



Implications of Laser Weapons for Ground Combat Operations

by

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Introduction

The intensity of combat between Hezbollah and the Israeli Defense Forces (IDF) in southern Lebanon in July and August 2006 caught much of the world by surprise. In the short course of the conflict, some 4,228 Hezbollah rockets struck northern Israel, killing 53 Israelis, wounding some 2,000 more, paralyzing the region and causing a million civilians to live in shelters. The overall damage to the Israeli economy was estimated at \$5.5 billion.¹

The Israeli counter to this barrage was relatively ineffective. IDF artillery counterbattery fire and airstrikes were unable to defeat the highly mobile Hezbollah rocket-launching crews firing from their home terrain and deftly employing cover, concealment and deception. Consequently, the IDF response was limited at times to providing warning of incoming fire to the vulnerable civilian population.

It might not have been so. The price Israel paid for lack of an effective anti-rocket defense was a consequence of past decisions not to complete development and fielding of a potentially valuable laser weapon system able to destroy Hezbollah's rockets in flight. Beginning in the early 1990s the U.S. military recognized the potential advantage of a laser-based defense against rockets, artillery and mortars and began developing such a capability. After a successful test of the Tactical High Energy Laser (THEL) was conducted against a Katyusha rocket in 1996, Israel joined the program. In subsequent years the system shot down many different types of rockets, artillery and mortar rounds in field tests but did not fare well in the competition for funding in Washington. By late 2004 the Army withdrew financial support for a mobile THEL.² Thus, in 2006 when even a prototype system not only might have saved lives and property in northern Israel but also demonstrated the revolutionary potential of laser weapons on the battlefield, nothing was available. The shattered lives and buildings in Israel once again provided stark testimony to the desirability of an effective, affordable defense against indirect-fire weapons—a defense now made feasible by advances in high-energy laser technologies.

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Weapons firing projectiles propelled by chemical reactions—bullets, artillery shells, missiles—have dominated the tactical level of warfare for centuries. Today, advances in technology of high-energy lasers allow the application of other physical principles in a new class of weapons. Development of high-energy lasers³ with military potential is leading to the production of light-beam weapons that transfer destructive energy to targets via coherent light. Over time, the primacy of chemically propelled projectiles may give way to dynamic coexistence and competition with directed-energy weapons as these next-generation weapons increasingly assume existing roles in the battlespace or new missions, such as active defense against projectiles.

The challenge to the U.S. military is that its understanding of laser weapons technologies is outpacing efforts to bring these capabilities into the force. Available funding for laser weapons development lags behind what would be necessary to bring technologies to maturity as quickly as possible. Equally threatening to the success of laser weapons in the field is the lack of attention to concept development for laser weapons' operational employment. Unfortunately, this means that weapons developers may move along at great speed in designing advanced systems with tremendous battlefield potential, but they do so in splendid intellectual isolation. Lacking the guiding hand of operational requirements, they are unable to properly prioritize resources or focus on the weapons capabilities that are most important to warfighters. Just as sadly, military forces can field an expensive and promising new capability that remains underutilized because warfighters do not fully understand how to employ it to its greatest advantage.

Growing Laser Weapons Capability

Effective laser weapons have already been developed and tested. The joint U.S. Army-Israel Defense Forces THEL has shot down short- and medium-range tactical missiles, artillery rounds and mortars, and has the ability to destroy other types of missiles in flight. Other laser weapons are making significant progress. The U.S. Air Force's antimissile Airborne Laser (ABL) aircraft is on track to conduct its first trial shootdown in 2008,⁴ and the Defense Department's solid-state laser program is well on the way to achieving militarily significant power levels in the laboratory.⁵

One of the challenges in understanding the operational implications of this progress lies in the varied characteristics of different laser weapons. The most technologically mature systems are chemical lasers that derive their very high power levels from chemical reactions that produce beams of intense infrared radiation. Electrically powered solid-state lasers (SSLs) are less powerful and pass electricity through a crystal or glass medium to produce laser beams. SSLs are also progressing rapidly and promise great tactical utility. A third class, Free Electron Lasers (FELs), uses electricity to create laser light on different wavelengths to match changing environmental conditions.

