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Directed-Energy Warfare, a Revolution in Military Affairs

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Military use of directed-energy technology has moved beyond the realm of science fiction. In the past two decades, directed-energy technologies have quickly matured from the research laboratory, to the operational force and have become highly effective instruments of war. Directed-energy technologies currently enable and enhance a multitude of weapons platforms. Furthermore, recent developments in directed-energy technology show immense potential for future military systems. The past two decades have also seen a Revolution in Military Affairs (RMA), driven by an influx of additional new technologies on the battlefield. Currently, there is a debate over which of these new technologies will become the most significant. The following analysis determines that directed-energy will soon be the most consequential and transformative technology of the present RMA.

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Abstract

Military use of directed-energy technology has moved beyond the realm of science fiction. In the past two decades, directed-energy technologies have quickly matured from the research laboratory, to the operational force and have become highly effective instruments of war. Directed-energy technologies currently enable and enhance a multitude of weapons platforms. Furthermore, recent developments in directed-energy technology show immense potential for future military systems. The past two decades have also seen a Revolution in Military Affairs (RMA), driven by an influx of additional new technologies on the battlefield. Currently, there is a debate over which of these new technologies will become the most significant. The following analysis determines that directed-energy will soon be the most consequential and transformative technology of the present RMA.

Directed-Energy Warfare, a Revolution in Military Affairs

Military use of directed-energy technology has moved beyond the realm of science fiction. In the past two decades, directed-energy technologies have quickly matured from the research laboratory, to the operational force and have become highly effective instruments of war. Furthermore, evidence shows that these technologies will soon dominate the modern battlefield.[1] The past two decades have also seen a Revolution in Military Affairs (RMA), driven by an influx of new technologies, such as stealth, drones, advanced computer technologies, space-based technologies, information warfare technologies, and robotics.[2] These recent technological advances, and their subsequent effect on operations, are transforming warfare. Currently, there is a debate over which of these new technologies will become the most significant, within the present RMA.

Militaries invest heavily in new technologies to ensure their forces are capable on the battlefield. Determining which technologies hold the greatest promise require the consideration of multiple factors, such as alternative investments and potential adversary countermeasures.[3] Directed-energy technologies currently enable and enhance a multitude of the present RMA's weapons platforms; targeting, weapons, mapping, and communications systems all utilize directed-energy. Furthermore, recent developments in directed-energy technology show immense potential for future military systems. Moreover, new threats posed by the present RMA suggest that directed-energy will rapidly become the most consequential and transformative technology.

Using a structured process, the following analysis will determine if directed-energy warfare will be the dominant aspect of the present RMA. First, this paper will explain RMA theory, and the present RMA concept. Second, it will describe directed-energy technology and its use in warfare. Third, it will provide an overview of the following categories of directed-energy warfare: laser range finders, directed-energy weapons, laser remote sensors, and directed-energy communications systems. Each category will include examples of directed-energy warfare technology, and how they will enhance the key elements of the current RMA. In addition, the paper will address the legal and moral issues surrounding directed-energy weapons. Finally, this analysis will determine how the U.S. military can best endorse and encourage future directed-energy technologies.

Defining a Revolution in Military Affairs (RMA)

RMA is a broadly used term with no universally established definition. However, it does have commonly agreed upon characteristics. Military experts typically characterize a RMA as a sporadic increase in military capability, ascending from concurrent and mutually supportive technological advances, operational processes, and military organizations.[4] New technology, dramatic modifications in military doctrine, and new organizational concepts characterize RMAs; resulting in significant changes to the character of military operations. In addition, RMAs characteristically involve immense changes, which spread quickly to military, public, and foreign affairs.[5] Many military experts agree that there is a RMA presently taking place. The present RMA is due to the application of various new technologies into a significant number of military systems.[6]

Defining the Current RMA

Just as there is debate over the definition of RMA, there is also debate over what is driving the present RMA. Despite these deliberations, many common factors define the present RMA. The present theory forecasts that success on the battlefield will require a military to use technologically superior platforms, curtail the number of ground-troops, engage adversaries from ever-greater distances, and operate in all war-fighting domains.[7] In addition, recent technological breakthroughs are driving the development of new weapons systems, which are fundamentally changing the character of warfare.[8] New technologies driving the present RMA include: stealth, drones, advanced computer technologies, space-based technologies, information warfare technologies, robotics, and directed-energy. In addition to new technological changes, the present RMA seeks to minimize civilian casualties and collateral damage.[9]

