China's Advanced Weapons Systems

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About the Authors

Delivery of this report was led by Tate Nurkin, a Senior Associate with Jane's. Tate previously established and ran Jane's Strategic Assessments and Futures Studies Center from December 2013 – February 2018. The SAFS Center was dedicated to tracking geopolitical, military and industry competitions and how innovations in technology, competitive strategies, and operational concepts can drive these competitions in new directions. Tate has 20-plus years tracking China's military modernization effort and the future of military capabilities. In March 2018, Tate started OTH Intelligence Group LLC.

The core Jane's team also included analysts Kelly Bedard and Cameron Scott as well as Jon Grevatt and James Clad, subject matter experts on China's defense industrial base and broader defense and geopolitical dynamics in the Indo-Pacific.

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Table of Contents

Acronyms

A2/AD	Anti-Access/Area Denial
AAW	Anti-Air Warfare
AECC	Aero-Engine Corporation of China / Aero-Engine Group of China
AFRL	Air Force Research Laboratory
AI	Artificial Intelligence
AR	Augmented Reality
ASAT	Anti-Satellite
ASBM	Anti-Ship Ballistic Missile
ASW	Anti-Submarine Warfare
AUV	Autonomous Underwater Vehicle
AVIC	Aviation Industry Corporation of China
BAT	Baidu, Alibaba and Tencent (three major Chinese high-tech companies)
BLOS	Beyond-Line-Of-Sight
BMD	Ballistic Missile Defense
C4ISTAR	Command, Control, Communications, Computers, Information/Intelligence, Surveillance, Targeting Acquisition and Reconnaissance
CASC	China Aerospace Science and Technology Company
CASIC	China Aerospace Science and Industry Company
CCP	Chinese Communist Party
CETC	China Electronic Technology Group Corporation
CFIUS	Committee on Foreign Investment in the United States
CHIRP	Commercially Hosted Infrared Payload
CIWS	Close-In Weapon System
CMC	Central Military Commission
CMI	Civil-Military Integration
CNSA	China National Space Administration
COMAC	Commercial Aircraft Corporation of China
CONOPs	Concept of Operations
CSIC	China Shipbuilding Industry Corporation
CSSC	China State Shipbuilding Corporation
DARPA	U.S. Defense Advanced Research Projects Agency
DoD	U.S. Department of Defense
DUI(x)	Defense Innovation Unit Experimental
EM	Electromagnetic
EML	Electromagnetic Launcher
EW	Electronic Warfare
FEL	Free Electron Lasers
GEUAV	Ground Effect Unmanned Aerial Vehicle
GPS	Global Positioning System
GSSAP	Geosynchronous Space Situational Awareness Program
HALE	High-Altitude Long Endurance
HAWC	Hypersonic Air-Breathing Weapon Concept
HGV	Hypersonic Glide Vehicles
HiFIRE	Hypersonic International Flight Research Experimentation
HSMW	High-Speed Maneuvering Weapons
HVP	Hyper-Velocity Projectile
IC	Intelligence Community
ICBM	Intercontinental Ballistic Missile
IED	Improvised Explosive device

IEPS	**Integrated Electrical Power System**
ISR	**Intelligence, Surveillance and Reconnaissance**
ISTAR	**Intelligence, Surveillance, Target Acquisition and Reconnaissance**
KE-ASAT	**Kinetic Energy Anti-Satellite**
kW	**Kilowatt**
LEO	**Low Earth Orbit**
MAHEM	**DARPA's Magneto Hydrodynamic Explosive Munition weapon**
MALE	**Medium-Altitude Long Endurance**
MaRV	**Maneuverable Re-entry vehicle**
MBT	**Main Battle Tank**
MGWOT	**Maximum Gross Take-Off Weight (sometimes MTOW/Maximum Takeoff Weight)**
MIIT	**Ministry of Industry and Information Technology**
MOR	**Mixed Ownership Reform**
MOST	**Ministry of Science and Technology**
MW	**Megawatt**
NORINCO	**China North Industries Group Corporation**
ONA	**U.S. Office of Net Assessment**
PISA	**Program for International Student Assessment**
PLA	**People's Liberation Army**
PLAAF	**People's Liberation Army- Air Force**
PLAN	**People's Liberation Army- Navy**
PLARF	**People's Liberation Army- Rocket Force**
PSC	**Politburo Standing Committee**
QUESS	**Quantum Experiments at Space Scale**
R&D	**Research and Development**
RELI	**U.S. Army's Robust Electric Laser Initiative**
RMB	**Renminbi**
ROV	**Remotely Operated Vehicle**
RPG	**Rocket Propelled Grenade**
S&T	**Science and Technology**
SASTIND	**State Agency for Science, Technology and National Defense**
SATCOM	**Satellite Communication**
SIPRI	**Stockholm International Peace Research Institute**
SLV	**Space Launch Vehicle**
SSBM	**Ballistic Missile Submarine**
SSN	**Nuclear powered submarine**
STEM	**Science, Technology, Engineering and Math**
STFC	**Science Technology Facilities Council**
TACAIR	**Tactical Air**
THAAD	**Terminal High Altitude Area Defense**
TPP	**Trans-Pacific Partnership**
UAV	**Unmanned Aerial Vehicle**
UCAV	**Unmanned Combat Aerial Vehicle**
UGV	**Unmanned Ground Vehicle**
USV	**Unmanned Surface Vehicle**
UUV	**Unmanned Underwater Vehicle**
VTOL	**Vertical Take-Off and Landing**

This paper uses Chinese designations for ships and other sea platforms where appropriate.

Ship Type	Chinese Designation	NATO Designation
Aircraft Carrier	Type 001	Liaoning-class
Aircraft Carrier	Type 002	(Forthcoming)
Attack Craft	Type 037G	Houxin-class
Submarine	Type 039	Yuan-class
Destroyer	Type 052	Luhu-class
Frigate	Type 053	Jianghu-class
Light Frigate	Type 053H3	Jiangwei II-class
Frigate	Type 054	Jiangkai-class
Destroyer	Type 055	Renhai-class
Corvette	Type 056	Jiangdao-class
Amphibious Transport Dock	Type 071	Yuzhao-class
Landing Ship Tank	Type 072	Yukan-class
Mine Countermeasure Vessel	Type 081	Wochi-class
Mine Countermeasure Vessel	Type 082	Wosao-class
SSN	Type 093	Shang-class
SSN	Type 094	Jin-class
SSN	Type 095	Sui-class
SSBN	Type 096	(Forthcoming)
Icebreaker	Type 272	(Unknown)
Intelligence-gathering Ship	Type 815	Dondiao-class
General Supply Vessel	Type 901	(Forthcoming)
Replenishment Ship	Type 903	Fuchi-class
Mine Countermeasure Vessel	Type 6610	(Unknown)

Executive Summary

Jane's research and analysis examined five categories of China's advanced weapons systems: counter-space, unmanned systems, maneuverable reentry vehicles, directed energy and electromagnetic railguns. In addition, this report also focuses on China's notable investment in and emphasis on development of artificial intelligence applications for national defense.

The following key themes and insights across four linked analytical categories emerged throughout the course of our research:

- The strategic context in which China's advanced weapons systems are being developed
- China's defense industrial base and science and technology community
- The advanced weapons themselves
- Policy measures and investments required to mitigate risk and capitalize on opportunity generated by China's advanced weapons systems and other dynamics identified in this paper.

Strategic Context

Through the Lens of a Changing U.S-China Strategic Competition: China's advanced weapons systems development is taking place within the context of an intense and complex geopolitical, military and technology acquisition and development competition.

At a geopolitical level, this competition results in part from China's perception that the United States and its allies and partners in the Indo-Pacific (Japan, South Korea, Taiwan, the Philippines, Australia, India, future Southeast Asian partners and possibly Vietnam) are cooperating to strategically contain China.[1] It also emanates from what the 2013 *Science of Military Strategy*—an authoritative book published by the PLA's Academy of Military Sciences—describes as a momentum of transition from an "unprecedentedly unipolar" world to a new 21st century "international balance that is characterized by multi-polarity and co-governance."[2] The United States remains the world's only superpower, but China is a critical player in this rebalanced world of diminishing U.S. power and influence. China views its role as capitalizing on the opportunities presented by globalization and the informatization of society to propel itself forward economically, socially and technologically.[3]

This geopolitical context has security and defense implications for China and for the region. China sees a change in the types of conflicts for which it needs to prepare and in the domains in which it will be required to compete and potentially contest. According to the 2013 *Science of Military Strategy*:

[1] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.7. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.
[2] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.70. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.4. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf
[3] Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.4. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

> "Generally, the possibility of a large-scale ground invasion by an adversary is minimal. However, the danger of being the target of high-technological warfare, such as air-naval, air-space, and space-cyber wars, is intensifying. The threat from the east is more severe than that from the west, the threat from the sea is more severe than that from the ground; the threat from space and cyber network is gradually becoming true. The probability of conducting military operations to protect rights and limited oversea war operations is ever increasing. The most severe war threat is a large-scale strategic sudden attack launched by a strong adversary, which aims at destroying our war potential to force us to surrender. The most probable war threat is a limited military conflict from the sea. The war we need to prepare for, particularly given the background of nuclear deterrence, is a large-scale, and highly intensive local war from the sea."[4]

Technological development is critical for maintaining deterrence in an environment in which "the emergence of new deterrence forces, based on new technology such as information, cyberspace, space, and new-material technologies, is revolutionarily changing the mechanism, method, and area of operation. It heralds a completely new method of deterrence, symbolized by constructing asymmetrical method of deterrence."[5]

Jane's analysis throughout our research effort strongly suggests that U.S. advantage in this regional competition is being eroded due in part to shifting perceptions of the reliability of U.S. technological superiority as well as the perception among allies and partners that the United States lacks a coherent vision for the region. U.S. advantage is also affected by China's aggressive and proactive pursuit of its interest across the region, which places pressure on regional actors, and accelerates and intensifies the need for a clear U.S. posture, regional vision and support.

Perspectives on China's Military Modernization: China's military modernization is in the midst of three transitions:

1. Enhanced focus on the maritime domain to support A2/AD[6] objectives
2. New emphasis on power projection capabilities
3. A growing imperative to develop artificial intelligence-infused platforms and systems to fully exploit emerging trends shaping the future of conflict and military capability

The first of these transitions is clearly the most urgent; however, the last—the move from informatized warfare to "intelligentized" or cognitive warfare—is likely to be the most impactful over the next 15–20 years.[7] It simultaneously offers China an opportunity to shift the nature and

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[4] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.7. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.
[5] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.142-143. Translation from Chase, Michael and Arthur Chan, "China's Evolving Approach to 'Integrated Strategic Deterrence". RAND Corporation. 2016. p. 19. https://www.rand.org/content/dam/rand/pubs/research_reports/RR1300/RR1366/RAND_RR1366.pdf.
[6] A2/AD (Anti-Access and Area Denial) refers to the "family of military capabilities used to prevent or constrain the deployment of opposing forces into a given theater of operations and reduce their freedom of maneuver once in a theater". Simon, Luis, "Demystifying the A2/AD Buzz," *War on the Rocks,* January 4, 2017. https://warontherocks.com/2017/01/demystifying-the-a2ad-buzz/.
[7] Intelligentized [智能化] warfare refers to the transformation of conflict from today's "informatized" warfare to an environment in which AI-enabled capabilities will support at least three types of novel capability. Indicative Chinese sources on intelligentized warfare include a publication on Xinhua by Li Daguang [[李大光], a professor with the National Defense University's Military Logistics and Military Science and Technology Equipment Teaching and Research Department, called "Artificial Intelligence Opens the Door to Intelligentized Warfare [[人工智能叩开智 能化战争大门," where he

trajectory of military competition with the United States beyond traditional platforms and systems in which China is currently viewed as being "behind" and also provides a pathway to gain advantage over the United States in future military capabilities.

China's advanced weapons systems support each of these transitions and also enhance China's position in critical military competitions, such as the undersea domain, space, the EM spectrum and missile versus missile defense, as described in Table 1 below.

Table 1: Summary analysis of China's advanced weapons systems programs and their implications for the United States

Advanced Weapons System Category	Implications for the United States
Counter-space: China has demonstrated each of the components of its counter-space program, including the highly provocative 2007 destruction of a disabled Chinese weather satellite in space by a kinetic kill vehicle. China continues to mature and refine its space-based capabilities.	**Space-based assets at risk:** The U.S. space-based architecture is currently vulnerable to China's counter-space program. However, the United States is taking aggressive steps to remedy this vulnerability through physical hardening of satellites and development of new concepts, such as disaggregation, that build in redundancy and resilience to U.S. space-based architecture and, as a result, to U.S. advantage in this domain. **Dual-use capabilities:** China benefits from the dual-use nature of its space program. It is able to develop and test sophisticated counter-space solutions under the guise of the furtherance of its civil space program. For example, directed energy lasers have both a scientific purpose and a military one.
Autonomous unmanned systems: China's unmanned systems industry is developing rapidly, especially in unmanned aerial vehicles (UAVs). China's defense industry has also demonstrated an impressive volume and velocity in the introduction of new unmanned surface vehicle (USV) designs while China's applied research community has been heavily involved in the development of unmanned underwater vehicles (UUVs). Given the importance of UUVs to the future trajectory of undersea competition with the United States, Jane's anticipates that China's navy will leverage UUV technologies and may already be engaged in classified programs.	**Undersea domain:** A proliferation of autonomous UUVs offers an opportunity for China to address critical vulnerabilities in the undersea domain. While the United States is also investing in UUVs, the combination of more of these systems and enhanced sensor nets, such as the Great Undersea Wall, could challenge the strategically invaluable U.S. advantage in the undersea domain. **Electromagnetic spectrum:** Unmanned systems will also play a prominent role in the rapidly intensifying electronic warfare competition as part of effort to jam, spoof and potential encrypt/decrypt communications spectrum. As with space, control of the EM spectrum is critical to bringing to bear many of the most consequential of U.S. military capabilities. **Reconnaissance strike complex:** Linked networks of more UAVs, USVs and UUVs will help address current shortcomings of China's C4ISTAR (Command, Control, Communications, Computers, Information/Intelligence, Surveillance, Targeting Acquisition and Reconnaissance) infrastructure. This will enhance capabilities associated with advanced

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discusses the military applications of AI. http://www.xinhuanet.com/mil/2017-01/23/c_129459228.htm. Another is Pang Hongliang's [庞宏亮] article in the *PLA Daily* "The Intelligentization Military Revolution Starts to Dawn" [智能化军事革命曙光初现] which discusses the U.S.' Third Offset Strategy and states that "the main technical fields it covers are based on the innovative application of artificial intelligence technology, reflecting the new trend of the world's military development is transitioning from informatization to intelligentization." January 28, 2016, http://www.mod.gov.cn/wqzb/2016-01/28/content_4637961.htm.

	weapons addressed in this paper, especially Maneuverable Re-entry Vehicles (MaRVs). **Cognitive warfare:** The intersection of China's unmanned systems development with advanced artificial intelligence will enable novel capabilities such as drone swarms that could pose a significant challenge to existing U.S. capabilities. Autonomous unmanned systems will be a prominent feature of future warfare and the competition between the United States and China to develop the most sophisticated artificial intelligence–infused unmanned capabilities will be critical to shaping the future military balance between them.
Maneuverable Re-entry Vehicles (MaRVs): China's anti-ship ballistic missiles (DF-21D and DF-26) already constitute a viable, if vulnerable, capability. Development of the maneuverability of the warhead and robustness of the reconnaissance strike complex continues in order to make this a more robust capability. **China's hypersonic glide vehicle (HGV) program** is also advancing, having completed seven tests since 2014 (six successful). The program is largely catalyzed by concerns that U.S. advanced missile defense systems, particularly and most recently the Terminal High Altitude Area Defense (THAAD), are severely undermining if not abrogating China's strategic and conventional nuclear deterrent. It also views the weapons as a potentially useful conventional strike capability to support both A2/AD and power projection activities.	**Challenge to air defense:** Successful deployment of MaRVs, especially HGVs, constitutes a powerful challenge to U.S. concepts of air and missile defense and will require accelerated investment in new capabilities (railguns, hyper-velocity weapons, directed energy, enhanced electronic warfare capabilities) and concepts (left of launch interventions, distributed lethality) to mitigate future operational and strategic vulnerabilities. **Destabilizing regional geopolitics:** HGVs are particularly destabilizing. The combination of hypersonic speeds and anticipated maneuverability of these systems makes them especially provocative and invites pre-emption. They also motivate development of other advanced weapons systems, such as directed energy and railguns, to meet the HGV threat.
Directed Energy Weapons: China's interest in directed energy weapons is primarily in counter-space weapons. It also has developed hand-held counter-drone weapons, truck-mounted close-in defense weapons and non-lethal weapons for crowd-control and peacekeeping missions.	**Counter-space:** Continued development of both satellite-carried and ground-based laser dazzlers that can blind, jam or destroy satellites constitutes a particularly worrying threat to U.S. space-based architecture and requires development of a suite of counter-counter-space capabilities. China is likely to continue to mature its counter-space directed energy program. **Counter-drone:** As unmanned systems of all-types become more prominent on the battlefield, the capacity to deal with more and more sophisticated unmanned systems and swarms is prioritized. China's directed energy program includes both hand-held and truck-mounted weapons capable of carrying out counter-drone operations. The use of directed energy to counter drones is also a priority investment area for the United States, driven in part by the rapid increase in the Islamic State's use of commercially available drones in Iraq and Syria to carry out surveillance and strike missions. **A2/AD and future naval applications:** Unlike the United States, China does not yet have the capacity to place directed energy weapons on a naval vessel due to persistent challenges with weight, energy capture and storage and power generation. However, China clearly has this ambition. If achieved, China could use directed energy weapons to drive both manned and unmanned platforms and systems out of

	contested waters at close range, a capability that could be useful in China's on-going maritime boundary disputes, such as in the South China Sea.
Electromagnetic Railguns: China continues to focus on this capability area and has engaged in an impressive amount of academic research on the broader topic of electromagnetic science. Progress in development of EM railguns and hypervelocity weapons has lagged behind development of other systems of interest to this report, though, as discussed in more detail in Chapter 9, photographs published in open sources in February 2018 may show an EM railgun on a naval vessel.	**Air and missile defense competition:** China's interest in EM railguns and weapons should be seen as part of the broader cascading implications of the missile versus missile defense competition that the introduction of HGVs and other MaRV-capable weapons is generating. **Ancillary benefits of electromagnetic research:** China also has leveraged this research to make strides in the development of electromagnetic launch (EML) catapults for its aircraft carriers. EML enables China's future carriers to carry heavier and more heavily armed aircraft, enhancing an important component of its future power projection capability.

China's Defense Industrial Base and Sciences and Technology (S&T) Efforts

China's Advancing Defense Industrial and S&T Base: China's state-owned enterprises dominate its defense industrial base, which Jane's rates as the most advanced in the Asia-Pacific region. Recent development of capability and capacity in China's traditional defense industry has enhanced its ability to "close the gap" in the on-going competition with the United States to field advanced platforms and systems. The United States maintains an overall advantage, but China's industry's ability to develop and refine A2/AD capabilities—including advanced weapons systems such as counter-space, unmanned systems capable of supporting China's information, network and electronic warfare efforts and anti-ship ballistic missiles (ASBMs)—that target U.S. and allied vulnerabilities pose credible threats to U.S. military superiority absent sufficient (and frequently costly) responses.

More broadly, China's defense industry and broader S&T community has achieved a series of high-profile technological successes in areas that have direct applicability to China's advanced weapons systems programs. These successes include advancements in deep underwater exploration, quantum computing and encryption, supercomputers, artificial intelligence, robotics and hypersonics.

China's Formula for Innovation Success: China's S&T successes in these areas are enabled by several common factors:

- **Sense of vulnerability (and opportunity):** The formula for innovation success typically begins with an urgent sense of a strategic vulnerability that needs to be redressed. For example, China's research in quantum computing and encryption was catalyzed by the Edward Snowden leaks, which revealed the degree to which the United States was monitoring conversations. China's MaRV program can be viewed as a response to the strategic challenges posed by U.S. carrier battle groups through ASBMs and the increasing sophistication of U.S. missile defense systems through HGVs.

  Successful innovation is also motivated by a frequently-linked perception that a moment of vulnerability is accompanied by opportunity to, over time, drive current technology and capability competitions towards different trajectories, ones in which China is better prepared to compete. China's burgeoning focus on Fourth Industrial Revolution technologies discussed in detail below is a particularly potent and relevant example of China's attempts to redefine and rebalance competitions in which it perceives it is vulnerable.

- **High-level direction:** High-level and top-down policy direction, typically in the form of an ambitious reform program or initiative is another consistent and common component of China's innovation success especially in focusing cross-industry collaboration and prioritizing research allocation. Examples referenced in this paper include Project Jinan's effort to develop an "unhackable" computer network, the "Made in China 2025" and "The Next Generation Artificial Intelligence Development Plan" (see Chapter 3).

- **High-level funding:** High-level direction brings high-levels of funding. While this funding may not always be used efficiently, injections of large amounts of government funding are seen as critical enablers of China's recent success in quantum encryption as well as its rapidly growing influence in artificial intelligence research across several industries.

- **Foreign technology and talent acquisition:** China's defense industry and its S&T community benefit from acquisition of foreign technology through several mechanisms, including:

    - Acquisition of Western companies
    - Partnerships with Western academic institutions and applied research centers (especially in Silicon Valley)
    - Joint ventures with companies seeking to enter the massive Chinese market (including U.S. aerospace giants and high-tech companies)
    - Direct and indirect investment in Western companies with interests in technologies such as sensors, artificial intelligence applications, big data analytics and advanced manufacturing.

    China has also been increasing its efforts to recruit Chinese scholars studying or teaching at U.S. academic institutions or working in U.S. high-tech sectors back to China to drive innovation in prioritized sectors.

Persistent Challenges: Two structural and incentive-driven challenges are inhibiting more fulsome, consistently system-wide innovation.

First, China's science, technology, engineering and math (STEM) educational system and research culture are still maturing, limiting the actual depth of indigenously trained experts in engineering disciplines from which China's industry can draw. Evidence of systemic research fraud, a conspicuously high number of retracted research articles from Chinese scholars and systemic cheating—all discussed later in this paper—combine to reflect a corrosive set of incentives and priorities within China's rapidly expanding university and applied research communities. As a result, legitimate innovation and achievement exists alongside institutionally incentivized corruption, a dynamic that serves to undermine the overall effectiveness and efficiency of the system, even if some parts of this system are capable of world-class innovation.

Second, China's defense industrial base has been slowed by a fractured and redundant structure that inhibits the competition and collaboration frequently required for innovation. Reforms designed to introduce more market-oriented approaches to innovation and development—most notably consolidation of and collaboration across state-owned enterprises, mixed ownership reform and enhanced engagement of China's private defense companies—have not yet achieved desired results.

Rather, China's industry's success is likely more directly linked to aggressive and effective technology acquisition efforts and enhanced policy focus on key technology areas.

China's Advanced Weapons Systems Summary

China and the Fourth Industrial Revolution— An Opportunity to Shift the Military-Technical Competition: China increasingly views exploitation of Fourth Industrial Revolution technologies as critical not only to economic resilience and national development, but also to China's national security and its capacity to gain ascendency (or the very least parity) with the U.S. advanced military capabilities.

Artificial intelligence stands out as an especially powerful catalyst of the development of "game changing" military capabilities that can:

- Greatly improve the capacity of intelligence communities and operators to understand their strategic and operational environment, discern patterns and imminent threats and identify and track adversaries in complex and fast-moving environments.

- Relieve some operators—especially pilots and vehicle drivers—of mundane tasks of interpreting multiple streams of C4ISR inputs and instead focus on the more mission critical tasks of flying/driving platforms and directing other assets to complete missions.

- Introduce new types of platforms and systems capable of cognitively responding to and seamlessly adapting to fluid operational environments to carry out missions without human intervention. Drone swarms, autonomous (or semi-autonomous) munitions and cognitive electronic warfare systems all pose new challenges to even the most technologically advanced militaries.

- Investments in quantum computing and encryption, advanced manufacturing and materials, robotics and cloud computing are improving China's military capabilities as well as the proficiency of China's industry to design and build more advanced capabilities.

"Full Speed Ahead": All of China's advanced weapons systems are moving forward at "full speed"[8] and are all seen as "priorities given [China's] overarching emphasis on finding a vulnerability in the U.S. armor."[9]

In addition, these weapons systems all support efforts to develop capabilities that will enable China to keep pace with the changing characteristics of conflict and confrontation articulated in the 2013 *Science of Military Strategy*:[10]

- "Confrontation of systems as the fundamental manner of confrontation": Warfare under informatized conditions is not limited to the defense sector or armed units. It is confrontational to all aspects of a country: political, economic, social, and legal systems as well

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[8] Telephone interview with Australian network member focused on China, September 2017.
[9] Telephone interview with Australian network member focused on China, September 2017.
[10] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.93. Translation from from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.7.
http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

- "Mid- and long-range accuracy strike as the determining method of operation": Technology has enabled wars to be conducted remotely

- "Power enhancement by using networked military information system": Information networks are vital to enhancing the capabilities and efficiency of militaries

- "Unification of information and artillery as the main method of operation": Information technology enhances the accuracy of distance striking, and informational attacks can cripple the ISR of an adversary

- "Area of operation expands from three-dimension to five-dimension": Warfare is conducted in the land, air and sea domains, but also space and cyberspace

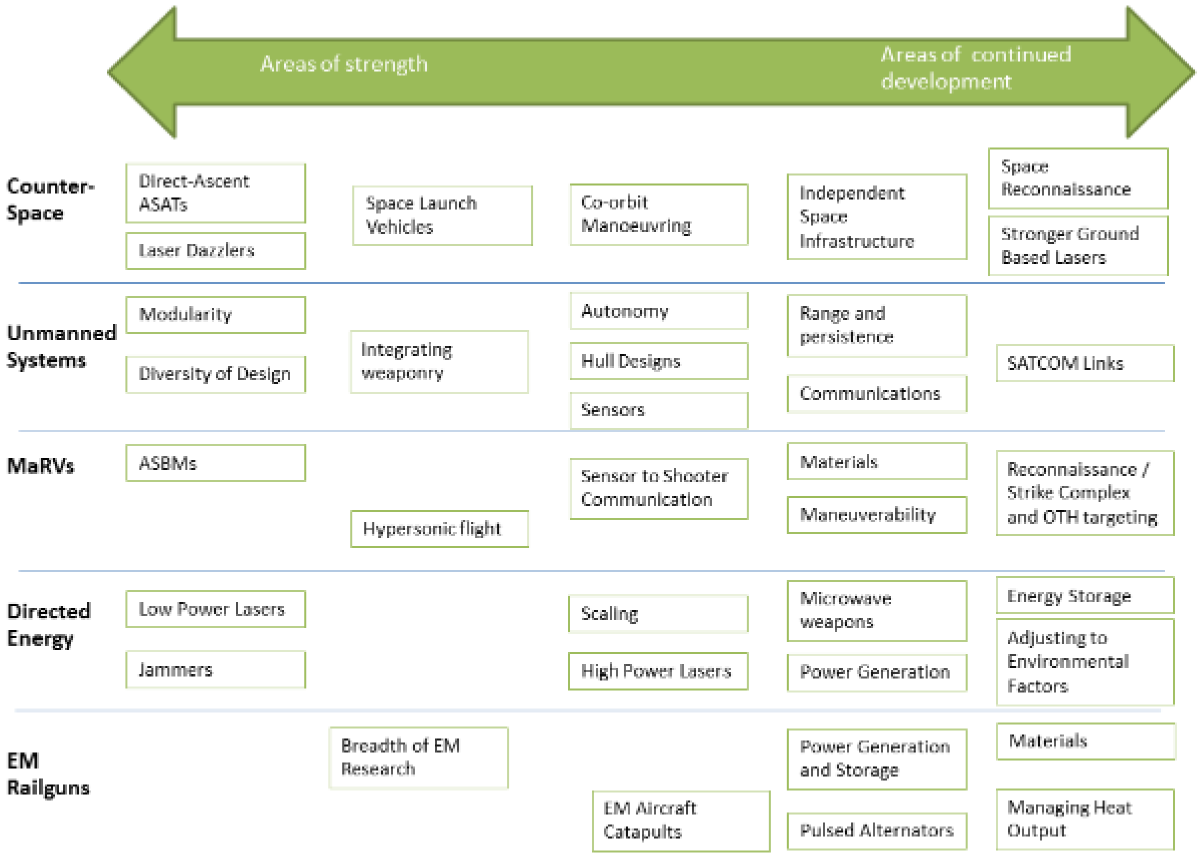
- "The fast-movers dominate the slow-movers": Time is a key component in modern war

- "Unmanned, invisible and inaudible wars are emerging": Weapons and military operations are using increasingly advanced technology[11]

And while these weapons systems are durable priorities for China, Table 1 below highlights several core technical areas in which China will require further development of requisite expertise to achieve fully mature capabilities in individual advanced weapons systems programs of interest to this paper and across several of them.

[11] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.93. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.8. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

Figure 1: Areas of continued technology challenges in each of the advanced weapons systems of interest to this paper. Generally, challenges can be divided into three categories: energy capture and storage, materials and communications.



"Game-Changer and Game-Leveler": Effective development and deployment of China's advanced weapons systems are "both a game-changer and game-leveler."[12] These weapons could upset current U.S. advantage or, at the least, affect stabilizing balances in the key domain area competitions that impact Indo-Pacific security.

However, the implications of the development of these weapons goes well beyond the operational realm. Success in China's advanced weapons systems programs will also undermine the "already slipping confidence in the U.S. and allied capacity"[13] to maintain an unquestioned military and technological advantage over China. Negative effects of this compounding loss of faith in U.S. power and commitment among regional allies and partners could include:

- Degraded alliances in which regional partners and potential partners are less likely to rely on the United States and more likely to hedge by deepening bilateral relations with China

- More aggressive behavior from regional allies vis-à-vis China or other regional actors to pursue their interests in an environment in which U.S. power does not act as an effective constraint on regional conflict

[12] Telephone interview with Australian network member focused on China, September 2017.
[13] Telephone interview with Australian network member focused on China, September 2017.

- More regional actors turning to China for military sales, especially in South and Southeast Asia, which will likely deepen the overall strategic relationship between these countries and China

The Amplifying Effects of Mutually Supporting Programs: Intersections between China's advanced weapons systems will amplify strategic and operational effects and create more significant challenges to U.S. military superiority. For example, the simultaneous development of artificial intelligence-infused weapons, counter-space weapons, hypersonic glide vehicles (HGVs) and cyber capabilities could combine to challenge U.S. capability in the linked domain areas of space and missile defense. These capabilities are central to American military dominance, potentially "discount[ing] not only U.S. military advantage, but also the way Americans prepare for and fight wars."[14]

Prioritizing Systems: This report evaluates five systems (counter-space, unmanned systems, maneuverable reentry vehicles, directed energy and electromagnetic railguns) plus artificial intelligence that supports them. Of the five systems evaluated (plus artificial intelligence), Jane's assesses that China's counter-space program is the highest priority due to the centrality of space-based assets for the U.S. reconnaissance-strike complex (command, control, communications, intelligence, surveillance, target acquisition and reconnaissance also known as "C3ISTAR") and the overall importance of space infrastructure to U.S. military power. The depth and breadth of China's counter-space capability could over the next decade degrade the effectiveness of U.S. space architecture or diminish or deny access to the architecture critical to exercising most U.S. military capabilities.

Counter-space capability was followed by autonomous unmanned systems, maneuverable reentry vehicles, directed energy and EM railguns in Jane's assessment of current priorities for development of China's advanced weapons systems.

Counter-space and autonomous unmanned vehicles are likely to exchange places on the list in the last half of the 2020s as autonomous unmanned systems and (at least semi-autonomous) weapons become a more common and in-demand feature of conflict. As of 2017, the technology behind the operational military use of artificial intelligence—not to mention operational concepts, organizational structures, training, ethical and legal issues associated with many applications of artificial intelligence on the battlefield—is still in the development and testing phase. However, the aggressive push to introduce more cognitive capabilities into combat—referred at points in this paper as the "intelligentization" of warfare—will ensure that gaining an edge in artificial intelligence-infused platforms (such as autonomous drone swarms), systems and weapons will become central to achieving military dominance in the late 2020s and beyond.

Implications and Recommendations

The existence and continued development, much less deployment, of China's advanced weapons systems presents challenges and opportunities—both as military capabilities designed to reshape military competitions in several domain/capability areas and as a more encompassing challenge to U.S. superiority in the Indo-Pacific region. Jane's estimates, given the maturity of some of these systems, that the United States has a small window, only a decade at most, to develop new capabilities and concepts for countering China's advanced weapons programs.

[14] China's Advanced Weapons Systems Implications and Recommendations Workshop, 5 October 2017, IHS Markit offices, Washington, D.C.

Jane's research and analysis suggests several policy recommendations for countering the military, economic, technological and geopolitical implications of China's advanced weapons systems. Components of our recommendations are weaved into the text throughout the paper and discussed in more detail in the Implications and Recommendations section at the conclusion of this paper.

Countering China's advanced weapons programs will require the United States to:

- *Up the United States' competitive game,* especially in terms of taking steps to engage allies in joint military programs, accelerate the reinstitution of "quadrilateral" collaboration between the United States, Japan, Australia and India and restrict access to high-value strategic technologies.

- *Mitigate the operational and strategic military risks* associated with the development of these programs through investments in capabilities such as directed energy, EM railguns and cognitive electronic warfare as well as operational concepts that help defray risks to specific military assets, especially in space and in the undersea domain and overall U.S. advantage in specific military domain area competitions.

- *Determine the type of capabilities required* to maintain U.S. advantage and stabilizing imbalances in military capability between China and the United States and its allies. Operational red teaming will be particularly useful in this effort.

- *Incorporate scenario planning and wargaming* to help explore alternative scenarios for the military, geopolitical and technology acquisition and protection competition in the Indo-Pacific and test competitive strategies. Wargames are useful for assessing second and third order consequences of strategic decisions. Futures-focused exercises also help analysts and decision-makers understand the balance of investment in capabilities, especially as the introduction of China's advanced weapons systems bring new dynamics and competitive trajectories to these domain area competitions.

- *Fund development of more complete intelligence* on the comparative strengths and vulnerabilities of China and the United States in this technological-military competition, among other regional actors, in order to develop effective competitive strategies for maintaining U.S. military superiority and for effectively protecting and pursuing U.S. interests—and those of our allies—in the region and beyond.

Background, Objectives, Methods and Structure

Background, Objectives, Methods and Structure

Jane's is pleased to provide this report to the U.S.-China Economic and Security Review Commission entitled *China's Advanced Weapons Programs.* This report marks the culmination of a research effort completed in January 2018 to assess five categories of China's advanced weapons systems. The programs and relevant capabilities within these categories as listed in the table below.

Table 2: The weapons systems investigated in this project

Advanced Weapons System Category	Description	Specific Weapons of Interest
Counter-Space	China has invested in a range of capabilities to deny space to the United States and its allies and to degrade or hold at risk U.S. space architecture.	• Anti-satellite (ASAT) missiles • Co-orbital satellites • Directed energy weapons • Cyber
Autonomous Unmanned Systems	Over the past five years, China has become a global leader in commercial and military unmanned aerial systems. It has also successfully tested the ability to use artificial intelligence (AI) to link over 100 drones in a single autonomous "swarm." Modern militaries have prioritized the development of autonomous unmanned vehicles, both as individual systems and as part of resilient and networked swarms, which are likely to be an increasingly prominent feature of the future battlefield over the next 10–15 years, according to Jane's Strategic Assessment and Futures Studies analysis.[15] China's industry has announced an array of new concepts for unmanned aerial vehicles (UAVs) and unmanned surface vehicles (USVs). Once mature, these new concepts could fill gaps in China's current anti-submarine warfare (ASW) capability, enhance China's airborne and surface intelligence, surveillance and reconnaissance (ISR) capabilities and further solidify China's position as a global leader in the unmanned systems export market.	• UAVs (fixed wing and vertical take-off and landing) • USVs • UUVs
Maneuverable Re-entry Vehicles (MaRVs)	China is attempting to develop multiple weapons that are launched by ballistic missiles but could vary from predictable ballistic trajectories upon reentry. These maneuverable weapons would pose a particularly daunting challenge for existing missile defenses and could upset delicate balances in the missile versus	• Hypersonic glide vehicles • Anti-ship ballistic missiles

[15] Nurkin, Tate, "Wonders at the Threshold: Tensions Shaping the Future of Military Platforms and Systems," DEFTECH Conference speech, Thun, Switzerland, November 15, 2017.

	missile defense competition in the Western Pacific.	
Directed Energy Weapons	China's industry has successfully developed several directed energy weapons, predominantly lasers and microwave weapons. These weapons are designed to carry out several missions including: close-in defense, jamming of platforms and systems and, over time, possibly missile defense. Directed energy weapons are also seen as a possible non-lethal weapon for crowd control during civil unrest and other missions.	• Lasers • Microwave and radio frequency weapons
Electromagnetic (EM) Railguns	U.S. development of advanced weapons, including hypersonic glide vehicles (HGV), is incentivizing China to evaluate additional options for air defense. One of these options is EM railguns, which use electromagnetic energy rather than a chemical reaction to strike targets with projectiles at speeds up to Mach 6.	• Naval railguns • Land based railguns • Handheld railguns

More specifically, our analysis of these programs focused on the following research areas and key questions:

- **Program Status and Features:** What are the key programs of interest within each category? What is their level of maturity both in absolute sense and relative to relevant U.S. capabilities? What are the challenges associated with development? Where are areas of considerable strength? What is the rate of progress associated with the development of these programs?

- **Motivations/Drivers:** What is the strategic and/or operational motivation for the development of these programs? How are they prioritized within China's political and military leadership and within the defense industrial base? How do China's advanced weapons systems programs interact with U.S. and allied capability developments? How does the broader competitive dynamic in the Western Pacific and Indian Ocean influence the direction of these programs? How does China's expanding list of priorities for its military modernization affect the development of these programs? Where do they fit in China's military modernization?

- **Inputs:** Who are the key industry, government and academia/research organizations involved in the development of these capabilities? What relationships are key to the development of these weapons? What are the technologies of interest to these programs?

- **Implications and Recommendations:** What does the existence of these programs mean for the United States, its allies and regional security and stability? What does the furtherance of these programs mean for the United States? What tools does the United States have available to slow the development of individual weapons systems programs? How might the United States engage its allies and partners in the region to blunt China's military modernization and the development of these weapons programs?

In addition to addressing these questions about the specific programs of interest to this project, our team also has developed a perspective on China's military modernization and the broader strategic context in which China's advanced weapons systems are being developed and possibly deployed. This analysis articulates our most fundamental assumptions about the competitive dynamics unfolding across the Indo-Pacific region and particularly between the United States and China.

It also seeks to explore and understand the transitions that are on-going in China's military modernization as well as how China's defense industrial base is evolving to provide more advanced and integrated capabilities. A key component of this analysis is an exploration of China's recently announced national development efforts to become a leader in Fourth Industrial Revolution[16] technologies—especially in industrial applications of Fourth Industrial Revolution technologies and in artificial intelligence, which has the potential to transform all aspects of human endeavor in the next twenty years, including warfare.

Research Methods and Sources

Jane's research approach involved several tools and methods:

Workshops: Jane's is a strong proponent of incorporating collaborative forums that bring together several experts with multiple and multi-disciplinary perspectives. We find that these forums frequently produce insights that cannot be generated by individual analysts working in isolation.

Over the course of this effort, Jane's held two workshops: A Framing Workshop held on 8 August 2017 near the beginning of the research effort, and an Implications and Recommendations Workshop on 5 October 2017. Each workshop brought together the Jane's research team with four to five outside experts to discuss the project's central issues. While outside participants were not experts on the specific weapons systems themselves, they did bring a range of relevant experiences and areas of expertise, especially in the study and assessment of:

[16] The term "Fourth Industrial Revolution" (also "Industry 4.0," though referred to throughout this paper as the Fourth Industrial Revolution) is used to describe the expansive, rapid and multi-dimensional innovation in a range of emerging technologies that are likely to transform most, if not all, aspects of modern life—from industrial and manufacturing processes and systems to the ways individuals and societies interact and connect, to governance best practice, national security and defense capabilities and environmental stewardship approaches. Specifically, the Fourth Industrial Revolution is largely built upon technologies that build efficiencies by connecting the physical and cyber domains; automate workflows, information processing and decision-making; build increased transparency and connectivity; and introduce new manufacturing techniques and materials that can minimize if not eliminate constraints on design and engineering of platforms, systems and buildings of current manufacturing processes. Frequently referenced and overlapping Fourth Industrial Revolution technologies include: robotics, artificial intelligence, blockchains, additive manufacturing, virtual and augmented reality, the Internet-of-Things, cloud computing, big data analytics, smart materials, smart sensors, biotechnologies and neuro-technologies and energy capture and storage technologies (i.e., renewables, among other ways of enhancing energy and power efficiency).

The three previous Industrial Revolutions are commonly identified as: 1) the introduction of spinning, weaving and machine tools in Britain's textile industry in the mid-18th century; 2) the introduction of the radio, telephone, television, electrical light, the internal combustion engine and advances in chemistry and physics between 1870 and 1930; and 3) the advancement of computing technology and theory that enabled the storage and manipulation of information at much higher speeds than in the past. The terminology of the Fourth Industrial Revolution is common, and many governmental, consulting, academic, policy and international organizations have published analyses of the parameters, trajectory and implications of the changes associated with this period of disruption. This footnote is informed by work published by Klaus Schwab, the Founder and Executive Chairman of the World Economic Forum and members of the World Economic Forum's expert network, including most recently the World Economic Forum's "Shaping the Fourth Industrial Revolution: A Handbook for Citizens, Policy-Makers, Business Leaders and Social Influencers." Advanced hard copies of this volume were distributed during the World Economic Forum's Annual Meeting of Global Futures Councils in Dubai in November 2017. The Lead Author of this paper attended the event as a member of the Future Council on International Security.

- U.S.-China strategic competition and Indo-Pacific regional defense and security dynamics
- China's military modernization, predominantly at a strategic level; that is, participants brought a robust understanding of the motivations for and strategic objectives of China's modernization activities
- Trends in the defense innovation and technology environment—especially acquisition and diffusion of advanced technologies—and the development of future military capabilities
- Advantages and constraints of the U.S. defense industrial base, relative to China's defense industrial base
- U.S. defense policy

The interaction between the Jane's team and these different, mostly strategically-focused, perspectives helped contextualize Jane's team's analysis of China's advanced weapons systems; vet, challenge and augment Jane's assumptions and frameworks; and provide insight into implications for the United States and its allies and partners in Asia. Insights and discussion points from these workshops are incorporated in various ways throughout this report.

Secondary Source Research: The central component of our effort was an extensive secondary source research effort. We engaged over 500 individual sources over the research effort. Categories of secondary sources engaged included:

- Jane's sources
- Chinese perspective sources (e.g., government, media and academics)
- International academic journals and scientific conferences
- U.S. government reports
- Foreign and allied government reports
- Think tank, consulting and academic reports, books and analysis
- International media reporting
- Company and university websites

Expert Network Engagement: Our team augmented this secondary source research by conducting in-person, telephone and email interviews with 14 in-network experts, including several located in the region, whose expertise and knowledge fell into five broad categories:

- Specific weapons systems of interest
- China's defense industry and industry reform
- China's military modernization
- Regional geopolitical competitions
- U.S. military capabilities and development programs

Many interviewees agreed to speak with us in a not-for-direct-attribution fashion. Their input is incorporated both directly into the text and aggregated into insights and analysis not attributed to a single interview.

Paper Structure and Contents

This paper is divided into three distinct sections, each designed to build off insights in the previous sections.

