The US Army War College Quarterly: Parameters

Volume 48
Number 4 *Parameters Winter 2018-2019*

Article 6

Winter 12-1-2018

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Ash Rossiter

Technological Innovation: Problems & Prospects

High-Energy Laser Weapons: Overpromising Readiness

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ABSTRACT: This article recounts some of the basic history of laser weapons in the context of the great-power rivalries of the United States, Russia, and China. The author then offers his perspective on the current escalation of investments in high-tech warfare.

Defense professionals increasingly believe high-energy lasers (HELs), which achieve continuous power output of at least 20 kilowatts (kW), are technologically mature enough to become the mainstay weapon of advanced militaries.[1] An examination of past efforts to develop such weapons, however, suggests caution. The history of actualizing lasers as a weapon can be summarized as one of repeated attempts to develop ambitious, big-ticket laser weapon systems before the associated technologies were sufficiently mature. This article argues the impetus for these premature—and ultimately disappointing—efforts was overexuberance within America's national security establishment about the potential military applications of lasers. This imbalance between promise and readiness resulted in the United States losing time and significant sums of money. To support this claim, the article examines the role of technological hype in the American experience of developing powerful laser weapons.

Current optimism about laser weapons is far from novel. At the end of the last millennium, the Chinese "Academy of Military Science, the People Liberation Army's leading think tank on future warfare, believe[d] lasers would likely become an integral aspect of twenty-first century combat."[2] At about the same time, the US Defense Science Board noted in a comprehensive review that such weapons had "the potential to change future military operations in dramatic ways."[3] For more than half a century, several countries—and as with most cutting-edge, defense-related technologies, the United States is the exemplar case—channeled significant sums into developing antimateriel laser weapons. But overall, these attempts yielded disappointing results.

Dr. Ash Rossiter, an assistant professor of international security at Khalifa University in Abu Dhabi, received his PhD from Exeter University in 2014. He specializes in the changing character of war, conflict and technology, and international security.

1 Jason. D. Ellis, *Directed-Energy Weapons: Promise and Prospects* (Washington, DC: Center for a New American Security, 2015); J. R. Wilson, "At Long Last, Laser Weapons Are Nearing Deployment," *Military & Aerospace Electronics* 28, no. 7 (July 25, 2017); and Andy Extance, "Laser Weapons Get Real," *Nature* 521 (May 2015): 408–10.

2 Mark A. Stokes, *China's Strategic Modernization: Implications for the United States* (Carlisle, Pa.: Strategic Studies Institute, 1999), 204.

3 Office of the Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L), *Defense Science Board Task Force on High Energy Laser Weapon Systems Applications* (Washington, DC: Department of Defense [DoD], 2001), iv.

Despite past failures, interest in HEL weapons has not waned. Many states today are looking to lasers to solve a range of near-term tactical and longer-term strategic challenges. As a response to the penetration of its airspace by North Korean drones, for example, South Korea plans to deploy HEL weapons at its border by 2020.[4] Staying with addressing threats on the Korean Peninsula, US defense planners are exploring a more ambitious scheme to fit high altitude, long endurance manned or unmanned aircraft with powerful lasers to intercept North Korean (and other) ballistic missiles during their boost phase.[5]

At one level, it is no surprise states would persist in pursuing HEL weapons. Humans have always sought advantages over each other through acquiring novel or superior technology. In the high stakes of war, maintaining a technological edge over adversaries is a life or death business. Though technologies usually advance incrementally, sometimes a sudden leap forward can lead to high levels of exuberance about a technology's potential to alter established ways of doing things.[6] For these reasons, break-through technologies command the imagination of military leaders. This perspective is especially true for states that pursue qualitative rather than quantitative advantages during arms races.[7] As Henry A. Kissinger wrote shortly before lasers were first successfully tested, "Every country lives with the nightmare that even if it puts forth its best efforts its survival may be jeopardized by a technological breakthrough on the part of its opponent."[8]

The laser possesses desirable properties emanating from the base concept of the technology—the production of very intense, highly focusable light—that make it highly attractive as a potential weapon, giving early adopters significant advantages.[9] The concept of focusing intense light against an enemy has long piqued the imagination of warfighters. One legendary account of the Siege of Syracuse in 212 BC tells of Greek forces setting fire to Roman sails by using mirrors to create a "flaming death ray" of sunlight.[10]

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4 KH Digital 2, "S. Korea To Develop Laser Weapons To Counter NK Drones by 2020," *Korea Herald*, January 6, 2017.

