SECURING TOMORROW

FUTURE WARFARE

CULTIVATING EMERGING TECHNOLOGIES

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Raytheon

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ON THE COVER: A software "shield" protects cities and infrastructure from an attack by hackers in this artists' conception of a future battle waged in cyberspace. Read more about cyber warfare on page 16.

INTRODUCTION

TOWARD A THIRD OFFSET STRATEGY

Machines that think and learn. Miniature munitions that strike with precision. Micro-networks that control swarming robots and tell soldiers where the enemy is hiding.

All are part of the Department of Defense's Third Offset Strategy, a plan to give the U.S. military a decisive and deterrent technological advantage over adversaries. And Raytheon, with expertise spanning cyber warfare, precision weapons and human-machine interaction, is working to bring those technologies to the battlefield.

The defense industry "is at the ready to partner with the DoD to develop the innovative, next-generation capabilities our warfighters need in a dynamic and uncertain threat environment," Raytheon Chairman and CEO Thomas A. Kennedy said at a recent forum.

In this book, Raytheon takes you inside its labs and factories to show you how we've been working on technologies related to the Third Offset. They include:

- Artificial intelligence: Company experts have developed robots that can teach themselves to perform tasks and programs that mimic human emotions.
- Human-machine interaction: The company is among several working on the Defense Advanced Research Projects Agency's Squad X Core Technologies program, which gives ground troops new, easy-to-use tools for tracking the enemy and protecting squadmates.
- Miniaturized munitions: Raytheon is breaking new ground in bringing guidance to small-arms systems, including the 40 mm Pike munition.

The Third Offset is all about the future — making sure the military overmatches adversaries for decades to come. But at Raytheon's research centers and testing ranges, the Third Offset is happening right now.

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THE OCTOPUS IN THE MACHINE

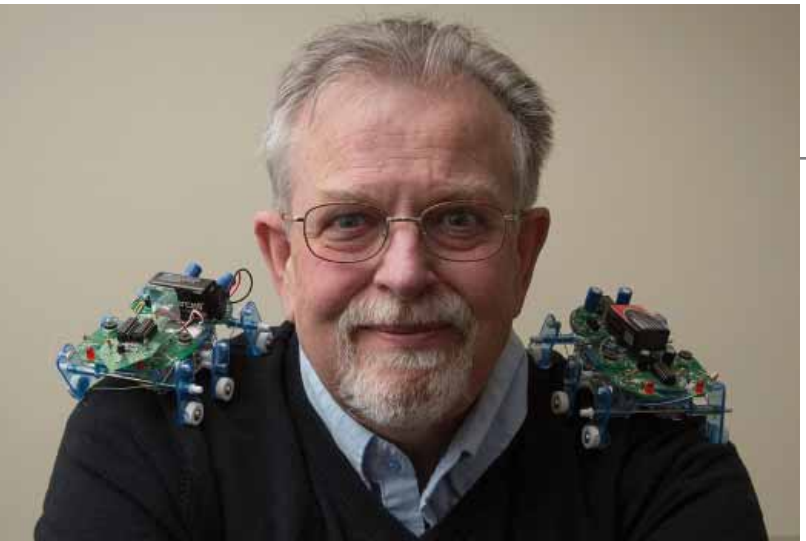
WITH LEARNING ROBOTS AND EMOTIONAL COMPUTERS, ARTIFICIAL INTELLIGENCE BECOMES REAL

The robotic cockroach was called Zeus, and it came into the world knowing only two things.

The first was that it hated light. The second was that it could move its body — though it didn't know how, or what parts it had.

Within five minutes, Zeus had learned to walk. Within 15, it could walk backwards. The little robot, searching for darkness, had figured out that backing up is sometimes more efficient than making a forward turn.

Zeus' tiny steps backward were an enormous step forward for its creator, James Crowder, one of Raytheon's experts in the field of artificial intelligence. Their work in creating things that think, learn and reason includes mechanical versions of insects and octopuses, simulated emotions, cultural coaches and computerized versions of schoolteachers. And it all comes as the United States military looks for innovation in artificial intelligence as part of its plan to find new ways of pairing humans and machines.



RAYTHEON ENGINEER JAMES CROWDER BUILT THESE ROBOTS, NAMED ZEUS AND HERCULES, AS PART OF HIS RESEARCH INTO ARTIFICIAL INTELLIGENCE. CROWDER'S ROBOTS HAVE NEURAL SYSTEMS SIMILAR TO THOSE OF COCKROACHES AND OCTOPUSES, AND HE HOPES HIS WORK WILL LEAD TO SYSTEMS OF GREATER COMPLEXITY AND CAPABILITY.

THINKING 'AT THE SPEED OF LIGHT'

Artificial intelligence is part of the Department of Defense's "Third Offset" Strategy, a plan to give the United States military strong advantages that would deter enemies from attacking.

Smart machines that "operate at the speed of light" could help troops make better battlefield decisions, Deputy Defense Secretary Bob Work said during a discussion of the Third Offset Strategy at the Reagan National Defense Forum.

"So when you're operating against a cyber-attack or an electronic warfare attack or attacks against your space architecture or missiles that are coming, screaming in at you at Mach 6," Work said, "you're going to have to have a learning machine that helps you solve that problem right away."

The advent of AI could change the way vehicles are designed, how pilots fly and how battlefield information is delivered, said Paul Scharre, a former U.S. Army Ranger and now a senior fellow at the Center for a New American Security.

"You're not going to eliminate people from warfare, but there are advantages to machine intelligence to augment the capacity of warfighters — the same way Google augments our ability to process information, or a smartphone," Scharre said.

STARTING SIMPLE

Artificial intelligence takes many forms. There's the classic chess-playing robot. The smartphone personal assistant. Seemingly sentient characters in videogames. Self-driving cars.

And in Crowder's case, there's the cockroach.

He knew if he was ever going to build a machine of true artificial intelligence — "a fully thinking, reasoning, intelligent, autonomous system," — he would have to start simple.

"If I can't do it at that level, I'm not going to do it at a C-3PO level," he said.

Zeus came first, running on a 9-volt battery and equipped with a basic brain: three neurons on each half, and a communications hub called an artificial prefrontal cortex.

Next came Hercules and Athena. And that's where things really got interesting.

Crowder programmed them to avoid light, just like Zeus. But he also designed them to run on solar power. When their batteries ran low, they felt an urge.

Hunger.

"They have to find light and charge up, only light still hurts them," Crowder said. "So now they have to balance the instincts of 'light still hurts, but if I don't find light, I die.'"

EMOTIONS IN MOTION

That conflict creates emotion. And emotion is essential to artificial intelligence, Crowder said, because how we feel influences everything we do.

"Our entire learning system in our human brain is tied to our emotions," he said.

Emotions help the brain decide how to use its resources — something called cognitive economy, he said. If you're feeling happy, you'll respond to an event accordingly. If you're anxious, or sad, or fearful, your brain might tell you to respond differently.

"We need the same thing in AI because no matter how robust you build the system, it has limited memory, limited processors, limited power," Crowder said. "So I have to understand how to allocate the resources. We do the same thing in our brain. If I have 25 things to worry about and one of them is going to kill me, obviously that one gets the resources."

Emotions such as fear and anxiety can help an artificially intelligent system survive. But other emotions are useful as well.

Affection and annoyance, for example. Which brings us to the laboratory of Bill Ferguson.

COMPUTERIZED CULTURE

How do you get a video game to like you?

If it's the game Ferguson helped build, you bow, point to yourself and say your name.

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THE OCTOPUS IN THE MACHINE CONTINUED

BILL FERGUSON, A RAYTHEON BBN TECHNOLOGIES ENGINEER, DEMONSTRATES A VIDEOGAME-STYLE SIMULATOR THAT USES ARTIFICIAL INTELLIGENCE TO INTERPRET THE USER'S BODY LANGUAGE. HIS TEAM HELPED BUILD THE SYSTEM FOR THE DEFENSE ADVANCED RESEARCH PROJECTS AGENCY.

