SECTION 2: CHINA'S PURSUIT OF ADVANCED WEAPONS

Key Findings

- China is pursuing a range of advanced weapons with disruptive military potential. Six types that China's leaders have prioritized are maneuverable reentry vehicles, hypersonic weapons, directed energy weapons, electromagnetic railguns, counterspace weapons, and unmanned and artificial intelligence-equipped weapons.
- China's advanced weapons programs align with the People's Liberation Army's overall modernization drive over the past several decades, but appear to reflect a more careful degree of planning as to the U.S. weaknesses they are designed to exploit.
- Current technological trends increase the difficulty of preserving an advantage in developing advanced weapons. The United States for the first time faces a peer technological competitor—a country that is also one of its largest trading partners and that trades extensively with other high-tech powers—in an era in which private sector research and development with dual-use implications increasingly outpaces and contributes to military developments.
- The requirements for developing advanced weapons are fundamental scientific knowledge, unique materials, and abstract skill-based enablers (i.e., abilities, tools, and techniques). China has clear policies to exploit government funding, commercial technological exchange, foreign investment and acquisitions, and talent recruitment to bolster its dual-use technological advances. For China, the only ultimate barrier to such advances is likely to be effort—time, will, and money—and it will be difficult for the United States and its allies and partners to deter this.
- While China has only achieved incremental innovation in military technologies in the past, its research efforts at the technological frontier indicate it may be moving from a phase of "catching-up" to pursuing "leap-ahead" technologies. China's limited returns on science and technology investments indicate shortcomings that may render its development of innovative advanced weapons more costly or protracted, but do not rule out successful innovation.
- China's achievement of a surprise breakthrough in one of these technologies is possible, due to the secrecy surrounding these programs and the uncertain nature of advanced weapons development in general. Such a breakthrough could have significant strategic implications for the United States, particularly in its

potential to further existing access challenges and hold forward deployed U.S. forces at risk.

- Given Beijing's commitment to its current trajectory, and the lack of fundamental barriers to advanced weapons development apart from time and funding, the United States cannot assume it will have an enduring advantage in developing weapons at the technological frontier.*

Introduction

China is pursuing a wide range of military technologies at the global technological frontier—weapons just now being developed or not yet developed by any country. These advanced weapons programs could yield potentially disruptive military effects, presenting important implications for the United States and its allies and partners in the Asia Pacific.

China's advanced weapons programs draw heavily on its wider effort to develop next frontier technologies, discussed in the preceding section. Over the coming decades, China is poised to challenge U.S. technological leadership in both commercial and military terms, in an environment in which dual-use commercial technology increasingly contributes to military technological strength. China's government has taken a comprehensive and state-directed approach to the development of key dual-use technologies, one that carefully considers how to leverage state funding, licit and illicit technological exchange, foreign investment, and talent recruitment opportunities to build national champions and advance its military capabilities. It is thus imperative for the United States to meet this challenge, and consider the security implications of China's high-technology weapons in particular, over the coming decades.

This section examines China's advanced weapons programs in six categories, selected based on their prioritization by China's leaders and their clear status as currently emerging and consequential technologies: maneuverable reentry vehicles, hypersonic weapons, directed energy weapons, electromagnetic railguns, counterspace weapons, and unmanned and artificial intelligence (AI)-equipped weapons. It specifically discusses the drivers behind China's advanced weapons programs, China's activities in each of the six areas, inputs to China's ability to develop advanced weapons, and implications for the United States. In doing so, it draws upon the Commission's February 2017 hearing on China's Advanced Weapons, unclassified statements by U.S. and Chinese officials, and open source research and analysis.

Drivers of China's Advanced Weapons Programs

China's pursuit of advanced weapons bolsters the interests of the ruling Chinese Communist Party (CCP), which seeks to strengthen the nation [1] and defend what it defines as the country's "core interests," [2] including Taiwan and other territorial claims, in order to maintain its hold on power.[3] China's advanced weapons programs specifically contribute to Beijing's longstanding goal of military

*For the Commission's recommendations regarding China's investment in advanced technologies in the United States, see Chapter 1, Section 2, "Chinese Investment in the United States."

modernization and its efforts to compete militarily with the United States. These programs also go hand-in-hand with the desire of China's leaders for the country to become a leading high technology power across commercial and dual-use areas.

Military Modernization

China's advanced weapons programs align with the People's Liberation Army's (PLA) overall modernization drive over the past several decades. China's military modernization began under then President Deng Xiaoping's reforms in 1978, and its programs to develop the advanced weapons discussed in this section appear to have originated in the 1980s and early 1990s [4] (with the exception of a 1960s military laser research program geared toward missile defense,[5] and unmanned and AI technologies, which emerged more recently). China's modernization efforts have specifically sought to narrow gaps in the PLA's ability to defend national interests and "win informationized local wars"[6] (wars incorporating information technology and networked information operations [7]), an objective reinforced by several crises that have highlighted the limited options available to Beijing in contingencies.[8] These events included the Taiwan Strait Crisis in 1996, the accidental U.S. bombing of the Chinese embassy in Belgrade in 1999, and the collision of a PLA fighter with a U.S. EP–3 reconnaissance aircraft in 2001. The 1991 Gulf War and 1999 North Atlantic Treaty Organization intervention in Serbia, while they did not directly involve China, also underscored the capability gaps China would face in a potential conflict and lent urgency to PLA modernization. All of these encounters contributed to Beijing's recognition of the need to address the limited options and capability gaps it might face in regional contingencies involving its core interests. This solidified the requirement for an antiaccess/area denial (A2/AD) or "counterintervention" component within PLA missions * in anticipation of potential outside interference.[9] In continuation of these efforts, the PLA is developing weapons at the global technological frontier.

Military Competition with the United States

In relation to its past modernization activities, China's advanced weapons programs appear to reflect a more careful degree of planning as to the U.S. weaknesses they are designed to exploit. In 1999, China's then President Jiang Zemin used the accidental bombing of China's embassy in Belgrade to underscore military gaps in relation to the United States. He initiated and reinforced major programs for the construction of asymmetric weapons designed to exploit U.S. weaknesses, stating, "That which the enemy fears most, that is what we must develop."[10] This objective is reflected in the Chinese term *shashoujian*, translated as "assassin's mace weapon," which general-

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*According to the U.S. Department of Defense, "antiaccess" actions are intended to slow the deployment of an adversary's forces into a theater or cause them to operate at distances farther from the conflict than they would prefer. "Area denial" actions affect maneuvers within a theater, and are intended to impede an adversary's operations within areas where friendly forces cannot or will not prevent access. China, however, uses the term "counterintervention," reflecting its perception that such operations are reactive. U.S. Department of Defense, *Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2013*, 2013, i, 32, 33; U.S. Department of Defense, *Air-Sea Battle: Service Collaboration to Address Anti-Access & Area Denial Challenges*, May 2013, 2.

ly refers to the idea of a weaker power utilizing a certain capability to defeat a stronger one.[11] The term has been applied in Chinese strategic writings and top leadership statements to antiship ballistic missiles in particular.[12] In addition, Chinese military writings on elements of the U.S. Third Offset strategy—which sets forth U.S. requirements for developing many of these advanced military technologies—often assess that the pursuit of these new systems is aimed at China,[13] and the PLA's focus on advanced weapons has only intensified in response to the Third Offset Strategy.[14]

Breakthroughs in any of the advanced weapons categories discussed in this section would contribute strongly to China's A2/AD capabilities and directly challenge U.S. advantages. Dr. Timothy Grayson, president of Fortitude Mission Research LLC, former senior manager at Raytheon, and former program manager at the U.S. Defense Advanced Research Projects Agency (DARPA), termed China's pursuit of advanced weapons "the next phase" of China's modernization strategy, testifying to the Commission:

> *Instead of simply relying upon overwhelming the U.S. with "catch-up" capabilities in large numbers, China is now developing weapons in key areas that may leapfrog the U.S., attempting to negate specific U.S. strengths. … Hypersonics [are] an extension of existing ballistic missile and cruise missile capabilities, but instead of saturating missile defenses with numbers, the speed and maneuverability of hypersonic weapons may make kinetic missile defenses obsolete. Directed energy and space control target the current overwhelming U.S. intelligence, surveillance, and reconnaissance (ISR) advantage. … New capability in directed energy threatens U.S. sensor capabilities with blinding or damage, and space control systems threaten U.S. satellites themselves.*[15]

To these observations can be added the potential effects of maneuverable reentry vehicles and large numbers of unmanned/AI-equipped weapons on large U.S. platforms and fixed bases key to the U.S. security posture in the Asia Pacific.

Broader Technology Plans

Chinese President and General Secretary of the CCP Xi Jinping's efforts to move China toward high-end innovation and establish the country as a global technology center, building upon and accelerating previous initiatives, are inseparable from China's push to develop advanced weapons. Many of the government plans that have funded China's defense modernization, including the advanced weapons programs discussed in this section, have spanned both military and commercial areas. For example, the High Technology Research and Development Plan (863 Plan), National Basic Research Plan (973 Plan), Medium and Long-Term Plan for the Development of Science and Technology (2006–2020) (MLP), "Made in China 2025" initiative, and various five-year plans have been instrumental for funding advances in China's computing, robotics, and biotechnology sectors.*

*"863" refers to March 1986, when then President Deng Xiaoping approved a proposal by leading scientists to fund research and development in strategic areas. "973" refers to a Plan established in March 1997 that sought to support "early-stage basic research on major scientific issues

In addition to the military benefits provided by advances in computing and robotics (discussed under "Inputs to China's Advanced Weapons," later in this section), portions of these plans have directly funded advanced weapons programs or their contributing technologies—the 863 Plan included funding for lasers, space technologies, unmanned systems, and AI;[16] the 973 Plan included funding for unmanned systems;[17] the MLP includes three secret military megaprojects that experts have suggested may be hypersonic vehicle technology, the second generation of the Beidou satellite navigation system, and a laser project for inertial confinement fusion;* Made in China 2025 guides investment in space and aviation equipment and new materials; and five-year plans have guided investment in Beidou, unmanned vehicles, space technologies, and AI, for example.[18] China's recent consolidation of its science and technology funding into five major plans continues this approach. The largest and most important of these, the 2016 National Key Research and Development Plan, supports research and development in both national security and commercial areas.[19]

China's Advanced Weapons Programs

Although information regarding China's advanced weapons programs is not always readily available in the public domain, numerous open source writings, government statements, and testing and deployment activities indicate Beijing has undertaken vigorous efforts in these areas. The following pages define each weapons type, summarize China's activities and objectives in each area, and evaluate their current status in relation to comparable U.S. programs.