5 Cristina Maza, "U.S. Has a New Plan To Fight North Korea: Shoot Down Kim Jong Un's Missiles as They Launch, But Can It Work?," *Newsweek*, April 12, 2018.

6 Harro van Lente, Charlotte Spitters, and Alexander Peine, "Comparing Technological Hype Cycles: Towards a Theory," *Technological Forecasting and Social Change* 80, no. 8 (October 2013): 1615–28.

7 Taik-young Hamm, *Arming the Two Koreas: State, Capital, and Military Power* (London: Routledge, 2012); Samuel P. Huntington, "Arms Races: Prerequisites and Results," *Public Policy* 8 (1958): 41–86; Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control*, with the assistance of Donald G. Brennan (New York: Twentieth Century Fund, 1961), 497–538; Hedley Bull, *The Control of the Arms Race: Disarmament and Arms Control in the Missile Age* (New York: Praeger, 1961); and Grant Tedrick Hammond, *Plowshares into Swords: Arms Races in International Politics, 1840–1991* (Columbia: University of South Carolina Press, 1993).

8 Henry A. Kissinger, "Arms Control, Inspection and Surprise Attack," *Foreign Affairs* 38, no. 3 (July 1960): 557–75.

9 W. Brian Arthur, "The Structure of Invention," *Research Policy* 36, no. 2 (March 2007): 274–87.

10 Jeremy Hsu, "Archimedes' Flaming Death Ray Was Probably Just a Cannon, Study Finds," *Christian Science Monitor*, June 29, 2010, https://www.csmonitor.com/Science/2010/0629/Archimedes-flaming-death-ray-was-probably-just-a-cannon-study-finds.

Regardless of the level of conceptual attractiveness, decisions to develop any novel technology are taken under conditions of great uncertainty. For one thing, unforeseen technical hurdles encountered during development can stymie efforts to produce an operationally viable system. Even when the technology reaches operational maturity, end users may struggle to incorporate the new system within their existing concept of operations or fail to see the value of adopting it in the first place.[11] When it comes to selecting a potential new technology to mature into a battle-winning weapon, there rarely is ever such a thing as a sure bet.

Every decision to invest in one technology comes with opportunity costs. Most countries face something approximating this dilemma, but it is especially acute for the United States. Current and upcoming decisions on the allocation of defense resources will have a major bearing on whether America can hold its traditional military technological superiority or will see this advantage erode over time. Indeed, there is growing concern among many senior defense officials that the United States is falling behind competitors, particularly China, who have embarked on ambitious plans to develop emerging technologies with military uses.[12]

At present, the vast majority of US defense investments go into long-cycle programs to build successors to legacy systems. Critics believe this approach undermines the American goal of maintaining military technological advantage. Instead, they propose the US military should focus more on harnessing new and emerging innovations, such as artificial intelligence and robotics, in order to retain the country's technological edge over its adversaries.[13]

Decisions about which technologies to develop into future weapon systems may be complicated by the influence of hype, which has long been recognized in business literature.[14] Hype can result in certain technologies attracting attention and resources disproportionate to their realistically known attributes. At worst, it can result in betting on the wrong horse. The analyses derived from this case study have implications for US strategists and defense planners charged with the difficult task of trying to achieve offset advantage by successfully leveraging America's technological prowess at a time of downward pressure on defense spending and an upward pressure of spiraling costs.

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11 Ash Rossiter, "Drone Usage by Militant Groups: Exploring Variation in Adoption," *Defense & Security Analysis* 34, no. 2 (2018).

12 Cade Metz, "Artificial Intelligence Is Now a Pentagon Priority. Will Silicon Valley Help?," *New York Times*, August 26, 2018.

13 John McCain, "Remarks by Senator John McCain at the U.S. Chamber of Commerce" (speech, U.S. Chamber of Commerce Procurement Council Policy Meeting, Washington, DC, July 29, 2015).

14 Mads Borup et al., "The Sociology of Expectations in Science and Technology," *Technology Analysis and Strategic Management* 18, no. 3–4 (July–September 2006): 285–298; and Harro van Lente, *Promising Technology: The Dynamics of Expectations in Technological Developments* (Eburon: Delft, 1993).

