AMERICAN FOREIGN POLICY COUNCIL

Directed Energy Weapons And Modern Warfare

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In a 2009 article entitled "Technology and Warfare," Professor Alex Roland of Duke University wrote that "...technology, more than any other outside force, shapes warfare."[1] In his article, Roland went on to explain how military technologies, while not being deterministic, open doors and provide opportunities - often referred to as 'opportunity space' in current military parlance - for the nations employing them.

The history of warfare is replete with examples of military technological advancements. Some of the most notable of these innovations, including ancient trebuchets and catapults, medieval longbows, artillery, and machine guns, provided immediate and decided advantage to their developers. Others - like submarines, military aircraft, and tanks - had less significant immediate impacts and required decades of evolution, if not longer, to achieve the potential possessed by these systems today. Precision guided munitions (PGMs) and military drones are two of the most recent technology-driven innovations that have reshaped the conduct of warfare.

As it has been with all military technological innovations, gaining "opportunity space" is the reason why numerous nations are currently pursuing the promise of directed energy weapons (DEWs). DEWs, specifically high energy lasers (HELs) and high-power radiofrequency (HPRF, generally referred to as high power microwave, or HPM) weapons, emit very high power, focused beams of electromagnetic radiation to affect their targets. High power is emphasized because low power radiofrequency (RF) and laser devices have been in use for several decades by militaries worldwide. Radars that can find targets at great distances and radar and communications jammers that confuse their targets with, for example, RF noise, have been in use since World War II. Similarly, lasers have been used to designate and guide munitions to their intended targets since the early 1970s and to dazzle or confuse an adversary's optical sensors and combatants for more than a decade.

BEAMS OF THE FUTURE

The current emphasis on the development of DEWs and the pace of these developments is accelerating for a variety of reasons. These reasons include the speed of the weapons, their potential range, their potential magazine (that is, the number of potential shots that can be fired before "reloading"), their potential to impact targets at very low costs as compared to traditional kinetic weapons, and the significant amount of research that has been done on DEWs and their component technologies over the past six decades. (Because the physics governing DEWs is quite complex, broad generalizations will be made here, and the reader is referred to the significant volume of nontechnical and technical publications for more information on this topic.[2])

Since electromagnetic radiation travels at the speed of light (186,000 miles per second), DEWs can potentially induce effects upon their targets very rapidly.[3] In the case of HELs, damage to a target is thermally induced by heating or burning through a target's control surfaces or outer skin to damage internal components, or by directly damaging its optical imaging or guidance sensors. In the case of HPRF weapons, the effects upon targets range from short-duration upsets to disruption or damage of electronic components.

To effectively employ DEWs, militaries generally need at least a basic knowledge of an intended target's design, materials, and internal components. Open-source and clandestine intelligence, modeling and simulation, and testing against surrogate targets can, however, provide sufficient information to enable DEWs to be effectively used against a wide variety of modern military targets including PGMs, drones, and critical components of air and missile defense systems.

HELs can potentially affect targets at significant ranges. The Airborne Laser (ABL) developed by the U.S. Air Force and successfully demonstrated by the Pentagon's Missile Defense Agency illustrates this well: the ABL was designed to destroy ballistic missiles while they were in their boost phase (powered flight), even though they might be hundreds of miles away. While the range of HPRF weapons is generally far less than that of laser weapons,[4] given the vast numbers of potential targets (any system or facility employing devices or equipment containing electronic components) and the potential impact of these weapons (from temporary upsets to permanent damage), their military value may be considerable. Since HEL and HPM beams are invisible and highly directional, it may also be possible to employ DEWs without an adversary's knowledge.

Since the vast majority of DEWs are electrically-powered,[5] they could potentially have unlimited magazines. The advantage here is two-fold. First, the number of targets that HEL and HPRF weapons could potentially engage is dramatically increased. This is especially important when militaries must defend against large numbers of low cost drones, rockets, artillery, and mortars, and, in the case of some advanced nations, cruise missiles. Additionally, since DEWs do not have to be "reloaded" the way ships, aircraft, and ground forces employing missiles, bombs, and artillery do, DEWs can potentially serve as a significant force multiplier, since combatants would not have to be resupplied or reequipped as often.

