Backgrounder

Published by The Heritage Foundation

No. 1931
April 28, 2006

The Viability of Directed-Energy Weapons

Alane Kochems and Andrew Gudgel

When directed-energy weapons are mentioned, most people think of "death rays" or Hollywood's latest science fiction movie. However, directed-energy weapons (DEWs) are a reality, and several have already been tested under battlefield conditions.[1] They may begin to appear on the battlefield within the next decade, bringing a revolution in weapons and how war is waged.

While DEWs are not the solution to all combat situations, these technologies would provide the U.S. military with additional flexibility in tailoring its response to different types of threats. However, considerable work still needs to be done before they can be deployed. These technologies need the full support of the armed services, and the Department of Defense (DOD) needs to generate clear guidelines for their use.

The Pentagon believes that DEWs are legal under international law, but human rights groups are arguing that DEWs could be used inhumanely. Putting the proper protocols in place should mitigate these concerns. While DEWs are not a panacea, the armed services should fully support research and development of these useful technologies.

Weapons Revolutions

From the Stone Age until the Middle Ages, a weapon's power was limited by the strength of the man wielding it or, in the case of bows, by the strength of material from which it was made. In the late Middle Ages, a revolution in the weaponry occurred when chemical-powered (gunpowder)

Talking Points

- Directed-energy weapons (DEWs) use the electromagnetic spectrum (light and radio energy) to attack pinpoint targets at the speed of light. They are well-suited for defending against threats such as missiles and artillery shells, which DEWs can shoot down in mid-flight. In addition, controllers can vary the strength of the energy put on a target, unlike a bullet or exploding bomb, using them as nonlethal means to neutralize human threats.
- DEW technologies, while not the solution to all combat situations, provide the U.S. military with additional flexibility in responding to different types of targets.
- The armed services need to move from just saying that DEWs are a good idea to fully supporting their development. The Defense Department needs to establish clear guidelines for their use.

This paper, in its entirety, can be found at:
www.heritage.org/research/nationalsecurity/bg1931.cfm

Produced by the Douglas and Sarah Allison Center for Foreign Policy Studies of the Kathryn and Shelby Cullom Davis Institute for International Studies

Published by The Heritage Foundation
214 Massachusetts Avenue, NE
Washington, DC 20002–4999
(202) 546-4400 • heritage.org

weapons began to replace swords and bows. This revolution changed the nature of warfare: not just tactics, but also the usefulness of armor, castles, and then-popular weapons.

Since the invention of gunpowder, a weapon's effectiveness has no longer depended on the wielder's strength, but on the chemical energy of the propellant or explosive. While centuries of technological advances have improved the power of these materials, the basic operating principle of chemical-powered weapons ultimately remains the same. Modern battlefield weapons are the descendents of muskets and cannon.

Another revolution in weaponry is currently underway, with directed-energy weapons on the cusp of replacing chemical-powered weapons on the battlefield. DEWs use the electromagnetic spectrum (light and radio energy) to attack pinpoint targets at the speed of light. They are well-suited to defending against threats such as missiles and artillery shells, which DEWs can shoot down in mid-flight. In addition, controllers can vary the strength of the energy put on a target, unlike a bullet or exploding bomb, allowing for nonlethal uses.

The Beginning of Directed-Energy Weapons

Both the Allies and the Axis powers conducted basic research and studies into primitive directed-energy weapons before World War II. However, British scientists calculated that the electronic systems of the time could not generate the power necessary for a "death ray," and research was redirected into early radar detection systems.[2]

During the Cold War, the U.S. and the Soviet Union studied the possibility of creating particle-beam weapons, which fire streams of electrons, protons, neutrons, or even neutral hydrogen atoms. The kinetic energy imparted by a particle stream destroys the target by heating the target's atoms to the point that the material literally explodes. These weapons were considered for both land and space-based systems. However, because beam strength degrades rapidly as the particles react with the atoms in the atmosphere, it requires an enormous power plant to generate a weapons-grade beam. The countries abandoned particle-beam weapon research as impracticable.[3]

How Lasers Work

Albert Einstein described the theoretical underpinnings of lasers in 1917. However, the first working laser was not built until 1960, opening an entirely new avenue of directed-energy research. Lasers produce narrow, single-frequency (i.e., single-color), coherent beams of light that are much more powerful than ordinary light sources.

