveraging expertise, facilities and capabilities on an international scale to address challenging research problems. For example, the ARL Center for Research in Extreme Batteries, established with the University of Maryland and the National Institute of Standards and Technology, focuses on the fundamental science for batteries with extreme properties, operating in extreme environments for defense, space and biomedical applications. At a recent meeting, more than 100 additional participants expressed interest in joining this center.

PERSONNEL EXCHANGES

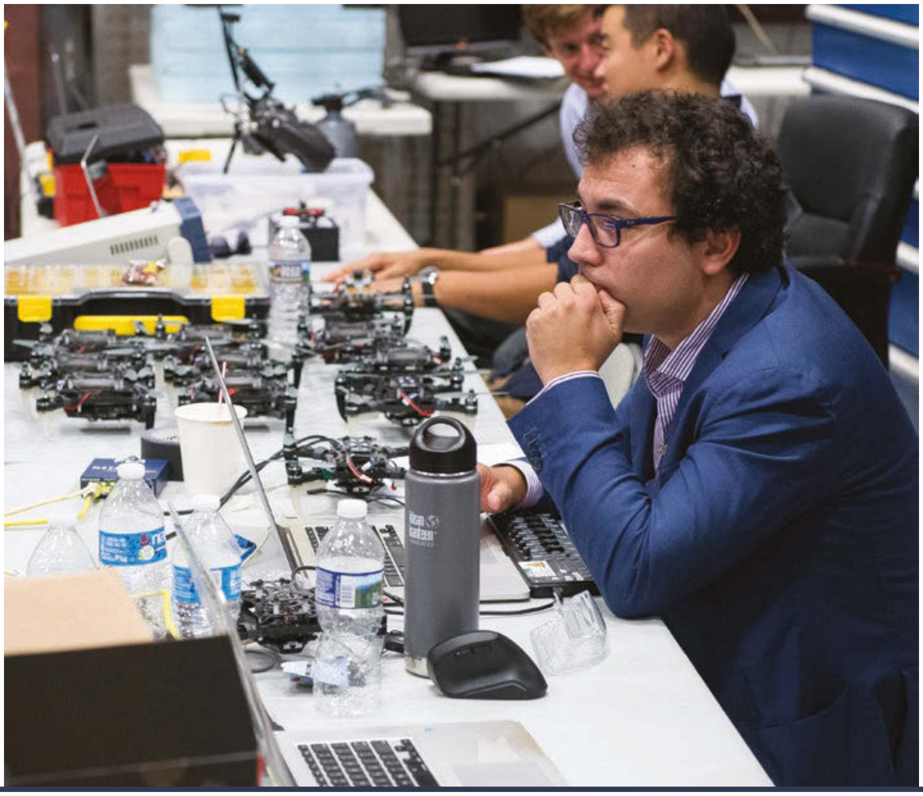
Through the Open Campus framework, ARL scientists and engineers work side by side with visiting scientists in ARL's facilities and as visiting researchers at collaborators' institutions. ARL is committed to a goal of having 10 to 15 percent of its approximately 1,300 Army civilian research staff on rotational assignments outside of the laboratory at partner locations, with at least that number of collaborators actively participating at ARL locations.

More than 700 participants established collaborative partnerships in ARL laboratories through the third quarter of FY17. These include 80 international collaborators from 22 countries, including China, India, Germany and Iran. Layered security mechanisms, commercial network access and the development and implementation of new security policies and procedures shield sensitive programs and enable U.S. and international partners to pursue fundamental research collaborations on-site with ARL scientists and engineers. In addition to collaborative engagement in existing ARL facilities, future phases of ARL's Open Campus will include opportunities for partners to establish new on-site facilities on our campuses.

Currently, ARL seeks to attract academic, government, small business and industry partners for collaborative engagement. More information on ARL's strategic research interests and collaborative research opportunities can be found at www.arl.army.mil/opencampus.

In addition, ARL staff are encouraged to pursue entrepreneurial opportunities in high-risk, high-payoff areas of potential strategic value to the Army through implementation of innovative workplace policies. ARL established the Entrepreneurial Separation Program as a means to assist ARL researchers in establishing collaborative partnerships. If a current ARL civilian employee decides to pursue an entrepreneurial opportunity, the employee resigns from federal service but is eligible for "priority consideration" for up to five years from the date of separation for positions that are similar to the one they vacated. Since 2015, eight employees have separated from ARL to pursue entrepreneurial opportunities in areas such as cybersecurity, solid-state batteries, natural language processing, high-performance computing and manufacturing technologies.