Section 1: Strategic Context Shaping China's Advanced Weapons Systems Development: This section provides an assessment of China's military modernization, its defense industrial base and regional geopolitical competitions. It also explores China's efforts to capitalize on the Fourth Industrial Revolution and its focus on artificial intelligence for economic and national development and national security advancement.

- Chapter 1: China's Military Modernization: Status, Objectives and Priorities
- Chapter 2: China's Defense Industrial Base Reforms, STEM Education and S&T Innovation Capacity
- Chapter 3: China, the Fourth Industrial Revolution and Artificial Intelligence

Section 2: China's Advanced Weapons Programs: The paper also includes profiles of each of the weapons systems of interest. These profiles provide background information on technologies and weapons of interest, summaries of China's activities in these areas, assessments of key players involved in development of these systems, possible pathways forward for development, motivations for and uses of each weapon systems and implications for China-U.S. competition.

The profiles focus on the same sets of questions generally, but vary in structure and specific content, reflecting the dimensions and nuances of the programs themselves. For example, discussion of China's autonomous unmanned systems is necessarily wide-ranging, given the scale of activity and diversity of types of platforms being developed across unmanned aerial, surface and underwater system categories. Conversely, our discussion of China's less mature electromagnetic railgun program is more focused on a small set of programs and initiatives.

Where appropriate, profiles also include analysis of adjacent areas of technological interest in order to best convey how core research in these technologies is supporting other advances in China's military modernization effort and national science and technology (S&T) development.

- Chapter 4: Overview of China's Advanced Weapons Systems Industry
- Chapter 5: China's Counter-space Capability
- Chapter 6: China's Unmanned Systems
- Chapter 7: China's Maneuverable Re-entry Vehicles (MaRVs)
- Chapter 8: China's Directed Energy Weapons
- Chapter 9: China's Electromagnetic Railguns and Hyper-Velocity Weapons

Section 3: Implications and Recommendations: The paper concludes with a review of key insights and implications of China's weapons programs and the broader strategic context as well as a series of recommendations in three categories.

- Chapter 10: Implications
- Chapter 11: Recommendations

Section 1

Strategic Context Shaping China's Advanced Weapons Systems Development

Chapter 1: China's Military Modernization: Status, Objectives and Priorities

Chapter 1 Key Themes and Insights

Multi-Layered Modernization: China's military modernization is pursuing three distinct objectives simultaneously—to a more maritime and regional focus, to power projection capabilities and to intelligentized warfare. Its overall procurement plans and the development of its advanced weapons systems programs will be designed to support each of these objectives, particularly if China's defense spending remains on a similarly steep upward trajectory. Funding constraints will require China to prioritize investments across and within these three objective areas.

- **Domain Area Competitions:** China's advanced weapons systems programs will also play an important role in reshaping operational and strategic balances in and across a series of military domain area competitions:
    - The undersea competition, especially autonomous unmanned systems
    - Missile versus missile defense, especially MARVs, electromagnetic railguns, and directed energy
    - Space versus counter-space, especially counter-space capabilities
    - The electromagnetic spectrum, especially unmanned vehicles, artificial intelligence and directed energy
- **Constraints:** Several strategic challenges could slow China's investment in its advanced weapons systems and military modernization effort in the mid- to long-term. Structural economic challenges intersecting with an ageing population and growing disparity in education and achievement between China's urban and rural populations could create cascading societal and political challenges that may a) reduce the amount of money available for China's advanced weapons systems and b) create a range of competing priorities that could force difficult decisions about the importance of China's advanced weapons programs and military modernization.

Overview of China's Military Modernization

China's military modernization is in the midst of three interlinked transitions: land to sea, regional to global power projection and "informatized" to "intelligentized"[17] warfare.

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[17] China recognizes that AI will transform warfare. First, effective integration of AI and big data analytics will greatly enhance intelligence and decision-making and enable human operators to focus on high-value tasks. Second, AI and other Fourth Industrial Revolution technologies will enable autonomy in individual platforms and systems and their ability to respond to changes in their operational environments without human intervention. Third, intelligentized warfare will introduce swarms of dozens (or more) autonomous systems, each operating in conjunction with other systems to achieve a specific mission. Future "Drone Swarms" will be resilient, redundant, potentially self-healing and difficult to defend against, constituting a novel challenge for air, surface and undersea defense.
Lieutenant General Liu Guozhi, director of the Central Military Commission's Science and Technology Commission believes the world is "entering the era of intelligentization" with rapid advancements in AI that will fundamentally change how militaries operate. He warns that the PLA does not want to fall behind. Major General Wang Kebin, then director of the General Staff Department Informatization Department sees intelligentization as the third stage of the information revolution.
Elsa Kania cites the game of Go where the AI player AlphaGo beat world champion Lee Sedol as one of the incidents that first exited the PLA about the military applications of AI. The China Military Science Editorial Department hosted a workshop to analyze the implications. China Military Science Editorial Department [中国军事科学 编辑部], "A Summary of the Workshop on the Game between AlphaGo and Lee Sedol and the Intelligentization of Military Command and Decision-Making" [围棋人机大战与军事指挥决策智能化研讨会观点综述], China Military Science [中国军事科学], April 2, 2016.
Kania, Elsa, "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security. November 2017. p. 4.

Individually and collectively, these transitions reveal a dynamic effort proceeding simultaneously along multiple time horizons and in support of multiple objectives and development priorities. These multiple transitions signal an acute acknowledgement of China's current strategic and operational vulnerabilities—especially, but not exclusively, relative to the United States. They also signal an ambition to catch up and eventually overtake the United States as a military power in the region and then globally while capitalizing on the opportunity to become the global leader in capabilities critical to the future of conflict.

Each transition is derived first from an Indo-Pacific focus and is rooted in a view of a shifting regional and global geopolitical landscape. According to the 2013 *Science of Military Strategy*, the global geopolitical landscape is moving from an "unprecedentedly unipolar" world dominated by the United States, to a new 21st century "international balance that is characterized by multi-polarity and co-governance." [18] While China acknowledges that the United States is the world's only remaining superpower, China sees itself as a critical player in the rebalancing to multi-polarity, and a force to limit U.S. global influence. China sees opportunities in globalization and the informatization of society to propel itself forward economically, socially and technologically.[19]

China views the military challenge in these Indo-Pacific geographies as being against "America-plus." That is, China is competing first and foremost against a long-standing and standalone American military advantage *plus* the "force multiplier" effect of U.S. alliances—in particular Japan and Australia—and increasingly aligned U.S. interests with India. China's perception is that the United States and its allies and partners in the Indo-Pacific (Japan, South Korea, Taiwan, the Philippines, Australia, India, future Southeast Asian partners and possibly Vietnam) are cooperating to strategically contain China.[20]

Changing geopolitical dynamics have security and defense implications for China and for the region. China sees a change in the types of conflicts for which it needs to prepare and in the domains in which it will be required to compete and potentially contest. As cited previously in this report, the 2013 *Science of Military Strategy* argues:

> "Generally, the possibility of a large-scale ground invasion by an adversary is minimal. However, the danger of being the target of high-technological warfare, such as air-naval, air-space, and space-cyber wars, is intensifying. The threat from the east is more severe than that from the west, the threat from the sea is more severe than that from the ground; the threat from space and cyber network is gradually becoming true. The probability of conducting military operations to protect rights and limited oversea war operations is ever increasing. The most severe war threat is a large-scale strategic sudden attack launched by a strong adversary, which aims at destroying our war potential to force us to surrender.[21]

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[18] Kania, Elsa, "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security. November 2017. p. 4.

[19] Kania, Elsa, "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security. November 2017. p. 4.

[20] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p. 7. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf, p.7

China believes that technological development is critical for maintaining deterrence in an environment in which "the emergence of new deterrence forces, based on new technology such as information, cyberspace, space, and new-material technologies, is revolutionarily changing the mechanism, method, and area of operation. It heralds a completely new method of deterrence, symbolized by constructing asymmetrical method of deterrence." [22]

Within this geopolitical and military context, meeting this "America-plus" military challenge and the anticipated types of conflict it will create are the primary drivers of China's military modernization. Weakening U.S. alliances and the durability of the United States' shared interests with its regional allies is a second motivation for, and objective of, China's military modernization and of the development of its advanced weapons systems. Each of the three transitions and the competition unfolding across the region drives separate acquisition and development priorities, but *all* tilt investment towards China's advanced weapons systems discussed in this paper.

Domain Area Transition

The most immediately relevant development—in terms of operational and strategic exigencies as well as timeframe—affecting the trajectory of China's military modernization is the transition in the focus of China's anti-access/area denial efforts from prioritizing coastal defense to prioritizing "near seas protection" in the first island chain (see Figure 2). Anti-access/area denial is also referred to by some People's Liberation Army (PLA) strategists as "counter-intervention,"[23] but hereafter in this paper as "A2/AD".

This transition has been on-going for much of this decade, but has increased in pace and intensity since 2015, leading to a pronounced and strategically notable shift in influence and investment concerns within the PLA. Asymmetric capabilities such as counter-space and cyber, as well as cruise missiles, anti-ship ballistic missiles (ASBMs) and unmanned systems remain a PLA priority. But so, too, now are maritime capabilities that operationalize a move from a land force dominated military with a predominantly territorial defense mission toward a more expansive—but still regional and defensive—force able to strategically manage the maritime domain.

The impetus of this transition is found in economic motivations, of course, but also an intense sense of a growing threat from the maritime domain that needs to be preempted, deterred and, in general, acknowledged and met. This concern was clearly articulated in the 2013 *Science of Military Strategy* document:

> "The most probable war threat is a limited military conflict from the sea. The war we need to prepare for, particularly given the background of nuclear deterrence, is a large-scale, and highly intensive local war from the sea." [24]

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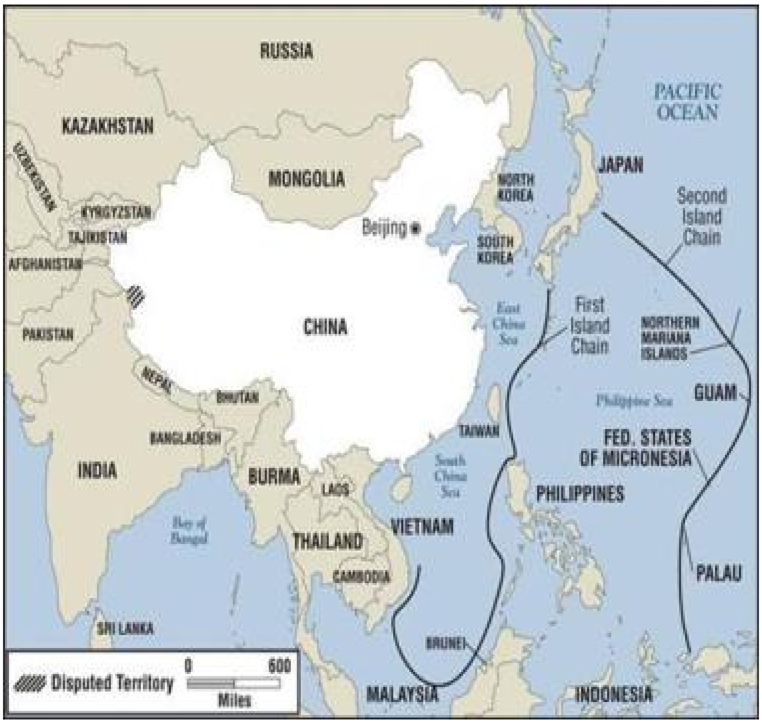
[22] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.142-143. Translation from Chase, Michael and Arthur Chan, "China's Evolving Approach to 'Integrated Strategic Deterrence". RAND Corporation. 2016. https://www.rand.org/content/dam/rand/pubs/research_reports/RR1300/RR1366/RAND_RR1366.pdf P.19

[23] In October 2016, Chief of Naval Operations Admiral John Richardson announced that the U.S. Navy would no longer use the term "A2/AD" as a "one size fits all . . . standalone term" to describe efforts by multiple actors to counter efforts of the U.S. Navy to access and operate in contested environments. However, the term continues to be used, especially in the context of China's military modernization and remains the most common term describing efforts to develop and deploy capabilities designed to deny adversaries or competitors the capacity to deploy to and operate platforms and systems within a given theater or area. Richardson, John, "Chief of Naval Operations Adm. John Richardson: Deconstructing A2AD," *National Interest*, October 3, 2016. http://nationalinterest.org/feature/chief-naval-operations-adm-john-richardson-deconstructing-17918.

[24] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p.7. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

China's emerging maritime focus was essentially codified during a July 2013 meeting of the Chinese Communist Party (CCP) Politburo to discuss maritime power. At this meeting, Chinese President and General Secretary of the CCP Xi Jinping stated China needed to "do more to take interest in the sea, understand the sea, and strategically manage the sea, and continually do more to promote China's efforts to become a maritime power."[25] President Xi also highlighted the importance of the maritime domain in the inaugural meeting of the Central Commission for Integrated Civilian and Military Development in June 2017.[26]

Figure 2: Map depicting the first and second island chains around which China's A2/AD modernization approach is centered



Source: U.S. Naval Institute

China's 2015 Military Strategy White Paper also emphasized this shift in the balance of focus of the land and sea domains and to the need to develop capabilities to "strategically manage" the sea: "the traditional mentality that land outweighs sea must be abandoned, and great importance has to be attached to managing the seas and oceans and protecting maritime rights and interests."[27]

Critically, while China focuses more in the maritime domain, its A2/AD strategy and maritime strategy both remain essentially regional in focus, largely concentrated on denying access to and protecting China's interests within the first island chain. The U.S. Department of Defense (DoD) made this point in the 2017 Annual Report to Congress on Military and Security Developments Involving the People's Republic of China, noting that "Jane's Defense Budgets expect China's defense budget to increase by an annual average of 7 percent, growing to $260 billion by 2020 for a force that, although expanding, is expected over the near-term to *remain primarily regional*."[28]

As a result, the make-up of China's military forces is evolving in the relative number of personnel in each branch of the PLA and the type of platforms and systems that China develops and deploys.

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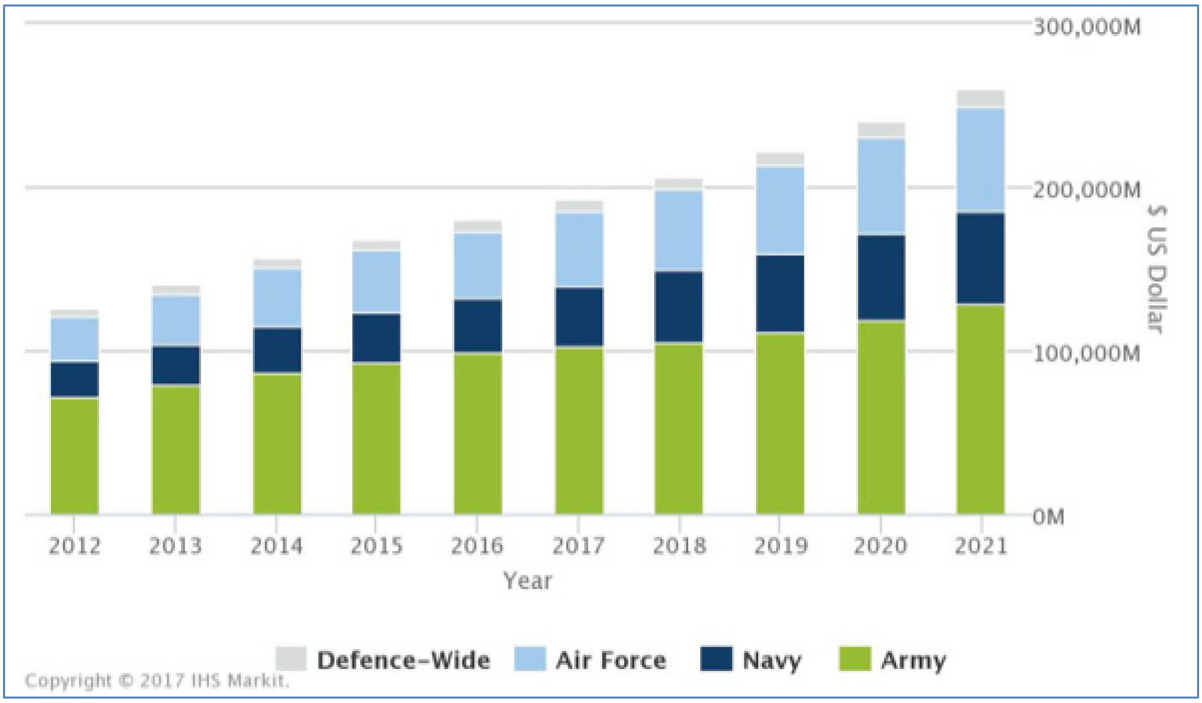
[25] Martinson, Ryan, "Jinglue Haiyang: The Naval Implications of Xi Jinping's New Strategic Concept," *China Brief*, Jamestown Foundation, January 9, 2017. https://jamestown.org/program/jinglue-haiyang-the-naval-implications-of-xi-jinpings-new-strategic-concept/.
[26] Grevatt, Jon, "China Inaugurates Commission to Lead Civil-Military Integration," *Jane's Defense Weekly*, June 21, 2017. https://janes.ihs.com/Janes/Display/FG_521331-JDW.
[27] China's Military Strategy, The State Council Information Office of the People's Republic of China, May 26, 2015, http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm
[28] U.S. Department of Defense, Office of the Secretary of Defense, *Annual Report to* Congress, May 2017, 66. https://www.defense.gov/Portals/1/Documents/pubs/2017_China_Military_Power_Report.PDF?ver=2017-06-06-141328-770.

Xu Guangyu, a retired Chinese military officer and a consultant to the China Arms Control and Disarmament Association, highlighted how recent reorganization of the PLA—which included a reduction of the overall force size by 300,000 troops—portends a rebalancing of the PLA structure. According to Xu: "My guess is that the PLA will try to adjust that to about 50% army, 25% navy and 25% air force in the coming years," away from the current "70% army, 15% navy and 15% air force."[29]

Whether that specific ratio of *overall force size* holds true, Jane's forecasts shifts in the overall focus of *defense spending* that indicate not only a pronounced absolute rise in spending on the PLA Navy (PLAN), but also a significant rebalancing of spending between the PLA and PLAN, as evidence by the chart below.

Figure 3: China's defense spending by service including defense-wide activities. The chart demonstrates a growing portion of China's overall defense budget being devoted to the PLAN, with a more pronounced increase in spending after 2015. Note: Data in this chart is based on Jane's forecast of China's *total defense spending* as opposed to China's *stated defense spending.* Jane's estimates that China's stated spending on defense is roughly 30 – 35% lower than its actual total defense spend.



Source: ***Jane's Defense Budgets: China***

Table 3 offers more granular insight into the Jane's data behind Figure 3, comparing the rise in PLAN spending to spending on the traditionally dominant PLA.

Table 3: PLA and PLAN Spending Forecasts (2015 - 2021). The table shows a notable rise in PLAN spending and overall percent of China's defense spending over the forecast period as well as a corresponding decline in the percentage of spending on China's PLA during this period.

	2015	2016	2017	2018	2019	2020	2021	Absolute Increase

[29] Kaimen, Jonathon, Makinen, Julie and Cloud, David S., "China Troop Cut Plan Is More About Modernization Than Peace, Analysts Say," *Los Angeles Times,* September 3, 2015. http://www.latimes.com/world/asia/la-fg-china-troops-20150904-story.html.

								from 2015 to 2021
PLAN Spending Forecast	$31,392.75	$33,862.00	$37,913.12	$43,410.00	$47,844.40	$52,199.00	$57,115.00	$25,722.25 (81.94% increase)
% of Total Annual Spending	18.70%	18.85%	19.70%	21.00%	21.50%	21.70%	21.90%	
PLA Spending Forecast	$92,331.62	$98,352.86	$101,999.79	$105,425.96	$111,266.04	$119,071.44	$127,793.50	$35,461.88 (38.41% increase)
% of Total Annual Spending	55.00%	54.75%	53.00%	50.99%	50.00%	49.50%	49.00%	
Total Defense Spending	$167,875.66	$179,639.91	$192,452.44	$206,751.57	$222,537.09	$240,548.31	$260,803.06	$92,927.4 (55.35% increase)

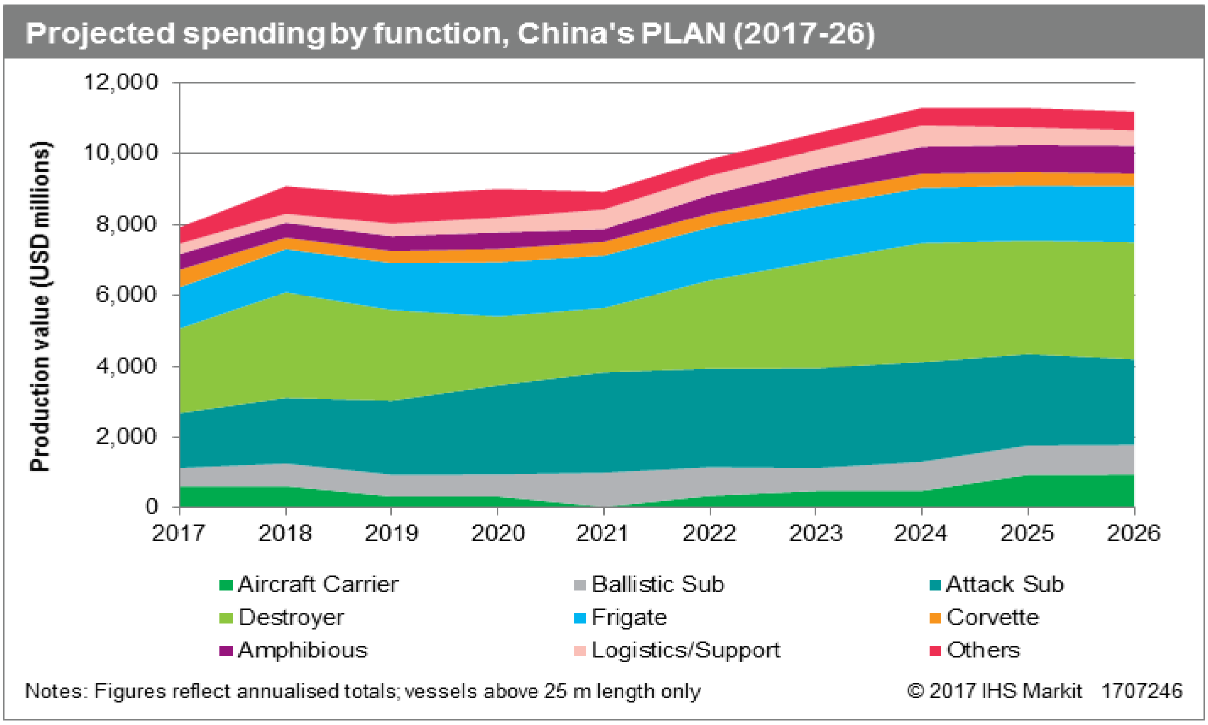
The increase in PLAN spending not limited to a specific class of ship, but Jane's forecast does indicate emphasis on a regional A2/AD mission.

The biggest area of investment is projected to be medium-large surface combatants that will be focused on local and regional A2/AD missions. Anti-air warfare (AAW) destroyers and frigates for ASW and escort roles should account for around 43% of the total projected spending. These ships will not only modernize assets due for replacement, but also enlarge current fleets.

Significant investment will also be made in attack submarines, with spending for new conventional and nuclear-propelled boats estimated to be approximately a quarter of the total naval procurement budget.[30] While there is an on-going debate within China's military about the respective roles of conventional and nuclear submarines (outlined in more detail below), the investment in conventional submarines at least indicates a strong continued commitment to close-in A2/AD missions and pressing China's maritime territorial interests in contested boundary areas, such as the South China Sea.

[30] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "Peoples Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.

Figure 4: China's projected spending by ship/capability function for China's PLAN, 2017 - 2026.



Source: Jane's Market Forecast Data

Key investments and developments in frigates, corvettes, amphibious warfare and other ships over the next decade include:[31]

Table 4: Assessment of China's forecast ship procurement over the next decade

Ship Type	Activities
Frigates	Medium-sized vessels are being procured at a steady pace, with the Type 054A frigates expected to form the backbone of China's PLAN fleet of surface combatants in the 2020s. Two ships of a new general-purpose frigate class were commissioned in 2005-2006, but follow-on units were built in series at Huangpu and Hudong shipyards to a modified design that integrates a vertical launching system for local air defense. 25 vessels have entered service by August 2017, to replace the ageing Type 053 frigates and expand the frigates fleets. A class of at least 30 is expected. Progressive improvements have been noted over the past decade, for instance the fitting of variable depth sonar and towed array in selected units of the class, as indicated by apertures cut in the transoms. Technological advancements made by the Chinese shipbuilding and sensors industries indicate even more strongly that follow-on frigates in the 2020s may be of a further modified design, potentially incorporating an integrated mast, as seen on the Type 055 destroyer and displayed at trade shows by industry. Moreover, industry has confirmed that a new class of around 2,500-ton trimaran-hulled frigates (similar to the U.S. Navy's Littoral Combat Ship design) is currently being built for the PLAN. The ship is understood to be more heavily armed than the American class and not configured to carry interchangeable/modular payloads. The U.S. Department of Defense classifies the Type 055 as a cruiser.

[31] All information contained in Table 4 is taken from: Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "Peoples Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.

Amphibious Warfare Ships	Despite efforts to increase the PLAN's blue water capacity, near-seas defense remains a top priority, especially because the navy would play a vital role in a number of potential regional flashpoints that the government considers "core interests"—namely Taiwan's sovereignty and territorial disputes in the South China and East China Seas. As such, investment in amphibious warfare vessels is projected to ramp up, with reports suggesting that the much-awaited procurement of a large landing helicopter dock for the PLAN, dubbed Type 075, has already started construction at Hudong-Zhonghua. Standing at a 40,000-ton displacement, the Type 075 LHD will be far larger than previous amphibious warfare ships constructed for the PLAN and will reportedly feature six spots on the flight deck for simultaneous airborne operations. Efforts to align amphibious operations concepts with those of Western navies were noted since at least 2006, when construction of the 20,000-ton Type 071 landing platform dock began. Four units have entered service since, with a fifth launched in June 2017. A large well deck area allows the ship to operate away from enemy's shores, making use of ship-to-shore connectors like air cushion vehicles of landing craft utilities.
Corvettes	To better enforce China's territorial claims in the East China and South China Seas and defend its regional waters, the PLAN is expected to continue the procurement of corvette-size surface combatants, such as the Type 056 corvette. Series production has been under way at four shipyards from around 2010/11, with the class expected to provide the replacement of older classes such as the Type 053 light frigates and Type 037IG attack craft, but also as a cheap vessel to improve patrol, surveillance, ASW and anti-surface warfare capabilities. In November 2013, a modified variant, expected to provide enhanced ASW capability, was noted to feature a hatch at the stern. Ten units of the ASW variant have entered service by March 2017, and more are estimated to follow. A total of 34 ships are reportedly in service as of July 2017, and a class of around 41-45 ships is expected by 2019/20 based on past production rates, in order to provide additional presence in nearby waters. Continued procurement of new corvettes is projected in the 2020s, to sustain industry activity and provide a stronger deterrent in regional scenarios. These units may be of a further modified variant, featuring additional design improvements; more may be fitted for ASW missions.
Other Ship Types	Although major surface assets and submarines often make the headlines, China is estimated to gradually build up a well-rounded navy, capable to accomplish a variety of missions in the near and far seas in the decades ahead. As such, the procurement focus is expected to shift also to other platform types. For instance, the PLAN has recently added a sixth Type 815 intelligence-gathering ship in January 2017. More vessels are estimated for the future, to provide the navy with theater intelligence collection in open seas, in light of future carrier strike group operations. Additional ocean surveillance ships are also estimated to increase capability in the roles. China has recently procured two new Type 272 icebreakers to replace the decommissioned Type 071 units. The two ships were commissioned in January and March 2016, but the overall number remains to be determined, given the reported interests of China in developments concerning the polar regions. New mine countermeasures vessels are under construction to replace the ageing Type 6610 and Type 082 classes. One unit of the new Type 082B design was commissioned in 2005, followed by four modified variants in 2011-2016. A parallel procurement of six Type 081A MCMVs was noted in the same timeframe, and additional hulls are estimated to follow.

In addition to the above referenced procurements, the PLAN has taken additional steps that reflect a growing orientation toward the capacity to meet regional contingencies and operate regionally, and even beyond, in the maritime domain. For example, in March 2017, the PLAN announced that it will be expanding its Marine Corps from 20,000 to 100,000.[32] China stated that the expansion will enable the Marine Corps "to protect the [country's] maritime lifelines and its growing interests overseas."[33] Most of PLAN's Marines are currently deployed with the South Sea Fleet.[34]

The PLAN has reported that it anticipates a near future requirement for 400 carrier-trained pilots to support "at least four carriers." *Global Times* reported that many carrier pilots were drawn from the PLAAF, but the PLAN Air Force is now working to recruit and train its own pilots.[35]

Support for and expansion of missions for China's Maritime Militia is also part of this transition from territorial defense to near seas protection. The Maritime Militia is a large pool of commercial fisherman and mariners that receive, among other military or dual use assets "inter-operable electronics; position, navigation and timing technologies; and even military training" from the Chinese government, ultimately constituting an "underestimated, ambiguous, quasi-stealth force" capable of supporting the PLA and PLAN, and increasingly of pressing China's interests in gray zone territorial disputes "that is analogous in the maritime domain to the 'little green men' Russia deployed in Crimea, Ukraine, in 2014."[36]

China's Maritime Militia has several historic missions, from "support the front" to provide logistics and sustainment support to the PLA and PLAN to response to fast moving incidents at sea, including weather emergencies and natural disasters. However, Andrew Erickson and Connor Kennedy argue that "a more recent evolution in Maritime Militia responsibilities is to conduct 'rights protection' (*weiquan)* missions. . . [these missions] include actions such as law enforcement in coordination with MLE forces, island landings, and work in disputed waters."[37] For example, the Maritime Militia reportedly played a significant role in the 2014 Haiyang Shiyou 981 oil rig standoff with Vietnam.[38]

Of course, securing the near seas relies on more than just a larger number of more capable surface ships, supporting capabilities and infrastructure or conventional and irregular naval and maritime capabilities. It also includes the capacity to deny access to competitor/enemy surface and undersea fleets, especially that of the United States and even irregular capabilities, including China's maritime militia.

And here again, China's investment in capabilities explicitly designed to better compete in the maritime domain—including novel capabilities and advanced weapons systems—has grown and become more focused. The development of a viable, though perhaps still vulnerable, ASBM capability, the DF-21D and DF-26 missiles, constitutes a significant breakthrough in China's A2/AD capability and broader efforts at both near seas protection.

[32] "China > Armed Forces," *Jane's,* July 13, 2017. https://janes.ihs.com/Janes/Display/chins100-cna.
[33] Dominguez, Gabriel, "PLA ground forces enhancing combat readiness, says report," *Jane's*, April 10, 2017. https://janes.ihs.com/Janes/Display/jdw65318-jdw-2017.
[34] Dominguez, Gabriel, "China plans to vastly expand size of marine corps, says report," *Jane's*, March 15, 2017. https://janes.ihs.com/Janes/Display/jdw65009-jdw-2017.
[35] Tate, Andrew, "China aims to speed up training of carrier pilots," *Jane's*, January 10, 2018. https://janes.ihs.com/Janes/Display/FG_714287-JDW.
[36] Clad, James and Manning, Robert, "Catching Controversy: China's Maritime Militia," *Jane's Defense Weekly*, 15 December 2016, https://janes.ihs.com/Janes/Display/jdw64077-jdw-2017.
[37] Erickson and Connor M. Kennedy, "China's Maritime Militia," CNA Corporation, March 7, 2016. https://www.cna.org/cna_files/pdf/Chinas-Maritime-Militia.pdf.
[38] Erickson and Connor M. Kennedy, "China's Maritime Militia," CNA Corporation, March 7, 2016. https://www.cna.org/cna_files/pdf/Chinas-Maritime-Militia.pdf.

As Richard Fisher, a Senior Fellow at the International Assessment and Strategy Center and frequent Jane's contributor, noted after the display of the DF-26 intermediate-range ballistic missile during China's September 2015 Victory Day parade: "Perhaps the most serious surprise was the revelation by the parade announcer that the DF-26 intermediate-range ballistic missile already is equipped with an anti-ship warhead."[39]

China is also rebalancing its air-fleet in order to better support near (and eventually far) seas protection missions. The table below demonstrates the imbalance in the PLA Air Force (PLAAF) fleet and highlights gaps in the quantity of support aircraft that can sustain and project a force out to the first island chain and beyond.[40]

Table 5: Balance of PLAAF Air Fleet versus the U.S. Air Force in 2013 and 2017

Year		United States	China
2013	% of Combat Aircraft	60%	85%
	% of Support Aircraft	40%	15%
2017	% of Combat Aircraft	79%	67%
	% of Support Aircraft	21%	23%

Source: Derived from Jane's Security and Military Assessments: China and United States data

China's industry has actively worked to develop indigenous capabilities to both address these gaps and to further enhance the capabilities of its combat aircraft fleet, including the development of two fifth generation designs (J-20 and J-31, the latter of which is designated for export). The indigenously developed Y-9 transport aircraft (with airborne early warning and control variants) and Y-20 transport aircraft are part of a broader plan to augment a formidable combat aircraft fleet with force multiplying capabilities such as strategic lift by the early to mid-2020s (see Figure 5 below).

Figure 5: IHS Jane's Overview of the four phases of China's airpower modernization efforts

1992 - 2002	2002 - 2012	2012 - 2022	2022 +
Tactical Air (TACAIR) modernization through imports • Imports of modern combat aircraft from Russia • Domestic aerospace sector transitioning from assembly to development of modern designs	**TACAIR modernization from indigenous sources** • Dramatic reduction in imports of combat aircraft • Production rates for indigenous combat aircraft accelerate	**Emergence of multiplying capabilities** • Pragmatic expansion of lift and tanker capabilities through imports • Development of indigenous Intelligence, Surveillance and Reconnaissance and lift platforms	**Full Spectrum, strategic modernizations** • Focus shifts from TACAIR to power projection • Domestic aerospace sector increasingly able to support all aspects of modernization

[39] Kaimen, Jonathon, Makinen, Julie and Cloud, David S., "China Troop Cut Plan Is More About Modernization Than Peace, Analysts Say," *Los Angeles Times,* September 3, 2015. http://www.latimes.com/world/asia/la-fg-china-troops-20150904-story.html.

[40] Hardy, James, "China's Military Power and Technology" briefing, September 2013.

In addition, the PLAAF is developing capabilities to operate at longer ranges from the Chinese homeland. In September 2016, former PLAAF commander General Ma Xiaotian stated that China is building a new strategic bomber aircraft to enhance its long-range strike capabilities.[41] In July 2017, PLAAF spokesperson Senior Colonel Shen Jinke announced that the PLAAF has increased its frequency of far-sea training activities from four times a year in 2015 to now several times a week.[42] In September 2017, PLAAF commander Lieutenant General Ding Laihang announced that the service will be shifting its focus to long-range missions to become a "strategic" airborne unit and to protect national interests "wherever they exist." Ding also noted that "we will continue to carry out long-distance training over oceans."[43]

Analysis of CCTV footage of a J-11B fighter on Woody Island suggests that China is starting to regularize deployment of combat aircraft to the Paracel Islands in the South China Sea (SCS). Specialized hangers have been built on SCS airbases to protect aircraft from humidity and weather. A Yunshuji-9 transport aircraft was recently deployed to Fiery Cross, suggesting that the PLAAF may begin to deploy fighters and other aircraft to the airbases in the Spratly Islands of the SCS.[44]

As is discussed in considerably more detail throughout this section and in Jane's review of China's unmanned systems, more active and effective efforts in the undersea domain are also prioritized as part enhanced focus on the undersea domain, including development of "the Undersea Great Wall": a network of undersea sensors and USVs designed to create a net to enhance detection of U.S. (and other actors') submarines and undersea assets.[45]

Power Projection in an Anti-Access/Area Denial Modernization

China's main focus is—and will continue to be—enhancement of its ability to meet contingencies in the region, especially around Taiwan, and to deny the United States' and other potential adversaries' access to the region. China is also developing capabilities that will enable it to project power—particularly naval power—beyond the Western Pacific in order to support China's increasingly global economic interests and its efforts to be perceived as a global power.

Building a robust aircraft carrier fleet is one key indicator of this transition. China's first carrier, the *Liaoning,* was commissioned into service in September 2012.[46] The ex-Ukrainian, Soviet-made carrier is viewed primarily as a "prestige" platform with a predominantly training mission.

However, China is indigenously developing and building a larger number of more sophisticated platforms. China's first indigenously-built aircraft carrier, the Type 001A, was floated in April 2017, and Jane's expects it will be commissioned "in the 2020s."[47] Two additional carriers are expected to be built in the 2020s, including one that is expected to feature EML that will enable Chinese carriers to be loaded with heavier planes equipped with more munitions than the current ski jump take-off configuration. As described in Chapter 9 (Electromagnetic Railguns), China's advancement in EML is

[41] "China- Air Force," *Jane's*, January 30, 2018. https://janes.ihs.com/Janes/Display/jwafa053-cna.
[42] Dominguez, Gabriel, "PLAAF sends fighters, bombers on 'regular patrol exercise' around Taiwan," *Jane's*, December 13, 2017. https://janes.ihs.com/Janes/Display/FG_699365-JDW.
[43] Dominguez, Gabriel, "PLAAF to increasingly focus on 'strategic projection', says new commander," *Jane's*, September 6, 2017. https://janes.ihs.com/Janes/Display/FG_638832-JDW.
[44] Fisher, Richard, "PLAAF seeks to regularize combat aircraft deployments to South China Sea," *Jane's*, December 7, 2017. https://janes.ihs.com/Janes/Display/FG_693368-JDW.
[45] Fisher, Richard D., "China Proposes 'Underwater Great Wall' That Could Erode US, Russian Submarine Advantages," *Jane's Defense Weekly*, May 17, 2016. https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016.
[46] "China hires Ukrainian engineer of aircraft carrier the Varyag (Liaoning)," People's Daily Online, September 6, 2017. http://en.people.cn/n3/2017/0906/c90000-9265324.html.
[47] Dominguez, Gabriel, "China Launches First Indigenously Built Aircraft Carrier," *Jane's Defense Weekly,* April 26, 2017. https://janes.ihs.com/Janes/Display/jdw65445-jdw-2017.

tied to a broader EM research initiative that supports China's electromagnetic railgun program, demonstrating one of many links between China's advanced weapons programs and its power projection efforts.

The EML system may actually be a necessity for China to fully leverage the potential of its carrier fleet. China has developed a single carrier-based fighter, the J-15, which weighs 33 tons fully loaded at take-off, a weight that would stretch the capacity of highly advanced steam catapults to launch. A Chinese military source noted to the *South China Morning Post* that "even the U.S. Navy's new generation C 13-2 steam catapult launch engines, installed on Nimitz-class aircraft carriers, would struggle to launch the aircraft efficiently" and that "EMALS' [General Atomics' Electromagnetic Aircraft Launch System program] experimental results showed the new technology is able to catapult the J-15 more easily and more efficiently."[48]

Moreover, the PLAN is also focusing on support of its carrier fleet by increasing the number of auxiliary vessels available with a mix of fleet replenishment tankers and larger combat support ships. These ships will be vital assets to enable other ship types in their forward-deployed positions on a sustained basis, so that, according to a September 2017 Jane's Defense Insight Report entitled *The People's Liberation Army Navy*: *Examining China's Current and Future Naval Capabilities,* "areas further from the homeland's shores can be reached for power projection missions."[49]

In August 2017, the first 45,000-ton Type 901 general supply vessel (which is similar to the Fleet Replenishment Oiler classification of the U.S. Navy) was commissioned into the PLAN.[50] The vessel is expected to provide future carrier strike groups with enhanced replenishment-at-sea and fleet support capacity. The *Hulun Lake* will be able to provide fuel oil (five hose rigs on the port side and four on the starboard side) for the carrier as well as aviation fuel and air-launched munitions.[51]

Medium auxiliary vessels are also being procured, and a new batch of the Type 903 replenishment ships started construction at two shipyards from around 2011. Additional units of the 23,000-ton vessel were delivered since, for a total of eight ships in service as of August 2017. More units may be acquired in the 2020s, although the focus is expected to be on larger platforms.[52]

Similarly, additional units of the 15,000-ton Type 904 general supply issue ship are estimated, following two units launched in 2014-2015 and one further ship reported under construction. Follow-on units in the 2020s may be built to a further modified design.[53]

China's investment in new destroyers is also a sign of greater ambitions to project power, particularly through carrier strike groups. The first ship of a new, larger class of AAW destroyers,

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[48] Chan, Minnie, "China's aircraft carrier conundrum: hi-tech launch system for old, heavy fighter jets", *South China Morning Post,* 19 November 2017, http://www.scmp.com/news/china/diplomacy-defence/article/2120391/chinas-aircraft-carrier-conundrum-hi-tech-launch-system.
[49] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[50] "China First Type 901 Replenishment Oiler Hulun Lake Commissioner with PLAN North Sea Fleet", Navy Recognition.com, September 1, 2017, http://www.navyrecognition.com/index.php/news/defence-news/2017/september-2017-navy-naval-forces-defense-industry-technology-maritime-security-global-news/5537-china-first-type-901-replenishment-oiler-hulun-commissioned-with-plan-north-sea-fleet.html.
[51] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[52] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[53] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.

dubbed Type 055, was launched in June 2017. The vessel appears to be in the tonnage and capability range of the USN Ticonderoga (CG-47), with displacement reported to be 10,000 tons. Satellite images confirm that at least four units are, as of September 2017, under construction at both the Changxing-Jiangnan and Dalian shipyards. As such, confidence in the design is assessed to be relatively high. Up to 12 hulls in total could be launched by 2026.[54]

More destroyers are projected by the middle of the next decade, in line with the aim of modernizing existing AAW assets and expanding this capability in order to provide better support for the potential deployment of future carrier strike groups. These destroyers could be a further modified design, or continued production of the Type 055 and/or Type 052D.[55]

In the meantime, production of the most advanced destroyer currently in service with the PLAN, the Type 052D, is set to continue for the years to come. With six units commissioned as of July 2017, at least 13 units are projected to be delivered by around 2020, until production switches to newer designs.[56]

Admiral (retired) Michael McDevitt, a Senior Fellow with CNA Strategic Studies, captures the nature and motivation for this second transition in a recent analysis of China's destroyer investment:

> "Just a few years ago few people cared very much about any PLAN destroyer, much less with what it was armed. That was because the central problem the PLAN posed for the U.S. in East Asia had nothing to do with destroyers. Instead, the focus of attention was China's 'A2' strategy. . . With its expanding global economic interests, China has developed global political interests as well. This has created a 'demand signal' for a PLAN that can support [United Nations]-sanctioned missions, protect [People's Republic of China] interests abroad with a show of force, respond to situations in which PRC citizens are in jeopardy …"[57]

More frequent deployments to places like the Gulf States and ports in the Indian Ocean, along with the opening of China's first overseas military base in Djibouti, signal an ambition to project power—even in an environment in which China's most immediate military priority is targeting operational vulnerabilities of modern, high-tech militaries as part of a broader A2/AD approach. So, too, does the recognition that these deployments, as well as more deployments in the near seas, will require increased coordination between service components in delivering and sustaining forces further away from the homeland—both within the region and beyond.