Laser light can be produced by a number of different methods, ranging from rods of chemically doped glass to energetic chemical reactions to semiconductors. One of the most promising laser devices is the free-electron laser. This laser uses rings of magnetically confined electrons whirling at the speed of light to produce laser beams that can be tuned up and down the electromagnetic spectrum from microwaves to ultraviolet light.[4]

Lasers produce either continuous beams or short, intense pulses of light in every spectrum from infrared to ultraviolet. X-ray lasers may be possible in the not too distant future. The power output necessary for a weapons-grade laser ranges from 10 kilowatts to 1 megawatt. When a laser beam strikes a target, the energy from the photons in the beam heats the target to the point of combustion or melting. Because the laser energy travels at the speed of light, lasers are particularly well-suited

1. On August 24, 2004, the Tactical High Energy Laser (THEL) system destroyed a salvo of mortar rounds in midair during a test. "Mobile/Tactical High Energy Laser (M-THEL) Technology Demonstration Program," *Defense Update*, at *www.defense-update.com/directory/THEL.htm* (March 10, 2006).
2. David E. Fisher, *A Race on the Edge of Time: Radar—The Decisive Weapon of WWII* (New York: McGraw-Hill, 1988), pp. 15–31.
3. Richard M. Roberds, Ph.D., "Introducing the Particle-Beam Weapon," *Air University Review*, July–August 1984, at *www.airpower.maxwell.af.mil/airchronicles/aureview/1984/jul-aug/roberds.html* (March 15, 2006).
4. *Encyclopedia Britannica*, 15th ed., s.v. "laser."

for use against moving targets such as rockets, missiles, and artillery projectiles.

One problem that affects laser beam strength is a phenomenon known as "blooming," which occurs when the laser beam heats the atmosphere through which it is passing, turning the air into plasma. This causes the beam to lose focus, dissipating its power. However, a variety of optical methods can be used to correct for blooming. Laser beams also lose energy through absorption or scattering if fired through dust, smoke, or rain.

The number of "shots" a laser weapon can produce is limited only by its power supply. Depending on the type of laser, this means that the weapon can have an almost "endless magazine" of laser bursts. In addition, a laser shot (including the cost of producing the energy) is much cheaper than a shot from a chemical-powered weapon system. For example, when deployed, the anti–ballistic missile Airborne Laser will cost approximately $1,000 per shot,[5] while each Patriot missile currently costs $2 million to $3 million.[6]

Current Laser Technology

Because they were invented several decades ago, lasers are the most mature of the DEW technologies. Laser dazzlers—devices that use laser light to temporarily blind sensors, optics, and personnel—are already available for law enforcement and military use. In 1995, the Chinese military marketed the ZM-87 laser interference device, a tripod-mounted battlefield laser dazzler designed to blind enemy soldiers and optics temporarily. In March 2003, North Korea may have used a ZM-87 to "paint" two U.S. Apache helicopters patrolling the Demilitarized Zone.[7]

The two U.S. laser weapons systems closest to actual deployment are the Tactical High-Energy Laser (THEL) and the Airborne Laser (ABL).

Development of the THEL began in 1996 as a joint program between the United States and Israel to develop a laser system capable of shooting down Katyusha rockets, artillery, and mortar shells. The THEL system uses radar to detect and track incoming targets. This information is then transferred to an optical tracking system, which refines the target tracking and positions the beam director. The deuterium fluoride chemical laser fires, hitting the rocket or shell and causing it to explode far short of its intended target.[8]

In August 2004, the THEL system shot down multiple mortar rounds during testing. However, the Army felt the fixed-base laser system was too large and cut funding for the program after the demonstration phase. Research was also conducted on a mobile version of the THEL called the MTEL.[9]

The ABL is a system that uses a megawatt chemical laser mounted on a modified Boeing 747 to shoot down theater ballistic missiles. The system consists of several modules: an infrared detection system to detect the missile's launch; the Tracking Illumination Laser (TILL); the Beacon Illuminator Laser (BILL); and the Chemical Oxygen Iodine Laser (COIL).[10]

Once tracked by the TILL, the BILL measures the atmospheric distortion between the COIL and the missile. These data are then passed on to the mirror

5. Suzann Chapman, "The Airborne Laser," *Air Force Magazine*, Vol. 79, No. 1 (January 1996), at *www.afa.org/magazine/jan1996/0196airbo.asp* (March 15, 2006).