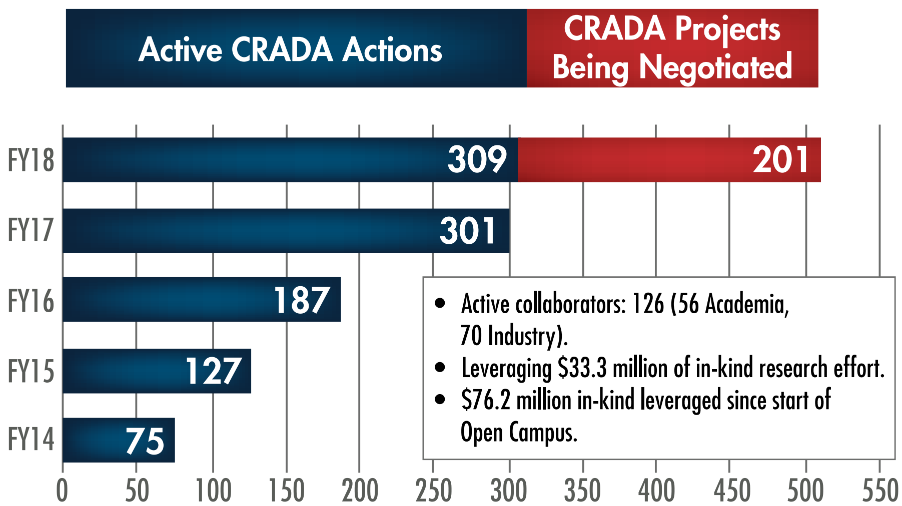
ARL researchers are encouraged to serve as visiting researchers, professors of practice at universities or as technologists at cutting-edge companies conducting joint research in ARL laboratories and the laboratories of their ecosystem partners. Open Campus relationships forged with academic partners expand opportunities for both faculty and ARL researchers, providing insight into the complex boundary



READY TO SET SAIL

Dr. Giuseppe Loianno, a research scientist at the University of Pennsylvania, readies a self-navigating drone for a demonstration at ARL's Aberdeen facilities in August 2017. The demonstration was part of the MAST program, which gave participants from industry and academia the chance to work with ARL to explore technologies that would enable autonomous micro-robots to work together. (U.S. Army photo by Jhi Scott, ARL)

FIGURE 1



BUSINESS IS BOOMING

CRADAs have grown rapidly in both number and diversity since ARL implemented the Open Campus approach. The number of CRADAs has increased each year by an average of 40 percent. The CRADAs also have generated millions of dollars' worth of in-kind research effort for projects that address Army-specific problems. Agreements have been developed for a range of efforts, including additive manufacturing, 3-D manufacturing and cyber intrusion. (Image courtesy of ARL)

conditions of defense-relevant problems. These partnerships can contribute to each academic institution's curriculum and breadth and provide unique insights into challenging defense problems that would be difficult to obtain otherwise. Collaborations between ARL and academia help shape the future national security workforce, provide exciting employment pathways for highly trained graduates of STEM academic programs, and help academic institutions build programs and attract new faculty by offering established links to the Army and DOD S&T network.

ARL and industry and small business staff exchanges with leading technology companies also help shape technology maturation timelines for transfer to the industrial marketplace and provide ARL and partner researchers with a view of the state of the art in many critical fields, and generate insight into emerging government and industry practices regarding technology development. These exchanges will encourage and provide incubation opportunities, empowering and leveraging the novel approaches of these entrepreneurs through access to infrastructure and through unique engagement and partnership opportunities between scientists and engineers.

Since 2014, ARL has developed a diversified, national hub-and-spoke infrastructure to more effectively partner across the national and international S&T ecosystem.

TECHNOLOGY TRANSFER

The Open Campus business model fosters the generation of joint intellectual property, incubation of spinoff companies for the pursuit of S&T innovations, and maturation and rapid transition of intellectual property and technologies to the industrial marketplace. A critical element of ARL's Open Campus strategy is technology transfer.

In FY17, the ARL Technology Outreach Portal was launched. It includes easily accessible information about almost 400 patents, a unique view of the facilities and equipment at ARL locations and e-learning modules for both ARL researchers and stakeholders external to ARL. A dramatic increase in newly signed patent license agreements realized since the start of Open Campus is projected to continue. These new mechanisms include licenses with academic, industry and small business partners, both domestic and international, in military as well as commercial applications.

For example, ARL's fundamental research in lithium-ion battery interfaces led to a 5-volt cathode with 30 percent increased energy that is safer and more stable than existing commercial solutions. A patent is pending, and the Canadian firm Hydro-Quebec has licensed the technology and is providing a 50 percent cost-share to further develop it. Another example is Per Vivo Labs Inc., which is licensing rate-activated tethers that incorporate new stretchable materials into resistance bands and other physical therapy aids. (See "Per Vivo Warms to Tech Transfer," Page 135.)

COMMERCIALIZATION AND INCUBATION

To help promote the commercialization of ARL intellectual property, ARL has developed partnership intermediary agreements (PIAs) with several partners. PIAs increase the likelihood of success in conducting cooperative or joint activities with STEM-oriented nonprofits, small businesses, educational agencies and colleges and universities, with partners serving as a liaison with outside, nonfederal entities.

In one such arrangement, the Energetics Technology Center (ETC) established incubator capabilities near ARL facilities in Adelphi, and recently conducted several lunch-and-learn and tech talks and two lean startup sessions. Sessions focused on ARL patents and were designed to help promote the commercialization of ARL intellectual property by providing a place for ARL researchers to collaborate with entrepreneurs and businesses interested in licensing ARL's patents. Three small business startups occupy space at the 7,000-square-foot incubator in Adelphi. ARL also established a PIA for using a small business technology incubator near its campus on APG.

