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Laser tailguns

Lockheed Martin tackles atmospheric turbulence for jet fighter laser weapons. PAGE 2

Energy storage

Militaries look to lithium-ion and energy storage innovations to power modern electronics. PAGE 15

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Laser weapons

Are directed-energy weapons, including lasers, ready for widespread military deployment? PAGE 6

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NOVEMBER 2015
VOL. 26, NO. 11

Military & Aerospace Electronics

2 TRENDS

3 NEWS IN BRIEF

COVER STORY

6 SPECIAL REPORT

Laser weapons at the crossroads

Directed-energy weapons like lasers have been in development for decades, show great promise, and are being field-tested in substantial numbers, but are they ready for widespread deployment?

15 TECHNOLOGY FOCUS

Feeding the power-hungry beast

Militaries look to lithium-ion and energy storage innovations to power myriad modern electronics.

25 RF & MICROWAVE

26 UNMANNED VEHICLES

27 ELECTRO-OPTICS WATCH

28 PRODUCT APPLICATIONS

29 NEW PRODUCTS

BY **JOHN KELLER**, EDITOR IN CHIEF

Lockheed Martin laser weapons tackle atmospheric turbulence

Laser weapons experts at Lockheed Martin Corp. are moving closer to overcoming one of the most difficult design roadblocks that so far has prevented deployment of laser cannons on supersonic jet fighters.

The problem involves compensating for atmospheric turbulence to enable a laser weapon to fire accurately from any angle on a fast-moving platform. Without compensating for atmospheric turbulence, a laser weapon mounted to an aircraft moving at near the speed of sound only could fire accurately at targets directly in front of it. Such a setup would be ineffective in countering manned and unmanned aircraft, as well as a variety of missile threats, which can attack from any direction.

Lockheed Martin Space Systems researchers in Sunnyvale, Calif., have completed nearly 60 flight tests of the Aero-adaptive Aero-optic Beam Control (ABC) turret, being developed for the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va. The ABC turret is demonstrating a 360-degree field of regard for laser weapon systems on an aircraft flying near the speed of sound, officials say. The tests have been on a business jet to simulate the supersonic environment of a jet fighter.

Lockheed Martin began developing the ABC laser turret in early 2013 under terms of a $9.5 million contract from DARPA for the ABC program's third phase to improve the performance of high-energy lasers on tactical aircraft against enemy aircraft or missiles in the aft field of regard.

The ABC test unit involves a low-power laser that fires through the turret's optical window to measure and verify the laser's performance in all directions. The design uses aerodynamic and flow-control technology to minimize the effects of turbulence on a laser beam. The tests have involved DARPA, the U.S. Air Force Research Laboratory (AFRL) at Wright-Patterson Air Force Base, Ohio, and the University of Notre Dame in South Bend, Ind.

The ABC turret system is designed to enable high-energy lasers to engage enemy aircraft and missiles above, below, and behind the aircraft. Flow-control and optical-compensation technologies counteract the effects of turbulence caused by the protrusion of a turret from an aircraft's fuselage. An optical-compensation system that uses deformable mirrors helps the beam to cut through the atmosphere to the target. Without compensation from the deformable mirrors the intense atmospheric turbulence around an aircraft flying at supersonic speeds would scatter the light of the laser beam.

Scientists from DARPA and AFRL will use results of the flight tests to fine-tune future requirements for laser weapons on high-speed aircraft.

Designing high-energy laser weapons for supersonic aircraft has the potential to revolutionize air-to-air and air-to-ground combat. Given a sufficient supply of electric power, laser weapons do not run out of ammunition. Laser weapons on a rotating turret, moreover, have the potential to be faster, more effective, and far more difficult to spoof than conventional air-to-air weapons. Missiles and bullets fly far more slowly than the speed of light, and are more prone to problems from atmospheric turbulence, high-G forces, and countermeasures to throw off guidance systems. Laser weapons would be immune to conventional electronic warfare (EW) jamming that can defeat many of even the most advanced radar-guided anti-aircraft missiles.

Laser weapons would force adversaries to spend time, effort, and money to devise optical countermeasures to laser weapons and usher in a new generation of optical warfare.

It's not clear how long it might take to devise a deployable laser weapon for high-performance jet fighters. It's unlikely we'll see deployed laser weapons on fighter aircraft until at least the next decade.

IN BRIEF

Exelis to EMP-harden missile warning radar

Radar experts at Exelis in Colorado Springs, Colo., will harden U.S. ballistic missile defense radar systems against the effects of electromagnetic pulse (EMP) under a $12.4 million contract. U.S. Air Force Life Cycle Management Center officials at Peterson Air Force Base, Colo., are asking Exelis to implement the Ground-Based Radar High Altitude EMP Certification program, and perform sustainment and system engineering on long-range radars involved in the Ballistic Missile Early Warning System, Phased Array Warning System, and Perimeter Acquisition Radar Attack Characterization System.

Northrop Grumman builds IED jammers

Electronic warfare experts at Northrop Grumman are producing backpack improvised explosive device jammers to protect deployed U.S. Marines. Officials of the Naval Sea Systems Command awarded a $95 million contract to Northrop Grumman Information Systems in Herndon, Va., for low-rate initial production of the Joint Counter Radio-Controlled Improvised Explosive Device Electronic Warfare system for the Marine Corps. Options could increase the value to $213.4 million.

Lockheed Martin to build Long Range Discrimination Radar

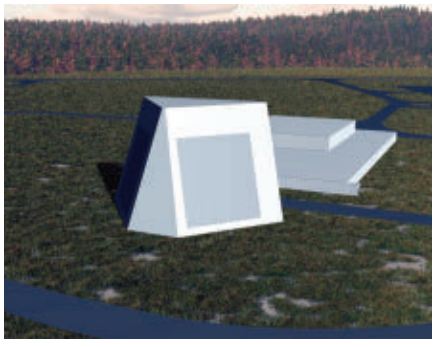
BY JOHN KELLER

HUNTSVILLE, Ala. — Lockheed Martin won a ballistic missile defense contract to build and operate an advanced long-range radar system near Fairbanks, Alaska, to help protect the U.S. from missile attack.

Missile Defense Agency (MDA) officials in Huntsville, Ala., announced a $784.3 million contract to Lockheed Martin Mission Systems and Training in Moorestown, N.J., to develop, deploy, test, and operate a Long Range Discrimination Radar (LRDR) at Clear Air Force Station, Alaska. The LRDR program is the backbone of the MDA's layered defense to protect the U.S. homeland from ballistic missile attacks of all ranges in all phases of flight.

LRDR is a long-range radar that will provide precision metric data to improve ballistic defense discrimination and replace existing sensors in the Ballistic Missile Defense System (BMDS). LRDR combines solid-state radar technologies with ballistic missile defense algorithms on an open-architecture designed for future growth. The solid-state, gallium nitride (GaN)-based radar uses Lockheed Martin's Open GaN Foundry model, which leverages relationships with strategic GaN suppliers.

The LRDR will serve as a BMDS midcourse sensor to counter evolving ballistic missile threats, as well as improve the ability to tell real ballistic missile warheads from decoys in any attack in the Pacific Ocean.



Lockheed Martin is designing a next-generation long-range ballistic missile defense radar system.

MDA officials are asking Lockheed Martin to have the BMDS finished and operational no later than 2020. Lockheed Martin will conduct operating frequency band system tradeoffs. Company experts also will consider the relative benefits of limited field of view or full field of view for an aperture of a given radar sensitivity. Company experts also will consider the potential scan loss that the terrain around Fairbanks, Alaska, imposes; the benefits and drawbacks of mechanical slewing in azimuth or azimuth-elevation; polarization selection and its potential effects on cost and sensitivity; resistance to electronic warfare jamming; opportunities to reduce power consumption; software and hardware reuse; and open-systems non-proprietary software architectures.

FOR MORE INFORMATION visit **Lockheed Martin** at *www.lockheedmartin.com*.

Northrop Grumman eyes next-generation ship self-protection laser weapon

BY JOHN KELLER

ARLINGTON, Va. — Scientists at Northrop Grumman are building a shipboard laser weapon prototype able to disable or destroy enemy fast attack boats, drones, and surveillance sensors. It will use existing shipboard power generation and will be appropriate for a variety of U.S. Navy surface warships, including Arleigh Burke-class destroyers.

Officials of the Office of Naval Research (ONR) in Arlington, Va., announced a $53.2 million contract to Northrop Grumman Aerospace Systems in Redondo Beach, Calif., for the initial phase of the Solid State High Power Laser Weapon System Demonstrator (LWSD) program. The prototype laser weapon will build on technologies developed for the Navy's AN/SEQ-3(XN-1) Laser Weapon System (LaWS), which deployed to the Persian Gulf in 2014 on the amphibious transport dock USS Ponce to counter unmanned and light aircraft, as well as small attack boats.

Northrop Grumman will demonstrate an enhanced laser weapon from a surface test ship during the day and at night for ship self-defense missions that include destroying or disabling fast attack boats, unmanned aerial vehicles, and sensor systems used for intelligence, surveillance, and reconnaissance. Navy officials say that LaWS technology could be even more lethal with adjustments to the laser weapon's power, beam quality, beam director, and system design. These are the enhancements that the LWSD program seeks to achieve.

