THE HIGH-ENERGY LASER

TOMORROW'S WEAPON TO IMPROVE FORCE PROTECTION

By AARON ANGELL

Think about the current laser designation capability used to direct precision-guided munitions (PGMs) to destroy an enemy target. Now, imagine replacing that laser designator with a high-energy laser (HEL) weapon that emits enough thermal energy to directly render a target ineffective without using a conventional munition. That HEL weapon will affect targets faster and with more precision and stealth than a conventional munition or weapons system. Additionally, that HEL weapon could affect targets across the domains of air, ground, sea, and space. Defensive HEL weapons could be used to counter indirect fire munitions (rockets, artillery, and mortars), aircraft, water vessels, vehicles, and even ballistic missiles. Offensive HEL weapons could be used for offensive air support and even strategic airstrike missions. In future

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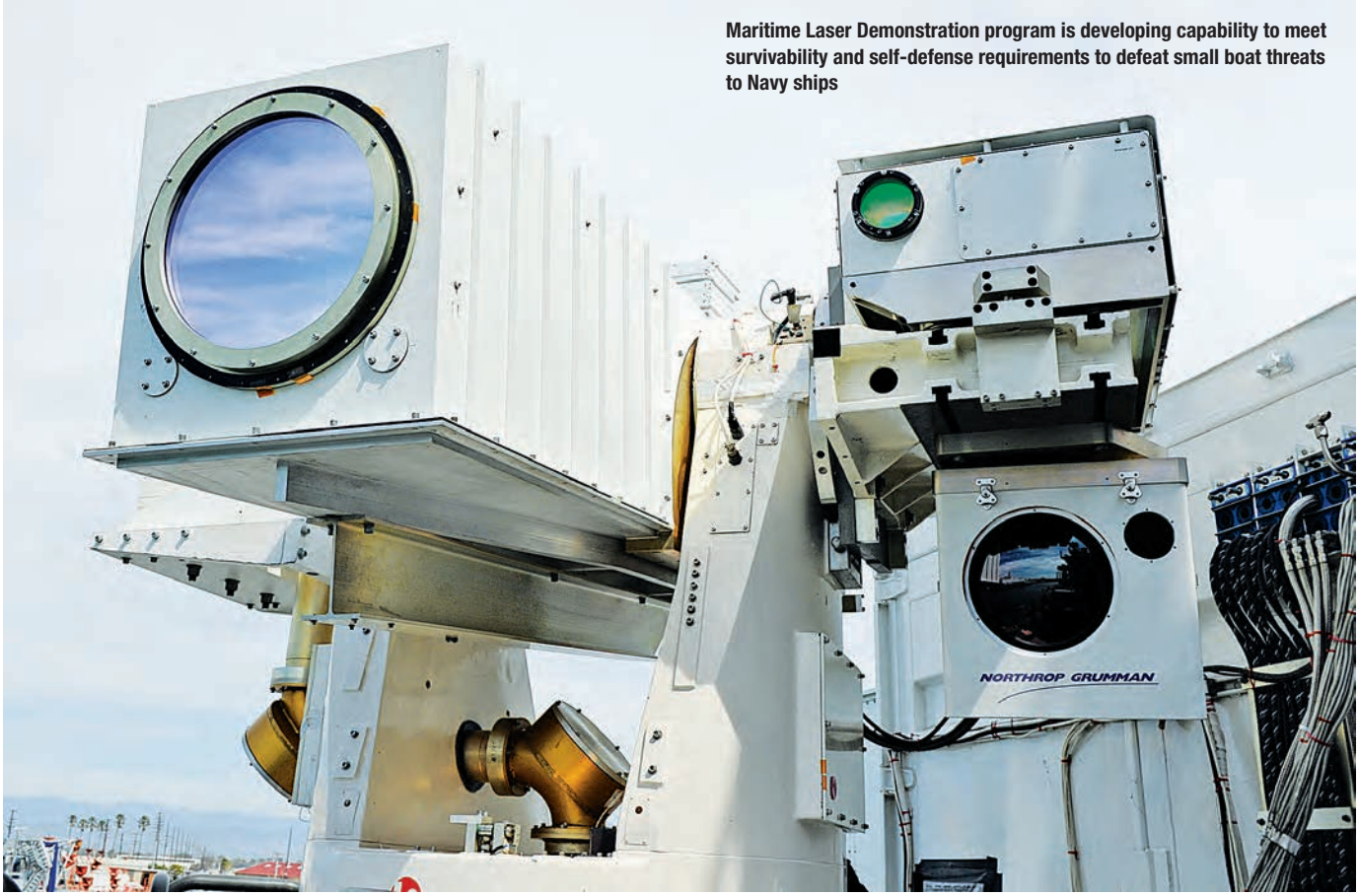