CONCLUSION

ARL's Open Campus is creating collaborative possibilities to generate a more adaptive, efficient and effective defense research environment that is responsive to future national security challenges. ARL continues to pursue academic, government, small business and industry partners for collaborative engagement.

The formal and informal interactions among scientists, engineers and business and technology specialists with multiple technical disciplines and globally diverse perspectives will lead to new fundamental knowledge, enhance the frequency of scientific and engineering breakthroughs and innovation, effectively transition technologies into engineered systems, and help guide strategic science, technology and acquisition policy.

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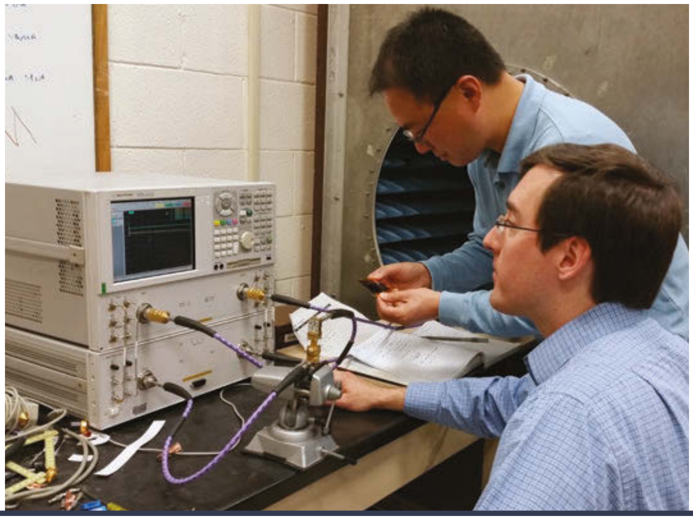
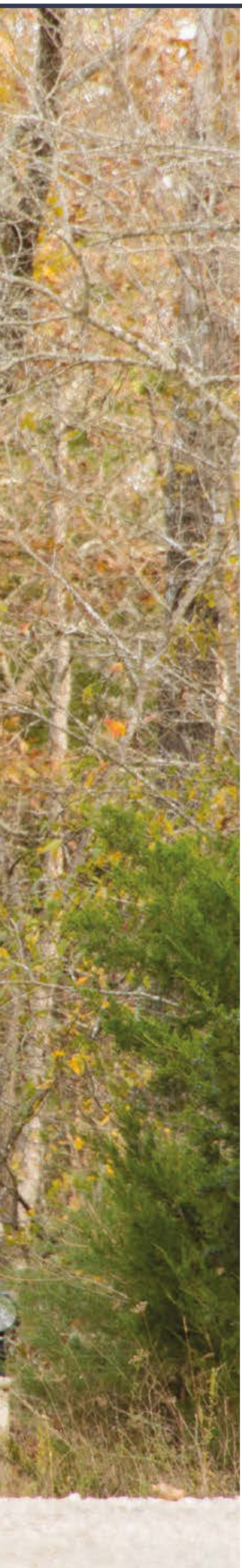


BRANCHING OUT
ARL researcher Dr. Steven D. Keller, foreground, works with Dr. Do-Hoon Kwon, associate professor at the University of Massachusetts Amherst, in Kwon's lab. Keller, part of the Antennas and RF Technology Integration Branch within ARL's Sensors and Electron Devices Directorate, recently completed a three-year detail at UMass Amherst on antenna research and fabrication that included the co-mentoring of doctoral students. Such relationships are encouraged by ARL and facilitated by the Open Campus framework. (Photo courtesy of University of Massachusetts Amherst)

EARLY PROTOTYPING, REDUCED RISK

A Medium Mine Protected Vehicle Type II, with a deployed interrogation arm, prepares to investigate a suspected roadside hazard during operational testing in October 2017 at Fort Leonard Wood, Missouri. Experimental prototyping gets S&T products into Soldiers' hands early, enabling further evaluations and reducing the risk for transition. (U.S. Army photo by Clay Beach, U.S. Army Operational Test Command Visual Information)



TECHNOLOGY MATURATION

Army unifies diverse efforts to bridge the gap between concept and acquisition for successful technology transitions.

by Ms. Julie I. Locker

Technology transition is the process by which a technology is determined mature enough to move from science and technology (S&T) into a DOD acquisition program. Transitions play a critical role in bridging the gap between technology development and implementation within a future Army system.

Successful transitions begin early during S&T development with the establishment of strong working relationships between the Army technologists within the research laboratories and the Army program executive officers (PEOs) and program managers (PMs). Through these relationships, stakeholders accomplish the ever-important early interpretation of user requirements and identify the technologies needed to meet user goals. The PM and the S&T developer can then forge technology transition agreements to establish a joint commitment based on a shared understanding of technology objectives and the associated technical hurdles and risks.

In 2017, the deputy assistant secretary of the Army for research and technology (DASA(R&T)) established a new portfolio to focus on key aspects of technology transition and innovation. The maturation portfolio magnifies the focus on improving transitions by merging several efforts under one technology portfolio: red teaming of S&T technologies; development of experimental prototypes through the Technology Maturation Initiatives Budget Activity (BA) 4; advanced development of manufacturing processes through the Army Manufacturing Technology (ManTech) BA7; and Small Business Innovation Research (SBIR).

