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High Energy Lasers: Applications for Ballistic Missile Defense

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Briefing Highlights

The adverse cost-exchange ratio between expensive interceptors and cheap and abundant ballistic missiles offers a path forward for adversaries who seek to deter U.S. intervention in various regions and conflicts.

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There are many varieties of kinetic weapons that deposit energy on targets. However, none of them provide the cost-effective capabilities needed to defeat mass raids that could involve scores or hundreds of incoming ballistic missiles and multiple warheads. Directing energy weapons, specifically high-energy lasers (HEL), offer the most promising solution.

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The military applications include using HEL to destroy incoming rockets, artillery, and mortars in flight, defeating unmanned aircraft, disabling or destroying swarms of small-high speed naval combatants, intercepting tactical cruise and short-range ballistic missiles, and other tactical missions.

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The MDA is focusing on the development of two alternative types of lasers for potential missile defense applications: coherent fiber lasers (CFL) and Diode Pumped Alkali Laser System (DPALS). The underlying question is whether these systems can be engineered to produce an integrated laser weapon system with the desired ratio of system weight to power output.

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The more efficient the laser, the more energy storage capacity can be built into the system, and hence the more shots available before the energy storage system needs to be recharged. The MDA has established a goal of 2 kg/KW in a deployed ("packaged") configuration.

For decades, ballistic missile defense (BMD) has been among the most controversial dimensions of national defense. Since the termination of the 1972 Anti-Ballistic Missile Treaty in 2002, the extensive proliferation of ballistic missiles on the world stage has prompted the gradual emergence of an international consensus supporting the acquisition of ballistic missile defense capabilities.[1] The proliferation of ballistic missiles is abetted by the present, low cost of creating a formidable offensive ballistic missile capability—a feature which has provided aspiring weapons states with new opportunities to acquire strategic capabilities. North Korea's SCUD-C ballistic missile, a homegrown enhancement of the German V-2 missile derived SCUD series, can deliver a 500-kg payload some 550 kilometers, and is estimated to cost just $3 million each to produce.[2] The underlying SCUD technology has formed the basis for the development of derived missiles for Iran, North Korea, and Pakistan at all ranges from short range (less than 500 kilometers) to intercontinental systems.

The low cost of SCUD-derived ballistic missiles creates a difficult set of circumstances for the defender. The most attractive strategy for an attacker to is to impose costs upon the defender. The profound cost advantage to the attacker (for example, an interceptor for the U.S. Ground-Based Missile Defense System costs approximately $70 million per unit) makes magazine exhaustion an attractive – and likely – tactic. Faced with the future prospect of adversaries armed with large numbers of ballistic missiles, especially in volatile regions in the Central and Eastern Europe, the Middle East, and East Asia, the United States needs to invert the BMD "cost equation," and make it less costly to defend against ballistic missiles than to use them to attack.[3]

Inverting the BMD "Cost Equation"

Further, extensive ballistic missile proliferation appears likely to be a characteristic of the 21st Century. The adverse cost-exchange ratio between expensive interceptors and cheap and abundant ballistic missiles offers a path forward for adversaries who seek to deter U.S. intervention in various

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regions and conflicts. The employment of America's formidable combined arms operations is infeasible against adversaries such as Iran and North Korea, making the acquisition of nuclear armed long-range ballistic missiles attractive for those actors. To mitigate or overcome these circumstances, the U.S. needs advanced technology that will have:

- a deep magazine, so as to defeat mass raids by adversary ballistic missiles with a favorable cost-exchange ratio;
- a short flight time, in order to permit the interception of incoming ballistic missiles at great range;
- ahigh single-shot kill probability (SSP_k) against adversary ballistic missile re-entry vehicles;
- low size, weight, and power (SWaP), so as to permit being carried by high altitude-long-endurance (HALE) unmanned aircraft; and
- a capacity to be integrated into existing maritime and terrestrial BMD battle management, sensor, and interceptor architecture.

There are many varieties of kinetic weapons that deposit energy on targets. However, none of them provide the cost-effective capabilities needed to defeat mass raids that could involve scores or hundreds of incoming ballistic missiles and multiple warheads. As a result, other means of directing energy to the target have been sought for decades. To date, the most promising of these is high energy lasers.

What is a Laser?