6. GlobalSecurity.org, "Patriot Advanced Capability–3 (PAC-3)," at *www.globalsecurity.org/space/systems/patriot-ac-3.htm* (March 15, 2006).

7. Bill Gertz, "N. Korea Fired Laser at Troops," *The Washington Times*, May 13, 2003, at *newsmine.org/archive/war-on-terror/north-korea/nkorea-fired-laser-at-troops.txt* (March 15, 2006).

8. "Mobile/Tactical High Energy Laser (M-THEL) Technology Demonstration Program."

9. *Ibid.*

10. Press release, "Airborne Laser Progress Continues as Northrop Grumman Runs Full-Power COIL Tests, Delivers Beacon Illuminator Laser," Northrop Grumman Corporation, January 4, 2006, at *www.irconnect.com/noc/pages/news_printer.mhtml?d=91869* (March 15, 2006).

system, which makes appropriate corrections so that, when the COIL fires, maximum energy is transmitted to the target. The skin of the missile heats up, melts, and deforms, and the target breaks up in midair.[11]

The megawatt-class laser was tested at full power in early 2006. The Beacon Illuminator Laser system, which measures and corrects for atmospheric distortion, has also been shipped to Boeing for testing.[12] A complete prototype ABL weapons system will be assembled in 2006.[13]

A related project is the Advanced Tactical Laser (ATL) system, which uses a less powerful version of the ABL's COIL laser, instead of missiles, to attack ground targets. The laser is being built and will be tested in mid-2006. Boeing has received a C-130H transport aircraft from the Air Force and is modifying it for installation of the laser system. The full system will be fitted to the aircraft by 2007 and test-fired against ground targets.[14]

One shortcoming of laser weapons is that their beams travel only in straight lines, which means they have no indirect-fire mode and cannot shoot beyond the system's visual horizon. The DOD Office of Force Transformation (OFT), in conjunction with the Air Force Research Laboratory, is developing the Tactical Relay Mirror System (TRMS), which would use a mirror system mounted on an aerostat or UAV (unmanned aerial vehicle) to redirect the beams from laser weapons such as the ATL and ABL. Design specifications are already being determined.[15]

How Microwave Weapons Work

Written off as impractical during World War II, technological advances have now made microwave weapons feasible. However, current research focuses on using them as a means of nonlethal area defense and as anti-electronic weapons rather than as "death rays."

High-power microwave (HPM) weapons work by producing either beams or short bursts of high-frequency radio energy. Similar in principle to the microwave oven, the weapons produce energies in the megawatt range.[16] When the microwave energy encounters unshielded wires or electronic components, it induces a current in them, which causes the equipment to malfunction. At higher energy levels, the microwaves can permanently "burn out" equipment, much as a close lightning strike could.

Semiconductors and modern electronics are particularly susceptible to HPM attacks. Electronic devices can be shielded by putting conductive metal cages around them; however, enough microwave energy may still get through the shielding to damage the device.

The short, intense bursts of energy produced by HPM devices damage equipment without injuring personnel. Mounted on properly shielded aircraft or ships, or dropped in single-use "e-bombs," HPM weapons could destroy enemy radars, anti-aircraft installations, and communications and computer networks and even defend against incoming anti-aircraft and anti-ship missiles. With the ever-increasing use of electronics in weapons systems, HPM devices could have a devastating but nonlethal effect on the battlefield.

Current Microwave Weapons

HPM weapon technology is based on the same technology as radar devices, which already have a long history of research and development. However, no military has yet openly deployed HPM

11. *Ibid.*

12. *Ibid.*

13. SPG Media, "ABL YAL 1A Airborne Laser, USA," at *www.airforce-technology.com/projects/abl* (March 15, 2006).

14. Press release, "Boeing Receives Aircraft for Laser Gunship Program," Boeing, January 23, 2006, at *www.boeing.com/news/releases/2006/q1/060123a_nr.html* (March 15, 2006).

15. Colonel Craig Hughes, Office of Force Transformation, U.S. Department of Defense, "Re-directed Energy: the Tactical Relay Mirror System," presentation at The Heritage Foundation, Washington, D.C., February 13, 2006.