In a September 13, 2016 ceremony, Xi Jinping formally conferred flags to joint logistics units for the establishment of a joint logistics force as part of broader military reforms. Xi described the move as having "far-reaching significance to establishing a modern joint logistics support force with Chinese characteristic and building a world-leading military." He also claimed that the joint logistics force "is a main force in the strategic battle support missions" and "urged the new force to deepen logistics preparedness for battle and better integrate the force into the joint operations system," according to *Xinhua* reporting on the ceremony.[58]

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[54] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[55] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[56] "China- Navy," *Jane's,* January 17, 2018. https://janes.ihs.com/Janes/Display/jwna0034-jwna.
[57] McDevitt, Michael, "The Modern PLA Navy Destroyer Force: Impressive Progress in Achieving a 'Far Seas' Capability," *China's Evolving Surface Fleet,* U.S. Naval War College, China Maritime Studies, Number 14, July 2017. https://www.hsdl.org/?abstract&did=802175.
[58] "China Sets up Joint Logistics Force, Xi Confers Flags", *Xinhua*, September 13, 2016, www.xinhuaet.com/english/2016-09/13/c_135685473.htm.

China's advanced weapons systems are an important component of its power projection effort as well as its A2/AD investments, reinforcing both the prioritization and versatile applications of these weapons programs in meeting the expanding missions, objectives and ambitions of its modernization effort.

HGVs, unmanned systems and counter-space programs stand out as capabilities developed in part to support China's interests and operations abroad in a material way and protect its deployed forces and its citizens living abroad. Directed energy, electromagnetic railguns and hypervelocity weapons could also contribute to the capacity to defend deployed assets from a range of current and future threats—from close-in defense against adversary unmanned systems or small craft and fires, to more sophisticated missile defense functions.

From "Informatized" to "Intelligentized" Warfare
China is also at the start of a third, and over time what Jane's assesses to be the most consequential, transition from a sole focus on capabilities to operate in an "informatized" operational environment a more "intelligentized" operational environment in which AI and other Fourth Industrial Revolution technologies are incorporated into transformational military capabilities.

The trends of the last two decades emphasizing connectivity, networks, increased access to information and ease and pace of communications will be initially augmented and ultimately, over the next approximately two decades, superseded by the introduction and refinement of advanced "cognitive" and autonomous capabilities and advanced manufacturing techniques. These advancements will bring to life military capabilities previously only contemplated by science fiction and video games, such as:

- Artificially intelligent and fully autonomous unmanned systems
- Drone swarms and mother ships
- Point-of-use 3D printed payloads and parts
- Hypersonic weapons and planes
- Shape-shifting and self-healing platforms
- Biomaterial-infused "invisibility cloaks"[59]

Development of an advanced ability to operate in informatized environments will remain a strategic and operational imperative for China's military modernization and a strong influence in its investment in advanced weapons capabilities, such as its counter-space and unmanned systems programs.

This investment will be increasingly augmented by attempts to harness the power of emerging technologies for military purposes, namely those listed below, all of which are mentioned in Chapter 2 as part of targeted technology acquisition efforts:

- Artificial intelligence (AI)
- Big data analytics
- Internet-of-Things
- Virtual and augmented reality (VR and AR)
- Smart sensors
- Additive manufacturing (also known as 3D printing)
- 4D printing and synthetic biology manufacturing

[59] Nurkin, Tate, "Wonders at the Threshold: Perspectives on the Future of Military Technology and Capabilities," DEFTECH Conference: Warfare in 2037, Thun, Switzerland, November 15, 2017.

- robotics and unmanned systems
- Novel and smart materials
- Quantum computing and encryption
- Semiconductors
- Energy capture and storage technologies

At a global level, significant innovation in many of these in-demand and transformational technologies is taking place outside of traditional defense industrial enterprises, a trend that certainly holds true in China. State actors capable of coordinating the conflating technology and innovation priorities of commercial high-tech, automotive, maritime, energy and financial sectors as well as traditional defense communities could gain relative advantages over those actors that struggle to exploit these efficiencies.

Cross-industry collaboration and coordination can take many forms and can be enhanced by the state. One model for state-directed collaborate can be seen in the 2013 partnership of French car manufacturer Valeo and aerospace and security company Safran—both subsidized by the French government—through which they jointly developed autonomy technologies that could be applicable to both cars and unmanned aircraft.[60] The Valeo equipped self-driving cars will draw on infrared imaging, algorithms and "dynamic mapping" used in Patroller drones and other Safran hardware.[61]

A Changing Operational Context

In a military context, the need for Fourth Industrial Revolution technologies (especially intelligentized and cognitive platforms and systems) is rooted in the complex and fast moving operating environment militaries will face. These environments are marked by uncertainty about the origin, nature, trajectory and pace of emerging threats as well as adversaries' capabilities, and in some cases even the identity and location of the adversary.

Such environments demand flexibility and agility to meet fast-moving and uncertain threats. They also require an enhanced capacity to collect, filter, process and use the surfeit of information available to strategic, operational and tactical decision-makers: much very useful, some wrong or intentionally deceptive, but all arriving to analysts and decision-makers with increasing velocity.

AI, Fourth Industrial Revolution Technologies and Military Capabilities

AI—and the various "cognitive" capabilities different applications of AI confer—is particularly relevant to the future of military capabilities and in meeting the challenges of the future battlefield.

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[60] Frost, Lawrence and Guillaume, Gilles, "Valeo's Self-driving Car Systems Learn From Safran Drones," *Reuters*, March 27, 2015, http://www.reuters.com/article/2015/03/27/valeo-safran-selfdrivingcar-idUSL6N0WS55220150327.

[61] Frost, Lawrence and Guillaume, Gilles, "Valeo's Self-driving Car Systems Learn From Safran Drones," *Reuters*, March 27, 2015, http://www.reuters.com/article/2015/03/27/valeo-safran-selfdrivingcar-idUSL6N0WS55220150327.

As U.S. Marine Corps Lt. General and Director of the U.S. Defense Intelligence Agency Vincent Stewart noted at the Department of Defense's Intelligence Information Systems Worldwide Conference in August 2017: "In the 21st century, facing so-called '5th Generation' warfare,[62] war is cognitive as much as it's kinetic."[63]

AI will help make humans, platforms, systems and even, plausibly, weapons more resilient and "smarter" and therefore more capable of filtering and digesting information, detecting difficult to sense threats and adapting to uncertain and changing operational environments.

One application for AI is to help analysts, operators and decision-makers better identify, queue, query, monitor, filter and process the abundance of information available to them through advanced sensors, human sources and social media/Internet-based sources.

U.S. Air Force Chief of Staff David Goldfein captured this challenge in a July 2017 speech to the Air Force Association in Washington, D.C.: "There's a significant…amount of that data that we collect that hits the floor and we never actually look at it because we don't have the analytical capacity."[64]

According to General Goldfein, for many intelligence activities—including monitoring terrorist and extremist social media activity—incorporation of machine learning applications of AI could greatly improve what is currently a "very human-centric methodology" by doing "that upfront analysis so that by the time it gets to the human level of analysis we've already refined it and focused it."[65] In other words, the use of machine learning and big data analytics to help monitor, organize and filter information can make humans much more efficient and focus them more on tasks like analysis in which their expertise and intuition will be more relevant and impactful.

AI and VR and AR are also being integrated into the design of future cockpits for helicopter pilots and tank commanders who are increasingly being asked to digest a wider range of inputs from sensors,

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[62] Fifth Generation Warfare (5GW) refers to an emerging irregular type of warfare that is increasingly unconstrained in both the means used to attack or influence adversaries and the targets selected for attack. It is most frequently applied to efforts to use an exceptionally broad range of levers, to include traditional military capabilities, but with particularly emphasis on exploitation of influence operations, the electromagnetic spectrum and both the opportunities and vulnerabilities associated with modern telecommunications technologies and information systems to undermine institutions, government control and military efficacy, frequently without effective attribution. The intent of 5GW is typically to expose weakness rather than achieve a specific operational objective. Lt. Colonel Stanton Coerr noted in an article in the *Marine Corps Gazette* in January 2009 that in "5GW fighters will win by…point[ing] out the impotence of secular military might…These fighters win by not losing, while we lose by not winning."
5GW builds upon concepts of Fourth Generation Warfare (4GW) in which irregular means are used in non-conventional ways by non-traditional combatants in support of ideological objectives. 4GW is most commonly used in the 21st century context in reference to the September 11, 2001 attacks against the United States and subsequent conflicts and counter-terrorism missions carried out throughout the world. 5GW is distinguished from 4GW both by the availability and effective use of novel military, commercial and dual use technologies that can be used or exploited and frequently by the lack of a coherent ideology driving 5GW operations. From a military and security perspective, enhanced cognitive and unmanned capabilities will be critical to detect imminent or in progress threats that may not otherwise be detectable and to allow unmanned systems to operate more autonomously in highly complex environments.
https://www.scribd.com/doc/50049562/Fifth-Generation-War-Warfare-versus-the-nonstate-by-LtCol-Stanton-S-Coerr-USMCR.
[63] Underwood, Kimberley, "Cognitive Warfare Will Be Deciding Factor in Battle," *Signal,* August 15, 2017, https://www.afcea.org/content/cognitive-warfare-will-be-deciding-factor-battle. Link includes an embedded video of the speech.
[64] Harper, Jon, "Air Force Leader: Artificial Intelligence Could Help Monitor Social Media," July 26, 2017, *National Defense*, http://www.nationaldefensemagazine.org/articles/2017/7/26/air-force-leader-artificial-intelligence-could-help-monitor-social-media.
[65] Harper, Jon, "Air Force Leader: Artificial Intelligence Could Help Monitor Social Media," July 26, 2017, *National Defense*, http://www.nationaldefensemagazine.org/articles/2017/7/26/air-force-leader-artificial-intelligence-could-help-monitor-social-media.

unmanned systems and other manned platforms and systems.[66] The principle is the same: using machines and algorithms to reduce the cognitive burden on humans and focus their attention and instincts on the critical function of assessing filtered information and taking action.

The future of AI on the battlefield will not only include enhancement of human effectiveness, it will also be employed to remove humans entirely "from the loop" for many types of missions. Autonomous swarms of dozens or more unmanned systems—air, ground, surface and/or undersea—offer a frequently cited example of the cognitive battlefield that goes beyond helping humans perform analysis or make better decisions.[67]

Individual systems within a given swarm will have specific functions—decoy, strike, air-defense suppression, surveillance, electronic warfare—but all unmanned systems in the swarm will communicate with each other to carry out a mission with decisions being made by software exploiting AI. Humans will provide the broad parameters of the mission—what targets are to be addressed, for example—and program the platforms, but the swarm will have the capacity to "cognitively" adapt to adversary counter-measures and a changing operational environment absent human intervention.[68]

Autonomous and swarmed unmanned vehicles have the potential to, as one engineer who supported China Electronic Technology Group Corporation's (CETC) June 2017 record-setting test of a swarm of 119 drones noted, "become a 'disruptive force' in military operations that "will change the rules of the game."[69]

China's Move Toward Intelligentized Warfare
China's military and political leadership recognize that they are at the start of changes that could transform warfare and the nature of the capabilities required to detect adversaries, deter and dissuade conflict and diminish, degrade and defeat adversary capabilities. Lieutenant General Liu Guozhi, director of the Central Military Commission's Science and Technology Commission, believes the world is "entering the era of intelligentization" with rapid advancements in AI that will fundamentally change how militaries operate.[70] On April 20, 2016, President Xi gave a speech to the Central Military Commission where he called on the commission to advance integration of advance technologies such as big data, cloud computing and AI.[71]

China's efforts to facilitate this transition reflect an understanding that the challenge is not just in taking existing platforms and systems and making them incrementally more effective. Rather, the

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[66] Osborn, Kris, "DARPA Tests Helicopter with Human-machine Interface," *Defense Systems,* October 27, 2016, https://defensesystems.com/articles/2016/10/27/darpa.aspx.
[67] "China launches record-breaking UAV swarm," *Jane's*, June 21, 2017. https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017
[68] One area in which the United States and several other states have expressed some concern about artificial intelligence on the battlefield is the concept of autonomous strike, or machines identifying and then engaging targets absent human control. The United States has invested in "semi-autonomous" weapons, such as the Long Range Anti-Ship Missile (LRASM), developed by Lockheed Martin. Semi-autonomous weapons ensure targets are (usually pre-) selected by humans, but provide the weapons system the capacity to alter originally targeting parameters in order to strike a potentially hidden or moving target or to otherwise adapt to the target's counter-measures or changes in the broader operational environment.
[69] Tate, Andrew, "China Launches Record-Breaking UAV Swarm," *Jane's Defense Weekly,* June 21, 2017, https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017.
[70] Kania, Elsa, "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," *Center for a New American Security*. November 2017. p.13.
[71] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Nation's Characteristics—Thoroughly Study Chairman Xi's Important Sayings When Inspecting the CMC Joint Operations Command Center [加快构建具有我军特色的联合作战指挥体系—— 深入学习贯彻习主席视察军委联指中心时的重要讲话], *Qiushi* [求是], August 15, 2016, http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm.

driver of success in this new environment will be the capacity of defense industries around the world to accommodate and integrate new actors, technologies, materials and manufacturing capabilities.

And here, China may well see an opportunity to leverage the centralized political structure that is frequently pointed to as a structural challenge and inhibitor of innovation and national development to *actually drive* this integration and collaboration in a way that may be more difficult—but clearly not impossible—in the United States.

China's commitment at a national level and also within its defense industry is demonstrated through:

- *Policy Statements and Investments:* Big data analytics and AI have long been a Chinese priority with implications for national development, economic growth and, of course, military capabilities. Release of the three-stage Next Generation Artificial Intelligence National Development Plan in July 2017 provided a direct and forceful indication of the overall importance the Chinese government is placing on China becoming the global leader in AI development and applications.[72] The plan's third phase—which runs from 2025-2030—in particular, includes discussion of military and national security applications of AI. This phase reveals that China thinks AI will become a central military capability by 2030.[73] (For more analysis on China's AI development, see Chapter 3.)

- *Autonomous Unmanned Systems Development:* CETC's successful world record test of 119 networked drones in June 2017 demonstrated China's growing competence in a capability area that will be critical to future conflict and also highlighted the power of the intersection between AI and unmanned vehicles. Recent interviews with members of China's unmanned systems industry by Jane's reporters reinforce both of these insights and reflect a belief that "unmanned systems will take on more and more mission sets in the future, particularly as the military continues on its transformation journey to the 'intelligentized' warfare era."[74]

- *Broader Applications*: In an August 2016 statement to *China Daily,* Wang Changqing of the China Aerospace and Industry Corporation, claimed that China's "future cruise missiles will have a very high level of artificial intelligence and automation…They 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."[75] This last function in this list indicates a missile with a cognitive capability to make targeting and navigation adjustments mid-flight absent human guidance or intervention based on its own autonomous reading of the operational situation.

Balancing Competing Priorities

Tensions between these three transitions shaping the future of China's military modernization—to a more maritime and regional focus, to power projection capabilities and to intelligentized warfare—are generating discussions within China's military establishment about how to balance varied priorities associated with these transitions.

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[72] China Copyright and Media, "A Next Generation Artificial Intelligence Development Plan," July 20, 2017, https://chinacopyrightandmedia.wordpress.com/2017/07/20/a-next-generation-artificial-intelligence-development-plan/.
[73] State Council of the People's Republic of China, "The State Council on the Issuance Notice of the New Generation of Artificial Intelligence Development Plan," AIDP, July 20, 2017, http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm.
[74] Email interview with Kelvin Wong, September 26, 2017.
[75] Lei, Zho, "Next Generation of Missiles to be Highly Flexible," *China Daily,* August 19, 2016. http://www.chinadaily.com.cn/china/2016-08/19/content_26530461.htm.

For example, evidence has emerged that debates are taking place about to how to balance investment in A2/AD and power projection capabilities. An article published in a prestigious Chinese naval research journal in early 2017, and analyzed by U.S. Navy War College researcher Lyle Goldstein, argued that the PLAN should abandon the complementary ideas that China's submarines are a) primarily defensive platforms supporting a coastal defense strategy and b) that they should therefore operate only "near to the island chain."[76]

Goldstein cited the authors as suggesting that China's *nuclear submarine force*—China has both nuclear and diesel-electric submarines—should not become bottled up in the Western Pacific and consumed by near seas protection and coastal defense; that these expensive platforms with considerable capabilities not become a "large effort put to small use."[77] Instead, the authors recommend using China's nuclear submarines to deploy into the far seas and using its conventional force for more local and regional missions, providing a blueprint for balancing the competing demands of managing an A2/AD modernization with a growing global economic, geopolitical and even military commitments and presence.

Similarly, Chinese military strategists are debating how to balance the development and deployment of traditional military capabilities to meet existing and near future threats with the need to develop capabilities to fight and win in an intelligentized environment.

Some within the PLA are arguing that attempting to match the United States in modern military capability is counterproductive.[78] Wang Weixing, a senior scholar and research director with the PLA, penned a *PLA Daily* article in June 2017 that provides a glimpse into some of the inevitable internal debates that accompany the introduction of intelligent and expendable weapons: "as people are still preparing for a high-tech war, the old and new are becoming intertwined to become a new form of hidden complex 'hybrid war'. Unmanned combat is gradually emerging. While people have their heads buried in the sand trying to close the gap with the world's military powers in terms of traditional weapons, technology-driven 'light warfare' is about to take the stage." [79]

This sentiment is echoed by several China experts interviewed for this project and by the regional and strategic experts that participated in Jane's workshops who articulated the belief that the most daunting challenge posed by China's military modernization is developing capabilities that "discount not just American advantage, but our entire way of fighting wars."[80]

More technologically advanced frigates, destroyers, aircraft carriers and stealthy aircraft may present a new scale of conventional military challenge by introducing more advanced platforms and systems capable of targeting U.S. military vulnerabilities, more closely matching U.S. conventional capability and competing in a more effective way. However, enhanced conventional Chinese capability likely does not fundamentally alter the nature of the challenge to U.S. military superiority in the region and, critically, the U.S. military is well prepared to meet this type of traditional and conventional challenge.

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[76] Goldstein, Lyle, "Is This the Future of Chinese Sub Power?" *The National Interest,* June 19, 2017. http://nationalinterest.org/feature/the-future-chinese-submarine-power-21229.
[77] Goldstein, Lyle, "Is This the Future of Chinese Sub Power?" *The National Interest,* June 19, 2017. http://nationalinterest.org/feature/the-future-chinese-submarine-power-21229.
[78] Feng, Emily and Clover, Charles, "Drone Swarms vs Conventional Arms: China's Military Debate," *The Financial Times,* August 24, 2017. https://www.ft.com/content/302fc14a-66ef-11e7-8526-7b38dcaef614?mhq5j=e6.
[79] Feng, Emily and Clover, Charles, "Drone Swarms vs Conventional Arms: China's Military Debate," *The Financial Times,* August 24, 2017. https://www.ft.com/content/302fc14a-66ef-11e7-8526-7b38dcaef614?mhq5j=e6.
[80] Quote taken from discussion in the Implications Workshop held on October 5, 2017 in Washington, D.C.

China's Advanced Weapons Systems through A Different Lens: Critical Domain Area Competitions

Assessing the current state and future importance and trajectory of China's advanced weapons systems programs requires not just an understanding of the tensions, transitions and varying priorities discussed above, but also analysis of four critical military domain area competitions in which these advanced weapons systems are likely to play a conspicuous role. Balances and imbalances in and across these competitions are critical to stability and security in the Western Pacific and to the capacity of the United States and its allies to pursue their interests in the region.

The Undersea Competition

In a September 2013 speech in Seattle, Washington, then Chief of Naval Operations Admiral Jonathan Greenert asserted that the United States Navy "owns" the undersea domain. According to Admiral Greenert, a key component of his job was to "ensure for you that we own the undersea domain forever. *And right now, we do* (emphasis added).[81]

"Strategists contemplating Asia-Pacific strategy quickly come to the conclusion that the undersea campaign is decisive."

-Lyle Goldstein, "America may soon find itself in an underwater war with China," The National Interest, 24 July 2017

This was a strong statement about what is the most significant and stabilizing competitive advantage for the United States and its allies in Asia—most of which are prioritizing the development and acquisition of enhanced undersea capabilities. This domination of the undersea domain provides a hedge that will allow U.S. forces to hold China's military and government command and control assets at risk, no matter how effective China's attempts to control and deny access to the space, information, air and surface domains.

But competition in the undersea domain has grown more intense. U.S. undersea dominance, especially in Asia, is being challenged and is vulnerable to being eroded over the next decade as a result of two developments. First, China is investing in undersea and ASW assets in order to better challenge the United States and its allies. As former U.S. Pacific Commander Admiral Samuel J. Locklear noted in 2014: "China's advance in submarine capabilities is significant. They possess a large and increasingly capable submarine force."[82]

China is expected to continue the acquisition of a mixture of ballistic missile submarines (SSBN) for strategic deterrence and attack subs—both nuclear powered submarines (SSN) and conventional powered submarines. One Type 094 SSBN could be added to the four currently in service in next few years, with industry efforts expected to then transition to a newer, more capable design—tentatively dubbed Type 096—for follow-on boats for the role. A total of around five to six boats may be launched by 2026.

[81] Greenert, Admiral Jonathan, "Slade Gorton International Policy Center Luncheon Speech," September 24, 2013, Seattle, Washington.
http://www.navy.mil/navydata/people/cno/Greenert/Speech/130924%20Slade%20Gorton%20International%20Policy%20Center%20Luncheon%20Seattle.pdf.

[82] *USNI News*, "Opinion: A New Era in Anti-Submarine Warfare, Lt. CDR Jeff W. Benson (USN)," August 27, 2014.
https://news.usni.org/2014/08/27/opinion-new-era-anti-submarine-warfare.

Nuclear attack submarines are another focus area, with industry reported to be working on expanding the four-boat strong fleet of Type 093 SSNs with around two to four extra boats, and then planning to switch production to a further improved design known as Type 095 in the 2020s. Six to seven SSNs in total are currently estimated to be delivered around 2022-30.[83]

Conventional propulsion submarines are also in production. Type 039/A/B/C submarine production has been reported at multiple ship yards, with the latest batch of three boats noted to undergo outfitting in 2017. Up to 20 boats are estimated by around 2021 to replace legacy classes, with production then projected to transition to a further modified or new design. This transition also depends on the outcome of the reported deal to transfer up to four air independent propulsion-capable Amur design boats and related technology with Russia. Delays have been noted, and the program seems to have reached a stall.[84]

In addition to investments in more and more capable submarines, China also seeks new and more robust ASW assets and systems. The "Underwater Great Wall" is an essential component of this strategy and will incorporate autonomous UUVs, USVs and UUVs, and a wide range of sensors and measuring capabilities.[85] USV concepts revealed in September 2017 include dedicated ASW platforms as well as other vehicles capable of being configured for ASW missions, as discussed in Chapter 6 of this report.

Even without increased Chinese investment in ASW and undersea capabilities, though, U.S. dominance beneath the surface of the sea could well be at risk due to the lack of investment in undersea assets, especially in the initial post-Cold War years during which the United States "procured a relative small number of SSNs"[86] which are the backbone of the U.S. undersea advantage. The effects of the lack of procurement of submarines during this period is now being felt, given the long development and procurement timelines associated with submarines, which can last up to 20 or more years. As older subs have been retired, fewer submarines have been built to take their place, resulting in a delayed, but manifest, reduction of force over time.

The U.S. Navy has determined a need for 66 nuclear-powered submarines in order to carry out its global missions. This minimum number of SSNs is based on the Navy's FY2017 30-year shipbuilding plan and is a marked increase over the previous minimum of 48 SSNs, which was based on previous visions of a 308-ship navy.[87] By 2025, the Navy will begin a period of 15 out of 16 years in which there are fewer than 48 SSNs in the fleet, bottoming out at 41 SSNs in 2029 and not returning to 48 boats until 2037. At no point in the 30-year plan does the Navy anticipate having 66 boats. Indeed, the most SSNs the Navy anticipates deploying during the 30-year plan horizon is 53 in 2018. The Navy will have fewer than 50 SSNs for a period of over two decades, from 2022 to 2044.[88]

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[83] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[84] Rahmit, Ridzwan, Capeleto, Michael, Pape, Alex, "People's Liberation Army's Navy: Examining China's Current and Future Naval Capability," September 17, 2017, Jane's Defense Insight Report, Sea Power.
[85] Fisher, Richard, "China Proposes 'Underwater Great Wall' that Could Erode U.S., Russia Submarine Advantage," *Jane's Defense Weekly*, May 17, 2016. https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016.
[86] O'Rourke, Ronald, "Navy Virginia Class (SSN-774) Class Attack Submarine Procurement: Background Issues for Congress," *Congressional Research Service*, October 24, 2017, 11–12. https://fas.org/sgp/crs/weapons/RL32418.pdf.
[87] Office of the Chief of Naval Operations, "Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2017,"July 12, 2016, 3-4. https://news.usni.org/2016/07/12/20627.
[88] O'Rourke, Ronald, "Navy Virginia Class (SSN-774) Class Attack Submarine Procurement: Background Issues for Congress," *Congressional Research Service*, October 24, 2017, 11–12. https://fas.org/sgp/crs/weapons/RL32418.pdf.

Table 6: Projected SSN Force Levels as shown in the U.S. Navy's FY2018 30-Year Shipbuilding Plan.[89]

Fiscal Year	Annual procurement quantity	Projected number of SSNs	Force level relative to new 66-boat goal	Force level relative to previous 48-boat goal
2017	2	52	-14	-
2018	2	53	-13	-
2019	2	52	-14	-
2020	2	52	-14	-
2021	1	51	-15	-
2022	2	48	-18	-
2023	2	49	-17	-
2024	1	48	-18	-
2025	**2**	**47**	**-19**	**1**
2026	**1**	**45**	**-21**	**3**
2027	**1**	**44**	**-22**	**4**
2028	**1**	**42**	**-24**	**6**
2029	**1**	**41**	**-25**	**7**
2030	**1**	**42**	**-24**	**6**
2031	**1**	**43**	**-23**	**5**
2032	**1**	**43**	**-23**	**5**
2033	**1**	**44**	**-22**	**4**
2034	**1**	**45**	**-21**	**3**
2035	**1**	**46**	**-20**	**2**
2036	**2**	**47**	**-19**	**1**
2037	**2**	**48**	**-18**	**-**
2038	2	47	-19	1
2039	2	47	-19	1
2040	1	47	-19	1
2041	2	47	-19	1
2042	1	49	-17	-
2043	2	49	-17	-
2044	1	50	-16	-
2045	2	50	-16	-
2046	1	51	-15	-

Derived by Jane's from Congressional Research Services' "Navy Virginia Class Attack and Submarine Procurement: Background Issues for Congress, authored by Ronald O'Rourke, September 2017.

Without a proactive intervention, new capability or changed strategic context, the U.S. Navy will be stretched thin and require longer deployments to maintain operational readiness. During the period of a sustained "valley" in the size of the SSN fleet from 2025 to 2037 (highlighted in green and bolded in the table above), it is likely that China's A2/AD capabilities and investments—both undersea and in other domains—will have reached higher levels of maturity, shifting the trajectory of the undersea competition and forcing the introduction of novel capabilities by all actors in the region.[90] Deepening investment from the United States and China (as well as other actors) in unmanned underwater and surface vehicles, increasingly capable of higher degrees of autonomy, will also shape future undersea capability balances, as is explored in Chapter 6 on unmanned systems.

[89] O'Rourke, Ronald, "Navy Virginia Class (SSN-774) Class Attack Submarine Procurement: Background Issues for Congress," *Congressional Research Service*, October 24, 2017, p.11–12. https://fas.org/sgp/crs/weapons/RL32418.pdf.
[90] O'Rourke, Ronald, "Navy Virginia Class (SSN-774) Class Attack Submarine Procurement: Background Issues for Congress," *Congressional Research Service*, October 24, 2017, p.11–12. https://fas.org/sgp/crs/weapons/RL32418.pdf.

Missile versus Missile Defense

Many of China's advanced weapons systems have particular relevance to the future of the missile versus missile defense competition, particularly maneuverable reentry vehicles, electromagnetic railguns, counter-space capabilities and potentially directed energy.

China's development of more, and more accurate and longer-range anti-ship cruise and ballistic missiles is challenging existing missile defense systems, which are more vulnerable to being overwhelmed by multi-axis saturation. New missile defense measures will be required to meet this iterative interaction between new strike capabilities and strategies introduced by the United States, China and other actors in the region and novel means of providing missile defense will be a central feature of the China-U.S. (and Japan and South Korea) military competition in East Asia over the next two decades.

China has rapidly and effectively upgraded both its cruise and ballistic missile capabilities, prioritizing missile development "over an organic carrier capability with the apparent goal of acquiring the capability to neutralize a U.S. carrier strike group."[91] According to the U.S. DoD's Quadrennial Defense Review; "Growing numbers of accurate conventional ballistic and cruise missile threats represent an additional cost-imposing challenge to U.S. and partner naval forces and land installations."[92] China's ASBM and MaRV programs, including HGVs, amplify this threat and complicate the missile versus missile defense competition.

China's missiles programs and saturation tactics in particular also pose a fiscal challenge to the United States as the missile versus missile defense competition is among the most acute examples of the cost-imposing challenges of the diffusion of advanced military, commercial and dual-use technology. The costs of resilient, adaptive and layered missile defense systems are considerably more expensive to develop, test and maintain than the cost of developing a viable cruise and ballistic missile threat. One *Jane's* expert referred to the cost for the highest-end interceptors on the market today as "eye-watering."[93]

The combination of these strategic, operational and budgetary threats is driving a suite of United States responses to China's missiles and MaRV programs.

Emerging low cost of shot/deep magazine solutions, such as directed energy and hyper-velocity projectiles (HVP) fired from naval powder guns or electromagnetic railguns offer some promise in changing current cost curves. So, too, do new operational concepts (for example, left–of–launch interventions[94]) and competitive strategies designed to minimize the need for intercepts in the first place. However, these capabilities and concepts are not yet mature, and the path from concept to

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[91] Gromley, Dennis; Erickson, Andrew; and Yuan, Jingdong, "China's Cruise Missiles: Flying Fast Under the Public's Radar," *The National Interest*, May 12, 2014. http://nationalinterest.org/feature/china's-cruise-missiles-flying-fast-under-the-public's-radar-10446.

[92] Gromley, Dennis; Erickson, Andrew; and Yuan, Jingdong, "China's Cruise Missiles: Flying Fast Under the Public's Radar," *The National Interest*, May 12, 2014. http://nationalinterest.org/feature/china's-cruise-missiles-flying-fast-under-the-public's-radar-10446.

[93] Nurkin, Tate, "Rising Tensions: Air and Missile Defense in Europe," supplement to *Jane's Defense Weekly,* November 23, 2016.

[94] Left-of-launch interventions refer to the capacity to inhibit the imminent launch of a missile or missiles through cyber techniques or jamming or spoofing communications from adversary command and control to the missile. The capability is of increasing interest to the U.S. missile defense community as part of a layered suite of capabilities to enhance U.S. resilience to the growing threat of ballistic missiles to U.S. assets, allies, personnel and homeland, in particular.

deployment of new technologies and concepts is longer, harder and more expensive than fully appreciated when concepts are being initially trialed or explored.[95]

Richard D. Fisher, Jr. summed up this competitive dynamic and the changing investment priorities for the United States: "The DF-21D and DF-26 anti-ship ballistic missiles…demonstrate that the PLA is making progress in being able to overwhelm U.S. Navy ships with coordinated missile strikes."[96] Fisher added, "The most powerful U.S. response to these developments would be for the United States to accelerate its development of energy weapons like (electromagnetic) railguns and (directed energy) lasers, which hold the potential to defeat swarms of attacking missiles."[97]

Still, even as these solutions are being developed and if they are deployed, reliance on advanced kinetic intercept systems is likely to persist for the foreseeable future and to have a powerful effect on the development and prioritization of China's advanced weapons systems.

The deployment of the U.S.-developed Terminal High Altitude Area Defense (THAAD) system in South Korea was cited in the Jane's Framing Workshop as well as in open sources from the West and China as an important motivation for the advancement of China's HGV program.[98] Professor He Qisong, a defense policy expert at the Shanghai University of Political Science and Law, viewed China's several HGV tests as being "aimed at causing a threat to the US, which plans to set up a missile defense system in South Korea."[99] Or, as Li Jie, identified by the *South China Morning Post* as a Beijing-based military expert, starkly assessed: "The DF-ZF [the designation of China's HGV program] is so far one of the offset weapons owned by China that could break the THAAD system."[100]

But the iterative, dynamic, competitive interaction in this domain does not end with HGVs and THAAD. China's (and Russia's) HGV program, in turn, is pushing U.S. investment in more sophisticated missile defense capabilities, including THAAD and in its own hypersonic weapons program, as discussed in more detail in Chapter 7 of this report.[101]

Space and Counter-Space

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[95] Nurkin, Tate, "Rising Tensions: Air and Missile Defense in Europe," supplement to *Jane's Defense Weekly,* November 23, 2016.
[96] Kaimen, Jonathon, Makinen, Julie and Cloud, David S., "China Troop Cut Plan Is More About Modernization Than Peace, Analysts Say," *Los Angeles Times,* September 3, 2015. http://www.latimes.com/world/asia/la-fg-china-troops-20150904-story.html.
[97] Kaimen, Jonathon, Makinen, Julie and Cloud, David S., "China Troop Cut Plan Is More About Modernization Than Peace, Analysts Say," *Los Angeles Times,* September 3, 2015. http://www.latimes.com/world/asia/la-fg-china-troops-20150904-story.html.
[98] For example, Pickrell, Ryan, "Russia and China Hate America's Missile Defense Systems for a Very Simple Reason ," *National Interest,* June 1, 2017, http://nationalinterest.org/blog/the-buzz/china-russia-hate-americas-missile-defense-systems-very-20949; and *South China Morning Post,* "China, Russia Ramping up Tests of Hypersonic Glide Vehicles to Counter New U.S. strategy: Analysts," April 28, 2016, http://www.scmp.com/news/china/diplomacy-defence/article/1939580/china-russia-ramping-tests-hypersonic-gliders-counter.
[99] *South China Morning Post,* "China, Russia Ramping up Tests of Hypersonic Glide Vehicles to Counter New U.S. strategy: Analysts," April 28, 2016, http://www.scmp.com/news/china/diplomacy-defence/article/1939580/china-russia-ramping-tests-hypersonic-gliders-counter.
[100] *South China Morning Post,* "China, Russia Ramping up Tests of Hypersonic Glide Vehicles to Counter New U.S. strategy: Analysts," April 28, 2016, http://www.scmp.com/news/china/diplomacy-defence/article/1939580/china-russia-ramping-tests-hypersonic-gliders-counter.
[101] Richardson, Doug, "Hypersonics Threat Spurs THAAD ER Development," *Jane's Missiles and Rockets,* January 12, 2017; McIntyre, Jamie, "The Hypersonic Threat that Keeps U.S. Commanders up at Night," *The Washington Examiner,* June 5, 2017, http://www.washingtonexaminer.com/the-hypersonic-threat-that-keeps-us-commanders-up-at-night/article/2624599.

The global competition in space is growing more intense—particularly between the United States and China—as the reliance on space-based assets of modern militaries increases. These assets are critical for communication, navigation, intelligence collection, surveillance, target acquisition and reconnaissance. Control of what the 2015 Military Strategy White Paper calls the "commanding heights" of space will be critical to U.S. power projection efforts and China's capacity to both deny access to the Western Pacific and globally project power.[102]

Moreover, as discussed in the Jane's Implications Workshop in early October 2017, the cost of going to space is on a relatively steep downward trajectory, meaning that more governments and commercial actors are launching their own communication and navigation satellites as well as other space-based assets. This higher accessibility further enhances the strategic value of the space domain and democratizes access to space for more countries and companies.

The democratization of space also suggests the commercial component having influence on the space/counter-space competition, which is also a feature of the U.S. competition in this domain. Both the United States and China maintain global navigation satellite networks—the global positioning systems (GPS) for the United States and Beidou ("Compass") for China. Both systems are dual-use, meaning that they are critical enablers of militaries and also provide navigation services to commercial markets.

China has offered access to its Beidou system to states in Southeast Asia, and participants in the Jane's Implications Workshop believed that it would be an essential part of China's "Belt and Road" initiative.[103] Initially established in 2013, the ambitious Belt and Road initiative seeks to use expansive infrastructure investment in Central and South Asia to link China directly over land to Europe as well as enhance investments in Southeast Asia and the Indo-Pacific. According to *The Economist,* "China is spending roughly $150 billion a year in the 68 countries that have signed up to the scheme."[104] Yang Changfeng, chief designer of the Beidou system, told *China Daily* in a 2015 interview that the Belt and Road Initiative provides the perfect platform for the Beidou system to promote itself globally, noting that the "central government has included the system in the initiative's strategic plan, with top leaders repeatedly asking us to speed up the internationalization of Beidou to serve the development of China and other nations."[105]

Access to and use of Beidou's position, navigation and timing capabilities could serve both to support the development of the infrastructure and as an export to Belt and Road partner countries to support "cross-border transportation, fishing management, customs clearance and modern agriculture," according to Yang.[106]

China's counter-space capabilities are clearly highly-relevant to this competition as are China's MaRV programs, which will rely on space-based assets to support China's maturing reconnaissance strike complex. Directed energy is also relevant to this competition, most immediately as one of China's types of counter-space weapons, but also in the longer-term as a potential missile defense weapon.

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[102] USNI, "Document: China's Military Strategy," May 26, 2015, http://news.usni.org/2015/05/26/document-chinas-military-strategy.
[103] "BeiDou navigation to cover Belt and Road countries by 2018," *China Daily*, September 13, 2017, http://www.chinadaily.com.cn/china/2017-09/13/content_31944312.htm.
[104] The Economist Explains, "What is the Belt and Road Initiative," *The Economist*, 15 May 2017.
[105] Lei, Zhou, "Beidou System to Aid Belt and Road," *China Daily,* June 2, 2015, http://europe.chinadaily.com.cn/china/2015-06/02/content_20884212.htm.
[106] Jane's Implication and Recommendations Workshop, October 5, 2017, IHS Markit offices, Washington, D.C.; Lei, Zhou, "Beidou System to Aid Belt and Road," *China Daily,* June 2, 2015, http://europe.chinadaily.com.cn/china/2015-06/02/content_20884212.htm.

The military and strategic competition in a more crowded space involves four components, which are shaping China's development of its counter-space capabilities as well as its directed energy program.[107]

- **Getting there**: Space is a critical domain for reconnaissance/strike complexes; missile defense; communication and navigation; and other critical military, commercial and civilian functions. More countries are spending more money to develop both military and dual-use infrastructures to be able to get to and successfully operate in space. SpaceX engagement with NASA and the U.S. DoD, and China's investment in next generation Long March rockets are good examples.

- **Denying space**: State actors are also investing in capabilities ranging from anti-satellite (ASAT) missiles to more elegant means of denying competitors either access to or effective operations in space, such as use of cyber-attacks and co-orbital and parasitic satellites. China's extensive counter-space program is developed in order to deny or hold at-risk competitor and potential adversary assets.

- **Staying there**: In response to the gathering counter-space challenge, military and civilian space organizations are seeking to harden their space assets against these threats and to develop more robust concepts of deterrence and dissuasion in space. Hardening measures are both technical—providing satellites the ability to maneuver more easily to avoid counter-space efforts—and conceptual—disaggregating capabilities and increasing redundancy of critical nodes and systems incorporated into space infrastructure.

- **Hedging bets:** Despite these extensive investments, some analysts believe the assets and infrastructure in space will be denied or severely degraded during an actual conflict or crisis. While the future denial of space is not certain, some states are hedging their space bets and seeking to develop capabilities to perform C4ISTAR (Command, Control, Communications, Computers, Information/Intelligence, Surveillance, Targeting Acquisition and Reconnaissance) functions absent space. These capabilities include position, navigation and timing technologies that do not rely on global navigation satellite systems.

Interactions at each of the layers of the space/counter-space competition will likely create new vulnerabilities for both China and the United States and drive new elements and focus areas of competition.

Electronic Warfare (EW) and the Electromagnetic (EM) Spectrum

In both the heavily informatized environment of warfare today (and likely over the next two decades) and the intelligentized environments of the more distant future, the ability of platforms and systems to send and receive signals, detect, surveil and emit is critical to operational efficacy and success.

These various types of communications take place across the EM spectrum and involve signals such as radio waves, infrared light or radar.[108] The EM spectrum intersects with space and the cyber domain. Efforts to affect communications across all three are frequently referred to as electronic warfare. Much like both space and the information domain, the EM spectrum is a critical enabler of modern military capability, allowing the U.S. to bring to bear the full weight of its technological

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[107] Framework developed by Jane's Strategic Assessments and Futures Studies Center and incorporated into multiple briefs and analyses since November 2015.

[108] Lockheed Martin, "Electronic Warfare," https://www.lockheedmartin.com/us/products/electronic-warfare.html; and Raytheon, "Electronic Warfare Overview," https://www.raytheon.com/capabilities/ew/overview/index.html.

superiority. As a result, it is also a particularly concerning potential area of vulnerability in which a growing range of actors with asymmetric capabilities (particularly low-cost ones) can pose a threat to U.S. forces.

As former Chief of Naval Operations Admiral Jonathan Greenert described in 2016:

> "The electromagnetic spectrum is an essential—and invisible—part of modern life [military and civilian]. Our military forces use wireless computer networks to coordinate operations and order supplies, use radars and sensors to locate each other and the enemy, and use electronic jammers to blind enemy radars or disrupt their communications. With wireless routers or satellites part of almost every computer network, cyberspace, and the electromagnetic spectrum now form one continuous environment."[109]

For much of the last 15 years, the United States and its allies have been in combat zones in Africa, the Middle East and Southwest Asia against adversaries with limited capacity to affect the ability of U.S. platforms, systems and personnel to communicate. For the most part, U.S. forces have dominated the EM spectrum and have not had to focus on managing what Admiral Greenert referred to in a 2013 speech as its "electromagnetic hygiene."[110]

However, dominance of the EM spectrum is being challenged by a wider range of state and non-state actors. More robust types of electronic warfare capabilities are being developed and diffused, including those that are commercially developed. These capabilities can enable competitors or adversaries to confuse or disable from longer ranges U.S. and allied capacity to operate in the EM spectrum through techniques such as jamming, [111] spoofing and cyber, a capability area in which China has demonstrated a formidable and evolving capability. Indeed, China's offensive cyber capabilities are a central and particularly effective component of its efforts to compete in the information and electronic warfare competitions that have been exercised against U.S. commercial and military targets in order to steal sensitive information and technologies, to hold at risk U.S. platforms and systems and to disrupt U.S. C4ISR functions. As a result, the topic of China's offensive cyber threat to the United States is expansive and complex, but the scale and nature of the challenge for the U.S. military and private sector organizations is effectively summarized by a February 2017 report from U.S. Defense Science Board Task Force on Cyber Deterrence:

> "Major powers (e.g., Russia and China) have a significant and growing ability to hold U.S. critical infrastructure at risk via cyber-attack, and an increasing potential to also use cyber to thwart U.S. military responses to any such attacks. This emerging situation threatens to place the United States in an untenable strategic position. Although progress is being made

[109] Wilson, J.R., "Today's battle for the electromagnetic spectrum," *Military and Aerospace Electronics,* 27: 8. http://www.militaryaerospace.com/articles/print/volume-27/issue-8/special-report/today-s-battle-for-the-electromagnetic-spectrum.html.
[110] Greenert, Admiral Jonathan, Chief of Naval Operations, speech to the Association of Old Crows, October 29, 2013, http://www.navy.mil/navydata/people/cno/Greenert/Speech/131029%20Association%20of%20Old%20Crows.pdf.
[111] Jamming is used to describe efforts to suppress emissions either emanating from or being received by platforms, systems or personnel. The effect of jamming is simply to limit the effectiveness of the target and ensure it does not carry out its transmissions or mission. Spoofing is used to describe a range of techniques designed to deceive platforms, systems or personnel or manipulate/misrepresent the location of electromagnetic signatures. For example, on June 22, 2017, the U.S. Maritime Administration documented an incident in which 20 ships off the Russian port of Novorossiysk in the Black Sea discovered that their global positioning systems (GPS) placed their ships at the wrong spot. The GPS indicated that all the ships were actually approximately 20 miles inland at the Gelendzhik Airport. No ships reported faulty equipment, leading many to believe that the faulty readings were the result of a spoofing attack. Clearly, manipulating position, navigation and timing data (as well as other data critical for platform, system and personnel) constitutes a significant threat to military operations.