Maritime Laser Demonstration program is developing capability to meet survivability and self-defense requirements to defeat small boat threats to Navy ships

U.S. Navy (John F. Williams)

conflict, HEL weapons will be utilized across the joint force to dramatically improve force protection of military and civilian infrastructure and populations.

This article links ongoing research and development of laser technology to show that HEL weapons will be a reality, develops some concepts of employment for HEL defensive and offensive weapons as they apply to the tactical and strategic levels of warfare, and presents several vignettes to illustrate possible HEL weapons applications accounting for the joint nature of tomorrow's fight.

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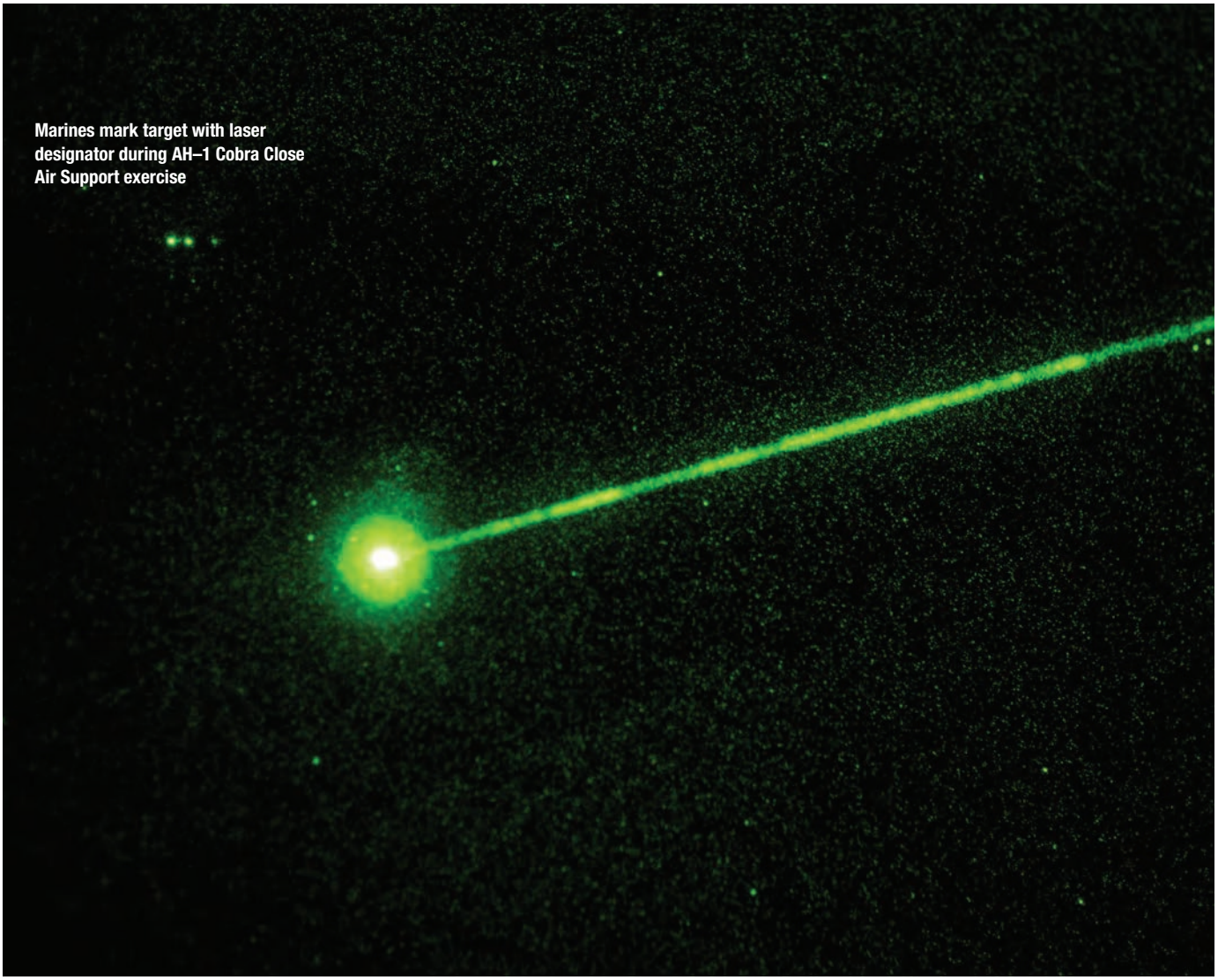
High-energy Laser Weapons