Ferguson, an engineer at Raytheon BBN Technologies in Cambridge, Massachusetts, helped work artificial intelligence into a training tool that teaches Americans how to approach strangers in a foreign land. The videogame-style simulator, built for the Defense Advanced Research Projects Agency, encourages making polite, friendly overtures before taking on tasks such as asking for directions.

"People in other cultures want to talk with you for a while. They want to get to know you," Ferguson said.

In one scenario, the user is lost but has a photograph of the destination. Two locals approach, speaking only Esperanto. Using a motion sensor, the system watches and interprets the user's body language. If the user seems pushy or rude, the characters might back away. If the user shows a little more finesse, the characters might offer a piece of fruit. Once the user has established a little goodwill, the characters will take a look at the photo and point out the way.

Behind the on-screen action is some clever programming that controls the characters' attitude and actions.

"When you smile at them, they have an urge to smile back at you," Ferguson said. "But they won't smile if they're irritated."

Other researchers are incorporating similar technology into Raytheon's Learning Platform. The electronic tutoring system detects when students are having trouble and adjusts its teaching style. Raytheon built the system for the military but is donating it to high schools nationwide for teaching physics and other subjects.

BRAINS THROUGHOUT THE BODY

Crowder has graduated from the neural system of the cockroach to that of the octopus. Octopuses have a main brain that issues broad commands like "eat" or "move," then a separate packet of nerves in each arm that knows how to carry out the order.

So he built one with an octopus-like neural system.

Crowder's goal is a network of machines that can work together through coordination by a central command unit, one most likely with a person at the helm. Think of a squadron of deep-sea minehunters that can scour the ocean floor on their own and report back to a human controller only when they find something of interest.

"They have a sense of their own defense and security, but the operator is the one who's giving the mission parameters," Crowder said. "They don't require a lot of care and feeding."

To Ferguson, who has been working on artificial intelligence systems for more than 30 years, the use of machines to replicate human thought is a clear next step in doing things faster, better and smarter.

"A guy with a calculator would have run circles around a guy without a calculator 40 years ago," he said. "It's just a new kind of tool that's helping human intelligence get farther." ■

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THE SOLDIER WITH 100 EYES

RAYTHEON TECHNOLOGY WILL HELP REALIZE DARPA'S VISION FOR SQUAD X. IN THIS DARPA IMAGE, SOLDIERS CARRYING TABLET COMPUTERS SHARE SCREENS FOR UNMATCHED SITUATIONAL AWARENESS.

RAYTHEON TECHNOLOGY WILL DELIVER UNIMAGINED ABILITIES ON THE BATTLEFIELD

The Pentagon has a vision: to create the omniscient foot soldier.

The fighter of the future will be connected to squad mates, support personnel and robots that can fly around corners or crawl through debris to spot hidden threats. It's a vision that's becoming real at Raytheon.

The inventions emerging from the company's laboratories and test ranges will help fulfill the U.S. military's Third Offset Strategy, which calls for developing new technologies to create overwhelming advantages.

"We believe we are at an inflection point on artificial intelligence and autonomy," U.S. Deputy Defense Secretary Bob Work said in a recent speech. "Ten years from now, if the first person through a breach isn't a friggin' robot, shame on us."

From hand-held computers that command those robots to apps that guide paratroopers to the ground, Raytheon is developing new battlefield technologies, under the Defense Advanced Research Projects Agency's Squad X Core Technologies and other programs.

"It's really about improved man-machine collaboration and combat teaming," said Dave Bossert, a senior engineering fellow at Raytheon's Missile Systems business. "The soldier's human-machine interface, his eyes into the system, is a tablet computer."

CONTINUED ON NEXT PAGE

THE SOLDIER WITH 100 EYES CONTINUED

A LASER PINPOINTS A TARGET AS A FOOT SOLDIER CALLS IN AIR SUPPORT IN THIS DARPA RENDERING. THE PERSISTENT CLOSE AIR SUPPORT SYSTEM ALLOWS SOLDIERS, GROUND-BASED CONTROLLERS AND PILOTS TO SHARE DATA IN REAL TIME.

THE ULTIMATE BACKUP: PERSISTENT CLOSE AIR SUPPORT

Raytheon's Persistent Close Air Support systems connect soldiers on foot, joint terminal attack controllers, or JTACs, on the ground and pilots in the air to share detailed information in real time. A PCAS-enabled soldier can call in air support, piloted or unmanned, in less than six minutes instead of nearly an hour, and for multiple targets.

The PCAS network shares the screens used by the pilot, the JTAC and a soldier with an Android tablet computer. Algorithms help to pinpoint targets, map attack routes and deploy just the right weapon.

"It is providing all the information on the target that the airplane has, passing it all down to the JTAC," said Bossert. "The JTAC can add his perspective, digitally sending it to the aircraft."

DARPA proved the concept with tests conducted near Nellis Air Force Base in Nevada. A JTAC on the ground called in an A-10 attack aircraft with as few as three clicks on a tablet computer.

THE APP THAT SAVES LIVES: ANDROID TACTICAL ASSAULT KIT

A tablet is only as effective as the program it runs. Raytheon BBN Technologies, one of the company's advanced research centers, helped develop that program: ATAK, or Android Tactical Assault Kit.

ATAK allows soldiers to chat, share video, map points of interest and plan routes, sharing information in real time. And it runs on off-the-shelf Android tablets and smartphones.

"It started out as a dynamic, moving map, but now ATAK has become a full situational awareness app with a lot of features built in for specific users," said Joe Loyall, a principal scientist at Raytheon BBN.

The app can be customized. Jump Master, for example, is a version for paratroopers, delivering detailed data on wind direction, target zones and even their progress on the way down.

Raytheon, one of a handful of core organizations behind ATAK, is continuing its development.

"We are working to develop a decentralized version of ATAK and ATAK servers together, so users will be able to reach back to other organizations, other databases, to get information," Loyall said.

Ultimately, ATAK may be able to fly a vehicle carrying a sensor to a specific location to collect information.

IN THE FUTURE, A VARIETY OF ROBOTS, BOTH ON THE GROUND AND IN THE AIR WILL ACCOMPANY SOLDIERS ON THE BATTLEFIELD, AS SHOWN IN THIS DARPA SKETCH.

IF THE SWISS ARMY MADE A RADIO: HYDRA SWARM

Separate devices for radio receiving, radio transmitting and geo-location mean a lot for a soldier to carry. Add a jammer — used to foil adversaries trying to detonate roadside bombs — and you've got quite a load.

Hydra Swarm replaces that load with a single, multiple-radio-frequency package.

"The original vision of Hydra was to try and shed between 50 and 80 pounds of gear off the soldier and combine it in one, lightweight device," said Jeff Feinberg, a program manager at Raytheon BBN.

That device is a radio to communicate, a direction-finder to navigate, and a jammer.

"We have a chipset inside the radio with a very flexible front end, so we can run any frequency and any wave form within reasonable limits," said Steven Weeks, the Hydra Swarm program manager.

Designers consulted with former soldiers to be sure Hydra Swarm was not only versatile, but practical. One result: the unit is really rugged.

"Drop it in the water," said Weeks. "You can do that."

SIT AND DELIVER: THE ICONNECT TACTICAL VEST NETWORK

There's no way around it: Those electronics need batteries, which have to be charged — something that's not always convenient in the field.

Enter Raytheon's iConnect tactical power vest.

Now being designed for the U.S. Army Natick Soldier Research, Development and Engineering Center in Massachusetts, the vest cuts the size, weight, cost and cabling soldiers will carry.

"What the army is focused on is a single, central battery that will connect to the other batteries and trickle-charge them," said Jeff Mazurek, iConnect program manager.

The vest is built with strips of conductive material that match up to similar strips built into the seats of Humvees or other military vehicles.

To charge the central battery, the soldier simply sits down.