Maneuverable Reentry Vehicles

Definition. A maneuverable reentry vehicle (MaRV) is a ballistic missile reentry vehicle that is capable of maneuvering after reentering Earth's atmosphere, in contrast to a standard reentry vehicle, which continues on its trajectory without any course correction capability.[20] MaRVs can be more difficult to intercept and therefore better able to penetrate adversary missile defenses.[21] They also offer greater potential than standard reentry vehicles for striking moving targets, if configured to do so.

China's Activities. China likely began preliminary research into MaRV technology in 1991 and engineering research and development (R&D) on its first ballistic missile system incorporating this technology in 2002.[22] Beijing publicly revealed two ballistic missile

related to economic and social development." The MLP seeks to promote science and technology development in areas deemed vital to competitiveness over a longer timeframe than five-year plans or the 863 and 973 plans. It includes funding for 16 "megaprojects," three of which are classified defense projects. For more information on all of these plans, see Tai Ming Cheung et al., "Chinese State Programs for Civilian and Defense Science, Technology, Energy, and Industrial Development and the Implications for the United States," *University of California Institute on Global Conflict and Cooperation* (prepared for the U.S.-China Economic and Security Review Commission), July 28, 2016, 27–37.

*This refers to attempts to use lasers to heat a target in order to achieve a nuclear fusion reaction that generates greater amounts of energy than was used to start the reaction, or "fusion ignition." U.S. efforts in this area have been ongoing since 2009 at the Department of Energy's National Ignition Facility, but these have yet to achieve ignition. The project may aid China's efforts to develop next-generation nuclear weapons and directed energy weapons. Lawrence Livermore National Laboratory, "What Is NIF?"; Lawrence Livermore National Laboratory, "Fusion and Ignition"; Michael Raska, "Scientific Innovation and China's Military Modernization," *Diplomat*, September 3, 2013.

systems that reportedly have MaRV capabilities in 2010 and 2015, respectively:

- China fielded the world's first antiship ballistic missile (ASBM) in 2010, a variant of the DF–21 family of medium-range ballistic missiles (MRBM) known as the DF–21D. It reportedly features a range of at least 1,500 kilometers (km) (932 miles [mi]) and is road mobile, meaning it can be driven by vehicle and launched from multiple locations.[23] At its maximum extent, this range would cover an area beyond the first island chain,* including large portions of the East, Philippine, and South China seas.[24]
- China unveiled the DF–26 intermediate range ballistic missile (IRBM) in 2015, reportedly also with an ASBM variant. The DF–26 has a credited range of 3,000–4,000 km (1,800–2,500 mi), and is also road mobile. At its maximum extent, this would cover U.S. military installations on Guam and most of the area within the second island chain.[25] This has prompted some analysts and netizens to refer to the missile as the "Guam Express" or "Guam Killer" (similar to the term "carrier killer" sometimes used to refer to the DF–21D).[26]

China's activities have also centered on developing the reconnaissance-strike complex necessary for these missiles to successfully strike a moving target at sea. As ASBMs require accurate "over-the-horizon" targeting support, this complex likely involves a combination of satellites and ground-based radar, possibly including microsatellites and even unmanned aerial vehicles (UAVs) for temporary augmentation.[27]

Questions regarding these ASBMs' true capabilities persist, and their combat effectiveness may never be fully certain to observers in the public domain outside of their actual employment in a conflict.[28] Seven years after the DF–21D's unveiling, neither ASBM has yet been reported to have been tested against a moving target at sea.[29] Dr. Andrew Erickson, professor of strategy at the U.S. Naval War College, testified to the Commission in 2017 that "the missiles themselves work," but "the ability of China's reconnaissance-strike complex to provide accurate targeting for its ASBMs remains unclear."[30] To successfully strike a moving target at sea, China would need to master an extremely complex process.[31] Put simply, the ship must be located, current location data must be uploaded to the reentry vehicle's sensors before firing, the vehicle must conduct a mid-course maneuver upon reentry to identify the target's signature, and then the vehicle must conduct a terminal maneuver to strike the ship before the ship has moved beyond the pre-programmed "box" within which it was originally detected to be operating. This presents several obstacles (notwithstanding any potential U.S. countermeasures):

- China probably does not yet have sufficient intelligence, surveillance, and reconnaissance (ISR) coverage, particularly at the far end of its ASBM ranges, to obtain this data in the first place.

*The first island chain refers to a line of islands running through the Kurile Islands, Japan and the Ryukyu Islands, Taiwan, the Philippines, Borneo, and Natuna Besar. The second island chain is farther east, running through the Kurile Islands, Japan, the Bonin Islands, the Mariana Islands, and the Caroline Islands. Bernard D. Cole, *The Great Wall at Sea: China's Navy in the Twenty-First Century*, Naval Institute Press, 2010, 174–176.

For this reason, it continues to launch Yaogan and Gaofen ISR satellites—as well as Beidou navigation satellites to improve missile guidance—to enable coverage of a greater area of the Pacific.[32]

- Coordination among the different service elements of the PLA involved in data fusion and command and control presents an organizational challenge. Dr. Erickson assesses that China's military reforms, aimed at making the PLA more joint and better structured to wage modern wars, will be helpful in this regard.[33] The creation of the Strategic Support Force in particular may enable better coordination of space-based functions.[34] The Force's mission is to integrate China's space, cyber, electronic warfare,[35] and signals intelligence capabilities.[36] Therefore, responsibility for the intelligence and reconnaissance functions involved in locating and tracking targets will be centralized rather than dispersed among different units.[37] Furthermore, some expert observers of the PLA have debated whether strategic level human intelligence collection capabilities have also been absorbed by the Force. The addition of these capabilities could likewise aid in focusing national-level collection assets for targeting purposes.* [38]
- The warheads and terminal guidance sensors themselves must be able to withstand the rigors of atmospheric reentry without adverse effects to their required performance.[39] Although the DF–21D reportedly includes a terminal guidance system,[40] its utility against an uncooperative target is again untested.

The performance of China's ASBMs is difficult to assess, given a decline in the availability of public Chinese technical writings, likely to conceal sensitive details.[41] However, Dr. Erickson notes that "China is constantly extending and improving its reconnaissance-strike complex. It is launching satellites at a pace that only the United States and Russia can hope to match."[42] In coming years, he assesses China is likely to achieve a robust architecture for finding carriers and large surface vessels.[43] In the nearer-term, Dr. Erickson states that placing ground-based radar on all of the Spratly and Paracel islands features China occupies in the South China Sea (one such installation is already in place on Cuarteron Reef in the Spratlys) would likely enable China to detect and target carrier strike groups across the vast majority of the South China Sea.[44]

China's Objectives. The PLA seeks the ability to hold adversaries' vessels at risk via multi-axis strikes launched from a wide range of platforms as part of its suite of A2/AD capabilities, of which ASBMs are a key component. The DF–21D in particular has been referenced as

* China's human intelligence operations were formerly managed by the Second Department (2PLA) of the PLA's General Staff Department. Following China's military reforms, some experts have assessed the Second Department is now included in the PLA's new Joint Staff Department, while others suggest it may be included in the Strategic Support Force. Peter Mattis, "China Reorients Strategic Military Intelligence," *IHS Jane's*, 2017, 3–4; John Costello, "The Strategic Support Force: Update and Overview," *China Brief*, December 21, 2016; U.S.-China Economic and Security Review Commission, *2016 Annual Report to Congress*, November 2016, 290; Zhao Lei, "New Combat Support Branch to Play Vital Role," *China Daily*, January 23, 2016; Lincoln Davidson, "China's Strategic Support Force: The New Home of the PLA's Cyber Operations," *Council on Foreign Relations*, January 20, 2016.

an "assassin's mace" weapon by China's leaders,[45] while the DF–26 is likely designed to reach Guam, viewed in PLA strategic and academic writings as an "anchor" of the United States' regional presence and its ability to surge forces into the region in a contingency.[46]

Hypersonic Weapons

Definition. Hypersonic speeds are usually defined as exceeding five times the speed of sound, or Mach 5 (3,836 mi per hour).* [47] Although ballistic missiles have long operated at these speeds, three emerging systems could be used to deliver a precision strike over long ranges at hypersonic speeds: terminally-guided ballistic missiles (including the MaRV-equipped ASBMs discussed previously), and two other systems that would utilize more advanced technologies[48] and are generally the focal point of discussions on "hypersonic weapons." These are (1) hypersonic glide vehicles (HGVs), which are launched from a large rocket on a relatively flat trajectory that either never leaves the atmosphere or reenters it quickly before being released and gliding unpowered to its target (the whole system, including the booster, is referred to as a "boost-glide weapon"); and (2) hypersonic cruise missiles, which are powered by a supersonic combustion ramjet or "scramjet" engine that activates after the missile's release from a ground, sea, or air launcher (see Figure 1).[49] The very high speeds of these two types,† combined with their potential maneuverability and ability to travel at lower, radar-evading altitudes compared to ballistic missiles, could make them far less vulnerable than existing missiles to some current missile defenses.[50]

Importantly, HGVs are a subset of MaRV technology at the high end of the maneuverability spectrum, while the MaRVs on China's ASBMs are on the low end.[51] Although both types are launched by rockets, an HGV glides to its target at shallow angles after separating from the rocket booster and covers a much greater distance, while the MaRV on an ASBM continues on a ballistic trajectory until reentry.[52] China's HGV program may be an outgrowth of its program to develop lower-end MaRVs.[53]

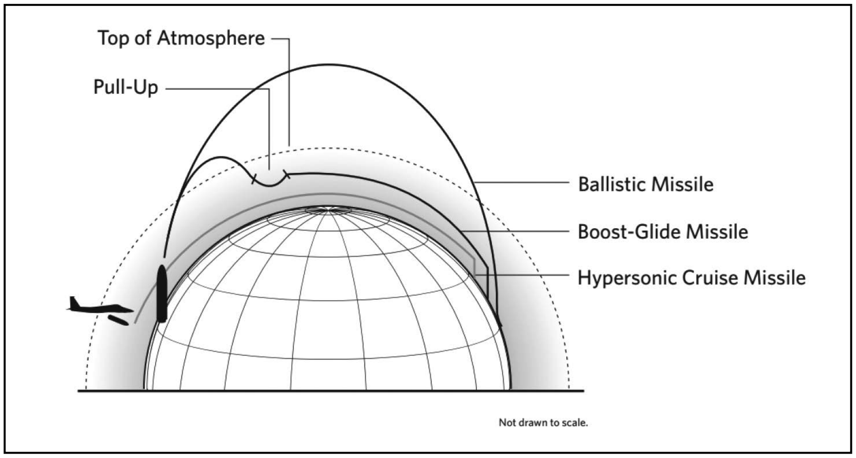
China's Activities. China has been working to develop both types of hypersonic weapons:

- *Glider.* Since 2014, China has likely conducted seven tests of its HGV, now referred to as the DF–ZF by China's news media and called the Wu–14 by U.S. officials (see Figure 2).[54] Beijing has not officially acknowledged testing an HGV, but experts have assessed that six of the seven tests may have been successful.[55]
- *Scramjet.* At a March 2017 conference on hypersonic technology hosted by the Chinese Academy of Engineering (subordinate to China's State Council), China acknowledged a 2015 scramjet engine flight test for the first time.[56] China's government previously had presented an award to a military engineer for developing and

*The speed of sound is Mach 1, and "supersonic" refers to speeds of Mach 1 to 5.