Northrop Grumman Corp. will develop the next-generation shipboard laser weapon by building on technologies developed for the Laser Weapon System (LaWS), shown above.

The LWSD program is an extension of long-term Navy plans to develop shipboard laser weapons that can acquire, track, identify, engage, and defeat a variety of surface vessels, manned and unmanned aircraft, and missiles. While LaWS is as powerful as 15 to 50 kilowatts, the LWSD program seeks to increase shipboard laser weapons power to 100 to 150 kilowatts using existing shipboard power and cooling.

Navy experts will install the LWSD for at-sea demonstrations aboard the former Spruance-class destroyer USS Paul F. Foster, the Navy's self-defense test ship. Navy experts eventually plan to install and test the LWSD aboard a commissioned late-model Burke-class destroyer.

The LWSD will have a solid-state laser, beam director, targeting and tracking, fire-control, power, and cooling subsystems that interface with existing shipboard systems.

Northrop Grumman will explore design tradeoffs between laser power, beam quality, optical path, duty cycle, aperture, mechanical robustness, and other physical and optical attributes to enhance lethality, integration, sustainability, and reliability.

Northrop Grumman experts will consider scalable architectures for lower-/higher-power levels; adjustable power on target to provide effects ranging from deny, disrupt, damage, and defeat; beam director and tracking technologies for low jitter; and ruggedizing the system against the effects of corrosion, shock, vibration, moisture, and electromagnetic environmental maritime effects.

During at-sea testing, Northrop Grumman engineers will provide system interfaces to simulate the Navy's Aegis combat system, and package the LWSD for future re-installation on a Burke-class destroyer with minimal modifications. Experts will integrate the LWSD prototype with the laser weapon console developed under the LaWS program, as well as with the Hybrid Predictive Avoidance Safety System, a safety system that prevents interference with satellites.

Northrop Grumman will do the work in Redondo Beach, Calif., and should finish by October 2016.

FOR MORE INFORMATION visit **Northrop Grumman Aerospace Systems** online at *www.northropgrumman.com*.

Laser weapons at the crossroads

Directed-energy weapons like lasers have been in development for decades, show great promise, and are being field-tested in substantial numbers, but are they ready for widespread deployment?

BY **J.R. Wilson**

Ray guns, Jedi lightsabers, Imperial blasters, Klingon disrupters, Federation phasers, Martian heat-rays—directed-energy weapons (DEWs) have been a staple in science fiction since H.G. Wells's *War of the Worlds* in 1898. While the first laser was not developed until 1960, there is a long list of real or imagined precursors dating back nearly 2,500 years, including:

- Secret, independent work on radar by pre-World-War-II researchers in France, Germany, Italy, Japan, the Netherlands, the Soviet Union, the United Kingdom, and the United States, which was seen as the possible basis for a "beam" weapon;
- Nikola Tesla's experiments with — and claims to have built and demonstrated — "charged particle

The Boeing Compact Laser Weapon System's beam director focuses the laser beam onto the fine aim point on a target during an engagement.

beam weapons" in the 1920s and '30s; and

- Greek inventor Archimedes's "burning mirror" weapon, which, according to legend, set afire Roman ships attacking Syracuse in 212 BC.

The U.S. military began to show real interest in directed-energy weapons in the 1980s, as part of President Ronald Reagan's Strategic Defense Initiative. In its early concept, SDI was seen as using orbiting lasers — first X-ray, then chemical — as part of a layered defense to destroy enemy missiles from launch through the exoatmospheric midcourse phase. Ultimately, the idea was scrapped for reasons of insufficient beam power and the need for hundreds of satellite-based lasers with low expectations of efficiency.

With the collapse of the Soviet Union, attention turned to development of an Air-Borne Laser (ABL) — a powerful chemical laser installed on a Boeing 747 jumbo jet flying a circular patrol pattern close to potential enemy missile launch sites. While initial test firings were deemed a success, only one ABL was built before that program was scrapped.

Steve Hixson, now vice president for directed energy programs at Northrop Grumman Aerospace Systems, was the company's ABL program manager. He explains why a megawatt-class chemical oxygen iodine laser (COIL) mounted inside a modified Boeing 747-400F represented a technological dead end — especially with the development of solid-state lasers (SSLs).

"A chemical iodine laser in a 747 has no future," Hixson says. "Aside from the logistics issues of the chemicals, the Air Force only had one other 747 in its inventory — and that was Air Force One. I don't see chemical lasers coming back now that we are on the march with solid-state lasers, where you don't need those chemicals, just power and cooling. Just like some kinetic weapons, chemical lasers have a limited magazine — once the chemical reaction is done, you have to return to base. With a solid-state system, you can persist," he says, adding high-energy (HE) SSLs now are part of every service's plans for the future.

Boeing's High Energy Laser Mobile Demonstrator proved the effectiveness of directed energy weapons in foggy, off-shore conditions during demonstrations in Florida. [Boeing photo]

"We got into solid-state lasers while looking at a commercial application for next-generation photolithography and found we could scale those to tactically relevant powers," Hixson says. "We were the first to demonstrate technology over 100 kilowatts in 2009 on a program called the Joint High Power Solid State Laser [JHPSSL]. Using that technology, we more recently [2011] demonstrated a maritime laser at sea. We hope to put lasers on surface ships and aircraft for self-defense."

Ground-based defense

The U.S. Army is looking at HE lasers for ground-based defensive — and, ultimately, potentially offensive — applications. Two such efforts are the Robust Electric Laser Initiative (RELI), designed to advance electric laser technology for the U.S. Army Space and Missile Defense Command for multi-service, next-generation laser weapons applications, and the Solid State Laser Testbed Experiment (SSLTE) at the Army's High Energy Laser Test Facility at White Sands Missile Range, N.M. Northrop Grumman's 105-kilowatt solid-state laser is at the core of the SSLTE.

"Any sort of ground-based laser will have to fit within some moving vehicle, as opposed to something stationary and vulnerable," Hixson says. "Looking at the Maritime Laser Demonstration and other programs ONR [the Office of Naval Research] is doing with the surface ship laser, those are all self-defense missions against swarming small boats, UAVs and, eventually, anti-ship cruise missiles. When we look at airborne applications, I can't think of anything in the near-term any customer is asking for that would be anything but self-defense."

The top leadership of the Army, Navy, and Air Force see high-energy lasers as a primary weapon system in the coming decades — especially with the savings on ammunition, logistics, maintenance, range- and endurance-limiting weight, and high precision with little risk of collateral damage. In a smaller, budget-constrained military, high-energy lasers are seen as force multipliers, with the ability to "dial" the force of the beam up or down to meet specific mission requirements reducing the need for multiple weapons in theater.

There is concern that the U.S. is falling behind rather than leading in the development and fielding of high-energy laser technology.

"Just two weeks ago, [the destroyer] USS Forrest Sherman (DDG-98) and her attached helicopter were repeatedly targeted by a laser from an Iranian-flagged merchant vessel. Last week 11 commercial airliners were targeted by lasers in the vicinity of a New Jersey airport," Navy Secretary Ray Mabus told the Directed Energy Summit on 28 July. "These are examples of how the world is getting faster and is changing exponentially — the world, that is, with the exception of the United States military."

Mabus noted the Navy's Mid-Infrared Advanced Chemical Laser (MIRACL), its first megawatt high-energy laser, was built in the 1980s, but it was not until 2012 that a prototype high-energy laser was installed on the flight deck of the [destroyer] USS Dewey (DDG-105) and two more years before the Laser Weapon System (LaWS) was deployed for operational tests aboard the amphibious transport dock USS Ponce, the Navy's interim Afloat Forward Staging Base in the Persian Gulf.

According to a Navy report at the time of the Ponce tests: "LaWS hit targets mounted aboard a speeding oncoming small boat, shot a Scan Eagle UAV out of the sky, destroyed other moving targets at sea, [and]

performed flawlessly, including in adverse weather conditions of high winds, heat, and humidity... exceeding expectations for both reliability and maintainability."

International laser weapons

Many other countries are working on offensive and defensive directed-energy weapons. Israel, China, and Russia, in particular, have invested billions into high-energy laser research.

At the 2014 Singapore Airshow, Israeli defense contractor Rafael unveiled its "Iron Beam," a mobile high-energy laser-based air defense system. According to company officials, Iron Beam, still in development, can incapacitate missiles as far away as 1.5 miles and "bring down mortars like flies."

China has been uncharacteristically public in reporting its own laser program successes, which include a defense system that can shoot down small-scale, low-flying UAVs flying at nearly 80 miles per hour at ranges exceeding one mile, according to a statement published by the China Academy of Engineering Physics.

Russia is working on surface and airborne lasers. Russian media reported that the nation's Defense Ministry "placed an order with the defense industry to resume development of combat lasers [three years ago]. [The daily newspaper *Izvestia*] quoted well-informed sources in the defense industry as saying the order focused on modernization of an A-60 flying laboratory on the basis of the Ilyushin-76 airlifter."