Initial Hype

As mentioned above, the level of interest a new piece of technology garners is influenced by its envisioned applications. Thus, when the laser was first demonstrated, it was said to be a solution in search of a problem. Before long, however, analysts started to see lasers as defensive weapons and possibly even as "the biggest breakthrough in the weapons area since the atomic bomb."[15] According to one defense analyst, US military interest during 1962 was such that "there [was] scarcely an Air Force, Army, and to a lesser degree, Navy, agency" disinterested in exploring "some type of basic or applied research or experimental development with optical masers," which were the forerunner of lasers.[16]

Pilot ideas ranged from using lasers as communication conduits to Chairman Mao Zedong instructing his chief scientist to "organize a group of people to specifically study [the death ray]. Have a small group of people specializing in it who do not eat dinner or do other things."[17] Working from the presupposition that "war has always had offensive and defensive aspects," Mao ordered his scientists to think about how lasers might have defensive uses as well as offensive ones.[18] Consequently, he approved the development of high-powered lasers "to counter high altitude bombers and reconnaissance platforms" under an advanced program known as Project 640-3.[19] Most early HEL military research programs funded in the United States were similarly for antiaircraft, antimissile, and anti-tank systems.[20]

For those would-be early adopters who tried, producing a viable HEL weapon proved harder than expected.[21] Huge technical obstacles related to laser power, beam quality and propagation abounded. Early laser programs at the lower end of the energy spectrum did, however, lead to many successful military applications in the United States and the Soviet Union, and later among some European nations. The most important operational contribution was in laser radars used for remote sensing, target designation, and range finding.[22] By the end of the decade, the United States had developed bombs with guidance systems that could home in on light reflected from a pulsed laser beam, ushering in the age

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15 Letter from Major General A. Schomburg to Lieutenant General J. H. Hinrichs, January 16, 1962, history office, US Army Missile Command, Redstone Arsenal, Huntsville, AL, quoted in Robert W. Seidel, "From Glow to Flow: A History of Military Laser Research and Development," *Historical Studies in the Physical and Biological Sciences* 18, no. 1 (1987): 114.

16 Barry Miller, "Services To Push Optical Maser Effort," *Aviation Week and Space Technology* 76 (January 15, 1962): 92–104.

17 "中国激光武器的起步：邓小平指出将是主力装备 [China's laser weapons commence: Deng pointed out they will be decisive equipment]," Ifeng, September 9, 2010, quoted in Richard D. Fisher Jr., *China's Progress with Directed Energy Weapons* (testimony, Hearing on China's Advanced Weapons, Before the U.S.-China Economic and Security Review Commission, Washington, DC, February 23, 2017).

18 "China's laser weapons," Ifeng.

19 Stokes, *China's Strategic Modernization*, 195–96.

20 Seidel, "From Glow to Flow."

21 Melissa Olson, "History of Laser Weapon Research," *Leading Edge* 7, no. 4 (2012): 28.

22 Vasyl Molenby et al., "Laser Radar: Historical Perspective—From the East to the West," *Optical Engineering* 56, no. 3 (2016).

of precision-guided munitions, a key component of the Second Offset.[23] In the mid- to late 1970s, America significantly scaled up the power output of chemical lasers.[24] This development led some members of the American and Soviet defense communities to consider lasers an ideal candidate for ballistic missile defense.[25] The prospect of high-energy lasers altering the strategic balance made the technology highly alluring; their readiness became a second order consideration.

Strategic Seduction

Because of its minimal diffraction, called collimation, a coherently emitted laser beam can reach long ranges while maintaining a small, precise spot of concentrated energy on a chosen target. This attribute makes lasers conceptually ideal for ballistic missile defense and for anti-satellite weapons. Indeed, as far back as the early 1960s, the United States funded research on the effects of high-energy laser pulses on missile warheads.[26] Renewed American interest in lasers for ballistic missile defense in the early 1980s coincided with theoretical studies on satellites using small nuclear explosions to "pump" x-ray laser weapons to defeat such intercontinental weapons. Despite broad skepticism about megawatt-class nuclear-powered lasers on satellites being feasible in this role, the concept formed a central plank of the Strategic Defense Initiative outlined in Reagan's so-called Star Wars speech.[27]

Although Moscow did not respond by attempting to develop an analogous system of space-based nuclear-powered lasers, Soviet leaders did embark upon a lower cost, asymmetric response, namely, a ground-based laser program for knocking out satellites.[28] Following the 1972 treaty banning antiballistic missile systems, the focus shifted toward producing anti-satellite weapons.[29] Complementary to these game-changing efforts to control space, the Soviet Union designed a module for combat that included capabilities for carrying, among other items, a laser weapon capable of disabling enemy satellite electronics. After the test model failed to reach orbit in 1987, Moscow tried to fit the prototype

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23 Peter DeLeon, *The Laser-Guided Bomb: Case History of a Development* (Santa Monica, CA: RAND Corporation, 1974).