16. U.S. Air Force Research Laboratory, "High-Power Microwaves," fact sheet, September 2002, at *www.de.afrl.af.mil/Factsheets/HPM.swf* (March 15, 2006).

weapons. Current HPM research focuses on pulsed power devices, which create intense, ultrashort bursts of electrical energy and would be used to power the microwave generator of an HPM weapon. The Air Force Research Lab's Propulsion Directorate has studied using generators that use high-temperature superconducting wire and high-voltage capacitors.[17]

Another power source, well-suited to one-time use in an e-bomb, is the Explosively Pumped Flux Compression Generator (EPFCG). The EPFCG uses chemical explosives to compress an electrically charged coil. This destroys the device but produces electrical pulses in the terawatt range—the equivalent of 10 to 1,000 lightning strikes.[18]

Paired with a microwave generator, an EPFCG could produce an ultrashort, intense microwave burst. Depending on factors such as burst height, microwave frequency, and the shielding around the target electronics, such an e-bomb could have an effective range of several hundred meters.[19]

A subset of HPM devices can affect the human body. Millimeter waveband energy can penetrate human skin to a very shallow depth, heating the tissue below. This produces a burning pain without actually damaging the tissue. The pain forces the person to flee the area. This type of weapon shows great potential as a riot-control device or area-denial system.[20]

The Active Denial System (ADS) is a nonlethal anti-personnel DEW that uses millimeter-wavelength beams to create a painful sensation in an individual without causing actual injury. It is relatively close to deployment. The system generates a focused beam of energy at the frequency of 95 gigahertz. These waves penetrate only a few millimeters into the skin and cause the sensation of heat. The sensation increases in intensity until the affected individual moves out of the beam or it is shut off. There is no injury to the target individual.[21]

A demonstration system was tested at Kirtland Air Force Base in 2000. A year later, testing showed that the ADS could produce effects at ranges beyond current small-arms range. A prototype ADS system mounted on a Humvee went into testing in August 2005.[22]

The Future of DEW

Future research will seek to increase the power and decrease the size of DEW systems. As they become smaller, DEW weapons will first be vehicle-mounted and then possibly man-portable. The death ray of science fiction may in fact become a reality in the not too distant future.

Lasers are becoming smaller and more powerful. For example, a recent test of a solid-state laser by Northrop Grumman produced a continuous 27-kilowatt beam that lasted just under six minutes.[23]

A possible future development is the electrolaser. Electrolasers make use of laser bloom, a normally undesired effect. In an electrolaser, twin laser beams create an ionized channel inside the atmosphere, which conducts electricity. A high-voltage electrical charge is then fed into one of the laser

17. Dr. Stephen Adams, "Electrical Power and Thermal Management for Airborne Directed Energy Weapons," U.S. Air Force Research Laboratory, September 2001, at *www.afrlhorizons.com/Briefs/Sept01/PR0101.html* (March 15, 2006).

18. Carlo Kopp, "The Electromagnetic Bomb—A Weapon of Electrical Mass Destruction," at *www.globalsecurity.org/military/library/report/1996/apjemp.htm* (March 15, 2006).

19. GlobalSecurity.org, "High Power Microwave (HPM)/E-Bomb," at *www.globalsecurity.org/military/systems/munitions/hpm.htm* (March 15, 2006).

20. *Ibid.*

21. U.S. Air Force Research Laboratory, "Active Denial System," fact sheet, September 2005, at *www.de.afrl.af.mil/Factsheets/ActiveDenial.swf* (March 15, 2006).

22. *Ibid.*

23. Press release, "Northrop Grumman Surpasses Power, Run-Time Requirements of Joint High Power Solid-State Laser Program for Military Use," Northrop Grumman Corporation, November 9, 2005, at *www.irconnect.com/noc/press/pages/news_releases.mhtml?d=89438* (March 15, 2006).

beams, striking the target. The electrical shock is enough to stun personnel, detonate improvised explosive devices, or destroy electronic equipment.

Improvements in energy-generating systems may also make particle-beam weapons feasible. Particle beams would have tremendous power as weapons. Like lasers, particle beams travel at the speed of light, but unlike lasers, the particles in a particle beam have mass, giving the beam tremendous kinetic energy.