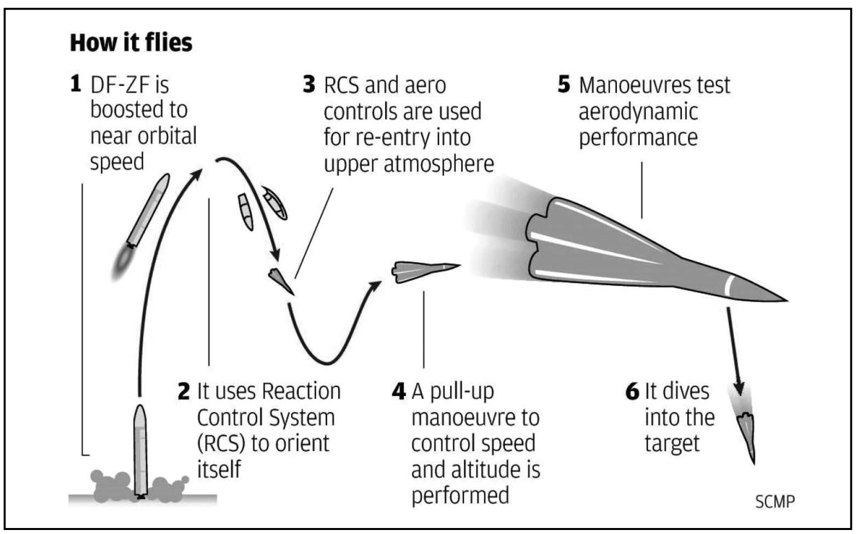
†Hypersonic glider speeds could potentially reach Mach 10 or higher, while hypersonic cruise missile speeds would almost certainly be closer to Mach 5. James Acton, Co-Director, Nuclear Policy Program, Carnegie Endowment for International Peace, interview with Commission staff, June 17, 2017.

Figure 1: Schematic Diagram of Generic Trajectories for Boost-Glide Missiles, Terminally Guided Ballistic Missiles, and Hypersonic Cruise Missiles



Source: James M. Acton, "Silver Bullet?: Asking the Right Questions About Conventional Prompt Global Strike," *Carnegie Endowment for International Peace*, 2013, 7.

Figure 2: China's DF–ZF Hypersonic Glide Vehicle



Source: Minnie Chan, "China, Russia Ramping Up Tests of Hypersonic Gliders to Counter New U.S. Strategy: Analysts," *South China Morning Post*, April 28, 2016.

testing a scramjet engine at the China Aeronautical Science and Technology Conference in 2015,[57] likely for work on the same program.[58] If true, this would make China one of five countries, along with the United States, Russia,[59] India,[60] and Australia (in conjunction with the United States)[61] to have reportedly test flown a scramjet engine. These efforts indicate China highly values the development of scramjet technology.[62] Scramjet technology would also be relevant to potential efforts by China to develop a spaceplane (discussed in "Counterspace Weapons" later in this section).

While China has moved rapidly on both fronts, its hypersonic program is still in development stages. James M. Acton, co-director of the Nuclear Policy Program at the Carnegie Endowment for International Peace, notes that "many tens" of tests of different systems with progressively longer ranges would likely be needed to develop an intercontinental range glider,[63] and numerous technical challenges would need to be overcome.* China would likely not be able to place its existing glider model, apparently tested at MRBM range,† on an intercontinental ballistic missile to achieve intercontinental range.[64] Dr. Acton also notes that "given the relatively short range of China's glider tests … it is possible, though by no means certain, that its glider is essentially a 'souped-up' version of an existing type of terminally guided reentry vehicle."[65]

Intended Capabilities. Mark Stokes, president of the Project 2049 Institute, testified to the Commission that "the primary driver for PLA investment into hypersonic weapons is to offset shortcomings in the face of a more technologically-advanced adversary equipped with missile defenses."[66] However, it remains unclear whether China ultimately intends to use hypersonic weapons for nuclear missions, conventional missions, or both. Dr. Acton testified to the Commission that there is significant uncertainty about why China is pursuing this technology, but he has no reason to doubt the assessment of the U.S. National Air and Space Intelligence Center that China's HGV is associated with its nuclear program.[67] He notes, "It is also possible that China does not currently have firm ideas about the purpose of a boost-glide system. China has a well-documented history of initiating advanced strategic military programs mainly because it worries about other states' opening up a technology gap, without necessarily being convinced [of] their ultimate military utility for China."[68]

Directed Energy Weapons

Definition. A directed energy weapon uses focused energy to damage or destroy a target.‡ Three types are most relevant:

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*For a detailed description of many of these challenges, see U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of James M. Acton, February 23, 2017.

†Chinese media sources have suggested the DF–ZF can be launched using a variety of short- and medium-range ballistic missiles as boosters. However, the type of booster China is using, and whether it is a new or existing model, is unclear. China's failed HGV test used a liquid-fueled booster—typically associated with its nuclear program—rather than one of its solid-fueled, conventionally-armed short-range ballistic missiles and MRBMs. U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of James M. Acton, February 23, 2017; U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of Mark Stokes, February 23, 2017; Erika Solem and Karen Montague, "Updated: Chinese Hypersonic Weapons Development," *China Brief* 16:7, April 21, 2016.

‡"Undirected" energy weapons, such as those that deliver an undirected electromagnetic pulse (EMP)—an intense energy field which can overload or disrupt electrical systems or microcircuits at a distance—are not discussed in this section. An EMP device could be nuclear or nonnuclear, and potentially deployed at high altitudes for wider effect. Nuclear warheads carried on ballistic missiles have an inherent EMP capability, but there have been no publicly confirmed Chinese programs for low-yield nuclear warheads or conventional high powered microwave systems tailored for this purpose. U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of Richard D. Fisher, Jr., February 23, 2017; Clay Wilson, "High Altitude Electromagnetic Pulse (HEMP) and High Power Microwave (HPM) De-

- **High energy lasers (HELs)** generate beams of electromagnetic energy to damage a target's physical structure. The amount of energy that hits the target is a function of the laser's power and ability to focus its beam, as well as atmospheric conditions and target characteristics. More power requires the HEL to be larger and heavier.* [69]
- **High-power microwave (HPM) weapons** generate short pulses of electromagnetic energy at discrete frequencies designed to disrupt, or even destroy, sensitive electronic components. The higher the energy, the greater the disruption.[70]
- **Particle beam weapons** use high-energy beams of atomic or subatomic particles to damage a target, generating additional highly-energetic particles and electro-magnetic fields inside the target; this technology is the least mature but perhaps the most destructive.[71]

A directed energy beam arrives at its target almost instantaneously, surpassing even the fastest-moving weapons currently fielded.[72] In addition, benefits envisioned include low costs per "shot," unlimited "ammunition" given power availability,[73] enhanced standoff ranges, tailorable and scalable effects, strikes with low collateral damage, and "counterswarm" abilities.† [74]

China's Activities. China's research into directed energy weapons likely dates back to at least the 1980s, when the 863 Plan included laser technology as a key investment area.[75] Chinese writings and public reports have long indicated a high level of activity in this area; the most tangible publicly observed developments have been a potential HPM antimissile system and a series of increasingly-powerful HELs.

HPM weapons. China's HPM weapons program received new public coverage in 2017, building on a deep history of research in this area. In January, the deputy director of China's Northwest Institute of Nuclear Technology received a first prize National Science and Technology Progress Award from China's State Council for his directed energy research; based on accounts of his remarks, this was related to achievements in developing an HPM antimissile system initially tested successfully in 2010.[76] The scientist, a leading figure in China's research on directed energy technologies since the 1990s, termed this a "disruptive technology" and "pioneering" achievement, as similar developments had yet to be publicly demonstrated elsewhere.[77] Based on analysis of the scientist's publication record, the system could be used as a ship-borne antimissile weapon, although

vices: Threat Assessments," *Congressional Research Service,* March 26, 2008, Summary; National Ground Intelligence Center, *China: Medical Research on Bio-Effect of Electromagnetic Pulse and High-Power Microwave Radiation*, August 17, 2005, 4–5; National Ground Intelligence Center, *Assessment of Chinese Radiofrequency Weapon Capabilities*, April 2001, 6.

*The medium used in a laser is liquid or gas in a "chemical laser" or solid crystal in a "solid state laser." Richard D. Fisher, Jr., senior fellow for Asian military affairs at the International Assessment and Strategy Center, noted to the Commission that electric-powered solid state lasers are eclipsing chemical lasers due to their greater potential for size reduction and ability to draw upon a "magazine" as long as power is available. U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of Richard D. Fisher, Jr., February 23, 2017.