> to reduce the pervasive cyber vulnerabilities of U.S. critical infrastructure, the unfortunate reality is that, for at least the next decade, the offensive cyber capabilities of our most capable adversaries are likely to far exceed the United States' ability to defend key critical infrastructures. The U.S. military itself has a deep and extensive dependence on information technology as well, creating a massive attack surface."[112]

And the combination of the massive scale of China's cyber activity as well as that of the United States—made public by the Snowden revelations—has led to an important cat and mouse competition between efforts to encrypt and decrypt communications. Chapter 2 will examine in more detail how China's quantum encryption and computing capabilities play into this competition. The changing nature of the competition in the EM domain was described by Joshua Niedzwiecki, Director of Sensor Processing & Exploitation at BAE Systems Electronic Systems, in 2016:

> "Right now, we're at a major juncture in EW [electronic warfare]. The proliferation of commercial technology in the telecom world has really accelerated everybody's capabilities. In the 1990s and before, the United States was dominant in a lot of specialized EW technology. But with the growth of the commercial wireless market, a lot of other countries now have that technology."[113]

Within the DoD, a renewed urgency to address new EM spectrum vulnerabilities is gaining momentum, after two decades of under-appreciation of the potential for intense and affecting competition in this domain. Dr. William Conley, Deputy Director of Electronic Warfare in the Office of the Undersecretary of Defense for Acquisitions, Technology and Logistics, highlighted this urgency in a June 22, 2017 speech on the state of electronic warfare given at the Mitchell Institute. According to Dr. Conley; "there is an appreciation on the dependency of our electronic warfare capabilities [and] to make sure that the force—all the platforms—are survivable. I think that appreciation is very real and very substantial."[114] Dr. Conley added: "the foot is fully on the gas pedal"[115] within DoD to make up for "twenty-five years of inattention" to electronic warfare.[116]

Electronic warfare is central to China's A2/AD efforts, a fact noted by Peter W. Singer, a Senior Fellow at the New America Foundation: "everything about forming an A2/AD environment is about being able to access the [electromagnetic] spectrum."[117] The result is a competition for dominance in this domain that is absolutely central to the future of military balances and therefore stability and security in the Indo-Pacific region. Dr. Conley stressed this point as well: "If [China says it wants] to dominate something and we say we want to dominate something, it is highly unlikely that both of us can achieve dominance."[118]

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[112] Task Force on Cyber Deterrence, Department of Defense Science Board, released by the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics, February 2017, https://www.acq.osd.mil/dsb/reports/2010s/DSB-CyberDeterrenceReport_02-28-17_Final.pdf
[113] Wilson, J.R., "Today's battle for the Electromagnetic Spectrum," *Military and Aerospace Electronics,* http://www.militaryaerospace.com/articles/print/volume-27/issue-8/special-report/today-s-battle-for-the-electromagnetic-spectrum.html.
[114] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.
[115] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.
[116] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.
[117] Magnuson, Stew, "DoD Puts 'Foot on Gas Pedal' to Catch Up on Electronic Warfare," *National Defense,* July 14, 2017, http://www.nationaldefensemagazine.org/articles/2017/7/14/dod-puts-foot-on-gas-pedal-to-catch-up-on-electronic-warfare.
[118] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.

China's efforts to gain advantage in this zero-sum competition with the United States in the EM spectrum and in the closely linked cyber and space domains have involved the development of new organizational structures, operational concepts and military capabilities.

Most notably, in November of 2015, as part of broader PLA organizational reforms, China established the Strategic Support Force (SSF) as a military service level organization reportedly "equal in standing to China's army, navy, air force and missile service."[119] The SSF reportedly combines three former PLA cyber, EW and intelligence services components:[120]

- The 3rd Department of the PLA (or 3PLA), which specializes in cyber-attacks and hacking
- The 4th Department of the PLA, described as China's military electronic intelligence and electronic warfare service
- The 2nd Department of the PLA (2PLA), the traditional military spy service

While uncertainty about the full scope of the SSF mission persists, analysts believe, and Jane's assesses that the main functions are to coordinate and execute electronic warfare, space/counter-space and cyber warfare activities. The establishment of this organization "reflects the on-going Chinese effort at being able to establish "information dominance"[121] and is central to China's efforts to achieve more fully execute operations associated with the concept of "integrated network electronic warfare" (INEW). [122]

According to Michael Raska, Assistant Professor at the S. Rajanatham School of International Studies in Singapore: "In Chinese strategic thoughts, INEW has a holistic representation that combines coordinated use of cyber operations, electronic warfare, space control and kinetic strikes designed to create 'blind spots' in adversary C4ISR systems."[123]

INEW can be seen as a central part of China's efforts to hold at risk adversary space and cyber-space capabilities in the increasing environment of five-domain warfare for deterrent as well as war-fighting capabilities, as described by the 2013 *Science of Military Strategy*:

> "The emergence of new deterrence forces, based on new technology such as information, cyberspace, space, and new-material technologies, is revolutionarily changing the mechanism, method, and area of operation. It heralds a completely new method of deterrence, symbolized by constructing asymmetrical method of deterrence"[124]

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[119] Gertz, Bill, "Chinese Military Revamps Cyber Warfare, Intelligence Forces," *Washington Free Beacon*, January 27, 2016, http://freebeacon.com/national-security/chinese-military-revamps-cyber-warfare-intelligence-forces/.
[120] Gertz, Bill, "Chinese Military Revamps Cyber Warfare, Intelligence Forces," *Washington Free Beacon*, January 27, 2016, http://freebeacon.com/national-security/chinese-military-revamps-cyber-warfare-intelligence-forces/.
[121] Gertz, Bill, "PLA's new Strategic Support Force remains an enigma," *Washington Free Beacon,* December 18, 2017, http://freebeacon.com/national-security/asia-times-plas-new-strategic-support-force-remains-enigma/.
[122] Raska, Michael, "China's evolving cyber warfare strategies," *Asia Times*, 8 March 2017, http://www.atimes.com/article/chinas-evolving-cyber-warfare-strategies/.
[123] Raska, Michael, "China's evolving cyber warfare strategies," *Asia Times*, 8 March 2017, http://www.atimes.com/article/chinas-evolving-cyber-warfare-strategies/.
[124] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.100. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. p. 14. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.
http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

At least three types of advanced weapons systems and capabilities discussed in this report are likely to feature as part of SSF electronic warfare efforts to augment an already robust and aggressive cyber capability that has targeted U.S. military and commercial assets for some time.

The first is directed energy, which can be used to jam platform or system signals or dazzle (i.e., inhibit the capacity of radars or sensors to "see") the capacity of the platform or a sensor on that platform or system to receive information. In March 2017, police in Wuhan, China used a directed energy rifle to jam an unidentified drone as it flew over a soccer game. By jamming the signal from the drone to its operator, the rifle forced the drone to switch to its automatic landing sequence.[125]

In addition, in January 2017, a team at the Northwest Institute of Nuclear Technology in Xi'an announced that they had developed a microwave weapon that can kill a platform or system's electronics. Open source information on the system was limited, but the weapon is reportedly small enough to fit on a lab work bench and could be mounted onto vehicles, aircrafts, missiles and even drones.[126]

Individual unmanned systems will also be utilized as EW platforms. In a November 2015 briefing, Jane's Senior Principal Analyst for Unmanned Systems Derrick Maple noted that EW is among the core future missions of individual high-altitude long endurance (HALE) and medium-altitude long endurance (MALE) unmanned systems.[127] Mr. Maple also highlighted the global trend toward EW payloads for individual systems with "increased range and power."[128]

EW is also a mission for smaller unmanned systems. In June 2016, the U.S. Air Force Life Cycle Management Center awarded a contract to Raytheon Missile Systems for more Miniature Air-Launched Decoy Jammers, which are small unmanned aircraft that jam enemy radar while spoofing the characteristics of much larger U.S. and allied aircraft.[129]

The goal of these miniature systems is "to force enemy missile batteries to fire ground-to-air missiles at the wrong targets,"[130] thus clearing a path for a larger manned attack aircraft when those enemy missiles are depleted. This concept of using unmanned systems to play a specific EW function within a broader team of networked capabilities is also the concept around AI-infused unmanned swarms discussed above, which will certainly play an important role in targeting and delivering EW capability from unmanned platforms.

Clearly, China is already thinking about these applications of both individual drones and larger swarms of unmanned systems, such as the one tested in June 2017 by CETC. In fact, *Xinhua* highlighted the presence of "16 items of the PLA's latest electronic warfare equipment that can disrupt enemy radar and communication in air defense and field battles" at the July 2017 PLA parade

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[125] Lin, Jeffrey and P.W. Singer. "Here's how China is battling drones," *Popular Science*. March 28, 2017. http://www.popsci.com/chinas-new-anti-drone-weapons-jammers-and-lasers#page-2.
[126] Lin, Jeffrey and P.W. Singer. "China's New Microwave Weapon Can Disable Missiles and Paralyze Tanks," *Popular Science*, January 26, 2017. http://www.popsci.com/china-microwave-weapon-electronic-warfare.
[127] Maple, Derrick, "Unmanned Systems: Reign of the Persistent Warriors," *Jane's Intelligence Briefing Series,* November 15, 2017, https://janes.ihs.com/Janes/Display/jibr2622-jibr.
[128] Maple, Derrick, "Unmanned Systems: Reign of the Persistent Warriors," *Jane's Intelligence Briefing Series,* November 15, 2017, https://janes.ihs.com/Janes/Display/jibr2622-jibr.
[129] Wilson, J.R., "Today's Battle for the Electromagnetic Spectrum," *Military and Aerospace Electronics,* http://www.militaryaerospace.com/articles/print/volume-27/issue-8/special-report/today-s-battle-for-the-electromagnetic-spectrum.html.
[130] Wilson, J.R., "Today's Battle for the Electromagnetic Spectrum," *Military and Aerospace Electronics,* http://www.militaryaerospace.com/articles/print/volume-27/issue-8/special-report/today-s-battle-for-the-electromagnetic-spectrum.html.

in Inner Mongolia marking the 90th anniversary of the PLA's founding.[131] Among those 16 items were "a group of military drones that can 'paralyze and suppress' enemy early-warning and command communications systems."[132]

Challenges and Constraints to China's Military Modernization

Overview
Over the last decade, China's military modernization has built considerable forward momentum in large part due to a robust funding environment. The rate of growth in China's official defense budget—which Jane's Defense Industry and Budgets Team estimates is about 35% less than the *actual amount* of defense spending[133]—has slowed in the last two years, but it is still growing aggressively. Jane's Defense Budgets expects China's defense budget to increase by an annual average of 7%, growing to $260 billion by 2021.[134] By comparison, Jane's forecasts the U.S. defense budget in 2021 to be just over $696 billion, $10 billion less than in 2012, but up from a low-point of $605 billion in 2015.[135]

China's steady and significant upward trend in defense spending has enabled the PLA to fund the development of a wide-range of platforms and systems and simultaneously manage the multiple transitions and objectives discussed above. In fact, Jane's research on China's conspicuous technological successes (Chapter 2) indicates that China's ability to invest—through its defense budget and other civil government funding mechanisms—in its own industry and S&T community as well as acquire Western businesses has been indispensable to its growing number of high-tech successes, such as in quantum computing and encryption. As one participant in the August 2017 Framing Workshop noted; "China's modernization effort has been successful at throwing a lot of stuff against the wall."[136] Another suggested that the modernization effort had yet to have to make "really big trade-offs."[137]

However, straight line projections of continued rapid progress in China's military modernization (not to mention national development and geopolitical influence) should not necessarily be taken for granted. China faces structural challenges that could constrain resources for its military modernization, and force strategically-affecting trade-offs in the nature of capabilities developed, acquired and deployed. Economic, political, environmental and demographic/societal issues are at the top of the list of frequently discussed structural issues that could slow or alter China's military modernization. In addition, challenges more squarely centered on the development and operational capacity of the PLA also exist.

None of these issues is likely to cause an imminent economic or political collapse or crisis in China—indeed, there are notable signs of resilience in China's economy, politics and society. But over time—a decade or perhaps more—the intersection of these challenges and the implementation of plans to address them will pose a material risk to China's capacity to maintain defense spending at levels required to simultaneously advance each of the components of its military modernization discussed

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131 "China Displays Electronic Warfare Equipment at Army Day Parade," *Xinhua*, July 29, 2017, http://www.xinhuanet.com/english/2017-07/30/c_136485220.htm.
132 "China Displays Electronic Warfare Equipment at Army Day Parade," *Xinhua*, July 29, 2017, http://www.xinhuanet.com/english/2017-07/30/c_136485220.htm.
133 Large chunks of defense spending in China are unaccounted for in the official defense budget. Jane's assesses that unreported spending is focused on manpower, research, development, testing and evaluation activities and procurements.
134 China Defense Dashboard, Jane's Defense Budgets, https://janes.ihs.com/dashboard/country/China.
135 United States Defense Dashboard, Jane's Defense Budgets data, https://janes.ihs.com/dashboard/country/United%20States.
136 Framing Workshop, August 8, 2017, Washington, D.C.
137 Framing Workshop, August 8, 2017, Washington, D.C.

above: A2/AD, power projection and intelligentization of PLA capabilities. Moreover, this discussion of even a few of China's structural vulnerabilities—especially those related to China's economy and the PLA—can help inform broader competitive strategies designed to tilt future military capability and technology acquisition competitions in the favor of the United States.

Economic Constraints
An economic crisis in China may not be looming, but signs of a slowing economy due to structural concerns are increasingly visible. China's GDP growth has dropped .5 points over the last three years. And while IHS Markit Economics' January 2018 forecast sees China's growth rate rising slightly from 6.7% in 2016 to 6.8% in 2017, the forecast also predicts China's GDP growth will drop to 6.5% in 2018 and 6.2% in 2019.[138]

An important test of China's economy is how it balances structural reform and the long-standing prioritization of growth. According to November 2017 analysis from IHS Markit Economics, "even though a [stated] high priority of the government is to resolve these structural problems, the desire to prop up short-term growth and ensure stability take precedence. One manifestation of this dilemma is China's goal of reducing currency volatility, via capital controls, which has led to an erosion of the renminbi's role as an international currency, as measured by its falling share in international payments."[139]

So far, though, China's economy has shown resilience in the face of efforts to balance these mostly competing priorities. IHS Markit Economics notes that the end of 2017, retail sales and export growth accelerated "a little" and construction growth "bounced back," leading to an expected fourth quarter year-on-year growth of 6.8%.[140] But again, IHS Markit assesses this level of growth as unsustainable as China takes steps to mitigate the risks associated with debt, shadow banking, excess capacity and pollution, in particular:

> "Three policy initiatives will restrain China's near-term growth trajectory: 1) supply-side reforms, which aim to remove excesses that the 2009-10 massive stimulus generated in industrial capacity, debt overhang, and housing inventory; 2) a regulatory crackdown on the shadow-banking section, which attempts to mitigate systemic risk of a financial crisis; and 3) the anti-pollution drive, which endeavors to reduce social discontent about living conditions. The economic impact of these policy campaigns is already apparent. Fixed investment in industries with severe excess capacity and/or pollution has cooled precipitously this year."[141]

In other words, China's attempts to address structural issues are necessary for sustained economic stability, but they also will slow growth and create new economic (and potentially related social and political) challenges that could slow the growth in China's defense spending over the next decade. This dynamic could also be accelerated or amplified by the cascading effects of demographic and social constraint and trends.

[138] IHS Markit Insights on the World Economy and Global Markets, September 2017.
[139] Behravesh, Nariman, "IHS Markit Insights on the World Economy and Global Markets," IHS Markit, November 2017.
[140] Behravesh, Nariman, "IHS Markit Insights on the World Economy and Global Markets," IHS Markit, January 2018.
[141] Behravesh, Nariman, "IHS Markit Insights on the World Economy and Global Markets," IHS Markit, January 2018.

Demographic and Social Constraints

China faces multiple demographic issues (see text box to the right) that either individually or in conjunction with one another could generate societal and economic strain and, in turn, affect the scale of resources available to invest in the different layers of military modernization discussed above.

Key Demographic Concerns in China

- Ageing population
- Gender imbalances and large number of unmarried men
- Rural-urban imbalances in health, education, achievement and wealth
- Migration from China's rural areas to its cities, further hollowing out China's rural areas

According to demographer Nick Eberstadt of the American Enterprise Institute; "All in all, [China's demographic problems] point to increasing constraints against very rapid economic growth on the one hand and stark unanswered social questions concerning inequality and even more sensitive issues on the other."[142]

While China's demographic and social issues are varied and complex, its ageing population and growing disparities in wealth, health and achievement between China's urban and rural populations stand out as particularly indicative and impactful.

China's population is growing older, placing increasing pressure on a relatively smaller working-age cohort to support ageing family members and, ultimately, population. As Table 7 below shows, nearly all the growth in China's population between 2018 and 2035 occurs in age cohorts over 50 years old. Younger working age cohorts all suffer considerable declines.[143]

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[142] Eberstadt, Nick, Urbanization and Migration in Contemporary China: Dimensions, Dynamics and Implications, prepared for the U.S. Government by IHS Jane's, September 2015.

[143] United States Census Bureau, International Database, accessed on 4 February 2018, https://www.census.gov/data-tools/demo/idb/informationGateway.php. A list of source data used by the United States Census Bureau can be found at https://www.census.gov/data-tools/demo/idb/metadata.php?R=Custom%20Region&C=China.
China projections were last updated in July 2015.

Table 7: China's estimated population by five-year age cohort in 2018 and 2035

Age Cohort Group	Total 2018 Population	Total Estimated 2035 Population	Percent Change
0-4	83,236,484	58,117,814	-43.2%
5-9	78,933,306	63,942,930	-19.0%
10-14	76,221,116	74,393,366	-2.4%
15 - 19	77,284,407	82,102,781	6.2%
20-24	93,340,458	79,061,009	-15.3%
25-29	117,229,363	75,360,505	-35.7%
30-34	110,122,260	71,888,704	-34.7%
35-39	97,952,225	83,149,925	-15.1%
40-44	98,933,199	51,786,642	-47.7%
45-49	122,946,840	123,199,046	0.2%
50-54	115,185,231	96,039,165	-16.6%
55-59	76,239,687	87,628,936	14.9%
60-64	80,958,510	104,697,449	29.3%
65-69	62,400,451	103,316,760	65.6%
70-74	39,668,490	76,604,332	93.1%
75-79	26,512,281	49,918,182	88.3%
80-84	17,265,883	37,728,773	118.5%
85-89	7,773,206	15,978,421	105.6%
90-94	2,155,640	4,842,848	124.7%
95-99	309,331	1,067,605	245.1%
100+	20,618	128,210	521.8%
Total Population	1,384,688,986	1,388,257,164	0%

Source: United States Census Bureau International Database

China’s urban-rural gap in wealth, status, achievement and education is increasingly worrying at a humanitarian level and could have strategic consequences for China. For example, a September 2017 report in *Science* magazine found that half of the approximately China’s rural 8th graders score below 90 on IQ tests, what is classified as “intellectually stunted.”[144] A normal population should only have 15% score below 90. Approximately 60%-70% of China’s youth live in rural areas. Therefore, when China’s current children reach working age, it is possible that one-third will have IQ scores below 90, ultimately meaning that up to 300 to 400 million future workers “are in danger of becoming cognitively handicapped,” unable to adapt to the rapidly changing world.[145]

China’s 2010 census isolated other important risks to rural populations:

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[144] This paper discusses gaps in China’s educational system in considerably more depth in Chapter 2, particularly its science, technology, engineering and math education.

[145] Normile. Dennis, “One in three Chinese children faces an education apocalypse. An ambitious experiment hopes to save them,” *Science*, September 21, 2017, http://www.sciencemag.org/news/2017/09/one-three-chinese-children-faces-education-apocalypse-ambitious-experiment-hopes-save.

- **Educational Attainment:** 31% of rural students drop out by grade nine while 90% of China's urban students finish high school.

- **Health:** There is a large divide in the health of young people as well: 27% of rural children suffer from malnutrition, 37% have intestinal worms and 20% have undiagnosed nearsightedness.[146]

China's 2010 census also found that only 24% of China's total labor force attended high school, putting China near the bottom of rankings for 79 middle income countries.[147] The accrued effect of these deficits, especially in China's rural populations, is that, according to Professor Scott Rozelle of Stanford University, "China has the lowest level of human capital in the middle income world,"[148] an issue that will affect not only social stability and economic output, but also, as discussed below, the quality of PLA recruits.

Political Conditions

President Xi's aggressive anti-corruption initiative and broader effort to consolidate his power could lead to what participants referred to as "tall poppy syndrome" within China's military establishment and defense industry, a dynamic in which those actors who excel or innovate in non-traditional ways –who grow taller than other poppies—are targeted for criticism and retaliation by the Party. Fear of "being cut" could disincentivize innovative individuals in the military and industrial base from offering discordant or challenging views. This fear could, subsequently, constrain the innovation necessary to further develop the advanced weapons systems of interest to this study as well as manage the three simultaneous transitions currently on-going in China's military modernization program.

The 19th Party Congress, held from October 18-24, 2017, helped to cement Xi's position, though some analysts have also suggested the event demonstrates that Xi is capable of negotiating and accommodating competing factions. Cheng Li of the Brookings Institution points out that the Politburo Standing Committee (PSC), China's most powerful decision-making body includes individuals from competing factions within the CCP: Li Keqiang and Wang Yang, both protégés of former General Secretary Hu Jintao (2002-2012) and Han Zheng and Wang Huning who are confidants of Hu's predecessor, Jiang Zemin (1989-2002), a rival CCP faction to that represented by Hu's protégés.[149] Nonetheless, Jane's believes the most important takeaway from the conference was the elevation of Xi, even if Xi demonstrated a pragmatic political approach to achieving that elevation.

Broad consensus emerged in Jane's workshops that China's heavily centralized political systems served as an inhibitor of innovation. However, Jane's research also indicates that this system and the centralized direction it provides stimulate an impressive volume and velocity of research and development (R&D) activities in prioritized areas. China's progress in AI and other Fourth Industrial Revolution technologies, such as quantum computing and encryption, can be attributed in part to

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[146] Normile. Dennis, "One in three Chinese children Faces an Education Apocalypse. An ambitious Experiment Hopes to Save Them," *Science*, September 21, 2017, http://www.sciencemag.org/news/2017/09/one-three-chinese-children-faces-education-apocalypse-ambitious-experiment-hopes-save.

[147] Normile. Dennis, "One in three Chinese children Faces an Education Apocalypse. An ambitious Experiment Hopes to Save Them," *Science*, September 21, 2017, http://www.sciencemag.org/news/2017/09/one-three-chinese-children-faces-education-apocalypse-ambitious-experiment-hopes-save.

[148] "The Growing Problems of Rural China: Trends, Solutions and Implications", CSIS Presents Lecture Series, September 14, 2017, CSIS Headquarters, Washington, D.C., https://www.csis.org/events/growing-problems-rural-china-trends-solutions-and-implications. Also cited in Wood, Peter, "PLA Attempts to Attract Higher-Quality Recruits," The Jamestown Foundation, September 21, 2017, https://jamestown.org/program/pla-attempts-to-attract-higher-quality-recruits/

[149] Li, Cheng, "The Paradoxical Outcome of China's 19th Party Congress," *Brookings Institution*, October 26, 2017, https://www.brookings.edu/blog/order-from-chaos/2017/10/26/the-paradoxical-outcome-of-chinas-19th-party-congress/.

the top-down funding that comes with national programs and China's capacity to marshal cross-industry and governmental resources to support development of key technology areas in a way that is difficult, though not impossible, for the United States.

PLA Reform and Recruitment

Demographic and social issues discussed above are combining with prevailing trends in modern warfare to underscore an additional and multi-levelled challenge to PLA recruiting activities and manpower requirements.

Trends toward "informatization" and "intelligentization" of conflict and military capabilities place a premium on the—frequently novel—use of advanced information technologies, space systems, robotics, AI and other Fourth Industrial Revolution technologies to carry out a broader set of critical military missions, redefining personnel requirements in most modern militaries.

At one level, China's move first toward informatization and then intelligentization is actually amplified by the effects of China's demographic, educational, health and social issues, which have reduced the pool of acceptable recruits available to the PLA. An August 28, 2017 article in China's *PLA Daily* provided some insight into the scale and nature of China's recruitment challenge. The article noted that "the number of people attending medical examinations in all places increased over the previous years, but the rate of medical examinations failed to rise markedly. A city medical check-out rate as high as 56.9%, indeed staggering."[150] Causes of the overall high rejection rate varied: poor vision, obesity, alcohol abuse, mental illness and poor nourishment, among other explanations.[151]

China's rural-urban disparities in education, wealth and achievement also factor into China's recruitment challenge, especially as more rural Chinese migrate to China's cities and the PLA increasingly focuses on recruits from these expanding urban areas.

In the wake of the August open source reporting on higher levels of failed recruitments, the PLA issued a staunch defense, stating that "the quality of our recruits is guaranteed and the headwaters of our military will flow long and strong."[152] However, observers of China's military interviewed for this paper expressed doubt that this was the case and instead suggested that the recognition of these recruitment challenges is actually helping to drive interest and investment in China's advanced weapons systems, particularly unmanned systems. As one Jane's contributor from the region observed based on conversations with representatives of China's unmanned systems industry, "there is an added impetus to developing increasingly advanced and capable unmanned systems to compensate for the generally poorer quality of military recruits compared to the rest of the developed world."[153]

At another level, China's advanced weapons systems development and broader efforts to incorporate high-tech military platforms and systems is creating a set of new challenges for PLA recruitment as it seeks to attract more educated and technology savvy recruits.

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[150] Duong, Liu, "Protect the homeland, think more about 'who we are'" (保家卫国，多想想"我们是谁), *PLA Daily,* August 28, 2017. http://www.81.cn/jfjbmap/content/2017-08/28/content_186595.htm.

[151] Duong, Liu, "Protect the Homeland, Think More About 'Who We Are'" (保家卫国，多想想"我们是谁), *PLA Daily,* August 28, 2017. http://www.81.cn/jfjbmap/content/2017-08/28/content_186595.htm; and Allen, Kerry, "No Fizzy Drinks: Chinese Army Tells Recruits to Shape Up," *BBC,* August 24, 2017, http://www.bbc.com/news/world-asia-china-41039233.

[152] Zhihao, Zhang, "Military Says Quality of Recruits is 'Guaranteed'," *China Daily,* August 23, 2017, http://www.chinadaily.com.cn/china/2017-08/23/content_30990977.htm.

[153] Email interview with Jane's contributor based in region, September 26, 2017

China has already begun the process of adapting its manpower requirements to fit current perceptions of the future of conflict. President Xi announced the reduction of 300,000 troops from an overall PLA force of 2.3 million at an event marking the 70th anniversary of China's victory over Japan in the "World Anti-Fascist War" in September 2015. The announcement marked the fourth time in 32 years that China has sought to reduce the size of its military forces, going from 4.2 million in 1985 to the aspiration of 2 million, and ultimately moving away from a mentality emphasizing masses of troops.[154]

Xi framed the reduction as a demonstration of China's desire for peace, stating that "in the interest of peace, China will remain committed to peaceful development. We Chinese love peace. No matter how much strong it may become, China will never seek hegemony or expansion."[155] Similarly, Yang Yujun, a spokesperson for China's Ministry of National Defense, reinforced this message offering that the reduction in troops "fully shows China's sincerity and aspiration to join hands with rest of the world to maintain peace."[156]

However, Jane's assesses that troop reduction is an acknowledgement of the need for a smaller, leaner, more educated force suited to operations in the informatized environments of today and intelligentized environments of the future.

The 2015 reforms reinforced the June 2014 PLA efforts to adjust recruitment processes and structures intended to "attract more young people with higher education backgrounds." Key components included reducing the height requirement, expanding the weight requirement, lessening the eyesight requirement and removing "mental illness"—specifically, schizophrenia, bipolar disorder, depression and dissociative disorder—from a list of disqualifying attributes of potential recruits.[157]

The reforms also targeted individuals with at least a high-school diploma through quotas and incentives. The municipalities of Beijing, Shanghai, Tianjin and Chongqing, provincial capitals and "regions with high concentrations of universities" were asked to "recruit only among those who have at least a high school diploma," according to *China Daily* reporting. Incentives were also offered for college educated recruits, including increased pay, priority admission to military colleges, the ability to suspend higher-education studies and return to them after service, tuition support and credits on the national post-graduate admission test.[158]

Operational Experience

Perhaps the most immediately affecting challenge or constraint facing China's military modernization is its lack of experience in carrying out military operations in combat or under duress. China has not fought a war since 1979, a fact experts interviewed for this project as well as

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[154] Jinping, Xi, "Full text of Chinese president's speech at commemoration of 70th anniversary of war victory," September 3, 2015, *Xinuanet,* http://www.xinhuanet.com/english/2015-09/03/c_134583870.htm.

[155] Jinping, Xi, "Full text of Chinese President's Speech at Commemoration of 70th Anniversary of War Victory," September 3, 2015, *Xinhuanet,* http://www.xinhuanet.com/english/2015-09/03/c_134583870.htm.

[156] Tiezzi, Shannon, "The Real Reason China is Cutting 300,000 Troops," *The Diplomat*, September 8, 2015, https://thediplomat.com/2015/09/the-real-reason-china-is-cutting-300000-troops/.

[157] Lei, Zhao and Wei, Cang, "PLA Eases Standards for Recruitment," *China Daily,* June 17, 2014, http://usa.chinadaily.com.cn/china/2014-06/17/content_17592194.htm.

[158] Lei, Zhao and Wei, Cang, "PLA Eases Standards for Recruitment," *China Daily,* June 17, 2014, http://usa.chinadaily.com.cn/china/2014-06/17/content_17592194.htm.

participants in the Framing Workshop repeatedly referenced as a vulnerability of China's ambitious military modernization effort.[159]

CNA Corporation Senior Research Scientist Roger Cliff highlights this same theme in his 2015 book "China's Military Power: Assessing Current and Future Capabilities," noting that "the one glaring area of weakness in the PLA's training in 2020 will likely be its lack of significant experience in a real-world military operation."[160]

The effect of this vulnerability on China's advanced weapons programs is mixed. On one hand, some experts interviewed for this project believed that it served as a constraint on how China's military capabilities, especially its advanced weapons systems, are *used*—at least until China feels more confident about the balances in key competition areas discussed above. Specifically, the lack of operational experiences was to instill what one Asia-Pacific-based interviewee called a "defensive mentality obscured by bluster…fed in part by a paucity of combat experience. 1979 [war with Vietnam] was a disaster."[161]

[159] Framing Workshop, August 8, 2017, Washington, D.C.
[160] Cliff, Roger, "China's Military Power: Assessing Current and Future Capabilities," Cambridge University Press, 2015, 137.
[161] Interview with Australian network member focused on China, September 2017.

Chapter 2: China's Defense Industrial Base Reforms, STEM Education and Science and Technology Innovation Capacity

Chapter 2 Key Themes and Insights

- **China's Advancing Defense Industrial Base:** China's state-owned enterprises' domination of the defense industry is rapidly advancing and is more capable of competing with the United States in fielding modern military capabilities and of winning international contracts. The United States retains overall superiority due in part to structural challenges still affecting China's defense industrial base, though Jane's does rank China's as the most advance industrial base in the Asia-Pacific.

- **Two-level Reforms and Efforts to Exploit the Fourth Industrial Revolution:** China is pursuing two levels of reforms to address these structural challenges. One is domestically-focused and designed to introduce market-oriented forces to enhance the efficiency, competitiveness and innovation capacity of its state-owned enterprises. These reforms are not yet achieving desired results of systemic improvements in innovation capacity.

  A second-level of policy initiatives, activities and reforms are being pursued to deepen and broaden China's technology acquisition efforts, particularly through acquisition of, investment in and joint ventures with Western companies as well as collaboration with Western academic and research institutions. These efforts have focused on acquisition of technologies required to further China's conventional military platforms and systems, such as position, navigation and timing technologies.

  China is also in the early stages of an effort to exploit Fourth Industrial Revolution technologies to shift the nature of military competition with the United States away from capability areas in which the United States holds relative advantage and into capability areas in which China has an opportunity to gain ascendancy in the next 10-15 years. Artificial intelligence, big data analytics, quantum computing and communication, robotics, advanced materials and electronics, additive manufacturing and human-machine interface technologies are indicative of this category of technologies. Most of these dual-use technologies are being developed in the commercial sector placing a premium on developing more focused and stronger connections between China's defense industry and its commercial high-tech industry.

- **Education and STEM:** China has experienced massive growth in the number of students entering and graduating college, with a particular focus on STEM-related disciplines. And while STEM graduates are in high-demand in the labor force, evidence indicates that persistent academic fraud and cheating is taking place across China's academic and research institutions. The scale of the problem and the degree to which academic misrepresentations have become a part of the research culture constitute a potential drain on innovation and development.

- **Drivers of S&T Success:** China has already seen conspicuous success in several emerging technology areas with relevance to China's advanced weapons systems programs, such as artificial intelligence, quantum computing, supercomputing and hypersonic flight. These successes are typically driven by the combination of a pressing strategic exigency, which motivates focused policy initiatives and an array of large programs, all funded at high levels. The combination of policy guidance, large programs and extensive funding attracts market-oriented private sector entrepreneurs from the high-tech industry and offers China's defense industrial base an opportunity to deepen the relationships required to fully exploit Fourth Industrial Revolution technologies for military purposes.

Overview on China's Defense Industrial Base: From Imitation to Innovation

China's defense industrial base has, over the last decade, made steady and significant progress in acquiring and developing the advanced conventional military capabilities required to indigenously produce platforms and systems to support China's multi-dimensional modernization. It has also made impressive strides in becoming a consistent member of the top 10 global defense exporters in a fiercely competitive export market.

Traditional perspectives of China's industry as predominantly holding deep competencies only in reverse engineering equipment (with "Chinese characteristics," as in, making it their own) acquired from international sources—especially from Russia—are being amended to account for a range of conspicuous successes both in traditional military capabilities and in S&T areas that have military, as well as broader, applications.

In November 2017, Jane's Defense Industry team released its Market Potential Index, which ranks the industrial proficiencies of nearly 100 defense industries worldwide. The Index employs a rigorous methodology to assess the technological sophistication, on a scale from 1 (lowest) to 5 (highest), and scale of defense industrial competencies in the land, sea, air and electronics domain.[162] China was rated as the most advanced defense industrial base in the Asia-Pacific region, ahead of U.S. allies Japan, Australia and South Korea, as reflected in the table below.[163]

Table 8: Jane's Market Potential Index scores for Asia-Pacific industries.

Country	Land industries score	Sea industries score	Air industries score	Electronics industries score	Final defense industrial rating
China	4.0	4.0	3.0	4.0	**3.75**
Japan	4.0	4.0	3.0	3.5	**3.63**
Australia	3.5	4.0	3.0	3.5	**3.50**
South Korea	3.0	4.0	3.0	3.5	**3.38**
Singapore	3.5	3.0	2.5	3.5	**3.13**
Taiwan	3.0	3.5	2.5	3.0	**3.00**
Pakistan	2.0	2.0	2.5	1.5	**2.00**
India	2.0	2.5	1.5	1.5	**1.88**
New Zealand	1.5	1.8	1.8	2.0	**1.88**
Indonesia	1.5	2.0	1.5	1.5	**1.63**

Source: Jane's Market Potential Index, 2017[164]

China's rating is negatively affected by a relatively low air industries score, reflecting challenges with indigenous aero-engine production, as well as systems integration challenges on large military platforms. Still, China's overall ranking of 3.75 places it as the eighth most sophisticated defense industrial base in the world, tied with Poland and closely trailing Italy (see Table 9 below). The United States maintains a sizable gap in overall capability at the top of the list, but even marginal

[162] For more on Jane's Market Potential Index blog and the methodology used, see https://janes.ihs.com/Janes/Display/jiq0227-jiq.
[163] Burton, Paul, "China's Defense Industry is Fastest Growing in Asia," *Jane's Aerospace, Defense and Security Blog,* November 21, 2017, http://blog.ihs.com/china%E2%80%99s-defense-industry-is-fastest-growing-in-asia.
[164] Jane's Defense Industry and Budgets Team, "Market Potential Index," *Jane's Navigating the Emerging Markets,* November 22, 2017, https://janes.ihs.com/Janes/Display/jiq0227-jiq.

continued development in traditional industries measured by the index would see China competitive with the United Kingdom, Russia and Germany.[165]

Table 9: Top ten defense industries as ranked by Jane's Market Potential Index

Country	Land industries	Sea industries	Air industries	C4 industries	Overall defense Industrial rating
United States	5.00	5.00	5.00	5.00	5.00
France	4.50	4.50	4.50	4.00	4.38
Germany	4.50	4.50	4.00	4.00	4.25
Russia	4.50	4.00	4.50	4.00	4.25
United Kingdom	3.50	4.50	4.00	4.50	4.13
Sweden	3.50	4.00	4.50	4.00	4.00
Italy	3.00	4.00	4.50	4.00	3.88
China	4.00	4.00	3.00	4.00	3.75
Poland	4.00	3.50	4.00	3.50	3.75
Japan	4.00	4.00	3.00	3.50	3.63

Source: Jane's Market Potential Index, 2017[166]

Jane's Associate Director for Defense Industry and Budgets Guy Anderson noted that success for China, as well as all the countries near the top of the Asia-Pacific list in Table 8, is due to "strong government-backed research and development investment, a long-term approach to the growth of [their] national defense industries and an emphasis on the involvement of domestic companies in national defense equipment programs." [167] Each of these are themes explored throughout Chapter 2 as foundational elements of China's growing defense industrial capability.

Despite this steady and significant progress, China still faces a series of structural and capability challenges that will need to be addressed in order for China to attain parity with the world's most advanced defense industrial bases and complete the transition of industrial capabilities from imitate to innovate." Most notably, China must address challenges related to:

- A tightly-controlled, highly-segmented and deeply fractured industry structure that does not trust private sector defense companies and therefore eschews private sector involvement
- Insufficient systems integration experience and expertise and lack of sophistication of quality control, processes and standards
- Limited sciences and engineering expertise in specific technologies and capability areas. Aero-engines and C4ISR systems stand out as notable examples.

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165 Jane's Defense Industry and Budgets Team, "Market Potential Index," *Jane's Navigating the Emerging Markets,* November 22, 2017, https://janes.ihs.com/Janes/Display/jiq0227-jiq.
166 Jane's Defense Industry and Budgets Team, "Market Potential Index," *Jane's Navigating the Emerging Markets,* November 22, 2017, https://janes.ihs.com/Janes/Display/jiq0227-jiq.
167 Burton, Paul, "China's Defense Industry is Fastest Growing in Asia," *Jane's Aerospace, Defense and Security Blog,* November 21, 2017, http://blog.ihs.com/china%E2%80%99s-defense-industry-is-fastest-growing-in-asia.

China's political and military leadership is not blind to these liabilities and has proactively and aggressively sought to address them through a series of reforms, many of which were introduced over the last decade, but that have gained considerable energy and pace since 2014. For the purposes of this paper, Jane's has separated these reforms into two broad categories:

1. **Domestically-focused activities and reforms** designed to reduce inefficiency in the current fractured structure, increase collaboration with the private sector, introduce competitive pressures to drive innovation and expand mechanisms for investment funding

2. **Externally-focused activities and reforms** designed to acquire technologies and know-how to fill gaps and gain an advantage in critical emerging technology areas

But assessment of China's defense industry and its future capability should not narrowly focus solely on its capacity to catch up to the United States in advanced military capabilities. Jane's believes that China is at the start of a national effort, driven by top-down policy guidance and high levels of funding, to develop a suite of capabilities based on Fourth Industrial Revolution technologies, many of the most impactful of which (i.e., AI) are being developed aggressively in the commercial sector.

The Fourth Industrial Revolution, then, may offer China an opportunity to further accelerate its progress and enhance its competitiveness with the United States by shifting the nature of the competition itself. Rather than competing with the United States capability areas in which the United States holds (and is likely to continue to hold) a relative advantage, Jane's assesses that China views the Fourth Industrial Revolution as an opportunity to gain an early advantage in the development of intelligentized capabilities based on technologies such as AI, advanced manufacturing, new materials, energy capture and storage, quantum computing and encryption, robotics and big data analytics. These are all areas in which China has had some degree of initial development success in its high-tech commercial sector *and* all areas that can further advance China's advanced weapons systems programs.

Development of these technologies requires a different approach and innovation culture than those considered fundamental to the development of advanced platforms and systems of the early 21st century. According to Jane's Defense Industry Asia-Pacific Reporter Jon Grevatt; "the culture and capabilities requires a different mindset—one that market-oriented private sector and high-tech companies in China are more likely to possess."[168] Ultimately, this shift places a premium on China's defense state-owned enterprises developing means of collaborating more closely with China's high-tech and electronics industries.

Issues Affecting China's Defense Industrial Base

An important element of China's military modernization program is the development of a domestic defense industry capable of providing the advanced capabilities required for China to achieve the evolving objectives of its military modernization. As China's 2013 Military Strategy White Paper articulates, China's aerospace and defense industry is tasked with "the development of new and high-technology weaponry and equipment to build a modern military force structure with Chinese characteristics."[169]

China's industry has clearly advanced in capability over the last decade-plus and is, as discussed above, one of the most rapidly maturing defense industrial bases in the world. But it is still hindered by a series of structural challenges that dampen internal competition, efficiency and in many cases

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[168] Email interview with Jon Grevatt, November 22-23, 2017.
[169] China's Ministry of National Defense, *China's Military Strategy 2013 White Paper*, website, http://eng.mod.gov.cn/Database/WhitePapers/2013-04/16/content_4442757.htm.

the type of game-changing science, technology and integration-related innovation that is frequently required to indigenously deliver modern military capabilities.

Industry Structure: Tightly Controlled, Highly Segmented and Deeply Fractured
China's aerospace and defense industry has long suffered from three amplifying structural challenges: it is tightly controlled by agents of the central government, highly segmented into more or less protected state-owned enterprises and it is overly complex, fractured and redundant.

China's aerospace and defense community and industry is highly-centralized. The State Council, through the Ministry of Industry and Information Technology (MIIT) and its subordinate body the State Agency for Science, Technology and National Defense (SASTIND) oversees the 10-large state-owned defense-focused enterprises and typically awards contracts through sole source procurements. The RAND Corporation assess that the centralized, monopolistic approach to the industry constitutes "one of the biggest hurdles PLA and civilian defense acquisition specialists point out" for China's defense industry.[170]

The defense industry is also highly fractured and compartmentalized, replete with redundancies in capabilities and expertise and deep structural inefficiencies. For example, the two main state-owned enterprises involved in China's dual-use space program are China Aerospace Science and Industry Company (CASIC) and China Aerospace Science and Technology Company (CASC), each of which is profiled in considerably more depth in Section 2.