Two additional factors define the present RMA, a pull for new requirements, and a push for new technology. An emerging operational task, and consequential development of new technologies, characterizes the requirement pull.[10] An example of this would be the proliferation of Unmanned Aerial Systems (UAS) and their associated technologies. To defeat the threat of UASs, many militaries have begun developing counter-UAS systems. An innovative technology that spurs the development of a new military system characterizes the technology push, such as the coupling of Global Positioning System (GPS) capabilities with standard bombs to create Precision Guided Munitions (PGMs). Recent and widespread combinations of the requirement pull, and the technology push, have become the main drivers the present RMA.[11]

For directed-energy technology to qualify as the most consequential and transformative technology of the present RMA, it must demonstrate significant capabilities at the strategic, operational, and tactical level. In addition, it must be effective within the war-fighting domains of land, sea, air, space, and cyberspace. Furthermore, the directed-energy technology must be survivable, responsive, accurate, effective, cost beneficial, reduce casualties, reduce collateral damage, and support command and control (C2) systems. During past RMAs, in order to consider a technology as “revolutionary,” it usually required an entirely new and cost effective technology to counter it.[12] Therefore, directed-energy technology must prove itself as a monumental military advancement, which only another monumental military advancement can successfully counter. Finally, the qualities of directed-energy technology must contribute to both the requirement pull and the technology push.

What is Directed-Energy?

The U.S. Department of Defense (DoD) describes directed-energy as an umbrella term, covering technologies that produce a beam of concentrated electromagnetic energy, or atomic or subatomic particles.[13] Directed-energy offers an entirely new assortment of military capabilities, by employing different wavelengths of the electromagnetic spectrum. Possible military applications of directed-energy include weapons, communications systems, three-dimensional (3D) mapping, energy resupply, counter-missile, counter-ship, and counter-UAS. Furthermore, directed-energy’s ability to travel at the speed of light provides abundant advantages. By traveling at the speed of light, it is unencumbered by the limitations of gravity, provides highly precise targeting, instant effects, and has the prospect of extremely long range. Due to these advantages, directed-energy technology has the means to support a wide spectrum of military equipment and capabilities.[14]

Recently, many developing technologies have seen a significant decrease in size; this trend includes directed-energy systems. Early models were typically large, awkward, and required immense amounts of energy; therefore, were impractical for placement on a weapons platform. Today’s directed-energy technology can fit in small containers, allowing for incorporation in satellites, UAS payloads, perimeter security systems, aircraft, and ground vehicles.[15] Consequently, directed-energy technologies are currently in military use as laser range finders, target designators, Directed-Energy Weapons (DEWs), laser remote sensors, and laser communications systems. The following will examine, in detail, each of the aforementioned directed-energy technologies and their specific military uses.

Laser Range Finders and Target Designators

Laser range finders and target designators are a common type of directed-energy technology on today's battlefield. For nearly fifty years, militaries have used lasers to assist traditional (i.e. chemically-powered) weapons with target engagement. Lasers improve targeting by reducing the timelines between identification, tracking, and shooting. Combined, laser range finders and target designators accurately mark targets by illuminating them with a tightly fixed beam of light. Once illuminated, the host platform or weapons system captures the light reflected from the target. The weapons systems, or platform, can then track the signal and provide the target's distance and speed data to the host weapon platform or weapon aiming system. The laser range finders and target designators are dependent upon cyberspace to transfer this data. In addition, laser range finders and target designators can provide three-dimensional vision control, positioning control, and level control for weapon and platform guidance systems.[16] Furthermore, laser range finders assist with determining distance between friendly and adversary satellites in the space domain. Although they have been on the battlefield for decades, militaries continue to find new applications.

The present RMA's weapons systems are highly dependent upon laser range finders and target designators. Present RMA weapons systems, such as missiles, robotics, UASs, satellites, and certain cyber systems, require laser range finders or target designators to operate effectively. In addition, laser range finders and target designators are in all of the warfighting domains of land, sea, air, space, and cyberspace. Therefore, it is reasonable to assume that laser range finders and target designators will continue to provide an effective enhancement to future RMA weapons systems and platforms.