†"Counterswarm" refers to these weapons' potential utility against convergent attacks by a group of units from multiple directions. Sean J. A. Edwards, "Swarming and the Future of Warfare," *RAND*, 2005, 2.

authoritative information on the program is not available.[78] Richard D. Fisher, Jr., senior fellow for Asian military affairs at the International Assessment and Strategy Center, notes that developing a system small and light enough to deploy on a ship would be a significant technological accomplishment.[79]

Examples of China's past publicly-known research on HPM weapons, dating back to the 1990s, include a 2005 article by authors from the then Weapons Equipment Academy of the PLA Second Artillery Force and the National University of Defense Technology that discussed the feasibility of using an HPM weapon to counter the seekers of antiradar missiles.[80] A declassified 2005 U.S. Army National Ground Intelligence Center report noted Chinese research into the bio-effects of HPM radiation, assessing this was to evaluate how to protect future human operators of these systems.[81] A declassified 2001 National Ground Intelligence Center report stated that China was "conducting research on high-power [radiofrequency (RF)] generation, susceptibility, and generation relevant to the development of RF weapons" and noted that China's first significant publications on HPM generation appeared in the early 1990s.[82] It identified six leading military and defense-affiliated facilities involved in directed energy research more broadly at that time.[83]

HELs. China is marketing low-power solid state laser weapons and has shown interest in using lasers on a range of platforms. China's first 10 kilowatt (kW) fiber optic laser reportedly emerged in 2013, developed by state-owned defense conglomerate China Aerospace Science and Industry Corporation.[84] State-owned Chinese defense contractor Poly Technologies has marketed a laser turret for shooting down small UAVs as a law enforcement tool since 2014, and displayed a 30 kW HEL called the Low-Altitude Laser Defending System at a 2016 military exhibit, reportedly with a 2.5 mi range and utility against swarms of small plastic UAVs.[85] Mr. Fisher told the Commission that an improved version of this system was displayed at a 2017 exhibit, and reported learning from a company official that the new laser's power was over 30 kW, but less than 100 kW.[86] He reported that officials indicated they were developing a naval version of this system, but it would be too large for an airborne version.[87] China's defense industry and private sector will certainly continue efforts to increase the power and reduce the size and weight of these early systems. China previously conducted research on antimissile-capable lasers in the 1980s and 1990s, yielding work on chemical lasers with counterspace implications (see "Counterspace Weapons," later in this section).[88]

Other efforts. Michael Carter, program manager for U.S. Department of Defense Programs at the National Ignition Facility and Photon Science Directorate, Lawrence Livermore National Laboratory (LLNL), stated in April 2017 that China is on a path to build a laser similar to the one used in LLNL's National Ignition Facility, currently the world's most "energetic,"* with 192

*"Energetic" refers to the amount of energy the laser delivers, measured in "joules" (watts multiplied by seconds).

beams and the size of three football fields.[89] LLNL's laser was constructed for the study of inertial confinement fusion;[90] China's laser could be linked to its potential megaproject for this purpose described previously. Researchers from the Chinese Academy of Sciences, working at the State Key Laboratory of High Field Laser Physics in Shanghai, reportedly demonstrated a beam that reached a peak power of 5.13 petawatts in 2015, a world record.[91] Researchers are now working on a 10-petawatt beam; although these "ultra-fast" lasers can only sustain their power for a fraction of a second and thus generate little energy,[92] this research demonstrates China's commitment to and capacity for pursuing breakthroughs in the field of directed energy.

Intended Capabilities. China's directed energy program is likely intended to negate specific U.S. strengths,[93] potentially by affecting sensors on U.S. precision strike weapons and satellites.[94] Chinese academic writings appear to show interest in using more advanced lasers on land, naval, air, and space platforms,[95] and microwave weapons on space platforms,[96] but specific information on their intended operational employment is highly limited. Potential capabilities against space platforms are discussed in "Counterspace Weapons," later in this section.

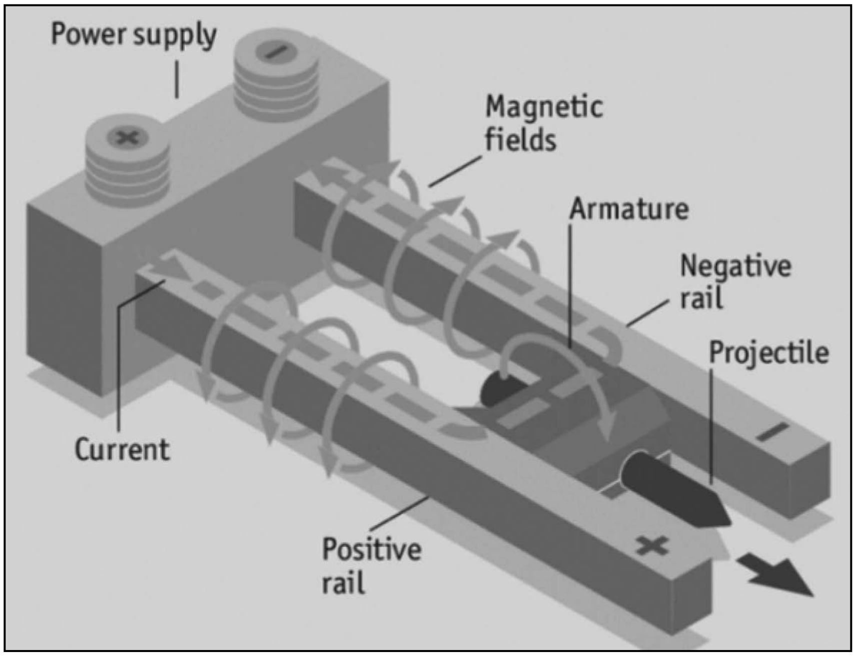
Electromagnetic Railguns

Definition. An electromagnetic railgun (EMRG) launches rounds using electromagnetic force rather than an explosive propellant.[97] The rails are a pair of parallel conductors through which an electromagnetic current, generated from an external source, is passed, firing the projectile along the rails (see Figure 3).[98] Mr. Fisher notes that railguns "offer potential advantages in numbers of 'rounds' and cost per round over missiles and other kinetic weapons, potentially transforming future battlefields."*

China's Activities. A research institute within China Aerospace Science and Industry Corporation, one of China's leading state-owned defense industry conglomerates, announced in 2015 that a project on high-powered electromagnetic launch technology had led to "major breakthroughs" in technologies for short-range air defense and projectile velocity.[99] This research institute also hosted the seventh Chinese Electromagnetic Technology Conference in 2015, where advances in material sciences to reduce railgun barrel wear were reported.[100] At least 22 research institutes in China were studying aspects of electromagnetic launch as of 2007, according to a report published that year by the Institute of Electrical and Electronics Engineers.[101] China has also reportedly built experimental railguns.[102] Research into railguns began in France in 1918 and has been ongoing in China since the 1980s; the challenge is not in building a railgun but in scaling up the technology and overcoming technical challenges.[103]

*For example, Mr. Fisher points out that "A U.S. Raytheon Standard SM–3 Block 1B missile interceptor may cost about $14 million, versus a $7 million Chinese anti-ship ballistic missile (ASBM), while a railgun hypersonic velocity projectile may only cost $50K." U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of Richard D. Fisher, Jr., February 23, 2017.

Figure 3: Electromagnetic Railgun Diagram



Source: Economist, "Rail Strike: America's Navy Wants to Arm Its Ships with Electrically Powered Superguns," May 19, 2015.

Intended Capabilities. Public writings on intended capabilities for China's railgun are scarce and do not appear to diverge from those envisioned for the United States' program.[104] China's system could be used for ship-based antisurface, shore bombardment, and antimissile operations as planned by the United States, and could also contribute to China's land-based A2/AD arsenal, for which power generation would be less of a challenge than for naval platforms.[105] Proposed applications for electromagnetic aircraft launch system technology appear to align with U.S. efforts related to its next generation of aircraft carriers.[106]

Counterspace Weapons

Definition. Counterspace threats can be divided into kinetic, non-kinetic physical, electromagnetic, and cyber categories, as Todd Harrison, director of the Aerospace Security Project at the Center for Strategic and International Studies, explained in testimony to the Commission:

- *Kinetic attacks attempt to strike a satellite directly, detonate a warhead in its vicinity, or disable critical support infrastructure on the ground. … Satellites are also vulnerable to co-orbital threats where a satellite already in orbit can be deliberately maneuvered to collide with another satellite, dock with an uncooperative satellite, or detonate a small warhead in the vicinity of a satellite.*

- *Non-kinetic physical attacks can be used to … degrade a satellite with less risk of debris and without directly touching it. Directed energy weapons, such as lasers and high-powered microwave systems, can target space systems within seconds and create effects that may not be immediately evident beyond the satellite operator.*

- *Electromagnetic attacks target the means by which data is transmitted rather than the physical satellite or ground support system. Satellites are dependent on radiofrequency communications for command and control and to transmit data to the ground. Jamming is the use of electromagnetic energy to interfere with these radio communications.*

- *Cyber attacks target the data itself and the systems that use this data.*[107]

China's Activities. China's advanced weapons discussed in this section that correspond with these threats are direct-ascent antisatellite missiles (kinetic), co-orbital systems (kinetic, non-kinetic physical, or electromagnetic), and ground-based directed energy weapons (non-kinetic physical or electromagnetic).*

Direct-ascent antisatellite missiles. China has tested two direct-ascent antisatellite missiles: rocket and missile tests of the SC–19, one of which successfully destroyed a target in low Earth orbit; and a rocket test of the larger DN–2, which reached higher orbits, where Global Positioning System (GPS) and most U.S. intelligence satellites reside. The SC–19 was responsible for China's highly publicized debris-generating antisatellite missile (ASAT) test in 2007, and was also tested in 2005, 2006, 2010, 2013, and 2014.[108] These missiles would only be able to launch on predetermined flight paths against targets passing over China.[109]

Co-orbital systems. China appears to have the technology required to build and launch small satellites for "rendezvous and proximity operations" that could be applied to counterspace missions.[110] David D. Chen, an independent analyst and expert on China's space programs, testified to the Commission that China has launched six space missions involving such operations over the past decade, as Table 1 describes in detail.[111] A space-based platform could be used to launch kinetic, non-kinetic physical, or electromagnetic attacks.