"When a soldier leaves the vehicle, the main battery is completely topped off for as much mission endurance as possible," said Mazurek.

The vest will be constructed from conductive textiles, which eliminates wires and connectors, and will allow soldiers to better distribute electronic devices.

"Our system allows for the soldier to place devices anywhere on his vest," said Mazurek, "and the system figures out the right kind of power to send to that device." ■

RAYTHEON IS HELPING TO DEVELOP NEW TECHNOLOGY TO GIVE SOLDIERS UNPRECEDENTED CAPABILITIES ON THE BATTLEFIELD, MANY ACCESSED THROUGH THE TABLET COMPUTERS THEY WILL CARRY. (IMAGE COURTESY JUGGERNAUT DEFENSE)

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ADVANCED MANUFACTURING

INSIDE THE SPACE FACTORY

LAB GEARS UP FOR NEXT MISSILE-DESTROYING "KILL VEHICLE"

On the outskirts of Tucson, Arizona, one of the cleanest factories in the world runs a one-of-a-kind operation: creating rocket-propelled "kill vehicles" that hunt down and destroy ballistic missiles in space.

Here, workers in clean-room suits assemble optics and sensors so sensitive that they can pick out warheads against the blackness of space from hundreds of miles away. Others install tiny thrusters so accurate they can steer into the path of a missile moving at 17,000 mph.

This is Raytheon's Space Factory, a workshop that is like no other in the world. Cleaning crews constantly Swiffer the floors and scrub surfaces with alcohol wipes. Pumps replace the air in some labs every 27 seconds.

"We have some very key people here and key infrastructure that doesn't exist anywhere else," said Sharon Walk, director of Raytheon's Space Systems Operations.

The Space Factory and its clean room technologies have helped make Raytheon the world leader in space-based kill vehicles. The company has decades of experience building

A GROUND-BASED INTERCEPTOR MISSILE CARRYING A RAYTHEON KILL VEHICLE ROARS INTO THE SKY.

A TECHNICIAN AT RAYTHEON'S SPACE FACTORY PREPARES "KILL VEHICLES" USED TO DESTROY MISSILES IN SPACE.

interceptors for the Ground-Based Midcourse Defense system and the Standard Missile-3, and it is now expanding the Space Factory to develop the next generation of kill vehicles.

In the factory, stainless steel is the metal of choice for the myriad of test chambers used to simulate the chill of space. Sensors throughout the building constantly measure air pressure, humidity and microscopic particles of dirt.

Even the dirtiest areas are cleaner than an operating room, and technicians use tools that go through a special rinsing process. Workers with colds aren't even allowed in the clean rooms for fear they might sneeze and cause contamination.

Raytheon opened the factory in 2002 after the U.S. government tasked the company with building a system to counter the rising threat of long-range ballistic missiles. It designed and rapidly deployed an exoatmospheric kill vehicle prototype two years later.

Kill vehicles carry no explosives; they destroy missiles by steering into their paths and slamming into them.

The prototype model is now flying on the Ground-Based Interceptor missiles used by the Ground-Based Midcourse Defense system. The company has continued to refine its designs, and the kill vehicle now used on the Standard Missile-3 incorporates these advances.

"Over time, we were able to leverage knowledge from the prototype and expand that into the SM-3 product line, producing three variants," Walk said. The latest SM-3 variant achieved five-for-five intercepts last year.

Cleanliness is key to Raytheon's success because a kill vehicle's optics and sensors have to be absolutely clear to pick out fast-moving targets against a field of stars, said Vic Wagner, director of advanced kill vehicles for Raytheon Air and Missile Defense Systems.

"We're measuring photons. That's how tight we are," he said.

Makers of computer chips only have to protect flat wafers, but the Space Factory has to keep three-dimensional objects clean — a far more difficult task, Wagner said.

"A clean room in the semiconductor industry is not designed to build kill vehicles," Wagner said. "We've built the infrastructure of air handling and test equipment that's second to none."

USS LAKE ERIE LAUNCHES A RAYTHEON STANDARD MISSILE-3 CARRYING A BLOCK 1B KILL VEHICLE DURING A TEST.

The factory is divided into three cleanliness classes. Only four to five people are allowed in the most restrictive zone.

But machinery and cleanliness aren't the only unique things about the Space Factory. The people who work in the labs have spent decades perfecting interceptor technology, a specialty shared by no other company in the world. In Tucson, they rub elbows with the world's foremost missile designers as well.

"It truly is a fertile ground and springboard for sharing knowledge," Walk said.

To prepare for the next-generation kill vehicle, the company is expanding the factory by almost 6,500 square feet and adding an even cleaner "microenvironments" area. The new addition will include more automation and is expected to be finished by year-end.

"We invented the business of building kill vehicles to defend the free world, and we're now ready to employ our collective knowledge, expertise and infrastructure to take it to the next level," Walk said. ■

A RAYTHEON TECHNICIAN INSPECTS A HIGH-PRESSURE GAS LINE DURING ASSEMBLY OF AN EXOATMOSPHERIC KILL.

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MICRODRONES WITH MULTIPLE MISSIONS

DUMPED FROM AIRCRAFT, THESE TINY PLANES CAN FLY IN VIOLENT WEATHER

It's small, it's quick, and it came from the desert, so they called it Coyote.

Only this Coyote can fly. For an hour. In a hurricane.

Coyote is a remote-controlled airplane that steps in when the job is too risky for manned aircraft. It hunts submarines. It takes surveillance images. It assesses combat damage. And now, it sizes up hurricanes. To do that, Coyote drops out of a P-3 weather surveillance plane and flies straight at them, braving violent winds and punishing rain to gather weather data and beam it back to meteorologists.

Raytheon experts in Tucson, Arizona, are developing the Coyote's forecasting capabilities alongside the National Oceanic and Atmospheric Administration and National Hurricane Center. Traditional weather instruments parachute from a plane and grab only a snapshot of humidity, wind speed and other factors, but Coyote's winged design enables it to linger and return to certain areas for more measurements.

"Coyote can fly for over an hour, at least 50 miles from its host aircraft, and into the lower altitudes where the P-3 is not safely allowed — below 2,000 feet in altitude — to gather and transmit data from the most intense area of the storm," said John Hobday, Raytheon Business Development lead for unmanned systems.

NOAA SCIENTIST PAUL REASOR HOLDS COYOTE, AN UNMANNED AIRCRAFT THAT FLIES INTO SEVERE STORMS TO COLLECT WEATHER DATA FOR METEOROLOGISTS. (NOAA PHOTO)

The system is a recent addition to Raytheon's family of high-tech weather forecasting technology, including the Visible Infrared Imaging Radiometer Suite instrument aboard NOAA's Suomi NPP spacecraft, and the Advanced Weather Interactive Processing System, a powerful analytics tool that helps meteorologists make sense of the massive amounts of weather data that modern sensors collect.

BREAKING THE BOUNDARIES

Coyote solves a problem that has long limited forecasters' ability to tell how hard a hurricane will hit. The secret behind the storm's punch lies in what is known as the "boundary layer" — a low-altitude area that includes the surface of the ocean.

"That's where the energy is extracted from the ocean to the atmosphere," said Joe Cione, a NOAA hurricane researcher. "Unfortunately, it is too difficult for us to go with manned aircraft to fly down there."

The best way — until now — was to use small, expendable sensors called dropsondes that plummet out of a plane and take quick measurements on their short-lived fall to the surface.

Coyote takes a different approach. It rides aboard the P-3 inside a 3-foot-long, 5-inch-wide tube called a sonobuoy. When the plane gets close enough to the storm, the tube drops out of a chute, and Coyote spreads its wings and springs into action.

COYOTE TAKES OFF

NOAA has already put Coyote to work. In 2014, the agency deployed four of the planes into Hurricane Edouard, a Category 3 storm. Scientists on board the P-3 received meteorological data in both the eye of the storm and the surrounding eye wall.