The Army S&T enterprise develops and advances technologies for ground maneuver, aviation, medical, Soldier, and command, control, communications and intelligence (C3I) that are critical to the Soldier's success. Specifically, these technologies are key to the successful fielding of the Army's six high-priority modernization efforts for long-range precision fires, the Next Generation Combat Vehicle, Future Vertical Lift, the network and C3I, air and missile defense, and Soldier lethality.

The maturation portfolio supports these priorities by determining ways to transition technologies rapidly as affordable, reliable systems. Following this article are two case studies of successful Army S&T efforts in technology maturation: the Third Generation Forward Looking Infrared (3rd Gen FLIR) and the Affordable Protection from Objective Threats (APOT) project to mature lower-hull manufacturing technologies associated with combat vehicles, providing advanced protection.

It is critical for technologists to understand the requirements that the PEOs and PMs have in order to meet the transition timelines for insertion into their acquisition programs. Technology road maps for these efforts are key to effectively managing advanced technology development efforts, with a stage-gate approach to measure progress along the way.

The stage gates represent checkpoints along the planning timeline that mark the achievement of a specific technology objective, associated metric or both. They support an overall progress check for the effort and serve as decision points as to whether a desired technology is achievable and whether the Army should continue investing in the technology. Road maps should also consider when to effectively initiate red teaming, Technology Maturation Initiatives and ManTech efforts to reduce the risk for transition.

RED TEAMING

The Army's S&T red teaming program provides early, in-depth vulnerability assessments of S&T products. To achieve these ends, the program conducts virtual, laboratory-based or live conceptualization, threat emulation and technology assessment. The timing, sequence and structure of these activities are tailored to the evaluation of individual technologies or groups of technologies.

An example of an S&T effort that greatly benefited from red teaming was individual blade control (IBC) technologies, which offer substantial improvements for rotorcraft flight control and performance. A series of red teaming assessments looked at the vulnerability of the IBC to ballistic threats; the results were critical in helping reduce the risk of potential IBC implementation in future aviation platforms. Efforts conducted as part of red teaming serve to make our S&T technologies stronger in hostile environments and reduce risk for their successful transition.

IDENTIFYING TECHNOLOGIES FOR MATURATION

When an S&T component, subsystem or system has been demonstrated in a relevant environment, then it has reached technology readiness level 6. Further maturation of the technology may be required to successfully integrate and transition it within an acquisition program.

The purpose of the Army's efforts on this front is to further mature technologies through experimental prototyping in advance of a future program of record. Experimental prototyping provides an

EXAMINING THE OUTCOME

Todd M. Turner, air portfolio director in the Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology, observes the effects of simulated ground fire on a rotor blade section. IBC technologies improve rotorcraft performance and were among the many Army S&T efforts improved by red teaming, now a core part of Army S&T's maturation portfolio. (U.S. Army photo by Conrad Johnson, U.S. Army Research, Development and Engineering Command) opportunity to get S&T products in Soldiers' hands early, thereby facilitating further evaluations to inform detailed system requirements and reduce the risk for transition.

The Army uses a strategically guided, top-down approach to manage Technology Maturation Initiative efforts. A four-star governance body called the Army's Science and Technology Advisory Group, co-chaired by the vice chief of staff of the Army and the Army acquisition executive, provides strategic guidance to the two-star Executive Steering Group chaired by the DASA(R&T). The steering group, in turn, provides guidance to the S&T community, executing commands for development and selection of future Technology Maturation Initiative efforts. Strategic top-down guidance and approval ensure that the efforts receive the necessary level of senior leader oversight to ensure alignment with the secretary of the Army's priorities.

An example of a system being matured through Technology Maturation Initiatives is the Modular Active Protection System (MAPS), which will enable the Army to provide optimized, layered defenses against the most advanced combat vehicle threats. This effort will develop and demonstrate experimental prototypes that fully integrate the MAPS architecture with advanced, autonomous countermeasures on ground platforms. The results will inform the Army's requirements for the Vehicle Protection Suite (VPS) and reduce the risk of rapidly transitioning VPS capabilities to the Army's combat vehicle fleet.

ARMY MANTECH

During S&T technology development, it is important to understand if there are any associated issues with the manufacture of technologies that could affect the ability to produce an item, or its affordability. Exploration of methods to manufacture technologies, in parallel with the execution of S&T efforts, ensures that any new manufacturing processes required for these technologies have been developed before transition. The Army's ManTech Program develops and refines manufacturing processes for affordable products, thereby reducing the risk of transition to programs of record.

The program leverages manufacturing research conducted jointly by the services through the Joint Defense Manufacturing Technology Panel. The panel of representatives from the Army, Navy, Air Force, Defense Logistics Agency, Missile Defense Agency and Office of the Secretary of Defense exists to avoid redundancies, identify and integrate requirements, and conduct joint planning.