Mr. Chen specifically assesses China has the requisite expertise, doctrinal underpinnings, and research and development experience for a counterspace directed-energy weapons program, which could be used for electromagnetic attacks launched from co-orbital platforms. He cites numerous writings by Chinese military, defense industry, and university scientists on potential counterspace electronic warfare effects against U.S. satellites.[112] For example:

*For a detailed discussion of China's efforts in the area of computer network operations that could produce cyber threats to U.S. satellites, see U.S.-China Economic and Security Review Commission, *2015 Annual Report to Congress*, November 2015, 296–297.

A 2012 paper by authors from the 36th Research Institute of the China Electronic Technology Group Corporation (CETC) proposed overcoming the high power requirements for jamming U.S. millimeter wave (MMW) satellite communications by using space-based jammers hosted on small satellites, in a "David versus Goliath" attack. The authors noted that reducing that distance with a small satellite platform would decrease the power requirements exponentially, and identified potentially susceptible USG assets as the AEHF (Advanced Extremely High Frequency), WGS (Worldwide Global Satcom), and GBS (Global Broadcast Service) satellite constellations.[113]

Other writings specifically reference *Iridium* (commercial communications) and *Defense Satellite Communications System* (U.S. government communications) satellites.[114] Some Chinese academic writings also envision space-based laser weapons.[115]

Table 1: China's Space Missions Involving Rendezvous and Proximity Operations

Program	Launched	Description
Banfei Xiaoweixing-1 (BX–1)	2008	*BX–1* was deployed from the orbital module of *Shenzhou-7* and relayed images of the main vessel while flying in co-orbital formation.[116]
Shijian-12 (SJ–12)	2010	*Shijian-12* maneuvered within 27 km (18 mi) of *Shijian-6F* two months after launch, then made a series of maneuvers to within a 300-meter distance, causing a likely low-speed contact resulting in orbital perturbations observed from the ground.[117]
Shiyan-7	2013	Rendezvoused with *Chuangxin-3* and *Shijian-7*; probable deployment of robotic arm.[118]
Tianyuan-1	2016	Satellite servicing/refueling experiment that transferred 60 kilograms (132 pounds) of fuel while in orbit.[119]
Aolong-1	2016	Experimental robotic manipulator payload for orbital debris mitigation.[120]
Banfei Xiaoweixing-2 (BX–2)	2016	A second *BX* was launched from the *Tiangong-2* space station as part of the *Shenzhou-11* manned mission in October 2016.[121]
Shijian-17	2016	Suspected geosynchronous orbit belt inspection or signals intelligence satellite.[122]

Source: U.S.-China Economic and Security Review Commission, *Hearing on China's Advanced Weapons*, written testimony of David D. Chen, February 23, 2017.

Ground-based directed-energy weapons. The U.S. Department of Defense reported in 2006 that China was pursuing "at least one … ground-based laser designed to damage or blind imaging satellites."[123] China also tested a laser against a U.S. ISR satellite in 2006, temporarily degrading its functionality; it is unclear whether this was intended to determine the satellite's location or to test China's ability to "dazzle" it, or temporarily blind its sensors.[124] These capabilities are likely a product of China's chemical laser development efforts dating back to the 1980s; China almost certainly has been working to develop more powerful lasers since this time.[125] Lasers can blind or damage a satellite's optical sensors at low energies, and can cause physical damage to satellites at high energies.[126]

In addition, since the mid-2000s China has acquired a number of foreign and indigenous ground-based satellite jammers,* designed to disrupt an adversary's communications with a satellite by overpowering the signals being sent to or from it. These could be employed to degrade or deny U.S. military systems' access to GPS and most satellite communications bands if they are operating within a few hundred kilometers of China.[127]

Spaceplane. Chinese media reports in 2016 indicated that state-owned defense conglomerate China Aerospace Science and Technology Corporation had begun advanced research on a spaceplane that could fly from the ground directly into orbit utilizing hypersonic technology.[128] Chinese military scientists have stated that China aims to master the relevant technologies over the next three to five years, test a propulsion system in 2025, and use the system to power a spaceplane that would enter service by 2030.† China reportedly plans to test a prototype propulsion system in late 2017.[129] In theory, such a craft could fly in near space (roughly 12 to 60 mi in altitude), circumnavigate the globe in a matter of hours out of the reach of traditional air defenses,[130] and potentially threaten U.S. space assets. These efforts have not been confirmed by official U.S. government sources, and achieving these technologies within this timeframe would likely be a significant challenge.[131]

Other plans. As the Commission reported in 2015, China plans to launch a permanent manned space station in several phases comprising an experimental "core module" in 2018 and two additional modules in 2020 and 2022.[132] This station could have dual use applications; China's Tiangong-2 spacelab was used to launch a satellite for a rendezvous and proximity operation in 2016, and China reportedly plans to orbit a space telescope alongside its space station in the 2020s,[133] the first time a space station will have been used as a support base for a satellite.[134] Chinese researchers, including the head of the China Manned Space Agency (a military organization responsible for managing China's

* China purchased ultra high frequency-band satellite communications jammers from Ukraine in the late 1990s. U.S. Department of Defense, *Annual Report to Congress: Military Power of the People's Republic of China 2007*, 2007, 21.

† Chinese engineers have suggested the scramjet engine would be the second of three used to power the envisioned spaceplane: a booster to leave the ground, the scramjet for hypersonic flight in near space, and a rocket to enter orbit. Jeffrey Lin and P.W. Singer, "China's Hybrid Spaceplane Could Reset the 21st Century Space Race," *Popular Science*, August 9, 2016.

manned space program[135]), have also written on the military use of space stations.[136] Some non-authoritative Chinese writings have discussed building a moon base with military capabilities, but Kevin Pollpeter, research scientist at CNA and an expert on China's space program, testified to the Commission that these should not yet be taken seriously.[137]

Intended Capabilities. As the Commission assessed in its *2015 Annual Report to Congress*, PLA doctrinal publications and military writings on space warfare and China's demonstrated and developmental counterspace capabilities indicate these are primarily designed to deter U.S. strikes against China's space assets, deny space superiority to the United States, and attack U.S. satellites.[138] The U.S. Director of National Intelligence stated in the May 2017 *Statement for the Record on the Worldwide Threat Assessment of the U.S. Intelligence Community:*

> *We assess that Russia and China perceive a need to offset any U.S. 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. Both will continue to pursue a full range of antisatellite weapons as a means to reduce U.S. military effectiveness.*[139]

Authoritative Chinese documents specifically indicate Beijing believes space superiority would be critical to almost every component of its military operations (particularly long-range precision strikes) during a potential Taiwan Strait conflict and against the United States and other potential adversaries in the region.[140] Experts also testified to the Commission in 2017 that Chinese military strategy emphasizes battlefield control in a multi-dimensional space (land, sea, air, space, and cyber),[141] and that counterspace operations are envisioned to "open up a window of opportunity" for potentially debilitating follow-on strikes in other dimensions.[142] Mr. Pollpeter noted to the Commission that counterspace capabilities are one component of the PLA's goal to achieve space superiority; another being an "operationally responsive space force" featuring road-mobile launch systems and a robust system of space-based remote sensing satellites.[143]

Within this context, Chinese writings discuss concentrating forces to attack certain types of space assets, rather than attacking all types.[144] Mr. Chen assesses that counterspace cyber and electronic warfare operations "should be considered as one tool in the quiver of a 'combined arms' counterspace campaign," and that "degradation, denial, and deception" effects are viewed as being as valuable as damage and destruction.[145] Ultimately, assessments by Chinese military writers view speed, within the multi-dimensional battlespace, as the key contribution of advanced weapons. For example, one recent PLA journal article suggests China can defeat the United States' "network-centric warfare" with "energy-centric warfare"—applying effects quickly to "get inside" the adversary's "OODA (Observe, Orient, Decide, Act) loop"—utilizing the near-instantaneous speed of systems such as directed energy weapons.[146]

Unmanned and AI-Equipped Weapons

Definition. Unmanned aerial, underwater, surface, or ground vehicles operate without an internal pilot. They can be remotely piloted or automated, which refers to systems governed by prescriptive rules that do not allow for deviations, or autonomous, meaning they are delegated the ability to independently compose and choose between different courses of action.[147] AI refers to the ability of computer systems to perform tasks normally requiring human intelligence, including learning and self-correction,[148] and is foundational to autonomous systems.[149]

China's Activities. China has made significant progress in developing and deploying automated unmanned systems, and has displayed strong interest and capabilities in developing autonomous programs.

Automated systems. China has developed unmanned aerial and underwater vehicles, and conducted research on unmanned ground and surface vehicles:

- China's **UAVs**, including attack variants, have met military requirements and entered the global market in great numbers. Chinese experts assess Chinese UAVs still lag behind their U.S. counterparts in areas such as engines, data links, and sensors.[150] However, as Elsa Kania, analyst at the Long Term Strategy Group, noted to the Commission, China's defense industry is developing a range of "cutting-edge" systems, including "high-altitude long-endurance UAVs that variously have stealth or anti-stealth, supersonic, and precision strike capabilities."[151] A high proportion consists of smaller, tactical models, but the PLA Air Force and PLA Navy have begun to introduce more advanced, multi-mission UAVs.[152] Recently-developed tactical models include a group of electronic warfare-equipped UAVs displayed at a military parade in June 2017 that could "paralyze and suppress" opposing early warning and command communication systems, according to state media.[153] U.S. observers also noted 2017 reports that China is developing a "sea-skimming" antiship UAV that could cruise below radar coverage at an altitude of 1 to 6 meters, potentially shortening a target vessel's detection and response times.[154]

- China has worked to develop **unmanned underwater vehicles (UUVs)** since the 1980s, and one series of UUVs is reportedly in service with the PLA Navy.[155] Researchers at U.S. company Defense Group, Inc. (DGI), which published a contracted report for the Commission on China's Industrial and Military Robotics Development in 2016, described China's progress on UUVs as "drastic" and enabling its systems to "travel farther and deeper, and perform more complex tasks and missions."[156] Chinese UUVs carried out mineral exploration missions in the southwest Indian Ocean in 2016.[157] In July 2017, Chinese media reported the maiden voyage of a

UUV able to stay underwater for 20 hours, as well as scientific observations by 12 UUVs in the South China Sea, terming this "the largest group of gliders to perform simultaneous observations in the region."[158]

- The PLA Navy is exploring options for **unmanned surface vehicles (USVs),**[159] and some Chinese research institutes have made progress on these systems. However, DGI's 2016 report assessed that Chinese military strategists appear to be minimally interested in USVs, potentially because China's maritime militia can already be mobilized for a variety of missions to support the PLA Navy.[160]