Both CASC and CASIC develop systems and equipment, such as launch vehicles, for the space program and also develop military systems, such as missiles, for the PLA.[171] Therefore, CASC and CASIC traditionally had many subsidiaries and research institutes that focus resources and R&D efforts on essentially the same problems to provide similar solutions, which are frequently procured without any competitive dynamics, ensuring interaction of or transparency into the activities of these organizations. CASIC and CASC (and overlaps in their capabilities) are discussed in more detail in this section. A full treatment of each organization's participation in China's advanced weapons systems programs is included in Chapter 4.

Processes and Standards
China also lacks modern R&D processes, standards and infrastructure from which to build and deepen efficiencies in its defense industry enterprises. Addressing these issues forms a growing preoccupation for the PLA and for China's defense industrial base and military leadership. The May 2015 Military Strategy White Paper stressed these points, saying, "[China's military leadership] will also intensify overall supervision and management of strategic resources, strengthen the in-process supervision and risk control of major projects, improve mechanisms for strategic assessment, and set up and improve relevant assessment systems and complementary standards and codes."[172] The same theme was highlighted by Wang Yingjie, the Director of the Management Innovation Department of China's recently consolidated Aero-Engine Corporation of China (AECC), who highlighted one of the main weaknesses slowing China's development of this key strategic technology is its lack of sophistication in "the formation of a standardized code system."[173]

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[170] Michael S. Chase et al., "China's Incomplete Military Transformation," RAND Corporation, 2015, 127. http://www.rand.org/content/dam/rand/pubs/research_reports/RR800/RR893/RAND_RR893.pdf.
[171] Written Testimony before the U.S.-China Economic and Security Review Commission, Hearing on "China's Space and Counterspace Programs," Tate Nurkin, February 18, 2015. https://uscc.gov/sites/default/files/Nurkin%20Written%20Testimony%202%209%2015.pdf.
[172] State Council Information Office of the People's Republic of China, "China's Military Strategy," May 2015, Beijing, http://eng.mod.gov.cn/Database/WhitePapers/index.htm.
[173] Wenyu, Sun, "China Plans to Catch up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.

China's Innovation and Integration Challenge

In his 2016 review of China's fifth generation fighter, Anthony Cordesman, the Arliegh A. Burke Chair in Strategy at the Center for Strategic and International Studies, effectively highlights and contextualizes the innovation challenges, organization, systems integration, structure, technical capacity and industrial process discussed above:

> "China still lacks the sophisticated technology required for highly advanced innovation in military equipment—in particular, advanced capabilities in material selection, process standardization, quality control and ensuring structural strength. When combined with integration, systems design and management problems, the result has been cost overruns, extensive testing and delays and many modifications of the design [of China's stealth aircraft]. Furthermore, the fragmented corporate structure of AVIC, the manufacturer of China's fifth generation aircraft, makes it difficult for the group to gain compliance from its sub-units."[174]

Similar assessments of China's aerospace, space and defense industry's innovation and systems integration capacity come from technical personnel working with China in these areas, and also from associated foreign academic institutions. The Rutherford Appleton Laboratory and its parent organization (the Science Technology Facilities Council) have close relationships with China's National Space Administration (CNSA) and the Chinese universities which provide research on aeronautics and space science, especially Beijing University.[175]

According to Chris Bee, then head of the STFC's business development unit, "innovation takes two forms: it is either something truly ground-breaking or you are doing something which you are already doing, a little bit better. And I think the Chinese tend to focus a little bit more on doing things a little bit better, while perhaps our innovation focus in the West is generally much more on the ground-breaking."[176]

McKinsey Global Institute explored this tension between China's demonstrated capacity to drive efficiency-driven innovation and its mixed results in delivering engineering and science-based innovation in an October 2015 report.[177] Figure 6 below offers some insight into areas in which a selection of 31 of China's industries—not just aerospace and defense—are over-performing and under-performing relative to expectations based on China's share of global GDP.

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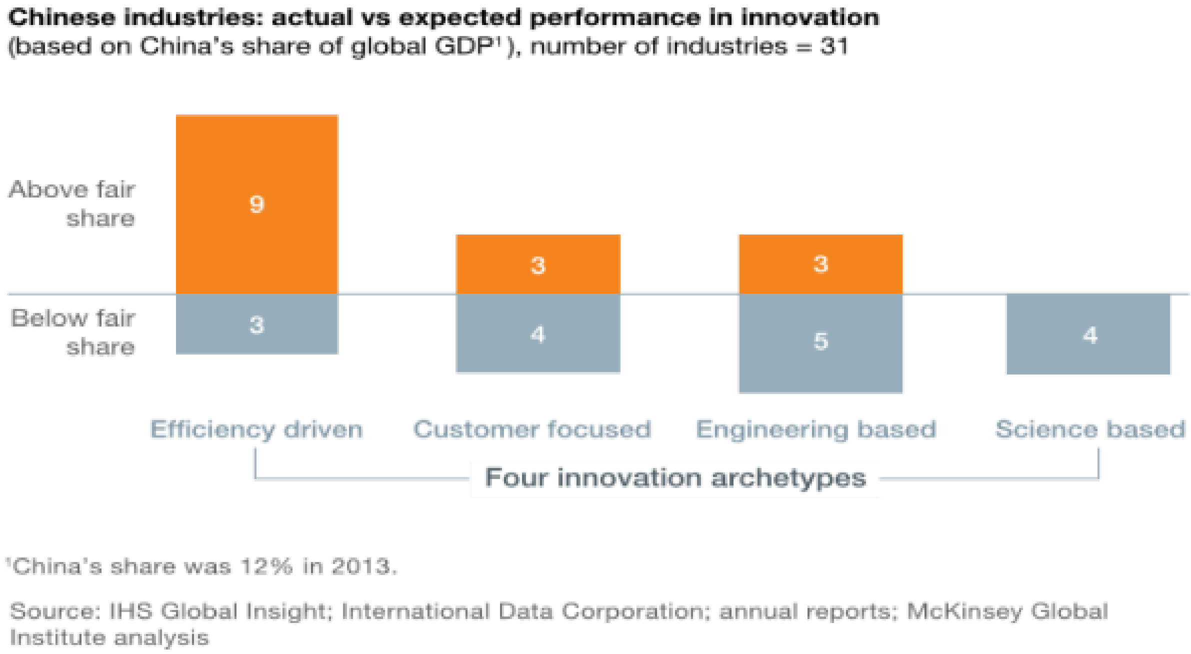
[174] Cordesman, Anthony, "China's Structure and Military Modernization in 2016," *Center for Strategic and International Studies,* December 8, 2016. https://csis-prod.s3.amazonaws.com/s3fs-public/publication/161208_Chinese_Strategy_Military_Modernization_2016.pdf.
[175] "New UK-China agreement to increase space education," RAL Space, September 6, 2017. https://www.ralspace.stfc.ac.uk/Pages/New-UK-China-agreement-to-increase-space-education.aspx
[176] "Interview with Chris Bee," *Go Taikonauts* January 2015. https://isulibrary.isunet.edu/opac/doc_num.php?explnum_id=704.
[177] Roth, Erik, Seong, Jeongmin and Woetzel, Jonathan, "Gauging the Strength of Chinese Innovation," McKinsey Global Institute, October 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/gauging-the-strength-of-chinese-innovation.

Figure 6: An assessment of how 31 Chinese industries perform versus expected performance in four categories of innovation type



Source: McKinsey Global Institute, using data from IHS

The data and accompanying analysis clearly reveal that Chinese companies operating in industries that rely on efficiency-driven innovation – that is, industries like manufacturing that have traditionally stressed doing things "a little bit better," in Mr. Bee's framework—are performing well. Chinese industries that rely on science-based innovation that "[generates] new discoveries,"[178] though, are *under-performing* their expectations. China's aerospace industry was categorized with other industries that rely on engineering-based innovation. These are "companies [that] innovate by solving engineering problems using accumulated know-how and integrating technologies from suppliers and partners—to engineer cars for better fuel economy, for example."[179] This category of companies has mixed-to-negative results.[180]

The predictable outcome of this dynamic, at least for China's aerospace, defense and space industries, has been an approach focused on S&T innovation, but in single technology areas rather than in engineering and integrating complex systems. Overcoming the limitations of single system innovation was the motivation behind a February 2012 agreement between CASC's China Academy of Launch Vehicle Technology and Glasgow's Strathclyde University on integrating design, manufacturing and engineering management of space technologies. CASC representatives stated

[178] McKinsey Global Institute, "The China Effect on Global Innovation: Executive Summary," October 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/gauging-the-strength-of-chinese-innovation.

[179] Roth, Erik, Seong, Jeongmin and Woetzel, Jonathan, "Gauging the Strength of Chinese Innovation," McKinsey Global Institute, October 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/gauging-the-strength-of-chinese-innovation.

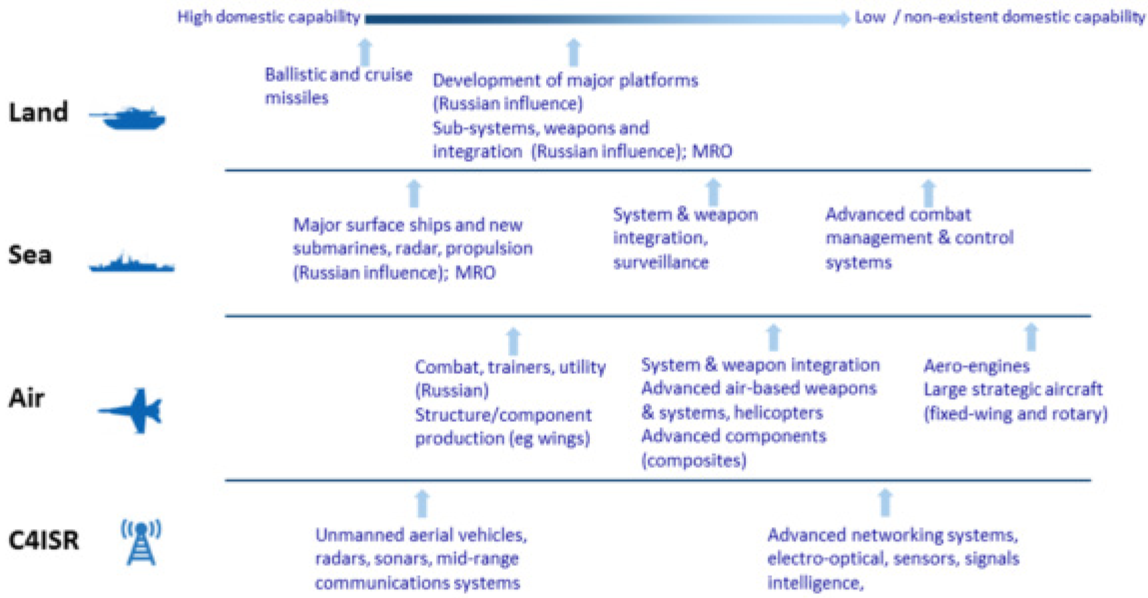
[180] Roth, Erik, Seong, Jeongmin and Woetzel, Jonathan, "Gauging the Strength of Chinese Innovation," McKinsey Global Institute, October 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/gauging-the-strength-of-chinese-innovation.

that their objective was to help Chinese defense and space R&D sector move "from single technology-oriented innovation to systems-based innovation."[181]

China's preference for single technologies and prototype development has not been without notable successes. The approach has been vital to the success of China's space efforts, such as the Tiangong and Chang'e programs that used multi-phase deployment programs to demonstrate and study technologies before fully developing final systems or pursuing more ambitious applications of these technologies. Development of China's J-20 and J-10 fighter jet programs followed a similar process.

Jane's assessment of China's technology and capability gaps and areas of strength in Figure 7 further demonstrates the point.

Figure 7: China's Strengths and Weaknesses in Technology and Capability Development across Land, Air, Sea, and C4ISR Domains



Source: Jane's Navigating the Emerging Markets, China

China has demonstrated the capacity to develop and deploy high-priority systems—such as ballistic and cruise missiles as well as unmanned systems—and in the development of major platforms, on which typically has relied on China's capacity to reverse engineer Russian platforms and systems and reimagine them with "Chinese characteristics." However, Jane's assesses that China has struggled in developing and integrating advanced and complex systems, which requires different skill-sets than innovation in large platforms or single technologies, including those in the text box below.[182]

McKinsey Global Institute's analysis also highlighted this gap in systems integration in China's commercial aerospace industry, particularly at the state-owned Commercial Aircraft Corporation of China (COMAC).

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[181] "Interview with Chris Bee, Head of Business Development for the Science Technology Facilities Council-STFC Rutherford Appleton Laboratory in Harwell, Oxford', Dr. William Carey, *Go Taikonauts!* e-magazine, issue 14, January 2015. https://isulibrary.isunet.edu/opac/doc_num.php?explnum_id=704.

[182] The mixture of hard and soft skill-sets included in the text box were derived from multiple discussions with aerospace and defense experts within Jane's and our close network, as well as engineers with systems integration experience in other fields, including civil and electrical engineering.

According to McKinsey, "COMAC has relationships with some of the world's top aerospace suppliers for everything from engines to avionics, but these partnerships do not provide the critical knowledge needed for successful integration of parts and subsystems, which is the central challenge in aircraft production."[183]

While none of these skill-sets listed in the text box to the right are likely to be considered novel or surprising, engineers and aerospace and defense experts interviewed for this report repeatedly stressed the enormous difficulty in developing and applying these skills in a modern aerospace and defense development program. Indeed, even in the United States, where large defense primes such as Lockheed Martin, Raytheon, Northrop Grumman and Boeing have "deep benches" of systems integrators with extensive experience and demonstrated expertise in managing large projects and supply chains and integrating complex technologies, over-runs in cost and delivery timelines still occur.

Jane's Assessment of Systems Integration Skill-Sets

- Knowledge of system engineering architecture principles, concepts and best practices
- Establishment of metrics
- Capacity to design and incorporate technologies in a way that accounts for broader system architecture constraints
- Assess all components of a system and understand how they fit together in order to ensure proper sequencing of technical integration
- Ability to plan, organize, manage and effectively monitor complex supply chains and, more broadly, large projects
- Training in critical thinking and problem solving
- Process standardization techniques

Ultimately, iterative experience in managing large and complex programs is frequently the best way to develop and refine these skills, which means that meaningful improvements and innovation in systems engineering capability must be developed over time frames measured in years or, more likely, one to two decades, rather than months or a small handful of years.

In addition to integrating complex technologies and systems during the design and manufacturing process, China's systems engineering challenge also has an operational component. As highlighted in Chapter 1 of this report, China's military modernization is hindered by its lack of operational experience, a limitation typically associated with the application of military equipment under combat equipment. Paul Burton, Director of Jane's Defense Industry and Budgets portfolio, closely follows China's military modernization effort and noted that the PLA's ability to take the range of advanced equipment that its industry has produced and "integrate it into a common operational practice, to get it all to talk to each other and to be able to leverage the efficiency of networks and multi-axis teams in a way that is repeatable in multiple environments" is still lacking.[184]

Aero-Engine Case Study

Perhaps no defense industrial base engineering and technology failure is more pronounced or frequently discussed than China's lack of capacity to indigenously develop advanced aero-engines. China has tried multiple pathways to resolve this problem, including extensive partnering with Russian and Ukrainian firms as well as the Italian firm—and GE subsidiary—Avio in 2010. None of these measures have worked.

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183 McKinsey Global Institute, "The China Effect on Global Innovation: Full Report," October 2015, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/gauging-the-strength-of-chinese-innovation.

184 Phone interview with Paul Burton, November 19, 2017.

In the summer of 2016, China's State Council tried another approach. All aero-engine development activities were consolidated under a single entity, the Aero-Engine Corporation of China (AECC, and also referred to in some sources as the Aero-Engine Group of China) in an effort to reduce inefficiency and redundancy and foster strengthened collaboration and innovation on aero-engine engineering and innovation across its aerospace and defense industrial base.[185]

Jane's believes the most important efficiency gained through the consolidation of China's aero-engines activities is political, rather than technical. The presence of an overarching organization endorsed by the State Council ensures funding—with estimates of a full R&D program for a "medium-large sized aero engine" between $2 to $3 billion. State funding is important, but adjacent and intersecting industries are also providing support.[186] Vice Chairman of AECC Lee Ronghuai hinted at the political dynamics at play in September 2017 when he stated: "Related enterprises are sparing no efforts to support us. They are supporting us *even at their own losses* [emphasis added] when we need specific steels in very limited amounts."[187]

And this prioritized support from across China's industrial base is likely to prove useful in advancing China's aero-engine efforts—though prioritization of aero-engines is not new—in addressing China's multi-dimensional weakness in aero-engines. According to Jane's experts, key gaps include:[188]

- Weak process standardization and overreliance on individual machine operators' skill and experience.

- Lack of indigenous integration and design ability, including, but not limited to, full-authority digital engine control (FADEC) technologies. FADEC is a sophisticated means of offering digital electronic control of engine activities; there is no direct pilot control, rather the systems are autonomous, self-monitoring, self-operating and redundant. FADEC systems allow engines to more efficiently optimize performance through efficient management of power as well as constant monitoring of engine performance, which in turn leads to more efficient maintenance cycles.[189] China reportedly demonstrated a FADEC system on a military engine in November 2014 at the Airshow China as part of the Minshan engine. Reporting at the time noted "how well Chinese industry might be able to adapt FADEC systems to newer fighter aircraft…remains a question."[190] Jane's research does not indicate that issues integrating FADEC systems into indigenous designs have been fully resolved.

- Lack of effective powder-metallurgy technology and fluency with aviation grade materials, such as titanium.

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[185] Grevatt, Jon, "China Consolidates AeroA-engines and Naval Shipbuilding Sectors," *Jane's Defense Weekly,* June 14, 2016. https://janes.ihs.com/Janes/Display/jdin90464-jdw-2016.
[186] Wenyu, Sun, "China Plans to Catch Up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.
[187] Wenyu, Sun, "China Plans to Catch Up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.
[188] The analysis is the result of a 2014 internal email discussion on China's aeroengine challenge among Jane's China and aircraft experts. The discussion was driven by analysis provided by Jane's contributor Reuben Johnson.
[189] "Full Authority Digital Control", FAA Aviation Safety Briefing, https://www.faa.gov/news/safety_briefing/2017/media/SE_Topic_17-12.pdf; and "Full Authority Digital Control" product information sheet, BAE Systems, https://www.baesystems.com/en-us/product/full-authority-digital-engine-control-fadec-systems.
[190] Johnson, Reuben, "Chinese Show Fadec System on Military Engine", AINOnline, 25 November 2014, https://www.ainonline.com/aviation-news/defense/2014-11-25/chinese-show-fadec-system-military-engine.

Much of Jane's analysis was confirmed by public statements by leaders within AECC made in September 2017. Yin Zeyong, head of AECC's S&T commission stated that "design capability is China's biggest weakness" in aero-engines while Wang Yingjie, Director of the Management Innovation Department of the AECC, believes that China still has "a long way to go in" the formation of a standardized code system.[191]

Only a year into this most recent consolidation effort, it is difficult to fully assess success or failure of AECC. In fact, the chairman of AECC, Cao Jianguo, assessed in September 2017 that China's timeframe for competing in this space is very much long term, saying "China plans to catch up with the advanced aero-engine producers in 20 years."[192]

Success over the next two decades will almost certainly mix the old and new: old ways of operating, such as partnerships and joint ventures with Russia, will mix with new technologies, approaches and processes and relationships with private sector companies outside of China's traditional defense industrial base. But two decades (or so) seems a reasonable, if conservative, time frame, especially when one considers that China's winding effort to master aero-engines is already two decades old, assuming continued funding, political and policy prioritization and the ability to acquire new talent and technologies.

China's Defense Industrial Base Reforms and Civil Military Integration

The Chinese government has introduced a range of reforms over the last decade (or in some cases, considerably longer) meant to address the structural challenges identified above. These reforms picked up considerable momentum in 2014.

Specifically, the reforms are designed to achieve multiple objectives. Most importantly, they are designed to increase the efficiency of China's defense industrial base and to foster innovation in the design, development and deployment of advanced military capabilities that support China's military modernization. They are also designed to provide enhanced funding and scale to China's state-owned enterprises, which will allow these firms to compete more effectively in the highly competitive global defense industry. Jeffrey Becker, a China Analyst at CNA Corporation, called the measures announced in 2014 "some of the widest ranging and most serious reforms in decades."[193]

Jane's assesses that, taken as a whole, the reforms can be segmented into two broad categories: domestically-focused and externally-focused.

Domestically-focused reforms include consolidation of and collaboration between state-owned enterprises (as seen with the formation of AECC), institution of mixed ownership reforms (MOR), development of new funding sources and general efforts to enhance privatization of the defense industrial base. These efforts are targeted at enhancing efficiency and competition and injecting new approaches to innovation from the more market-focused private sector. To date, China's domestically-focused reforms have struggled to achieve the hoped-for effects, undermined by deeply-rooted structural issues, fixed-interests and a lack of trust in China's private defense industry in many capability areas.

Externally-focused reforms are designed to leverage China's growing international economic influence and the attractiveness of its domestic market to a range of foreign industries—from high-

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[191] Wenyu, Sun, "China Plans to Catch Up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.
[192] Wenyu, Sun, "China Plans to Catch Up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.
[193] Becker, Jeffery, "The Future of China's Military Innovation," Center for International Maritime Security, July 24, 2015, http://cimsec.org/future-chinas-military -innovation/17483.

tech to commercial aerospace to automotive and beyond—to acquire technologies, talent and know-how required to advance China's defense industrial base. Growing emphasis on *acquisitions of* and *joint ventures with* Western companies as well as the continued refinement and expansion of China's technology acquisition strategies—of both gap fill and aspirational technologies—are all components of these externally-focused reforms and efforts. More importantly, these efforts to acquire and leverage foreign technology, talent and knowledge are also a central piece of China's efforts to fully leveraging the transition from informatized to intelligentized warfare.

Civil-Military Integration[194]

These two areas of reform are proceeding in tandem, bound by the connective tissue of civil-military integration (CMI), described by Jane's as "the integration of commercial and defense industry capabilities to promote dual-use technologies and production processes and the use of personnel and facilities that can, to a degree, undertake both disciplines."[195]

China's initial efforts at CMI can be traced back to the 1980s. Originally conceived narrowly as a means to convert military factories over to civilian production[196] under the direction of the State Council and provincial and municipal governments,[197] the concept has expanded and sharpened in the last twenty years. Government and policy emphasis related to CMI has shifted in this time, but many components have remained consistent and are incorporated into CMI definitions from Chinese, U.S. and other foreign sources:

- CMI involves the combining of China's defense and civilian industrial bases so that common technologies, manufacturing processes and equipment, personnel and facilities can be used to meet both defense and commercial needs.[198]

- The "spin-on" nature of the technology transfer—from commercial entities to military ones—enables China to get around U.S. and European arms embargos and technology export control restrictions.

- Commercial acquisition of technologies, equipment and processes, and subsequent diffusion of these technologies to the military sector offer an opportunity for China to close the gap and eventually leapfrog its competitors, particularly the United States, in terms of military capabilities.

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[194] Some institutions prefer to translate China's military-civil integration as "military-civil fusion". Greg Levesque and Mark Stokes of Pointe Bello argue that China's military-civil efforts should be called "fusion" as they go beyond traditional civil-military integration by aiming to build "a national infrastructure that connects the PLA, state-owned defense research, development, and manufacturing enterprises, government agencies under the State Council, universities, and private sector firms". However, English text from China's State Council and state news outlets use the term "integration". Thus, this report uses the term Civil-Military Integration (CMI). Jane's reporters following China's defense industrial base use the term civil military integration and believe the two terms to be "interchangeable". Levesque, Greg and Mark Stokes, "Blurred Lines: Military-Civil Fusion and the 'Going Out' of China's Defense Industry," Pointe Bello, December 2016. https://static1.squarespace.com/static/569925bfe0327c837e2e9a94/t/593dad0320099e64e1ca92a5/1497214574912/062017_Pointe+Bello_Military+Civil+Fusion+Report.pdf.

[195] Grevatt, Jon, "China-Defense Industry," *Jane's World Defense Industry*. May 20, 2015. https://janes.ihs.com/Janes/Display/jwdia069-jwdi.

[196] Bitzinger, Richard, "Civil-Military Integration and China's Military Modernization," *Asia Pacific Security Studies*, Volume 3, Number 9, Asia-Pacific Center for Security Studies, December 2004, http://www.dtic.mil/dtic/tr/fulltext/u2/a495828.pdf

[197] May, M.M (ed), "The Cox Committee Report: An Assessment," Center for International Security and Cooperation, Stanford University, December 1999, http://carnegieendowment.org/pdf/npp/coxfinal3.pdf

[198] Ao, Temjenmeren, "China's New Commission for Enhancing Civil-Military Integration," *Forum for National Security Studies,* Centre for Air Power Studies, (India), February 8, 2017, http://capsindia.org/files/documents/CAPS_Infocus_TA_11.pd.f.

- The use of the defense industrial base to drive innovation and growth in the Chinese economy as a whole, which has "been accepted as an article of faith by China's central planners for years now."[199]

- CMI is designed to advance China's overall objective of technological self-sufficiency.

Focus on CMI in policy documents over the last six to seven years has been acute. For example, the 12th Five Year Plan (2011–2015) states that the Chinese government "vigorously promotes the open sharing of military and dual-use technologies for mutual transfer…and to improve national defense capabilities and military capabilities."[200] This emphasis has seemingly been amplified by several investments and policy statements since.

In early 2013, CASIC established a Renminbi (RMB) 1 billion ($150 million) venture capital fund to bolster CMI engagement with companies in Beijing, with a focus on dual-technology fields including networked-enabled capabilities, cyber security and communications. [201] In June of 2013, the PLAN signed an agreement with SASTIND to promote CMI by creating a facility to focus on joint public-private R&D programs for the PLAN's modernization efforts.[202] In December 2013, the MIIT issued directories to local companies to help "private enterprises enter the field of military research and production."[203]

China's 2015 Military Strategy White Paper devoted an entire section to CMI, an "unprecedented" level of attention, according to Jane's China analysts.[204] It prioritizes "accelerating CMI in key sectors, building a mechanism for operating CMI and improving the systems and mechanisms of national defense mobilization."[205] The section focuses heavily on not only accelerating CMI, but also refining the processes through which CMI occurs, including improving shared infrastructure; improving mechanisms for military-civilian coordination; management responsibilities of relevant military and civilian institutions; and the general standards for both the military and the civilian sectors.[206]

The CMI policy has direct implications for the organizations involved in China's advanced weapons systems programs. Both CASIC and CASC have played a critical role in leading the CMI strategy. Both corporations have been cited by the SASTIND in official documents that were intended to shape the CMI policy in China's 13th Five-Year Plan.[207]

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[199] Johnson, Reuben, "China Still Struggling with Civil-Military Integration Issues," *Jane's Defense Weekly,* September 28, 2017, https://janes.ihs.com/Janes/Display/FG_652161-JDW.
[200] Grevatt, Jon, "China Defense Industry," *Jane's World Defense Industry,* May 20, 2015. https://janes.ihs.com/Janes/Display/jwdia069-jwdi.
[201] Grevatt, Jon, "Chinese Government Establishes Venture Capital Fund to Aid Civil-Military Integration," *Jane's Defense Industry*, January 21, 2013, https://janes.ihs.com/Janes/Display/jdin85606-jdw-2013.
[202] Grevatt, Jon, "Chinese Navy, government, sign civil-military industry teaming agreement," *Jane's Defense Industry,* June 25, 2013. https://janes.ihs.com/Janes/Display/jdin86124-jdin-2013.
[203] Grevatt, Jon, "China issues industry directories to enhance civil-military integration," *Jane's Defense Weekly,* December 12, 2013. https://janes.ihs.com/Janes/Display/jdin86822-jdw-2014.
[204] Gupta, Rukmani, Jon Grevatt and James Hardy, "Analysis: Parsing China's Latest Defense White Paper," *Jane's Defense Weekly*, May 26, 2015. https://janes.ihs.com/Janes/Display/jdw58752-jdw-2015.
[205] USNI, "Document: China's Military Strategy," May 26, 2015, http://news.usni.org/2015/05/26/document-chinas-military-strategy.
[206] USNI, "Document: China's Military Strategy," May 26, 2015, http://news.usni.org/2015/05/26/document-chinas-military-strategy.
[207] Jon Grevatt, "Chinese Government Establishes Venture Capital Fund to Aid Civil-Military Integration," *Jane's Defense Industry*, January 21, 2013, https://janes.ihs.com/Janes/Display/jdin85606-jdw-2013.

Another CMI directory was released by SASTIND in November 2015. It was not made public but SASTIND reported that the directory outlined the priority areas of CMI. The directory also created the expectation that state-owned companies such as AVIC, CASC, CASIC, CSSC, CETC and CSGC would lead the CMI strategy.[208]

On March 11, 2016, SASTIND announced that at the end of the 12th Five-Year Plan there had been a 127% increase in the number privately-owned defense companies in China, totaling over 1,000.[209] By August 2016, China's military procurement website was open for the first time to private sector firms to bid on military R&D projects. Sensitive projects were excluded.[210]

China's 13th Five-Year Plan (2016 – 2020) contains a section on "coordinated economic and defense development" which includes a commitment to establishing a funding mechanism for integrated military-civilian development projects; further institutional reform of defense-related science and technology industries; and an advancement of legislation "related to the integration of military and civilian development." The Five-Year Plan also commits to piloting further reforms to support a mixed-ownership economy.[211]

Efforts to boost CMI were also key initiatives throughout 2017. On January 22, 2017, China officially announced the formation of the Central Commission for Integrated Military and Civilian Development.[212] The Commission reports to the Central Politburo of the CCP and is chaired by President Xi, demonstrating its importance to China's overall national development and military modernization efforts. The Commission will manage CMI activities across the country, prioritize national objectives, and seek to improve efficiency and effectiveness of CMI efforts.[213] During the Commission's first meeting on June 20, 2017, President Xi articulated China's principal CMI priorities, including "advanced weapons and defense equipment, science and technologies, maritime, space, cyber defense and alternative energy."[214] In September 2017, the Commission's recommended reforms for the national defense industry were adopted by the Chinese government. China stated that the reforms were guidelines on advancing "highly integrated military and civilian development in military logistics" through 2020 but no other details were given.[215]

The establishment of the Commission follows the early January formation of China's National Defense Industry Enterprise Military and Civil Integration Alliance, which was set up to support CMI efforts across national defense and commercial interests.[216]

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[208] Grevatt, Jon, "China Outlines Priority Areas for Civil-military Integration," *Jane's Defense Weekly,* November 19, 2015. https://janes.ihs.com/Janes/Display/jdin89695-jdw-2016.
[209] Grevatt, Jon, "China to Accelerate Reforms Promoting Private Sector Industrial Growth," *Jane's Defense Industry,* March 14, 2016. https://janes.ihs.com/Janes/Display/jdin90127-jdin-2016.
[210] Grevatt, Jon, "China opens military R&D to the private sector," *Jane's Defense Industry*, August 8, 2016. https://janes.ihs.com/Janes/Display/jdin90679-jdin-2016.
[211] "The 13th Five-Year Plan for Economic and Social Development of the People's Republic of China (2016 – 2020)," Central Committee of the Communist Party of China. http://en.ndrc.gov.cn/newsrelease/201612/P020161207645765233498.pdf.
[212] Grevatt, Jon, "China Launches Civil-Military Integration CommissionLCMIC," *Jane's Defense Weekly,* January 23, 2017. https://janes.ihs.com/Janes/Display/jdin91298-jdin-2017.
[213] Grevatt, Jon, "China Launches Civil-Military Integration Commission," *Jane's Defense Weekly,* January 23, 2017. https://janes.ihs.com/Janes/Display/jdin91298-jdin-2017.
[214] Grevatt, Jon, "China Inaugurates Commission to Lead Civil-Military Integration," *Jane's Defense Weekly,* June 21, 2017. https://janes.ihs.com/Janes/Display/FG_521331-JDW.
[215] Grevatt, Jon. "China formally adopts industry reforms," *Jane's Defense Weekly*. September 25, 2017. https://janes.ihs.com/Janes/Display/FG_649066-JDW
[216] Grevatt, Jon, "China Launches Civil-Military Integration Commission," *Jane's Defense Weekly,* January 23, 2017. https://janes.ihs.com/Janes/Display/jdin91298-jdin-2017.

In April 2017, *Global Times* reported that the Chinese government had launched a RMB 6 billion ($872 million) investment fund for up to 2,000 private-sector R&D projects in military and related activities.[217]

In August 2017, China's Ministry of Science and Technology (MOST) and the Central Commission for Integrated Military and Civilian Development released its civil-military integration plan for 2017–2020. The plan provided more detail on the priority technologies to be targeted by CMI activities. Specific technologies highlighted by the report include:[218]

- Unmanned systems
- Space missions
- Information networks
- Navigation systems
- Satellite communications (SATCOMs)
- Supercomputers

The prioritization of these—admittedly broad—categories of technologies is notable for many of China's advanced weapons programs, especially unmanned systems, counter-space and MaRVs as well as China's on-going interest and investment in AI capabilities.

The interest in enhancing UAV technologies highlighted in the plan could help improve key elements of China's rapidly advancing indigenous unmanned systems programs across air, surface and sea with a current focus on improving a series of capability areas of inherent interest to all unmanned systems manufacturers:

- Communications
- Power storage and efficiency to drive persistence/endurance
- System autonomy
- Training and simulation and sophistication
- Strength, weight, power and cost (SWAP-C) ratios
- Diversity of payloads carried by unmanned systems

In addition, enhancing SATCOM capabilities could further enhance the range of China's unmanned systems.

Improved technology supporting navigation systems is also of relevance to unmanned systems and would be important to improving overall system performance and accuracy of its missions. This category of technologies could also include internal inertial navigation systems and their supporting technologies, such as atomic clocks, gyroscopes and accelerometers, which could enable position, navigation and timing of unmanned systems even in environments in which U.S. counter-space capabilities have degraded or denied China's access to global navigation satellite systems (i.e., Beidou).

Space mission technologies is a vague and broad category but could have implications for China's counter-space programs as would China's interest in SATCOMs, how to bolster them and possibly how to degrade them. Navigation and SATCOMs would also further efforts to build a more robust

[217] Grevatt, Jon, "China to Fund Private-sector Research and Development Projects," *Jane's Defense Industry,* April 18, 2017. https://janes.ihs.com/Janes/Display/jdin91640-jdin-2017
[218] Grevatt, Jon, "China Releases Civil-Military Integration Plan," *Jane's Defense Industry,* August 25, 2017 http://www.janes.com/article/73364/china-releases-civil-military-integration-plan.

and resilient reconnaissance strike complex to support China's advanced missiles and MaRV efforts, a vulnerability highlighted in 2016 by Andrew Erickson of the U.S. Navy War College.[219]

But simply listing and prioritizing these technologies for innovation, acquisition and development does not ensure success in this endeavor. Indeed, Jane's reporting and analysis published in September 2017 offers the view of "Western specialists" that China's CMI efforts have "made negligible progress" and is a "troubled and struggling campaign."[220]

This perspective is buttressed, in Jane's view, by the conspicuous attention CMI has received since the 2015 Military Strategy White Paper, especially through a series of announcements –including announcements from President Xi in June and September 2017 urging "integrated military and civilian development"—that all stress the need for accelerated and deeper CMI efforts. The regularity and focus of these statements indicate "insufficient or perhaps slowing effectiveness of CMI to bring about the results that were hoped for in terms of closing the technology gap."[221]

In addition, these numerous, successive announcements may also reflect a recognition that the areas of most pronounced success of CMI have been "secured through pursuing CMI in some of the areas that China is now prioritizing—such as AI, 3-D printing [and] robotics."[222] Spin-on technology from commercial to military sectors in these areas is likely to be a powerful engine for the development of future capabilities that will enable operations in an intelligentized environment.

Electronics are another area in which China has seen substantial success. According to officials quoted in a November 2017 *China Daily* report, over "85 percent of the key electronic parts in Chinese defense and high-tech equipment are now domestically made, meaning the country has the ability to be self-sufficient in advanced electronic components."[223]

Domestically–Focused Reforms

China's domestically-focused reforms include efforts to drive efficiency and reduce redundancy through measures such as consolidation of and collaboration between China's state-owned enterprises with defense interests. It also includes measures to inject market forces—and presumably the competition that comes with these forces—into the defense industrial base through enhanced privatization, new funding mechanisms and MOR. On the whole, these reforms have yet to achieve their desired effects.

Consolidation and collaboration

A principal piece of China's domestically-focused reforms has been an effort to consolidate state-owned enterprises in China's aerospace and defense sectors (or adjacent sectors) and simultaneously facilitate collaboration between state-owned defense enterprises.

These consolidation activities have direct implications for China's advanced weapons programs, but their focus is much broader than driving efficiency across the five programs of interest to this report.

The first major aerospace and defense industry-related consolidation as part of this effort occurred in 2007 with the re-integration of AVIC, China's leading commercial aerospace company that has

[219] Erickson, Andrew, "Raining Down: "Assessing the Emergent ASBM Threat," *Jane's Navy International,* March 16, 2016, https://janes.ihs.com/Janes/Display/jni77556-jni-2016.
[220] Johnson, Reuben, "China Still Struggling with Civil-Military Integration Issues," *Jane's Defense Weekly,* September 28, 2017, https://janes.ihs.com/Janes/Display/FG_652161-JDW.
[221] Email interview with Jon Grevatt, November 23–24, 2017.
[222] Email interview with Jon Grevatt, November 23–24, 2017.
[223] Zhihao, Zhang, "Advanced Electronics Needs Met in China," *China Daily,* November 21, 2017, http://www.chinadaily.com.cn/business/tech/2017-11/21/content_34794721.htm.

interests in China's unmanned systems programs. AVIC was broken up into AVIC I and AVIC II in the late 1990s in an effort to drive competition and innovation. But that initiative failed due to an effective segmenting of each business and the monopolistic practices that have dominated China's defense industry throughout its recent efforts to modernize.

More recently in 2014, China's growing instinct to consolidate large industry sectors drove a dramatic consolidation of the country's shipbuilding industry, which was comprised of several hundred entities. In September 2014, China's MIIT announced a list of 51 shipyards that would receive state benefits, such as tax rebates and easier credit. Nine entities were added to this "white list" in December 2014, effectively cutting all but those 60 companies out of the industry. The majority of the government endorsed shipyards are subsidiaries of China State Shipbuilding Corporation (CSSC) and the China Shipbuilding Industry Corporation (CSIC)—the latter of which is also involved in China's unmanned maritime vehicles programs. Nearly all support both commercial and military programs, indicating the continued importance of the ambition of CMI-related transfers of technology, equipment, personnel and processes to China's defense industrial efforts.[224]

Consolidation of this magnitude has not yet affected CASC and CASIC, the two main organizations involved in China's missile and space programs, and responsible for the development of many of China's advanced weapons systems. Together these groups operate several hundred academies, factories and research institutes. The capabilities of many of these subsidiaries overlap, particularly in lower-level supply chains and in management and administrative functions.[225]

Still, SASTIND has recognized a need for consolidation of some of these activities to promote synergies and efficiencies. The consolidation has been channeled through a "co-operation framework agreement" between CASIC and CASC signed in 2014. Announcing the accord, SASTIND said it facilitates "resource sharing, common development, comprehensive co-operation, mutual respect and a focus on the future."[226]

SASTIND added that the pact covers activities including several of interest to advanced weapons programs, such as strategic research, space, weaponry and CMI. It also facilitates "all-round strategic co-operation" in areas such as capital operations, international business, personnel, corporate cultures and public services.[227] Both CASC and CASIC also agreed to a future program to "deepen consolidation further in order to improve competitiveness and sustainable development and support the realization of a strong space, military and aerospace industry," said SASTIND.[228]

Three years into the collaboration, there is little evidence of material progress or collaboration in any major aerospace or weapons programs—advanced or otherwise. In April 2015—roughly one year after the original collaboration agreement was signed—CASIC and CASC conducted "informal discussions on how to deepen the strategic cooperation between the two parties." [229] In this "re-engagement," CASIC and CASC reiterated their intent to "strengthen cooperation in such fields as

[224] Grevatt, Jon, "China Looks to Spur Shipbuilding Consolidation," *Jane's Defense Industry,* December 12, 2014. https://janes.ihs.com/Janes/Display/jdin88412-jni-2015.
[225] Grevatt, Jon, "Chinese Aerospace Giants CASIC and CASC Sign Consolidation Agreement," *Jane's Defense Industry,* July 4, 2014. https://janes.ihs.com/Janes/Display/jdin87737-jdin-2014.
[226] Grevatt, Jon, "Chinese Aerospace Giants CASIC and CASC Sign Consolidation Agreement," *Jane's Defense Industry,* July 4, 2014. https://janes.ihs.com/Janes/Display/jdin87737-jdin-2014.
[227] Grevatt, Jon, "Chinese Aerospace Giants CASIC and CASC Sign Consolidation Agreement," *Jane's Defense Industry,* July 4, 2014. https://janes.ihs.com/Janes/Display/jdin87737-jdin-2014.
[228] Grevatt, Jon, "Chinese Aerospace Giants CASIC and CASC Sign Consolidation Agreement," *Jane's Defense Industry,* July 4, 2014. https://janes.ihs.com/Janes/Display/jdin87737-jdin-2014.
[229] China Aerospace Technology Group, "The Same Root with the Same culture, Two Space Groups Agree to Collaborate [CollaborateC 同根同源同文化，航天两大集团"走亲戚],"" April 15, 2015, http://chuansong.me/n/800993352257.

system demonstration, aerospace, civilian industry, personnel training [and] aerospace brand building."[230] The prevalence of lofty rhetoric and foundational statements of intent fully one year after the signing of the agreements suggests that little movement toward collaboration had actually taken place.

More recently, in November 2016, tangible evidence emerged that enhanced competition, not enhanced collaboration, was actually taking place. *Aviation Week* reported that CASIC was preparing to build a medium-capacity launcher while also moving into liquid-propellant technology, both moves directly challenging two of CASC's core market areas.[231]

Linked closely to reforms to promote consolidation, the Chinese government has supported in recent years collaboration across the defense industrial base in a bid to spur capability advancement and efficiencies.

In 2014, for example, CASIC entered a collaborative technology development arrangement with CSSC, which emphasizes the co-development of naval mission systems.[232] Advanced weapon technologies such as networking, SATCOMs, information and intelligence and unmanned sea systems are a focus of this collaboration.

Highlighting a central theme running throughout this chapter and much of Section 1 of this report, collaboration agreements have not been signed solely between China's state-owned defense industrial giants. Similar technology agreements have been signed by both CASIC and CASC with tertiary institutes and research agencies in China as well as, most importantly, with Chinese private firms in advanced technologies. One of the more notable partnership was announced by CASIC in June 2017 and provides a framework for cooperation with Chinese telecommunications giant Huawei in areas including "industrial Internet,"[233] automation, networking technologies and new materials.[234]

Privatization and Mixed Ownership Reforms (MOR)

The Huawei/CASIC collaboration agreement is one example of China's efforts to increase engagement between typically closed defense procurement process and private companies (i.e. those not part of a state-owned enterprise). Privatization reforms gained steam in November 2014 when the State Council allowed non-state-owned enterprises to function as prime contractors in support of defense research, development and production programs as well as military training programs.[235]

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[230] China Aerospace Technology Group, "The Same Root with the Same culture, Two Space Groups Agree to Collaborate [(同根同源同文化，航天两大集团"走亲戚],")," April 15, 2015, http://chuansong.me/n/800993352257.
[231] Perrett, Bradley, "China's CASIC Challenging CASC with Big Solid Rockets," *Aviation Week,* November 4, 2016, http://aviationweek.com/zhuhai-2016/china-s-casic-challenging-casc-big-solid-rockets.
[232] CASIC, "China Aerospace Science and Industry and CSSC Sign Strategic Cooperation Framework Agreement in Beijing Tianhai Connected to Promote Innovation and Development [中国航天科工与中船集团公司在京签署战略合作框架协议 天海相连推动创新发展]," September 23, 2014, http://www.casic.cn/n103/n133/c1955364/content.html.
[233] The "Industrial Internet of Things" or "Industrial Internet" was coined by General Electric in 2012. It examines how industry can be digitized by networking machines, analytics and people to create a system that monitors, collects, exchanges, analyzes and delivers insights to industrial companies for better business decisions, lower energy consumption, proactive maintenance and safeguarding systems from cyber-attacks. "Everything You Need to Know About the Industrial Internet of Things," GE Digital. https://www.ge.com/digital/blog/everything-you-need-know-about-industrial-internet-things
[234] CASIC, "China Aerospace Science and Industry Corporation and Huawei to Carry out Cooperation [中国航天科工与华为公司开展合作对接]," June 20, 2016, http://www.casic.cn/n103/n133/c3682326/content.html.
[235] Grevatt, Jon, "China Allows Private Sector to Bid for Military Training Contracts," *Jane's Defense Industry,* November 26, 2014. https://janes.ihs.com/Janes/Display/jdin88352-jdin-2014.

