China's Progress with Directed Energy Weapons
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Introduction

For the United States, decades of technology investments in directed energy weapons—lasers, railguns and high power microwave—are finally nearing the point of providing "next generation" capabilities over potential enemies. Effective early defensive laser weapons plus defensive-offensive railguns could be deployed in the early 2020s, while multi-platform high power but compact laser weapons could be realized in the 2030s.

However, it appears increasingly likely that any period of advantage from these weapons could be shorter than expected due to China's large investments in energy weapons development. As in many areas of advanced military technology development, it is difficult to assess precisely China's successes or progress toward the fielding of energy weapons. While Chinese military transparency has improved gradually in some areas, with few exceptions, it does not approach that of the U.S. in energy weapons.[1] "Grey Sources" can provide some insights but they do not allow for a full understanding of potential threats.

That said, China's development of laser technology dates back to the early 1960s, aided by an early and enduring commitment by top Chinese political and military leaders. Today, early Chinese low-power electric Solid State Laser (SSL) "kill" weapons are being marketed as there are indications China is also developing more powerful laser weapons, showing interest in using them on land, naval, air and space platforms.

China has also made impressive investments in electromagnetic launch (EM) technology as there are indications it has produced experimental railguns and may have tested an early electromagnetic aircraft launch system (EMALS) for a future aircraft carrier. Larger electromagnetic launch systems may serve as space launch system, and China also appears interested in electro-thermal launch to boost the power of conventional artillery. Chinse sources confirm great interest in high power microwave (HPM) weapons, including HPM cannons and bombs, and so far, initial "active denial" systems are being marketed.

China's energy weapons program has a breadth and intensity that should greatly concern American and Allied defense planners. Some Chinese military experts expect that energy weapons will become more prevalent in 10 to 20 years and will dominate the battlefield in 30 years. As such, it is imperative that the United States redouble its focus to achieve technology breakthroughs needed to realize decisive energy weapon capabilities and be ready to cooperate with critical allies to accelerate co-developments. The U.S. should also retain the flexibility to deploy energy weapons from diverse platforms, including space platforms, to meet what could be rapidly emerging new Chinese energy weapon threats.

For the U.S., the Promise of Directed Energy Weapons Gets Closer

A matter of great interest in the U.S. Department of Defense since the late 1960s, energy weapons have long been viewed as "the weapons of the future, and always will be." However, the last decade has seen greater Department of Defense support for directed energy weapons, as this technology improves, including increases in power and size reduction of Solid State Lasers, and the advance of electromagnetic launch technology. These, along with a scaling back of capability ambitions, may result in the nearterm emergence by early in the next decade of useful American energy weapons.

Electric powered Solid State Lasers (SSL), railguns, and microwave weapons offer potential advantages in numbers of "rounds" and cost per rounds over missiles and other kinetic weapons, potentially transforming future battlefields. A U.S. Raytheon Standard SM-3 Block 1B missile interceptor may cost about $14 million,[2] versus a $7 million Chinese anti-ship ballistic missile (ASBM), while a railgun hypersonic velocity projectile may only cost $50K. Energy weapons have the potential for ending the advantage that China and North Korea gain from large numbers of tactical and theater- range missiles, while offering new defensive and offensive capabilities for land, naval, air and space platforms.

Nearterm transformation by the early to mid-2020s could come from the Electromagnetic Launch Gun (EMLG) or railgun.[3] The system currently under development for the U.S. Navy by British Aerospace Systems (BAE) and Boeing, may fire a shot at hypersonic Mach 7 speed, suitable for intercepting maneuvering missiles with "shotgun" pellets, or attacking targets at 200 nautical miles (370km). Deployment on nuclear powered aircraft carriers or "electric" powered ships like the USS Zumwalt could allow defeat of China's much-vaunted ASBM. General Atomics is marketing its smaller 100km range "Blitzer" railgun, now in advanced development, for naval and land platforms.[4]

In the 1970s and 1980s, U.S. scientists examined the development of missile defense satellites using nuclear-pumped Free Electron X-Ray and chemical powered lasers to defeat Soviet nuclear ICBMs, an ambition that became part of Ronald Reagan's March 1983 Strategic Defense Initiative.[5] While a U.S. laser-satellite missile defense network was never realized,[6] one result of this effort was the Boeing YAL-1 airborne megawatt (millions of watts) class Chemical Oxygen Iodine Laser (COIL). Intended as a battlefield missile defender, it was an impressive achievement that aided large military laser development and did shoot down missiles. But based on a large Boeing 747 platform, only one was built and retired in 2011,[7] due to its high cost, volatile chemical fuel, low 20 "round" magazine, and limited laser range making the large platform tactically vulnerable.