- The PLA Army has begun experimentation to a limited extent on **unmanned ground vehicles (UGVs)**,[161] and they are a priority in China's defense plans. Numerous civilian and military research institutes, universities, and companies are involved, with high levels of government funding support. Nevertheless, their deployment appears to be limited at this time.[162]

Autonomous systems. AI research receives top-level leadership support and funding in China, as discussed in Chapter 4, Section 1, "China's Pursuit of Dominance in Computing, Robotics, and Biotechnology." While China's broad-based progress across military and civilian sectors is more readily identifiable than tangible individual military efforts at this time, the following activities can be observed:

- **Cruise missiles:** A Chinese media report noted in 2016 that China is developing a family of cruise missiles with "a very high level of artificial intelligence and automation" that "will allow commanders to control them in real time manner, or to use a fire-and-forget mode, or even to add more tasks to in-flight missiles," quoting a defense industry official.[163] The terminology used was ambiguous and shed little light on intended capabilities.[164]

- **Swarming UAVs:** China demonstrated a record-breaking formation of 1,000 rotary-wing UAVs at the Guangzhou Airshow in February 2017, using pre-programmed routes.* Chinese military experts noted this technique could be used to create a distributed armed system.[165] Leading state-owned defense industry conglomerate China Electronics Technology Group Corporation reportedly operated a formation of 119 fixed-wing UAVs (using small, inexpensive commercial drones) in June 2017, also a record.[166] A previous formation of 67 UAVs in 2016 reportedly demonstrated autonomous swarm control.[167]

*The previous record for a demonstration of this type was 500 UAVs launched by Intel in November 2016. Echo Huang, "Watch a Record-Setting 1,000 Drones Take to the Sky in China to Celebrate the Lantern Festival," *Quartz*, February 13, 2017; Keely Lockhart, "China Launches 1,000 Illuminated Drones into Night Sky in Record-Breaking Display, *Telegraph*, February 13, 2017.

- **Autonomous UUVs:** Autonomous UUVs appear to be a priority for the PLA Navy, with multiple research institutes and designated key laboratories conducting research in this area. Universities have developed a "robofish" prototype (a UUV with bio-inspired movements) and tested an autonomous unmanned underwater glider.[168]

- **Autonomous USVs:** The Underwater Engineering Research Institute at Shanghai University has tested multiple versions of the "intelligent" *Jinghai* USV, a project begun in 2010.[169] The vehicle can reportedly navigate and avoid obstacles autonomously, and has been evaluated by the PLA's former General Armaments Department and the PLA Navy Equipment Department, potentially indicating intentions to acquire the system.[170]

Intended Capabilities. China's automated UAVs have been incorporated into all four PLA services—the PLA Army, Navy, Air Force, and Rocket Force (former Second Artillery Force)—and likely the Strategic Support Force in limited numbers. These systems are expected to contribute to China's A2/AD capabilities. The PLA views these vehicles—as well as eventual "intelligentized systems"—as force multipliers for its military power in the long term. In the near term, Ms. Kania assesses that probable missions will include "[ISR]; integrated reconnaissance and strike; information operations, especially electronic warfare; data relay, including communications relay and guidance for missiles engaged in over-the-horizon targeting; and military operations other than war, such as counterterrorism and border defense."[171]

Much of China's academic literature on military AI has been abstract and speculative, and most of it deals with U.S. activities.[172] However, it is clear that PLA strategists expect autonomy to have a dramatic impact on traditional operational models. Ms. Kania assesses the PLA's focus on swarm warfare involving "intelligentized" systems indicates a recognition that these tactics will likely be useful for saturating and overwhelming the defenses of high-value weapons platforms such as aircraft carriers.[173] According to a July 2017 state-run media report, China's developmental autonomous UUV could eventually lead to a new generation of PLA Navy patrol vessels equipped to guard ships or drilling platforms in the South China Sea.[174] Looking to the far future, Chinese writings have recently discussed the concept of a "battlefield singularity," in which command and control would itself become intelligentized should machines surpass humans in battlefield decision making and planning.[175]

Table 2: Comparison with Publicly-Reported U.S. Advanced Weapons Programs

Category	U.S. Activities
MaRVs	The United States destroyed all of its ground-based missiles ranging between 500 and 5,500 km (310 and 3,418 mi), including the MaRV-equipped Pershing-II, when it became a signatory to the Intermediate Range Nuclear Forces (INF) Treaty in 1983.* U.S. programs to develop MaRVs in the 1960s and 1970s contributed to its later efforts to develop hypersonic weapons,[176] but it has not developed more advanced MaRV-equipped antiship ballistic missiles since this time, as China has.
Hypersonic Weapons	U.S. hypersonic weapons development efforts appear to be significantly more advanced than China's. Dr. Acton notes that the United States has been investigating these technologies since the 1950s and has a sizeable lead in testing.[177] For example, U.S. HGV tests have been conducted at significantly greater ranges and generally involved much greater cross-range maneuvering.[178] The U.S. Army's Advanced Hypersonic Weapon was tested across 3,800 km (2,361 mi) in 2011 and was due for testing across 6,000 km (3,728 mi) before controllers aborted the test due to booster issues,[179] while China appears to have tested at no farther than 2,100 km (1,305 mi).[180] The United States also conducted its first successful scramjet flight test in 2004.† [181] The swift progress made by China and other countries, however, has prompted recent warnings from observers including the National Academies of Sciences, Engineering, and Medicine that the United States could lose its lead.[182]
Directed Energy Weapons	The United States has a longstanding lead in pursuing directed energy weapons. However, as U.S. Chief of Naval Operations Admiral John Richardson argued at the 2017 Directed Energy Summit in Washington, DC, the United States is in a "true competition" with China, and its past non-competitive mindset has resulted in a "closer score" than expected in pursuing directed energy technologies.[183] U.S. officials have recently opted not to discuss U.S. directed energy programs publicly, citing the newly-recognized reality of U.S.-China competition and revelations about what competitors such as China were learning from these discussions.[184]

*Signed by the United States and Soviet Union in 1987, the INF Treaty required "destruction of both parties' ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 km (310 and 3,418 mi), along with their launchers and associated support structures and support equipment," altogether eliminating 846 U.S. and 1,846 Soviet missiles. Although titled a "Nuclear Forces" Treaty, INF's prohibition of conventional systems, including MaRV-equipped systems, is more relevant to the current discussion. China, not a signatory to the agreement, has exploited the restrictions placed on the United States and Russia by the INF to develop an asymmetric advantage, building a vast arsenal of ground-launched conventional intermediate-range ballistic and cruise missiles in recent years. Amy F. Woolf, "Russian Compliance with the Intermediate Range Forces (INF) Treaty," *Congressional Research Service*, June 2, 2015, 8; U.S. Department of State, *Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Elimination of their Intermediate-Range and Shorter-Range Missiles (INF Treaty)*, December 8, 1987.

†The U.S. defense-wide Conventional Prompt Global Strike program currently funds three programs for HGVs and related technologies: the U.S. Army's Advanced Hypersonic Weapon, the DARPA/U.S. Air Force Hypersonic Test Vehicle (HTV–2), and the U.S. Air Force's Conventional Strike Missile. The U.S. Air Force is also developing scramjet technologies in collaboration with DARPA, the National Air and Space Administration (NASA), and the U.S. Navy, and tested a scramjet vehicle four times from 2010 to 2013 (this was the X–51A "Waverider" program, which has ended but will inform further programs). NASA previously conducted three scramjet tests from 2001 to 2004 as part of the X–43A "Hyper-X" program. These technologies are still in early development stages. U.S.-China Economic and Security Review Commission, *Hearing on Chi-*

Table 2: Comparison with Publicly-Reported U.S. Advanced Weapons Programs—*Continued*

Category	U.S. Activities
Directed Energy Weapons—*Continued*	Several notable examples of U.S. programs have been publicly discussed. In 2016 the U.S. Navy announced plans to test a 150 kW ship-based laser "in the near future."* The U.S. Air Force is reportedly moving toward a proof of concept HEL based on a helicopter gunship;[185] it also plans to test a 50 kW laser on a transonic and supersonic platform in the next four years, and a 150 kW laser on these platforms in the 2021 to 2025 range.[186] The U.S. Army and U.S. Special Operations Command, in conjunction with Raytheon, conducted a feasibility test in June 2017 in which a helicopter-based HEL "acquired and hit an unmanned target."[187] The U.S. Missile Defense Agency plans to test demonstrators of unmanned aerial vehicles equipped with low-powered lasers by 2021, which could eventually lead to higher-powered lasers for boost-phase ballistic missile defense.[188] After 50 years of U.S. military research on HPM weapons that had apparently reached a dead end, according to Ms. Kania, the United States successfully tested an HPM system on a missile under the U.S. Air Force Research Laboratory-led Counter-electronics High-Powered Microwave Advanced Missile Project (CHAMP).[189] Experts have assessed that the United States could likely field short-range air defense laser systems by the end of 2017 if desired,[190] and is prepared to produce counter-unmanned aerial systems for warfighters (i.e., to shoot down quadcopters, not drones).[191] The United States nonetheless faces inherent technical challenges to making directed energy a reliable weapon capability. Dr. Grayson notes that "power scaling, size reduction and packaging, system reliability, and overall cost still remain large questions for the U.S. as well as China."[192]
Electromagnetic Railguns	Railgun research has been primarily dominated by the United States in the past, although the level of power required and the rapid destruction of the rails with repeated use have been persistent obstacles.[193] A March 2017 Congressional Research Service report notes, "In January 2015, it was reported that the [U.S.] Navy is projecting that EMRG could become operational on a Navy ship between 2020 and 2025. In April 2015, it was reported that the Navy is considering installing an EMRG on a Zumwalt (DDG–1000) class destroyer by the mid-2020s."[194]

na's Advanced Weapons, written testimony of James M. Acton, February 23, 2017; Amy F. Woolf, "Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues," *Congressional Research Service*, February 3, 2017, 16, 38–39; Erika Solem and Karen Montague, "Updated: Chinese Hypersonic Weapons Development," *China Brief* 16:7, April 21, 2016; James M. Acton, "Silver Bullet?: Asking the Right Questions About Conventional Prompt Global Strike," *Carnegie Endowment for International Peace*, 2013, 56.