In December 2014, Alexander Khramchikhin, a deputy director of the Institute of Political and Military Analysis, told Russia's TASS news agency: "It is clear as daylight now

that the transformation of *Star Wars* scenarios into reality has flopped, but laser weapons should develop as part of tactical air defense strategies. That's the only niche, but there's no alternative to lasers in it. It's more or less clear today that lasers don't have any other combat use, as the problems of energy and dispersal of the beam at long distances cannot be resolved at the current stage."

Europe, including NATO, is lagging behind. It was not until November 2014 that NATO's Science & Technology Organization approved the creation of a group to examine the tactical implications of next-generation directed-energy weapons, focusing on issues surrounding their use in a shared NATO battlespace.

"The [November 2014 kickoff] meeting was very productive and the group achieved consensus to pursue a three-year program of work that will have several main products. First will be a briefing suitable for senior NATO leadership to provide better awareness of the rapid advancement in high-energy laser weapon capabilities, the tactical scenarios that are likely to be suitable for employment of such systems and the implications for collaborative military operations," NATO officials said in a statement on 8 December 2014.

"The main thing is to have a focus on this as a cohesive whole instead of a program here, a program there, stovepiped, one for surface, one for air, one for lasers, one for railguns, one for this, one for that," says Mabus, who plans to issue a roadmap before the end of 2015 placing one group in charge of determining Navy needs for directed-energy weapons.

"[The roadmap] charts our course for research, development, and fielding of high-power, radio-frequency weapons, lasers, and directed-energy countermeasures," Mabus says.

Middle East deployment

The Navy has extended the LaWS deployment in the Middle East to follow up on its early success, especially in narrow operating environments such as the Strait of Hormuz at the entrance to the Persian Gulf.

The U.S. Navy Afloat Forward Staging Base (Interim) USS Ponce (AFSB(I)-15) conducts an operational demonstration of the Office of Naval Research-sponsored Laser Weapon System while deployed to the Arabian Gulf. [U.S. Navy photo by John F. Williams]

"The variable intensity of directed energy gives commanders the power to choose whether to deter, disable, or destroy all with one system," Mabus explains. "The cost of a single laser 'shot' from our Laser Weapons System is less than one dollar, compared to hundreds of thousands — in some cases, millions — of dollars for current self-defense payloads.

"Not only has that laser proven its ability to withstand the intense heat in the region and the maritime environment, it has proven its ability to defeat small boats and airborne targets," Mabus adds. "It only takes one sailor to operate and can also be used as a telescope."

Naval Sea Systems Command (NAVSEA) Chief Engineer Rear Adm. Bryant Fuller told the same conference everything they have learned so far about the operational use and rules of engagement for LaWS also will apply to larger future laser weapons, such as the 100-to-150-kilowatt Solid State Laser Technology Maturation program being pursued by the Office of Naval Research to produce a prototype for at-sea testing by no later than 2018.

The U.S. Army has been testing the Boeing-built, truck-mounted High Energy Laser Mobile Demonstrator (HEL MD) against air and ground targets. In 2013 and '14, the HEL MD engaged more than 150 aerial targets, from 60-millimeter mortars to UAVs. In those demonstrations, the HEL MD used a 10-kilowatt laser — far below the planned power of an operational weapon — mounted on an Oshkosh tactical military vehicle. It was the

Army's first mobile high-energy laser counter-rocket, artillery, and mortar platform. The next step is to increase the laser's power to 50 to 60 kilowatts and ultimately to 100 kilowatts.

"As proven at White Sands Missile Range in New Mexico in 2013 and at Eglin Air Force Base [in 2014], HEL MD is reliable and capable of consistently acquiring, tracking, and engaging a variety of targets in different environments, demonstrating the potential military utility of directed energy systems," says David DeYoung, director of laser & electro-optical systems at Boeing Defense, Space & Security.

"With capabilities like HEL MD, Boeing is demonstrating that directed energy technologies can augment existing kinetic strike weapons and offer a significant reduction in cost per engagement," DeYoung says. "If you look not just at lasers, but the entire way of doing engagements, in a budget-limited environment, you don't want to use an $8,000 missile to take on a $1,500 drone; to fire a laser is basically just the cost of electricity to take that shot. Lasers also replace the missile's resupply chain. With only the cost of diesel fuel, the laser system can fire repeatedly without expending valuable munitions or additional manpower."

Destroying UAVs

In summer 2015, Boeing destroyed a free-flying UAV over a California test site with its latest high-energy laser system — the Compact Laser Weapon (CLW), which is much smaller and lighter than the HEL MD. The CLW weighs about 650 pounds and fits into four suitcase-sized containers and can be set up in minutes by two warfighters, making it much more portable and therefore of great interest to small, fast-moving military units, such as the Marines or Special Operations.

Earlier in the year, Boeing experts demonstrated the CLW's surveillance capabilities to the Marine Corps in a field exercise in which the weapon tracked and identified flying helicopters and UAVs at distances of several miles. The first CLW prototype already has been delivered to an unidentified military customer while DeYoung's team develops a second-generation version, based on customer recommendations.

"We are working with various customers to turn the CLW into a fielded product, with counter-UAV as its primary mission, although it is capable of other things, such as counter-ISR [intelligence, surveillance, and reconnaissance]. We also are looking at the next generation of larger weapons systems and remain involved with the HEL MD, the Army's ground-based laser program, working on minor upgrades to allow it to accept a higher power laser," DeYoung says.

Reflecting the U.S. Department of Defense requirement for interoperable systems that avoid research duplication, Boeing is leveraging its work on HEL MD and CLW to design a prototype High Power Beam Control Subsystem (HP BCSS). This system is compatible with high-energy and solid-state laser systems that other companies are designing for ONR's Solid State Laser Technology Maturation (SSL-TM) program.

SSL-TM involves developing shipboard laser weapons for a fast, inexpensive, and precise defense against a variety of surface and air threats, including future anti-ship cruise missiles and swarms of small boats. High-energy laser technology would

eliminate any maneuver advantage such threats would have over current ship's defenses and save its expensive missiles for higher-priority targets. The high-energy laser's overall benefits to the Navy include multiple target engagement, non-explosive magazines, counter-surveillance at sea, flexible defense of battle group, advanced maritime situational awareness, and high-resolution imagery with beam director — all working synergistically with current and future kinetic weapons.

Fiber and free-electron lasers

Future naval defensive and offensive directed-energy weapons will focus on fiber laser and free-electron laser components. ONR says the development of beam control technologies are applicable to different types of directed-energy weapons, including modeling and simulation to support directed-energy weapon development and testing. Given the size, weight, and power requirements of existing lasers — and the primary targets for enemy anti-ship attacks — the first naval directed-energy weapons likely will go aboard Navy aircraft carriers.

Rear Adm. Michael Manazir, director of air warfare, calls the carrier "a wonderful platform for the installation of directed energy" — first for defense, but, as the technology advances, later for offense. The new Ford-class carriers were designed to accommodate such systems, able to generate three times the electrical power of the older Nimitz-class — 13,800 volts compared to 4,160 volts. Its four 26-megawatt generators provide the ship with a total of 104 megawatts of power.

That massive power production, combined with enhanced energy storage, will come in handy; future naval high-energy lasers will need as much power as 300 kilowatts. At that stage they not only will complement the service's electromagnetic railgun (EMRG), now in testing, and other next generation weapons, but ultimately may replace missiles like the $1.1 million Rolling Airframe Missile (RAM) and the $1.5 million Evolved Sea Sparrow Missile (ESSM).

U.S. Navy personnel operate the Office of Naval Research-sponsored Laser Weapon System aboard the Afloat Forward Staging Base (Interim) USS Ponce. Directed energy weapons counter asymmetric threats, such as unmanned and light aircraft and small attack boats. [U.S. Navy photo by John F. Williams]

Air Force high-energy laser efforts include the High-Energy Liquid Laser Area Defense System (HELLADS), jointly funded by the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va., and the Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio. Recently HELLADS moved from the lab into active field tests at White Sands, where it is being tested against rockets, mortars, vehicles, and surrogate surface-to-air missiles.

After nearly a decade and a half of research, HELLADS is closing in on its original goal of developing a 150-kilowatt laser only one-tenth the size and weight of standard lasers of comparable power — down to three cubic meters in size and less than five kilograms per kilowatt of power, enabling it to fit aboard tactical aircraft.

"The technical hurdles were daunting, but it is extremely gratifying to have produced a new type of solid-state laser with unprecedented power and beam quality for its size," says DARPA Program Manager Rich Bagnell.

"The technology is ripe [for airborne lasers]. I have the space, I have the weight, and I have the power on an AC-130J 9 [four-engine utility turboprop aircraft] to put a high-energy laser on an aircraft," Lt. Gen. Bradley Heithold, commander of the U.S. Air Force Special Operations Command (AFSOC), told the Air Force Association conference on 15 September, adding that capability could reverse the shrinking utility of the AC-130J due to a growing threat environment. "First move is let's get into a defensive capability to ensure that I can fight my way to the target, I can fight on the target, and I can fight my way off the target — that's our job."