Chemical lasers, however, are being eclipsed by increasingly powerful electric powered SSLs, with greater potential for size reduction and with a "magazine" theoretically limited by available power. Defensive SSLs could see deployment by the early 2020s. In late 2014 the U.S. Navy declared as an operational weapon its Kratos Defense and Security Solutions AN/SEQ-3 (XN-1) Laser Weapon System (LaWS), a 30 kilowatt (thousands of watts) laser capable of defeating swarming drones and small ships at close range. The Navy could test a 150 kilowatt class laser by 2018 and deploy it by 2020.[8] Boeing and Northrop-Grumman are developing a defensive

laser pod that by the early 2020s could enable U.S. combat aircraft to disrupt or jam anti-aircraft missile seekers.[9] U.S. officials envision a reduction in laser system size, to 5 kilograms per kilowatt, as enabling tactically sized 300 kilowatt SSLs. By the early 2030s, these may allow "hard kill" against air or ground targets from F-35B fighters, future tankers or from ship or land platforms.

Nuclear weapons release a powerful Electromagnetic Pulse (EMP) broad spectrum of microwave energy that can destroy electronics at long distance or fry flesh up close. After lengthy development in which there has been some skepticism of success,[10] the U.S. is nearing success in developing High Power Microwave (HPM) weapons, which harness discreet spectrums microwave energy to attack electronic targets with little collateral effect on humans. Boeing has reportedly tested the Counter-electronics High-powered Advanced Missile Project (CHAMP), a cruise missile equipped with a Raytheon HPM payload that flew over a building and attacked targeted electronics.[11] Earlier in the last decade the U.S. developed Active Denial Systems (ADS), which projects microwave energy that can boil the water in skin to control hostile crowds, but has not deployed this weapon. Thought deployed to Afghanistan it apparently was not used out of fear it would cause a political backlash.

China's Early Energy Weapons Ambitions

Starting in the early 1960s, according to recent Chinese history articles, key Chinese Communist Party (CCP) leaders and early CCP-era military-technology leaders strongly embraced the potential of directed energy weapons.[12] This commitment, which endured the chaos of the Cultural Revolution, has exceeded that of the U.S. civil-military leadership. Mao Zedong and even Lin Biao are given credit for early leadership, later sustained by Deng Xiaoping. Early military technologists playing key roles include Marshal Nie Rongzhen and the pivotal U.S.-educated Qian Xuesen. .

On 16 December 1963 Mao met with Marshall Nie Rongzhen, then Chairman of the State Science and Technology Commission and leader of China's atomic weapons effort. Regarding lasers, Mao reportedly stressed, "On the death ray, organize a group of people to specifically study it. Have a small group of people specializing in it who do not eat dinner or do other things…In addition to offensive weapons potential, study defensive uses…war has always had offensive and defensive aspects...[13]

Soon afterwards Marshal Nie began to organize "relevant departments" for laser research and development, starting with the Chinese Academy of Sciences.[14] Into 1964, Mao's discussions with Qian Xuesen led to the creation of the 640 Program to develop China's first missile defense systems.[15] The sub-program called "640-3" was tasked to develop military lasers for missile defense. The year 1964 saw the establishment of the Shanghai Institute of Optics and Fine Mechanics (SIOM), which remains the leading Chinese laser research and development organization. In 1970 China established the Anhui Institute of Optics and Fine Mechanics (AIOM), perhaps its second most important laser research organization.

Of these early years, Deng Xiaoping was said in 1989 to recall attending a March 1964 meeting with Qian Xuesen relaying Mao's instructions, likely about the 640-Program decision, during

which, "one third of the time was spent discussing the possibility of defensive lasers."[16]
In March 1979, a month during which now Chinese leader Deng Xiaoping was engaged in war against Vietnam, he had time to think about the future and explain the importance of laser weapons to a Central Committee meeting, saying:

> "They can be used in defensive ways, or offensive ways, like attacking airplanes and tanks. They will be important weapons and definitely be useful. A Chinese American scientist once told me that Americans have experimented on using laser weapons to hit satellites, and they have succeeded in getting down one satellite. People will use laser weapons to attack tanks, and the air war will be dominated by laser weapons too, space as well. It was said that the cost is much cheaper than other weapons."[17]

While there is no open source record of the U.S. using a laser to shoot down a satellite in the 1970s, one point of interest is Deng's assertion that well before the 1983 announcement of Reagan's Strategic Defense Initiative, it appears that a "Chinese American scientist" may have briefed the Chinese, and Deng personally, on emerging U.S. research regarding laser satellite based missile defense technology. Was Deng made aware of U.S. research that may have been part of Project Excalibur?

But Deng's clear foresight about the importance of laser weapons contrasted sharply with his later criticism of Reagan's SDI. Deng would say to visiting former President Richard Nixon in September 1985, "We are concerned about the escalation of the nature of the arms race and are opposed to any arms race in outer space. We are against whoever goes in for the development of outer space weapons."[18] It might be considered that given his longstanding advocacy for laser weapons, even in space, and considering China's overall post-Mao strategic weakness, that Deng was offering a "deception." For Deng, it appears, opposing U.S. space weapons development would help China gain time to catch up. In a similar vein, China has long campaigned publicly against U.S. missile defense programs while having pursued its second missile defense program since the early 1990s.