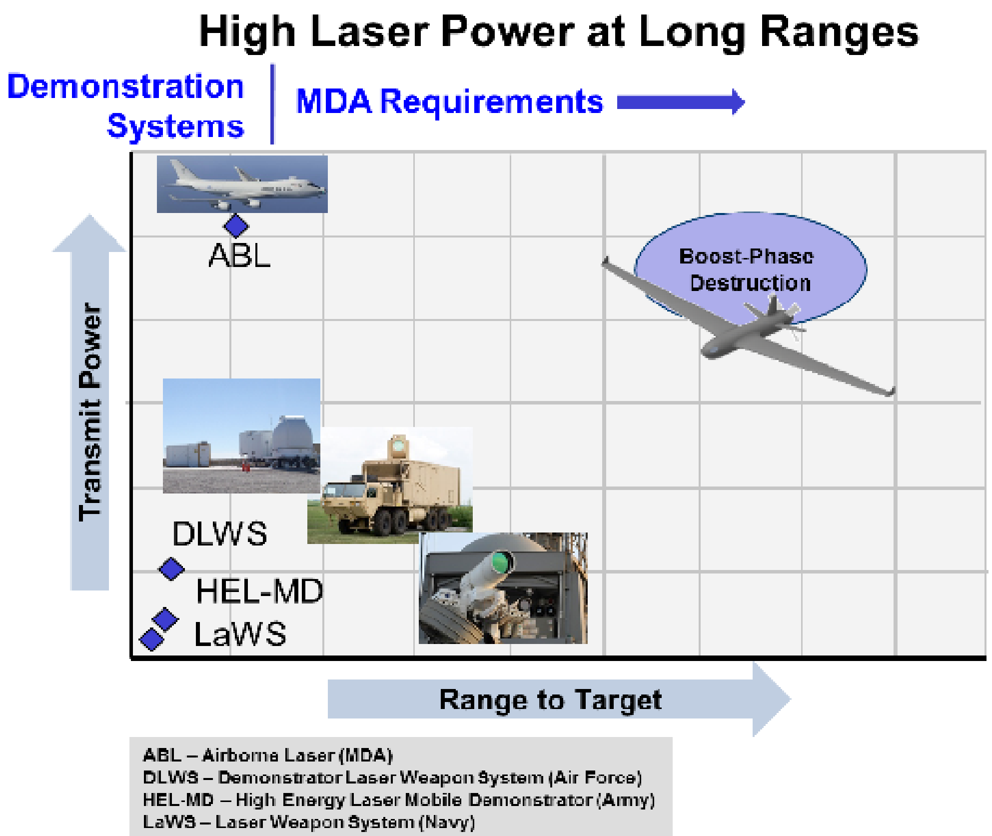
A laser deposits energy on a target by directing an extremely powerful and intense coherent beam of electro-magnetic radiation. This energy travels at the speed of light,[4] and is characterized by a unique frequency or range of frequencies, the active laser medium, and the energy level employed. Lasers have the highest degree of coherence of all light sources—a crucial quality for military applications. It is the coherence of laser beams that produces the militarily useful properties of:

- intense "brightness" – the luminous power per unit area;
- directionality;
- a single wavelength, and
- a high degree of polarization

The development of high energy laser (HEL) systems, particularly for BMD applications, has been a long-standing R&D effort in the Department of Defense. Perhaps the best known (and most successful, in scientific terms) was the Airborne Laser Test Bed. This program employed a chemical-based lasing medium to produce a megawatt class laser system (COIL: "Chemical-oxygen-iodine laser"). The system demonstrated that a HEL could destroy a target at great range, but the developmental system was not a practical military system. It was installed in a B747 aircraft, had limited magazine depth (~20 shots) and could not fly at a high altitude. Nevertheless, the notion that HEL could be employed in BMD applications in a suitable airborne platform was successfully demonstrated.[5]

Advanced lasers have numerous military applications for non-BMD missions, from target designation to target destruction. The DoD spends approximately $300 million on applications supporting the needs of the Military Departments. These programs are funded by both the Military Departments themselves, and by the Defense Advanced Research Projects Agency (DARPA). The military applications include using HEL to destroy incoming rockets, artillery, and mortars in flight, defeating unmanned aircraft, disabling or destroying swarms of small-high speed naval combatants, intercepting tactical cruise and short-range ballistic missiles, and other tactical missions. The specific application of HEL to the strategic BMD mission, however, is funded only by the Missile Defense Agency. At current planned funding levels, the MDA envisions a 2025 time-frame "to integrate a compact, efficient, high power laser into a high altitude, long endurance aircraft capable of carrying that laser and destroying targets in the boost phase."[6]