"We've got to subsystem downselect, we've got to publish the [capability development document and] we've got to conduct the test and evaluation," Heithold says, adding AFSOC already is developing concepts of operation (CONOPS) and tactics, techniques, and procedures (TTPs). "You have to have a wheelbarrow full of paperwork before you get a wheelbarrow full of money. Nobody's going to give you money

unless you have fleshed out what you want this to look like and what's the overall cost of the system."

DOD budget concerns

As is becoming all-too-common in this age of super-fast leaps in technology, the bureaucratic hurdles almost certainly will be more difficult than the technological. As Frank Kendall, Undersecretary of Defense for Acquisition, Technology, and Logistics, told the Directed Energy Summit, he has been hearing about the "great promise of instantaneous kill and an unlimited magazine" for more than four decades. Noting the Pentagon already spends about $300 million a year on directed-energy weapon development, "there's no magic that will allow us to go faster.

"I can't promise the budget is going to get bigger — but I don't think it's going to get smaller," Kendall says, noting DARPA, AFRL, ONR, and others will push forward with key experiments decisive to the future of directed-energy weapons. "We have a series of demonstrations that will culminate in the next five to six years that will position us to move toward operational weapons. That's about the right pace. We've made a lot progress. But we're not there yet."

Most lawmakers and their staff simply are not yet ready to embrace this next revolution in warfare, says Rep. Jim Langevin, D-R.I., co-chair of the House Directed Energy Caucus, which is working to increase high-energy laser awareness and support.

"It's not the easiest thing in the world to explain what the systems are and how they create effects," Kendall told reporters at the Summit. "It takes time and effort to wrap their heads around the basics of the technology, let alone what the capabilities would mean for future war fighting. And that's before you factor in decades of directed energy being oversold and under-realized. That's our biggest enemy."

Even so, AFSOC is not alone in seeing lasers as part of aviation's near-term future.

"I believe that we will have a directed-energy capability in a pod that can be mounted on a fighter aircraft very soon," Gen. Herbert "Hawk" Carlisle, commander of the

Air Combat Command, told the Air Force Association, adding he sees that becoming reality by 2020, at the latest—and he is pushing for it to happen even sooner.

Another player in next-gen, high-energy lasers is General Atomics in Poway, Calif., which is best known for its UAVs, such as Predator. At the Navy League Sea-Air-Space Exposition in April 2015, the company unveiled its Generation 3 laser, which officials claim incorporates classified technologies making it more compact, powerful, and advanced than the LaWS tested on the Ponce. Powered by a lithium-ion battery, the Gen-3 is being developed for offensive and defensive applications, says Mike Perry, vice president for mission systems at General Atomics.

"It's very different than the lasers you have seen [in test videos from the USS Ponce]. The laser technology is more mature. We are far beyond killing boats and unmanned aerial vehicles," Perry says, but adds the military is "just now starting to grapple with lasers as a reality," so it will take time for the energy technology to gain a standard role in the battlespace.

The future of laser weapons

Future evolutions of high-energy laser and directed-energy weapons in general still face a number of challenges, including keeping up with and incorporating fast-changing technologies in computing, power, cooling, and materials, and making what is still technology dominated by commercial development military-capable.

"Under development is being able to put significant power on these tactical systems, as well as ruggedization of existing technology," says Boeing's DeYoung. "Technologies existing today are capable of accomplishing these missions, they just need to be ruggedized and militarized."

Northrop Grumman's Hixson says more improvement is needed to meet requirements. "Industry is looking hard at getting the laser head SWaP down to being fairly compact, but we also have to think about the cooling and power systems required to be carried on the same platform with these lasers and about miniaturizing the entire system, not just the laser. So we're taking a systems approach on how we can meet some pretty tight SWaP-C requirements," he says. "In the future, we need to start looking at miniaturizing the beam control, cooling and power subsystems, and ensuring they all fit within the existing command and control architecture of a ship or airplane or ground vehicle.

"I wouldn't say military requirements are driving development; I would classify them more as environmental requirements. The technology is ready for deployment now — that is, the physics of directed energy are developed and well-known. The question becomes is it suitable, reliable, maintainable, [and able to] survive exposure to salt spray in the marine environment, aircraft vibration, and take-off and landing loads. So the suitability within a platform is what needs to be worked on now, in the environment in which it has to work."

Up to the warfighter

Ultimately, it comes down to the warfighter, what the enemy is using, and how best to deal with those.

"The big threats now are low/slow/small UAVs, which lasers can handle. More than anything, it allows warfighters to save their more expensive missiles for engagements where, economically or logistically, it makes more sense to use those for more expensive targets. So it gives the warfighter more choices," DeYoung says. "There are so many things you can do with lasers."

Feeding the power-hungry beast

Militaries look to lithium-ion and energy storage innovations to power myriad modern electronics.

BY **Courtney E. Howard**

NATO officials partnered with industry and academia to test a variety of energy-efficient and renewable-energy innovations during the Capable Logistician 2015 exercise in Hungary.

"Since the introduction of the internal combustion engine in the 1850s, energy resources have played an important role in military thinking," says Osman Askin Bak in "New Energy Ideas for NATO Militaries: Building Accountability, Reducing Demand, Securing Supply," a report by the Sub-Committee on Energy and Environmental Security, North Atlantic Treaty Organization (NATO) Parliamentary Assembly. "Since the advent of fuel-hungry jets in the 1950s, military energy consumption has grown exponentially, rendering the provision of energy of central importance to military planners."

U.S. soldiers in Iraq consumed 27.2 gallons of fuel per day, compared to 1.66 gallons during World War II, Bak says. "The growing energy requirements of modern soldiers' combat gear and of the sophisticated electronic devices deployed on military bases have resulted in a significant increase in the amount of electricity consumed," he adds. "The ever-growing amounts of fuel and electricity necessary for powering modern warfare have created the need for expensive logistics and supply lines."

Delivering energy to deployed soldiers presents security and safety risks. "On average there is one casualty for every 24 fuel resupply convoys to Afghanistan; 3,000 U.S. soldiers were killed or wounded from 2003 to 2007 in attacks on fuel and water convoys in Iraq and Afghanistan," according to NATO figures.

Efficiency is an operational imperative for militaries everywhere, according to NATO officials, who offer the following statistics:

- For each gallon of fuel to Afghanistan as much as four gallons are consumed for transport.
- Two-thirds of the fuel that a conventional diesel generator burns is blown out as heat; only one third is converted into electricity.
- In a typical military camp, 60 to 70 percent of fuel is used to produce electricity to heat and cool water or air.

Smart energy

The NATO Energy Security Center of Excellence — coordinated by Allied Command Transformation in Norfolk, Va., and considered to be an international military organization — conducted the Capable Logistician 2015 exercise in Hungary this past June. Its long-term goal is to introduce technologies that can reduce the energy consumption by troops deployed on military operations.

For the exercise, NATO partnered with members of industry, academia, and military organizations to test more than 50 energy-efficient solutions in energy production, storage, distribution, and consumption for cutting costs and enhancing interoperability and military effectiveness.

Thirty experts from defense agencies and research institutes joined

NATO representatives and 1,700 soldiers at Bakony Combat Training Center near Veszprem, Hungary, to analyze how equipment using different energy-efficient technologies interact. Technologies applied included: micro grids to improve a camp's energy management; renewable energy sources, such as wind and solar power; insulation against heat and cold; low-energy technologies for water purification; LED lights; and small portable fuel cells.

Fueling the future

Reducing military energy consumption is an "economic, environmental, and strategic imperative," NATO Parliamentary Assembly members say, noting that energy efficiency can save money, save soldiers' lives, and improve the mobility and endurance of military forces. NATO launched its Smart Energy program in 2011 to improve the energy efficiency of allied armed forces through a wide range of means, including increased use of renewable energy and better energy management.

"NATO Smart Energy is about empowering the soldier of the future and an important mission enabler for the modern military. It reduces cost and risks of military operations, as well as the environmental footprint of the military," says Ambassador Sorin Ducaru of Romania, assistant secretary general of NATO's Emergency Security Challenges Division.

Ducaru recognizes the need for partnership, cooperation, and integration to advance and institute energy-efficient systems, solutions, and practices. "Now is the time to start thinking about multinational cooperation," he says. "Exploiting the promises that lie in technological innovation has always been critical for achieving military success."

Capable Logistician 2015 marked the first time that civilian defense companies were tied directly into the execution of such an exercise, NATO officials say. In fact, defense contractors ran accommodations for 200 troops off a micro grid system throughout the 12-day event.

Powering the U.S. military

"Operational energy equates exactly to operational capability," says Gen. John Allen, former commander of the International Security Assistance Force. And so, the U.S. military consumes copious amounts of energy.

The U.S. government is the largest energy consumer in a nation that consumes more energy than any other in the world; the U.S. Department of Defense (DOD) uses the most energy in the federal government, reports Worldwatch Institute staff in Washington. In fact, the DOD is reportedly one of the largest consumers of energy in the world, ranking roughly between Denmark and Syria.

DOD officials are working to reduce the department's overall energy use, and have achieved some success. DOD energy use has fallen to its lowest since 1975, data from the U.S. Department of Energy's Federal Energy Management Program (FEMP) reveals.