Despite their current success, laser range finders and target designators have limitations and drawbacks. Lasers require a clear line of site to properly illuminate the target. Therefore, topography, foliage, structures, and thick smoke can prevent illumination of potential targets. Furthermore, if a laser beam cannot be reflected back to its host sensor, it will be unable to find, fix, and track its target. Militaries have already begun working on reflective and absorptive vehicle coatings that can prevent laser effectiveness.[17] Although these factors limit the use of laser range finders and target designators, future technology may find ways to mitigate these issues.

Directed-Energy Weapons (DEWs)

The U.S. DoD defines a DEW as "a system using directed-energy, primarily as a direct means to damage or destroy enemy equipment, facilities, and personnel."[18] Its ability to concentrate and manipulate both the electromagnetic spectrum and sound waves make directed-energy technology an effective weapon. Conventional munitions, such as rockets, bullets, and artillery rounds destroy targets through the transfer of kinetic energy. In contrast, DEWs use electromagnetic energy, or sound waves, to produce the same destructive effect.[19]

DEWs come in three categories: laser weapons, microwave weapons, and sonic weapons. Lasers, microwaves, and sound waves use different properties of the same form of energy. The primary differences between the three categories reside in their wavelengths and frequency range. Power is the definitive factor in determining the type and variance for different varieties of laser weapons, microwave weapons, and sonic weapons. For example, a standard classroom laser pointer and a high-powered laser weapon have the same frequency, but the laser weapon's power is far greater. Similarly, a microwave oven and a high-powered microwave weapon operate on the same frequency and wavelength, but power levels define their differences.[20] The third category, sonic weapons, uses sound waves to produce both physiological and physical effects upon an adversary. Sonic weapons are a category of DEWs, because sound waves are a form of energy.[21]

Directed-Energy Weapons Features Supporting the Present RMA

In the past decade, DEWs technologies have quickly matured from the research laboratory, to become effective armaments. Evidence shows that DEWs will soon replace traditional (i.e. chemical-powered) weapons on the battlefield.[22] In the future, DEWs will provide a number of capabilities and advantages over traditional weapons. When paired with complex sensors, DEWs can track, aim, and fire with pinpoint accuracy. In addition, they have few moving parts and a virtually unlimited magazine capacity, which allows for lower operating and maintenance costs. Furthermore, DEWs are silent, offer plausible deniability, can travel immense distances, and engage multiple targets. Moreover, an operator's ability to adjust power and frequency of DEWs allows a wide range of scalable options. This scalability allows DEWs to generate non-lethal effects to equipment, such as: sensor blinding and burning circuitry. In addition, it allows non-lethal effects on the human body, such as exhaustion, sickness, convulsions, and momentary paralysis.[23]

Laser Weapons' RMA Potential

Laser weapons are beams of focused light that cause damage to a target by creating heat.[24] The power level produced and the operational mission performed determines a laser weapon's classification. The laser's specific wattage level categorizes it as either low-energy, medium-energy, or high-energy. Low-energy lasers produce less the one kilowatt (kW) of power, and are typically used for jamming sensors in communications systems, blinding the eyes of an adversary, or simulating weapons during training events. Medium-energy lasers generate 10 kW to 100 kW of power that blind and damage optical or optoelectronic devices on the ground, in the air, or in space. High-energy lasers produce more than 100 kW of power, and can physically destroy electronic components within aircraft, missiles, and satellites.[25] Placement on ground vehicles, ships, aircraft, and satellites optimize the mission of a laser weapon.

Several militaries regularly use low-energy lasers for a variety of missions. The most common military use of low-energy lasers is in training devices; an example of which is the Multiple Integrated Laser Engagement System (MILES). MILES enhances military training by using blank ammunition and low power lasers to simulate a variety of weapons systems. It uses sensors attached to soldiers and equipment, to collect laser fire that mimics the effective range of actual ammunition.[26] Another commonly used low-energy laser is the dazzler. Dazzlers use laser light to temporarily blind sensors, optics, and personnel.[27] Dazzling is especially effective because it can perform as a non-lethal and non-permanent weapon against various ground, sea, and airborne targets. In addition, low-energy lasers can detect communications jammers, human activity, and munitions.[28]

Today's medium-energy lasers have the ability to damage a wide variety of sensors and circuitry. Most contemporary weapons platforms use various optical or optoelectronic sensors to assist with finding, fixing, and destroying an adversary's capabilities. In recent tests, medium-energy laser weapons have been effective at inflicting physical damage to optical and optoelectronic devices in the war-fighting domains of land, sea, and air. Medium-energy lasers can also be used to permanently blind personnel over a large area. Lasers can permanently blind an entire unit, without warning, and in less than two-millionths of a second. Moreover, a medium-energy laser has the power to enter the human eye obliquely. Therefore, it does not have to directly target the eye to cause blindness.[29] The ability to permanently blind numerous advisories over a wide area makes the medium-energy laser a highly effective weapon. Medium-energy lasers have already proved effective during testing, and will soon be operational on the battlefield.