Power levels, however, are not the only measure of laser weapons' technological maturity. To create an effective weapon, the laser must be integrated into a complete system that can acquire, track and destroy targets and is fully mated with its carrying platform's power, control and other systems. At current funding levels, it could be seven to nine years before an integrated solid-state laser weapon system can be delivered from the laboratory to the testing range (see figure 1).⁶

Progress in Laser Weapon Systems Integration

Developers are also progressing with design concepts for integrating laser weapons into existing and new air, land and sea weapon systems. For example, much design work has already

Power Required to Affect Targets of Interest

Increasing Lethality or Increasing Range for Same Effect

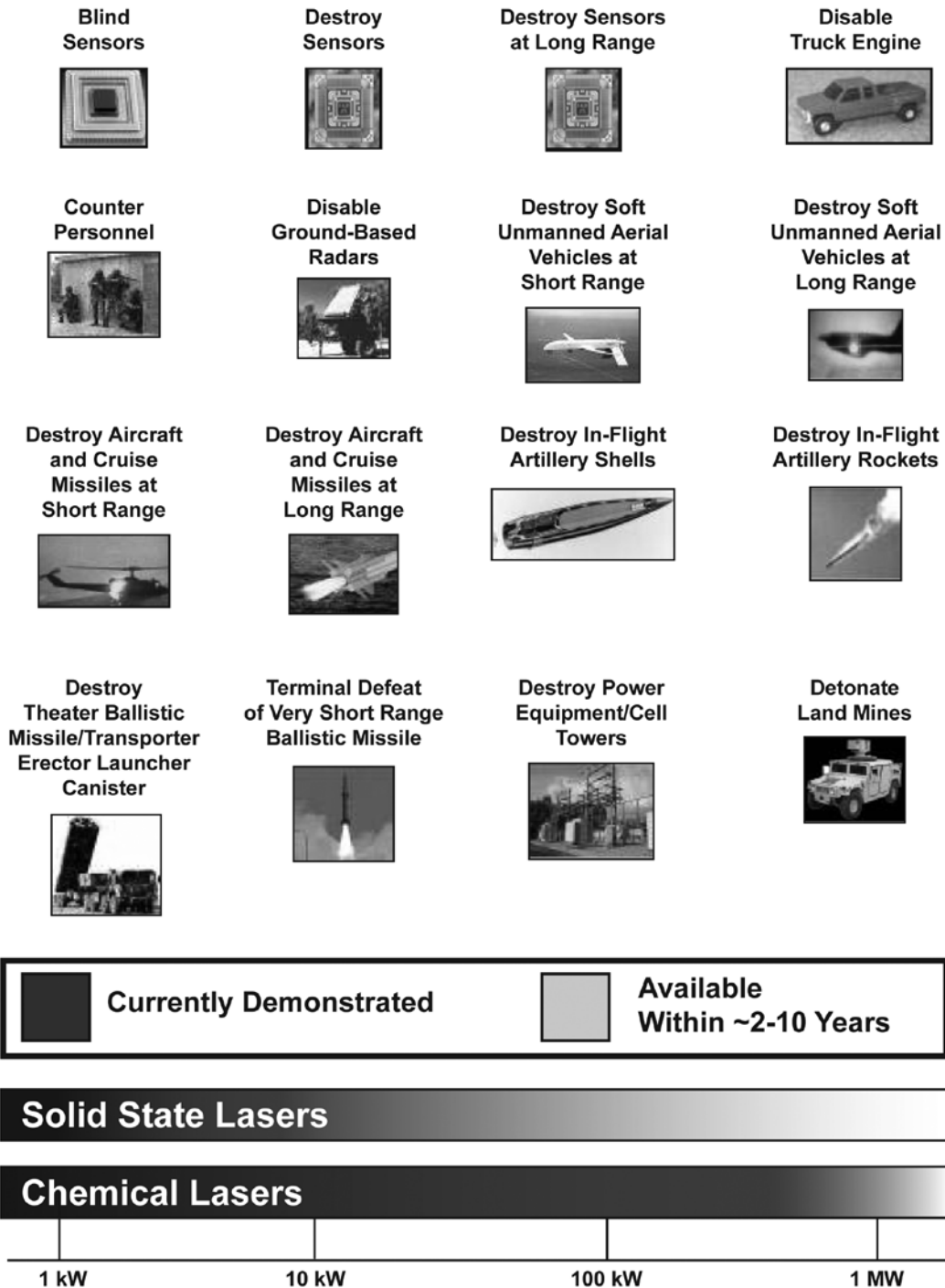


Figure 1. Power Required to Affect Targets of Interest

been done to modify the THEL into a deployable combat system known as High Energy Laser-Rockets, Artillery and Mortars (HELRAM) that can be used to destroy multiple types of threats, including rockets and artillery and mortar rounds (see figure 2).

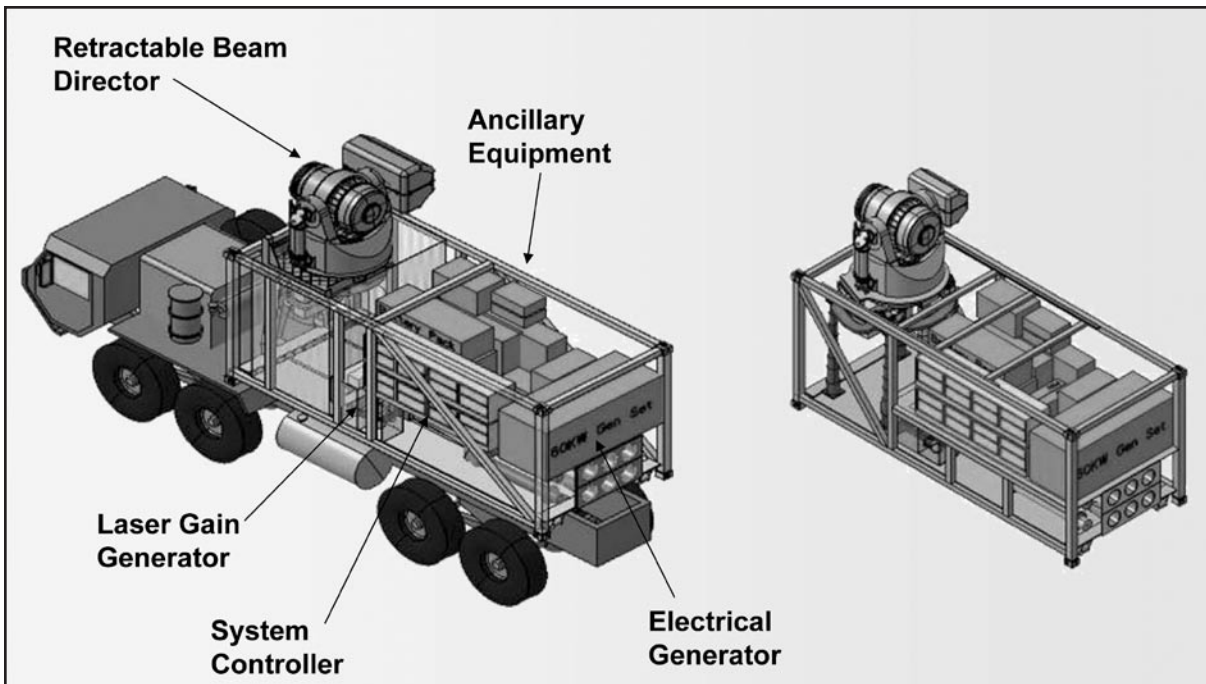


Figure 2. High Energy Laser-Rockets, Artillery and Mortars (HELRAM)

Systems concepts for SSLs have also been developed, although their technical maturity is four to five years behind that of chemical laser systems.⁷ Because SSLs draw very large amounts of electric power, weapons developers have focused on power supply. For example, a laser weapon could be carried on a hybrid electric ground fighting vehicle (figure 3) and powered by the electrical system.