A reduction in military operations in Iraq and Afghanistan and several initiatives by the federal government and DOD are credited for the decline in energy usage. The DOD has invested in generating energy in locations where military forces operate rather than transporting fuel over long distances,

Airborne electronics

BAE Systems Electronic Systems in Nashua, N.H., needed power electronics components for the integrated flight control electronics (IFCE) fly-by-wire (FBW) system on the Boeing 777X passenger jumbo jet. They found their solution at Crane Aerospace & Electronics Power Solutions in Lynwood, Wash.

BAE Systems engineers selected Crane's ELDEC-brand power conditioning modules (PCMs) and batteries for the Boeing 777X IFCE FBW system. Crane's power electronics products will provide high-integrity, uninterruptible power for the IFCE, company officials say.

The BAE Systems IFCE FBW provides computing for the 777X's all composite wing with load alleviation, as well as its advanced high lift and folding

wingtips. The 777X is the newest family of twin-aisle airplanes that first will be built in 2017 and delivered in 2020.

Crane supplies power conversion equipment and batteries for flight control electronics on Boeing 777 and 787 Dreamliner passenger aircraft.

U.S. Energy Information Administration (EIA) officials report. "This approach could result in safer missions as well as reduce additional operational demands when replenishing energy supplies."

The DOD's Operational Energy Strategy Implementation Plan also aims at improving methods to monitor and measure energy usage, establishing goals for energy efficiency and fuel reduction in each branch of the military, and pursuing alternative fuel sources, according to the EIA.

Rise in renewables

DOD officials are working to reduce the use of fossil fuels and generators to power electronics in the field, and moving toward renewable and alternative energy sources with a focus on solar panels, battery storage, and microgrids.

The DOD is investing in energy efficiency, new technologies, and renewable energy sources at its installations, and these efforts are achieving real-world results, says John Podesta, former counselor to the President of the United States. "In 2012, energy efficiency and renewable energy improvements like tactical solar gear at combat outposts in Afghanistan saved roughly 20 million gallons of fuel — taking 7,000 truckloads worth of fuel off the battlefield. By 2025, private-sector investments on DOD installations will be generating 3,000 megawatts of renewable energy." Making smarter energy investments not only "makes our military stronger," he says, but also "saves money, reduces demand, and protects the environment."

Officials at the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) partnered with Raytheon Co., Primus Power, and Advanced Energy to test a system that potentially could benefit the DOD by reducing its reliance on fossil fuels for energy and maximizing the benefits of renewable resources.

The test, conducted at NREL's Energy Systems Integration Facility in Golden, Colo., demonstrated an advanced microgrid system capable of islanded (off-grid) operation using stored and high-penetration renewable energy. Primus Power's EnergyPod 706-kilovolt ampere power

train, two AE 100-kilovolt ampere solar inverters, and Raytheon's Intelligent Power and Energy Management (IPEM) Microgrid Controller combined in an Energy Storage System-driven microgrid with conventional photovoltaic (PV) inverters.

The microgrid achieved 100 percent PV penetration while retaining the power quality necessary to satisfy critical facility loads. It made the most of the solar energy used and minimized the need for conventional fuel-burning generators, as well as reduced operational costs, logistical burdens, and carbon footprint.

The demonstration validated component and system functions and control features that serve as the basis of an Environmental Security Technology Certification Program (ESTCP)-funded demonstration system, which is being fielded at Miramar Marine Corps Air Station, Calif., officials explain.

"Raytheon's Intelligent Power and Energy Management Microgrid Controller leverages unique capabilities designed to provide enhanced energy management functionality to the Department of Defense," says Paul Ferraro, vice president of advanced technologies programs at the Raytheon Integrated Defense Systems segment. "Our IPEM technology enhances energy security and efficiency, which are essential components required to meet current and future DOD energy objectives."

Solar system

U.S. Navy's, Western Area Power Administration, and Sempra U.S. Gas & Power of San Diego agreed in August to build a 210-megawatt direct-current solar facility to help power more than a dozen military installations. The agreement marks the largest purchase of renewable energy made by a federal entity, officials say.

Navy officials selected Sempra U.S. Gas & Power's Mesquite Solar 3 project, a solar plant located 60 miles west of Phoenix, involving the installation of more than 650,000 photovoltaic panels on ground-mounted, horizontal single-axis trackers. The plant will provide one-third of the energy needed to power 14 Navy and Marine Corps installations. Construction of Mesquite Solar 3 is in progress and should be completed by the end of 2016.

"The collaboration on Mesquite Solar 3 is a triumph of innovative problem solving, and will help to increase the Navy's energy security by diversifying our power portfolio and improving energy efficiency," says Navy Secretary Ray Mabus. "This agreement also is projected to save the Navy at least $90 million over the life of the project."

Lockheed Martin selected Saft batteries for the Joint Light Tactical Vehicle (JLTV).

In addition to the energy security benefits to the Navy, the Mesquite Solar 3 project will help the 14 installations comply with California's Renewable Portfolio Standard; moreover, at 210-megawatt, the solar facility will contribute 21 percent of the power needed to meet Secretary Mabus' goal of bringing one gigawatt of renewable energy into procurement by the end of 2015.

In 2009, Congress mandated that the DOD produce or procure 25 percent of total DOD facility energy from renewable sources by 2025, with each service responsible for generating a portion of that renewable energy. Mabus accelerated that goal, directing the Navy to procure one gigawatt of renewable energy by the end of 2015.

The installations that will receive solar energy from the Mesquite 3 Solar farm include San Diego, Coronado, Point Loma, and Ventura County Naval Bases; Monterey Naval Support Activity; Seal Beach, Fallbrook, and Det Norco Naval Weapon Stations; Camp Pendleton Marine Corps Base; 29 Palms Marine Corps Air Ground Combat Center; Miramar Marine Corps Air Station; Barstow Marine Corps Logistics Base; San Diego Marine Corps Recruitment Depot; and Bridgeport Marine Corps Mountain Warfare Training Center.

U.S. Army officials have launched a $7 billion renewable and alternative energy power production program for DOD installations.

The U.S. Army Energy Initiatives Task Force (EITF) and the U.S. Army Corps of Engineers, Engineering, and Support Center in Huntsville, Ala., established the $7 billion Multiple Award Task Order Contract (MATOC) primarily for renewable or alternative energy projects greater than 10 megawatts. The MATOC includes 49 solar technology companies, 15 biomass technologies, 6 geothermal technologies, and 20 wind technologies.

The initiative supports the Army's congressionally mandated energy goal of 25 percent production of energy from renewable sources by 2025. Army officials also are eyeing new technologies related to higher-

The U.S. Marine Corps Expeditionary Forward Operating Base concept uses solar power. (Photo: Maj. Paul Greenberg)

capacity batteries and rapid charge capabilities, in an effort to reduce the burden of carrying multiple, heavy batteries.

Portable battery technologies

"Soldier backpacks are too heavy," declares Richard Kidd, the deputy assistant secretary of the Army for energy and sustainability. "That load has grown in almost direct proportion to the various communications equipment soldiers now carry, from 40 pounds at the beginning of the war in Afghanistan to somewhere between 120 and 140 pounds now," says "Ideally, we'd like to increase the power density of the batteries on our soldiers and go to wireless induction power transfer so that a soldier just walks into a tent, a vehicle, or other space and their battery just gets charged up and then they're able to power their peripherals without wires or connections."

The Army's conventional batteries no longer can handle the power demands for wearable devices such as Nett Warrior, a handheld tool that provides situational awareness and mission command capabilities. "The introduction of 'soldier in the network' brings with it an unprecedented level of capability and amount of power consumers that are worn on the individual warfighter," says Steve Mapes, product director for Soldier Power within PEO Soldier's Project Manager Soldier Warrior.

Although soldier networked systems succeed in sending and receiving data, these networks also drain batteries rapidly because the systems search continuously for a signal. "You have a power burden that has never before been imposed on soldiers, particularly the small-unit leaders," Mapes says. "The traditional power strategy for the individual warfighter was fast becoming impractical and irrelevant."

Soldier solution

Today, a soldier carries an average of seven different batteries weighing 17.6 pounds, plus reserves, according to NATO statistics. Engineers at Aberdeen Proving Ground, Md., are developing a battery to reduce the soldier's power burden and increase agility on the battlefield.

The U.S. Army Research, Development and Engineering Command (RDECOM) and Program Executive Office (PEO) Soldier have partnered to fulfill the requirements of today's networked soldier with the flexible Conformal Wearable Battery (CWB), which integrates into a soldier's body armor and conforms to his body to provide a significant upgrade to traditional batteries, which resemble heavy cubes.

"Our role is to develop smaller, lighter, cost-effective power sources," explains Christopher Hurley, an electronics engineer who leads the battery development projects team at RDECOM's Communications-Electronics Research, Development, and

Engineering Center (CERDEC). "Providing a wearable, ergonomic, comfortable footprint is key."

The Army's standard batteries, the BA-2590 and BA-5590, were designed for battery boxes and large communication equipment, not for the soldier to power his electronics, Hurley says. In contrast, the CWB is designed for a tactical vest. It provides more power, reduces the need for re-charging and spares, and serves as one source of power for all wearable electronic devices.