Recently, there has been a renewed interest in high-energy lasers, resulting in subsequent advances in their technology. A number of new threats, such as Improvised Explosive Devices (IED), UAS swarms, small boat swarms, and the proliferation of rockets and missiles, have spurred laser energy technology developments.[30] The recent introduction of numerous weapons platforms, traveling at high-speed and located in multiple domains, has created a significant challenge to the modern warfighter. Contemporary chemically powered weapons lack the ability to counter these new and complex threats. When compared to DEWs, contemporary chemically powered weapons are heavy, have a slow rate of fire, have limited ammunition, are expensive, and their destructive power is difficult to adjust. In order to close the capability gap, militaries must have defenses that can engage multiple, high-speed, and maneuverable targets. A laser with an uninterrupted power source has a limitless amount of ammunition. Therefore, it can engage multiple targets, multiple times. In addition, lasers provide the warfighter the option to strike from beyond visual range, at the speed of light, with precision and instantaneous effects. Moreover, the cost per shot of a laser is significantly lower than that of conventional weapons. The U.S. Navy's Office of Naval Research has suggested that a typical 110kW high-energy laser, for a multi-second shot would cost less than a dollar per round.[31] In addition, the logistical footprint of lasers is far less than conventional weapons, when considering the weight, bulk, and hazards of storing and transporting chemically powered munitions. Improvements and further advancements of high-energy lasers provide for unlimited possibilities.

High-energy lasers that can intercept ground vehicles, ships, aircraft, and satellites are no longer in the realm of science fiction. Currently, several militaries across the globe are testing high-energy laser weapons. One of several U.S. laser weapons presently in development is the U.S. Army Space and Missile Defense Command's (USASMDC) Mobile Experimental High Energy Laser (MEHEL). The MEHEL is a 5kW laser weapon, mounted on a Stryker armored fighting vehicle. Recently the MEHEL participated in, and won, the Joint Improvised-Threat Defeat Organization's (JIDO) UAS Hard-Kill Challenge. The purpose of the Hard-Kill Challenge was to assess technologies that would be most proficient at the shoot-down of an enemy UAS system. In addition, the Hard-Kill Challenge informed senior decision-makers on the current state of various technologies, and how they can best deal with single and multiple UAS targets.[32] The MEHEL's recent success at the Hard-Kill

Challenge serves as an example of how high-power laser weapons can be effective against emerging threats in the present RMA.

Assaults from swarms of small ships, swarms of UASs, and missiles, will be prevalent in future conflicts. Naval vessels will be especially vulnerable to these types of attack, due to their large size, slower speeds, and large electronic footprint. Recognizing this vulnerability, the U.S. Navy developed, installed, and deployed the AN/SEQ-3 Laser Weapons System (XN-1 LaWS) on the USS Ponce. The XN-1 LaWS is specifically designed for use against low-end asymmetric threats, such as small boats and UASs. One of the most important aspects of the XN-1 LaWS is its capability for scalable actions. The XN-1 LaWS can temporarily blind personnel, and burn through electronics on aircraft, ship engines, on-board ship munitions, and inflight UASs. Currently, the commander of the USS Ponce has authorization to use the system as a defensive weapon during its operations in the Persian Gulf. The XN-1 LaWS has demonstrated the capability to be effective against the present RMA's modern weapons systems located in the sea and air domains.[33]

High-energy lasers have demonstrated some of their greatest potential in the space domain. Civilian infrastructure and military systems are increasingly reliant on space-provided capabilities. Recognizing this reliance, potential adversaries are quickly developing ways to disrupt the use of the space domain. In recent years, high-energy laser weapons have revealed increased capabilities in space. In 2006, the director of the U.S. National Reconnaissance Office (NRO) confirmed that a ground-based laser, operating in China, had illuminated one of its spy satellites.[34] Recently, numerous civilian and military earth-observation satellite owners have reported temporary blinding caused by laser dazzlers.[35] Although these attacks did not produce permanent damage, they demonstrate that lasers have the ability to target satellites, with more powerful lasers capable of destroying sensors and critical circuitry.