First, it is important to understand what a HEL is. Current military HELs are generally defined as having laser power greater than 1 kilowatt (kW). However, most HELs being developed and tested for military application have laser powers ranging from tens of kilowatts to 100 kilowatts for tactical-level employment and up to multi-megawatts for strategic-class application.[1] A powerful laser pointer that emits less than 1 watt can cause permanent eye damage in less than 1 second, while average power outputs of 300 watts to 1 kilowatt are commonly used for industrial laser cutting.[2] In comparison, these examples are far below the laser power output measurements of military HELs currently being tested. This illustrates the remarkable potential impact for damage and harm by a HEL. Another common measurement to classify a HEL is the emission of a single pulse of energy exceeding 30 kilojoules. To qualify this measurement, just 0.2–0.4 joules per square centimeter (cm^2) over 10 nanoseconds can burn skin, and just 10 kilojoules/cm^2 in 0.2 seconds could result in damage to the structure of an aircraft or missile without armor.[3] Other qualifiers can be used to classify different types of HELs, but the aforementioned power and energy parameters are two key measurements used to distinguish HELs from low-energy lasers.

With these high-power emissions and pulse energies, HELs will achieve extraordinary thermal effects on a target within seconds of initial engagement. Most likely, the optimal engagement time for achieved effects will be between 2 and 4 seconds. In



Marines mark target with laser designator during AH–1 Cobra Close Air Support exercise

U.S. Marine Corps (Cruz G. Sotelo)

some cases, HELs may only need to engage targets for less than a second to achieve desired effects. Even with these short engagement times, HELs can:

- induce an "explosive reaction of the high explosive" contained within.[4] Targets containing high explosives heated beyond the auto-ignition point, or fuel heated greater than the flash point, will be swiftly destroyed.
- perforate a critical surface (a fragile aircraft wing, hull of a watercraft, or even the tire of a vehicle), resulting in disruption or prevention of critical capabilities of a targeted threat
- ignite a critical surface or component (resulting in temporary distraction, at a minimum)
- disrupt the optics or control systems of a threat by temporarily or permanently blocking a sensor from operating or even blinding an operator.[5]

Whether the thermal effects of a HEL on a target induce explosion, perforation, burning, or blinding, the effects will be measurable and swift.

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Additionally, the speed of a HEL makes it superior to most conventional weapons systems and munitions. Lasers operate at the speed of light,[6] resulting in an almost immediate impact from laser initiation to the target. With a "zero time of flight," a HEL may immediately affect the target following positive identification. This will reduce the time to engage a target by seconds or even minutes compared to most conventional subsonic and supersonic weapons systems and munitions.[7] This nearly instantaneous ability to affect a target practically eliminates the time for an enemy to react. Furthermore, with a zero time of flight, a HEL ostensibly can engage and affect many more targets in a given period than a conventional gun.[8]