The potential to achieve very low cost-exchange ratios with DEWs offers significant advantages to their developers. As Mark Gunzinger, a Senior Fellow at the Center for Strategic and Budgetary Assessments, pointed out in two recent works, the ability to destroy or damage a cruise missile costing hundreds of thousands of dollars with a HEL or HPRF weapon that only costs a couple of dollars to use (the cost of the fuel used to power the electric generators powering the weapon) is a true game changer. By contrast, the missiles the U. S. Navy currently uses to engage an adversary's cruise missiles can cost a million dollars or more each, and two or more of these interceptor missiles may be launched to ensure the incoming cruise missile is defeated.[6] Since inflicting unacceptable costs on an adversary is clearly an objective of war, the combatant that can inflict the most damage upon his adversary at the lowest cost is decisively advantaged.

While there are significant technological challenges that must be overcome before DEWs can be deployed,[7] the state of the art in the requisite technologies has advanced to the point where the first operational DEWs could be fielded within a couple of years. The significant increase in the number of conferences, articles, news stories, and press releases addressing DEWs over the past five to ten years attests to this, as do major demonstrations conducted by several nations. That several major defense contractors are developing and actively marketing DEWs also points to this fact.

COMBAT ROLES OF DEWS

There are a wide variety of potential offensive and defensive combat roles for DEWs. The first combat role envisioned for HELs was ballistic missile defense in nuclear weapons exchange scenarios. Both ground and space-based HELs for terminal-phase, point defense were envisioned, but for a variety of reasons these applications proved to be extremely difficult (if not impossible) and excessively expensive. Some of the most discussed potential DEW applications are summarized below.

TABLE 1. Potential DEW Uses in Combat

As a several authors have pointed out recently, DEWs are neither universally applicable nor single-point solutions for military missions.[9] As Mark Gunzinger has noted, "Although the advent of mature DE capabilities could significantly change the way the U.S. military conducts future operations, it is unlikely that DE alone will underpin a new military revolution that renders obsolete or subordinate existing means for conducting war."[10] One of the most significant insights of his assessment is that DE applications complement kinetic systems and can significantly increase their effectiveness, rather than obviate the need for them.

DEW DEVELOPMENT EFFORTS

Numerous nations are currently developing DEWs. While the following list is not meant to be comprehensive, care has been taken to ensure most of the major development efforts have been captured to give a good idea of both the breadth and scope of DEW development efforts globally.

TABLE 2: Some Current HEL Development Efforts

TABLE 3. Some Current High Power RF Weapon Development Efforts

Several other nations have openly stated their desire to develop and field DEWs. Given the potential impact of these weapons, it can be surmised that unreported programs also exist.

INNOVATE, OR PERISH

The maturity and number of DEW development efforts underway and the significant volume of both technical and nontechnical reports on the topic of directed energy make it clear that these weapons will be employed in warfare in the future. As General Guilio Douhet, the father of strategic airpower noted, "Victory smiles upon those who anticipate the changes in the character of war, not on those who wait to adapt after the changes occur."[13] Given this prospect, nations possessing "first capabilities" will have advantages over their adversaries that may potentially be very significant. As General Robert Cone, past Commander of the U.S. Army's Training and Doctrine Command remarked, "What keeps me awake at night is, are we going to miss the next big technological advance? And perhaps an enemy will have that."[14]

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NOTES:

[1] Alex Roland, "Technology and Warfare," Foreign Policy Research Institute, February 27, 2009.
[2] See, for example, Ronald O'Rourke, *Navy Shipboard Lasers for Surface Air and Missile Defense* (Washington, DC: Congressional Research Service, 2015); "Team Bravo Capstone Project Report: Viable Short-Term Directed Energy Weapon Naval Solutions--A Systems Analysis of Current Prototypes," Naval Postgraduate School, 2013.
[3] HEL weapons can take up to several seconds to induce the desired damage on their intended targets.
[4] HPM weapons have much shorter ranges than HELs because the divergence of their longer wavelength beams significantly reduces the amount of energy deposited on a target. Additionally, HPM radiation must, in many cases, traverse circuitous routes (through power cords, joints and cracks in component cases, attached cables, etc.) to get into electronic components to upset or damage the components.
[5] Most of the HEL systems currently under development are electrically-powered. Early HELs were chemically-powered (the laser beams were generated as a result of chemical reactions involving chemicals that in many cases were highly toxic or corrosive), and some nations may still be developing chemical HELs and other types of HELs for some applications.
[6] Mark Gunzinger, *Changing the Game: The Promise of Directed Energy Weapons* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012), and Mark Gunzinger, *Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016).
[7] Ibid; See also Jason Ellis, *Directed-Energy Weapons: Promise and Prospects* (Washington, DC: Center for a New American Security, 2015) and O'Rourke, *Navy Shipboard Lasers for Surface Air and Missile Defense*.
[8] "Missile Defense Agency solicits industry for low power laser demonstration," Flightglobal.com, September 2, 2016.
[9] See, for example, Gunzinger, *Changing the Game* and Ellis, *Directed-Energy Weapons: Promise and Prospects*.
[10] Gunzinger, *Changing the Game*.
[11] "US Army to Test Powerful New Truck-Mounted Laser 'Within Months,'" *Defense One*, March 16, 2017; "Navy, MDA Experimenting With Laser Prototypes For Surface Warfare, Ballistic Missile Defense," *USNI News*, March 29, 2017; Northrop Grumman Corporation, "US Navy Selects Northrop Grumman to Design and Produce Shipboard Laser Weapon System Demonstrator, " December 22, 2015; "Air Force Moves Aggressively On Lasers," *Breaking Defense*, August 7, 2015; "MDA Plans FY '17 Contract Awards For Airborne Laser Demonstrator," *Defense Daily*, December 14, 2016; "AFSOC Expects C-130 Laser Tests Within Year," *Breaking Defense*, March 2, 2017; "The Future of U.S. Laser Weapons," *Real Clear Defense*, March 14, 2017; General Atomics, "GA-ASI Launches Team Reaper Australia," February 28, 2017; "DARPA moves ahead with plan to put anti-missile lasers on drones," *Defense Systems*, August 19, 2016; "'Dragonfire' - the Laser Gun Being Developed for British Forces," *Telegraph* (London), September 16, 2016; MBDA, "Ministry of Defence Finalising High Energy Laser Demonstration Programme with UK DRAGONFIRE," September 16, 2016; "MBDA Deutschland Successfully Tests Laser 'Effector,'" optics.org, November 23, 2016; "Rheinmetall Conducts Sea Trials of a Naval Laser Gun," *Defense Update*, February 19, 2017; Rheinmetall, "Modern Air Defence: Rheinmetall "HEL-lights" A Fully Integrated Air Defence High-Energy Laser Weapon System at IDEX 2015," February 22, 2015; "'Iron Beam' enhances U.S., allies' security," NWI.com, May 10, 2016; "Israeli Contractor Rafael Shows Off Anti-Drone Laser In Korea," *Popular Science*, October 20, 2015; "Drones, Lasers, and Tanks: China Shows Off Its Latest Weapons," *Popular Science*, February 27, 2017; Richard D. Fisher, Jr., Testimony before the U.S.-China Economic and Security Review Commission, Washington, DC, February 23, 2017, https://www.uscc.gov/sites/default/files/Fisher_Combined.pdf; "Russia's combat laser weapons declassified," *Pravda* (Moscow), March 8, 2016; "The 7 Most Impressive Weapons Russia Is Developing Right Now," *Business Insider*, August 24, 2015.
[12] "Counter-electronics High Power Microwave Advanced Missile Project," Wikipedia, n.d.; "Active Denial System," Wikipedia, n.d.; U.S. Department of Defense, "RadioFrequency Vehicle Stopper, Non-Lethal Weapons Program," n.d.; O.S. Zucker, "Photoconductive Switch-Based HPM for Airborne Counter-IED Applications," *IEEE Transactions on Plasma Science* 42, iss. 5, May 2014; Robert J. Capozzella, *High Power Microwaves on the Future Battlefield: Implications for U.S. Defense*, Air University Press, 2010; Diehl Defence, "HPEM Effectors for Convoy-, Object protection, Car Stopping and Countering Small, Unmanned Aerial Vehicles," n.d.; "BAE Systems Amps Up Directed Energy Work," *Aviation Week*, October 15, 2014; "The PLA's Potential Breakthrough in High-Power Microwave Weapons," *The Diplomat*, March 11, 2017; "U.S. Military Wants to Blow Up Landmines with Lasers," *Popular Science*, June 24, 2015; "New Russian Directed-Energy Weapon Could Complicate U.S. Military Strategic Planning," *Military and Aerospace Electronics*, July 7, 2015; "Russia: Revolutionary Secret Warfare System Tested With Capability to 'Switch Off Enemy Weapons,'" *International Business Times*, July 6, 2015.
[13] Guilio Douhet, *The Command of the Air* (Dino Ferrari, trans.) (Washington, DC: Air Force History and Museums Program, 1998), 30, https://media.defense.gov/2010/Sep/24/2001329765/-1/-1/.../AFD-100924-017.pdf.
[14] Mike Morones, "Interview with GEN Robert Cone," *Defense News*, December 16, 2013