The present RMA relies on space for numerous military systems and operations, and lasers provide effective space weapons. A satellite in Low Earth Orbit travels at nearly 17,500 miles per hour, and is 150 to 1500 miles above the earth's surface. A satellite's hyper-speed and high altitude make it a challenging target. Therefore, high-energy laser weapons are an obvious choice for use against an adversary's satellites, due to their long range, accuracy, and ability to create effects at the speed of light. In addition, gravity and wind conditions have minimal effect on laser weapons. This is especially helpful with accuracy when shooting hundreds of miles from the earth's surface into the zero gravity domain of space. Furthermore, a laser weapon's potential to engage a target multiple times in a matter of seconds significantly increases the likelihood of hitting a target in space. The aforementioned demonstrates that a laser's ability to operate in the space environment makes it an ideal anti-satellite weapon.

Although DEWs possess advantages to the current and future forces, they also have limitations. Distance and weather conditions provide severe restrictions for laser weapons. Particulates in the air, such as smoke, dust, and water molecules, scatter and absorb laser light, resulting in power loss. An infrared laser will lose half its potency after traveling 2.5 miles on a clear day and less than a mile on a humid day.[36] The heat generated by lasers provides another drawback. In the process of delivering heat to a target, lasers also generate heat within their own operating system. Therefore, DEWs require a cooling system to prevent overheating between shots. Consequently, cooling systems add an enormous amount of bulk that can burden ground and air weapons platforms.[37] Laser cooling systems have significantly decreased in size over the past 30 years. However, it may take substantial time to reduce a high-energy laser's cooling system to an adequate operational size. Another limitation is that laser beams can only travel in straight lines. Consequently, they can only hit targets in direct line-of-site, or above the horizon. In the future, relay mirrors on UASs or satellites may solve the direct line-of-site issue.[38] It is likely that laser technology will continue to evolve and alleviate these issues, but at present, lasers are limited to short-range, mostly defensive weapons.

High Powered Microwave (HPM) Weapons

The present RMA is characterized by advanced weapons and C2 systems that utilize electronics and microchip technology.[39] Furthermore, militaries in the current RMA look to reduce civilian casualties and collateral damage.[40] High Powered Microwave (HPM) weapons support the present RMA by providing non-lethal fires against both personnel and equipment. In addition, HPM systems provide speed-of-light delivery, all weather capability, large area coverage, multiple target acquisition, and virtually unlimited ammunition.[41] Current HPM weapons development focuses on two main areas, anti-electronics and non-lethal area defense.

Anti-electronic HPM weapons work by generating continuous beams, or short bursts, of high-frequency electromagnetic energy. Microwave energy causes equipment malfunctions by producing an electrical current that runs through wiring, circuits, and electronic components exceeding the normal design parameters of the system. Similar to a lightning strike, HPMs with enough power can permanently incapacitate equipment by burning out its components. Using brief, powerful bursts of energy, a HPM weapon can successfully damage equipment without wounding personnel. Modern electronic equipment, found in contemporary military platforms, is especially vulnerable to HPM weapon attacks. Currently, HPM weapons have the capability to destroy radars, air defense systems, and computer networks. In the near future, anti-electronic HPMs will have the capability to destroy enemy rockets, aircraft, and missiles.[42] Anti-electronic HPMs are already on the battlefield. Today in Afghanistan and Iraq, HPMs are successfully used to counter adversary trigged IEDs.[43] Based on current capabilities, one can deduce that the use of HPMs reduces collateral damage and casualties, making them an effective tool in the present RMA.

HPM weapons will soon prove effective in the present RMA by controlling an area, without creating casualties or collateral damage. By producing pain without causing any physical destruction, non-lethal HPM weapons are effective for riot-control or area denial. HPM area denial weapons work by using microwave energy to penetrate and heat the tissue just below the surface of the skin. The pain will increase in intensity until the affected individual moves out of the HPM beam, thus vacating a contested area.[44] These qualities support the present RMA by providing an area denial weapon that exerts force, without permanently damaging people or equipment.