Another remarkable advantage of a HEL is long-range precision. Lasers are intrinsically accurate, as has been proven by their use for medical surgery. Now magnify the energy output of that surgical laser in an operating room and place it on the battlefield—giving a new meaning to the phrase *surgical strike*. However, conducting surgically accurate fires against targets that may be moving (or perhaps maneuvering) on a vast battlefield demands precision aiming. To overcome these challenges, advanced systems such as the high-resolution laser radar and high-power phased array transceiver are also being developed to improve accuracy in acquiring, identifying, and tracking targets at distant ranges.[9] Furthermore, another new development, the precision aimpoint maintenance using continually updated templates, can be used to translate from the identification of an adversary system to aim points that will direct a HEL weapon onto specific system vulnerabilities (such as fuel tanks, wings, optics, areas with less armor, and so forth).[10] Marrying a surgically accurate HEL to ancillary advanced acquisition, identification, tracking, and aiming systems will create a promising and effective HEL weapons system.

Lastly, the stealth of a HEL weapon will add a psychological impact when used on the battlefield. "Mysterious weapons have a psychological effect," wrote Montgomery Miegs in reference to the evolution of military innovation.[11] A HEL weapon certainly could fall into this category of mysterious weapons, as an adversary may not know if a HEL weapon is being used or is even on the battlefield until it is too late. Most lasers operate in a spectrum that is not visible to the naked eye, and therefore lasers may not be immediately detected by an enemy receiving effects. In fact, there may be no recognition of laser effects on a target until there is no time left for the target to react for survival. Currently, only a limited number of existing systems have the frequency and bandwidth detection capabilities to identify a HEL while in use. To lessen the effects of a laser weapon, possible reaction maneuvers by an intended target could include a change in speed, attitude, or altitude; a counterattack; or a movement to a concealed position. However, even when an enemy discerns the effects of a laser, he may not know the direction or distance of the source of the effects, as there is no smoking gun or combustion flash from the laser "shot." Therefore, an adversary may not be capable of effectively conducting reactionary maneuvers. At least initially, even the sound and appearance of a HEL weapon, let alone a HEL shot, will not be recognizable by the enemy, making a stand-alone laser weapons system difficult to target. The current limited ability to detect a HEL weapons system or the effects of a HEL weapon will result in tactical asymmetry on tomorrow's battlefield.

Laser Weapon Employment

Since HEL weapons encapsulate into one system the enhancements of speed, precision, and stealth, their use for future military application is inevitable. HEL weapons will provide a marked advantage over existing conventional weapons, to include indirect fire munitions, aircraft, water vessels, vehicles, and even ballistic missiles. In 2008, the U.S. Army formally recognized the potential of HEL technology for future weapons by awarding a contract to Boeing for the HEL Technology Demonstrator. The justification identified the following capability gaps that HEL weapons could fill: "1) Defeat In-Flight Projectiles such as rockets, artillery, mortars, anti-tank guided missiles, and man-portable surface-to-air missiles, 2) Ultra-Precision Strike with little to no collateral damage, 3) Disruption of Electro-Optical (EO) and Infra-Red (IR) sensors, and 4) Neutralizing mines and other ordnance from a stand-off distance."[12]

Scenarios

In 2009, Lieutenant General George Flynn, who was then the U.S. Marine Corps Deputy Commandant for Combat Development and Integration, formally recognized the recent advances in solid-state laser technology, citing the "near zero time of flight, low shot cost, and ostensibly 'deep-magazine' capability to counter the primary low altitude unmanned aerial system (UAS) threat."[13] There is a vast list of employment scenarios for HEL weapons across the domains of land, sea, air, and space. The following vignettes and analysis of current research and development tests illustrate the potential for HEL weapons on the battlefield.

Background. *It is December 2020. North Korea has taken military action to threaten South Korea. International disputes have escalated regarding island territories and the maritime border between North*

U.S. Marine Corps (Benjamin R. Reynolds)

GBU–54 Laser Joint Direct Attack Munition with DSU–38 Guidance Unit under F/A–18 Hornet wing

Korea and South Korea. North Korea has increased the size of navy fleets at bases on the east and west coasts. From these bases, the North Korean navy has deployed numerous torpedo craft, missile craft (PTG), and patrol craft to guard the southeastern and southwestern coasts. Reports from merchant ships have shown these craft are frequenting waters between 10 and 30 miles off the coast. The North Korean air force has increased air patrols over coastal airspace to the south. The North Korean army also appears to be mobilizing toward the south. Pyongyang seems to be posturing to conduct limited military operations under centralized control in order to provoke military action against them first, intending to deliver a strong and immediate counterattack.