ManTech yields reduced costs and improved products for the warfighter. As one example of numerous successes, its APOT project has matured lower-hull manufacturing technologies associated with combat vehicles, providing advanced protection. This effort enabled the U.S. to domestically produce a new aluminum alloy with processes needed to form, forge and weld it into a structure for the underbody hull, providing a new standard in blast protection. The successes from APOT are informing requirements for future combat vehicles.

SBIR PROGRAM

The SBIR Program fosters innovation in all phases of S&T and shapes successful transitions by aligning small businesses directly with technology capability gaps. For instance, the 3rd Gen FLIR sensor suite leveraged small business efforts from the SBIR program. With the shift of Army S&T efforts toward mid- and far-term technologies, SBIR efforts are critical for filling near-term technology needs.

The Army is providing additional strategic guidance to the SBIR community to ensure that its work aligns with the Army's modernization priorities. The additional guidance will help small businesses focus investments in areas where the Army has critical needs.

CONCLUSION

Strengthening a transition and reducing risk to an existing or future program of record require detailed action plans to effectively link planned S&T advanced technology development, Technology Maturation Initiatives and ManTech, while using SBIRs to promote innovation throughout the technology development life cycle.

A proactive, forward-focused strategy is critical. Managing the maturation efforts within one S&T portfolio helps to ensure alignment with Army priorities and ensure that action plans are in place to link efforts, ultimately reducing overall risk and ensuring successful transition to the PEOs and PMs.

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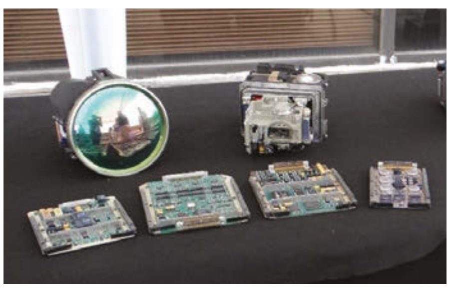
A FLIR for Innovation

Moving objects appeared as glowing blobs in early infrared vision equipment. Clarifying the picture so Soldiers could distinguish people from background objects, combatants from noncombatants, required imagination, initiative and information.

by Dr. Richard Nabors and Mr. Nathan Burkholder



PROTOTYPE FOR SUCCESS

The 3rd Gen FLIR products seen here are examples of a new and innovative program from the research community making the sometimes treacherous transition into field use. (U.S. Army photo by CERDEC)

Innovation isn't just a matter of creating something new. Rather, it's the process of translating an idea into goods or services that will create value for an end user. As such, innovation requires three key ingredients: the need (or, in defense acquisition terms, the requirement of the customer); people competent in the required technology; and supporting resources. The Catch-22 is that all three of these ingredients need to be present for innovation success, but each one often depends on the existence of the others.

This can be challenging for the government, where it tends to be difficult to find funding for innovative ideas when there are no perceived requirements to be fulfilled. With transformational ideas, the need is often not fully realized until after the innovation; people did not realize they "needed" a smartphone until after the iPhone was produced. For this reason, revolutionary innovations within DOD struggle to fully mature without concerted and focused efforts from all of the defense communities: research, requirements, transition and acquisition.

Despite these challenges, the Army has demonstrated its ability to generate successful innovative programs throughout the years. A prime example is the recently completed Third Generation Forward Looking Infrared (3rd Gen FLIR) program. It exemplifies the Army process of transitioning a new and innovative program from the research community into the military platforms in use today.

WHAT'S THAT BLOB DOING?

The first implementation of FLIR gave the Army a limited ability to detect objects on the battlefield at night. Users were able to see "glowing, moving blobs" that stood out in contrast to the background. Although detectable, these blobs were often challenging to identify. In cluttered, complex environments, distinguishing nonmoving objects from the background could be difficult.

These first-generation systems were large and slow and provided low-resolution images not suitable for long-range target identification. In many ways, they were like the boom box music players that existed before the iPhone: They played music, but they could support only one function, had a limited capacity, took up a lot of space, required significant power and were not very portable. Third Gen FLIR was developed based on the idea that greater speed, precision and range in the targeting process could unlock the full potential of infrared imaging and would provide a transformative capability, like the iPhone, that would have cascading positive effects across the entire military well into the future.

Because speed, precision and accuracy are critical components for platform lethality, 3rd Gen FLIR provides a significant operational performance advantage over the previous FLIR sensor systems. With 3rd Gen FLIR, the Army moved away from a single band (which uses only a portion of the light spectrum) to a multiband infrared imaging system, which is able to select the optimal portion of the light spectrum for identifying a variety of different targets.

The Army integrated this new sensor with computer software (signal processing) to automatically enhance these FLIR images and video in real time with no complicated setup or training required (similar to how the iPhone automatically adjusts for various lighting conditions to create the best image possible). Third Gen combines all of these features along with multiple fields of view (similar to having multiple camera lenses that change on demand) to provide significantly improved detection ranges and a reduction in false alarms when compared with previous FLIR sensor systems.

Using its wider fields of view and increased resolution, 3rd Gen FLIR allows the military to conduct rapid area search. This capability has proven to be invaluable in distinguishing combatants from noncombatants and reducing collateral damage. Having all of these elements within a single sensor allows warfighters to optimize their equipment for the prevailing battlefield conditions, greatly enhancing mission effectiveness and survivability. Current and future air- and ground-based systems alike benefit from the new FLIR sensors, by enabling the military to purchase a single sensor that can be used across multiple platforms and for a variety of missions. This provides significant cost savings for the military by reducing the number of different systems it has to buy, maintain and sustain.