"Coyote will gather data specifically in the eye wall, or in the areas on the verge of the eye wall, where it can provide information for forecasters to predict intensity from a safe distance," Hobday said. This is a significant difference for researchers: instead of providing a snapshot of data, it's a "full-length movie."

Engineers at Raytheon and the NOAA Aircraft Operations Center have upgraded Coyote's sensor systems and improved its communications package to allow it to talk to the plane over longer distances, said Andrew Osbrink, Raytheon's Coyote program manager.

"The P-3 will be able to place the Coyote in the storm and continue on its mission without stopping or doing anything related to Coyote and continue doing the rest of their hurricane mission, undisturbed, and still receiving Coyote data at all times," he said. "This is a much better and much more efficient use of time and resources."

For Cione and his colleagues, Coyote is a critical tool that allows them to accomplish their mission.

"At the end of the day," Cione said, "my job is to use science, knowledge and my abilities to save lives and protect property." ■

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CLOUDS SWIRL AT THE EYE OF HURRICANE EDOUARD IN 2014. THE STORM MARKED THE FIRST USE OF RAYTHEON'S COYOTE UNMANNED AERIAL SYSTEM AS A WEATHER-FORECASTING INSTRUMENT. (NOAA PHOTO)

RAILGUN

LIGHTNING IN A BOX

RAYTHEON PUTS THE POWER BEHIND NAVY'S NEW MACH 6 RAILGUN

The shell screams down the rails at six times the speed of sound — so fast the air catches fire. It launches out over the open sea, and in about four minutes, it will strike a target more than 100 miles away.

That's the power of the U.S. Navy's new railgun, a futuristic weapon that fires projectiles at hypersonic speeds using electromagnetic energy instead of rocket motors or explosive charges.

Shooting something so far and so fast requires an immense burst of electric energy, and Raytheon is building a system to provide it. The company delivered the first piece of that system to the Navy in February, a crucial step forward in the testing and fielding of a weapon that physicists and engineers have been trying to build for about a century.

"People who have spent their lives trying to make this a reality are excited because they see it on the cusp of being real," said Tim Norcott, Raytheon's program manager for the power system. "It's there."

THIS PHOTO, TAKEN FROM A HIGH-SPEED VIDEO CAMERA, SHOWS A TEST FIRING OF THE U.S. NAVY'S NEW RAILGUN. THE RAILGUN USES ELECTROMAGNETIC ENERGY INSTEAD OF CHEMICAL PROPELLANTS TO SHOOT PROJECTILES AT MORE THAN SIX TIMES THE SPEED OF SOUND. (U.S. NAVY PHOTO)

NEW TECHNOLOGY, OLD IDEA

The Navy's railgun is a new iteration of an old idea. Railgun patents have been filed as long ago as 1921, and hobbyists have been building smaller, lower-powered models for decades. A railgun even showed up in the movie "Transformers 2: Revenge of the Fallen," firing from the deck of a U.S. Navy Arleigh Burke-class destroyer to take out an evil robot named Devastator that was demolishing a pyramid in Egypt.

In the real world, the Navy started pursuing the railgun as a high-tech addition to the arsenal currently on its warships. First of all, it's fast — the projectile would go from 0 to 5,000 mph in less than a millisecond, striking with such great kinetic energy that no explosive warhead is necessary, U.S. Navy Secretary Ray Mabus said in a June 2015 summit on directed energy.

Next, its round is lighter — 23 pounds, compared to the 70-pound shot that fires from the Navy's current 5-inch gun. Lighter, nonexplosive ammunition is both easier and safer to carry, meaning Navy fighters can stockpile rounds in greater numbers before shipping out.

The key to the Mach 6 shot isn't just the amount of energy required, but the speed at which the gun releases it. That power is measured in units called megajoules, and the Navy has specified that it wants the railgun to fire a 32-megajoule shot. That's about the same amount of force as 11 pounds of C4 explosives, Mabus said at the energy summit.

To produce that kind of pop, Raytheon has designed what is known as a pulse power container — a 20-foot-long, 8-1/2-foot-tall box that holds and connects dozens of smaller units called pulse power modules. The job of each of those modules is to draw in energy over several seconds and release it in an instant. Chain enough of them together, and they crank out enough power to make the Mach 6 shot.

Provided, of course, that they release all that power quickly, said Peter Morico, one of the engineers who worked on the system.

"If you had a 100-watt lightbulb and you sat in front of it 24 hours a day for 12 days, you'd absorb 100 megajoules. You could easily survive that," Morico said. "But release that same amount of energy in 10 milliseconds, and you, your house, your neighbor, your neighbor's house and your neighbor's neighbor's house are gone."

SHOCK TEST

Each module undergoes extensive testing before it graduates to the pulse power container.

The test starts with the push of a big green button.

A generator kicks on and the power starts to flow — 60 kilowatts, enough to light up 20 or 30 houses. The module, locked away in a test chamber for safety, drinks in the juice for about five seconds, then spits it out in an instant — directly into a water-filled barrel that absorbs the shock.

RAYTHEON BUILT THIS PULSE POWER CONTAINER TO PROVIDE THE MIGHTY 32-MEGAJOULE JOLT THAT THE U.S. NAVY'S NEW RAILGUN REQUIRES. THE RAILGUN WOULD FIRE A PROJECTILE AT SIX TIMES THE SPEED OF SOUND.

"It's like winding up a big spring for five seconds and letting it go," Morico said.

Except that spring would flap and flail from all the energy. In this test, if it goes well, nothing much happens at all. Only a malfunction such as a power arc would produce the kind of flashes and bangs you might expect from a test of such powerful electronics.

Inside the chamber, two high-definition cameras keep a close watch on the module. They show absolutely nothing happening; the video is so still it's indistinguishable from a photograph. The only noise is a modest pop, like a champagne cork shooting out of a bottle.

And while there's no actual champagne in the test chamber, this noise is both a sign of success and a cause for celebration.