Scenario 1. *On December 1, 2020, North Korea conducts an artillery attack on Yeonpyeong Island with a mixture of 170-millimeter (mm) and 152mm artillery rounds launched from mainland North Korea. While approximately 100 rounds were destined to impact on the island, only 50 actually impacted with no loss of life and no destruction to critical infrastructure due to networked land and maritime laser defense systems. The U.S. Army had previously deployed land laser defense systems (LLDS) to protect the population center and economic port of Yeonpyeong from rocket and artillery attack. Additionally, U.S. Navy ships from the* George Washington *battlegroup had recently been upgraded with the maritime laser defense system (MLDS) for ship and area defense against rockets, missiles, and unmanned aerial vehicles (UAVs). On December 1, the networked LLDS and MLDS engaged and forced detonation of all artillery rounds with trajectories destined for the port and city at Yeonpyeong.*

> HEL weapons can provide point defense against surface and air threats both ashore and in a maritime environment

Ground forces are already looking to apply HEL weapons to target rocket, artillery, and mortar (RAM) threats. Northrop Grumman's Skyguard laser defense system has proven effective against RAM threats at a range of 5 kilometers (km).[14] Skyguard, more recently known as the Tactical High Energy Laser (THEL), has the interest of the U.S. and Israeli armies. Further advancement in laser technology has resulted in the Mobile THEL (MTHEL) as a point defense weapon that can be displaced to a base, key operational node, or population center to engage and destroy RAM threats for force protection. During testing, the MTHEL engaged and destroyed 28 122mm and 160mm Katyusha rockets, multiple artillery shells and mortar rounds, and a salvo attack by mortars. The MTHEL, which is the size of a single container-sized semi trailer, can be deployed today to an expeditionary environment to protect military or civilian infrastructure or personnel.[15] Additionally, Raytheon has developed a HEL weapon for short-range air defense against RAM threats and aircraft. In June 2006, Raytheon mounted a HEL on the turret of its Phalanx close-in weapon system, which is already in use for ship-and land-based short-range air defense. Known originally

as the Laser Area Defense System (LADS), the short-range point defense HEL weapon included a 20-kW fiber laser and a bench-mounted beam director attached to the top of a Phalanx mount. During testing, the LADS detonated a 60mm mortar at a range of 550 meters.[16] The MTHEL and LADS are potential tactical HEL weapons capable of terminal defense of a local area against RAM threats.

HEL weapons will also be used for defense against enemy offensive aircraft. In December 2008, Boeing successfully tested a kilowatt-class laser weapon on its Avenger air defense system that shot down a UAV. The acquisition, tracking, and aiming systems acquired and tracked three small UAVs; then the HEL was used to shoot down one of them "from an operationally relevant range" by burning a hole through the vehicle.[17] Although this could be considered a minor success against a UAV, it is indicative of an expeditionary mobile tactical HEL antiaircraft capability for protection of key infrastructure or even a halted tactical convoy.

Scenario 2. *On December 2, 2015, North Korea launched two surface-to-surface missiles (SSMs) at USS* Normandy *from a PTG approximately 20 miles west of Namp'O naval base. USS* Vicksburg *initiated its two MLDS for 6 seconds each to detonate both SSMs before they reached the* Normandy. *Simultaneously, the* Normandy *utilized its MLDS in manual mode to engage the North Korean PTG. The PTG was neutralized when the MLDS ignited its engine after laser weapon engagement for 20 seconds.*

There is great potential for using HEL weapons for maritime defense. In June 2010, Raytheon's maritime variant of the HEL with a Phalanx mount, dubbed the Laser Weapon System by the U.S. Navy, detected, engaged, and downed a "threat representative" UAV in a simulated combat encounter at sea.[18] More recently, on April 10, 2011, the Navy demonstrated the ability to use a HEL against watercraft by setting an outboard engine of a small boat on fire from a distance of a few miles.[19] An additional advantage of a maritime HEL is the logistically friendly "deep magazine" effect as compared to the traditional Phalanx that expends 3,000–4,500 20mm rounds per minute. Furthermore, the high electrical power required for the Laser Weapon System is readily available aboard the ship. HEL weapons can provide point defense against surface and air threats both ashore and in a maritime environment.