24 Elihu Zimet and Christopher Mann, *Directed Energy Weapons—Are We There Yet?* (Washington, DC: National Defense University, 2009), 2.

25 Ellis, *Directed-Energy Weapons*, 24; and Bob Preston et al., *Space Weapons, Earth Wars* (Santa Monica, CA: RAND, 2002).

26 Seidel, "From Glow to Flow," 121.

27 Frances FitzGerald, *Way Out There in the Blue: Reagan, Star Wars, and the End of the Cold War* (New York: Simon & Schuster, 2000), 370–411; and Leslie H. Gelb, "Vision of Space Defense Posing New Challenges," *New York Times*, March 3, 1985.

28 Stephen M. Meyer, "Soviet Strategic Programmes and the US SDI," *Survival* 27, no. 6 (November 1985): 274–92; David Holloway, "The Strategic Defense Initiative and the Soviet Union," *Daedalus* 114, no. 3 (Summer 1985): 257–78; and Don Oberdorfer, "Military Response Planned to 'Star Wars,' Soviet Says," *Washington Post*, March 8, 1985.

29 Sebastien Roblin, "Russia's Cold War Super Weapon (Put Lasers on Everything It Can)," *National Interest*, July 16, 2017.

anti-satellite laser onto a modified military transport aircraft, which was equally unsuccessful.[30]

American interest in lasers was also driven not by technological developments but perception of Soviet progress in this area. Throughout the latter half of the 1980s, the Pentagon repeatedly warned of a "laser gap" opening up if the Soviets converted their anti-satellite lasers into a ballistic missile defense system.[31] Despite considerable scientific research, though, the Soviet Union failed to take HELs past a nascent prototype.[32] The myth of the Soviet "killer" laser nonetheless kept US military research money channeled toward lasers.[33] American research and development (R&D) spending on HELs peaked in 1989, but fell off rapidly after Moscow's slow progress became evident.

Undeterred by technical hurdles and tremendous development costs, the United States pursued lasers for ballistic missile defense through the mid-1990s. The Air Force initiated the Airborne Laser project, which entailed aircraft carrying lasers above the dense layer of atmosphere at 12,000 meters. Beams emitted from the chemically powered onboard devices were expected to cause an enemy's ballistic missile fuel storage tank to explode at ranges of hundreds of kilometers. But after three-and-a-half decades of underperformance, HELs still generated tremendous hype.

Commenting on the project in 1997, Secretary of the Air Force Sheila E. Widnall declared, "It isn't very often an innovation comes along that revolutionizes our operational concepts, tactics, and strategies. You can probably name them on one hand—the atomic bomb, the satellite, the jet engine, stealth, and the microchip. It's possible the airborne laser is in this league."[34] Despite high expectations—and a successful test against a missile in flight—size, weight, and power issues plagued the project. With $5 billion spent before the program was canceled in 2012, the chemical laser could only be carried by a Boeing 747, and the weak beam required the aircraft to orbit extremely close to an adversary's launch sites.[35]

The prospect of potentially upending strategic calculations, rather than the estimated merits of the technology, best accounts for much of the sustained hype in HEL weapons. As some point out, ballistic missile defense is "an issue heavily encrusted with multiple policy and ideological considerations lying outside the general parameters of

30 Alexander Korolkov, "Laser Warfare: Sci-fi Fantasy or Future Reality," *Russia Beyond*, November 18, 2014.

31 Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, NY: Cornell University Press, 1988), 258–61.

32 Bengt Anderberg and Myron L. Wolbarsht, *Laser Weapons: The Dawn of a New Military Age* (New York: Plenum Press, 1992), 133.