While HPM weapons have a number of benefits to the warfighter, there are drawbacks. Three challenges to the use of HPM weapons are: repeatability, battle damage assessment, and unforeseen effects. The power from an HPM weapon can differ from one shot to the next, causing variations in each shot with unpredictable effects. In addition, it is difficult to determine if a HPM weapon strike is successful. Without physical access to an adversary's system, it is challenging to conclude if the target remains operational. An intended target may have simply shut itself down around the time of attack, making it difficult to determine if the HPM weapon had any real effect. When using HPMs, there are second and third order effects to consider. For example, destroying an enemy's phone and computer networks may result in lost intelligence.[45] Lastly, an adversary can protect electronic equipment from microwave attacks with metal shielding. However, microwaves with enough power can still penetrate shielding and cause damage.[46]

Sonic Weapons

Sonic weapons are another type of DEW that provide scalable and non-lethal effects. Militaries have been experimenting with sound waves since World War II, but have had little success in making them truly effective weapons. Recently, there has been a great deal of renewed interest in sonic weapons. They have proven capable of producing psychological and physical effects on the human body. Furthermore, future weapons may have the capability to inflict physical damage on objects, such as vehicles and buildings. In the past thirty years, various militaries have deployed sonic weapons for use in interrogation, crowd control, and the creation of psychological fear.[47]

Sonic weapons typically fall within two categories, either infrasound (low frequency) or ultrasound (high frequency). The frequency determines the type of damage, while power determines the level of damage. Sonic weapons can cause biological symptoms, such as fatigue, blurred vision, nausea, organ damage, or death. In addition, sonic weapons can cause a number of psychological effects, such as sadness, fear, and anxiety. Tests have proven that at higher decibel levels, sonic weapons can produce lethal effects, such as burns and harmful organ resonations.[48]

Based on the scalability of effects, sonic weapons technology may soon be significant contributors to the present RMA.

Sonic weapons have already shown the ability to create scalable non-lethal effects for area denial in Northern Ireland, Iraq, Afghanistan, and Israel.[49] Furthermore, sonic weapons are inexpensive, easy to maintain, readily deployable, and require a small logistical footprint. Sonic weapons can also be used against targets on land, at sea, and even below the water's surface. In addition, they have the capability to engage multiple targets for long periods. These capabilities help defend against modern weapons and tactics, such as small ship swarms or suicide attacks.[50] Sonic weapons' ability to work in multiple domains, and engage multiple targets for extended periods of time, will significantly contribute to the present RMA.

Although sonic weapons hold a great deal of promise, there are some limitations. Most sonic weapons require immense power in order to be effective. In addition, sonic weapons require a large aperture to project the low or high frequency noise they produce. Large power generators and noise apertures make sonic weapons difficult to place on mobile weapons platforms. Furthermore, range is limited, due to the rapid dissipation of sound waves in the air.[51] Future advances may solve a number of these limitations, but for now, defensive and small area denial weapons are the only uses for sonic technology.

Directed-Energy Weapon Legal and Moral Issues

DEWs raise a multitude of legal and moral issues that do not apply to today's conventional weapons. International laws and treaties have been unable to adapt to the fast rate at which DEW technology is advancing. DEWs can blind, burn, and create long-term psychological effects. Therefore, they may be categorized, under the Geneva

Convention, as weapons designed to cause excessive suffering. For example, The Geneva Convention's Protocol on Blinding Laser Weapons states: "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."[52] Furthermore, many human rights groups see DEWs as horrific weapons that can cause substantial collateral damage, and kill in large numbers. However, a strong counterargument to their perspective is that DEWs are far more humane than traditional weapons. First, DEWs are scalable, which allow for non-lethal use. Second, their extreme accuracy produces far less collateral damage. For example, a laser weapon could target a limited portion of a vehicle, such as the engine, and disable it without affecting the crew.[53] The international community must develop similar rules and guidelines for using DEWs that are currently in place for conventional weapons.

Laser Remote Sensing

Remote sensing is another way in which directed-energy supports military operations. Remote sensing is a technique for measuring and monitoring objects without making physical contact with that object.[54] It can provide accurate and timely mapping data of land and ocean surfaces. In addition, remote sensing gives military planners significant advantages by allowing observations of hazardous and contested areas. Recently, directed-energy technology has proven to be one of the most efficient and economical ways to conduct remote sensing, from both air and space based platforms.[55]

Laser Imaging Detection and Ranging (LIDAR) is one of the most common remote sensing techniques. LIDAR is an active, electro-optical, remote sensing system, used for 3D imaging and mapping, which works on the same principle as radar. The LIDAR system projects laser light to an object, that object subsequently interacts with and modifies the laser light. Some of the light reflects back to the LIDAR system, allowing analysis of the received data. Changes in the reflected light's properties determine certain characteristics of the target object. These characteristics may be color, size, shape, or chemical makeup. Therefore, LIDAR data supports 3D terrain mapping, battle damage identification, battle damage assessment, chemical agent detection, IED detection, and landmine detection. In addition, the use of space based LIDAR platforms may soon assist missile warning and missile defense systems.[56] LIDARs ability to support intelligence and long distance strikes enhances the decision making process within the present RMA.