"The conformal battery is a centralized power source for all the things that a soldier needs to carry — GPS, smart phone, radio, and other electronics," Hurley adds. It also eliminates the need to carry extra batteries for each individual item, he says. "No longer do you need to carry extra radio or GPS batteries. You only need to carry spares for the conformal battery."

Today's tactics

Aerospace and defense applications are taking advantage of lithium-based battery technologies.

Existing battery technologies such as lead acid and lithium-ion (Li-ion) batteries are expected to dominate the battery market for the next 10 years, says Franco Gonzalez, senior technology analyst at IDTechEx in Cambridge, England. "Lithium-ion is the best battery technology we have ever seen," Gonzalez says. "It has increased energy density by 5 percent per year and decreased its cost at 8 percent per year."

Aerospace and defense engineers are selecting lithium-ion batteries for myriad harsh-environment applications. When engineers at The Boeing Company needed batteries for its

U.S. Army engineers developed the Conformal Wearable Battery for networked soldiers.

telecommunication satellites, they opted for lithium-ion technology.

Saft, a designer and manufacturer of high-tech batteries in Bagnolet, France, won a long-term agreement with Boeing to provide "a steady and reliable supply of Li-ion batteries to meet the rigorous demands of the space environment," officials explain. Boeing engineers use Saft Li-ion cells in their battery design to power the satellites when solar rays are blocked by the Earth, support the entire geosynchronous orbit (GEO) mission duration, and to enable a lightweight satellite, which results in significant launch cost savings for Boeing and other spacecraft manufacturers.

More than 145 satellites have been powered by Saft advanced Li-ion technology solutions, says Thomas Alcide, president of Saft America Inc. and general manager of Saft's Specialty Battery Group. Saft's Li-ion technology and solutions have been used to withstand extremely demanding missions with GEO and medium earth orbit global positioning satellites, and to support specific applications such as high-power telecommunications to observation and defense low earth orbit satellites, officials say.

Ground vehicles

Lockheed Martin engineers needed advanced Li-ion battery systems to power the company's entry in the Joint Light Tactical Vehicles (JLTV) program, which ultimately was won by Oshkosh Defense. The multi-service initiative is developing a family of next-generation, lightweight and networked vehicles to replace many High Mobility Multipurpose Wheeled Vehicles (HMMWVs) currently used across the armed forces.

"This partnership represents the growing adoption of lithium-ion battery technology to support the increasingly higher power demands of today's modern military vehicles," says Saft's Alcide.

On Lockheed Martin's JLTV prototypes, Saft's Li-ion battery system provide starting, lights, ignition, and silent-watch mission capabilities, while also producing critical mobile power to recharge personal electronics like night sights and GPS devices, company officials say. The system features an advanced, lightweight design within the dimensions of a traditional lead-acid battery, enabling easy integration into the vehicle. Yet, the 28-volt, 60-ampere-hour battery achieves higher, more compact power and energy efficiency, helping to reduce battery replacements and life cycle costs.

Thales Australia engineers also tapped Saft to deliver Li-ion battery systems to power Hawkei military tactical vehicles. Saft started delivering advanced Li-ion batteries for use in prototype vehicles in the first quarter of 2015.

The Hawkei mobile, armed, and light ground vehicles are designed to provide protected mobility for defense forces challenged by improvised explosive devices (IEDs), mines, or small arms ambushes. The

helicopter-deployable Hawkei is small to move stealthily, remain hidden, and provide coverage and safety critical to military use, and is equipped with weapons and systems for situational awareness and lethality.

The Saft Li-ion battery system features a lightweight design within the dimensions of a traditional lead-acid battery for easy integration; powers starting, lights, ignition, and silent watch capabilities for the Hawkei vehicle; and meets mission objectives for compact power and energy efficiency and fewer battery replacements, officials say.

Leaving lead acid

The most prominent military vehicle battery is the 6T, which historically has been based on lead-acid chemistry. Engineers at Navitas Systems LLC in Woodridge, Ill., aim to change that with a family of drop-in lithium-ion lead acid replacement batteries.

The standard battery for ground combat vehicles in the U.S. and many NATO countries is the 6T battery. A HUMVEE vehicle uses two 6T batteries, while an Abrams tank can have from six to twelve 6T batteries.

Navitas, a provider of energy-enabled system solutions, energy storage products, and power electronics, won a contract from Alion Science and Technology Corp. in McLean, Va., to develop a next-generation, lithium-ion "6T" battery system for military applications, with a focus on ground combat vehicle applications.

The Navitas Ultanium family of lithium batteries in popular lead acid battery sizes includes the Ultanium 6T battery, targeted at dual-use commercial and military applications and engineered to deliver a long-lasting, lightweight battery system for engine start and long-duration "Silent Watch" functionality.

Silent Watch capability in military ground vehicles transfers motive power to the tires from the vehicle's internal-combustion engine to electric power — much like a commercial hybrid automobile. Running electric power for limited periods enables the vehicle to move extremely quietly so as not to give its presence away to the enemy.

"The goal is to develop a battery

that will enable high efficiency to vehicles that spend extended time with engines idling to power onboard electronics," officials say. "Eliminating engine idling dramatically improves fuel economy and reduces emissions."

Alion Science and Technology contracted three companies — Eagle Picher, Navitas Systems, and Saft — to develop a first-generation lithium 6T battery. Navitas won an additional contract to develop a second-generation, lithium-ion 6T battery.

Company officials are leveraging the award to enhance the current Ultanium Military 6T battery, increasing the energy and power density over the first generation lithium version, and to develop cell and pack technology for the second-generation version. The Ultanium 6T Generation

KAI jets

Korea Aerospace Industries (KAI) officials chose Saft to provide maintenance-free, nickel-based batteries for military aircraft applications on the KAI T-50/A-50 series aircraft.

KAI's advanced fixed-wing jets use Saft's Aviation Maintenance-Free Batteries (AMFB). The nickel-based batteries provide a nominal voltage of 24

KAI and Lockheed Martin partner on the T-50 family of multirole aircraft.

volts; boast leak-proof, thermo-welded cells, seam-welded plate tabs, and copper cell links and terminals; and are constructed using separator material and a semi-flooded membrane design.

KAI, an emerging competitor in military and commercial aviation, provides advanced jet aircraft to the Republic of Korea Air Force, as well as the military forces of Indonesia, Iraq, and Philippines.

II battery will be designed and assembled in Ann Arbor, Mich.

"Navitas Systems' focus is on lightweight, long-lasting, high-performance 6T batteries engineered to meet the specific, demanding requirements of our military's vehicle programs," says Les Alexander, general manager of Navitas Advanced Solutions Group. "The demands of the Army are second to none and they require a battery that will improve performance and efficiency for our troops in the field on a daily basis."

Post lithium progress

Lithium-based batteries are likely to command the aerospace and defense space for the next decade, but other advanced technologies are on the rise — largely in niche markets and from new business start-ups, say IDTechEx analysts.

Advanced and post lithium-ion batteries potentially could make up 10 percent of the entire battery market by 2026.

"Advanced and post lithium-ion battery technologies can reach a market value of $14 billion in 2026," according to IDTechEx's latest research report: "Advanced and Post Lithium-ion Batteries 2016-2026: Technologies, Markets, Forecasts."

"A new generation of battery technologies will be necessary to address the existing and future challenges of the increasingly complex energy systems our society will require. Better batteries will be needed," predicts IDTechEx's Gonzalez.

This new generation of technologies, referred to as "advanced and post lithium-ion batteries," includes silicon anode batteries, lithium sulphur batteries, sodium ion batteries, magnesium batteries, lithium air batteries, solid state batteries, and lithium capacitors.

"Emerging electronic devices, such as wearable electronics, will not reach their full potential and penetrate the market with existing battery technologies," Gonzalez explains. "New batteries will need to be smaller and hold more energy."

Thin-film and printed batteries

The worldwide market for

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Ship-wide energy storage

Engineers at DRS Technologies, a Finmeccanica Company in Arlington, Va., are designing and building Energy Storage Modules (ESM) that will function as a ship-wide uninterruptable power supply (UPS), enabling fuel savings and new mission capabilities while providing electric power support for U.S. Navy DDG 51 class ships.

DRS's Power and Control Technologies business won an initial $17 million contract from the U.S. Naval Sea Systems Command to design, engineer, and support the energy storage system. If options are exercised, the total value could exceed $88 million.

DRS, in turn, selected Lithiumstart in San Francisco to provide its BluFlex Energy Storage System (ESS) for the program. DRS engineers are packaging Lithiumstart's lithium-ion battery ESS component with DRS Power Electronic Modules to provide an integrated solution to the Navy. The Lithiumstart ESS features scalable 48V modules which stack to reach up to 2kV and 100MW+. The modules and BluFlex Battery Management System are based on commercialized military technology deployed with 14 militaries worldwide.

DRS will design, manufacture, and qualify the ESM, which will enable the ship's electric plant to run on one gas turbine generator under certain conditions to conserve fuel while maintaining vital power in the event of a generator failure. The Navy plans to retrofit this system on the existing flight I and II DDG 51 class ships.

thin-film and printed batteries over the next seven years will be 32 times larger than it is today, predict analysts at market researcher n-tech Research (formerly NanoMarkets) in Glen Allen, Va.