Third Gen FLIR was effective in implementing the three key ingredients mentioned above (requirements, expertise and available resources). A closer look explains how the 3rd Gen FLIR program

RAPID AREA SEARCH

U.S. Army Spc. Roland Merrill of 1st Brigade Combat Team, 3rd Infantry Division watches over tanks in his unit with a 3rd Gen FLIR-equipped Long Range Advanced Scout Surveillance System during Decisive Action Rotation 18-01 in October 2017 at the National Training Center (NTC), Fort Irwin, California. With its wider fields of view and increased resolution, 3rd Gen FLIR allows Soldiers to rapidly search an area and identify objects with a much higher degree of confidence than older infrared imaging equipment. (U.S. Army photo by Master Sgt. Horace Murray, NTC Operations Group) helped solve some of the challenges it faced in those areas to arrive at its accomplishment today as an Army innovation success.

REQUIREMENTS

The 3rd Gen FLIR program struggled early in its development, as do most new and innovative efforts, to identify requirement documentation crucial to help support the planning and resourcing necessary to sustain a successful program. Without the user community understanding what could be possible, the requirements at the time were all based around the perceived limitations of what technology could provide. To reiterate the old adage attributed to Henry Ford, "If I had asked the people what they wanted, they would have said faster horses." To overcome this, the research community developed a comprehensive strategy for educational outreach on the full potential of what 3rd Gen FLIR could achieve and executed it to help inform the Army's requirement developers, military officers and industry. This campaign highlighted not only the need, but also what was possible, and served as the catalyst to bring the entire community together to make 3rd Gen FLIR a reality for the warfighter.

EXPERTISE

The expertise required to achieve 3rd Gen FLIR success was spread across a variety of organizations and industries. More than 16 significant research and development projects from multiple organizations were integrated to create this program:

- Thirteen percent were from Small Business Innovation Research program efforts, which brought in companies outside of the traditional large defense contractors.
- More than 25 percent of the activities involved applied research funding, which served to partner in-house expertise with external communities through cooperative research and development agreements.
- Thirty-one percent of the efforts were Manufacturing Technology (ManTech) initiatives, working with focal plane array and substrate manufacturers to develop the technology necessary to drive down future costs and ensure the stability of long-term manufacturing capabilities. (Focal planes are like the digital film in modern digital cameras that record the images.)
- Thirty-one percent of activities were executed through advanced technology development funding with traditional large defense contractors who work on sensor development and system integration.

All of these ingredients were critical to create the 3rd Gen FLIR system. But ingredients by themselves do not make a masterpiece; a chef is needed to bring them together in the right sequence with the proper proportions to achieve the desired result. For 3rd Gen FLIR, the talented workforce across the Army research community played this vital role, strategically aligning these individual activities and working them together to provide a comprehensive, interconnected final solution.

RESOURCES

Neither requirements nor expertise would count for much were there not appropriate, sustained investments over time to support the development of 3rd Gen FLIR. The program took many years of consistent investments into

UNLOCKED POTENTIAL

A Soldier views the 3rd Gen FLIR's capabilities. Third Gen FLIR enables greater speed, precision and range in the targeting process and promises to unlock the full potential of infrared imaging. (U.S. Army photo by CERDEC)

BETTER SIGHT FOR MULTIPLE PLATFORMS

An MQ-1C Gray Eagle unmanned aerial system, equipped with 3rd Gen FLIR sensors and belonging to Company D, 10th Aviation Regiment, prepares to conduct a mission from Al Asad Air Base, Iraq, in September 2017. Third Gen FLIR sensors are used in current and future air- and ground-based systems, allowing the military to purchase a single sensor that can be used across multiple platforms and for a variety of missions, at significant cost savings. (U.S. Army photo by Staff Sgt. Isolda Reyes, 29th Combat Aviation Brigade)

innovations and breakthroughs in areas such as substrate growth (the digital film that converts light into signals), dual-band focal plane arrays (digital film that can capture two different types of light at the same time), variable apertures (adjustable focus), modeling and simulation (automated computer optimization of imagery), and sensor miniaturization (portability).

Obtaining the support of industry and leveraging their internal research and development investments required the Army to build trust in the overall program through focused, appropriately timed acquisition activities conducted simultaneously across multiple fronts. By creating partnerships with others, such as the U.S. Army Communications-Electronics Research, Development and Engineering Center (CERDEC) Night Vision and Electronic Sensors Directorate (NVESD) and ManTech, 3rd Gen FLIR was able to integrate multiple funding sources to ensure a secure resource foundation.

CONCLUSION

As the Army reorganizes to modernize its capabilities, it can look to the success of the 3rd Gen FLIR program as a prototype. The program has demonstrated several key elements critical to the successful implementation of an innovative program, which illustrates the transition from good ideas into actual capabilities in the hands of warfighters.