China's private sector is now contributing to some of the advanced weapons systems programs, especially in support of China's fast-growing unmanned systems industry. While CASC and AVIC tend to dominate the large fixed-wing military requirements, China's commercial drone industry, which dominates the global commercial and retail drone market, is developing smaller platforms and vertical take-off and landing (VTOL) platforms for military use.

Another example of increased involvement of China's private sector in defense and advanced weapons activities is CASIC Fourth Academy's production of the DF-21C guided medium-range ballistic missile which involved more than 20 sub-contractors, of which less than half were CASIC subsidiaries.[236] In addition, restrictions on private sector involvement in China's defense-related activities have eased in recent years, resulting, for example, in the launch of the PLA procurement portal, a new mobile phone "procurement app,"[237] easing of licensing requirements and administrative hurdles as well as declassifying patents,[238] among other measures.

Nonetheless, Jane's still believes that outside of unmanned systems and episodic involvement at second and third tiers of major program supply chains, private-sector industrial involvement in advanced weapons is certain to remain limited and restricted by a government that remains wary of such participation in sensitive programs. A cursory glance at China's defense procurement portal set up by the PLA in 2015 (http://www.weain.mil.cn/) shows that most private sector involvement is limited to ancillary products and services and Tier 2/3 manufacturing.

The limitation of these reforms—the discrepancy between the rhetoric of engagement and the reality of restrictions—is rooted in the fact that, according to Grevatt, "the Chinese state, generally speaking, doesn't fully trust the private sector." In many ways, this is understandable because, as Grevatt points out, China's private sector capability is largely untested.[239]

China's "Made in China 2025" program and other top-down directives designed to capitalize on Fourth Industrial Revolution technologies will likely have some salutary effect on the involvement of private sector entities in the development and manufacture of China's defense capabilities. However, much of this engagement will be focused on companies in non-core defense industries, such as high-tech and electronics, potentially creating a bifurcated privatization approach—especially in advanced weapons systems—such as deep engagement between China's state-owned enterprises and high-tech and unmanned private companies, and shallow/episodic engagement with private sector companies specializing in core defense capabilities.

Another reform designed to enhance private sector engagement in the defense industrial base is the MOR, which encourages private sector organizations to invest in state-owned enterprises and for these state-owned entities to divest interests in certain defense-related activities.

CASC was identified in May 2017 as one of four Chinese state-owned defense enterprises to require further restructuring under the MOR program. And while CASC's most sensitive academies are unlikely to be opened up for such investment, the overall strategy is geared towards driving efficiency improvements across all business units including efforts to enhance the development of

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[236] Mark A. Stokes with Dean Cheng, "China's Evolving Space Capabilities: Implications for US Interests," *Project 2049 Institute* (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012, https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[237] Grevatt, Jon, "China Develops App for Military Procurement," *Jane's Defense Industry,* August 21, 2017, https://janes.ihs.com/Janes/Display/FG_629769-JDIN.
[238] Grevatt, Jon, "China Declassifies Patents in Effort to Spur Private Sector," *Jane's Defense Weekly,* March 8, 2017, https://janes.ihs.com/Janes/Display/jdin91497-jdw-2017.
[239] Email interview with Jon Grevatt, November 23–24 2017.

advanced weapons. Under the mixed-owned program, Lei Fanpei, CASC's party secretary and chairman, in June 2017 stated that the group is aiming to "accelerate" its transformation to "eliminate backward productivity."[240]

But here again, there is evidence that China's instincts toward empowering state-owned enterprises and the structures that enable this empowerment are limiting the true access of private sector companies to meaningful ownership in state-owned enterprise activities.

One inherent shortcoming of MOR is highlighted in a recent memorandum by Curtis Millhaupt and Wentu Zheng of the Paulson Institute that argues that MOR is hollowed out by a difficultly to get to the truth about the reach of the Chinese state, especially in economic and defense activities. According to the memorandum, "the state's influence on firms in China extends well beyond the matter of 'control' in the corporate management sense….in China's present institutional environment, the state could exert influence over firms irrespective of its direct or indirect ownership stakes. As a result, ownership loses much of its explanatory power in accounting for the relationship between firms and the state in China."[241]

A second—and closely related—limitation of the scale and effectiveness of MOR is rooted in the lack of experience (and therefore trust) of China's private industry in working on sensitive defense programs, which, in turn, would seemingly disqualify private companies from owning significant stakes in sensitive military capability areas, especially those covered by China's advanced weapons systems programs.

MOR has prompted some large defense state-owned enterprises to announce that they have sold off some of their assets, but it is unlikely that these transactions constitute a fundamental shift in approach in the development of sensitive military equipment. For example, in September 2017, China's largest arms manufacturer, China North Industries Group Corporation (NORINCO) announced it had started mixed ownership pilot reforms at its main battle tank (MBT) factory in China's Inner Mongolia Autonomous Region—also known as the 617 Factory. "We've introduced private capital and reallocated resources, so it's no longer a state-owned company," said Yin Jiauxu, Chairman of NORINCO.[242]

However, there is reason to be skeptical of this report. The only mention of the divestiture was to the *Global Times.*[243] One expert interviewed for this report noted that the *Global Times*, "makes mistakes and has an agenda to pursue."[244] The actual headline of the published report— "China's arms industry reform bears fruit"—reads as if it could have been written by SASTIND or the State Council. No mention of this significant development—divestiture of a MBT factory—was found in a survey of company press releases and statements. Indeed, the statement from the Chairman of NORINCO on the divestiture from the *Global Times* report included the statement that the factory "is

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[240] Xinhua Finance, "Mixed Ownership Reform in Central SOEs to Speed Up," June 27, 2017, http://en.xfafinance.com/html/Companies/2017/353333.shtml.
[241] Millhaupt, Curtis J. and Zheng, Wentu, "Why Mixed Ownership Reforms Cannot Fix China's State Sector," *Paulson Policy Memorandum*, Paulson Institute, January 2016.
[242] *Global Times,* "China's Arms Industry Reform Bears Fruits," September 17, 2017, http://www.globaltimes.cn/content/1066735.shtml.
[243] The *Global Times* refers to itself as "an English – language Chinese newspaper under the People's Daily" on its Twitter account, https://twitter.com/globaltimesnews. In the People's Daily English-language website "About" page, the paper refers to itself as "News of Communist Party of China." These self-categorizations have led Jane's to define the *Global Times* as a state-run newspaper.
[244] The expert requested Jane's not attribute this quote directly due to on-going relationships with China's state agencies. The comments were delivered in an interview on November 24, 2017.

now transparent financially, but, of course, the *defense technology remains confidential* [emphasis added]."[245]

If NORINCO has divested assets in its MBT plant in Inner Mongolia its most likely—contrary to *Global Times* reporting—investment in ancillary interests/units, further bolstering the idea that absent more fundamental changes in structures and mentalities—both of which will change only over time and with confirming experiences—about China's private sector defense industry, privatization reforms and MOR will achieve only modest success in introducing market-oriented thinking and best practice into China's broader defense industrial base.

Financing and Market Forces

The final category of China's domestically-focused defense industry reforms are efforts to increase both the amount and number of available channels for funding the aerospace and defense industry, with specific earmarks for R&D functions within these industries.

Both CASC and CASIC have been at the forefront of Chinese defense programs to spur capability advancements through funding sourced from state-owned banks, placements of shares (a private sale of shares) and establishing capital investment funding schemes.

For instance, in 2014, CASIC signed a financial agreement with the state-owned Industrial and Commercial Bank of China, which provided the defense company with an unspecified amount of funds for CASIC's development of "new generation of technologies" related to a range of capabilities associated with advanced weapons including launch technologies, unmanned systems, sensors and communications systems.[246] CASIC signed a similar agreement in December 2016 with the China Minsheng Bank.[247]

CASIC previously generated about $127 million in funds for its communications business by issuing a private placement of shares.[248] CASIC also has links with the state-owned investment group CITIC Capital Holdings, which is also focused on supporting aerospace science and technologies.[249]

On a much larger scale, CASC was involved in setting up a capital investment fund valued at $22 billion to invest in emerging strategic industries in 2017.[250] While advanced weapons were not mentioned as a specific beneficiary of the funding, related sectors—including communications, robotics and IT—were. Several of these related sectors are outlined for investment and expansion as part of Beijing's Made in China 2025 program.[251]

Investment in strategic capabilities that could positively impact advanced weapons has also been evident recently. In January 2017, for instance, CASC inaugurated a new rocket innovation center,

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245 *The Global Times,* "China's Arms Industry Reform Bears Fruits," September 17, 2017, http://www.globaltimes.cn/content/1066735.shtml.
246 Grevatt, Jon, "China's CASIC Signs Funding Deal for New Market Growth," *Jane's Defense Industry*, August 7, 2014. https://janes.ihs.com/Janes/Display/jdin87895-jdw-2014.
247 CASIC, "China Aerospace Science and Industry and Minsheng Bank Signed a Strategic Cooperation Agreement" [中国航天科工与民生银行签署战略合作协议]," December 9, 2016, http://www.casic.cn/n103/n133/c3046987/content.html.
248 Grevatt, Jon, "CASIC Subsidiary Raises Funds Through Private Share Placement," *Jane's Defense Industry*, December 11, 2013. https://janes.ihs.com/Janes/Display/jdin86817-jdw-2014.
249 CASIC, "China Aerospace Science and Industry and CSC Securities to Discuss Cooperation [中国航天科工与中信建投证券商谈合作]," May 10, 2016. http://www.casic.com.cn/n103/n133/c2629410/content.html.
250 "Chinese SOEs Establish 150 Bln Yuan Investment Fund," *Xinhua*, May 16, 2017. http://news.xinhuanet.com/english/2017-05/16/c_136289098.htm.
251 "'Made in China 2025' to Outline Future Roadmap for Manufacturing," *Xinhuanet,* April 27, 2015, http://news.xinhuanet.com/english/2015-04/27/c_134189459.htm

which it said is intended to benefit national defense S&T innovation.[252] Moreover, in June 2017, CASIC said it was discussing with Chinese stock exchanges undertaking potential bond and equity financing mechanisms in a bid to "boost enterprise transformation and upgrading."[253]

China has also sought to drive increased funding through the private placement of stock in state-owned companies. In December 2013, CASIC subsidiary Aerospace Communications Holding raised around $127 million through the private sale of just over 9 million shares of stock to selected Chinese companies, including CASIC and its subsidiaries, which accounted for roughly 25% of the placement. The money raised was in part designed to help Aerospace Communications Holding expand its international presence and technological base through mergers and acquisitions.[254]

Internationally-Focused Reforms and Activities

China's attempts to drive efficiency, innovation and competitiveness in its defense industrial base also rests on a series of reform efforts, policies and commercial activities designed to amplify the effects of China's domestically-focused reforms and enhance its ability to identify and acquire critical technologies, talent and know-how that will enable the country to both fill known technological gaps and drive novel new capabilities.

Traditionally, China has focused technology acquisition efforts on meeting known gaps in capabilities (such as aero-engines or active electronically scanned array radars) and the underlying technologies that enable these capabilities. In support of this objective, China's technology acquisition is best viewed as an amplifying and catalytic force that will, if executed efficiently, drive China's efforts at indigenous innovation along a progressively steeper and more self-sufficient new trajectory.

These gap-fill activities, motivated by an acknowledgement of vulnerability, remain core to China's technology acquisition program and engagement—both licit and illicit—with international research, academia, commercial, civil government and defense organizations. However, increasingly these activities are being carried out in conjunction with efforts, motivated by an acknowledgement of opportunity, to innovate in Fourth Industrial Revolution technologies that China sees a promising pathway to not just competition-levelling, but also competition-shifting capabilities.

Currently, efforts to acquire gap-filling technologies to compete with the United States and its allies in the Indo-Pacific and efforts to acquire technologies to change the nature of the competition exist in tandem, even overlapping in some technology areas. However, over time, Jane's anticipates that China's success in the second category will create a new, third, category of technology acquisition activities: those to reinforce areas of perceived (by China) competitive advantage. One could imagine quantum encryption, discussed in more detail later in this chapter, as being an early entry in this category.

Across all categories of acquisitions and reforms, progress and ultimate success will rely on a technology acquisition program that is expansive, aggressive and centrally-directed.

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[252] CASC, "National Defense Science and Technology Industrial Revolution Rocket Innovation Center Was UnveiledUnveiledRICWU [国防科技工业战略火箭创新中心在一院揭牌成立]," January 6, 2017. http://www.spacechina.com/n25/n144/n206/n214/c1554694/content.html.
[253] CASIC, "Leaders of Shanghai Stock Exchange Visited Aerospace Science and Industry [上海证券交易所领导一行到访航天科工]," March 9, 2017, http://www.asiacoating.com/n3053244/n3053490/c3296425/content.html.
[254] Grevatt, Jon, "CASIC Subsidiary Raises Funds Through Private Share Placement," *Jane's Defense Industry,* December 11, 2013. https://janes.ihs.com/Janes/Display/jdin86817-jdw-2014.

China's Technology Acquisition Program

The underlying concept of China's historical technology acquisition effort—known as *ti-yong, or keeping the essence Chinese while taking advantage of a function or understanding the difference between sense and function*—was articulated in 1878 by Zhang Zhidong in his essay *Quan Xue Pian:* "Keep China's style of learning to maintain societal essence and adopt Western learning for practical use."[255] This approach still heavily informs China's current technology acquisition efforts.

Assessing the full scale of China's technology acquisition efforts is difficult, given that many—but not all—components rely on illicit or surreptitious means, such as cyber espionage and theft and other means of state or state-affiliated resources to acquire sensitive, and in many cases controlled, technologies.

The U.S. Defense Security Service releases an annual unclassified report entitled "Targeting U.S. Technologies: A Trend Analysis of Cleared Industry Reporting," which articulates key trends in tech acquisition in four regions: Near East, South and Central Asia, Europe and Eurasia and East Asia and the Pacific. The report is careful not to identify specific countries in any region, though Jane's independent assessment is that the report's insights about the East Asia and the Pacific region accurately represent the scale and priorities of China's technology effort.

The report finds that in U.S. government fiscal year 2016, the "East Asia and the Pacific" region "remained the most significant collectors of significant or classified U.S. technology and information reported by cleared industry," a status the region has held since "at least 2004."[256] Technology acquisition efforts from the East Asia and the Pacific region constituted 39% of the Defense Security Service's overall "threat score," considerably larger than the Near East (23%), South and Central Asia (13%) and Europe and Eurasia (11%) or other regions not covered in the report. The report assesses that East Asia and the Pacific region collectors targeted "almost all technology areas," the technologies of most interest included: electronics, aeronautic systems, and C4 technologies."[257]

Methods of technology acquisition are both varied and sophisticated and stretch across licit and illicit methods as well as approaches that combine elements of licit and illicit acquisition, as reflected in Figure 8 below:

Figure 8: An overview of China's licit and illicit technology acquisition activities

Licit	Illicit	Gray Area
•Academia, Research Institutes and Foreign Student Exchanges •Conferences and Trade Shows •Repatriation of engineers, scientists and technology experts •Delegation Visits •Leveraging China's Dual-Use Space Program •Joint Ventures, International Investment and Acquisitions •Open Source Collection and Exploitation	•Cyber-Theft •Espionage •Solicitation and Sales	•Solicitation and Sales •Academic, Research Institute and Foreign Student Exchanges •Conferences and Trade Shows •Joint Ventures, International Investment and Acquisitions

Source: Jane's Strategic Assessment and Futures Studies Center

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[255] Hannas, William C., Mulvenon, James, Puglisi, Anna "Chinese Industrial Espionage: Technology Acquisition and Military Modernization," Routledge Publishing, May 22, 2013, pages 28 - 30
[256] "Targeting U.S. Technologies 2017: A Trend Analysis of Cleared Industry Reporting," Defense Security Services, September 7, 2017, http://www.dss.mil/documents/ci/2017_CI_Trends_Report.pdf.
[257] "Targeting U.S. Technologies 2017: A Trend Analysis of Cleared Industry Reporting," Defense Security Services, September 7, 2017, http://www.dss.mil/documents/ci/2017_CI_Trends_Report.pdf.

While cyber-theft, solicitation and espionage of various kinds are highly-effective, China has also benefitted from growing intersections between commercial and military technologies, a phenomenon one participant in the Jane's Framing Workshop referred to as the "dual-utilization" of the global technology and innovation environment. In this environment, several predominantly licit acquisition methods have become increasingly relevant to China's capacity to support its military modernization and, especially, China's efforts to develop Fourth Industrial Revolution technologies.

- **Inter-Governmental and Academic S&T Relationships:** China has become both a more influential geopolitical actor and more active and prominent in global S&T research communities. China's economic growth and focus on technology acquisition has made China attractive as a partner in general S&T research and development efforts. This confluence of increased influence and activity has enabled China to develop relationships with an impressive number of states seeking to gain advantage from engagement with China's growing S&T community and the financing that China can provide to joint S&T programs.

  For example, in April 2017, China Electronics Technology Corporation (CETC) formed a partnership with University of Technology Sydney in Australia to establish the Australia-China Research Innovation Centre in Information and Electronics Technologies. CETC will provide $20 million over five years for the Centre, which will engage in research programs focused on:[258]

  - Big data technologies (mobile sensing and communications, electromagnetic metamaterials and devices, big visual data analytics, transfer learning and Internet of Things)
  - Quantum computing and quantum communications
  - AI
  - Simultaneous localization and mapping assisted robots, and robots for infrastructure monitoring and maintenance
  - Advanced materials and electronics (THz devices, environmental and industrial sensors and integrated circuits)

  According to a January 2017 statement released by the MOST, China has S&T relationships with 158 "countries and regions," including "Inter-Governmental S&T accords" with 111 of these countries and regions. [259] MOST asserted that these agreements allow for China to "integrate into the global network of scientific and technological innovation"[260] and, as such, are a critical component of China's CMI efforts. The statement also reported that China has established 70 S&T offices across embassies, consulates and diplomatic missions in 47 countries and regions. It has also accredited 146 Chinese diplomats to build inter-governmental co-operation and to establish networks of S&T contacts.[261]

- **Conferences, Conventions and Trade Shows:** The Defense Security Services report highlights conferences, conventions and trade shows as forums for foreign entities to interact directly

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[258] *University of Technology Sydney*, "Joint IET Research Centre with China Electronics Technology Group Company," April 26, 2017. https://www.uts.edu.au/about/faculty-engineering-and-information-technology/news/joint-iet-research-centre-china.
[259] Grevatt, Jon, "China Grows Its International Technology Network," *Jane's Defense International*, January 19, 2017. https://janes.ihs.com/Janes/Display/jdin91289-jdin-2017.
[260] Grevatt, Jon, "China Grows Its International Technology Network," *Jane's Defense International*, January 19, 2017. https://janes.ihs.com/Janes/Display/jdin91289-jdin-2017.
[261] Grevatt, Jon, "China Grows Its International Technology Network," *Jane's Defense International*, January 19, 2017. https://janes.ihs.com/Janes/Display/jdin91289-jdin-2017.

with cleared contractors from the United States defense industry. As a result, "these venues also provide an opportunity to spot and assess cleared contractor personnel for potential exploitation or future targeting." According to the report, "East Asia and the Pacific commercial entities were the most conspicuous actors exploiting [CC&Ts] by taking unauthorized photos, soliciting for business partnerships and exchanging business cards with cleared contractor personnel." Moreover, "military officers, defense attaches, research institutes, and academics…were far more aggressive in their collection activities of technology and cleared contractor personnel in attendance."[262]

- **China's Dual-Use Space Program:** China's dual-use space program is another effective avenue for acquisition of advanced technologies, many of which are relevant to the advanced weapons systems of interest to this project. Research and academic institutions associated with China's space program—which is run by the PLA, but has civilian and commercial applications in addition to military ones—have had extensive and regular engagement with space agencies and research institutes across Europe in particular, including joint projects with the European Space Agency and national space agencies.[263] The relationship between the United Kingdom's space community and China's appears to be particularly strong.[264]

  An interview with Chris Bee of the STFC during the 2014 International Aeronautical Conference highlights the close connections between academic and research institutes: "A few years back, [Beihang] sent us a student who spent 18 months at RAL [Rutherford Appleton Laboratory] and was working on cold atom technology. We have seen a lot of cooperation in that area. There even has been a joint UK-China laboratory facility on terahertz technology in Beijing. A lot of that is using the Rutherford Appleton Laboratory, the terahertz componentry and terahertz understanding."[265]

- **Joint Ventures:** U.S. and Western firms are increasingly compelled to seek ways to either enter or expand their presence in the large China market. These firms have also seen an opportunity to "globalize their innovation cycle and tap expertise and resources around the world, including the relatively cheap, skilled and well-trained pools of R&D personnel in China."[266]

  For its part, China fully understands the opportunity created by this market leverage across a growing range of industries and wants to ensure that it fully capitalizes on this U.S. and Western interest. Indeed, China's 2006 Mid-to-Long Term Plan explicitly calls for China's government and industry "to encourage scientific research institutes, universities and overseas research and development institutions to establish joint laboratories or research and development centers…and to encourage multi-national companies to set up research and development institutions."[267] As a result, the number of U.S./Western Joint Ventures

[262] "Targeting U.S. Technologies 2017: A Trend Analysis of Cleared Industry Reporting", Defense Security Services, September 7, 2017, http://www.dss.mil/documents/ci/2017_CI_Trends_Report.pdf.
[263] "China Talking with European Space Agency about Moon Outpost," *Bloomberg*, April 26, 2017. https://www.bloomberg.com/news/articles/2017-04-26/china-talking-with-european-space-agency-about-moon-outpost.
[264] "New UK-China agreement to strengthen space education," Science & Technology Facilities Council, September 6, 2017. http://www.stfc.ac.uk/news/new-uk-china-agreement-to-strengthen-space-education/.
[265] Interviews at IAC 2014: Interview with Chris Bee, Head of Business Development for the Science Technology Facilities Council- STFC Rutherford Appleton Laboratory in Harwell, Oxford', *Go Taikonauts!,* Issue 14, January 2015. 27-28. http://www.go-taikonauts.com/images/newsletters_PDF/GoTaikonauts14.pdf.
[266] Hannas, William, Mulvenon, James, Puglisi, Anna, "Chinese Industrial Espionage: Technology Acquisition and Military Modernization". Routledge Publishing, May 22, 2013, page 103.
[267] Hannas, William C., Mulvenon, James, Puglisi, Anna, "Chinese Industrial Espionage: Technology Acquisition and Military Modernization". Routledge Publishing, May 22, 2013, page 113.

with Chinese organizations and R&D centers in China has greatly expanded across a range of industries, including in aerospace.

This dynamic was also singled out by the Defense Security Service report, which noted:

> "The number of U.S. companies establishing business relationships with East Asia and the Pacific companies will most likely continue to increase. The growing commercial interdependence between the United States and the region and the growing capacity and complexity of the region's economies portend considerable opportunities for U.S. companies to invest and develop. East Asia and the Pacific countries, mindful of U.S. companies' strong desire to access their markets, will likely continue to exploit business relationships in order to acquire proprietary or sensitive U.S. defense information and technology."[268]

International Collaboration

Both CASIC and CASC have strengthened links with Russian industry in recent years, although these agreements are more firmly focused on defense and space technologies. China and Russia are likely to place additional emphasis on bilateral collaboration in advanced military technologies as a result of the western military sanctions to which both countries are subjected.

In late 2013, CASIC signed a deal with industrial group Russian Technologies to collaborate on engine technologies, composite materials, optoelectronics and C4ISR.[269] In October 2014, CASC signed an agreement with the same Russian organization to collaborate on areas including information technologies, communications, automation systems and new materials.[270]

In addition to collaboration with Russia, CASIC and CASC's partnerships with foreign companies (such as Thales and Siemens) in commercial sectors and technologies, as part of their CMI commitments, are likely to have a positive impact on weapons development through spin-on CMI transfers from commercial sides of these state-owned enterprises to their military sides. While these deals are not focused on military applications of the technologies of interest to these deals, technology and knowledge transfers associated with these deals will help advance capabilities such as navigation, communications and automation, all areas of concern to advanced weapons systems programs, especially counter-space, MaRVs and unmanned systems. CASIC signed an agreement with Thales in 2010, for instance, with emphasis on security systems, avionics and satellite navigation.[271] In 2017, CASIC signed a similar accord with Siemens focused more on digital production techniques but still intended to spur capability advancement.[272]

Acquisitions, Investments and Joint Ventures

China has seen more success—and is likely to continue to see more success—in its efforts to acquire "gap-fill" and "aspirational" technologies through the acquisition of foreign firms and through joint ventures with Western firms seeking to do business in China's large domestic market.

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[268] "Targeting U.S. Technologies 2017: A Trend Analysis of Cleared Industry Reporting", Defense Security Services, September 7, 2017, http://www.dss.mil/documents/ci/2017_CI_Trends_Report.pdf

[269] Grevatt, Jon, "CASIC and Russian Technologies Agree to Defense Collaboration," *Jane's Defense Industry*, December 20, 2014. https://janes.ihs.com/Janes/Display/jdin86870-jdin-2014.

[270] Rostec, "Rostec Signs Agreement with China Aerospace Science and Technology Corporation," October 14, 2014. http://rostec.ru/en/news/4514812.

[271] Grevatt, Jon, "Chinese Aerospace Company Signs Accord with Thales," *Jane's Defense Industry*, July 9, 2010. https://janes.ihs.com/Janes/Display/jdin81644-jdin-2010.

[272] Siemens, "Siemens Partners with China on Digitalization," July 5, 2017, https://www.siemens.com/press/en/pressrelease/2017/corporate/pr2017070361coen.htm?content[]=Corp.

In 2013, the HiWing Mechanical & Electrical Technology Corporation (HiWING Group), which is linked with CASIC's Third Academy, secured CASIC's first foreign acquisition with the purchase of Luxembourg firm IEE,[273] a developer of sensing solutions for a range of markets: automotive, building management and security, input devices and sports and healthcare. Solutions in and across these four categories would be of interest to a modern military, especially one seeking to capitalize on Fourth Industrial Revolution technologies to help drive and shape the future intelligentization of warfare, including the sample list included in Table 10 below:[274]

Table 10: Technological specialization of IEE by category of application with some insight into how these capabilities could support future military operations if they were to diffuse to the military sector.

Industry Category	Technology Type	Applications for Defense
Automotive	Occupant sensing	Could be used to enhance safety and stability of humans controlling or riding in modern platforms and systems.
	Human-Machine Interface	Capitalizing on AI and automation requires more usable and intuitive means for humans and computers to engage with one another.
Building management and security	Access control People counting Object surveillance	All three of these areas indicate a broader capability in traditional sensing missions that could support force protection, internal security and crowd control missions.
Input devices	Input devices for smart devices	Making miniaturized electronics easier to use due to IEE sensors.
Sports and health care	Training and sports performance	Monitoring human behavior and condition will be a critical component of future conflict. More focus will be placed on enhancing human physical and cognitive performance.
	Rehabilitation	The ability of humans to recover from strenuous battlefield conditions or missions will also be an important element of human performance enhancement.

HiWing Group's acquisition of IEE is just a single data point (of many) reflecting China's success in acquiring Western companies to help fill key technology gaps. Most acquisition targets have a similar profile: small companies primarily in an adjacent industry, such as commercial aerospace or sensors, some with small commercial plays in defense.

AVIC, which plays a prominent role in China's unmanned systems development, has been particularly active in its acquisition of Western aerospace companies since 2010, shown in Table 11 below.[275]

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[273] IEE Corporation, "IEE Finalizes Acquisition by HiWing, SAIC and Ascend," April 3, 2013. http://www.corporatenews.lu/en/archives-shortcut/archives/article/2013/04/iee-finalizes-acquisition-by-hiwing-saic-and-ascend?author=IEE+S.A.
[274] IEE website, https://www.iee.lu/en/applications/input-devices/input-devices.
[275] According to Jane's, AVIC has had a total of 14 acquisitions since 2011, 10 of which have happened *outside of the aerospace industry*, including acquisitions in shipbuilding and automotive. Grevatt, Jon, "China's AVIC Pledges to Expand International Presence Through Acquisitions," EIPTA, January 22, 2016, https://janes.ihs.com/Janes/Display/jdin89913-jdw-2016.

Table 11: List of AVIC acquisitions in the aerospace industry from 2010 through 2015. The list demonstrates some of the aerospace related technologies that are particularly of interest to China's aerospace and defense industry. It is also indicative of the high pace of international acquisition activity being pursued by China's aerospace and defense companies.

Date of acquisition	Company Acquired	Technology Areas Acquired
January 2010	Fischer Advanced Composite Components—an Australian aircraft composites manufacturer	• AVIC's first international acquisition • Executed by AVIC subsidiary Xi'an Aircraft Industry Group • Composites
April 2010	Epic Air—a U.S.-based aircraft manufacturer	• Epic was a kit aircraft manufacturer • Bought after being forced to file for bankruptcy
December 2010	Continental Motors and its affiliate Mattituck Services, acquired by AVIC International Holding Corporation for $186 million	• Continental Motors specializes in the design, development and production of aircraft piston engines and ignition systems
March 2011	Cirrus, acquired by AVIC's turbo-prop subsidiary AVIC General Aviation	• Light aircraft manufacturing
July 2013	Thielert Aircraft Engines, a German manufacturer of diesel aircraft engines	• The deal is designed to complement the acquisition of Continental Motors and deepen technology and processing techniques related to piston engines
April 2015	Align Aerospace, a U.S. Company	• Components, systems and fittings primarily for the commercial aerospace sector
November 2015	AIM Altitude, a U.K.-based company involved in commercial aerospace activities, but with a presence in defense	• Aircraft interiors and composite products, including radar panels, missile containers, radomes and sensor probes

In interviews with Jane's and network experts, consensus emerged that acquisitions of Western firms broadly have been useful, on the whole, in filling technology gaps, especially in the development of composite materials and manufacturing know-how, and that these deals are frequently more effective at driving domestic innovation than the reforms highlighted above. According to one expert, "It does seem as if tech acquisition through corporate acquisitions and other methods is working, at least in filling some very niche gaps and ultimately building or expanding the foundational knowledge of key systems. So, it's both lifting specific technologies and building broader engineering perspectives and understanding how things fit together, how others do things."[276] In fact, this success is "likely one of the reasons China keeps asking its state-owned enterprises to acquire more and providing more money to do so."[277]

These acquisitions were followed in January 2016 by a pledge to expand its international presence in "developed countries" during China's 13th Five Year Plan (2016–2020).[278] The United Kingdom is one "developed country" whose aerospace and high-tech industry has become a particularly attractive target for acquisition by Chinese state-owned enterprises as well as private companies. In addition to AVIC's November 2015 acquisition and investment of AIM Altitude, in January 2017, the Kuang-Chi Group, a Chinese technology conglomerate with some defense and security interests, announced that it was investing $30 million in Gilo Industries, a U.K.-based firm that makes rotary engines for

[276] Interview with Jane's Asia-based China defense industry analyst, November 21, 2017.
[277] Interview with Jane's Asia-based China defense industry analyst, November 21, 2017.
[278] Grevatt, Jon, "China's AVIC Pledges to Expand International Presence Through Acquisitions," *Jane's Defense Weekly,* January 22, 2016, https://janes.ihs.com/Janes/Display/jdin89913-jdw-2016.

unmanned vehicles, among other aerospace and defense activities. The investment reportedly will give Kuang-Chi a 40% stake in the company.[279]

Kuang-Chi said that the investment would be sourced from a company fund set up in early 2016 to secure international acquisitions in "disruptive technology" sectors, particularly in the United Kingdom,[280] highlighting the value China sees in acquiring technologies that could shift technology and economic competition. Kuang-Chi said that the fund is expected to grow to $300 million and that its investments in the United Kingdom are expected to be "even larger in subsequent years."[281] Kuang-Chi's Chairman Ruopeng Liu reiterated the importance of United Kingdom companies noting that "investing in British startups and technology companies in the growth stage is a key part of our long-term strategic plan."[282]

A second Kuang-Chi investment fund—known as Global Community of Innovation II—was launched on October 31, 2016 to invest $250 million in global technology companies active in the areas of: smart city/smart home, Internet-of-Things, AI, VR and AR and robotics. This fund would be supported by a new China-based incubator, established by Kuang-Chi to help bring its portfolio companies to the Chinese market.[283] This second initiative has a particular emphasis on investments in Israel, another country with a vibrant high-tech start-up culture, including the establishment in January 2017 of an Israel-based International Innovation Headquarters.[284] Other Kuang-Chi interests in "developed countries" include investments in the following AI, biometrics and unmanned systems technologies:[285]

- Video intelligence provider, Agent Video Intelligence (Agent VI, Israel)
- Leading gesture control firm, eyeSight (Israel)
- Emotions analytics pioneer, Beyond Verbal (Israel)
- Biometric authentication provider, Zwipe (Norway)
- UAV surveillance company, SkyX (Canada)

China's acquisition, investment and joint venture efforts are not limited to the United Kingdom and Israel, of course. As indicated by the list of AVIC's acquisitions, China has been active in investments with U.S.-based companies, including those seeking to enter the large Chinese electronics and commercial aerospace markets. Figure 9 below provides an overview of key deals between Chinese state-owned enterprises and U.S. aerospace companies.[286]

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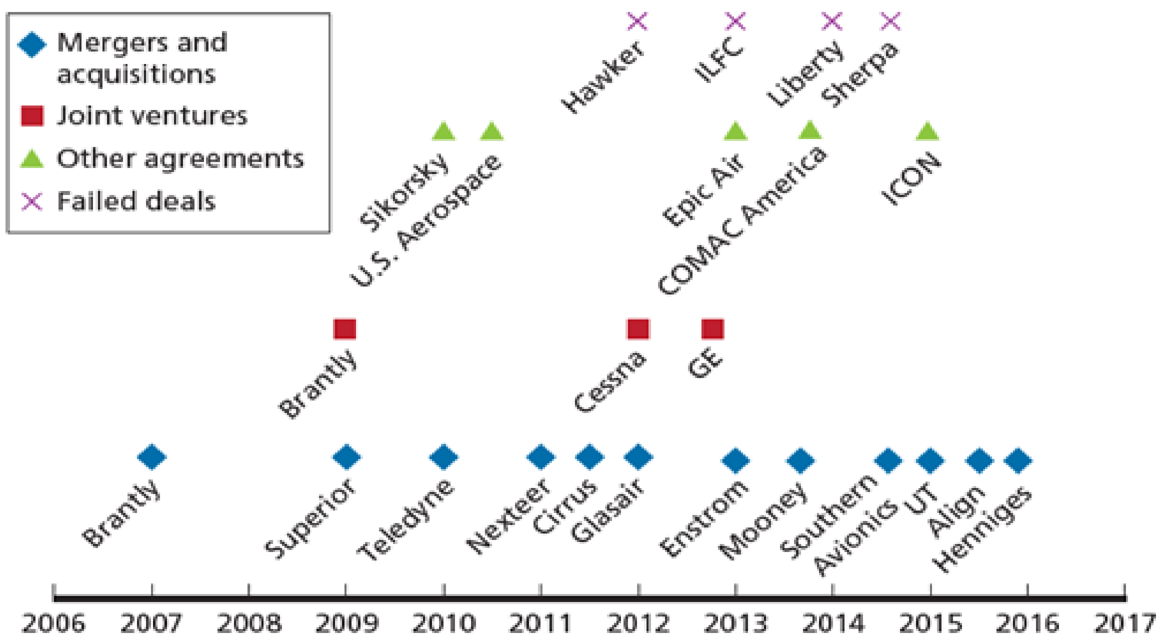
[279] Grevatt, Jon, "China's Kuang-Chi Invests in UK Technology Firm," *Jane's Defense Industry,* January 17, 2017, https://janes.ihs.com/Janes/Display/jdin91273-jdw-2017.
[280] Grevatt, Jon, "China's Kuang-Chi Invests in UK Technology Firm," *Jane's Defense Industry,* January 17, 2017, https://janes.ihs.com/Janes/Display/jdin91273-jdw-2017.
[281] Grevatt, Jon, "China's Kuang-Chi Invests in UK Technology Firm," *Jane's Defense Industry,* January 17, 2017, https://janes.ihs.com/Janes/Display/jdin91273-jdw-2017.
[282] Grevatt, Jon, "China's Kuang-Chi Invests in UK Technology Firm," *Jane's Defense Industry,* January 17, 2017, https://janes.ihs.com/Janes/Display/jdin91273-jdw-2017.
[283] Kuang-Chi website, "Kuang-Chi GCI Fund to Invest $250m in Global Startups," November 2, 2017, http://www.kuang-chi.com/en/index.php?ac=article&at=read&did=1130.
[284] *Cision Newswire PR,* "New USD 250M Kuang-Chi GCI Fund Focuses on Israel Tech Opportunities," January 11, 2017, https://www.prnewswire.com/news-releases/new-usd-250m-kuang-chi-gci-fund-focuses-on-israel-tech-opportunities-300389322.html.
[285] Kuang-Chi website, "Kuang-Chi GCI Fund to Invest $250m in Global Startups," November 2, 2017, http://www.kuang-chi.com/en/index.php?ac=article&at=read&did=1130.
[286] Ohlandt, Chad J.R., Morris., Lyle J., Thompson, Julia A., Chan, Arthur, Scobell, Arthur, "China's Investment in U.S. Aerospace," RAND Corporation, 2017, https://www.rand.org/content/dam/rand/pubs/research_reports/RR1700/RR1755/RAND_RR1755.pdf.

Figure 9: A list of prominent acquisitions of and joint ventures and agreements with U.S. aerospace companies by Chinese companies



Source: RAND Corporation, China's Investment in U.S Commercial Aerospace

Other indicative joint ventures undertaken between Chinese companies and U.S. aerospace and defense firms include:

- In April 2014, Rockwell Collins formed its joint venture with CETC to develop communication and navigation systems. According to *Aviation Week*, the Rockwell-CETC joint venture "has been extended in scope to include engineering and production of indigenous navigation communication equipment for other Chinese programs."[287]

- GE Aviation announced in November 2009 an agreement to establish a joint venture with AVIC to help GE gain access to the exceptional commercial opportunity presented by the Chinese market, specifically the C919 single aisle aircraft. Former GE Chief Executive Officer Jeff Immelt explained at the time of the agreement the nearly irresistible draw of the Chinese market for commercial aerospace companies, noting that "the Chinese civil aviation industry will likely, over the coming decades, be one of the biggest, if not the biggest, in the world."[288] The promise of the scalable revenues and sales of China's massive market is also a strong motivation of engagement of other U.S. companies and industries: high-tech, telecommunications, social media, automotive, to name just a few.

  In a 2011 press release, GE noted that the joint venture offered opportunities that it "would not have on its own." Specifically, as part of the joint venture, GE will contribute its

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[287] "Rockwell Collins Simulator JV Become Reality," *Aviation Week*, November 11, 2014, http://aviationweek.com/zhuhai-2014/rockwell-collins-simulator-jv-becomes-reality.
[288] "GE and China's AVIC to Form Avionics Joint Venture," *Reuters*, November 14, 2017, https://www.reuters.com/article/us-ge-avic/ge-and-chinas-avic-to-form-avionics-joint-venture-idUSTRE5AE08W20091115.

commercial Integrated Modular Avionics technology to the joint venture. The joint venture will supply IMA technology, displays, on-board maintenance systems, flight recorders and flight management system for the C919. The 2011 press release includes a section on "national security," which seeks to preemptively allay fears of diffusion of dual–use technology that could enhance China's military capability: "No military applications are involved in this joint venture, and significant measures are in place to safeguard against any unauthorized transfer of intellectual property."[289]

China's Educational Challenges and Opportunities

China's S&T community and defense industrial base have both benefitted over the last nearly two decades from impressive growth in the *number* of students attending and graduating from college in China. While the overall *quality* of student and S&T focused research will be examined in further detail later in this section, indicative measures of China's rapid and sustained growth in the number of college attendees and graduates are, on the surface, impressive:

- In 1999, the Chinese government launched a program to expand university attendance and saw a 50% increase just in the first year.[290]

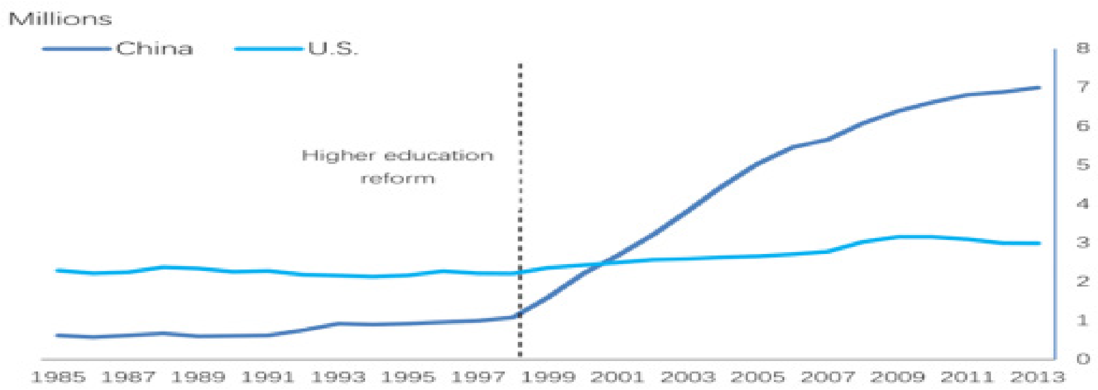
- The country had 8 million students graduate university in 2017, twice the number of U.S. university graduates for this year and *ten times* the number China had in 1997.[291]
- China is second to India (78 million) in the global ranking of total university graduates with 77.7 million people. The United States is in third place with 67.4 million. China is projected to have a 300% increase in graduates to reach 200 million graduates by 2030,[292] larger than the entire U.S. workforce.[293] By comparison, the United States is projected to only have a 30% increase in graduates to 87.62 million during that timeframe.[294]

Add to these numbers the growing number of Chinese high-school and college students studying in the United States (see Figure 10). According to an August 2017 report from the Institute of International Education (IIE), roughly 40% of international students at U.S. high schools are from China while the total number of students in U.S. high schools rose 48% between 2013 and 2016. Rajka Bhandari, the Director of the IIE Center for Academic Mobility Research and Impact summarized a dynamic captured by the report: "What we're really seeing is sort of a continued interest on the part of the Chinese students to aim for a U.S. credential, except that we're now seeing that interest play out at younger age."[295]

[289] GE Aviation, "Avionics Joint Venture (JV) with Aviation Industry Corporation of China (AVIC)," October 5, 2011, https://www.geaviation.com/press-release/jv-archive/ge-aviation-avionics-joint-venture-jv-aviation-industry-corporation-china.
[290] Stapleton, Katherine, "Inside the World's Largest Higher Education Boom," *The Conversation*, April 10, 2017, https://theconversation.com/inside-the-worlds-largest-higher-education-boom-74789.
[291] Stapleton, Katherine, "Inside the world's largest higher education boom," *The Conversation*, April 10, 2017, https://theconversation.com/inside-the-worlds-largest-higher-education-boom-74789.
[292] McCarthy, Niall, "The Countries with the Most STEM Graduates," *Industry Week*, February 6, 2017, http://www.industryweek.com/workforce/countries-most-stem-graduates.
[293] Chen, Lulu Yilun, "China's Tiger Moms Are Spending Big on Tech Classes for Their Kids," Bloomberg, December 20, 2016, https://www.bloomberg.com/news/features/2016-12-20/china-s-tiger-moms-are-spending-thousands-for-stem-education-and-robot-classes-for-their-kids.
[294] McCarthy, Niall, "The Countries with the Most STEM Graduates," *Industry Week*, February 6, 2017, http://www.industryweek.com/workforce/countries-most-stem-graduates.
[295] Fuchs, Chris, "Report Finds China Sends Most International Students to U.S. High Schools," *NBC News*, August 14, 2017, https://www.nbcnews.com/news/asian-america/report-finds-china-sends-most-international-students-u-s-high-n792681.