Scenario 3. *While conducting a Combat Air Patrol (CAP) mission in the vicinity of the* George Washington *battlegroup in the Yellow Sea, a U.S. Navy F/A–18 Super Hornet was illuminated by a land-based Fan Song radar, presumably associated with an SA–2 launcher. In response, the F/A–18's onboard airborne laser defense system (ALDS) immediately engaged the radar operating system, rendering it inoperable before the SA–2 was launched.*

Offensive air support against ground targets will also be enhanced by HEL weapons. Unlike ground forces, a pilot's "bird's eye" view of the battlefield is often less obstructed by terrain, although it can be severely diminished by vegetation. Nonetheless, pilots will make frequent use of direct-fire HEL weapons for offensive air support. This is the concept for the U.S. Air Force Advanced Tactical Laser (ATL). Currently mounted on a C–130, although envisioned for other aircraft to include the V–22 Osprey, the ATL is designed as a close air support weapon using a Mega-Watt class HEL.[20] In September 2009, the ATL penetrated an unoccupied stationary vehicle in 8 seconds from an undisclosed altitude and distance.[21] While

United Launch Alliance Delta IV Heavy launches from Space Launch Complex-6 with National Reconnaissance Office payload

(Pat Corkery)

this may seem negligible in effect, the high heat generated with precision accuracy from a moving aircraft reveals the reality of close air support with a HEL for limited high-value target engagement.

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Scenario 4. *On December 3, 2015, a section of U.S. Air Force F–16 Fighting Falcons was conducting a CAP north of Seoul, South Korea, when they were engaged by four MiG–19 Farmers. The result was an immediate and short air-to-air engagement. All four MiG–19 Farmers were destroyed: one by 20mm cannon fire, another by an AIM–7 Sparrow, and two by the ALDS. While the two F–16s each engaged a MiG–19 using conventional munitions, their respective onboard ALDS targeted and detonated the drop tanks of the remaining two enemy aircraft.*

The ability of aircraft to conduct counterair warfare will be greatly enhanced by a HEL weapon. It could provide a counterair capability that operates distinctly from the primary mission of the aircraft and pilot. In other words, while a pilot is conducting his assigned aviation mission (for instance, offensive air support or aerial reconnaissance), a HEL weapon could automatically identify, acquire, target, and engage an enemy missile or aircraft. The counterair capability of HEL weapons will enhance the survivability of pilots, especially aboard aircraft not designed specifically for that purpose.

Onboard airborne HEL defense weapons could be used to protect more than just tactical fighter and attack aircraft. The Defense Advanced Research Projects Agency High-Energy Liquid Laser Area Defense System competition has the goal of creating a 150 kW laser weapon within a 3-cubic-meter space and weighing no more than 5 kilograms/kW. The intent is to create an airborne HEL that is small enough to fit in a bomber, transport, or tanker aircraft without interrupting the main function of the aircraft. The milestones for the project include a ground test in 2011 to shoot down two SA–10 class surface-to-air missiles simultaneously and then an airborne test in 2012–2013.[22] These tests are encouraging the evolution of tactical defense HEL weapons beyond military application.

Scenario 5. *On December 4, 2015, North Korea launches a Scud-ER from a northern province. The Scud appeared to be on a trajectory to impact in the vicinity of Pusan, South Korea, where coalition forces were conducting reception, staging, onward movement, and integration for potential follow-on land operations against North Korea. A U.S. Air Force strategic airborne laser defense system detected, engaged, and detonated the Scud-ER while it was still in North Korean airspace. What remained of the detonated Scud-ER fell to the ground within North Korea.*