Figure 1



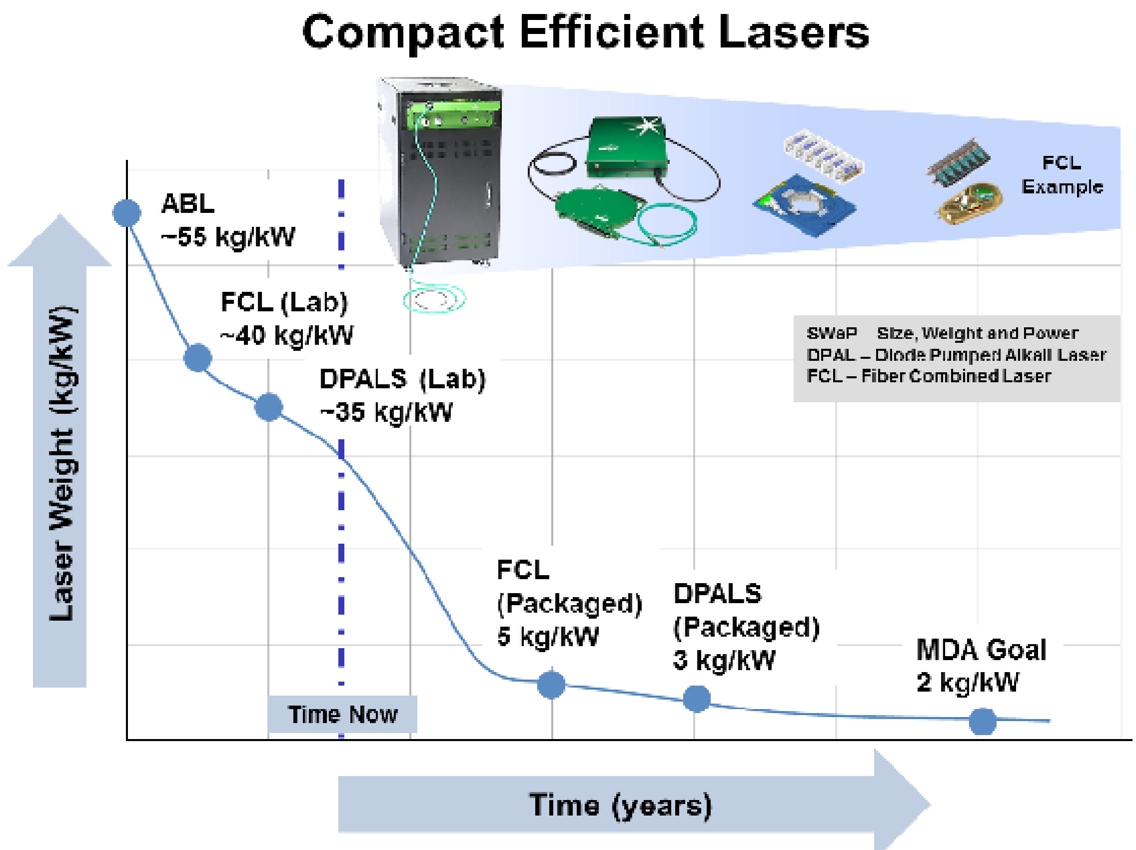
Source: Briefing of VADM James Syring, Director, US Missile Defense Agency, to the "Defense Summit", 23 June 2016

Types of HEL for BMD Applications

The U.S. Missile Defense Agency has funded two major programs specifically aimed at the strategic ballistic missile defense mission. The strategic mission differs from tactical missions because of the need to engage incoming warheads at great distances—several hundred kilometers or more—in order to reduce the number of incoming warheads to a manageable level that can be engaged by other terrestrial and maritime components of the larger national missile defense system. Moreover, to avoid atmospheric attenuation, the strategic HEL systems need to operate above the atmosphere—an altitude of 65 thousand feet or more. The successful intercept of a target by the B747-based Airborne Laser took place at a lower altitude, but an operational system is likely to be unmanned and will exploit the technologies of autonomy to provide a highly effective persistent defense against ballistic missile attack.[7]

The range/altitude and HEL power needed to support the strategic ballistic missile defense mission are illustrated in a notional graphic presented by MDA Director Vice Adm. James Syring to the "Directed Energy Summit," a defense industry conference, in June 2016 [Figure 1]. The chemical-energy laser used in the B747-based airborne laser test bed produced HEL power in the megawatt class. However, due to the relatively low altitude from which it fired the laser, the laser energy that destroyed the target was subject to atmospheric attenuation that limited the range of the system. Several other HEL experiments conducted by each of the Military Departments lacked the power and range to be effective against ballistic missiles launched

Figure 2



Source: Briefing of VADM James Syring Director . US Missile Defense Agency, to the "Defense Summit", 23 June 2016

at intercontinental ranges, even though they are likely to be very useful in other military applications.