Developing Operational Concepts for Laser Weapons

Despite these technical advances in laser weapons, much of the military operational community remains unaware of their potential. Despite several nascent efforts to understand the military worth of these systems, appreciation of their potential throughout the military operational community remains low.

Since World War II, an underlying assumption of U.S. defense planning has been that U.S. forces will enjoy a technological edge over potential adversaries. That might not be true of laser



Figure 3. Hybrid Electric Ground Fighting Vehicle

weapons. Because they offer an opportunity to overcome the huge U.S. advantage in advanced missiles and other high-technology capabilities, other countries and non-state actors may pursue directed-energy weapons based on their own security, economic and political objectives.⁸ While the United States is believed to hold a significant lead in laser weapons development, there is no guarantee that we will not face an enemy with at least some laser weapons capability in the not-too-distant future.

Operational Characteristics of Laser Weapons and Their Potential Application

To appreciate how different laser weapons and their varied characteristics might impact future warfare, it is important to understand the unique capabilities and limitations of these weapons.

Capabilities. The following capabilities make lasers attractive for operational uses:

- **Highly agile speed-of-light delivery:** Laser weapons engage targets at the speed of light—there essentially is no time of flight as for projectile weapons. This makes them well suited for engaging close-in maneuvering targets—e.g., surface-to-air missiles (SAMs), air-to-air missiles (AAMs), unmanned aerial vehicles (UAVs) and cruise missiles—and extremely fast ballistic targets, e.g., rockets, artillery and mortars rounds. However, laser weapons do require some time to acquire and track targets and have to “dwell” on the target long enough (several seconds) to deposit sufficient energy to destroy or neutralize it.
- **Multiple target engagements and rapid retargeting:** Because laser weapons have few moving mechanical parts and are constantly powered or reloaded by recharging their chemical or electrical energy stores, they can engage multiple targets very quickly, limited for the most part only by their ability to be supplied with fuel or electrical power or to dissipate waste heat. Shifting from one target to another involves only repointing and refocusing mirrors. Thus, they are well suited for the types of multiple-target engagements that might be required to deal with salvo firings of artillery or rockets.
- **Deep magazines:** Because lasers consume only chemical fuel or electricity, the total number of shots they can fire is limited only by the amount of chemical fuel available or, in the case of solid-state lasers, the fuel available to drive the electrical power source. However, SSLs can be fired for only so long before they have to shut down to recharge batteries or eliminate heat.
- **Low incremental cost per shot:** For a projectile weapon system, the incremental cost per each shot is essentially the cost of the ammunition expended. Guided missile systems in particular expend much expensive hardware (i.e., rocket motors, guidance systems, avionics, seekers, airframes, etc.) in the form of missiles every time they fire. Laser weapons, on the other hand, expend only energy.
- **Exceptional accuracy and adjustability:** Once cued by radar or other sensors, laser weapons use a low-powered beam to acquire and track their targets. This beam can be focused anywhere on the target with great precision before the co-aligned high-power laser is engaged, delivering the desired level of damage at that exact point on the target with little collateral damage.
- **Lower logistical support requirements:** Unlike guns that must be resupplied with ammunition or missiles that must be replaced once expended, laser weapons require only additional chemical fuel or fuel to generate the electricity needed for power.

- **Flexibility:** Laser weapons are modular and scaleable. Several identical laser modules can be “stacked” to create a higher-powered laser.

Limitations. Laser weapons do have unique limitations that could impact on operational utility:

- **Atmospheric attenuation and turbulence:** Because laser beams must be propagated through the atmosphere, they can be affected by airborne particles (dust, smoke), water vapor or atmospheric turbulence that absorb, bend or scatter laser energy.
- **Line-of-sight dependence:** Laser weapons require direct line-of-sight to engage a target. Their effectiveness is reduced by screening or shielding materials that cannot be readily burned through.
- **Target suitability:** Because of their relatively low power levels, laser weapons will probably lack the “punch” of larger non-laser chemical or kinetic weapons for some time. They are best suited for targets that must be engaged very quickly and precisely, such as rockets, missiles or artillery rounds in flight, or that can be killed or disabled by focusing damage on small areas, such as thin-skinned vehicles. Their effects are minimal on hardened structures like bunkers or even buildings. Against armored vehicles they are effective only in disabling vulnerable components such as antennas, sensors and external fuel stores.
- **Eye-safety issues.** Eye safety is a major concern in the use of laser weapons. While some chemical lasers operate at eye-safe wavelengths, high-power SSLs currently do not.⁹ Because any laser energy that is not absorbed by the target is either scattered or reflected, this non-absorbed energy poses an eye-safety risk to friendly personnel without laser eye protection and to civilians in the target’s vicinity.
- **Chemical fuels and exhaust.** Chemical lasers require chemical fuels and generate exhaust when they fire. Some fuels, like the highly corrosive fuel of the ABL’s Chemical Oxygen Iodine Laser (COIL), require multiple safety systems and risk mitigation plans. Others, like the deuterium fluoride reactants used by the THEL, are relatively safe.

Operational Implications

If the United States—or another power—successfully fields laser weapons on different warfighting platforms, how might they affect the conduct of military operations? This question is fundamental in prioritizing operational requirements to guide the technical development of laser weapons.

Analyzing the capabilities and limitations of laser weapons in an operational context implies they are well suited to roles in two key mission areas:

- **Force protection:** Lasers can provide air, land, sea and space platforms the ability to defend themselves, other platforms and geographic areas. They can defend against missiles, aircraft, bombs, artillery shells or rockets by destroying or neutralizing these threats before they reach their intended targets. For missile defense, lasers can provide point defense of a specific target or area defense against theater ballistic and cruise missiles as a complement to defensive missiles.
- **Offensive strike:** Lasers can provide the capability to achieve highly precise lethal or nonlethal effects against a range of suitable targets, mostly as a complementary capability for chemical and kinetic weapons.

The following sections address the operational implications of laser weapon capabilities for several ground combat mission areas.

Enhanced Survivability

Ground forces can profit from the enhanced survivability provided by active force-protection lasers. Because high-power laser defensive systems will probably weigh several thousand pounds for the foreseeable future, they are not man-portable. These systems will be mounted on dedicated vehicles that provide active-area force protection for other combat systems and Soldiers and units within their coverage range. But the improvements in survivability offered by laser systems may enable the design of lighter combat vehicles, supporting efforts to build more strategically deployable, tactically mobile ground forces.

Today, most losses on the conventional ground battlefield are caused by indirect fire weapons—including artillery, rockets and mortars that follow ballistic trajectories—and air-delivered bombs. Guided direct-fire weapons, such as antitank guided missiles (ATGMs) and man-portable air defense systems, are also very lethal. Hyper-velocity large-caliber tank rounds are another significant direct-fire threat. An example is the armor-piercing discarding sabot (APDS) round—essentially a yard-long depleted uranium rod traveling at thousands of feet per second—fired by the Army’s M-1 Abrams tank.

Protecting against these weapons at present requires heavy armor, leading to massive vehicles such as the 70-ton M-1 tank that require considerable resources to deploy and consume large amounts of fuel on the battlefield. Active laser force-protection defenses could improve the survivability of lighter vehicles by defeating some of these threats before they reach their targets. Together with indirect fire systems providing counterbattery fire, lasers can make enemy indirect fire much less effective on the battlefield. The THEL has already destroyed rockets, artillery and mortar rounds in flight, demonstrating that lasers can deal with these indirect-fire threats.¹⁰ Given THEL’s demonstrated capabilities, it appears that similar laser systems would also be capable against manned aircraft.

In addition to protecting combat forces, active laser defenses can also protect key fixed facilities and infrastructure, such as logistic bases, airfields and ports, from indirect fire. In counterinsurgency environments, such as Iraq and Afghanistan, this would probably be their key role.

Complement Soldier and Unit Force Protection

However, lasers are not well suited for defeating direct-fire threats, such as ATGMs, tank rounds and rocket-propelled grenades (RPGs). The flat trajectories, very short times of flight, and mass of these munitions make them difficult targets for a laser system, which must dwell on a target long enough to cause it to explode or veer off course. Consequently, laser unit protection systems will work best when complemented by other active defense systems. Current development efforts have focused on detecting and tracking incoming direct-fire threats with millimeter-wave radars or infrared sensors, then engaging them at close range with proximity-fused grenades or at longer ranges with rockets. These rocket and grenade active defense systems will most likely remain the preferred solution to direct-fire threats for the foreseeable future.