33 Frank von Hippel and Thomas B. Cochran, "The Myth of the Soviet 'Killer' Laser," *New York Times*, August 19, 1989.

34 Angelo M. Codevilla, "This Missile Defense Program Just Won't Fly," *Wall Street Journal*, October 22, 1997.

35 "Airborne Laser System (ABL) YAL 1A," Air Force Technology, accessed April 9, 2019; and Katie Drummond, "RIP, Raygun: Pentagon's Laser Plane Laid to Rest," *Wired*, February 21, 2012.

whether or not the critical intercept technologies actually work."[36] Large defense contractors also likely have incentives to tout the possibilities for lasers given the potential reward of government funding for high risk, high reward research.

Promise-Readiness Equilibrium

In the early twenty-first century, America's emphasis shifted from pursuing ambitious airborne and space-based kilowatt-class laser projects to developing less powerful devices intended to intercept smaller objects over shorter distances.[37] Cold War priorities—especially the "hard kill" of ballistic missiles—required incredibly powerful lasers that could apply beams accurately on a target for several seconds over great distances. Laser systems for defeating small objects over shorter ranges have lower technical requirements.

While laser weapons can potentially kill targets in the open faster and at much greater ranges, they cannot fire in a ballistic arc over a hill or over the horizon like conventional artillery without a sophisticated relay of mirrors.[38] Other properties of HEL systems do, however, give them comparative advantages over conventional weapons for point defense against rockets, artillery, mortars, and other small objects. Laser weapon systems can fire quickly and engage multiple targets simultaneously, and depending on the power source, they potentially have a limitless magazine.

Unlike most conventional kinetic weapons, lasers can produce tailored effects to cause a specified level of damage to a target and to minimize collateral damage. The cost per shot is potentially negligible, which makes laser weapon systems a cost-effective, long-term option for intercepting numerous, inexpensive targets. This favorable cost-exchange equation is an important budgetary attribute in a world where weaker opponents can use plentiful, cheap weapons to overwhelm more technological advanced nations.[39]

American laser projects for countering rockets, artillery, and mortars in the 2000s initially built upon prototypes of the much more powerful devices developed and tested in the 1980s and 1990s, such as the joint US-Israeli tactical high-energy laser demonstrator.[40] Though this system successfully destroyed rocket, artillery, and mortar rounds in flight during field tests between 2000 and 2005, major challenges associated with portability, the logistics of handling hazardous chemicals, and

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36 Roger Handberg, *Ballistic Missile Defense and the Future of American Security: Agendas, Perceptions, Technology, and Policy* (Westport, CT: Praeger, 2002), 3.

37 Sydney J. Freedberg Jr., "Laser Weapons: Lower Expectations, Higher Threats," *Breaking Defense*, May 19, 2014.

38 Stephen D. Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, NJ: Princeton University Press, 2004), 53.

39 T.X. Hammes, "Cheap Technology Will Challenge U.S. Tactical Dominance," *Joint Forces Quarterly* 81 (2nd Quarter 2016): 76–85.

40 Kenneth Katzman, *Israel: Missile Defense Cooperation with the United States*, RS20516 (Washington, DC: CRS, 2000).

escalating costs led to the program's cancelation.[41] By 2007, the Defense Science Board pointed to "lack of progress" and a "marked decline in interest on the part of operational customers, force providers, and industry," indicating pessimism about the near-term viability of tactical HELs had returned.[42] Consequently, the United States curtailed much of its spending on HELs.[43]

Some efforts to develop tactical lasers within the 10 to 100 kW range did continue, focusing on resolving size, weight, and power incompatibilities with operational platforms. The Army's 10-kW high-energy laser mobile demonstrator and the Navy's 30-kW laser weapon system provide notable examples of systems on platforms.[44] To enhance operational viability during the last decade, researchers developed fiber lasers to be compact and below the high-energy power threshold. The ability to combine their beams coherently allows the total output power to be increased while maintaining good beam quality.[45] Driven by greater commercial interest, the parallel development of fiber lasers as well as image-recognition and targeting systems increase beam accuracy, range, and quality while reducing the size and the weight of the weapon systems relative to their power output.[46] This new innovation infrastructure has closed the gap between the promise and technological readiness of tactical laser weapon systems.