Deng also made an enduring contribution to China's military laser and other energy weapons programs by approving the creation of the 863 Program, which starting the mid-1980s began funding broad basic scientific research for military modernization in addition to numerous specific military-technical modernization efforts. Laser technology was one of seven early technology investment areas for the 863 Program. In his important 1999 study, Mark Stokes observed, "…an estimated 10,000 people, including approximately 3,000 engineers, in 300 organizations are involved in China's laser program. Almost 40 percent of China's laser R&D is for military purposes."[19]

The Book *Light War*

It is certainly important that China has one of the world's most vigorous directed energy research and development sectors, but just as important, there appears to be ongoing consideration of how directed energy weapons may radically change the nature of warfare and impact the strategies or doctrines of the PLA. In July 2015 the book *Light War* or *Light Warfare*, written by Li Bingyuan, Huyan Ning and Wang Shenliang, was published by the People's Liberation Army

Press.[20] *Light War* on one level constitutes a normal product of the small but vigorous community of Chinese military-political scholars that debate and help shape future military and government strategies.[21] But then this book was given a degree of attention in the wider "military press" to suggest that its themes may have a wider resonance within the Party-PLA leadership. This is suggested by author Li Bingyuan's long career with People's Liberation Army Daily,[22] which plays a key role in conveying the Party-Army leadership's evolving views to the PLA rank and file.

In short, the authors seek to conceptualize the next phase in the evolution of warfare, in a manner similar to that played by Andrew Marshall, the legendary former leader of the Pentagon's Office of Net Assessments, or U.S. think tanks like the Center for Strategic and Budgetary Assessment. They try to discern what will follow impact of the "information revolution" on warfare, which also reflects the early 2000s PLA strategy/doctrine emphasis on achieving "Informatization." Their view is that this next phase will be characterized by combining manipulations of "Big Data" and increasing autonomy/artificial intelligence, with directed energy weapons at the core. They place particular emphasis on autonomous space based laser weapons.[23]

As such, *Light War* suggests that decades of Chinese investments in directed energy weapons will be accompanied by deep consideration within PLA strategy and leadership councils about their impact on strategies and how the PLA will configure to fight in a battlefield dominated by energy weapons. The authors expect that in the next 10 to 20 years directed energy weapons will become more prevalent and in 30 years they will dominate the battlefield. Perhaps the PLA is already reconfiguring for such a new era inasmuch as a major mission the new Strategic Support Force may be to lead the weaponization of the information realm and outer space.

Laser Weapon Progress

Even though Deng cancelled most of the 640 Program in 1980 for financial reasons, he continued the 640-3 laser research and folded this into the 863 Program. China pursued two military anti-missile capable lasers, Free Electron Lasers (FEL) and Chemical Oxygen-Iodine Lasers (COIL). FEL research started at the Chinese Academy of Engineering Physics in 1985, resulting in the activation of the SG-1 laser in 1993. The Dalian Institute of Chemistry and Physics started research on COIL in the 1980s and an early model of tested out to a range of 140km in 1993.[24]

Ground Based Anti-Satellite Laser This research has resulted in Chinese chemical laser weapons. In September 2006 the U.S. publication *Defense News,* citing unnamed U.S. officials, was the first to report that China had used ground based lasers to "dazzle" or blind U.S. optical surveillance satellites on multiple occasions. While the news created a furor in Washington at that time, U.S. officials later downplayed the effects of the laser on U.S. satellites. But over a decade later it is likely that China has developed more powerful ground-based lasers.

Possible Chinese confirmation of their ground-based laser testing appeared in the December 2013 issue of *Chinese Optics* was an article titled "Development of Space Based Laser Weapons" written by Gao Min-hui, Zhou Yu-quan and Wang Zhi-hong, all from the Changchun

Institute of Optics, Fine Mechanics and Physics. It is one of China's leading institutes for the development of civil and military application laser technology. The article states:

> "In 2005, we have successfully conducted a satellite blinding experiment using a 50-100 KW capacity mounted laser gun in Xinjiang province. The target was a low orbit satellite with a tilt distance of 600 km. The diameter of the telescope firing the laser beam is 0.6 m wide. The accuracy of ATP (acquisition, tracking and pointing) is less than 5 [microradians.]"[25]

This would constitute militarily useful performance; an accuracy sufficient to track a large number of Low Earth Orbit (LEO) surveillance satellites and to degrade their optical imaging systems. A "tilt" distance of 600km means it can reach higher if the target passes closer to the laser. While the target satellite for the 2005 test was not identified, the ground-based laser was likely located in Korla, Xinjiang Province. Starting with the 640 Program, Korla has hosted a major base deeply involved in testing China's anti-missile and anti-satellite weapons.

Airborne laser ? The Changchun Institute authors described unrealized U.S. space-based chemical laser concepts of the 1980s and other chemical laser efforts like the Boeing YAL-1 Airborne Laser Testbed cancelled in 2011. Apart from the article, it is noteworthy that during the military celebration activities of the October 2009 Chinese Communist Party anniversary that a museum displayed an image of a four-engine aircraft using a laser to attack a satellite. Early in the last decade it was revealed that the Xian Aircraft Corporation had a four-engine wide body airliner program. Perhaps China had, perhaps still has an airborne COIL program, but instead of missile defense its main mission may be anti-satellite warfare.