It exemplifies how the military can benefit when Army communities work together to combine requirements with resources, technology innovation and cooperation. With all of the participants collaborating, from the requirements community to the acquisition and development communities, the Army overcomes barriers and is able to create an environment where innovation thrives, equipping its warriors with the best technology in the world.

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A TEAM EFFORT

Award-winning ManTech program to create a new kind of blast-resistant aluminum vehicle hull resulted from a variety of new and existing R&D.

by Dr. Bryan Cheeseman

During the autumns of 2014 and 2015, the Army demonstrated a force protection capability using a newly designed aluminum hull for combat vehicles. These tests involved a large underbody blast gauged on enemy threats as part of the U.S. Army Manufacturing Technology (ManTech) project called Affordable Protection from Objective Threats (APOT).

The research and development (R&D) on the APOT program offers tremendous improvements and great promise in force protection for the future. APOT focused on the maturation of lower hull manufacturing techniques, pulling together a number of applied research, advanced technology development, operational systems development and Small Business Innovation Research (SBIR) programs, along with efforts being conducted as part of a cooperative research and development agreement (CRADA) and a U.S.-Israel project agreement. The result was the fabrication of multiple lower hulls into notional ballistic hull and turrets (BH&Ts). (A BH&T is a bare vehicle structure used for ballistic testing. It does not typically contain a functional powertrain, suspension, communication equipment, etc.)

After the APOT team outfitted the BH&Ts with energy-absorbing and impulse-mitigating technologies and anthropomorphic test devices (crash dummies), the BH&Ts were tested with an explosive charge significantly larger than a previous test or a typical improvised explosive device (IED) used by adversaries in Iraq and Afghanistan. Assessments of the dummies indicated limited or no injuries. Results from this

MAIDEN VOYAGE

The forged aluminum hull, affixed to a massive test rig, undergoes an objective-level underbody blast test. The test, conducted in October 2014, resulted in minimal hull deformation. (U.S. Army photo)

collaborative effort provided experts at the U.S. Army Training and Doctrine Command (TRADOC) Maneuver Center of Excellence (MCOE) with data to write requirements for underbody blast protection.

The APOT ManTech project advanced lower hull manufacturing technologies for aluminum-hulled combat vehicles and provided a better means of maturing several structural features for validation and incorporation into the Armored Multi-Purpose Vehicle. The program achieved these results—and received the 2017 Defense Manufacturing Technology Achievement Award—through cooperation across multiple agencies, programs and even nations.

INADEQUATE PROTECTION

Aluminum-hulled combat vehicles historically have been vulnerable to underbody blasts. Fielded in the 1960s, both the M113 Armored Personnel Carrier (APC) and M551 Airborne Reconnaissance Assault Vehicle were required to be air-droppable, which restricted their weight and corresponding aluminum armor thicknesses. Requirements writers at the time deemed anti-tank mine resistance to be impractical for air-droppable vehicles; therefore, these vehicles were developed with only a modicum of blast resistance, equivalent to an anti-personnel mine. Their vulnerability to underbody blast events soon became evident when they were deployed in Vietnam.

Fielded in 1981, the M2 and M3 Bradley Infantry Fighting Vehicles featured a lower hull similar in design and armor thickness to the M113 APC, with the exception of an additional steel armor plate under the front third of the vehicle. It too proved vulnerable to underbody blasts, in this case IEDs in Operation Iraqi Freedom, so a steel add-on armor kit for the Bradley was fielded expediently. However, when this configuration was tested by the Office of the Secretary of Defense Live Fire Test and Evaluation (OSD LFT&E) program in 2012, the results indicated "severe vehicle and occupant vulnerabilities." OSD's evaluation set the foundation for the APOT effort, which began in 2012.

HARNESSING OF EFFORTS

The APOT ManTech effort sought to mature more effective manufacturing methods to provide protection not only from typical conventional underbody blast devices, but from blasts many times the power of a typical IED explosion (defined as objective level) and significantly more than the amount of explosive used in the OSD LFT&E evaluation of the Bradley. In after-action accounts of hull failures caused by large underbody blasts, battle damage assessments noted that hulls failed because of welds rupturing and the relatively thin aluminum belly plates fracturing.

To mitigate these failures, APOT sought to fabricate thicker aluminum hulls using fewer welds. Specifically, APOT matured the forging of a monolithic aluminum hull; the forming of a hull from thick aluminum plate; and the welding of thick aluminum plate using high energies, which reduces the number of weld passes by up to 90 percent as compared with typical hand welds. Industrial partners for these efforts were Alcoa Defense with Alcoa Forgings and Extrusions (now

Arconic Inc.), Constellium N.V. and BAE Systems Inc., respectively. The forged-hull effort was the first innovation and is the focus of this article.

Stakeholders from the U.S. Army Research, Development and Engineering Command (RDECOM), the Program Executive Office for Ground Combat Systems (PEO GCS) and the MCOE determined the desired results for the APOT project. PEO GCS experts sought affordable hull designs with integrable manufacturing techniques, while the MCOE needed hard data to inform underbody blast requirements being drafted for a number of programs.