The strategic impact of a HEL against a ballistic missile still provides promise. The U.S. Air Force has continued research and development evolving from the Strategic Defense Initiative concept to use a laser weapon against ballistic missiles. Specifically, the AL–1A Airborne Laser (ABL) has been designed to attack ballistic missiles in the boost phase. The intent is to cause slight damage to the booster skin that will result in catastrophic failure and ultimate detonation. The concept of employment is to deploy the ABL to borders of a nation threatening ballistic missile attack and to detect, track, and attack the missiles once they clear the cloud base. The debris would then fall back to the nation that launched the weapon or some other safe environment. Once the system is more mature, it could be used against short, intermediate, and intercontinental ballistic missiles, as well as high-flying aircraft and cruise missiles.[23] In February 2010, the Missile Defense Agency announced that the ABL shot down a liquid-filled Scud-like target.[24] However, in the most recent test in October 2010, "preliminary indications are that the system acquired and tracked the plume (rocket exhaust) of the target, but never transitioned to active tracking. Therefore, the HEL [shot] did not occur."[25] Even with these recent setbacks, this initiative is likely to result in a strategic HEL weapon that will provide a defense against a ballistic missile.

Challenges

Obstacles that will have to be overcome before HEL weapons are commonplace are costs, counter-laser defense, and collateral damage. None of these obstacles is insurmountable. Additionally, these obstacles will likely remain even when HELs are operational.

A cost-benefit analysis is necessary to determine the right time to integrate HEL weapons into the Department of Defense (DOD) arsenal. In 2006, Northrop Grumman stated that its first Skyguard/THEL systems would cost $150 million–$200 million due to nonrecurring developmental costs, but that the cost would drop to $25 million–$30 million per system.[26] That price is very likely to be reduced even more through further research and development of the three components of laser action: laser medium, pumping stations, and resonant optical cavities.[27] In contrast to the high price, even the cost of a few million dollars for each HEL weapon is minimal compared to the loss of a Navy ship, an aircraft, a key facility, or a grouping of military or civilian personnel. The monetary cost of HEL is high, although at some point the cost will be deemed worthwhile for force protection.

Time is also a cost when considering that global competitors are likely also developing HEL weapons. Russia is developing the Almaz-Antey HEL directed energy weapon (HEL DEW) air defense system, which has already engaged a target drone. The expected concept of employment of this weapon is like the U.S. and Israeli THEL, although with enhanced capability to engage surface-to-air missiles and PGMs for point defense. Russia has also developed an airborne Almaz/Beriev A–60 HEL DEW "Testbed" capability.[28] Additionally, in 2007, DOD presented evidence that the Chinese People's Liberation Army funded a well-developed and advanced HEL program intending to attack low orbit satellites, cruise missiles, and PGMs, while also providing point defense.[29] Most recently, India released information regarding its testing of a laser ballistic missile defense system with capability of producing 25kW pulses that can reportedly destroy a ballistic missile at a range of 7km, as well as an air defense laser capable of engaging aircraft at a range of 10km. India's laser research has even resulted in a hand-held laser sensor capable

of identifying an impending laser threat.[30] While the Russian, Chinese, and Indian HEL weapon capabilities do not appear to be as robust as the U.S. initiatives, there is potential for a future HEL arms race. Therefore, even time is a cost when it comes to developing HEL weapons for military employment.

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The cost to effectively counter a HEL will also be high. It is just a matter of time for every innovation to be countered. A seemingly obvious counter to a laser weapon is to use a material with reflectivity that either dissipates or fully reflects the transfer of energy from a laser. In many cases, these surface material innovations will just delay the thermal effects of a HEL by a matter of seconds. For the adversary, this counter will be costly financially and temporally, as producers will have to redesign and field modified materials on current equipment or design completely new equipment.

Lastly, forethought is necessary to understand the possible collateral damage of a HEL weapon. At the strategic level, DOD is developing "decentralized predictive avoidance" measures to prevent unintended collateral damage of satellites on the trajectory of a stray laser. At the tactical level, HEL weapons could cause unintentional permanent and temporary personnel blinding. As reflectivity of material is further advanced, it is even possible that a "thermal ricochet" could result in collateral damage. While the precision of a HEL weapon will likely reduce collateral damage, more research must be done to predict and regulate that damage.