At the college and university level, during the 2015-2016 academic year the IIE estimated that there were 328,547 Chinese students studying at U.S. colleges and universities, accounting for over 31% of the total number of international students at U.S. colleges and universities. The number constituted an 8.1% year-on-year increase and was by far the most of any foreign cohort. At just over 165,000, India sent the second most students to study at U.S. colleges and universities, less than half of the number from China.[296]

Figure 10: A graph depicting the steep growth curve of Chinese students enrolled in higher education institutions each year versus the number of U.S. students enrolled in higher education institutions each year. Since approximately 1999, China has seen a sevenfold increase in the number of new students enrolling in higher education institutions.



Source: *The Conversation*[297]

The fields of science, technology, engineering and math (STEM) stand out as particularly popular for students and as in high demand by employers. However, analysis later in this section indicates the quality of these graduates is uneven and that there are structural deficiencies in higher-education STEM-related research in China. Nevertheless:

- China has four times as many graduating students as the US (1.3 million vs. 300,000).[298]
- In 2013, 40% of Chinese graduates completed a degree in a STEM subject, more than twice the share in American third level institutions.[299]
- In 2016, China had 4.7 million recent STEM graduates while the United States had 568,000.[300]

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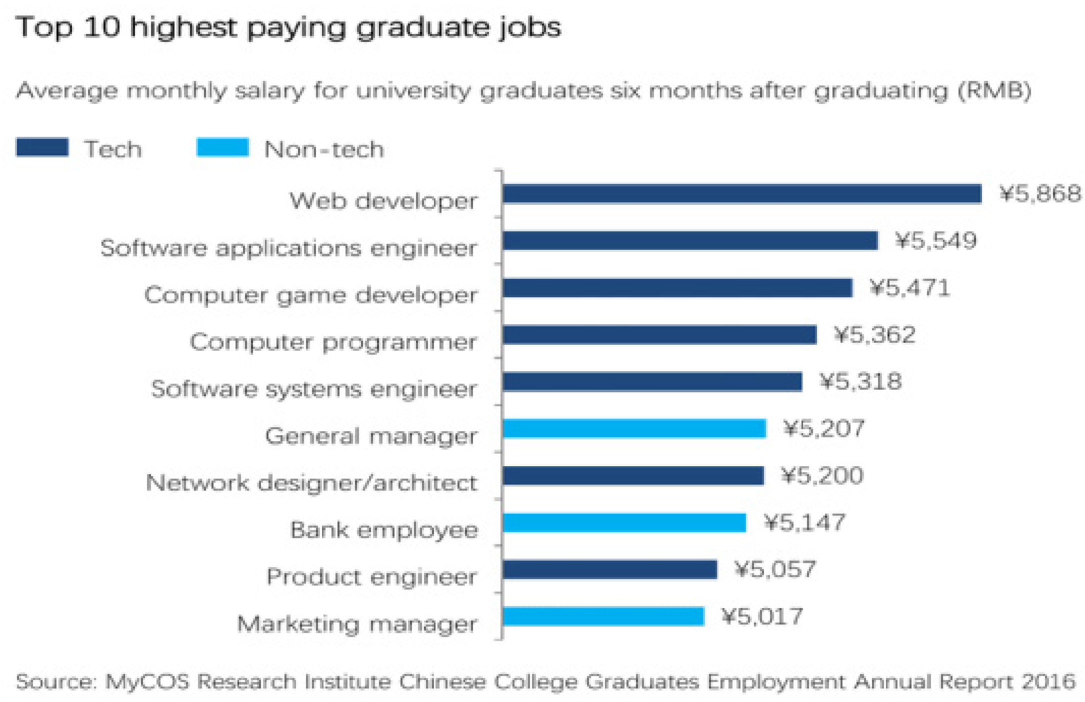
[296] IIE, "Open Doors Report: 2015-2016," November 13, 2016, https://www.iie.org/Research-and-Insights/Open-Doors/Data/International-Students/Places-of-Origin.
[297] Stapleton, Katherine, "Inside the World's Largest Higher Education Boom," *The Conversation*, April 10, 2017, https://theconversation.com/inside-the-worlds-largest-higher-education-boom-74789.
[298] Allison, Graham, "America Second? Yes, and China's Lead is Only Growing," *Boston Globe*, May 22, 2017, https://www.bostonglobe.com/opinion/2017/05/21/america-second-yes-and-china-lead-only-growing/7G6szOUkTobxmuhgDtLD7M/story.html.
[299] McCarthy, Niall, "The Countries with the Most STEM Graduates [Infographic]," *Forbes*, February 2, 2017, https://www.forbes.com/sites/niallmccarthy/2017/02/02/the-countries-with-the-most-stem-graduates-infographic/#6b4a4f1d268a.
[300] McCarthy, Niall, "The Countries with the Most STEM Graduates [Infographic]," *Forbes*, February 2, 2017, https://www.forbes.com/sites/niallmccarthy/2017/02/02/the-countries-with-the-most-stem-graduates-infographic/#6b4a4f1d268a

- Projections show that by 2030 China and India will have 60% of the STEM graduates from major economies, while the United States will only have 4%.[301]

Interest in STEM degrees can be explained largely by government focus and by the disparity in employment opportunities after graduation between STEM graduates and others. Non-STEM graduates make up a large share of China's college graduate under-employment problem; 25% of China's graduates work in low-paying, part-time jobs making a salary less than that of a migrant worker.[302] The job market for STEM graduates is far more attractive. Eight of the top 10 highest paying jobs for university graduates immediately out of university are STEM-related (see Figure 11).

Figure 11: Eight of the top 10 highest paying jobs in China for Chinese university graduates six months after graduation are in STEM-related fields.



Source: *The Conversation*[303]

Focus on STEM education is affecting more than the university level of education in China. Recognition of the importance of STEM education in a future economy that will be built upon increased use of Fourth Industrial Revolution technologies, particularly AI applications and robotics, has spurred a cottage industry of start-ups offering training in coding, robotics and 3-D printing. Nora Yeung, founder of one of these start-ups captured the growing perception among China's youth and their families that coding and other skills will be central to finding a job when today's secondary school students will be entering the workforce in a decade or less: "we need to prepare these kids for jobs that don't exist yet."[304]

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301 Schleicher, Andreas, "China Opens a New University Every Week," *BBC* News, March 16, 2016, http://www.bbc.com/news/business-35776555

302 Stapleton, Katherine, "Inside the World's Largest Higher Education Boom," *The Conversation*, April 10, 2017, https://theconversation.com/inside-the-worlds-largest-higher-education-boom-74789.

303 Stapleton, Katherine, "Inside the World's Largest Higher Education Boom," *The Conversation*, April 10, 2017, https://theconversation.com/inside-the-worlds-largest-higher-education-boom-74789.

304 Chen, Lulu Yilun, "China's Tiger Moms Are Spending Big on Tech Classes for Their Kids," Bloomberg, December 20, 2016, https://www.bloomberg.com/news/features/2016-12-20/china-s-tiger-moms-are-spending-thousands-for-stem-education-and-robot-classes-for-their-kids.

Judging the outputs of this increase in numbers of educated Chinese is difficult, in part because of the way that China approaches (and is allowed to approach) the Organization for Economic Co-operation and Development's Program for International Student Assessment (PISA) test. The test is designed to gauge the academic performance of 15-year-old students in 70 countries throughout the world in reading, math and science. While China has consistently performed better than the United States in results, the Organization for Economic Co-operation and Development allows China to select who is tested and which scores are released, meaning that China can effectively "game" the results to portray the country's most well-trained students as indicative of all its students.[305]

China formerly used students only from Shanghai as representational of the rest of the country. In 2015, China used Beijing, Shanghai, Jiangsu and Guangdong, all high-performing districts in education.[306] "China does not take the PISA test," says Tom Loveless, Non-resident Senior Fellow on Governance Studies at Brookings Institution's Brown Center on Education Policy, "a dozen or so provinces in China take the PISA, along with two special administrative regions (Hong Kong and Macao)." Shanghai constitutes only 1.7% of China's population and also invests highly in its students.[307] On top of that, only the best schools are selected, and their best students are picked to take the test.[308]

The United States, meanwhile, uses sampling from across the country. For the 2015 test, Macau (China) finished sixth overall in science, reading and math performance; Hong Kong was ninth; and Beijing-Shanghai-Jiangsu-Guangdong—the four cities chosen by China as indicative—finished 10th. The United States finished 25th.[309]

Quantity versus Quality: Assessing China's Educational Outputs

Despite the abundance of quantitative measures indicating a rapid rise in the number of university educated people in China and STEM-related success, there are also compelling indicators of deeply rooted challenges affecting the quality of China's STEM research and capabilities.

While there is a growing number of universities in China, the *Times Higher Education* World University Rankings 2018 list only includes two Chinese universities in its top 100. The rest of the list is dominated by American and European schools.[310] Though *Times Higher Education* notes that "China is rapidly gaining ground on various measures of university performance."[311]

Perhaps more fundamental to China's STEM education-related challenges are apparent concerns about academic integrity at Chinese universities. Academic fraud, faked peer reviews, plagiarism and

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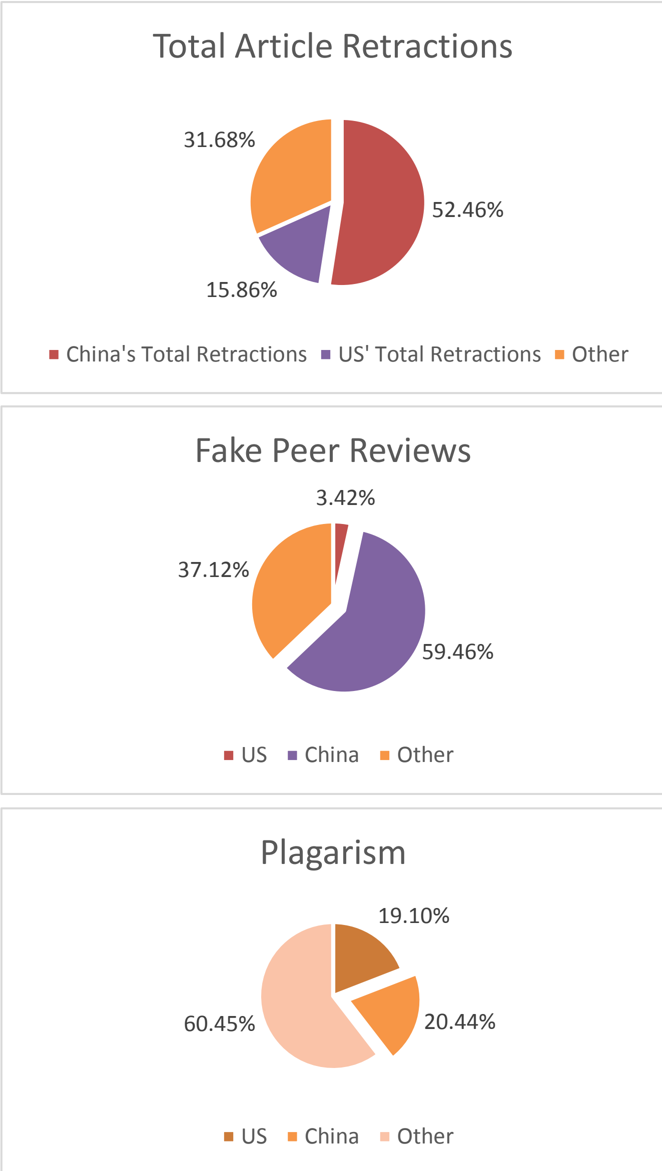
[305] Dews, Fred, "Tom Loveless: Shanghai PISA Test Scores Almost Meaningless; Hukou a Factor," Brookings Institution, December 3, 2013, https://www.brookings.edu/blog/brookings-now/2013/12/03/tom-loveless-shanghai-pisa-test-scores-almost-meaningless-hukou-a-factor/.
[306] Sands, Gary, "Are the PISA Education Results Rigged?," *Forbes,* January 4, 2017, https://www.forbes.com/sites/realspin/2017/01/04/are-the-pisa-education-results-rigged/#52eb425b1561.
[307] Loveless, Tom, "PISA's China Problem," *Brookings*, October 9, 201320132013, https://www.brookings.edu/research/pisas-china-problem/.
[308] Sands, Gary, "Are the PISA Education Results Rigged?" *Forbes,* January 4, 2017, https://www.forbes.com/sites/realspin/2017/01/04/are-the-pisa-education-results-rigged/#52eb425b1561.
[309] "PISA Results in Focus," OECD, 2016, http://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf.
[310] "World University Rankings 2018," *The Times*. https://www.timeshighereducation.com/world-university-rankings/2018/world-ranking#!/page/0/length/-1/sort_by/rank/sort_order/asc/cols/scores "World University Rankings 2018," *The Times*. https://www.timeshighereducation.com/world-university-rankings/2018/world-ranking#!/page/0/length/-1/sort_by/rank/sort_order/asc/cols/scores
[311] Baker, Simon, "China's universities: significant progress, but more to do," *Times Higher Education,* April 10, 2017. https://www.timeshighereducation.com/news/chinas-universities-significant-progress-more-do

cheating are particularly prominent problems in China's educational system (see Figure 12 below). Retraction Watch's Retraction Database was launched in 2010 and provides a list of articles retracted from journals, including an explanation as to why articles were retracted. Jane's analysis of the database shows that 52.5% of retracted articles came from Chinese researchers compared to 15.9% from American researchers.[312]

Of all articles retracted for faked peer reviews—a common tactic in which individuals are hired to pose as researchers and offer glowing "peer reviews" of a paper so that it will be published—Chinese researchers were responsible for 59.5% versus 3.4% for American researchers.[313] On plagiarism, the United States and China were about even with 19.1% and 20.44% respectively.[314]

Figure 12: Figures displaying the proportion of total article retractions in scientific journals by Chinese authors, U.S. authors and other authors. China has a disproportionately large percentage of total retractions and retractions due to fake peer reviews. The U.S. and China were roughly even in retractions due to plagiarism (derived from Retraction Watch)



The high percentage of retractions and the fraud that generates these retractions is largely a problem of incentives and oversight. China uses the Science Citation Index or SCI to evaluate a researcher's impact. The index ranks researchers' importance based solely on how many times their articles are cited in other papers or journals. Universities also give out bonuses to researchers who are published in "high impact" journals. This has created an "obsession" over the number of articles a researcher publishes that, coupled with a lack of oversight and weak punishments, has created an environment that incentivizes fraud as well as cheating.[315]

Chinese blogger Fang Shimin tracks fraud among China's academic and research communities.[316] He believes that because the problems of fraud and cheating are so pervasive there

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[312] *Retraction Watch,* "The Retraction Database," Accessed November 10, 2017, http://retractiondatabase.org/RetractionSearch.aspx.
[313] *Retraction Watch,* "The Retraction Database," Accessed November 10, 2017, http://retractiondatabase.org/RetractionSearch.aspx.
[314] *Retraction Watch,* "The Retraction Database," Accessed November 10, 2017, http://retractiondatabase.org/RetractionSearch.aspx.
[315] Qin, Amy, "Fraud Scandals Sap China's Dream of Becoming a Science Superpower," *New York Times,* October 13, 2017, https://www.nytimes.com/2017/10/13/world/asia/china-science-fraud-scandals.html.
[316] His blog can be found at: http://www.xys.org/. For more information, see Henry, Ben Andrew, "The Past and Present of Research Integrity in China," *The Scientist,* March 1, 2017, http://www.the-scientist.com/?articles.view/articleNo/48577/title/The-Past-and-Present-of-Research-Integrity-in-China/.

are few incentives for self-regulation by academic and research institutions, which is facilitating the normalization and legitimization of cheating.[317]

Students see cutting corners as a way to speed up their advancement in a highly competitive environment. More importantly, few see, if any, consequences for behavior that would-be career-limiting, if not career-ruining in the United States. Zhang Lei, a professor of applied physics at Xi'an Jiaotong University, highlighted this discrepancy: "In America, if you purposely falsify data, then your career in academia is over. But in China, the cost of cheating is very low. They won't fire you. You might not get promoted immediately, but once people forget, then you might have a chance to move up."[318]

Yu Yanru was China's first individual to lose a degree because of academic misconduct in 2015 when it was revealed that one of her dissertations was nearly entirely plagiarized. Polling done after the decision to revoke her degree was made indicated an essentially nonplussed public ready to forgive: 60% of those polled believed the punishment was "too harsh," and 10% believed that her tutors should have been held accountable.[319]

The Chinese government's own studies on the issue at the end of the last decade have had alarming results. One study in 2010 found that one-third of the 6,000 scientists at the nation's top 6 institutions admitted to plagiarism or falsifying data. A 2009 study by the China Association for Science and Technology found that 55% of 32,000 scientists polled admitted to knowing someone who had committed academic fraud.[320] Open source research on the topic published in the intervening years indicates a research culture still lacking in "integrity" and beset with "rampant fraud."[321]

One anecdotal indicator of the scale of the problem was seen in Luoyang, where authorities launched a drone to look for radio signals being sent to hidden earpieces on students taking the National College Entrance Examinations.[322]

Centenary College in New Jersey shut down its satellite branches in Shanghai, Beijing and Taipei after finding "rampant cheating" on its final exams for graduating students. The college withheld degrees for 400 students. When it offered the students a chance to take another exam for their degree, 398 of the students declined.[323] The firm that runs the SAT test cancelled all testing in 45 test centers in China and Macau back in 2016 when it became concerned that some students had already seen the test.[324]

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[317] Jacobs, Andrew, "Rampant Fraud Threat to China's Brisk Ascent," *New York Times,* October 6, 2010, http://www.nytimes.com/2010/10/07/world/asia/07fraud.html.
[318] Qin, Amy, "Fraud Scandals Sap China's Dream of Becoming a Science Superpower," *New York Times,* October 13, 2017, https://www.nytimes.com/2017/10/13/world/asia/china-science-fraud-scandals.html.
[319] Xin, Yang, "Academic Integrity a Forgotten Lesson in China's Higher Ed," *Beijing Today*, March 16, 2015, https://beijingtoday.com.cn/2015/03/academic-integrity-a-forgotten-lesson-in-chinas-higher-ed/.
[320] Jacobs, Andrew, "Rampant Fraud Threat to China's Brisk Ascent," *New York Times,* October 6, 2010, http://www.nytimes.com/2010/10/07/world/asia/07fraud.html.
[321] This assertion is made based on the articles cited in this section as well as others.
[322] Chan, Emily and Edward Chow, "Schools in China are Now Using DRONES to Stop Students Cheating in High-pressure University Entrance Exams," *Daily Mail*, June 4, 2015, http://www.dailymail.co.uk/news/peoplesdaily/article-3110734/Drones-used-Chinese-officials-stop-students-cheating-gaokao.html.
[323] Jacobs, Andrew, "Rampant Fraud Threat to China's Brisk Ascent," *New York Times,* October 6, 2010, http://www.nytimes.com/2010/10/07/world/asia/07fraud.html.
[324] Mandak, Joe, "SAT Tests Canceled in China, Macau over Cheating Concerns," *Diverse*, January 21, 2016, http://diverseeducation.com/article/80439/.

Among the most egregious examples of China's academic fraud problem occurred in June this year when the international medical journal, *Tumor Biology*, retracted 107 Chinese papers from the past five years. 101 were retracted due to fake peer reviews. MOST has promised to take a "no tolerance" approach and that it will investigate and may strip the researchers of their positions. In the meantime, the ministry stopped all grant funding to the institutions involved.[325] 486 of the 521 authors implicated in the investigation were found guilty of academic misconduct, 314 of which were blamed for negligence that enabled fraud. 376 authors were banned from research programs by their institutions. He Defang, a ministry official, vowed that the researchers will face punishment.[326] This crackdown is China's "harshest ever."[327]

That the punishment for the *Tumor Biology* scandal seems so harsh and notable reflects the degree to which the phenomenon of academic fraud is entrenched in China's research culture. It is also a theme that will be explored tangentially in Chapter 3's discussion of China's rapid ascent in the total number of articles published on various applications of AI.

Jane's believes that the depth and breadth of research fraud, in particular, constitutes a significant obstacle to China's S&T community and efforts, in three interconnected ways:

1. It casts doubt on the legitimacy of research published by researchers from China, making it more difficult for legitimate research to gain exposure

2. It drains resources and distracts the focus of China's research community as it seeks to slow and then arrest the untoward practices leading to mass retractions. Instituting cultural shifts within institutions can be expensive and take a considerable amount of time to execute.

3. It ensures that individuals who have taken short cuts are being promoted into more senior research roles without demonstrating the applied skill sets and research methods to warrant those roles. This, of course, can affect the quality of research activity being performed and further institutionalizes improper behavior.

China's Conspicuous Successes

In spite of some of the structural and research culture challenges identified above, China has achieved—and in many cases made very public statements about—innovation milestones over the last two years that support the narrative of a defense industrial base and S&T community making progress in its capacity to innovate, especially in Fourth Industrial Revolution technologies.

Some of these purported successes are apocryphal. For example, in December 2016, an article published in *Science and Technology Daily,* the official newspaper of MOST, claimed that China had been performing "key technology research" for five years on electromagnetic drives, a technology that enables the sort of reactionless propulsion seen in science fiction films like Star Wars.[328] The

[325] Yang, Yuan and Archie Zhang, "China Launches Crackdown on Academic Fraud," *Financial Times*, June 18, 2017, https://www.ft.com/content/680ea354-5251-11e7-bfb8-997009366969
[326] *China Daily*, "Result of Academic Fraud Investigation Announced," July 29, 2017, http://www.chinadaily.com.cn/china/2017-07/29/content_30288129.htm
[327] Normile, Dennis, "China Cracks Down After Investigation Finds Massive Peer-review Fraud," *Science*, July 31, 2017, http://www.sciencemag.org/news/2017/07/china-cracks-down-after-investigation-finds-massive-peer-review-fraud.
[328] *Daily Galaxy*, "China Trumps NASA with Working 'Star Trek' EM Propulsion Drive—Testing now Aboard the Tiangong -2 Space Laboratory," DecemberDecember20, 2016. http://www.dailygalaxy.com/my_weblog/2016/12/china-trumps-nasa-with-working-startrek-em-propulsion-drive-testing-now-aboard-the-tiangong-2-space-.html.

"inventor" of the concept of the EM drive, British scientist Roger Shawyer calculated that EM drive could power a craft to Mars in just 70 days.[329]

The Chinese Academy of Space Technology followed up the article with a press conference in which it claimed to have developed EM drive prototypes that were currently being tested on the Tiangong-2 space craft. The flurry of China's announcements on EM drive technologies were conspicuously timed, just weeks after a NASA team published a peer-reviewed article in American Institute of Aeronautics and Astronautics' *Journal of Propulsion and Power* that controversially claimed that EM drive technology was *theoretically possible.* Even that assertion was met with considerable resistance from the U.S. scientific community, with some scientists arguing that EM drive technologies violated Newton's third law of motion (for every action there is an equal and opposite reaction).[330]

In June 2017, the Chinese Academy of Sciences highlighted China's transition from "Copied in China" to "Created in China" with a list of the "7 firsts" in China's science and technology achievements from 2012–2017:

1. World's first artificial cornea
2. World's largest single aperture telescope
3. World's first quantum communications satellite
4. World's first prototype exascale supercomputer
5. World's first photon quantum computer
6. World's largest shockwave hypersonic wind tunnel
7. World's first 100-meter iron-based super-conducted wire

Source: *China Daily*, 15 June 2017, http://www.chinadaily.com.cn/china/2017-06/15/content_29752320.htm

But not all of China's claims of scientific, technological or engineering success are quite so dubious or unproven. In fact, China has made several notable advances in S&T areas that are directly relevant to the future of China's military modernization and to advanced weapons programs of interest to this project. China's growing influence and demonstrated capacity in AI fields stands out as a particularly important and very credible success for China's high-tech industry and S&T community. Jane's discusses this topic in detail in Chapter 3.

An examination of China's success in quantum encryption and computing is another indicative example of China's conspicuous S&T successes. It also provides considerable insight into the levers and conditions enabling success in innovation and novel capability development, most prominently:

- Urgent strategic motivation, typically based on a perceived threat from the United States.
- China's ability to use top-down directives and policy initiatives to focus industry on specific technology areas and objectives.
- Capacity to spend considerable amounts of money to acquire technologies and know-how and invest in indigenous development.

[329] Poitras, Colin, "To Mars in 70 Days: Expert Discusses NASA's Study of Paradoxical EM Propulsion Drive," *Phys.org*, December 7, 2016. https://phys.org/news/2016-12-mars-days-expert-discusses-nasa.html.
[330] "China Trumps NASA with Working 'Star Trek' EM Propulsion Drive—Testing now Aboard the Tiangong -2 Space Laboratory," *Daily Galaxy*, December 20, 2016 http://www.dailygalaxy.com/my_weblog/2016/12/china-trumps-nasa-with-working-startrek-em-propulsion-drive-testing-now-aboard-the-tiangong-2-space-.html; *Futurism*, "China Claims Its Made the Impossible EM Drive Possible," https://futurism.com/china-claims-its-made-the-impossible-emdrive-possible/.

The latter two of these measures—government focus and funding—have the added effect of attracting private sector entrepreneurs, who, in turn, inject market-oriented approaches that can foster competition and innovation velocity, as explored in Chapter 3.

Background: China's Success in Quantum Encryption and Computing
China has had a strong focus on the development of quantum computing and quantum encryption. The progress of China's S&T community in quantum encryption, in particular, has been impressive.

Quantum computing leverages the "strange laws of quantum mechanics"[331] to provide considerably more processing power for computers to solve problem sets that take traditional computers an exceedingly long period of time to solve. For example, quantum computers can employ algorithms that allow for the solving of optimization problems with large numbers of variables. Quantum computing can do this through the use of quantum bits—qubits—that, unlike binary bits used by traditional computers (either a "0" or a "1"), can exist in superposition; that is in both the 0 and 1 positions until measured. Qubits are also entangled, which means that multiple qubits are connected so that "measuring the quantum state of one qubit provides information about the others."[332]

Quantum encryption leverages principles of quantum entanglement to ensure that any efforts to tamper with communications are known instantly to both sender and receiver as well as alter the composition of the message being sent. Quantum communication is not "hack-proof" or "unhackable" as some like to claim, rather, it is "tamper resistant." With a quantum encryption, any attempt by a third party to view the quantum particle that is being used as an encryption key destroys it, garbling the message and alerting the two parties of the attempted unauthorized access. Quantum communication has been likened to "sending a message written on a soap bubble," one touch and it pops.[333] This built-in self-destruct sequence makes quantum communication highly appealing in the Post-Snowden world.

China's list of apparently significant achievements in this field is growing longer and includes the launch of the world's first "quantum satellite," the Quantum Experiments at Space Scale (QUESS) in August 2016.[334] The QUESS program aims to build a quantum key distribution network by 2020 and a global quantum communication network by 2030.[335] The program is almost certainly being pursued due to Chinese concerns about espionage and information security following the Snowden revelations. Chinese scientists will also use QUESS to test "other quantum technologies such as photon teleportation, transmission error reduction and random number generators."[336]

China also reportedly "unveiled the world's first "unhackable computer network," known as the Jinan Project, in August 2017.[337] The project "uses the city of Jinan as a quantum computer hub" to boost a quantum network between Beijing and Shanghai, due to its central location between the

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[331] Schwaub, Klaus, "Shaping the Fourth Industrial Revolution," *World Economic Forum*, 2017, pg. 46.
[332] Schwaub, Klaus, "Shaping the Fourth Industrial Revolution," *World Economic Forum*, 2017, pg. 46.
[333] Hackett, Robert, "What the World's First Quantum Satellite Launch Means," *Fortune,* 17 August 2016, http://fortune.com/2016/08/16/china-quantum-satellite-launch/
[334] Fei, Yu and Haitao, Xu, "Feature: A life of quantum entanglement," *Xinhua*, July 10, 2017. http://news.xinhuanet.com/english/2017-07/10/c_136432026.htm.
[335] Lin, Jeffrey, Singer, P.W. and Costello, John, "China's Quantum Satellite Could Change Encryption Forever," *Popular Mechanics*, March 3, 2016. https://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever.
[336] Lin, Jeffrey, Singer, P.W. and Costello, John, "China's Quantum Satellite Could Change Encryption Forever," *Popular Mechanics*, March 3, 2016. https://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever.
[337] Ward, Tom, "China Has Unveiled the World's First 'Unhackable Computer Network'," *World Economic Forum*, August 14, 2017. https://www.weforum.org/agenda/2017/08/why-china-is-leading-the-world-in-developing-quantum-communication-networks.

two cities.[338] The network is over 2,000 kilometers (km) (1,250 miles) long and will be used for communications between government entities and the financial districts of the two cities.[339] One test of the system successfully completed a transaction from Shanghai to Beijing at the Bank of Communications over the quantum network.[340] Zho Fei, Assistant Director of the Jinan Institute of Quantum Technology noted that China plans "to use the network for national defense, finance and other fields."[341]

In September 2017, China achieved another important milestone when scientists held a videoconference between Austria and China secured by the QUESS satellite, which distributed a quantum key to encrypt the video transmission. [342] The call linked Chunli Bai, president of the Chinese Academy of Sciences in Beijing and quantum physicist Anton Zeilinger, president of the Austrian Academy of Sciences in Vienna. The call was described as a "huge achievement," by University of Waterloo quantum physicist Thomas Jennewein.[343]

Quantum computing-related projects have focused on quantum radars and remote sensing, quantum navigation and quantum communications, including efforts undertaken by China's defense state-owned enterprises. China is looking at quantum communications as a possible secure underwater communications route.[344] Reportedly, the Chinese government will issue national standards for quantum key distribution equipment in the next two years.[345]

The next stage for China's quantum satellite project is to launch another satellite into a higher orbit, possibly 20,000 km (about 12,427 miles), to cover a larger part of the Earth's surface. By 2022, China plans to put a quantum communications payload on its future space station. The payload could be maintained and upgraded on the space station by humans, unlike the systems on satellites. The ultimate goal is a world-spanning network of quantum satellites in geostationary orbits.[346] China plans to have a Sino-European quantum key distribution network by 2020 and a global system by 2030.[347]

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338 Ward, Tom, "China Has Unveiled the World's First 'Unhackable Computer Network'," *World Economic Forum*, August 14, 2017. https://www.weforum.org/agenda/2017/08/why-china-is-leading-the-world-in-developing-quantum-communication-networks.

339 Yang, Yuan, "China Trial Paves Way for 'Unhackable' Communications Network," *Financial Times,* 10 July 2017, https://www.ft.com/content/899458ca-655c-11e7-8526-7b38dcaef614,

340 Bhunia, Priyankar, "World's longest unhackable communications link opened between Beijing and Shanghai," *Open Gov Asia*, 28 October 2017, http://opengovasia.com/articles/8091-worlds-longest-unhackable-quantum-communications-link-opened-between-beijing-and-shanghai

341 Ward, Tom, "China Has Unveiled the World's First 'Unhackable Computer Network'," *World Economic Forum*, August 14, 2017. https://www.weforum.org/agenda/2017/08/why-china-is-leading-the-world-in-developing-quantum-communication-networks.

342 Connor, Emily, "Quantum Video Chat Links Scientists on Two Different Continents," *Science News*, September 29, 2017. https://www.sciencenews.org/article/quantum-video-chat-links-scientists-two-different-continents.

343 Connor, Emily, "Quantum Video Chat Links Scientists on Two Different Continents," *Science News*, September 29, 2017. https://www.sciencenews.org/article/quantum-video-chat-links-scientists-two-different-continents.

344 Kania, Elsa, "China's Trump Card," *Prospect,* October 23, 2017, https://www.prospectmagazine.co.uk/other/chinas-trump-card.

345 Bhunia, Priyankar, "World's Longest Unhackable communications Link Opened Between Beijing and Shanghai," *Open Gov Asia*, October 28, 2017, http://opengovasia.com/articles/8091-worlds-longest-unhackable-quantum-communications-link-opened-between-beijing-and-shanghai.

346 "The First Quantum-cryptographic Satellite Network Will Be Chinese," *The Economist,* August 31, 2017, https://www.economist.com/news/science-and-technology/21727889-quantum-cryptographys-early-birds-first-quantum-cryptographic-satellite.

347Lin, Jeffery and PW Singer, "China Launches Quantum Satellite In Search Of Unhackable Communications," *Popular Science,* August 17, 2016, https://www.popsci.com/china-launches-quantum-satellite-in-search-for-unhackable-communications.

There are several technical limits to current quantum technologies. The photons needed for quantum communication deteriorate over optical fibers, requiring repeater stations at every 100 km. These repeater stations will be weak points in the "unhackable" network that will be prime targets for intercepting the signal. Entangled photons transmit better through the air, meaning that quantum satellites are more promising for communicating over long distances.[348] But quantum satellites have their limits as well; the QUESS satellite currently passes over China for less than 5 minutes at night because sunlight would disrupt the quantum signal.[349]

Current quantum computers are currently too fragile to be viable. The qubits these computers are composed of need to operate at temperature of 20 millikelvin, or 250 times colder than deep space, and any noise or observation can cause data loss or disentangle the qubits.

Current quantum computers are not yet powerful enough to be viable, either, requiring more than 50 qubits to be faster than conventional computers and entirely new programming software that can interpret the results and correct for errors.[350] Intel unveiled the most powerful quantum computer yet, a 49-qubit computer, at the 2018 Consumer Electronics Show. Intel's corporate vice president Mike Mayberry estimates that quantum computers will need to reach 1 million qubits to be commercially relevant.[351] But qubits can quickly lose their quantum entanglement or give incorrect values, limiting how much quantum computers can compute and how much their results can be relied on.[352] Mr. Mayberry believes the industry will take five to seven years to tackle these engineering problems.[353]

Nevertheless, China is determined to develop quantum computers and mitigate these scalability and reliability issues.

An Assessment of China's Quantum Success

China's success in quantum encryption and its broader interest in developing quantum computing solutions has stemmed from the combination of an urgent strategic motivation, policy directives and initiatives and, most importantly, funding.

The motivation behind China's quantum encryption efforts comes from the sense of vulnerability that accompanied the Edward Snowden revelations of U.S. intelligence community activities, including hacking into Chinese systems. As Professor Pan Jianwei, a quantum physicist at the University of Science and Technology of China in Hefei, noted, "We learnt after the Edward Snowden affair that we are always being hacked." Pan added that "since most of the products we buy come from foreign companies, we wanted to accelerate our own program. This is very urgent because classical encryption was not invented in China, so we want to develop our own technology."[354]

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[348] Pease, Roland, "China's Quantum Satellite in Big Leap," *BBC News,* June 15, 2017, http://www.bbc.com/news/science-environment-40294795.

[349] Pease, Roland, "China's Quantum Satellite in Big Leap," *BBC News,* June 15, 2017, http://www.bbc.com/news/science-environment-40294795.

[350] Mandelbaum, Ryan, "We've Entered a New Era of Quantum Computing," *GIZMODO,* January 5, 2018. https://gizmodo.com/weve-entered-a-new-era-of-quantum-computing-1821807439

[351] Hruska, Joel, "Intel Unveils 'Breakthrough' Quantum Computer," *Extreme Tech,* January 9, 2018. https://www.extremetech.com/computing/261734-intel-unveils-new-quantum-computer-declares-quantum-breakthrough

[352] Mandelbaum, Ryan, "We've Entered a New Era of Quantum Computing," *GIZMODO,* January 5, 2018. https://gizmodo.com/weve-entered-a-new-era-of-quantum-computing-1821807439

[353] Hruska, Joel, "Intel Unveils 'Breakthrough' Quantum Computer," *Extreme Tech,* January 9, 2018. https://www.extremetech.com/computing/261734-intel-unveils-new-quantum-computer-declares-quantum-breakthrough

[354] Moore, Malcolm, "China Builds Computer Network Impenetrable to Hackers," *The Telegraph,* November 2014, http://www.telegraph.co.uk/news/worldnews/asia/china/11216766/China-builds-computer-network-impenetrable-to-hackers.html

This sense of strategic urgency to mitigate risk and address a pressing vulnerability has led to a focus at the national level on facilitating and directing the development of large top-down driver projects—such as the quantum satellite and Jinan Project. The biggest output of this top-down direction, of course, is funding.

In fact, much of China's success in this area has come from its willingness to increase its spending on new research while competitors such as the United States and Japan have stagnated their investment.[355] China has increased its spending on R&D dramatically since 2000, at which point it was spending just as much as France on quantum technologies. In 2015, China was second only to the United States in spending on "non-classified quantum technology."[356] China spent around €200 million (about $250 million) in 2015 while the United States spent €360 million (about $450 million). One quantum expert interviewed for this project believed that China's ability and desire to invest in quantum computing and encryption technologies was "not quite limitless, but certainly very ambitious" and "was the central driver of [China's] success."[357]

Implications for China's Advanced Weapons Systems Programs

While technical limitations on range due to ground interference and scalability remain, China's quantum computing and encryption efforts are enabling more efficient and effective China's advanced weapons systems.

First, quantum computing will be a key technology for AI and decryption, as quantum computers will be far more powerful, faster and able to facilitate deep learning.[358] This power and speed will also allow quantum computers to crack current forms of encryption, possibly even in real time. New techniques will need to be developed to protect data from quantum algorithms. In addition, previously obtained encrypted data could be cracked instantly. Snowden's leaks revealed that the NSA had protocols for storing encrypted communications for future decryption. It's likely that other intelligence institutions have done the same.[359]

Second, quantum encryption could enable more secure communications between China's advanced weapons platforms and systems, including between ground stations and China's space and counter-space platforms and systems.

Third, China is reportedly looking at quantum communications as a possible secure underwater communications technique, which could provide China's future UUVs and submarines with a novel capability to support undersea surveillance/ASW operations as well as more offensive missions.[360]

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[355] Qin, Amy, "Fraud Scandals Sap China's Dream of Becoming a Science Superpower," *New York Times,* October 13, 2017, https://www.nytimes.com/2017/10/13/world/asia/china-science-fraud-scandals.html.
[356] Van Noorden, Richard, "China By the Numbers," *Nature,* June 22, 2016, https://www.nature.com/news/china-by-the-numbers-1.20122.
[357] Interview with a member of the World Economic Forum's Future Council on Quantum Computing on November 12, 2017 at the World Economic Forum's Annual Meeting of Futures Councils in Dubai, UAE.
[358] Metz, Cade, "The Race to Sell True Quantum Computers Begins Before They Really Exist," *Wired,* March 6, 2017, https://www.wired.com/2017/03/race-sell-true-quantum-computers-begins-really-exist/.
[359] Bauer, Meredith Rutland, "Quantum computing is coming for your data." *Wired,* July 19, 2017. https://www.wired.com/story/quantum-computing-is-coming-for-your-data/
[360] Kania, Elsa, "China's Trump Card," *Prospect,* October 23, 2017, https://www.prospectmagazine.co.uk/other/chinas-trump-card.

Fourth, on-going programs in quantum navigation and position offer an opportunity to navigate with greater accuracy in environments in which GNSS satellites are denied or degraded, which would improve capabilities of MaRVs and unmanned systems as well as targeting for HVPs.[361]

Other Advanced Weapons Systems-Related Conspicuous Successes
Quantum computing and encryption are not the only areas in which China has been able to achieve S&T success with relevance to its advanced weapons systems. Table 12 below provides several indicative examples.

Table 12: A partial list of S&T successes related to China's advanced weapons systems programs

Innovation	Description and Relevance to Advanced Weapons Systems Programs
Anti-ship ballistic missiles (ASBM)	China has established a viable but vulnerable ASBM capability, which is discussed further in the MaRV section. China's DF-21D and DF-26 are the only two ASBMs in service throughout the world.
Integrated Electronic Propulsion Systems (IEPS)	In June 2017, PLAN Rear Admiral Ma Weiming, a leading authority on naval electrical systems engineering, claimed in an interview with state broadcaster China Central Television that China now has a significant lead over U.S. and Western navies in the development of IEPSs.[362] According to Jane's, the claim that China has leap-frogged Western IEPS development to gain a significant lead appears to be based on the adoption of a DC power distribution system, rather than the AC system used in the Zumwalt- and Type 45 destroyers as well as the UK's Queen Elizabeth-class aircraft carriers.[363] A DC system would use a simpler single-voltage distribution and not need to condition and filter the power supply, adding efficiency.[364]
Unmanned System Swarm Test	In June of 2017, China's CETC set a record for the world's largest drone swarm, successfully testing a swarm of 119 drones. This beat a record previously held by the U.S. Air Force.[365]
World's Fastest Supercomputer	In June 2016, China tested the world's fastest supercomputer, the Sunway TaihuLight, which reportedly can make 93,000,000 calculations per second. The computer was made entirely in China with Chinese-made chips and is expected to be used to support big data analytics, among other tasks. Supercomputers have several military applications

[361] "Quantum positioning system steps in when GPS fails," New Scientist, May 14, 2014. https://www.newscientist.com/article/mg22229694-000-quantum-positioning-system-steps-in-when-gps-fails/
[362] Tate, Andrew, "China Navy Claims Lead in IEPS Development," *Jane's Defense Weekly,* June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.
[363] Tate, Andrew, "China Navy Claims Lead in IEPS Development," *Jane's Defense Weekly,* June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.
[364] *Jane's International Defense Review,* "China Heads for a Step Change in Naval Capabilities," November 3, 2017, http://janes.ihs.com/Janes/Display/FG_677078-IDR.
[365] Grevatt, Jon, "China Launches Record Breaking UAV Swarm," *Jane's Defense Weekly,* June 21, 2017. https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017.

	including modelling nuclear weapons and simulations, among others.[366]
Deep Diving Unmanned Underwater Vehicles (UUVs)	Since 2016, China has demonstrated a growing capacity to deploy UUVs that can dive to extreme depths of the ocean. In March of 2017, the Haiyi sea glider reached a depth of 6,239 meters, breaking the record for the deepest operating glider, previously held by a U.S. vessel.[367] Other Chinese submersibles (not gliders) have reached 10,000 meters, making China the third nation to have a submersible operate at that depth, behind only the United States and Japan.[368] China has also claimed to have collected the world's deepest seismic profile data in exploration of the Mariana Trench in February 2017.[369] These achievements are discussed in more depth later in this paper, but clearly the capacity to operate multiple types of unmanned vehicles at great undersea depths is a capability that China will leverage to address its perceived weakness in the undersea domain.
Hypersonic Wind Tunnel	China claims to have the world's largest hypersonic wind tunnel—the JF12 shockwave hypersonic wind tunnel, also known as the hyper-dragon. The wind tunnel covers 660 acres and is located 6 kilometers West of the Mianyang airport, Sichuan. It can test prototypes up to speeds of Mach 5-9. In May 2016, the American Institute of Aeronautics and Astronautics presented the 2016 Ground Testing Award to Chinese Academy of Sciences scientist Jiang Zonglin, who led China's R&D for the JF12.[370]

[366] Vincent, James, "Chinese Super Computer is World's Fastest—and Without Using U.S. Chips," *The Verge,* June 20, 2016. https://www.theverge.com/2016/6/20/11975356/chinese-supercomputer-worlds-fastes-taihulight.
[367] Chinese Academy of Sciences, "China's Underwater Glider Sets New World Record," *China Daily*, March 24, 2017. http://www.chinadaily.com.cn/china/2017-03/23/content_28653437.htm.
[368] Chinese Academy of Sciences, "10767 meters Below Sea Level China's Submersible Sets New Record," *Xinhua*, August 23, 2016. http://news.xinhuanet.com/english/2016-08/23/c_135627084.htm.
[369] *Chinese Academy of Sciences*, "China Acquires World's Deepest Seismic Prolife Data," March 7, 2017. http://english.cas.cn/head/201703/t20170307_174644.shtml.
[370] Dan, Jin, "AIAA Awards Chinese Scientist its Top Prize," *China Daily*, May 25, 2016. http://usa.chinadaily.com.cn/china/2016-05/26/content_25476138.htm.