At some point in the future, entire military units may be armed with only DEWs. A mechanized unit advancing through a town, protected by an anti-artillery and anti-missile laser shield, clearing the surrounding buildings of snipers and enemy troops with an active denial system, and using electrolasers to stun them before taking them prisoner, all while using HPM weapons to render the enemy's communications useless, would be a powerful military unit indeed.

Policy and Legal Implications for DEWs

Weapons designed to cause undue suffering are banned under the Geneva Convention, and human rights groups argue that directed-energy weapons raise a host of new legal and moral concerns that do not apply to previous generations of conventional weapons. For example, while the Chinese ZM-87 laser interference device is technically a laser dazzler, it can permanently damage the human eye at a distance of two to three kilometers.[24] Would the permanent blinding of a soldier struck by a ZM-87's laser beam be considered intentional or accidental? Does the mere use of a weapon that can cause permanent blindness constitute inflicting undue suffering? The humanitarian community is also concerned about the long-term biological effects of DEWs (microwaves in particular) and their possible use against civilian targets.[25]

However, a stronger counterargument is that directed-energy weapons, especially lasers, are more humane than conventional weapons because they can strike pinpoint targets, thus causing less collateral damage. A laser weapon could target not only a single vehicle in a convoy, but also a specific spot on that vehicle (e.g., the engine) and disable it without injuring the passengers. Furthermore, the power of lasers and microwave weapons has decreased, allowing for nonlethal uses.

DEW technology is changing faster than international laws and treaties can adapt. General DOD policy is that directed-energy weapons can be used legitimately on the battlefield. As with all new weapons, the DOD General Counsel reviews each DEW for compliance with international and U.S. laws before the Pentagon is allowed to field it.[26] Most DEWs are not yet far enough along in development and thus have not received this final stamp of approval.

As the Pentagon addresses these issues, it should do so in the same way that it would for any other category of weapon that it has reviewed. While some uses may be illegal (e.g., targeting an unarmed civilian who in no way poses a threat), other uses are just as assuredly legal and legitimate.

Fixing the Research and Deployment Bottlenecks

While directed-energy research is advancing, inadequate funding is hindering more rapid development and deployment of these technologies. The military has rhetorically embraced the wonders of DEWs, but it has not always opened its wallet to fund the technologies.

True support for a program is often best measured by the resources that an organization is willing to devote to it. For instance, the Active Denial

24. China North Industries Corporation, "ZM-87 Portable Laser Disturber Fact Sheet," quoted in Human Rights Watch, "Blinding Laser Weapons: The Need to Ban a Cruel and Inhumane Weapon," September 1995, at *www.hrw.org/reports/1995/General1.htm* (March 15, 2006).

25. "Electromagnetic Weapons: Come Fry with Me," *The Economist*, January 30, 2003, at *www.globalsecurity.org/org/news/2003/030130-ebomb01.htm* (March 15, 2006).

26. David Ruppe, "Directed-Energy Weapons: Possible U.S. Use Against Iraq Could Threaten International Regimes," Global Security Newswire, at *www.globalsecurity.org/org/news/2002/020816-dew.htm* (March 15, 2006).

System was not ready for deployment when the United States invaded Iraq, in part because the money was not there. The Defense Department and Congress should start to fund promising and proven DEW technology so that promising weapon systems can move from the lab to the battlefield where they can help military personnel.

Conclusion

DEW technology and its enabling infrastructure have matured to the point that DEWs can begin moving from the lab to the battlefield. While directed-energy technology is not the panacea for all situations that its most ardent advocates claim, it can give the U.S. military flexibility in tailoring its responses (e.g., lethal or nonlethal) to different types of targets (humans or machines).

Much work needs to be done before DEWs are deployed. The armed services need to move from just saying that DEWs are a good idea to fully supporting their development. The Defense Department needs to establish clear guidelines for using the technology. The speed, ultraprecision, and nonlethal capabilities of directed-energy weapons are all good reasons why the United States should continue to research, develop, and, where appropriate, field these technologies.

—*Alane Kochems is a Policy Analyst for National Security in the Douglas and Sarah Allison Center for Foreign Policy Studies, a division of the Kathryn and Shelby Cullom Davis Institute for International Studies, at The Heritage Foundation. Andrew Gudgel, a former Army Warrant Officer, is currently a freelance writer.*