Development of effective force-protection lasers would assist ground force designers in balancing the conflicting requirements for strategic deployability and tactical mobility and

survivability. Survivability requires armor that adds weight and reduces deployability and mobility. In combination with rocket or grenade active defenses against direct-fire threats, active defense lasers can enhance survivability and reduce the requirement for heavy armor, reducing the weight of combat vehicles and thus increasing their strategic deployability and tactical mobility.

Ballistic Missile Defense (BMD) for Affordable Layered Defense

Ballistic missiles armed with either weapons of mass destruction or advanced capability conventional warheads pose one of the greatest threats to forward-deployed or -deploying U.S. forces. Although missiles such as the Patriot Advanced Capability-Phase 3 (PAC-3) have proved relatively effective against theater ballistic missiles (TBMs), they are expensive. Scuds and other TBMs based on 1940s technology are relatively inexpensive (around \$1 million)¹¹ while a single PAC-3 costs approximately twice as much.¹²

For budgetary reasons, then, defensive missiles tend to be low-density/high-demand items for even the most wealthy and advanced military powers. Defending a point target¹³ such as an air base against theater ballistic missiles with a high level of confidence can require two defensive missiles for each attacking missile. Defending more than a few critical targets against large numbers of missiles quickly becomes cost-prohibitive. Because offensive missiles can be retargeted against any target within their range arcs, even relatively robust missile defenses can be overwhelmed if the enemy is willing to expend the required number of offensive missiles.

An attacking ballistic missile goes through three phases of flight en route to the target: boost phase, when the rocket motors are firing; mid-course, when the missile is coasting along its ballistic trajectory; and terminal, when it is descending toward its target. One of the basic principles of missile defense is to create as many different “layers” of defense in as many of these phases of flight as possible because each defensive layer increases the probability that the enemy missile will be destroyed before it hits its target. Longer-range defensive systems can provide area defense of large areas; shorter-range systems provide point defense of specific targets.

The projected role of the Airborne Laser in boost-phase missile defense is well known, but ground-based lasers are also well suited to terminal point defense of critical targets. These lasers can fire tens of shots against offensive missiles very quickly, making them difficult to overwhelm. The chemicals consumed per shot cost less than \$10,000, much less than the millions of dollars for defensive missiles. Thus, even taking into account the initial cost of the laser weapons, laser-based point BMD may prove to be a highly effective—and more affordable—means of adding an additional layer of defense against TBM attack.

Because they are more affordable, laser defenses can be more widely spread. They can complement missile defense missiles of longer ranges. Megawatt-class chemical lasers could defeat theater ballistic missiles. Multi-megawatt class lasers (much larger than any system under development today) would be required to defeat the faster and much harder targets presented by intercontinental ballistic missile (ICBM) reentry vehicles (RVs). In both cases, effectiveness of a laser defense would depend on developing systems concepts that overcome the potential effects of clouds, fog or dust storms. For example, aircraft basing would allow the laser weapon to operate above these weather effects.

Offensive Operations

Because lasers put considerably less destructive energy into a target than the larger chemical or kinetic munitions, offensive applications of lasers will most likely be dedicated to those missions where their other characteristics (e.g., precision, speed and numbers of engagements) are more important than pure destructive power.

Ground Operations: Ideal Ultra-Precision Strike Systems

Because of their size, weight and lack of heavy armor-piercing/deep-penetration capability, offensive applications of laser weapons in ground combat will most likely be dedicated to those missions where the precision, speed-of-light engagement time, adjustability and minimal collateral damage of laser weapons are desired. For counter-sniper missions, for example, a laser weapon paired with acoustic and optical sensors that track a sniper's bullet back to the firing point almost instantly could automatically be aimed to engage the sniper before he is able to take cover. The advantages of laser weapons over conventional machine guns are that lasers have no "time of flight" and produce little collateral damage.