Robotics and autonomous vehicles are quickly becoming a component of the present RMA. Robots and autonomous vehicles are currently dependent on LIDAR technology to see their operating environment. LIDAR sensors build points of reference by using lasers to measure distance to objects. They accomplish this by sampling up to 1.5 million points of reference per second. This sampling rate enables robots and autonomous vehicles to detect and create 3D models. Software then categorizes and reacts to the LIDAR provided information.[57] Currently, without the use of LIDAR technology, robotic and autonomous vehicles lack the ability react to objects in their environment.

Laser remote sensing supports the present RMA with its ability to deliver increased situational awareness, and provide object discrimination to robots and autonomous vehicles. The improved situational awareness provided by laser remote sensing facilitates the present RMAs need for stealth, distant strikes, missile warning, and decreased collateral damage. In addition, laser remote sensing can support multi-domain operations, with its ability to identify objects on land, at sea, and in space. Furthermore, laser remote sensing can enable other current RMA technologies by providing computer-generated eyesight, through 3D object discrimination.

There are limitations to LIDAR technology, because it relies on the measurement of time for a laser beam pulse to return to a sensor. If the target object has a highly reflective or absorptive surface, it may scatter the laser beam's return to the sensor. Environmental factors can also affect LIDAR readings. Fog, snow, and rain can scatter the emitted laser pulse. In addition, LIDAR's relatively slow refresh rates can cause significant problems for robots and autonomous vehicles. For example, when an autonomous vehicle moves at a fast rate of speed, LIDAR has difficulty discerning objects.[58] The most substantial drawback for LIDAR technology is the exorbitant price tag of LIDAR systems. However, the costs associated with LIDAR should dramatically decrease as it gains popularity in civilian robotics and autonomous vehicles.[59]

Laser Communications

The present RMA requires the transmission of immense volumes of secure data, to numerous locations across the globe. In the past twenty years, militaries have considerably increased the use and broadcast of Intelligence, Surveillance, and Reconnaissance (ISR) imagery, video data, C2 data, UAS transmissions, and encrypted information. These demands increase congestion of the radio spectrum, thus creating a communications logjam. In order to conduct its peacetime mission, the U.S. military must share blocks of the electromagnetic spectrum with several commercial providers.[60]

Ever increasing bandwidth requirements will soon necessitate different methods of communications for both civilian and military users.

Laser communications, also known as free space opticals, provide an alternative to traditional radio wave communications. Lasers can communicate information without the use of radio waves or fiber cable. They conduct line-of-site communications, by sending high bandwidth data to receivers on concentrated beams of light.[61] Although laser communications technology is in its infancy, it appears to be gaining traction.[62] Interest in laser communications has steadily grown in the private sector, and its proponents proclaim that it is ready for military use. Lasers have already successfully performed communications from ground-to-ground, ground-to-airplane, ground-to-satellite, and satellite-to-satellite.[63] Recently, several defense contractors have begun developing laser communications technology for both military and civilian use.[64]

Laser communications provide numerous advantages over tradition radio or fiber communications. They are not susceptible to electromagnetic interference (EMI), do not produce stray signals, and are substantially lighter than most radiofrequency (RF) systems. Laser communications also have the ability to transmit enormous quantities of data, at a rate of 100 to 1,000 times faster than traditional RF systems. Furthermore, laser communications provide a covert method of voice and date transmission. Traditional radio transmissions are easy to jam, geo-locate, and de-encrypt, while laser communications are nearly impossible to trace or intercept.[65]

The present RMA is dependent on information technology and the transfer of enormous volumes of data. Furthermore, excessive congestion of the RF spectrum inhibits the massive amounts of data that the present RMA requires. In addition, the recent increases in cyber and electronic attacks have revealed the vulnerabilities of traditional communications systems. Fiber and RF are easy targets for disruption and interception. The present RMA demands that forces have constant worldwide access to critical information. Denying data flow by jamming or destroying communications infrastructure is devastating to modern military operations. Laser communications systems provide a faster, more robust, and more secure way of moving data than traditional communications systems. Laser communications effectively prevent the exploitation signals caused by spoofing, decoding, or position monitoring.[66] For these reason, lasers provide the ideal means for militaries fighting in the present RMA.