The flat batteries market will grow from $34 million this year to $183 million in 2018, and finally to $1.1 billion by 2022, driven by smart cards, packaging, consumer electronics, wearable devices, and the Internet-of-Things, n-tech analysts explain.

Company analysts outline their predictions in "Thin-Film and Printed Batteries Markets 2015-2022," a report examining the latest developments in thin-film and printed battery technologies, from materials and design to manufacturing.

Despite these optimistic prospects for growth, the thin-film and printed battery market has not come close to earlier projections. NanoMarkets, the precursor to n-tech Research, predicted seven years ago that thin-film and printed battery technology would represent a $5.6 billion market today, while it actually remains at $34 million.

Wearable electronic devices offer great promise for thin batteries, analysts say. Among the technology drivers will be sensors in Internet of Things devices, which today are too big, too expensive, and limited in functionality, analysts say.

SMIRF project seeks to boost military SIGINT, EW, and C4ISR capabilities

BY **John Keller**

WRIGHT-PATTERSON AFB, Ohio — Three U.S. defense industry researchers are investigating passive and active RF systems and advanced signal processing for their potential application to targeting and fire control, advanced communications, sensors and sensor processing, and pinpointing RF and microwave transmitters.

Officials of the U.S. Air Force Research Laboratory at Wright-Patterson Air Force Base, Ohio, are working with the three companies as part of the Source Multiple Integrated Radio Frequency (SMIRF) research and development program.

Companies selected for the SMIRF program are:

- MacAulay-Brown Inc. in Dayton, Ohio;
- the Northrop Grumman Corp. Electronic Systems segment in Baltimore; and
- Georgia Tech Research Institute in Atlanta.

Each of the SMIRF contractors will receive $500,000 up-front, and then will share the $22.5 million remaining from the original $24 million contract based on task orders assigned to each organization.

The goal of the Air Force SMIRF program is to conduct research and development of passive and active RF systems. Active RF systems transmit and receive radio waves, while passive systems simply receive radio waves.

Air Force researchers are focusing the SMIRF program on targeting fire control solutions; simultaneous transmit and receive RF concepts; RF sensor resource management; geolocation algorithm development; simulation; test and evaluation; and integrated sensor systems.

The Air Force is combining active and passive RF, as well as signal processing, for targeting, communications, and sensors.

Ultimately, researchers would like to apply the technologies and concepts developed in the SMIRF program to signals intelligence (SIGINT); measurement and signature intelligence (MASINT); geospatial intelligence (GEOINT); electronic warfare (EW); global positioning system (GPS); command, control, communications, computers intelligence, surveillance, and reconnaissance (C4ISR); and joint/special operations.

The three SMIRF contractors are likely to conduct engineering trade studies, and develop concepts or prototypes of structural, aerodynamic, electrical, and physical architectures, Air Force researchers say. ←

FOR MORE INFORMATION visit the **Air Force Research Laboratory** online at *www.wpafb.af.mil/AFRL*.

L-3 combining sensors and radar to detect explosives

L-3 Communications Security & Detection Systems (SDS) in Woburn, Mass., is applying expertise in baggage screening and airport security to develop a handheld explosives detection system that combines a metal detector and ground-penetrating radar. Officials of the U.S. Army Contracting Command at Fort Belvoir, Va., intend to award a contract for L-3 SDS to move forward with the Next Generation Handheld Multi-Sensor Explosive program to help the military detect roadside bombs and other improvised explosive devices (IEDs). L-3 SDS engineers will continue developing an experimental handheld system that can detect explosive hazards and trigger mechanisms.

BAE Systems, Navy develop EW technologies

The Office of Naval Research announced an $11 million contract to BAE Systems Electronic Systems in Nashua, N.H., as part of the Electronic Warfare Technology program, intended to develop and demonstrate RF and microwave technologies for next-generation EW. BAE Systems engineers will design and demonstrate a full-spectrum staring electronic support receiver with instantaneous direction finding that capitalizes on electronic and photonic component technologies and provides an end-to-end EW system. ←

DARPA Blue Wolf UUV program adds Boeing and Lockheed Martin

Two of the nation's largest defense contractors are joining a U.S. military research program to develop revolutionary underwater propulsion and drag-reduction technologies to enable manned and unmanned military undersea vehicles to move through the water faster and more energy-efficiently than ever before. Officials of the Naval Undersea Warfare Center (NUWC) in Keyport, Wash., have selected the Boeing Co. and Lockheed Martin Corp. on behalf of the U.S. Defense Advanced Research Projects Agency (DARPA) in Arlington, Va., for the DARPA Blue Wolf program, which aims at sea testing of undersea energy, hydrodynamic lift, and drag-reduction technologies for manned and unmanned underwater vehicles (UUVs). On the Blue Wolf program, Boeing and Lockheed Martin join the Charles Stark Draper Laboratory in Cambridge, Mass. The Blue Wolf program will develop and demonstrate integrated underwater vehicle prototypes able to operate at speed and range combinations previously unachievable in fixed-size platforms, while retaining traditional volume and weight fractions for payloads and electronics.

Solar-electric propulsion for deep-space is aim of NASA ARRMS program

BY **John Keller**

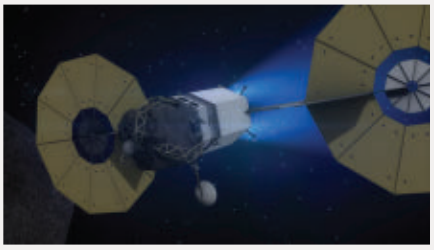
PASADENA, Calif. — U.S. space researchers are asking industry for ideas on developing spacecraft solar-electric propulsion for deep-space missions that could lead to a future robotic spacecraft able to retrieve a 20-ton rock from a near-Earth asteroid.

Officials of the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) in Pasadena, Calif., have released a solicitation (DMS-2672-080416I) for the first phase of the Asteroid Redirect Robotic Mission Spacecraft (ARRMS) program.

The Asteroid Redirect Robotic Mission is part of NASA's plan for using cislunar space — the area between Earth and the moon — as a proving ground for future human spaceflight beyond low-Earth orbit.

NASA scientists envision the ARRMS demonstrating: a 20-fold improvement in deep-space solar electric propulsion to move and maneuver large payloads; retrieving a boulder heavier than 20 tons from a near-Earth asteroid and redirecting it to a crew accessible orbit around the moon; and joining integrated crewed and robotic vehicle operations in deep space. NASA officials would like to develop the solar-electric, propulsion-based bus using commercially available U.S. industry capabilities and technologies developed in the future.

Scientists are developing the ARRMS solar-electric propulsion in two phases: formulating a preliminary design with help from U.S.-only companies, and then developing the flight spacecraft bus. For now, NASA scientists are interested only in the ARRMS solar-electric propulsion preliminary design, in which several contractors may be involved. Funding will come in January 2016 after NASA receives its annual congressional appropriation.



NASA scientists are trying to develop solar-electric propulsion for demanding deep-space missions, and to support a future mission to Mars.

The NASA Asteroid Redirect Mission will use robotic unmanned spacecraft technology to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the moon. Once the big space rock is in orbit around the moon in the 2020s, astronauts will explore it and return to Earth with samples. This mission is part of NASA's plan to advance the new technologies and spaceflight experience necessary for a human mission to the Martian system later in the 2030s. NASA officials plan to launch the robotic spacecraft at the end of this decade.

MORE INFORMATION IS online at *http://1.usa.gov/1RrmAug.*

ELECTRO OPTICS watch

FLIR to provide visible-light and infrared cameras for fast surface vessels

BY **John Keller**

CRANE, Ind. — U.S. Navy maritime surveillance experts needed long-range, electro-optical, forward-looking infrared sensors for surface warships operating in coastal waters and harbors. They found their solution at FLIR Systems Inc. in Billerica, Mass.

Officials of the Naval Surface Warfare Center in Crane, Ind., announced a $49.9 million contract to FLIR Systems to provide Combatant Craft Forward Looking Infrared variant 2 (CCFLIR2) cameras. The CCFLIR2 is a day-and-night, visible-light camera with infrared imaging that enables operators to detect surface targets at tactically significant ranges in all operational environments, officials say.

The sensor system, packaged in a stabilized gimbal assembly, provides increased detection, recognition, and identification ranges in all conditions over what is available today, as well as constant interrogation of targets across the spectrum of naval operations. The CCFLIR2 provides enhanced situational awareness with high-definition imaging and zoom capability, and includes improved optics and image processing that enable the user to see the same target in several different wavelengths to highlight target features and discriminators.

CCFLIR2 integrates with embedded navigational systems and other shipboard systems to provide target and way-point geolocation and tracking functionality, and is part of a collection of intelligence, surveillance, and reconnaissance (ISR) systems available for use on special operations force maritime vessels.

FLIR Systems is providing tactical visible-light and infrared cameras to help fast Navy surface vessels stay focused on target.