Future Space Lasers The main goal of the Changchun authors was to argue for the feasibility of a Chinese space laser weapons satellites. According to the authors, in about a decade, or by about 2023, it should be possible for China to build a space-based laser battle platform weighing 5 tons and carrying 2.5 tons of chemical laser fuel. This platform could be able to fire a 1 Megawatt laser for up to 100 seconds. Such a laser should also have a 5,000km range and an accuracy of .5 microradians.

The Changchun Institute authors discuss options for space based laser systems, noting that the all gas iodine laser (AGIL) has more technological advantages than hydrogen fluoride (HF) and chemical oxygen iodine lasers (COIL), but AGIL is not technologically mature. They also note that the hydrogen fluoride overtone (HFOT) laser does not yet produce enough power, while COIL is considered more stable. The authors do not appear to state a preferred laser technology.

For future laser platforms, the authors highlight the utility of a "deployable membrane launching telescope," which utilizes a large but very thin Kevlar adaptive mirror which unfolds in space. This concept is strikingly similar to the Membrane Optical Imager for Real-time Exploitation (MOIRE) satellite. This is a U.S. Defense Advanced Research Project Agency (DARPA) concept for a massive 20 meter diameter membrane-mirror geosynchronous orbit Earth surveillance satellite revealed in 2013.[26]

However, the Changchun Institute authors foresee using this technology as an integral part of the space laser combat platform. A combat exercise would first use orbital forecasting and ground-based radar to follow a target, followed by precision targeting using a wide angle charge-coupled device (CCD) camera on the platform and then the deployable membrane telescope. The deployable membrane telescope would then reflect and focus the laser beam on its target.

The authors conclude: "In future wars, the development of ASAT [anti-satellite] weapons is very important. Among those weapons, laser attack system enjoys significant advantages of fast response speed, robust counter-interference performance and a high target destruction rate, especially for a space-based ASAT system. So the space-based laser weapon system will be one of the major ASAT development projects."[27]

While strict censorship ensures that such academic articles are rarely descriptive of ongoing Chinese military programs they can be instructive when combined with other indicators. But when such articles are prescriptive and the Changchun authors do indicate possible options for future Chinese space based lasers, it could be a sign of lobbying within China's military-industrial decision making process.

It is noteworthy that China's next generation space launch vehicle, the Long March-5 (CZ-5) is advertised as being able to loft 25 tons into LEO so it may be able to loft four or five 5-ton laser combat platforms. Inasmuch as the Changchun Institute contributes to ongoing Chinese space programs like the docking systems used by the *Shenzhou* space craft and *Tiangong* small space station, and the larger future 100 ton space station, it could contribute to making these craft "dual-use," or optionally armed for space combat.

So far, China's *Shenzhou* and *Tiangong* platforms have proven to be "dual use," conducting optical and radar surveillance missions for Chinese civil and military uses. China's next large space station follows the concept of the Soviet-era Energia "Mir" space station, utilizing large modules that could quickly be replaced with military modules, perhaps carrying directed energy weapons.

Early Fiber Optic Laser Weapons Electric powered fiber-optic lasers have received great attention in China as they have in the United States, because they have proven to be a fast solution to developing both powerful and compact, relatively light weight weapon systems. A laser technology supported under the 863 Program, China's first 10 kilowatt fiber optic laser reportedly emerged in 2013 under the leadership of the China Aerospace Science and Industry Corporation (CASIC).[28]

At the 2014 Zhuhai Airshow the China Academy of Engineering Physics displayed its "Low Level Guard-1," a 10 kilowatt electric powered fiber optic laser. This fixed device consisted of a power module and an equipment module housing the laser and optical guidance/tracking systems. This apparently became the basis for the 30 kilowatt Low-Altitude Laser Defending System (LASS) first displayed by the Poly arms marketing company at a September 2016 military exhibit in South Africa. It claims to have a 4 kilometer range at the 30 kilowatt power level and is useful mainly for defeating swarms of small plastic drones.[29]

Then at the February 2017 IDEX show in Abu Dhabi, Poly displayed its "Silent Hunter," with one Poly official saying it was an improved version of the LASS, and said it was deployed to defend the September 2016 G-20 Summit in Hangzhou, China.[30] Available in both fixed and mobile versions, like LASS it consists of power and equipment modules. One official claimed that Silent Hunter's laser was more powerful than 30 kilowatts but less than 100. A Poly video showed this laser could "ablate" or penetrate five 2 millimeter steel plates at a range of 800 meters, and an official stated it could penetrate 5 millimeters of steel at 1,000 meters. Poly officials stated they are working on more powerful versions, but that its size prevented an airborne version of Silent Hunter.

It is likely that the China Academy of Engineering Physics may develop fiber optic lasers in the 100 kilowatt class to form the basis for more powerful laser weapons useful on multiple platforms. When asked if they were working on a similar laser for space applications, a Poly official quipped, "No, that would be another department."