*The U.S. Navy already has an operational 30 kW laser weapon mounted on a ship, the *USS Ponce*, called the "Laser Weapon System" or "LaWS." According to a 2016 Center for Strategic and Budgetary Assessments report, the 150–300 kW range is a "breakpoint for laser weapons," allowing multiple new uses. Mark Gunzinger and Bryan Clark, "Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses," *Center for Strategic and Budgetary Assessments*, 2016, 42.

Table 2: Comparison with Publicly-Reported U.S. Advanced Weapons Programs—*Continued*

Category	U.S. Activities
Counterspace Weapons	The United States most recently demonstrated a direct-ascent antisatellite missile capability when it shot down a crippled and toxic-fueled satellite in low Earth orbit in 2008,[195] and the new SM–3 Block IIA interceptors of the Aegis ballistic missile defense system, first tested in February 2017, could potentially reach nearly all satellites in low Earth orbit.[196] China, however, has conducted a rocket test that indicates it is developing an ASAT capability to target satellites in medium Earth orbit, highly elliptical Earth orbit, and geosynchronous Earth orbit; in addition to successfully destroying a target in low Earth orbit in 2007.[197] The United States has not deployed weapons in space, and is a signatory to the Outer Space Treaty, which bans nuclear weapons in space.* (China, also a signatory, is not known to have yet deployed weapons on space-based platforms either.) In the area of rapid launch, DARPA announced in May that it had selected Boeing to design its Experimental Spaceplane, or XS–1, and stated it plans to test a technology demonstration vehicle in 2019 and conduct 12–15 flight tests in 2020.[198] If achieved, this would dramatically assist U.S. rapid launch capabilities, potentially lower U.S. launch costs by a factor of ten,[199] and likely outpace China's spaceplane efforts. Since 2010, the U.S. Air Force also has been testing the X–37B Orbital Test Vehicle, an experimental test program intended to "demonstrate technologies for a reliable, reusable, unmanned space test platform."[200]
Unmanned and AI-Equipped Weapons	Despite significant progress, China lags behind the United States in unmanned vehicles in key areas such as engines, data links, and sensors. China's intensifying focus on "intelligentized" systems indicate it may be less inclined to invest in satellite links for its automated unmanned systems, and instead focus on moving more rapidly toward autonomy.[201] The U.S. long-range antiship missile under development already incorporates semiautonomous capabilities,[202] outpacing China's efforts to introduce autonomy into cruise missiles. The U.S. Department of Defense demonstrated a swarm of 103 fixed-wing micro-drones in 2016.[203] Chinese military authors have also published few opinions on the ethical dimensions of unmanned and lethal autonomous weapons systems (systems able to independently decide to use lethal force),[204] whereas the United States has seen robust debate on this issue[205] and the U.S. Department of Defense issued a directive banning fully autonomous lethal systems for a ten-year period (absent a high-level waiver) in 2012.[206]

*Among other provisions, parties to the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, signed in 1967, agreed not to deploy weapons of mass destruction in space and to limit the use of the moon and other celestial bodies to peaceful purposes, forgoing the installation of bases and weapons. U.S. Department of State, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*.

Inputs to China's Advanced Weapons Programs

The factors that enable a given high-technology weapons program can be divided into three categories, as Dr. Grayson suggested in testimony to the Commission. These are (1) fundamental scientific knowledge; (2) critical components or materials the weapons might require, including information technology capabilities; and (3) abstract skill-based "enablers" such as advanced manufacturing techniques, modeling and simulation abilities, and testing techniques and facilities.[207] The following pages assess China's capacity in each category.

Scientific Knowledge

China is able to access scientific knowledge that contributes to its development of advanced weapons through publicly available information and its strong efforts to cultivate human talent. For example, unclassified Chinese writings on hypersonic gliders draw heavily on unclassified U.S. literature on the subject,[208] and China has built upon data and lessons learned from the U.S. hypersonic program.[209] The fundamental physics behind directed energy weapons is well-known and available in public academic publications.[210] China's early research into electromagnetic launch was reportedly inspired by exchanges with U.S. academic counterparts, and China has participated heavily in international symposia in this field.[211] Mr. Chen notes that Chinese writings indicate China's space system researchers already possess foundational knowledge that could be used for a cyber-electronic warfare counterspace R&D program;[212] jamming technology in particular is commercially available and relatively inexpensive.[213] Most notably, China is actively acquiring and investing in foreign AI companies, particularly in Europe, guided by national plans.[214] China is also often able to bypass U.S. International Trafficking in Arms Regulations (ITAR) by relying on domestic expertise or importing needed technologies from other foreign sources.[215]

China's efforts to develop and recruit technical talent have also positioned it to take advantage of the wealth of public knowledge on these systems. China has taken a well-publicized worldwide lead in recent STEM (science, technology, engineering and mathematics) graduates,[216] and also benefits from opportunities to develop and recruit talent from overseas. One survey estimated that over 15 percent of the graduate degrees granted in the United States in physics since 1990 have gone to Chinese citizens, for example,[217] and Beijing has policies such as the Thousand Talents Program* in place to incentivize these students to return to China. Martin Seifert, former chief executive officer of U.S. laser company Nufern, noted in public statements at the 2017 Directed Energy Summit that this program, which receives significant funding from China's defense industry, had succeeded in luring Nufern employees to China.[218] Mr. Seifert

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*China's "Thousand Talents" or "Recruitment of Global Experts" Plan, initiated in 2008, is a government effort to recruit "strategic scientists or leading talents who can make breakthroughs in key technologies or can enhance China's high-tech industries and emerging disciplines" to work at key academic institutions, scientific institutions, and state-owned enterprises in China. It includes incentives targeted at both non-Chinese citizens working outside China and Chinese citizens who have traveled abroad to study. Recruitment Program of Global Experts, *The Thousand Talents Plan*. *http://www.1000plan.org/en/plan.html*.

noted in particular the draw of China's nonmilitary demand for industrial lasers as a global manufacturing power; possibly as many as one million industrial lasers are in use in China every day, operating at low power levels around 10 kW,[219] and China accounted for 17.7 percent of the global industrial laser market in 2016.[220] This commercial demand contributes to a wider base of knowledge and talent in China, which can then be applied to military programs. As of mid-2014, the Thousand Talents Program had reportedly recruited over 4,000 returnees since the program's inception in 2008.[221]

Materials and Components

China does not lack the critical materials and components necessary to construct the six types of advanced weapons examined in this section, relative to the United States. In fact, China dominates in access to some key materials: 90 percent of the global mining and refining of neodymium, a rare earth element that enables solid state lasers, is conducted in China, for example.[222] In addition, China's advances in computing and robotics serve as critical components for next frontier weapons.* U.S. Defense Secretary James Mattis emphasized these developments and the increasing role of the commercial sector in testimony to the Senate Armed Services Committee in June 2017:

> *Rapid technological change includes developments in advanced computing, big data analytics, artificial intelligence, autonomy, robotics, miniaturization, additive manufacturing, meta-materials, directed energy, and hypersonics—the very technologies that ensure we will be able to fight and win the wars of the future. … The fact that many of these technological developments will come from the commercial sector means that state competitors and non-state actors will also have access to them, a fact that will continue to erode the conventional overmatch our nation has grown so accustomed to.*[223]

Specifically, semiconductors are key to intelligent weapons systems; supercomputing is crucial for weapons design and testing (Dr. Acton specifically notes its importance for HGV design[224]); industrial robotics enhances the quality and efficiency of manufacturing; and national champions† in the commercial robotics and AI sectors are well positioned to provide next frontier military applications.

Skills and Techniques

Dr. Grayson assesses skill-based enablers to be the most important factor in developing advanced weapons. He notes that while these can only be obtained through trial and error, they can be achieved with sufficient time and funding.[225] In this area, China lags behind the United States for each advanced weapons type (except antiship ballistic missiles) because it has spent less time on

*See Chapter 4, Section 1, "China's Pursuit of Dominance in Computing, Robotics, and Biotechnology," of this Report.

†National champions are domestic firms leading in their industry—based on market share, volume of sales, and size—that enjoy strong political and financial support from the Chinese government. For more discussion of China's national champions in the high-tech industry, see Chapter 4, Section 1, "China's Pursuit of Dominance in Computing, Robotics, and Biotechnology," of this Report.

their development, as presented in Table 2. However, China appears to have the long-term plans, consistent funding, and human talent in place to eventually develop capable advanced weapons.[226] Dr. Grayson states, "There are no serious fundamental barriers to China eventually obtaining an effective directed energy weapon system. … the only fundamental barrier to learning these abstract elements and achieving a practical weapon capability is effort—time, will, and money."[227] Dr. Acton similarly notes that sufficient time and resources should enable China to overcome challenges to developing a long-range hypersonic glider, although the process is "unlikely to be quick or painless."[228] Should the United States falter in its own efforts, this indicates China is well prepared to close the gap further than it already has.

Nevertheless, China has shown limitations to its innovation capacity. In a 2016 report prepared for the Commission, the University of California Institute on Global Conflict and Cooperation found that China's massive state expenditures on science and technology through state-run plans have yielded results, but a small overall return on investment.[229] Recent research by the Center for Strategic and International Studies describes China as a "fat tech dragon"—a country that invests a great deal of resources but does not translate these efficiently into commercially successful outputs, based on innovation indices.*[230] Dissatisfied with duplication, waste, and insufficient original innovation in its science and technology system, China's leadership has recently sought to consolidate its plans and prioritize advancement to higher-end innovation.[231] While China's defense science and technology plans have been more successful in generating innovative outputs than those in the civilian sector,[232] China has often relied on foreign technology to boost its advanced weapons programs. China may have incorporated technologies from the U.S. Pershing II MRBM into its ASBMs,[233] and its HGV may be an enhanced version of a MaRV developed for an existing ballistic missile, for example.[234] According to Ms. Kania, China's UAVs appear similar to U.S. models, which could indicate mimicry or commercial cyber espionage in some cases.[235] Mr. Harrison explained that there is a large "second mover advantage in defense,"[236] meaning China can gain ground by absorbing key foreign technologies and skipping various phases of development.[237] In some cases, it may be more readily able to make transitions: from manned to unmanned systems[238] or from long-range automated UAVs to autonomous technologies,[239] for example.