The CCFLIR2 will be a significant upgrade to the fielded legacy CCFLIR surface ship sensor system, and will enhance and expand shipboard day, night, and infrared imaging capabilities. FLIR systems will provide a CCFLIR2 system with stabilized gimbal assembly; hand control unit; display bracket assembly; installation kit; interface cable kit; and reusable shipping container. The stabilized gimbal assembly includes: high-definition medium-wave infrared imager, high-definition color imager, near-infrared imager, laser range finger, laser pointer, optics and zoom lenses, and combination anti-spoofing GPS receiver and inertial measurement unit. It offers 360-degree panoramic views and dual-band, high-definition, medium-wave infrared and long-wave infrared imaging sensors.

FOR MORE INFORMATION visit **FLIR Systems** online at *www.flir.com*.

Three companies to prototype advanced surveillance sensors

Officials of the Naval Surface Warfare Center Crane Division in Crane, Ind., announced potential $49 million contracts to three companies for prototypes of advanced sensors and sensor systems in support of intelligence, surveillance, reconnaissance, and force-protection missions. The three companies are: Consolidated Resource Imaging in Grand Rapids, Mich.; Manufacturing Techniques (MTEQ) in Kilmarnock, Va.; and Northrop Grumman Xetron in Cincinnati. Each of the three contractors will receive $2,500 up-front, and will compete for separate delivery orders based on their proposals for sensor prototypes.

BAE Systems to develop mine-hunting lidar

Electro-optics engineers at BAE Systems are designing a lidar-based, multi-sensor suite and onboard processing to detect, identify, and pinpoint moored and drifting sea mines from manned and unmanned aircraft. U.S. Office of Naval Research officials in Washington announced an $8.9 million contract to BAE Systems Spectral Solutions LLC in Honolulu for the Passive Electro-Optics/Infrared and Light Detection and Ranging (LIDAR) Environment for In-stride Classification and Neutralization program. The sensor suite will consist of a visible-to-near-infrared multispectral imaging sensor, broadband longwave infrared sensor, and 2D light detection and ranging sensor.

PRODUCT applications

AVIONICS

Rockwell Collins upgrade kits convert KC-135 jets to glass cockpits

U.S. Air Force avionics experts needed digital glass cockpit technology for the Air Force fleet of KC-135 refueling tanker aircraft. They found their solution at Rockwell Collins in Cedar Rapids, Iowa.

Officials of the Air Force Life Cycle Management Center at Tinker Air Force Base, Okla., announced a $105.9 million contract to Rockwell Collins for KC-135 Block 45 cockpit analog/digital upgrade Group B kits as part of a fleet modification program to upgrade Air Force Boeing KC-135 cockpit avionics from analog mechanical instruments and gauges to digital instruments on digital displays.

The KC-135 Block 45 program will install a new autopilot, flight director, radar altimeter, electronic engine instrument display, and enhanced navigational capabilities aboard the Air Force's fleet of more than 400 KC-135s. This upgrade is to solve obsolescence problems and enhance the KC-135's situational awareness.

Rockwell Collins will do the work on this contract in Cedar Rapids, Iowa, and should be finished by September 2024.

FOR MORE INFORMATION visit **Rockwell Collins** at *www.rockwellcollins.com*.

RUGGED COMPUTERS

DRS Laurel to manufacture open-systems computers for warships

U.S. Navy shipboard electronics experts needed a company to manufacture open-systems rugged computers and data storage for Navy surface warships. They found their solution at DRS Laurel Technologies in Johnstown, Pa.

Officials of the Naval Sea Systems Command in Washington announced a $17 million contract to DRS Laurel Technologies for the Common Processing System (CPS) Technology Insertion 16 production.

CPS is a shock-resistant, open-architecture computing system for Navy cruisers, destroyers, and other programs. CPS provides computer processing and memory, data storage and extraction, and I/O interfaces to support software applications of combat systems aboard Navy surface warships. CPS computers will support Aegis new-ship construction, Ship Self Defense System, Aircraft Carrier Tactical Support Center, and the Surface Electronic Warfare Improvement Program.

The CPS, designed by Global Technical Systems (GTS) in Virginia Beach, Va., provides a common computing infrastructure for ship combat systems. CPS uses commercial off-the-shelf (COTS) hardware and software such as BladeCenter technology that supplies common infrastructure for processing and network fabric. Plug-in components are accessible, hot-swappable, and battle-ready protected by the GTS Advanced COTS Enclosure.

The CPS consists of the CPS enclosure assembly and three subsystems: processing, storage/extraction, and I/O. The processing subsystem provides the computing resources to execute navy combat system application programs on Navy surface ships. The storage/extraction subsystem provides the mass storage resources required for operating system image storage, program storage, data extraction, and database management. The I/O subsystem provides the resources required to interface the processing and storage hardware to various external elements.

FOR MORE INFORMATION visit **DRS Laurel Technologies** online at *www.drs.com/locations/drs-laurel-technologies-johnstown-pa*.

new PRODUCTS

To submit new products for consideration, contact John Keller at jkeller@pennwell.com.

CONNECTORS

Rugged connector for military SATA applications introduced by Smiths

Smiths Connectors in Hudson, Mass., is introducing its Nebula Serial Advanced Technology Attachment (SATA) 6-gigabit-per-second rugged connectors for aerospace, defense, and industrial rugged data storage. The Nebula series from Smiths Connectors (formerly Hypertronics

Corp.) offers high-speed data rates with 100-ohm impedance matching and minimal losses. The Nebula uses the industry-standard PCB soldering footprint to avoid changes to SATA drive layouts, as well as the Hypertac hyperboloid contacts to resist the effects of shock and vibration, and provide more than 100,000 mating cycles. Its current carrying capacity is as much as 1.5 amps per contact. The connector's pins are protected by recessed contacts within insulators made from high-temperature rated durable liquid crystal polymers that resist cracking even in harsh operating environments.

FOR MORE INFORMATION visit **Smiths Connectors** online at *www.smithsconnectors.com*.

DIGITAL SIGNAL PROCESSING

FMC subsystems for radar and communications introduced by Pentek

Pentek Inc. in Upper Saddle River, N.J., is introducing the FlexorSet series of integrated FPGA Mezzanine

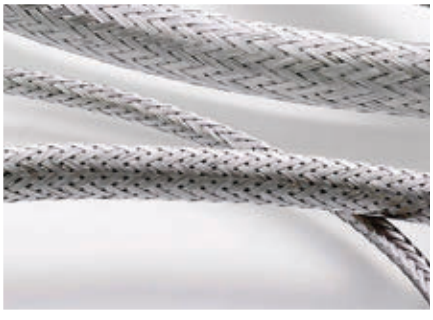
Card (FMC) embedded computing subsystems for radar, communications, and general data acquisition applications. The FlexorSet combines the Flexor line of FMC embedded modules and Virtex-7 field-programmable gate array (FPGA) FMC carriers. FlexorSets are preconfigured with optimized IP and supported with software development tools. The first offerings are the FlexorSet Model 5973-317 for 3U VPX and Model 7070-317 for PCI Express. The Flexor Model 3316 8-Channel A/D FMC is installed on either of two Flexor FMC carriers containing Pentek's eight-channel digital down converter (DDC) intellectual property (IP), matched to eight 250 MHz, 16-bit A/D converters on the FMC.

FOR MORE INFORMATION visit **Pentek** online at *www.pentek.com*.

INTERCONNECT PRODUCTS

Lightweight braid system introduced by TE

TE Connectivity in Harrisburg, Pa., is introducing Raychem INSTALITE, a lightweight braid system for aerospace and defense cabling and connector applications. The new product offers as much as 50 percent weight savings over traditional copper braids and is made from a high-performance, nickel-plated copper alloy. The RoHS-compliant, pull-on braid provides better low-frequency performance than plated fibers or microfilaments, TE officials say. Existing low-weight screening solutions are more limited with reduced electrical screen performance at low frequencies and lower protection against lightning



strike. Plated fibers and microfilament stainless-steel braids are more expensive options. TE's INSTALITE lightweight braid is available in 3-to-20-millimeter diameters.

FOR MORE INFORMATION visit **TE Connectivity** online at *www.te.com*.

I/O MODULES

Fiber-optic I/O modules for image and radar processing introduced by Mercury

Mercury Systems in Chelmsford, Mass., is introducing the Ensemble IOM-300 series of fiber-optic I/O embedded computing modules for complex image and radar processing and other high-bandwidth, low-latency sensor processing and networking applications. The open systems architecture-based Express Mezzanine Card (XMC) modules

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FOR MORE INFORMATION visit **Mercury** online at *www.mrcy.com/IOM300.*

ADVERTISERS INDEX

ADVERTISER	PAGE
Aerospace Optics	4
ASEG	14
Behlman Electronics	C3
CD-adapco	13
Coilcraft	C4
Crane Aerospace & Electronics	11
Crystal Group	17
Daisy Data	21
Evans Capacitor Company	7
Gaia Converter US	22
IBI Systems Inc.	30
IR HiRel, an Infineon Technologies Co.	1
Master Bond Inc.	30
Mercury Systems	9
MS Kennedy Corporation	5
Phoenix International	31
Pico Electronics Inc.	19
R&D Interconnect Solutions	23
RGB Spectrum	30
SPIE	32
TTI Inc.	C2
Winchester Systems	31

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