"I love that sound," Morico said. ■

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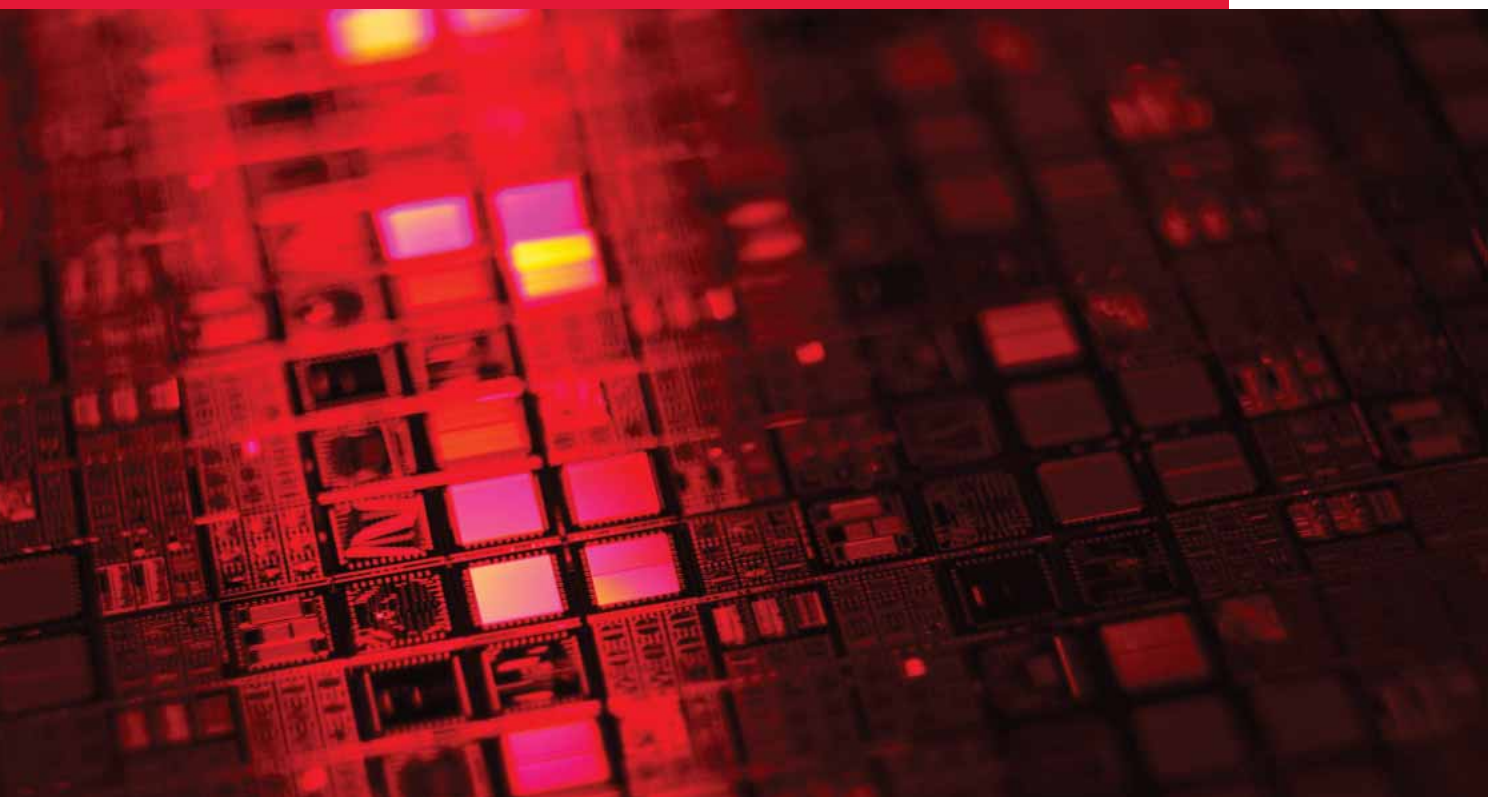
WRITING CYBER INTO WARFARE



CYBER ATTACKS ARE CHANGING THE WAY MODERN WAR IS WAGED, WRITES RAYTHEON'S WILLIAM LEIGHER, A FORMER U.S. NAVY ADMIRAL.

FROM BOOT CAMP TO THE BATTLEFIELD, CYBER HAS A ROLE IN EVERY ELEMENT OF THE MILITARY

This year, more than ever, the conversation about international conflict is turning to cybersecurity — protecting computer networks and everything attached to them. Cyber is constantly changing the way conflicts and combat unfold. Here, former U.S. Navy Rear Adm. William Leigher offers insights on adapting the principles of kinetic warfare to handle the ever-evolving cyber threat.

THE FUTURE OF CYBER WARFARE STARTS AT BASIC TRAINING

One of the most remarkable things about boot camp is that a kid can go in not knowing what an M16 looks like, and come out able to assemble one while taking enemy fire. Cyber warfare demands the same type of weapon — powerful, portable and effective even in the hands of novices.

Our experts call it the "easy button," and they caution that the enemy already has it. Hackers no longer need to know lines upon lines of computer commands; today they simply launch a program and tap or click their way to calamity. Our service men and women deserve cyber capabilities with the same ease of use — powerful software running on a cleanly designed interface that will allow even the greenest soldiers, sailors, Marines and airmen to venture out into the field and knock out power to an enemy base or jam a computer network to thwart an incoming attack.

DETERRENCE LOOKS DIFFERENT

Deterrence is a classic military tactic: The more visible power you have, the less likely your adversaries are to attack. Deterrence has worked brilliantly throughout history, but when it comes to cybersecurity, the strategy falls apart.

Think about deterrence tactics — an army parading its tanks down the street. Now imagine if showing off those tanks gave away every possible means of defeating them. That's what we're dealing with in cyber warfare. Showing adversaries what you have allows them to render it useless.

Unlike other acts of war, cyber attacks don't necessarily happen in close combat — they take place from afar. The perpetrators aren't flying their national flag — they often operate in isolation and secrecy. You can deter a hostile nation-state's military by having them outnumbered and outgunned, but keeping a shadowy cyber force at bay is far more complicated.

CYBER TRAINING SHOULD BE PART OF BOOT CAMP, RIGHT ALONGSIDE FIREARMS INSTRUCTION AND DRILLS, ACCORDING TO RAYTHEON'S WILLIAM LEIGHER, A FORMER U.S. NAVY ADMIRAL. IN THIS PHOTO, AIR FORCE RECRUITS FOLLOW INSTRUCTION DURING A BASIC TRAINING DRILL. (U.S. AIR FORCE PHOTO)

ATTACKS AREN'T OBVIOUS

There's a lot of talk in cyber circles about how the next major act of war will happen online — a "cyber Pearl Harbor." The problem with the comparison is that the attack on Pearl Harbor became obvious as soon as the ambush started. Skilled cyber attacks are far more insidious.

They unfold slowly and strategically. Just like military operations, they begin with intelligence — information-gathering. Dossiers. Reconnaissance. Then comes the analysis — picking the information apart, creating aim-points and deciding how, when and where to attack. But unlike traditional military attacks, the intelligence breaches and battle damage from cyber strikes isn't always immediately obvious — in fact, it can take months or even years to detect.

For years, cybersecurity experts have warned that high-stakes hacks were inevitable — a matter of when, not if.

It's time to take the thinking one step farther. It's time to assume the attacks, or at least the groundwork for them, are happening now.

MEASURING MEGABYTES LIKE MISSILES

All the tools of traditional warfare have something in common: They are quantifiable. Every radar has a range, and every missile has a blast radius. We know how far something can go and how powerfully it can strike, and we can also use physics and other science to extrapolate the damage it can do to its target. All that math goes into the very same battle simulations the military uses to ensure efficiency and effectiveness.

The problem with cyber warfare is that it doesn't conform to the same science. Without some meaningful method of measurement, it's infinitely more complicated to say what something can do and how well it works. That's where a lot of the hard thinking is right now — figuring out what a cyber blast radius looks like, and how best to measure it. ■

AIR FORCE CADETS UNDERGO CYBER OPERATIONS TRAINING. DEVELOPING INNOVATIVE, EASY-TO-USE CYBER WEAPONS WOULD ALLOW EVEN THE LEAST EXPERIENCED MILITARY PERSONNEL TO WAGE EFFECTIVE ATTACKS, ACCORDING TO RAYTHEON'S WILLIAM LEIGHER.

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IMPROVING MUNITIONS

SMALLER AND SMARTER

BREAKTHROUGHS POINT WAY TO MINIATURIZED WEAPONS THAT NEVER MISS

High-tech guidance systems are fitting into increasingly smaller weapons as engineers work to bring them the same pinpoint accuracy once found only in mammoth missiles and hulking bombs.

Miniaturized weapons not only require microscopic electronics, but something to protect them from the crushing G-forces that their launchers create. Raytheon's engineers have made advances on both fronts: The company's laser-guided Pike™ munition is nearly as narrow as some large-caliber ammunition, while the microelectronics in Raytheon's Excalibur artillery shell can withstand bullet-like acceleration — 0 to 760 mph in a fraction of a second.

"We've come really far. Now we have, basically, smart munitions you can hold in the palm of your hand," said Frank Antenori, a former U.S. Army Special Forces soldier who now manages the Pike program for Raytheon Missile Systems.

Smaller circuit cards and better shock protection for electronics made guidance feasible for precision mortars and artillery shells. Now, miniaturized guided weapons — rockets, artillery, GPS-guided mortars, radar-seeking and anti-armor weapons — are likely to become a major part of ground warfare, U.S. Deputy Defense Secretary Bob Work said in a recent speech at the U.S. Army War College in Pennsylvania.

"We're not too far away from guided .50-caliber rounds," Work said.