The MDA is focusing on the development of two alternative types of lasers for potential missile defense applications: coherent fiber lasers (CFL) and Diode Pumped Alkali Laser System (DPALS). CFL is being developed by the Lincoln Laboratory, and employs laser energy that is transmitted through many optical fibers like those used in the modern civil telecommunications industry. The laser energy delivered through these optical fibers is coherently combined to produce a single high-powered laser beam that can be directed to the target.[8]

A second type of laser, DPALS, is being developed by the Lawrence Livermore National Laboratory. [9] The DPALS approach is a gas-based (Rubidium) laser that is based on direct electrical discharge for energizing ("pumping") the lasing medium. Figure 2 (also presented by MDA Director Syring in June 2016) summarizes the progress being made toward creating compact and efficient laser that will contribute to the DoD's ability to field a practical system in a high altitude unmanned aerial vehicle. The airborne laser test bed in 2010 achieved 55 kg/KW.

Both the coherent fiber and DPALS approach seem likely to be able to produce high powered lasers. Recent DPALS experiments have "retired the physics risk" in scaling the laser to the high power level required for BMD. FCL is likely to achieve greater than 500-kw power, and DPALS in excess of one megawatt, though the two programs operate at different wavelengths. This makes the DPALS laser approximately 40 percent more intense than the FCL. The underlying question is whether these systems can be engineered to produce an integrated laser weapon system with the desired ratio of system weight to power output.

A complete weapon system includes an energy storage and recharging system sufficient to provide an operationally relevant number of shots over a period of time sufficient to successfully engage massed missile raids. The more efficient the laser, the more energy storage capacity can be built into the system, and hence the more shots available before the energy storage system needs to be recharged. The MDA has established a goal of 2 kg/KW in a deployed ("packaged") configuration.

A Key Priority

The development of HEL systems suitable for strategic BMD applications is funding, rather than "idea," limited. However, the risks associated with the foreign nuclear weapons and long-range missile threat has grown more rapidly in the past five years than the U.S. government has anticipated. While immediate risks need to be mitigated and deterred by currently available capabilities, sustaining deterrence will be best served in the years ahead by pressing ahead more rapidly to create a modern directed energy system that can deal with the scale of threat that will emerge over the next decade.

Endnotes

[1] W. P. S. Sidhu, "Why Missile Proliferation Is So Hard to Stop," Bulletin of the Atomic Scientists, June 28, 2016, http://thebulletin.org/too-late-missile-nonproliferation/why-missile-proliferation-so-hard-stop

[2] R. S. Clarke, The Regional Emergence of Strategic Missiles; A Force of Rooks for a Black King," Air Power Studies Centre Paper 55, http://fas.org/irp/threat/missile/paper55.htm. See also Yuri Osokin, "The SCUD: A missile destined for universal cloning," Russia Beyond the Headlines, July 14, 2014, https://rbth.com/defence/2014/07/14/the_scud_a_missile_destined_for_universal_cloning_38185.html

[3] Unlike the U.S., Israel's approach to the calculation of BMD cost-effectiveness considers the value of assets defended in addition to the marginal cost of the interceptor. Yossi Melman, "Analysis: Hezbollah's 100,000 rockets and Israel's new missile defense system," Jerusalem Post, December 23, 2015, http://www.jpost.com/Arab-Israeli-Conflict/Analysis-Hezbollahs-100000-rockets-and-Israels-new-missile-defense-system-438084

[4] A useful (though dated) description of the military applications of lasers is contained in a 1984 MS thesis for the Naval Post-Graduate School by R. F. Ziska, entitled "High Energy Lasers: A Primer on Directed Energy for Space Use." It is available online at https://archive.org/stream/highenergylasers00zisk#page/19/mode/2up

[5] U.S. Missile Defense Agency, "Airborne Laser Test Bed Successful in Lethal Intercept Experiment," February 11, 2010, https://www.mda.mil/news/10news0002.html

[6] US Missile Defense Agency, "Advanced Technology," June 2016, https://www.mda.mil/system/advanced_technology.html

[7] Defense Science Board, Autonomy (U.S. Department of Defense, June 2016), http://www.acq.osd.mil/dsb/reports/DSBSS15.pdf

[8] Office of Naval Research, "Solid State Fiber Laser," n.d., http://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Solid-State-Fiber-Laser.aspx

[9] Lawrence Livermore National Laboratory, "Diode-Pumped Alkali Laser: A New Combination," n.d., https://lasers.llnl.gov/science/photon-science/directed-energy/dpal

DEFENSE TECHNOLOGY PROGRAM BRIEF

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A revolution is taking place in the nature of warfare. The proliferation of ballistic missiles and weapons of mass destruction has given rogue states and terrorist groups unprecedented access to potentially devastating capabilities, while space and cyberspace have emerged as distinct new arenas of strategic competition. The American Foreign Policy Council's (AFPC) work in these areas is aimed at helping U.S. offcials understand and respond to this new, and increasingly complex, threat environment.

For more information about the program, please contact Richard Harrison, Director of Operations and Defense Technology Programs at Harrison@afpc.org.

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