HEL weapons are on the cusp of becoming a reality for use across the joint force. They will provide a precise and nearly undetectable direct-fire capability with "zero time of flight" against conventional weapons systems and munitions. HEL weapons will significantly improve force protection of civilian and military infrastructure and populations against rockets, artillery, mortars, aircraft (manned and unmanned), watercraft, vehicles, and missiles in the domains of land, sea, air, and space. Furthermore, offensive HEL weapons will improve speed and precision of fire support, counterair, and strike capability, while also providing capacity for fires from nontraditional aircraft platforms. Since HEL weapons provide such significant advancement in defensive and offensive capability and capacity, they will be included in the arsenal of military assets to operate in tomorrow's conflicts. **JFQ**

NOTES

[1] Major Billy Short, Office of Naval Research, email correspondence to author, December 9, 2011.

[2] Industrial Laser Systems, LLC, Laser Cutting Services and Systems, "Important Laser Information," available at <www.laser-industrial.com/pweld3.htm>.

[3] Bengt Anderberg, *Laser Weapons: The Dawn of a New Military Age* (New York: Plenum Publishing, 1992), 93.

[4] J. Thomas Schriempf and Brian Hankla, "Navy HEL Lethality Program," lecture given at the High Energy Laser Joint Technology Office Directed Energy Professional Society Annual Review, Albuquerque, NM, May 5, 2010.

[5] United Nations, Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects, Protocol IV on Blinding Laser Weapons, Article 1, negotiated and adopted in Vienna, October 13, 1995, says, "It is prohibited to employ laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision, that is to the naked eye or to the eye with corrective eyesight devices. The High Contracting Parties shall not transfer such weapons to any State or non-State entity."

[6] For the physics, see R.P. Feynman, R.B. Leighton, and M.L. Sands, *The Feynman Lectures on Physics* (Reading, MA: Addison-Wesley Publishing Company, 1963).

[7] Carlo Kopp, "High Energy Laser Directed Weapons," Technical Report APA–TR–2008–0501, May 2008, 3.

[8] Anderberg, 96.

[9] Dan Marker, "Hi-power Phased Array Transceiver (HiPAT)," lecture given at the High Energy Laser Joint Technology Office Directed Energy Professional Society Annual Review, Albuquerque, NM, May 5, 2010.

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[11] Montgomery C. Meigs, *Slide Rules and Submarines: American Scientists and Subsurface Warfare in World War II* (Washington, DC: National Defense University Press, 1989), 214.

[12] Kopp, 46.

[13] Ashley G. Johnson, Office of Naval Research brief, "POM13–07: Ground Based Air Defense On-the-Move," July 9, 2010.

[14] Jefferson Morris, "Northrop Unveils Skyguard Laser Air Defense System," *Aviation Week*, July 13, 2006.

[15] Kopp, 37–47.

[16] Ibid., 53.

[17] Graham Warwick, "Boeing Claims First Laser UAV Shootdown," *Aviation Week*, January 27, 2009. In 2007, Boeing used an earlier variant of the Avenger laser to neutralize improvised explosive devices and other unexploded ordnance.

[18] David Wichner, "Laser Ship-defense Test a Win for Raytheon, Navy," *Arizona Daily Star*, June 4, 2010.

[19] "Laser Gun Fired from U.S. Navy Ship," BBC News, April 11, 2011.

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[21] "Boeing Advanced Tactical Laser Defeats Ground Target in Flight Test," media release, September 1, 2009.

[22] Graham Warwick, "Solid-state Laser Programs Advance," *Aviation Week*, January 11, 2009.

[23] Kopp, 14–36.

[24] Robert Wall, "Airborne Laser Shoots Down Scud-like Target," *Aviation Week*, Defense Technology blog, February 12, 2010.

[25] "Airborne Laser Test Bed Exercise Conducted," Military Defense Agency news release 10–NEWS–0014, October 21, 2010.

[26] Morris.

[27] Anderberg, 18.

[28] Kopp, 54–60.

[29] Ibid., 65.

[30] Jay Menon, "India Looks at Laser Weapons for Air and Missile Defense," *Aviation Week*, April 28, 2011.