Naval Lasers The Changchun Institute may also be leading the development of new ground and naval tactical laser weapons. In a July 2012 article in Changchun's journal *Optics and Precision Engineering*, "Angle Displacement Measurement Device For Fast Steering Mirror In Vehicular Laser Device," the authors from the Institute describe a mirror for slewing a laser on a ground or naval platform. Informal Chinese sources have suggested that the PLA Navy's Type 055 next-generation cruiser may eventually employ a tactical laser weapon.

At the 2017 IDEX show, officials from the Poly Corporation said they were developing a naval version of their 30+ kilowatt "Silent Hunter" fiber-optic laser system.[31] Such a laser should be able to damage swarming light-hulled small attack craft or drones at ranges of more than one kilometer. With more accurate targeting it may be useful in damaging seekers on subsonic missiles or precision guided munitions. It should be expected that more powerful versions of this system will also lead to improved naval variants.

Electromagnetic Launch Systems

According to one insightful account from 2007, China had the second largest research and development sector for electromagnetic launch outside the United States. One early Chinese researcher who devoted his career to this technology starting in 1981, Wang Ying of the Ordinance Engineering College in Hebei, as of 2007 had started 22 other EM research and development institutes at military and civil universities.[32] This author also makes clear that beginning in the 1980s China's EM programs benefited greatly from exchanges with American academics.

Currently China is likely flying aircraft from a ground based electromagnetic aircraft launch system (EMALS), and is developing an aircraft electromagnetic recovery system, and has likely tested a variety of railguns. There are also indications that China is developing an electromagnetic launch system for space vehicles.

Today at the PLA Navy Air Force training base at Huangdicun, near the Bohai Sea, one can see two newly built ground-based catapults for training carrier pilots. One of the catapults is widely

believed to be an EMALS, taking up much less space than the steam powered catapult next to it. China's first test EMALS was spotted in 2015 near the city of Wuhan,[33] which hosts a number of important Chinese naval research and development facilities. China's next aircraft carrier to be launched in 2017 will not use catapults, but the following carrier, called the Type 002 is widely expected to use a steam catapult. The following carrier to be launched in the mid-2020s may be the first to use EMALS. [34]

EMALS systems are larger than railgun weapons and are thus slightly less challenging. But China also has a vigorous program to develop railguns. In 2011 this analyst found what may be an image of an early railgun test model.[35] It features a small caliber but also had a compact design. In a 2013 article, engineers from the Northwest Institute of Mechanical and Electrical Engineering described the design and simulation of a railgun capable of firing a 200mm, 20 kilogram projectile up to a speed of 2.5 kilometers per second.[36]

The China Aerospace Science and Industry Corporation (CASIC) 206 Research Institute has also been reported in the Chinese press to have made breakthroughs in achieving useful electrothermal launch.[37] This involves using an electric charge to obtain more power from a conventional gunpowder explosion to propel an artillery shell much faster, but not as fast as a railgun. CASIC is also developing a ground-based electromagnetic launch system that could reduce the cost of launching payloads into space.[38]

High Power Microwave Weapons

Informal Chinese sources suggest that China's 863 Program has funded research toward the development of high power microwave (HPM) weapons. This field was given a jolt in 2001 when Russia began offering to overseas buyers its RANETS-E and ROSA-E high power microwave air defense and electronic attack systems. It is not known if China was able to purchase this system or its underlying technology, as the Russians were asking for development funding as part of the sale.[39] RANETS-E may be able to damage enemy weapon system electronics up to a range of 7 miles.[40]

In August 2005 authors from the Weapons Equipment Academy of the Second Artillery and the National University of Defense Technology published an article on the feasibility of using an HPM weapon to counter the seekers of anti-radar missiles (ARMs)—one of the missions of the RANETS-E. They concluded, "the current high-power microwave sources cannot entirely meet the needs of countermeasures against antiradiation guided missiles as weapons. Based on the theoretical and technical analyses, however, this is absolutely feasible."[41]

Fast forward to January 2017, when the Chinese media hailed Huang Wenhua, a high power microwave weapon expert and Deputy Director of the Northwest Institute for Nuclear Science. Huang won a first prize in a national technology award series for having developed a HPM weapon capable of defending warships from anti-ship missiles. Researcher Henri Kenhmann discovered that Huang has been working on HPM technology since 1992. [42] Reducing the size and power source to fit on a ship would be quite an accomplishment and may also mean China could have a mobile HPM system capable of attacking electronics on aircraft and anti-radiation missiles.

In addition, at the 2014 Zhuhai Airshow the Poly Corporation revealed its WB-1 microwave active-denial system. Similar to U.S. active denial systems intended for crowd control, it can project skin frying microwaves out to 80 meters. At the 2017 IDEX show a Poly official said there have been no domestic or foreign customers for the WB-1.[43]

Impact on US Policy

An understanding of the Chinese Communist Party's and People's Liberation Army's commitment to developing directed energy weapons, and their potential for rapidly conceptualizing and organizing for a "next generation" of warfare, points to one main conclusion: China is working to dominate a potential next generation of warfare centered on directed energy weapons. Furthermore, this is not a "defensive" Chinese drive rooted in a fear of an American threat such as the Strategic Defense Initiative. China's drive to dominate the era of directed energy weapons began with Mao Zedong's ambitions in the early 1960s, well before SDI. This drive for superiority is consistent with China's drive for global economic dominance to be followed by eventual military dominance; dominance of the seas and of outer space.