More states are now developing such systems. Britain, for example, plans to test its combined fiber laser weapon, dubbed the Dragonfire, against land and sea targets by 2019.[47] Similar projects are underway in many other technologically advanced nations, especially China.[48] Thus, tactical lasers have likely reached a point of maturity whereby they will soon be fielded in a greater number of real operational settings.[49]

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41 Sharon Weinberger, "Laser Weapons Better Against Rockets?," *Wired*, February 25, 2008; Michael R. Dahlberg and Michael E. Cochrane, "Tactical High-Energy Laser (THEL) as a Weapon System in Future Theater Air and Missile Defense (TAMD)," ed. Ernest A. Dorko, *Proceedings of the Society of Photo-Optical Instrumentation Engineers (SPIE)* 3612 (June 1999): 111–16.

42 AT&L, *Defense Science Board Task Force on Directed Energy Weapons* (Washington, DC: DoD, 2007), ix.

43 Mark Gunzinger and Chris Dougherty, *Changing the Game: The Promise of Directed-Energy Weapons* (Washington, DC: Center for Strategic and Budgetary Assessments, 2012), 56.

44 Joseph Trevithick, "The US Army's Laser-Armed Stryker Has Blasted Dozens of Drones," The Drive, April 17, 2017; "HEL MD Destroys Mortars Midflight," Boeing, accessed April 15, 2019; and Kashmira Gander and Rob Williams, "Laser Gun: US Navy Unveils New Weapon with Video Showing Speedboat Explosion," *Independent*, December 10, 2014.

45 Zejin Liu et al., "High-Power Coherent Beam Polarization Combination of Fiber Lasers: Progress and Prospect [Invited]," *Journal of the Optical Society of America B* 34, no. 3 (2017): A7–A14; and Zejin Liu et al., "Coherent Beam Combining of High Power Fiber Lasers: Progress and Prospect," *Science China Technological Sciences* 56, no. 7 (July 2013): 1597–1606.

46 "Fiber Laser Applications," SPI Lasers, accessed April 15, 2019; and Extance, "Laser Weapons," 410.

47 "Case Study: UK Dragonfire—Transforming Future Weapons Technology," QinetiQ blog, November 23, 2017.

48 Liu Zhen, "How China's Military Has Zeroed In on Laser Technology," *South China Morning Post*, May 4, 2018; David Szondy, "Rheinmetall's 50kW High-Energy Laser Weapon Successfully Passes Tests," News Atlas, December 20, 2012; and Burak Ege Bekdil, "Turkish Indigenous Laser Weapon Advances," Defense News, February 14, 2015.

49 Ellis, *Directed-Energy Weapons*, 4.

Despite these advances, tactical HEL weapon systems remain bulky, costly, and sensitive to vibration—features warfighters do not find appealing. Furthermore, the systems require highly skilled operators and maintenance crews to keep them functioning. Yet the smaller and more efficient laser systems become, the more likely it is that militaries will look to use them for point defense or for protecting expeditionary ground, naval, and air assets.[50]

Great-Power Rivalry

Against the backdrop of today's great-power rivalry, some types of sophisticated HEL systems are viewed as potential solutions to key problems in power projection (in the case of the United States) or as a means of exploiting a critical vulnerability of an adversary (in the case of China and Russia). Aside from ballistic missile defense, America's most ambitious efforts enhance the survivability of air, and potentially maritime, platforms in an anti-access/area denial environment. This capability is especially relevant in the western Pacific, where China has fielded a series of interrelated missile, sensor, guidance, and other technologies to restrict regional access, threatening core international security interests.[51]

The success or failure of the US response to this challenge is highly contingent on the ability to penetrate heavily defended airspace.[52] In this context, the possibility of plane-mounted lasers for air platform survival generates considerable hype in the United States. Size, weight, and power issues as well as targeting considerations—not least, keeping a beam focused on the vulnerable spot of a target for a minimum dwell time to achieve a "kill"—make fitting laser systems onto fast-moving air platforms tremendously more challenging than mounting a device on a ship or vehicle.

Nonetheless, by 2021, the Air Force hopes to demonstrate a 50-kW airborne laser can feasibly acquire, track, aim, and fire a beam at a dynamic target, such as an incoming missile, from a fighter jet traveling at transonic and supersonic speeds.[53] By 2030, the United States expects to arm an aircraft with high-energy lasers capable of defending itself against integrated air defenses.[54] Clearly, the allure of lasers as a revolutionary technology has returned, and not just in America.