RAYTHEON'S 40 MM PIKE GUIDED MUNITION WEIGHS TWO POUNDS AND MEASURES 16.8 INCHES LONG. IT GIVES GROUND TROOPS A LIGHTWEIGHT PRECISION WEAPON THAT DOES NOT RELY ON A GROUND LAUNCHER.

Raytheon's Pike weapon measures 40 mm in diameter, only a half-inch larger than the 25 mm rounds fired by some military machine guns like those in the F-35 fighter jet and the M2 Bradley Fighting Vehicle. Soldiers can fire the two-pound, 16.8-inch long Pike munition from a rifle-mounted grenade launcher.

The benefit for ground troops: A lightweight precision weapon that doesn't tether them to a vehicle launcher. Using a laser designator that resembles a pistol, one soldier points at a target such as a light enemy vehicle, while another fires the munition. The goal, as with all precision weaponry, is to save innocent lives.

"When you have the capability to send something a mile and a half and hit within five yards or less of a bad guy, you are achieving what our troops have always wanted — take out a specific target and minimize collateral damage," Antenori said.

The Pike munition contains a rocket engine, which accelerates more slowly than a bullet or artillery shell. But engineers are also building guidance systems that can withstand the more jarring acceleration of those weapons.

RAYTHEON'S PYROS BOMB WEIGHS 12 POUNDS AND WAS DESIGNED TO LAUNCH FROM SMALL PLANES. THE WEAPON IS PART OF RAYTHEON'S LINE OF SMALL PRECISION ARMS.

Excalibur, a GPS-guided artillery shell, can fly 31 miles (50 kilometers) and strike within 6 1/2 feet (2 meters) of a target. Engineers encased the shell's electronics in a "hockey puck" filled with a putty-like material to protect them during firing.

Raytheon is developing a laser spot tracker that will allow Excalibur to strike moving targets and counter attempts to jam the GPS. A sea-based variant is also under development.

The Pike and Excalibur munitions are part of a growing line of increasingly small weapons, including:

- Pyros, a 12-pound, 22-inch-long bomb that uses laser and GPS guidance. Pyros launches from small unmanned aircraft, rotary-wing scout platforms, light attack aircraft and special mission aircraft.
- Griffin, a 33-pound, 43-inch-long missile that uses laser and GPS guidance. Its variants fire from platforms such as the C-130 aircraft, rotary- and fixed-wing aircraft , ground launchers and naval ships.
- The Precision Extended Range Munition, a 120 mm GPS-guided mortar designed for the United States Marine Corps' expeditionary forces. The system, codeveloped with Israeli Military Industries, doubles the range of current ballistic mortars while reducing collateral damage. Raytheon test-fired the projectiles successfully in December 2014.

Raytheon's larger guided weapons include the laser-guided AGM-65 Maverick missile, first produced more than 40 years ago; and the Paveway family of laser-guided bombs, which use laser and GPS guidance.

With smaller guided arms, Raytheon is striving to give ground troops the same level of dominance long exercised by U.S. and allied jet fighters, Antenori said.

"No one will fly against an F-15. No other air force in the world will do that because the F-15 will shoot you down well before you even know it's there," he said. "We've given that capability to the Air Force, and they've been enjoying that for a long, long time, but we've not given that capability to the infantry until now." ■

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TO PRINT A MISSILE

RAYTHEON RESEARCH POINTS TO 3-D PRINTING FOR TOMORROW'S TECHNOLOGY

The day is coming when missiles can be printed.

Researchers at Raytheon Missile Systems say they have already created nearly every component of a guided weapon using additive manufacturing, more commonly known as 3-D printing. The components include rocket engines, fins, parts for the guidance and control systems, and more.

"You could potentially have these in the field," said Jeremy Danforth, a Raytheon engineer who has printed working rocket motors. "Machines making machines. The user could [print on demand]. That's the vision."

The progress is part of a companywide push into additive manufacturing and 3-D printing, including projects meant to supplement traditional manufacturing processes. Engineers are exploring the use of 3-D printing to lay down conductive materials for electrical circuits, create housings for the company's revolutionary gallium nitride transmitters, and fabricate fins for guided artillery shells.

The process may reduce costs associated with traditional manufacturing, such as machining of parts. It allows for quick design and rapid changes because engineers only need change the digital model representing the part. As long as they stay within set parameters, they can have new parts in hours instead of weeks.

"You can design internal features that might be impossible to machine," said Raytheon engineer Travis Mayberry, who is researching future uses of additive manufacturing and 3-D printing. "We're trying new designs for thermal improvements and lightweight structures, things we couldn't achieve with any other manufacturing method."

With commercially available high-end equipment and specially modified versions of low-cost 3-D printers, Raytheon researchers have created nearly every component of a guided weapon using 3-D printing, including rocket engines, fins, parts for the guidance and control systems, and more.

"Ensuring consistent production integrity will be part of the next steps to realize this vision," said Dr. Teresa Clement, a Raytheon materials expert who also serves as the chair of the executive committee of America Makes, an initiative of the National Additive Manufacturing Innovation Institute.

A CUTAWAY MODEL SHOWING THE PRINTABLE COMPONENTS OF A SMALL MISSILE.

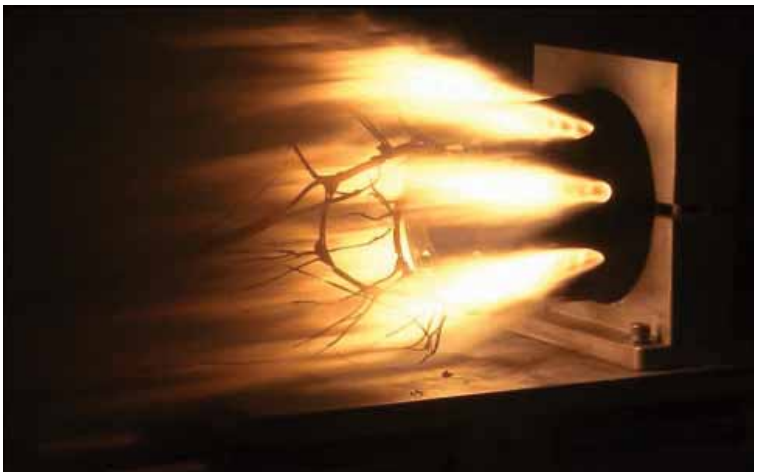
3-D printing could someday streamline the manufacturing process, said Leah Hull, additive manufacturing manager for Raytheon.

"When we print something, we have fewer piece parts, so your supply chain becomes simpler," Hull said. "Your development cycles are shorter; you're getting parts much faster. You can get a lot more complex with your design because [you can design] angles you can't machine into metal."

Engineers at the Raytheon University of Massachusetts Lowell Research Institute are developing ways to print complex electronic circuits and microwave components — building blocks of sophisticated radars used in products like Raytheon's Patriot air and missile defense system.

The current method of building microscopic circuits involves removing material to create a circuit pathway. In contrast, 3-D printing lays down just the material needed to build the electronic pathway.

"The word 'printing' implies lower cost," said Chris McCarroll, Raytheon director for the institute. "It's additive manufacturing. When we make integrated circuits [now], it's all subtractive. We put down very expensive materials and wash away everything we don't need."



AN ARRAY OF MID-MISSILE ROCKET BOOSTERS BUILT WITH 3-D PRINTING FIRE IN THIS IMAGE TAKEN FROM VIDEO.

Circuits can already be printed with inkjet printers. The goal is to print more complicated circuits in three dimensions, with the very high resolution and performance of silicon, he said.

"There's currently a hierarchy in our manufacturing. We make the structures, the housings, the circuit cards, with the right materials, and then we integrate them into a system," said McCarroll. "What we see in the near future is printing the electronics and printing the structures, but still integrating. Eventually, we want to print everything together. An integrated system."

Engineers at the research institute are already able to lay down the conductors and dielectrics needed for printed electronics. They can even lay down carbon nanotubes, tiny structures made of linked carbon atoms, and are working to align them to build futuristic circuits, according to McCarroll.