But while China's top laser engineers conceptualize future laser-equipped space stations and PLA strategists seek to integrate fast evolving technology streams of information and directed energy, a similar enthusiasm may exist in U.S. military circles but political leaders show mixed views. For example, while the Obama Administration supported a robust U.S. directed energy weapons program, it also opposed militarization, or U.S. weapons in space and its termination of the former Bush Administration's Moon program gave China time to pursue its program to get to the "high ground" of the Moon.

The breadth of China's directed energy program also indicates that any military advantage the U.S. may hope to gain from its directed energy weapon developments could be short-lived. It is interesting that while the U.S. Navy's 30 kilowatt fiber optic laser went to sea in 2014,China's early 10 kilowatt fiber optic laser would emerge the same year, and its 30 kilowatt version by 2016. China may by now have an active space laser combat satellite program, whereas the U.S. most likely has no such program. The U.S. Navy's EMALs will begin operations when the nuclear powered aircraft carrier USS Ford begins operations, while U.S. Navy railguns may emerge by the mid-2020s. China's EMALS could enter service by the mid-2020s, and it is not inconceivable that it could by then begin fielding early railguns. While early U.S. HMP weapons like CHAMP may be in advanced testing today, it is also conceivable that Chinese HPM weapons could enter service by the turn of the decade.

As a consequence, as the next realm of competition beyond directed energy plus information dominance is not yet apparent, and the U.S. could be entering a close arms race with China regarding energy weapons, it would appear that the United States may be required to: 1) devote greater resources to developing energy weapon technologies; and 2) exploit potential military coalition advantages while seeking necessary geostrategic advantages.

One way to efficiently devote more resources to directed energy weapons development would be to foster greater competition between companies. For example, while BAE and Boeing were

chosen by the U.S. Navy to develop their large 200nm range railgun, it decided not to fund weapon development of General Atomics' earlier experimental work leading to a smaller railgun. This decision should be reconsidered, especially if there is a potential for earlier deployment a working weapon. Or, following thorough review of potential information security risks, allow a competing company to find technology development partners in closely allied countries, also for the purpose of accelerating technology development.

In order to achieve necessary strategic advantage, it is likely that the United States will need to more vigorously defend its access to outer space and not hesitate to respond to potentially threatening Chinese moves in space. It may not be sufficient for the U.S. to simply develop airborne lasers, potentially on very fast, high altitude unmanned aircraft, to defend its space assets. Nor will it be sufficient for the U.S. to allow China to get away turning manned space platforms into "dual use" systems optionally equipped with energy or other weapons. As long as China demonstrates its willingness to exploit much of its space program for potential military missions, the U.S. must possess options for at least neutralizing potential threats, preferably short of threatening lives.

Furthermore, any potentially realized Chinese vision for a "Light War" revolution in military affairs will likely require control of the Earth-Moon System, or control of the Moon and the Lagrangian Points to dominate Earth orbits. Washington can show leadership by neutralizing potential conflict over the Moon, by promoting an early multinational return to the Moon. In this vein the Trump Administration's apparent early preference for returning the Moon is a positive development. Building a robust government and private sector infrastructure for getting to and staying on the Moon can potentially help deter China from militarizing the Moon. Or if China is not deterred, then we will have the infrastructure for an appropriate rapid response.

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[1] There is no Chinese open source counterpart to the "Directed Energy Weapons Summit" hosted in 2015 and 2016 by Booz Allen Hamilton and the Center for Strategic and Budgetary Assessment (CSBA). For reports, see: "July 28, 2015, Directed Energy Summit Final Report," http://www.boozallen.com/content/dam/boozallen/documents/2016/03/2015-directed-energy-summit-summary-report.pdf ; and "Directed Energy Summit 2016," http://www.boozallen.com/content/dam/boozallen/documents/Viewpoints/2016/09/de-report-2016.pdf

[2] Office of the Undersecretary of Defense (Comptroller) Chief Financial Officer, *Program Acquisition Cost by Weapon System*, United States Department of Defense Fiscal Year 2017 Budget Request, p. 4-2.

[3] For an excellent overview of U.S. Navy energy weapon programs, see Ronald O'Rourke, "Navy Laser, Railgun and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, October 21, 2016.

[4] Richard D. Fisher, Jr. "General Atomics commits private funding to develop 10MJ medium-range railgun," *IHS Jane's Navy International*, May 23, 2016, http://www.janes.com/article/60546/general-atomics-commits-private-funding-to-develop-10-mj-medium-range-railgun

[5] It is not the purpose here to review the history of the debate over SDI other than to review that largely at Lawrence Livermore Laboratories starting in the mid-1970s, in what became Project Excalibur, research began regarding the feasibility of developing satellites that would utilize small nuclear explosions to optically "pump" X-Ray lasers to defeat Soviet ICBMs. Promoted by Dr. Edward Teller and others, this ambition became part of the SDI Program.