Russia and China consider lasers a means of obviating key US advantages in space such as satellite-based military reconnaissance and

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50 Ellis, *Directed-Energy Weapons*, 38.

51 Stephen Biddle and Ivan Oelrich, "Future Warfare in the Western Pacific: Chinese Antiaccess/Area Denial, U.S. AirSea Battle, and Command of the Commons in East Asia," *International Security* 41, no. 1 (Summer 2016): 7. See also, Evan Braden Montgomery, "Contested Primacy in the Western Pacific: China's Rise and the Future of U.S. Power Projection," *International Security* 38, no. 4 (Spring 2014): 115–49.

52 Air-Sea Battle Office, *Air-Sea Battle: Service Collaboration to Address Anti-Access & Area Denial Challenges* (Washington, DC: Air-Sea Battle Office, 2013), 3.

53 GEN James "Mike" Holmes, "Directed Energy Summit" (speech, Directed Energy Summit, Washington, DC, March 29, 2017).

54 Holmes, "Directed Energy Summit."

surveillance as well as satellite-based communications that can affect economic transactions. Thus, fielding anti-satellite systems makes sense to America's adversaries. As Daniel R. Coats, the director of the Office of National Intelligence, told lawmakers, "Russia and China perceive a need to offset any US military advantage derived from military, civil, or commercial space systems and are increasingly considering attacks against satellite systems as part of their future warfare doctrine."[55]

Given the sensitivities surrounding Russian defense projects, it is difficult to gauge progress accurately, however, some evidence suggests Russia has revived its original airborne laser weapon project for anti-satellite capabilities.[56] Consistent with Moscow's record of exaggeration, Russian defense officials have also recently boasted of an impending breakthrough in laser weapons.[57] In contrast, Beijing's efforts to develop laser weapons to counter space advantages became apparent during the late 1990s only when reports on "Chinese efforts to purchase or develop low- and high-powered laser technology, [radio frequency] jammers, and other capabilities that could be used against satellites" surfaced.[58] A more recent report confirmed China's 2005 success "of a ground-based laser weapon that was used to 'blind' an orbiting satellite."[59] More recently, the Chinese government allowed scientists to speculate the country could develop a space-based laser weapon to target satellites.

Therefore, a major breakthrough in HEL weapons, especially in a period of rising tensions, could be highly destabilizing. China would view an increased US ability to penetrate its anti-access/area denial environment with alarm. Likewise, the United States would consider the development of more advanced anti-satellite laser weapon systems provocative. But given the long lead times involved in maturing and testing HEL weapon systems, surprises are unlikely. Furthermore, there are other ways to destroy or disrupt satellites.[60]

To be sure, guard must be kept against being surprised by leap-ahead technologies. But as current confrontations attest, states are just as likely to be surprised, and perhaps outmaneuvered, by enemies creatively employing simple and established technologies. Moreover, the biggest threats to American satellites are perhaps nonkinetic, such as the jamming of satellite-based positioning and communications

55 *Hearing on Worldwide Threats Before the Senate Armed Services Committee*, 115th Cong. (2017) (statement of Daniel R. Coats, Director of National Intelligence), 8.

56 Patrick Tucker, "China, Russia Building Attack Satellites and Space Lasers: Pentagon Report," Defense One, February 12, 2019.

57 "Russia's Hypersonic Ballistic Missile and Laser System in Final Tests, Putin Says," *Moscow Times*, April 11, 2019.

58 Eric Heginbotham et al., *The U.S.-China Military Scorecard: Forces, Geography, and the Evolving Balance of Power, 1996–2017* (Santa Monica, CA: RAND Corporation, 2015), 245.

59 Bill Gertz, "Get Ready for China's Laser-Weapons Arsenal," *National Interest*, April 12, 2017.

60 Sandra Erwin, "U.S. Intelligence: Russia and China Will Have 'Operational' Anti-Satellite Weapons in a Few Years," *Space News*, February 14, 2018.

capabilities.[61] But anti-satellite laser weapons hold a unique niche in conducting difficult-to-attribute attacks due to the difficulty of proving if a satellite failure was caused by a technical issue or an attack.[62]

Global power distribution differs much from the Cold War when the United States lacked a technological peer. China is already fielding comparable, if not superior, weapon systems and investing in such military innovations as robotics, artificial intelligence, and autonomous vehicles. In all these cases, commercialization feeds technology development and eases acquisition costs.