Laser communications have limitations and technological challenges. Varying environmental conditions, such as heavy fog, smoke, or high temperatures, can degrade laser communication links. In addition, lasers are limited to point-to-point and line-of-site communications. However, similar to the challenge with DE weapons, the future use of reflectors and relay stations on vehicles, ships, aircraft, and satellites may mitigate laser communication shortcomings. Another limitation of laser communications systems is that they only work for short-range transmissions. However, the U.S. military has successfully experimented with ground, air, sea, and undersea laser communications links to mitigate this issue.[67] Despite current limitations, future technological developments will allow lasers to become a vital means of communication in the present RMA.

Future Military Uses for Directed-Energy Technology

In the future, militaries may have additional uses for directed-energy technology. Someday, lasers could illuminate battlefields, transform weather, project holograms, and provide power to UASs. Lasers beamed from an aircraft or satellite, could be used to provide light during nighttime operations. Additional light would improve target acquisition, illuminate landing zones, and improve security. Furthermore, lasers may have the capability to change weather, by providing enough energy to heat the atmosphere within a localized region. Although, laser created holograms are currently in existence, they has proven difficult to produce in an open-air environment. Soon, military personnel could use holograms to see information in a 3D view, improving decision-making. Hologram technology may provide a more collaborative and interactive environment, offering a better view of operations. Lasers may soon beam power to UASs, providing for longer flight times and heavier ordinance.[68] Although these are theoretical technologies, their future development may significantly influence the RMA.

The Way Ahead

Since the 1960s, few military technologies have held as much promise as directed-energy. Early failures led to program defunding. However, today's directed-energy technologies have reached a point of operational maturity.[69] Technological advances may soon solve directed-energy challenges, such as weather, power loss, and line-of-site restrictions. The U.S. military must recognize that directed-energy technology may soon replace contemporary weapons and communications systems. In order to move forward with directed-energy technologies, the U.S. military must establish the same clear guidelines, doctrine, training, organizations, and funding streams that it provides to traditional weapons.[70]

The U.S. military should take the following actions to move forward with directed-energy technologies: fully fund development programs, conduct an assessment of directed-energy's use against future threats, encourage cooperation with other federal departments, and facilitate the sharing of directed-energy technologies with allies. Although directed-energy research is progressing, insufficient funding has hampered its development and deployment. The U.S. military has voiced praise for directed-energy technologies, but has not always been enthusiastic with funding. The U.S. military must move on from mere words of praise for directed-energy technologies, and begin to fully embrace development.[71] Furthermore, the U.S. military must identify and categorize potential threats that directed-energy technology can defeat. Matching a requirement gap to a potential directed-energy technology will help increase awareness and funding. In order to create greater efficiency in directed-energy technology, the DoD should establish cooperative programs with other agencies and departments, such as the Department of Homeland Security (DHS), Department of Justice (DOJ), Department of Energy (DOE), and the intelligence community. Cooperation amongst federal entities can accomplish more, at an increased speed. Failure to cooperate on development will result in duplicate research, redundancy, increased cost, and less production. Finally, the U.S. should begin a dialogue concerning directed-energy with its partners and allies. The U.S. should not only share directed-energy technology, but also work towards a consensus on its military use.[72]

Conclusion

Directed-energy technology is already an indispensable component of the present RMA and has tremendous future potential. The evidence indicates that directed-energy will soon become the most significant technology in the present RMA. The present RMA's technological enablers, such as robotics, information technology, space technology, and drones, are all supported by directed-energy technologies.

Moreover, directed-energy is the best defense against new threats in the present RMA, such as cyber warfare, missile proliferation, armed drones, and small boat swarms. Furthermore, directed-energy technologies can support many operational tasks synonymous with the present RMA, such as curtailing the number of ground troops, reducing collateral damage, long distance strikes, and improved situational awareness. Finally, directed-energy can support weapons platforms and communications systems located in all war-fighting domains. In order to meet the challenges posed by the present RMA, the U.S military should immediately embrace the war-fighting potential that directed-energy technologies possess.

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