[6] One irony is that the Soviet Union came the closest to testing a Low Earth Orbit 1-megawatt carbon dioxide laser combat-satellite, code named Polyus/Skif-DM, but it was lost in a May 1987 launch failure

at a time when Soviet leader Mikhail Gorbachev was losing interest in the Soviet Union's expensive space warfare ambitions. In recent years Russia has revived an airborne chemical laser program using an Ilyushin Il-76 platform, which may be intended for attacking Low Earth Orbit satellites.

[7] Amy Butler, "Lights Out for the Airborne Laser," *Aviation Week and Space Technology,* December 21, 2011, http://aviationweek.com/awin/lights-out-airborne-laser

[8] Michael Fabey and Chris Osborn, "The US Navy plans to fire laser weapons off of ships within a year," *Business Insider,* January 25, 2017, http://www.businessinsider.com/us-navy-laser-weapons-2017-1

[9] "Boeing gets $90 million contract to develop laser pod for fighter jets through 2021," *The Next Big Future,* December 19, 2016, http://www.nextbigfuture.com/2016/12/boeing-get-90-million-contract-to.html

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U.S.-China Economic and Security Review Commission Hearing, February 23, 2017
Testimony of Richard D. Fisher, Jr, International Assessment and Strategy Center
Appendix: Images of China's Energy Weapons Progress

1. American Energy Weapon Ambitions

American energy weapon ambitions for early and later in the next decade include: 1) Eventual development of a 100kw solid state laser for insertion into a F-35B fighter that would defend against enemy missiles; 2) US Navy concept for a testing a 100kw to 150kw laser on a destroyer, perhaps before 2020; and (left) 3) A prototype Electromagnetic Railgun (EMRG) seen in 2014. Sources: Northrop-Grumman, U.S. Navy

2. Chinese Laser Weapon Ambitions

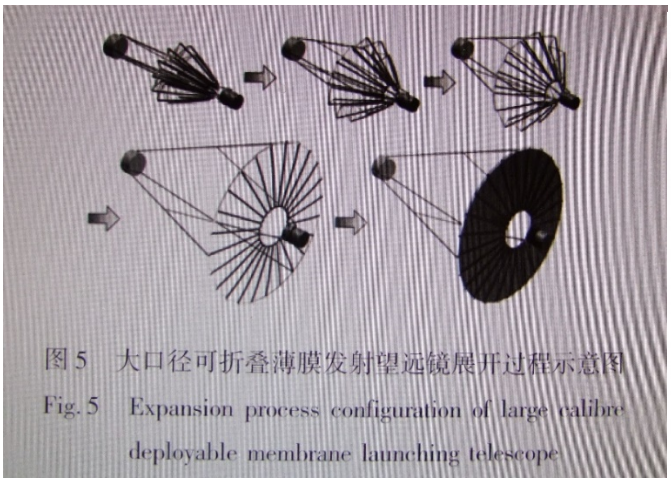
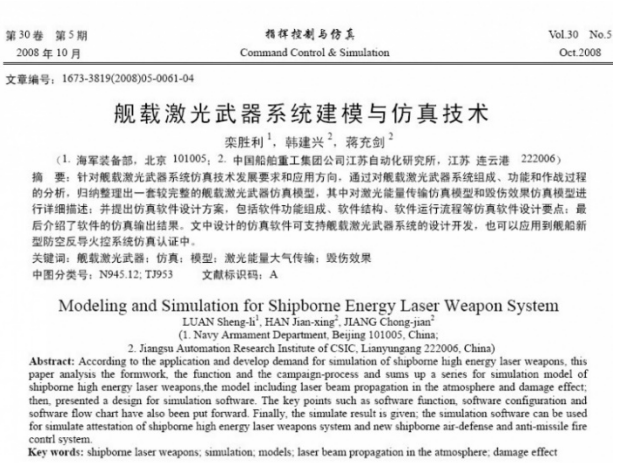


图 5 大口径可折叠薄膜发射望远镜展开过程示意图
Fig. 5 Expansion process configuration of large calibre deployable membrane launching telescope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舰载激光武器系统建模与仿真技术

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摘 要：针对舰载激光武器系统仿真技术发展要求和应用方向，通过对舰载激光武器系统组成、功能和作战过程的分析，归纳整理出一套较完整的舰载激光武器仿真模型，其中对激光能量传输仿真模型和毁伤效果仿真模型进行详细描述；并提出仿真软件设计方案，包括软件功能组成、软件结构、软件运行流程等仿真软件设计要点；最后介绍了软件的仿真输出结果。文中设计的仿真软件可支持舰载激光武器系统的设计开发，也可以应用到舰船新型防空反导火控系统仿真认证中。

关键词：舰载激光武器；仿真；模型；激光能量大气传输；毁伤效果

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Modeling and Simulation for Shipborne Energy Laser Weapon System