So could soldiers someday print and assemble missiles on the spot, in the same way that artillery crews custom-load their rounds or weapons handlers mount guidance kits on some types of bombs? McCarroll said that's still a ways off.

"Before a warfighter can print a missile in the field," he said, "you need quality, controlled processes to fabricate all the component materials: the metallic strongbacks, and the plastic connectors, the semiconductors for processors, and the energetics and propulsion systems. The hard part is then making the connections between these components, as an example, the integrated control circuit that receives the command to light the fuse. At some relatively near-term point you may have to place chips down and interconnect them with printing. Or, in the future, maybe you'll just print them."

Yet as clear as the challenges are, so is the promise. "There are folks in industry printing warheads," said Danforth. "We are printing demos of many of the seeker components. And we demonstrated a printed rocket motor. We've already printed 80 percent of what would go into a missile." ■

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A BOLD NEW INTERNET

RAYTHEON LEADS REDESIGN OF A NET DROWNING IN DATA

High school students gaze into a microscope, panning and zooming to watch microbes whirl inside a drop of water. The students are in Chattanooga and the microscope is in California, but what's truly novel is the sleek new way the Internet is delivering the torrent of high-resolution images.

What makes it possible for the students to work the controls and see the slide from 2,000 miles away is something called GENI, or the Global Environment for Network Innovations. Raytheon BBN Technologies leads the National Science Foundation-funded project, a years-in-the-making effort by researchers around the world to bring the Internet's decades-old design up to speed with the data-laden demands of new technology.

"The Internet was designed 40 years ago," said Mark Berman, a Raytheon BBN Technologies executive and the head of the project. "How would we design it now, given what we know today?"

GENI's powers go far beyond allowing students to use a microscope from across the country. Its ultra-fast delivery of data can also enable meteorologists to predict storms on shorter notice and even help first responders examine an emergency scene while still en route.

Regular conferences bring together hundreds of university researchers and others who have been experimenting with the futuristic Internet framework, said Erwin Gianchandani, deputy division director for computer and network systems at the National Science Foundation's computer and information science engineering directorate.

"People get together, they roll up their sleeves, and they say, 'Here's where we're going and how we get there,'" Gianchandani said.

RETHINKING THE RULES

GENI has been under way for eight years, with contributions from some of the world's foremost computer experts, but its basic principle is simple: It seeks faster and more efficient ways for data to move. Researchers are seeking alternatives to the fundamental rules that govern how data goes from

ENGINEERS AT RAYTHEON BBN TECHNOLOGIES ARE LEADING EFFORTS TO REDESIGN THE INTERNET FOR MODERN, HIGH-BANDWIDTH USE. THE PROJECT, CALLED GLOBAL ENVIRONMENT FOR NETWORK INNOVATIONS, IS AN INITIATIVE OF THE NATIONAL SCIENCE FOUNDATION. (NATIONAL SCIENCE FOUNDATION ILLUSTRATION)

one place to another, such as Transmission Control Protocol/Internet Protocol, or TCP/IP.

Under that system, which BBN Technologies helped to develop, a computer divides information into bursts and sends it into a network to be re-assembled at the other end. GENI, meanwhile, removes inefficiencies through techniques such as stashing clouds of certain data at various places in the pipeline.

"There are a lot of really clever things you can do to make things more efficient if you put just a little bit of storage and computation in different places," Berman said. "Now instead of shipping many, many copies of very, very popular information to some source, you pre-stage it in different places and deliver it locally."

That's already happening to an extent, but GENI would open the technique to smaller companies, Berman said.

"One change that GENI technology brings about is that in the next Internet, a new company doesn't need to be a big player to offer a similar service, because they can use shared infrastructure," he said.

GENI's goal, Gianchandani said, was to keep the everyday Internet intact while creating a separate environment for academics and other experts to devise and experiment with new and better ways to make it work.

"The Internet has come a long way," Gianchandani said, "and it is an economic driver for this nation and the world, but we need to be constantly innovating."

MARK BERMAN OF RAYTHEON BBN TECHNOLOGIES IS THE PROGRAM MANAGER FOR GENI, A NATIONAL SCIENCE FOUNDATION-FUNDED EFFORT TO IMPROVE THE WAY DATA MOVES THROUGH THE INTERNET.

THE TECHNOLOGY TAKES HOLD

What GENI can bring the world ranges from simple conveniences — losing the buffering bar when you stream a movie — to significant improvements in medicine and emergency response, Berman said.

"You can do most or all of these things with the current Internet. It just takes more work to do it and makes less efficient use of resources," Berman said. "GENI lets researchers and service providers experiment with and develop these capabilities more rapidly and efficiently."

Oncologists, for example, could enter information from a patient's genome and compare it quickly to cases around the world to determine the best course of treatment. Paramedics could see live drone video of an accident scene as they race to respond to it.

Other applications include weather forecasting — GENI can enable faster processing of data from weather radar in remote locations to spot far-away storms sooner — and even fitness; one program in particular can record video of an exercise routine and use image-processing algorithms to analyze the user's technique in real time.

These tools are no longer theoretical — they're actually happening. At STEM School Chattanooga, students can punch up a live feed from a lab at the University of Southern California and see a slide under a research-grade microscope, with insight and commentary from professional microbiologists.

"The Internet is already starting to look a lot more like the GENI vision," Berman said. ■

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CYBERSECURITY AT 1:16TH SCALE

RAYTHEON HACKS INTO MODEL TRUCK IN CREATIVE CYBERSECURITY DEMONSTRATION

Raytheon engineers hacked into a radio-controlled model truck to show how the company's technology can pinpoint vulnerabilities and fight off a cyber attack.

The demonstration, held by Raytheon's Cyber Operations and Development Evaluation (CODE) center, took place at the Association of the U.S. Army (AUSA) Annual Meeting and Exposition in Washington, D.C.

"We could've shown customers a 36-page slideshow that showcases the CODE center's capabilities," said Scott Harlan, the Raytheon engineer who drove the R.C. vehicle at AUSA. "But this car's way cooler."

While hacking an R.C. truck may seem innocuous, the vulnerabilities Raytheon engineers exploit to manipulate a toy mirror those cyber criminals could exploit to gain access to real-world systems.

A RAYTHEON ENGINEER CHECKS A RADIO-CONTROLLED TRUCK BEFORE ATTEMPTING TO HACK INTO ITS SYSTEMS.

REAL THREATS

Last year, a 14-year-old hacked a car's computer during the Battelle CyberAuto Challenge in Troy, Michigan, allowing him to activate the remote starter, the windshield wipers and the horn — with a device he built in less than a night, using $15 in electronics store parts. The hack was a strong reminder that every item connected to the Internet of Things — from military systems to mobile devices to vehicles — must be protected.

"Much of the public thinks that cyber vulnerabilities only exist on their PCs or cell phones," said Steve Rosenblum, senior director of the CODE center. "But in today's Internet of Things, anything with an IP address or wireless connectivity — including smart TVs, new cars, thermostats, door locks and now even watches — can be hacked if it isn't secure."

Raytheon began the demonstration with a command and control attack.

"We'll be adding state-of-the-art sensors including video cameras, telemetry, GPS, radios and other electronic equipment to the platform, which will be potential vectors for cyber attacks," Harlan said. "For example, we'll be able to exploit GPS hardware to show the driver they've reached a waypoint by displaying pre-recorded footage. But in reality, we'll have commandeered the vehicle."

"We could even show an episode of Baywatch if we wanted," Harlan said.

PREVENTING DATA THEFT

After Raytheon's cyber ranges identify exploits, their Electronic Armor anti-tamper solution can prevent reverse engineering, modification and theft of critical information found in computer software and firmware.

"Electronic Armor solution has tamper detection and a 'penalty response,'" said Damon Hardy, a mission manager for Raytheon's Centers of Innovation. "For example, if someone were to insert a thumb drive into a computer to steal data, Electronic Armor could respond by uploading decoy data, setting off alarms, encrypting or erasing the data, or 'bricking' the computer."