These shortcomings may render China's development of innovative advanced weapons more costly or protracted, but do not rule out successful innovation. Indeed, the possibility of China achieving breakthroughs at the global frontier appears to be increasing. Dr. Grayson suggests China may be moving from a phase of "catching up" to one of pursuing "leap-ahead advanced technologies."[240] Ms. Kania states that "China's capability to pursue independent inno-

*The report specifically points to skyrocketing R&D expenditures and intensity (inputs), but continued low intellectual property values and small shares of manufacturing value added (and high-tech value added in particular) relative to GDP (outputs). For the full report, the first in a series examining innovation policies in China, see Scott Kennedy, *The Fat Tech Dragon: Baseline Trends in China's Innovation Drive*, Center for Strategic and International Studies, Washington, DC, May 25, 2017.

vation has increased considerably," citing "cutting-edge advances in emerging technologies, including artificial intelligence, high-performance computing, and quantum information science."[241] Mr. Pollpeter assesses that "there are fewer and fewer barriers for China to innovate or to develop advanced technologies. … They are maybe reaching a threshold where they may be relying less on foreign technology and doing their own innovative research."[242] He cites other space technologies such as quantum communications, pulsar navigation satellites, and an electromagnetic drive, not previously developed, which China has reportedly been testing.[243]

Implications for the United States

Direct Military Implications

China's objectives for its advanced weapons programs, if realized, could have disruptive military effects and necessitate altering U.S. strategic calculations in the Asia Pacific.[244]

Maneuverable reentry vehicles, a key component of China's larger counterintervention effort,[245] have already raised questions regarding whether U.S. surface ships would need to avoid venturing into the "range ring" of China's ASBMs in a contingency.[246] If China succeeds in building a system capable of successfully targeting moving aircraft carriers—which may never be fully known by public observers outside of actual combat—U.S. defensive options will be expensive and attempts to strike before launch highly escalatory. Ultimately, by compounding existing A2/AD challenges, these and other advanced weapons could delay or significantly increase the costs of a U.S. intervention in a regional contingency.[247]

The United States has been investing in responses to these weapons since at least 2004, although the competition between defensive and offensive measures will likely be an ongoing one. China's development of the reconnaissance-strike complex to target these ASBMs will be expensive and increase its reliance on space-based assets, while the missiles themselves will be reliant on satellite data links, making them vulnerable to electronic warfare countermeasures such as jamming.[248]

Hypersonic weapons could, in the medium term, confer maneuverability upgrades relative to China's existing ballistic and cruise missile arsenal, and speed upgrades relative to its existing cruise missiles. In the long run, they could also enable increases in range.[249] According to a 2016 report by the National Academies of Sciences, Engineering, and Medicine commissioned by the U.S. Air Force, high-speed, maneuvering weapons "could hold at risk the fundamental U.S. construct of global reach and presence" (which depends on forward deployment) based on the difficulty of defending against these systems' combination of speed and maneuverability and their operation below a ballistic missile trajectory but above typical cruise missile operating altitudes.[250] The report argues that there is no established architecture for defending against these weapons, as exists for ballistic missile defense.[251] The weapons' level of maneuverability—in particular, whether it is capable of evading interceptors—will be a critical factor in its ability to penetrate defenses. Dr. Acton testified to the Commission that hypersonic weapons would likely be specifically useful for penetrating "area" defenses (which aim to defend large amounts of territory) rather than "point" defenses (which aim to defend small targets)—after adaptation, point defenses may actually perform better against gliders and hypersonic cruise missiles than against China's existing ballistic missiles. This means that conventionally armed hypersonic weapons at regional ranges probably would not significantly alter the threat U.S. forces already face in the Western Pacific. Nuclear-armed gliders would preserve the status quo, as China's nuclear arsenal can already inflict damage on the United States, meaning that conventionally armed intercontinental range gliders would present the most disruptive threat. If a conventionally-armed glider or hypersonic cruise missile with a regional range was capable of sufficiently rapid terminal maneuvering to evade point defenses, however, it could be a "game changer," in his view.[252] Lastly, the possibility of nuclear or conventional capability could complicate U.S. determination of China's strategic intent for hypersonic weapons, particularly for an HGV launched on a ballistic missile.[253]

Directed energy weapons such as HEL and HPM systems could give China a breakthrough capability to target U.S. platforms and enhance China's A2/AD capabilities. They could also undermine future U.S. military concepts such as reliance on distributed, low-cost platforms to assure access to contested environments, a threat China could not efficiently counter with more expensive traditional missiles. In addition, as the United States does not utilize conventional ballistic missiles as offensive weapons, China's directed energy program has a much easier goal: damaging a seeker on a guided U.S. precision strike weapon or a satellite sensor as opposed to burning a hole through a ballistic missile body, meaning China could do more with less power. These development efforts are high-risk and extremely uncertain, however, underscoring the importance of understanding China's technological capabilities in this area.[254]

Electromagnetic railguns could provide China with higher numbers of rounds and significantly lower costs per round relative to its existing missile arsenal.[255] This could enhance China's A2/AD capabilities,[256] specifically providing a cheaper alternative to counter U.S. attempts to assure access in contested environments through distributed, low-cost platforms (as in the case of directed energy weapons[257]).

Counterspace weapons could be used to deny key space-based C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) and navigation systems to the U.S. military in a contingency. Combined with attacks against non-space-based nodes, this could complicate the United States' ability to flow forces into the region and conduct operations effectively. These weapons could also increase the PLA's effectiveness against less capable militaries.[258] China has tested capabilities that could threaten U.S. satellites in nearly all orbits,[259] and satellites are highly vulnerable to directed energy effects due to their sensitive electronics and low tolerance for sub-system failure.[260] Mr. Chen advised the Commission that the United States should specifically watch for the development and deployment of a co-orbital system able to deliver electronic warfare attacks.[261] As China's technologies mature these threats will continue to increase.

In addition, China's non-kinetic and electromagnetic counterspace weapons could enable less-escalatory "gray zone" attacks on satellites to test U.S. responses, prepare the battlefield by degrading key capabilities, or deter further U.S. involvement. Whether the public would be aware of such attacks, whether they could be attributed in a timely manner (if a jammer in a third country were used, for example), and what would be a proportionate response are unclear, meaning traditional methods of deterrence may be less effective against these threats.[262]

Given these threats, continued U.S. investments in hardened and distributed satellites as well as launch systems that can rapidly replace satellites take on additional importance.[263] The United States currently has the opportunity to implement more resilient new architectures as it begins follow-on programs for communication and missile warning satellites; more than 90 percent of the current military satellite communications bandwidth is not equipped with techniques to protect against jamming that are incorporated into "protected" communications satellites.[264] Importantly, China's ongoing military modernization and extension of its power projection capabilities also render it increasingly reliant on its own space assets,[265] which could potentially increase the utility of U.S. counterspace systems and its efforts to deter warfare in space.

Unmanned/AI-equipped weapons in large numbers could pose challenges for U.S. air defenses, particularly by using swarm technology.[266] Ms. Kania notes, "Within the next several years, a number of sophisticated UAVs, reportedly including those with stealth, anti-stealth, and supersonic capabilities, armed with multiple forms of precision weapons, could enter service with the PLA."[267] These could specifically expand the PLA's C4ISR and long-range precision strike abilities.[268] Broader advances in AI could further expand the threat posed by China's precision strike arsenal, enable machines better equipped for blockade and denial missions, and enable better control of cyber weapons and defenses, with real-time discovery and exploitation of U.S. cyber vulnerabilities.[269] In the long term, AI could contribute to navigation or even targeting for China's future precision-strike hypersonic weapons.[270] U.S. officials have noted the utility of directed energy systems to be used as possible "counterswarm" weapons.[271]

For each of these technologies, a breakthrough that outpaces current predictions could magnify the military challenge and "change [U.S.] strategic calculations in the Asia Pacific and beyond," as stated by Mr. Stokes.[272] Dr. Grayson notes that predicting technological breakthroughs is always challenging, even for U.S. systems, but this challenge is compounded for the weapons China is pursuing at the global technological frontier with limited public information available.[273]

Broader Competitive Implications

Given Beijing's commitment to its current trajectory, and the lack of fundamental barriers to advanced weapons development beyond time and funding, the United States cannot assume it will have an enduring advantage in developing next frontier military technology.[274] In addition, current technological trends render the preservation of any advantage even more difficult.[275] The United States now faces a peer technological competitor in an era in which commercial sector research and development with dual-use implications increasingly outpaces and contributes to military developments[276]—a country that is also one of its largest trading partners and that trades extensively with other high-tech powers. As the United States seeks to ensure it is prepared to deter aggression and defend key interests in the Asia Pacific region, such as the security of allies and partners, the peaceful resolution of disputes, and freedom of navigation,[277] recognizing this challenge will be crucial.

China has also centrally directed and managed policies for exploiting government funding, commercial technological exchange, foreign investment and acquisitions, and talent recruitment to bolster its dual-use technological advances. Along with traditional and cyber espionage,[278] it engages in state-backed overseas investments and acquisitions in the United States that touch on national security-related areas (see Chapter 1, Section 2, "Chinese Investment in the United States," for more on this topic). Reuters reported in June 2017 that "an unreleased Pentagon report, viewed by Reuters, warns that China is skirting U.S. oversight and gaining access to sensitive technology through transactions that currently don't trigger [Committee on Foreign Investment in the United States] review."[279] Ms. Kania noted that China likely will use advances from partnerships with U.S. AI companies for dual-use purposes.[280] China also seeks to obtain key components in commercial markets both inside and outside the United States, and traditional U.S. export controls typically only capture tangible technologies, not procedures and other supporting skills.[281] Dr. Grayson noted to the Commission that a pilot program based on an advanced weapon such as an HEL could help test a new approach: a weapons system-based, top-down process that locates required core capabilities that are not commercially available, instead of the current technology-based, bottom-up method that includes many commercially-available technologies.[282] Foreign partners could also be involved in an export control strategy designed around these critical capabilities.[283] China has also offered incentives to U.S.-based students and experts through its Thousand Talents Program, underscoring the importance of U.S. efforts to recruit and retain science and technology talent. Finally, as China injects high levels of government funding into its pursuit of advanced military technologies, the United States cannot take its leadership for granted.

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