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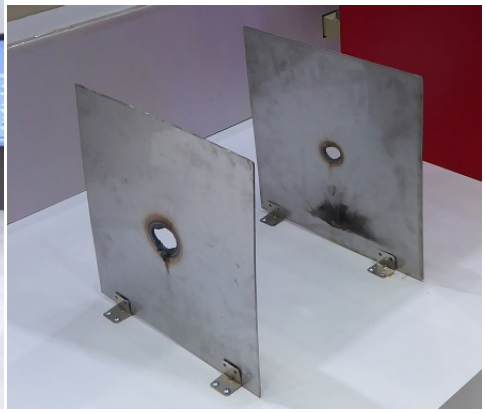
Abstract: According to the application and develop demand for simulation of shipborne high energy laser weapons, this paper analysis the formwork, the function and the campaign-process and sums up a series for simulation model of shipborne high energy laser weapons,the model including laser beam propagation in the atmosphere and damage effect; then, presented a design for simulation software. The key points such as software function, software configuration and software flow chart have also been put forward. Finally, the simulate result is given; the simulation software can be used for simulate attestation of shipborne high energy laser weapons system and new shipborne air-defense and anti-missile fire contrl system.

Key words: shipborne laser weapons; simulation; models; laser beam propagation in the atmosphere; damage effect

In December 2013, (right) engineers from the Changchun Institute of Optics, Fine Mechanics and Physics, a leading Chinese laser research center, published an article proposing the use of large folding adoptive mirrors as the basis for a 5-ton orbiting chemical laser weapons platform. China has also devoted much attention to the potential use of laser weapons on naval platforms, illustrated by an October, 2008 article from the journal *Command, Control and Simulation,* "Modeling and Simulation for Shipborne Energy Laser Weapon System." Sources: Chinese Internet



As part of a new museum display (left) to celebrate the 2009 anniversary of PLA Air Force, a wall and model mural depicted a 4-engine airliner firing a laser weapon to attack a satellite. Ambition or active development program? At a the February 2017 IDEX show in Abu Dhabi POLY revealed its "Silent Hunter" fiber-optic electric laser air defense system. This laser may have power greater than 30 kilowatts and can ablate 5mm of steel at a range of 1,000 meters. POLY says it is working on a naval variant and on more powerful versions. Source: Chinese Internet; and RD Fisher

3. Chinese Electromagnetic Launch System Ambitions

· 10 · 火炮发射与控制学报 JOURNAL OF GUN LAUNCH & CONTROL 2013 年 9 月

超大炮口动能电磁轨道炮设计与仿真

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摘 要：论证了 1 门 200 mm 口径超大炮口动能电磁轨道炮用以进行亚超声速发射，目标是将 20 kg 弹丸的初速提高到 2 500 m/s，其炮口动能将超过 62 MJ。通过多个不同算例的计算，综合考虑电枢受力、电流密度与峰值电流、电感梯度和技术风险等因素，最终选择了一种简单轨道炮结构。基于 200 MJ 电容器组储能式脉冲电源系统，建立了轨道炮系统仿真模型并进行了分析，设计的发射器身管长为 8 m，铜轨道电感梯度约为 0.4 μH/m，峰值电流约为 7 MA，有效电流不低于 6 MA，弹丸炮口初速可达到 2 540 m/s，炮口动能达到 64 MJ，系统效率为 31.8%。

关键词：电磁轨道炮；仿真；炮口动能

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Design and Simulation of a Extra Large Muzzle Kinetic Energy Railgun

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Abstract: A large muzzle kinetic energy railgun was developed to demonstrate the supersonic launch of 200 mm projectiles. A trade study that evaluated over 30 different railgun cases, and resulted in the selection of a simple railgun as the choice. The goal of the railgun was to launch a 200 mm diameter projectile with a mass of greater 20 kg to a velocity of 2 500 m/s, and the muzzle kinetic energy was more than 62 MJ. The analysis and modeling of the electromagnetic launch resulted in an adequate design. The final design concluded with The 200 MJ pulsed-power-supply system was based on capacitors, a 8m barrel and was characterized by the following parameters: conducting rails with an inductance gradient about 0.4 μH/m, a peak current of about 7 MA, an effective current of no less than 6MA, the projectile muzzle velocity of 2 540 m/s, the muzzle kinetic energy of more than 63 MJ and the system efficiency of 31.8%. A more detailed study will be presented in this paper.

Key words: railgun; simulation; muzzle kinetic energy

In early 2011 an image appears on Chinese web pages (left) of what appears to be either a model or a test article of what may be an early concept for a Chinese railgun. A September 2013 article (right) in the Journal of Gun Launch and Control remarks about a Chinese railgun firing a 200mm projectile up to 2.5km per second. Source: Chinese Internet

China may already be testing a prototype Electromagnetic Aircraft Launch System (EMALS) (left) that could be used on a future Chinese aircraft carrier. In addition, China may be seeking to develop electromagnetic launch to assist access to space (right).

4. Chinese Microwave Weapon Ambitions

At the 2014 Zhuhai Airshow (left) China's POLY company revealed their WB-1 "active denial" microwave weapon, which can repel unruly crowds out to 80 meters. Images of a possible experimental microwave weapon component (right) appeared on Chinese web pages in early 2017, coinciding with reports late January 2017 Chinese press reports of an award for an engineer with the Northwest Institute of Nuclear Technology, for having developed microwave weapons that could defend ships from attacking missiles. Source: Huanqiu and Chinese Internet