PROTECTING MILITARY HARDWARE AND SYSTEMS

Raytheon requires that its military radars and weapons systems pass rigorous tests in real-world conditions. Bill Leigher, advanced solutions director at Raytheon's Intelligence, Information and Services business, says cybersecurity technology must also meet rigorous standards.

"Raytheon is well aware of the many serious cyber threats in the world today," said Leigher. "For many years, we've ensured that if our equipment comes under cyber attack, it will continue to work as advertised."

As hackers and their tools become more sophisticated, their targets are expanding from military hardware to other connected items. Though electronics built in the '80s, '90s and '00s are still in use, they weren't designed with cybersecurity in mind. This makes them prime candidates for cyber exploitation.

Rosenblum warned that equipment designed with protection against today's threats may not be secure tomorrow. But he said Raytheon technology is designed to keep pace with adversaries that are constantly changing tactics and developing more sophisticated tools.

"Raytheon's cyber-defenses are every bit as fluid and ever-changing," he said. ■

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QUANTUM COMPUTING

THE (QUANTUM) MECHANICS' SHOP

SUBATOMIC SCIENCE HIGHLIGHTS RAYTHEON'S FUTURISTIC RESEARCH

In an unassuming brick building in Cambridge, Massachusetts, a lab buzzes — literally — with technology so powerful it could lead to the discovery of new planets, help detect cancer earlier, create hacker-proof computer networks and transmit live video from the surface of Mars.

Welcome to Raytheon's hub of quantum computing, a new field that uses subatomic particles to store digital information. It's one of hundreds of futuristic research programs at Raytheon, from "intelligent" power systems to computer chips made of diamond.

"We're inventing things here," said Jonathan Habif, a senior scientist at Raytheon BBN Technologies. "There's so much technology that's yet to be explored and discovered."

Habif works in the Quantum Information Processing group, which is learning to use subatomic particles instead of silicon circuits to store the 1s and 0s that make up computer data. Unlike normal "bits" of data, quantum bits — or "qubits" can exist in both states at the same time.

SCIENTIST BLAKE JOHNSON WORKS WITH AN ELECTRON BEAM EVAPORATOR, USED TO CREATE SMALL COMPUTER CHIPS FOR RAYTHEON'S QUANTUM COMPUTING RESEARCH.

Scientists can use quantum technology to protect data by sending encryption keys encoded on photons, or tiny particles of light. If a third party tries to eavesdrop, the communication ends immediately.

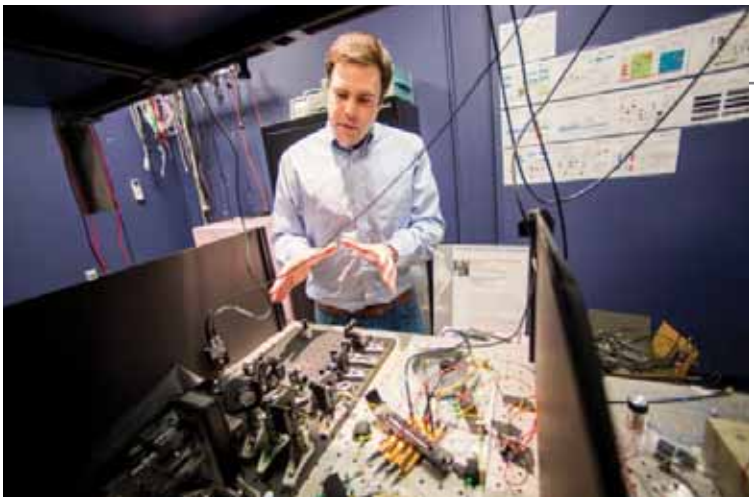
"It's secured by the laws of physics," said Zachary Dutton, who leads the Quantum Information Processing group. "In an academic environment, you'd write a paper and leave it at that. But here we're preparing technologies that can be used in actual applications."

In laboratories around the world, Raytheon researchers are pushing new technologies to the edge of human knowledge. In nearby Andover, Massachusetts, they're putting circuits on slivers of artificial diamond to create more efficient electronics. In El Segundo, California, they're building satellite sensors that can "see" the Earth in 22 bands of the electromagnetic spectrum at once.

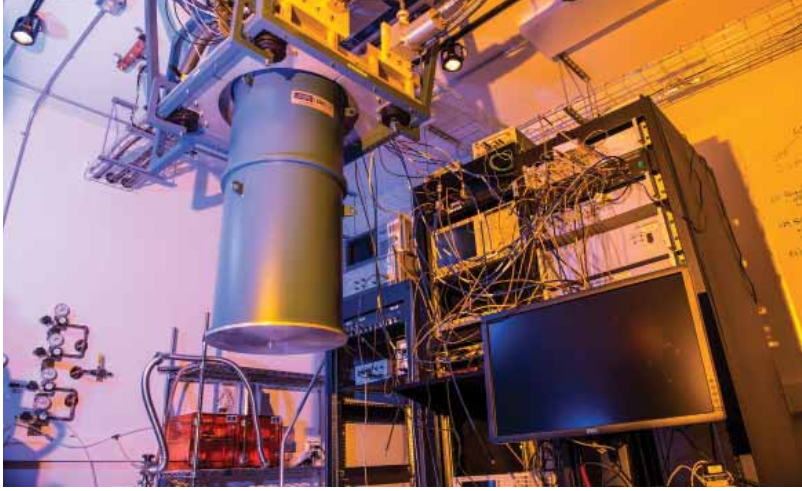
Other engineers are working on nanotechnology or building electrical systems to power missile-destroying lasers. In addition to customer-funded projects, Raytheon invests significant resources in research and development each year. The company's engineering magazine, "Technology Today," publishes hundreds of new Raytheon patents in every issue.

THE VIEW FROM MARS

Habif's lab is filled with lenses, photon detectors, optical fibers and other instruments so precise that Habif can't even be in the room during tests because his movement and body heat would affect the results.



SENIOR SCIENTIST JONATHAN HABIF EXPLAINS THE LENSES, PHOTON DETECTORS AND OTHER INSTRUMENTS IN THE RAYTHEON BBN TECHNOLOGIES OPTICAL COMMUNICATIONS LAB. HABIF IS USING QUANTUM MECHANICS TO DEVELOP NEW WAYS OF TRANSMITTING INFORMATION.



RAYTHEON RESEARCHERS USE THIS DILUTION REFRIGERATOR TO CREATE SUPERCONDUCTING COMPUTER CHIPS.

A single ray of light coming into the room would throw off the quantum mechanics research he's doing on optical sensing systems. So the lab has no windows.

Habif is developing receivers that use quantum mechanics to collect encoded information from the dimmest rays of light. With this technology, astronauts on Mars could use lasers to beam back live video and other information.

CHANGING THE WORLD

Researchers hope that quantum technology could eventually lead to lightning-fast computers that might aid everything from cancer research to astronomy.

Down the hall from Habif's optics lab, a 5-foot-tall cylinder in the quantum computing lab "whooshes" like a high-pitched heartbeat. It's the sound of helium and other gases being pumped in and out of the tank, known as a "dilution refrigerator."

The device creates temperatures colder than any naturally-occurring place in the solar system — 1/100 of a degree Kelvin above absolute zero, to be exact.

Scientist Blake Johnson uses the extreme cold to forge superconducting computer chips. A quantum computer using these chips could be orders of magnitude more powerful than fastest desktop PCs, opening up whole universes of technological possibility.

"What we're doing here will change the world," Johnson said over the din. "I know it sounds corny, but it's true." ■

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FROM MATERIALS SCIENCE TO CYBER RESEARCH, FROM SPACE TO THE DEEPEST PARTS OF THE OCEAN, RAYTHEON IS CHALLENGING THE LIMITS OF HUMAN KNOWLEDGE AND ABILITIES.

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