Conversely, powerful HELs have a small, albeit growing, commercial footprint that results in the majority of R&D funding coming from defense sources. Moreover, the United States placed severe export restrictions on end-state and component technologies. As a consequence, China and Russia will likely find it more difficult to keep pace with developments in advanced HEL systems, especially those designed for air, maritime, and ballistic missile defense. These lasers could remain an area of technological competition in which America can potentially maintain significant long-term advantages.

Conclusion

Despite the hype and the disappointment associated with emerging technologies and the reality that research funding evaporates in the absence of immediate success, high-energy lasers are an anomaly.[63] At their inception, lasers were not a solution-orientated defense technology. Over time, however, the potential for one laser that can perform a variety of weaponized tasks contributed to the technology's enduring attractiveness to the defense industry. Large defense contractors, incentivized by the prospect of securing government funding for conducting high-risk R&D, have likely encouraged additional hype about the possibilities of developing and fielding ambitious laser weapon systems. Defeating ballistic missiles has been the primary rationale for their development, but enthusiasm for the potential of lasers in an air platform defense role within an anti-access/area denial environment exists.

Unlike the hypothetical megawatt weapons or the highly sophisticated systems being developed for air platform survival, ground-based and ship- and vehicle-mounted tactical lasers have established an operational viability. This role is especially useful for countering rockets, artillery, and mortars as well as defeating cheap, plentiful drones and small, unmanned, boats. At a time of downward pressure on Western

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61 Lin Jinshun et al., "Countermeasure Technology for MMW Satellite Links," *Aerospace Electronic Warfare*, October 2012, 20–22, referenced by David D. Chen (testimony, Hearing on China's Advanced Weapons, Before the U.S.-China Economic and Security Review Commission, February 23, 2017).

62 Todd Harrison, Kaitlyn Johnson, and Thomas G. Roberts, *Space Threat Assessment 2018* (Washington DC: Center for Strategic & International Studies [CSIS], April 2018), 10.

63 van Lente, *Promising Technology*; Jon Guice, "Designing the Future: The Culture of New Trends in Science and Technology," *Research Policy* 28, no. 1 (January 1999): 81–98; and Daniel E. O'Leary, "Gartner's Hype Cycle and Information System Research Issues," *International Journal of Accounting Information Systems* 9, no. 4 (2008): 240–52.

defense budgets, the full integration of high-energy lasers into future warfighting concepts will depend on overcoming the reputation of exaggerated expectations and poor technical outcomes, such as the degradation of laser propagation through the atmosphere.

Calculating precisely the part hype has played in the technological maturation of HELs and their ostensible readiness in a tactical role today is hard. Because hype helps to channel resources at critical junctures in the innovation life cycle, it may prove a significant factor in the emergence of some long-fuse technologies.[64] Enthusiasm for a particular technology may not be ill-placed. An unrealistic appreciation of the timeframe for its readiness, however, is often the problem: "We invariably overestimate the short-term impact of a truly transformational discovery, while underestimating its longer-term effects."[65] As America's military seeks to retain its edge, the experience for developing laser weapons should serve as a warning about being drawn in by a technology's promise to deliver rapid advantages.

With little commercial interest in powerful HELs until recently, the industry has relied on enduring military interest and the corresponding allocation of R&D defense dollars to fund crucial advances in the technology. In contrast, much of the technology identified in the Third Offset Strategy is being developed in the commercial sector for civilian uses. The United States is attempting to leverage its technological superiority beyond commercial, off-the-shelf technologies that are also available to its adversaries. Unique advantages can only be derived from greater symbiosis between military and commercial innovation.[66] America would therefore do well to invest its defense R&D funds in an array of emerging technologies and across the full industry ecosystem, including nondefense commercial firms, to see what grows over time. The Department of Defense should follow this approach to maintain technological military superiority rather than allowing money to follow hype.

64 van Lente, Spitters, and Peine, "Comparing Technological Hype Cycles."

65 Francis S. Collins, "A Genome Story: 10th Anniversary Commentary by Francis Collins," *Guest Blog, Scientific American*, June 25, 2010.

66 Arati Prabhakar in Kathleen H. Hicks et al., *Assessing the Third Offset Strategy* (Washington, DC: CSIS, 2017), 8.