The "stealth" characteristics of lasers also make them ideal ultra-precision strike systems. Unlike their portrayal by Hollywood, real laser weapons have no visible beam and have no sonic "report," muzzle flash or recoil. Under most atmospheric conditions, the only way an enemy would know he was being engaged by a laser would be to see the effect on the target. The systems use low-power lasers to establish the aim point for co-aligned high-power lethal lasers. Once the aim point has been established, the operator has only to energize the high-power laser to kill the target—the epitome of the sniper's "one shot, one kill" motto. Such use of lasers permits less collateral damage than today's precision guided missiles.

The precision and adjustability of laser weapons could make them highly effective in counterinsurgency or stability and support operations (SASO) where force must be applied carefully to achieve a desired effect. For example, laser weapons could be used to kill or neutralize armed insurgents hiding within a crowd where other weapons would injure innocent civilians. At lower power levels, lasers might achieve only nonlethal effects. For these purposes, laser weapons would probably be most effective when mounted on UAVs or helicopters and used at extended ranges. Operational planning must take into account existing treaty constraints that prohibit the intentional blinding of combatants and noncombatants by lasers.

Recommendations

As important as these consequences may be, experience shows that technological innovation may generate even more important consequences that are impossible to predict. This makes it imperative that the U.S. defense community pursue a robust process toward enhancing understanding of the operational implications of laser weapons and development of operational concepts for their use.

The first requirement is to develop a true appreciation of laser weapons capabilities by hands-on, practical experience with them. This means pressing on with existing laser weapons programs as rapidly as practical. Serious consideration should be given to fielding a productized prototype of the THEL as quickly as possible. With its proven effectiveness against rockets, artillery and mortars, relatively modest improvements in the existing test system would allow

prototypes to defend key facilities and bases in Iraq and Afghanistan. This is an important objective in itself, but it would also demonstrate the combat effectiveness of active defense lasers, serving to spur interest and progress in laser weapons development. Experts have said that either laser weapons will prove themselves in current combat operations or it will be another ten years before they are fielded.¹⁴

Other efforts to speed the U.S. defense community's appreciation for laser weapons should include an aggressive wargaming and experimentation program. This program should take the following standard steps for operational concept development:

- tabletop wargames to identify critical areas of focus;
- detailed modeling and simulation that will in turn guide the development of prototype weapons and employment concepts;
- prototype modular laser weapons packages that can be mounted on operational aircraft, vehicles and vessels for hands-on field experimentation; and
- field experimentation in operational units to develop tactics, techniques and procedures for laser weapon employment.

Conclusion

From the technology development standpoint, operational laser weapons are right around the proverbial corner. Given adequate resourcing, a “productized” chemical laser weapon could be shooting rocket and mortar rounds from battlefield skies within 18 months.¹⁵ Solid-state and free-electron laser weapons, adding to the range of laser weapons capabilities, may be less than a decade away.¹⁶ Meanwhile, the personnel who will make key decisions on the development, acquisition and employment of these systems are already half-way or more through their military careers, but most have developed little awareness of the potential implications of laser weapons.

Even a relatively cursory examination of the potential capabilities of laser weapons indicates that their introduction to operations can cause significant shifts in warfighting dynamics, especially in the competition between offensive and defensive capabilities. Lasers can provide effective active defenses against a range of increasingly capable threats that are now difficult or impossible to defeat, such as SAMs, AAMs, rockets, artillery and mortars—and, potentially, theater ballistic missiles. Major improvements in accuracy, range and lethality have made these attacking weapons increasingly dangerous, but laser weapons may reverse this trend by making it much easier for forces to defend themselves. Offensive use of laser weapons may make possible the much more precise application of force from a variety of combat platforms.

If laser weapons live up to the potential they have shown thus far and if their development proceeds as fast as projected, warfare may enter the age of laser weapons much sooner than most expect. To leverage this emerging capability, the United States needs operational concepts to guide investment in the transformational technology of laser weapons. The implications for national security are so significant that developing these operational concepts merits top priority for U.S. military intellectual energy.

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