While experts agreed that manufacturing a lower hull and live-fire testing with an explosive charge similar to an IED would be useful, that would not answer the essential question: "What does it mean for force protection for the Soldier?" Experts concluded that to answer this question would mean taking the lower hull and fabricating an entire BH&T, installing energy-absorbing seats and floors along with crash dummies, conducting live-fire testing and then assessing injuries. To accomplish all this, the team looked for partners.

Fortunately, at the time, the Defense Advanced Research Projects Agency (DARPA) Soldier Protection Systems (SPS) program was also "developing and demonstrating lightweight armor material systems to defeat current and potential ballistic and blast threats with performance substantially better than today's protective armor systems." As part of that effort, it awarded BAE Systems a project to develop an aluminum combat vehicle hull capable of withstanding very large underbody IED blasts. Collaboration among APOT, SPS and BAE Systems project managers led them to agree that the APOT underbodies would form the basis for the SPS designs. Select designs would be fabricated into BH&Ts to demonstrate the first element of force protection.

A HULL NEW DEFENSE

The forged hull effort kicked off in summer 2013; APOT forming and welding efforts started a year later. Acquisition stakeholders required material used for the hull to be weldable using conventional Army practices, and TRADOC requested data in one year. The APOT effort was scheduled to produce a hull in 18 months; however, Alcoa made it possible to accelerate the program by funding the massive 180-ton steel die set required for forging.

During fall 2013, the forged hull geometry was developed and refined through modeling and simulation. The hull design, along with the material requirements, drove the team to select a European aluminum armor alloy, 7020, which had never been produced commercially nor forged in the United States. Fortunately, the U.S. Army Research Laboratory (ARL) studied aluminum alloy 7020 in a 2011-13 foreign technology assessment program and developed a good understanding of its weldability and ballistic response. However, as 7020 had never been manufactured in the United States, the Army needed to develop the alloy chemistries and process parameters for large-scale domestic industrial production.

In fall 2013, the U.S. Army and the Israeli Ministry of Defense were closing out capability assessment activities as part of the Ground Combat Vehicle analysis of alternatives. The Israelis learned of the forged hull effort and expressed interest in collaborating. Since high-performing, energy-absorbing technologies were required for the BH&T, a U.S.-Israel project agreement on armored vehicle underbody blast testing allowed energy-absorbing technologies developed by Israel to be adapted and installed into the forged BH&T.

During this time, RDECOM's Tank Automotive Research, Development and

SINGLE HULL FORGED

This single-piece hull of 7020 aluminum alloy was successfully forged by Alcoa (now Arconic) in July 2014, one year after the APOT program's kickoff. It's the world's largest aluminum forging. (Photo by Arconic Inc.)

READY FOR TESTING

The forged BH&T, which BAE Systems worked rapidly to fabricate from the forged hull, complete with energy-absorbing seats, floors and crash dummies, sits on the test pad at the Aberdeen Test Center, Maryland, in December 2014, awaiting live fire testing. (U.S. Army photo)

Engineering Center (TARDEC) was executing the Concept for Advanced Military Explosion-mitigating Land (CAMEL) Occupant Centric Protection Technology Enabled Capabilities Demonstrator. As part of this effort, TARDEC developed high-performing, energy-absorbing seats and floors for the CAMEL wheeled combat vehicle demonstrator. The APOT program presented a great opportunity for the engineers working on the demonstrator to determine the effectiveness of its technologies in the APOT BH&T. Additional energy-absorbing seats were provided from ongoing DARPA and ARL efforts.

ALUMINUM BEARING FRUIT

By spring 2014, all of the R&D projects were effectively aligned, and as a result, the APOT program began to make rapid progress. Alcoa forged the one-piece aluminum hull, the largest aluminum forging ever performed. BAE Systems worked rapidly to fabricate the BH&T from the forged hull and to install the energy-absorbing technologies. The BH&T was delivered and outfitted for the live fire test.

While the assessment showed injuries to the crash dummies during testing, the forged BH&T itself was relatively unscathed. Subsequently, the BH&T was refurbished, re-outfitted with the same energy-absorbing technologies, and through an RDECOM CRADA, TenCate Advanced Armor USA provided and installed an active blast defense system. The BH&T was again tested with an objective-level charge, with remarkably positive results. Through the effective alignment of multiple R&D efforts that brought together alternate manufacturing methods and advanced protection technologies, the project answered the essential question, "What does it mean for force protection for the Soldier?" For this case, no injuries occurred in an objective-level underbody blast test.

CONCLUSION

The Army ManTech APOT project matured lower hull manufacturing techniques and demonstrated aluminum hulls that can withstand objective-level underbody blasts. In addition, APOT served as a focal point to bring together a number of R&D efforts from several DOD agencies, along with SBIR, CRADA and international activities, which collectively answered the essential question and demonstrated what can be achieved through careful planning and collaboration.

This work has had an impact on both current vehicle design and future vehicle requirements, ensuring a lasting legacy for the APOT effort.

For more information, go to ***http://www.armymantech.com/APOT.php***.

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"There's a purpose to what we do. It's not just science for science's sake. It's not just engineering for engineering's sake. There's an outcome, and I think that's a tremendously satisfying experience as a scientist or engineer."

Dr. Thomas P. Russell
Deputy Assistant Secretary of the Army for Research and Technology

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