Chapter 3: China, the Fourth Industrial Revolution and Artificial Intelligence

Chapter 3 Key Themes and Insights

- **China's Interest in the Fourth Industrial Revolution:** China seeks to exploit the Fourth Industrial Revolution and the technologies that are shaping it to serve as a hedge against economic and societal challenges; accelerate the transformation and reform of its defense industry; and allow its military to catch up; and even shift the nature of the military-technology competition with the United States. CETC's successful test of 119 drones in an autonomous swarm and advanced manufacturing initiatives such as CASICloud reveal China's progress.

- **Policy Prioritization:** The Made in China 2025 and Next Generation Artificial Intelligence Plan policies provide two examples of top-down guidance and, most importantly, investment in key technologies. They also signal China's intent to become a global leader in artificial intelligence by 2030 and to build increasingly advanced abilities in other Fourth Industrial Revolution capability areas over the next thirty years. As one professor at Zheijang University's College of Computer Science told *Forbes* magazine, "China is devoting a lot of strength, a lot of determination and a lot of money to AI."

- **China's Investment in the United States High-Tech Sector:** Chinese firms have spent some of this money referred to above to invest in U.S. AI start-ups in order to avoid scrutiny from the Committee on Foreign Investment in the United States (CFIUS), which does not currently cover joint ventures, minority stakes and early-stage investments. Chinese companies have reportedly invested $700 million across 51 U.S. AI companies with some of these companies having links to the U.S. military and other adjacent and strategically important government organizations.

- **China's Levers:** In addition to policy directives and investment, China has several other levers to further enhance its artificial intelligence abilities:
    - China's research and academic communities
    - The scale of data available to China's high-tech companies and researchers
    - A dynamic, opportunistic and highly-competitive indigenous high-tech market environment and entrepreneurial culture
    - Connections to Silicon Valley and the U.S. high-tech community
    - Talent recruitment, especially the repatriation of Chinese nationals from the U.S. high-tech industry and academic institutions
    - The lure of China's commercial market for U.S. and Western firms and capacity to force U.S. companies to share data collected in China

- **China versus the U.S.:** The U.S. currently retains overall global leadership in artificial intelligence, especially in core concepts. However, the velocity of China's progress and alignment of its many levers for further artificial intelligence advancement suggest this advantage will be challenged, first in specific applications of artificial core concepts and then in the game-changing core concepts themselves.

Made in China 2025

China has developed an ambitious program to become a world leader in Fourth Industrial Revolution technologies over the coming decade and beyond. The core of this plan is the government's "Made in China 2025" program, which was introduced in 2015. According to China's State Council, the Made in China 2025's objective is to transform the country from a "manufacturing giant" into the "world's manufacturing power" in which China will lead a range of industries, many of which are closely aligned with aerospace and defense.[371]

While the current iteration of the Made in China 2025 program sets ambitious targets for industry to achieve by 2025, the plan is only the first of three phases designed—in conjunction with China's broader industry reforms discussed above—to drive innovation, collaboration and supply chain management out to 2049.

Within China's aerospace and defense sector and advanced weapons systems industry, CASIC is taking the lead in developing Made in China 2025 mechanisms and capabilities. Most significant is CASIC's emphasis on using cloud manufacturing and smart manufacturing to enhance engagement with China's non-state-owned enterprise and private industry, and to increase efficiency of supply chain management.[372] Such advances are also expected to benefit advanced weapons development, albeit indirectly.

The focus on facilitating such engagement was highlighted by a CASIC announcement in May 2016 about a plan to channel a greater scope of work to suppliers.[373] In that statement, CASIC said this outsourcing program would cover contracts worth RMB 43 billion ($6.31 billion), although the corporation did not specify a timeframe. It also stated that the program would focus on integration with suppliers through a web-based portal set up by the corporation in 2015 called CASICloud.com.[374] The portal promotes cloud manufacturing and seeks to utilize cloud computing technologies for a range of manufacturing applications and related services. Citing CASIC, the state-run newspaper *China Daily* reported in June 2017 that the CASICloud.com initiative had attracted 800,000 companies, including 3,000 foreign companies, with more than 90% being small, privately-owned firms.[375]

Analysis of open-source information suggests that CASICloud places CASIC at the forefront of developments of Fourth Industrial Revolution initiatives in the defense industry, though other defense industrial state-owned companies such as AVIC, CASC and CETC are also engaged, supported in some cases by strong links with foreign companies and agencies.

For instance, French company Dassault Systems formed an alliance in 2017 with AVIC to create an "innovation center" that will support the development of robots, 3-D printers and "other new production technologies." The center will also be made available to "companies, research institutes and students." Dassault is expected to provide software for this new facility.[376]

CASC, meanwhile, has made investments in supporting the development of new technologies for

[371] Grevatt, Jon, "Briefing: China on The Brink of Industry 4.0 Revolution," *Jane's Defense Weekly*, September 19, 2017. https://janes.ihs.com/Janes/Display/FG_646326-JDW.
[372] State Council of the People's Republic of China, "Joint Efforts to Implement Made in China 2025," English.gov.cn. http://english.gov.cn/premier/news/2017/02/15/content_281475568073500.htm.
[373] CASIC, "China Aerospace Science and Industry Will Release over 40 Billion Collaborative Procurement Requirements in Aerospace Cloud [中国航天科工将在航天云网发布超 400 亿协作采购需求,]," April 9, 2016. http://www.casic.com.cn/n103/n133/c2597167/content.html.
[374] Lei, Zhao, "Cloud to Aid Aerospace Manufacturing," *China Daily,* June 17, 2017. http://www.chinadaily.com.cn/china/2017-06/17/content_29782208.htm.
[375] Lei, Zhou, "Cloud to Aid Aerospace Manufacturing," *China Daily,* June 17, 2017. http://usa.chinadaily.com.cn/china/2017-06/17/content_29782244.htm.
[376] Protais, Marine "Dassault Systems Will Create an Innovation Center in China with AVIC," *L'Usine Nouvelle*, June 21, 2017, https://www.usinenouvelle.com/editorial/bourget-2017-dassault-systemes-va-creer-un-centre-d-innovations-en-chine-avec-avic.N556158.

rockets (in collaboration with research centers, academia and industry) as part of CASC's CMI activities.[377] CASC has also engaged Russia on collaborating in areas including information technologies, automatic control systems and new materials.[378]

CETC's efforts to capitalize on Fourth Industrial Revolution technologies include entering into the above-referenced agreement with the University of Technology Sydney to pursue research into areas such as advanced materials and electronics, AI, big data, quantum computing as well as simultaneous localization and mapping systems.[379]

Figure 13: The header from the University of Technology Sydney Website for the page describing the Australia China Research Innovation Centre in Information and Electronics Technology

Source: University of Technology Sydney

In addition to supporting China's aerospace and defense industry, China's defense industrial restructuring is geared to support the development of Fourth Industrial Revolution initiatives. This is intended to be achieved through optimizing industrial processes, which, in turn, is intended to spur innovation. The most recent example of this strategy is CETC's announcement in September 2017 that it aims to accelerate industrial restructuring in order to "optimize [the] corporate structure and encourage innovation." It is notable that this is a major undertaking, with CETC already integrating 19 research institutes into seven.[380]

Additionally, the MIIT announced in October that "local authorities" would allocate at least RMB 10 billion ($1.5 billion) towards projects to boost sectors including "manufacturing innovation, including the Internet of Things, smart appliances and high-end consumer electronics." In addition, the MIIT has said it will also cooperate with China Development Bank to provide "Made in China 2025" projects with "loans, bonds, leasing to support" worth about RMB 300 billion ($45.2 billion) during the 2016-2020 period.[381]

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377 *Jane's*, "China's CASC Inaugurates Military Rocket Innovation Centre," January 13, 2017, http://janes.ihs.com/Janes/Display/1793509.
378 Rostec, "Rostec Signs Agreement with China Aerospace Science and Technology Corporation," October 14, 2014, http://rostec.ru/en/news/4514812.
379 UTS, "UTS to Launch Centre in China to Promote Research and Commercialization," C December 14, 2016, http://newsroom.uts.edu.au/news/2016/12/uts-launch-centre-china-promote-research-and-commercialisation.
380 Si, Ma, "CETC Speeds Reform Efforts," *China Daily,* September 16, 2017, http://europe.chinadaily.com.cn/business/2017-09/16/content_32069943.htm.
381 *Xinhua*, "China to Invest Big in 'Made in China 2025' Strategy," October 12, 2017, http://english.gov.cn/state_council/ministries/2017/10/12/content_281475904600274.htm.

Artificial Intelligence

China has become increasingly invested and competitive in AI technologies. While it has not yet caught or surpassed the United States in technological capability or scientific theory, China has become an important and powerful center of gravity, shaping the future of AI development, especially applications. This growing competitiveness has been brought about in part by the government prioritization and funding of this technology, the accelerating velocity of China's research on AI, an aggressive talent acquisition effort and a culture of entrepreneurship that drives competition and innovation.

Policy Priority

The PLA reportedly first became interested in AI in the spring of 2016 after witnessing the computer program AlphaGo defeat international champion Lee Sedol in the ancient Chinese game *weiqi* "Go."[382] On April 20, 2016 President Xi gave a speech to the Central Military Commission in which he called on the commission to advance integration of advance technologies such as big data, cloud computing, and AI.[383] China's State Council has released several plans and programs that either mention AI or touch on one component or application of AI, including:

- Made in China 2025 (May 2015)
- Internet Plus (June 2015)
- 13th Five Year Plan (March 2016)
- "Internet Plus" Artificial Intelligence Three-Year Action Plan (May 2016)[384]
- Next Generation Artificial Intelligence Development Plan (July 2017)

Collectively these policy initiatives have provided a sharpening focus for the range of companies across various industry verticals in China (i.e., high-tech, aerospace and defense, communications, automotive, healthcare, etc.) with interests in AI and guidance for the sizable public and private sector investments being made in AI across these industries.

Wu Fei, a professor at Zheijiang University's College of Computer Science, effectively captured the robust emphasis China's government has placed on AI, as well as how this emphasis is translating at a broad level into funding for AI-related programs. According to Wu, "China is devoting a lot of strength, a lot of determination and a lot of money to AI. Science budgets are growing by

> *"China is devoting a lot of strength, a lot of determination and a lot of money to AI. Science budgets are growing by leaps and bounds in recent years, and the investment and support are indeed much better than abroad."*
>
> *– Wu Fei, professor at Zheijiang University's College of Computer Science*

[382] Kania, Elsa, "Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power," Center for a New American Security. November 2017. P.15
[383] CMC Joint Staff Department [中央军委联合参谋部], "Accelerate the Construction of a Joint Operations Command System with Our Nation's Characteristics—Thoroughly Study Chairman Xi's Important Sayings When Inspecting the CMC Joint Operations Command Center [加快构建具有我军特色的联合作战指挥体系—— 深入学习贯彻习主席视察军委联指中心时的重要讲话], *Qiushi* [求是], August 15, 2016, http://www.qstheory.cn/dukan/qs/2016-08/15/c_1119374690.htm.
[384] National Development and Reform Commission, *"Internet Plus" Artificial Intelligence Three-Year Action Plan*, May 2016, Translation. http://www.sdpc.gov.cn/gzdt/201605/W020160523589036011904.pdf.

leaps and bounds in recent years, and the investment and support are indeed much better than abroad."[385]

Examples of the scale of funding being made available for AI projects are becoming more prominent. Funding for the HeGaoJi initiative is one such example. Originally unveiled in 2009, the program is expected to receive more than $15 billion by 2020–over $1 billion per year—to develop better chips and computing software.[386]

On November 1, 2017, the Sunshine Insurance Group, a state-backed fund focused on investments in the insurance industry rather than technology, led a group of six investors[387] in making a $460 million investment in Beijing-based facial recognition start-up Megvii.[388] This is the largest amount of funding raised for any AI company, surpassing the $410 million raised by SenseTimeGroup, another Chinese facial recognition company in July 2017.[389] Previously, in December 2016, Megvii received $100 million in series C funding from Sinovation Ventures, a high-profile Beijing-based venture capital firm that invests in AI projects in the United States and China (and is discussed below).[390]

The most notable and ambitious of the policy initiatives referenced in the above list is the Next Generation Artificial Intelligence Development Plan. Released by the State Council in July 2017, the plan lays out the value China sees in the technology and serves to establish a comprehensive plan with measurable milestones to rapidly surpass the United States and become the global leader in the field.[391] As Andrew Ng, co-founder of Coursera and Google Brain and later the chief scientist at China's technology giant Baidu, noted in October 2017, "When the Chinese government announces a plan like this, it has significant implications for the country and the economy. It's a very strong signal to everyone that things will happen."[392]

China's Rapid Robotization

In addition to China's growing investment and interest in artificial intelligence, the country has also invested heavily in robotics. In August 2017, Bloomberg Intelligence claimed China bought 90,000 robots in 2016, accounting for almost one-third of the global total as part of an effort to "raise China's economic competitiveness." China also produced 72,400 industrial robots in 2016, up 34.3% year-on-year. The report also cites numbers from the International Federation of Robotics that China is expected purchase 160,000 robots in 2019. Sales are expected to reach RMB 50 billion ($7.26 billion) in 2020, "all in accordance to Made in China 2025."

Setting up a robust robotic infrastructure in sectors such as manufacturing and health will enable China to capitalize on breakthroughs in AI as they develop.

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[385] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017, https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.
[386] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017. https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.
[387] Crunchbase database, Megvii entry, https://www.crunchbase.com/organization/megvii
[388] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017. https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.
[389] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017. https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.
[390] Crunchbase database, Megvii entry, https://www.crunchbase.com/organization/megvii.
[391] State Council of the People's Republic of China, "*Next-Generation Artificial Intelligence Development Plan* [新一代人工智能发展规划的通知]," July 20, 2017, Translation. http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm.
[392] Knight, Will, "China's AI Awakening," *MIT Technology Review,* October 10, 2017. https://www.technologyreview.com/s/609038/chinas-ai-awakening/.

The plan includes three stages to be executed between 2017 and 2030. The relatively short timeline of the plan—by comparison the Made in China 2025 plan also includes three stages covering a period from 2015 to 2049—underscores current perceptions of the health and competitiveness of China's AI research and industry efforts. Perhaps more importantly, the timeline and plan reveal the multi-layered natured of China's acute interest in AI.

Economic Motivations: AI has the potential to transform nearly all aspects of modern life. China will look to AI to serve at first as a hedge against the potentially cascading fiscal and societal challenges that result from structural economic challenges as well as labor force issues stemming from China's ageing population and "left behind" children in the rural areas, a topic discussed in Chapter 1 of this report. The plan also reveals that China also views AI as a fundamental engine of economic transformation, especially in conjunction with other Fourth Industrial Revolution advances and investments such as those being made in industrial automation in line with the Made in China 2025 (see text box above's discussion on China's robotization[393]).

Prestige and National Development Motivations: According to the Next Generation Artificial Intelligence Development Plan, countries that "occupy the commanding heights of artificial intelligence"[394] will accrue geopolitical and economic power and influence. Furthermore, development of China's AI capability is likely to have salutary knock-on benefits for other areas of China's national development. For example, the capacity to leverage machine learning, voice and facial recognition, translation, video analysis and other AI-enabled capabilities could lead to the development and broad adoption of relevant, faster, more efficient and possibly culturally and societally transformational social media, commercial and governance applications.

National Security and Defense Motivations: AI is certain to feature more prominently on the future battlefield as militaries seek to find means of dealing with complex and fast-moving operational environments and the explosion of information available to operators and decision-makers.

> *"China hopes to leap-frog the U.S. and other Western countries by vast and fast investment in the AI industry,"*
>
> *Hongbin Zha, AI researcher and professor at Beijing's Peking University*

Drone swarms are one prominently discussed application of AI on the battlefield. Individuals within China's weapons programs development community are already planning for this future. According to Wang Changqing, director of the General Design Department of the Third Academy of CASIC, China's "future cruise missiles will have a very high level of AI and automation. They will allow commanders to control them in a real-time manner, or to use a fire-and-forget mode, or even to add more tasks to in-flight missiles."[395]

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393 *Xinhua*, "China to Upgrade Robot Industry in Next Few Years," *Xinhua*, April 6, 2017, http://www.chinadaily.com.cn/china/2017-04/06/content_28823494.htm.

394 State Council of the People's Republic of China, "Next-Generation Artificial Intelligence Development Plan [新一代人工智能发展规划的通知]," July 20, 2017, Translation. http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm; State Council of the People's Republic of China, "The State Council on the Issuance Notice of the Next Generation of Artificial Intelligence Development Plan," http://english.gov.cn/policies/latest_releases/2017/07/20/content_281475742458322.htm.

395 Lei, Zho, "Next Generation of Missiles to be Highly Flexible," *China Daily,* August 19, 2016. http://www.chinadaily.com.cn/china/2016-08/19/content_26530461.htm.

AI will be a powerful force multiplier for the PLA, allowing it to stay ahead of the disruptive changes intelligent weapon systems will bring to warfare. This will especially be the case if China surpasses the United States in developing AI,[396] a possibility that should be considered, given China's ambition, resources, technology and talent acquisition approaches and other structural advantages discussed below. The ambition is certainly there. As Hongbin Zha, an AI researcher and professor at Peking University, noted: "China hopes to leap-frog the United States and other Western countries by vast and fast investment in the AI industry."[397]

Gaining advantage in this space is seen by many militaries, including the U.S. military, as vital to success on the future battlefield even if understanding the nature of an adversary's development in AI will be very difficult. Former Deputy Secretary of Defense Robert Work touched on the importance of AI and the potential risks of algorithm-driven combat in a May 2017 speech to the U.S. DoD Applied Physics Lab: "Surprise is going to be endemic because a lot of the advances that the other people are doing on their weapons systems, we won't see until we fight them. And if they have artificial intelligence then that's better than ours, that's going to be a bad day."[398]

Societal Engineering and Management: One area of application of AI that has drawn interest from China's leadership is the broad area of "social management." Meng Jianzhu, head of the CCP's Central Commission for Political and Legal Affairs, summarized the CCP's interest in AI designed to help better understand, shape and, critically, capture and track individual and societal behaviors, stating in September 2017 that: "Artificial intelligence can complete tasks with a precision and speed unmatchable by humans, and will drastically improve the predictability, accuracy and efficiency of social management."[399]

Phase 1 (2017–2020)
The plan's first phase runs from 2017 to 2020 and stresses the need for China's AI research to keep pace in development at an "advanced level." It singles out advances in big data, swarm intelligence, autonomy and hybrid intelligence. On the commercial side, the plan calls for China's artificial-related business to reach $22 billion and the size of China's AI-related fields to be $148 billion.[400]

Phase 2 (2020–2025)
The plan's second phase, which runs to 2025, envisions that China will achieve a leading level in AI research, at parity with other global leaders. During this time period, AI will become the main driver of China's economic transformation and begin to serve as an engine of growth. China's AI related business will reach $59 billion, a nearly 270% expansion of the market within China over five years, and AI-related fields in China will be worth $740 billion, five times higher than the estimate for 2020. A key component of phase two development is a focus on developing governance, legal, ethical and

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[396] Kania, Elsa. "China May Soon Surpass America on the Artificial Intelligence Battlefield," *The National Interest*, February 21, 2016. http://nationalinterest.org/feature/china-may-soon-surpass-america-the-artificial-intelligence-19524?page=2.
[397] Zhou, Adelyn, "These 20 Leading Technologists are Driving China's AI Revolution," *Forbes,* June 21, 2017, https://www.forbes.com/sites/adelynzhou/2017/06/21/chinese-leaders-in-artificial-intelligence/2/#39ec77287568.
[398] Freedberg, Sydney J., "War Without Fear: DEPSECDEF Work on How AI Changes Conflict," *Breaking Defense,* May 31, 2017. https://breakingdefense.com/2017/05/killer-robots-arent-the-problem-its-unpredictable-ai/.
[399] Mortimer, Caroline, "China's Security Boss Planning to Use AI to Stop Crime Before It Even Happens," *Independent,* 22 September 2017. http://www.independent.co.uk/news/world/asia/china-ai-crimes-before-happen-artificial-intelligence-security-plans-beijing-meng-jianzhu-a7962496.html.
[400] State Council of the People's Republic of China, "Next-Generation Artificial Intelligence Development Plan [新一代人工智能发展规划的通知]," July 20, 2017, Translation.http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm; Kania, Elsa, "China's Artificial Intelligence Revolution," *The Diplomat*, July 27, 2017. https://thediplomat.com/2017/07/chinas-artificial-intelligence-revolution/

regulatory guidelines to facilitate the dramatic increase in incorporation of AI into all aspects of life in China, including national defense and security.[401]

Phase 3 (2025–2030)
The final phase concludes in 2030. Over the final five years of the plan, China will become the premier innovation center capable of achieving major breakthroughs in R&D to "occupy the commanding heights of AI technology." In addition, AI use will be embedded in more industries and domains, including national defense. The plan sets targets for China's AI industry to reach $148 billion (RMB 1 trillion) with AI-related fields growing to $1.48 trillion (RMB 10 trillion). Phase three will also see the establishment of global leading training bases, highlighting China's prioritization of recruiting and retaining key workforce talent.[402]

Jane's has summarized key elements of the plan in the table below:

Table 13: Next Generation Artificial Intelligence Development Plan's Key Development Milestones and Focus Areas

Phase	R&D Status	Technology Area Focus	Economic Relevance	Industry Size	Governance	Training & Recruitment
Phase One	Keeping Pace at an Advanced Level	Swarm, big data, hybrid and enhanced intelligence	Supporting economic growth	**Industry:** 150 billion RMB ($22.65 billion) **Related Activities**: 1 trillion RMB ($151 billion)	Framework for laws, etc.	Advanced in talent identification and recruitment
Phase Two	Leading level in R&D	Expand use in more domains ranging from manufacturing to national defense	Primary engine of economic transformation	**Direct Industry:** 400 billion RMB ($60.4 billion) **Related Activities:** 5 trillion RMB ($755 billion)	Achieved progress in the creation of laws and regulations	Advanced in talent identification and recruitment
Phase Three	World's premier innovation center	Even broader and deeper incorporation in national defense	Transformed economy	**Direct Industry:** 1 trillion RMB ($151 billion) **Related Activities:** 10 trillion RMB ($1.51 trillion)	Comprehensive regulatory framework	Training center leader

Source: **Compiled by Jane's.**

Artificial Intelligence Talent Training and Recruitment
Among the main vulnerabilities of any S&T-related development program (whether it is in China or elsewhere) is the capacity of organizations to recruit and retain the talent to drive innovation and

[401] State Council of the People's Republic of China, "Next-Generation Artificial Intelligence Development Plan [新一代人工智能发展规划的通知]," July 20, 2017, Translation. http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm; Kania, Elsa, "China's Artificial Intelligence Revolution," *The Diplomat*, July 27, 2017. https://thediplomat.com/2017/07/chinas-artificial-intelligence-revolution/.

[402] State Council of the People's Republic of China, "Next-Generation Artificial Intelligence Development Plan [新一代人工智能发展规划的通知]," July 20, 2017, Translation. http://www.gov.cn/zhengce/content/2017-07/20/content_5211996.htm; Kania, Elsa, "China's Artificial Intelligence Revolution," *The Diplomat*, July 27, 2017. https://thediplomat.com/2017/07/chinas-artificial-intelligence-revolution/.

entrepreneurship in novel technologies and applications. Demand frequently outstrips supply, a dynamic that definitely applies to the AI space. Chinese high-tech giant Tencent's 2017 AI Talent White Paper found that there are 300,000 AI researchers and practitioner worldwide, but the demand is for several million.[403] And this statistic only provides the broad parameters of the problem: there are fewer than 1,000 people capable of steering the direction of AI research and development globally. The U.S. has approximately 46% of the available pool of talent while China has roughly 20 universities performing AI research, all of which are newer to AI research than many of the more advanced universities in the U.S.[404]

Even in the U.S., AI talent is still in high-demand as more companies both within the high-tech industry and in adjacent industries, such as automotive, with a nascent interest in autonomy and other AI applications, compete for talent. The *New York Times* reported in October 2017 that "typical AI specialists, including both Ph.D.'s fresh out of school and people with less education and just a few years of experience, can be paid from $300,000 to $500,000 a year or more in salary and company stock in order to cope with this potential constraint."[405] Companies with deeper pockets and more compensation levers have an advantage in this competition.

China's Next Generation Artificial Intelligence Development Plan concentrates considerable energy on the need to address the talent gap by not only identifying and engaging S&T talent, but also by establishing China as a training center for future generations of AI-related talent and thereby creating a self-sustaining pipeline of future AI talent.

In the short-term, China has sought to fix its existing AI talent gap problem through recruitment of skilled Chinese citizens from abroad with experience and expertise in AI-related fields to support industry development. Some notable examples include:

- Baidu recruited Andrew Ng away from Google in 2014 to "oversee and expand its research in AI based in the Silicon Valley." Ng left Baidu in 2017.[406]

- Baidu also recruited Lin Yuanqing, the former head of the Media Analytics Department at NEC Labs America, to run its Institute of Deep Learning.[407]

- Baidu's chief scientist is Xu Wei, who has worked for U.S. companies, including Facebook where he reportedly worked on the algorithm for Facebook's recommendation system.[408]

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[403] Chen, Celia, "China's AI dreams stymied by shortage of talent, with the US home to lion's share of experts", *South China Morning Post,* December 1, 2017, http://www.scmp.com/tech/innovation/article/2122488/chinas-ai-dreams-stymied-shortage-talent-us-home-lions-share-experts A Chinese-language version of the whitepaper can be accessed at http://www.tisi.org/Public/Uploads/file/20171201/20171201151555_24517.pdf.
[404] Chen, Celia, "China's AI dreams stymied by shortage of talent, with the US home to lion's share of experts", *South China Morning Post,* December 1, 2017, http://www.scmp.com/tech/innovation/article/2122488/chinas-ai-dreams-stymied-shortage-talent-us-home-lions-share-experts; A Chinese-language version of the White Paper can be accessed at http://www.tisi.org/Public/Uploads/file/20171201/20171201151555_24517.pdf.
[405] Metz, Cade, "Tech Giants Are Paying Huge Salaries for Scarce A.I. Talent," *New York Times,* October 22, 2017, https://www.nytimes.com/2017/10/22/technology/artificial-intelligence-experts-salaries.html.
[406] He, Yujia, "How China Is Preparing for an AI-powered Future," *Wilson Briefs,* June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.
[407] He, Yujia, "How China Is Preparing for an AI-powered Future," *Wilson Briefs,* June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.
[408] Wei Xu's Linkedin Profile: https://www.linkedin.com/in/emailweixu.

- Ya-Qin Zhang, former corporate vice president and chairman of Microsoft's Asia-Pacific R&D group left to join Baidu as the president of technology, emerging business and global business operations.[409]

- Qi Lu, former executive vice president at Microsoft joined Baidu in 2017 as the chief operating office for the company's new $200 million fund for AI, AR and deep learning.[410]

- Dr. Yu Dong was selected by Tencent to head its new AI lab in Seattle which will focus on speech recognition and natural language processing. Dr. Dong is one of the leading researchers in speech recognition and was the first to apply deep learning to it.[411]

Many of these repatriated individuals were included in a June 2017 list published by *Forbes* of the 20 leading technologists driving China's AI revolution; a list that demonstrates the scale and impact of the repatriation of AI scientists and entrepreneurs from the United States to China. Eight of the top 10 named individuals had professional and/or educational links to the United States in the biographical profiles provided by *Forbes*. Overall, 16 of the 20 listed individuals had previous educational and/or professional experience in the United States, Japan or Western Europe.[412]

Table 1 below lists the range of U.S.-based commercial and academic organizations individuals on the *Forbes'* Top 20 Chinese AI technologists have been affiliated with during their careers.

Table 14: List of U.S. companies and universities with which individuals on a recent list of 20 top technologists driving China's artificial revolution had professional or academic affiliation prior to returning to China or joining a Chinese technology company

Commercial	Educational
Microsoft	Columbia University
Apple	Carnegie Mellon University
Google	University of Minnesota
IBM	University of Michigan
NEC Labs America	University of Pennsylvania
Facebook	University of Idaho
Yahoo	Rutgers
	Stanford University

Given the fierce global competition for AI talent, some participants in the October 2017 Implications Workshop believed that changing U.S. immigration and visa policies could incentivize Chinese graduate students and post-doctoral students specializing in AI to stay in the United States rather than returning home. One participant in Jane's October Workshop pointed out the disconnect between a policy that freely grants student visas, making it easy for individuals to learn in the United States, but difficult to stay due to cutbacks on H-1B visas. [413]

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[409] *Baidu,* "Ya-Qin Zhang," http://ir.baidu.com/phoenix.zhtml?c=188488&p=irol-govBio&ID=239174.
[410] CNBC, "Baidu Names Former Microsoft Exec as COO in Artificial Intelligence Push," January 17, 2017, https://www.cnbc.com/2017/01/17/baidu-names-former-microsoft-exec-as-coo-in-artificial-intelligence-push.html.
[411] *PR Newswire,* "Tencent Appoint Dr. Yu Dong as AI Lab Deputy Director and Opens New AI Lab in Seattle," May 2, 2017, https://www.prnewswire.com/news-releases/tencent-appoints-dr-yu-dong-as-ai-lab-deputy-director-and-opens-new-ai-lab-in-seattle-300449405.html.
[412] Zhou, Adelyn, "These 20 Leading Technologists are Driving China's AI Revolution," *Forbes,* June 21, 2017, https://www.forbes.com/sites/adelynzhou/2017/06/21/chinese-leaders-in-artificial-intelligence/2/#39ec77287568.
[413] Jane's Implications and Recommendations Workshop, October 5, 2017, IHS Markit office, Washington, D.C.

In addition, Chinese firms have used investment in U.S. AI start-ups to try to avoid scrutiny from the Committee on Foreign Investment in the United States (CFIUS). Joint ventures, minority stakes and early-stage investments are currently not under the scope of CFIUS' review.[414] According to the research firm CB Insights, Chinese companies have invested $700 million across 51 U.S. AI companies.[415] And some of the companies targeted by this investment have direct links to the U.S. military and other adjacent and strategically important government organizations. For example, China's Haiyin Capital, a "government-linked fund," invested $1.2 million in Boston-based Neurala, an AI start-up that has "licensed its mapping and navigation software to NASA and the U.S. Air Force."[416]

Research Volume

Another noticeable manifestation of China's rapid rise as an AI power is the marked increase in the number of academic papers authored by Chinese researchers on these issues, either in support of global AI conferences or published in scientific journals. For example, at the 2017 Association of Advanced Artificial Intelligence meeting, the number of accepted conference papers authored by researchers based in China was roughly equal to those from authors based in the United States, a development described by the Association of Advanced Artificial Intelligence chief as "impressive given how different it was even three, four years back."[417]

In October 2016, the Obama Administration's Office of Science and Technology Policy found that China had overtaken the United States as the leader in the number of journal articles and the number of publications cited at least once on "deep learning," a type of AI.[418] The number of Chinese publications on deep learning has increased rapidly from roughly 50 in 2013 to 350 in 2015, overtaking the United States in 2014. Chinese researchers also surpassed the United States in the number of publications on deep learning cited at least once, with more than 80 in 2015 compared with the United States at around 70.[419] As Kai Fu-Lee,[420] a Taiwanese-born AI researcher, former head of Google China, and current chairman and chief executive officer of Sinovation Ventures,

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[414] Stewart, Phil, "U.S. Weighs RestrictingR Chinese Investment in Artificial Intelligence," *Reuters*, June 13, 2017, https://www.reuters.com/article/us-usa-china-artificialintelligence/u-s-weighs-restricting-chinese-investment-in-artificial-intelligence-idUSKBN1942OX.

[415] Cosgrave, Paddy, "Confidence in US Innovation Falling; China Leads Way on AI," *Asia Times*, July 8, 2017, http://www.atimes.com/article/confidence-us-innovation-falling-china-leads-way-ai/.

[416] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017, https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.

[417] Zhang, Sarah, "China's Artificial Intelligence Boom," *The Atlantic*, February 16, 2017. https://www.theatlantic.com/technology/archive/2017/02/china-artificial-intelligence/516615/.

[418] National Science and Technology Council, Networking and Information Technology Research and Development Subcommittee, *The National Artificial Intelligence Research and Development Strategic Plan*, October 2016, 13. https://obamawhitehouse.archives.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/national_ai_rd_strategic_plan.pdf.

[419] National Science and Technology Council, Networking and Information Technology Research and Development Subcommittee, *The National Artificial Intelligence Research and Development Strategic Plan*, October 2016, 13. https://obamawhitehouse.archives.gov/sites/default/files/whitehouse_files/microsites/ostp/NSTC/national_ai_rd_strategic_plan.pdf.

[420] Kai-Fu Lee was ranked as the number one most important figure shaping the future of China's artificial intelligence industry by *Forbes* in June 2017. He previously established Google China and currently leads a venture capital firm funding artificial intelligence projects in both the U.S. and China. *Forbes* describes him as having "celebrity status" and notes that he has over 50 million followers on Chinese social media networks. Zhou, Adelyn, "These 20 Leading Technologists are Driving China's AI Revolution," *Forbes,* June 21, 2017, https://www.forbes.com/sites/adelynzhou/2017/06/21/chinese-leaders-in-artificial-intelligence/2/#39ec77287568

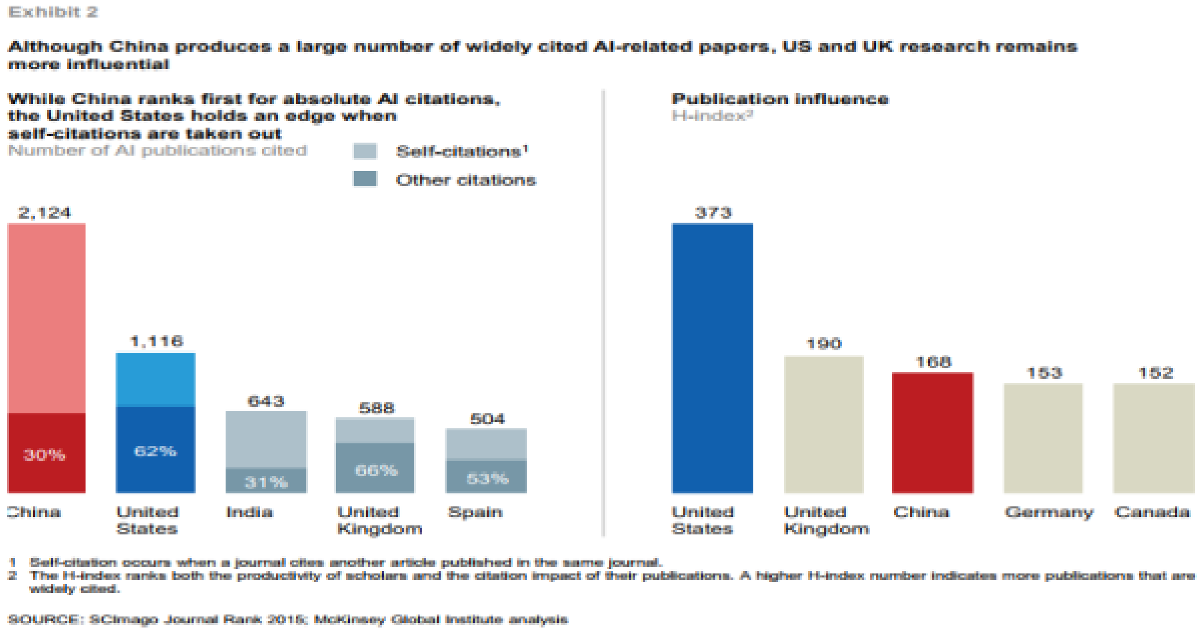
assessed in early 2017: "It is indisputable that Chinese authors are a significant force in AI and their position has been increasing drastically in the past five years."[421]

Quantity versus Quality and Impact

One caveat associated with China's steep rise in the volume of research on AI is that quantity of research does not necessarily translate into leadership in quality or impact (see Figure 14). Based on data from the Scmago Journal Rank's 2015 database, a McKinsey Global Institute report entitled *Artificial Intelligence: Implications for China* assessed that China has nearly twice as many absolute citations on AI than the United States, just over three times as many as India and nearly four times as many as the United Kingdom.[422] However, when this data is adjusted for self-citations—when a journal publishes an article that cites another article in the same journal, a practice that could conflate a given article or research community's actual influence—China's influence is diminished. Only 30% of citations of Chinese articles on AI in 2015 were not self-citations as opposed to 62% of non-self-citations associated with U.S.-authored articles.[423]

Similarly, the report also attempts to measure influence through a metric known as the H-index, which ranks both the productivity of scholars and the citation impact of their publications. Here again, the U.S. score is approximately twice that of China, which is ranked third behind the United States and United Kingdom.[424]

Figure 14: Graphs included in the April 2017 McKinsey Global Institute paper on China's artificial intelligence research activities and broader implications of artificial intelligence for China.



Source: McKinsey Global Institute

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[421] Markoff, John and Rosenberg, Matthew, "China's Intelligent Weaponry Gets Smarter," *New York Times*, February 3, 2017. https://www.nytimes.com/2017/02/03/technology/artificial-intelligence-china-united-states.html.

[422] McKinsey Global Institute, "Artificial Intelligence: Implications for China," Paper presented at the 2017 China Development Forum, April 2017. https://www.mckinsey.com/global-themes/china/artificial-intelligence-implications-for-china.

[423] McKinsey Global Institute, "Artificial Intelligence: Implications for China," Paper presented at the 2017 China Development Forum, April 2017. https://www.mckinsey.com/global-themes/china/artificial-intelligence-implications-fo r-china.https://www.mckinsey.com/global-themes/china/artificial-intelligence-implications-for-china.

[424] McKinsey Global Institute, "Artificial Intelligence: Implications for China," Paper presented at the 2017 China Development Forum, April 2017. https://www.mckinsey.com/global-themes/china/artificial-intelligence-implications-for-china.

Other more subjective assessments of the relative quality of United States versus China AI research focus on the differences between innovation in foundational and core concepts and applications of those concepts. According to Ng; "The very clever ideas on changing network architecture, I see those in the U.S.," but China's researchers have been effective in their capacity to then take those concepts and develop applications for their use.[425]

Zha Hongbin, a professor of machine intelligence at China's Peking University, made a similar appraisal, highlighting the current pressure in China to rush to "write algorithms to parse various data sets" rather than innovate in ways to teach machines to behave like "sentient humans," an area in which "the U.S. still leads."[426]

Ultimately, China's recent steep curve in the volume of research on, and overall activity in AI, reveals impressive leaps forward in the field and the creation of a new center of gravity for AI research, even if China has not yet fully closed the gap on the United States.

Kai-Fu Lee offered perhaps the most trenchant analysis of the current relative maturity of Chinese and U.S. AI research through use of a chess analogy: "We might say that grandmasters are still largely North American, but Chinese occupy increasingly greater portions of the master-level A.I. scientists."[427]

Commercial Velocity: Leveraging Scale and Culture
China is also well-positioned for continued growth due to the scale of its domestic market and a culture of opportunistic entrepreneurship that combine to drive an impressive velocity of commercial activity in AI.

Kai-Fu Lee believes that China has several conditions that will enable it to become a "critical hub in the global development of AI": a large talent pool, companies with extensive money to invest in AI, the largest internet market in the world and barriers for outsiders to enter, but also marked by an openness for Chinese companies to explore.[428]

For China's high-tech companies, such as Baidu, Alibaba and Tencent (collectively known as "BAT"), the sheer scale of their home market—and the amount of data that can be collected from that market—provides a key advantage to designing AI applications and technologies.

The Economist notes that "no other country could generate such volume of data to enable machine learned patterns" and estimates that China has over 700 million smart phone users.[429] Tencent claimed its WeChat messaging app had 963 million active monthly users at the end of the second quarter of 2017.[430] These users reveal their preferences and demonstrate common behaviors on a

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[425] Zhang, Sarah, "China's Artificial Intelligence Boom," *The Atlantic*, February 16, 2017. https://www.theatlantic.com/technology/archive/2017/02/china-artificial-intelligence/516615/.
[426] Wang, Yue, "Will the Future of Artificial Intelligence Look Chinese," *Forbes,* November 6, 2017. https://www.forbes.com/sites/ywang/2017/11/06/will-the-future-of-artificial-intelligence-look-chinese/#695ad9237fdc.
[427] Markoff, John and Rosenberg, Matthew, "China's Intelligent Weaponry Gets Smarter," *New York Times*, February 3, 2017. https://www.nytimes.com/2017/02/03/technology/artificial-intelligence-china-united-states.html.
[428] Kai-Fu, Lee, "This is Why China Has the Edge in Artificial Intelligence," *World Economic Forum*, January 12, 2017, https://www.weforum.org/agenda/2017/01/this-is-why-china-has-the-edge-in-ai/.
[429] *The Economist*, "Why China's AI Push is Worrying," July 27, 2017. https://www.economist.com/news/leaders/21725561-state-controlled-corporations-are-developing-powerful-artificial-intelligence-why-chinas-ai-push.
[430] Boxall, Andy, "WeChat Reaches 963 Million Monthly Active Users; Prepares to Reach a Billion in 2017," *Business of Apps*, August 23, 2017. http://www.businessofapps.com/wechat-reaches-963-million-monthly-active-users-prepares-to-pass-a-billion-in-2017/.

minute-by-minute basis as they surf, download, buy and otherwise engage with phones and apps, all being captured by Tencent and used, with few if any governmentally enforced privacy restrictions, to support AI development.

China's commercial AI activity also benefits from what a participant in Jane's Implications Workshop called a new culture of "aggressive entrepreneurship"[431] that has generated considerable competition across China's high-tech sector as well as other sectors for which development of AI is ever more important.

In defense and adjacent sectors (aerospace, communications), the government supports entrepreneurship through reforms to spur private-sector involvement in investment as well as research, development and production. Sample categories of initiatives that incentivize competition and entrepreneurship include:[432]

- Expanding areas in which non-state-owned companies can do business
- Becoming more transparent in non-sensitive defense procurement requirements
- Reforming pricing mechanisms for military products
- Enabling loans and other incentives to promote private sector R&D
- Encouraging greater collaboration between state-owned and private sector companies.

Entrepreneurship, of course, is also spurred by investment. In this sense China is investing billions in Fourth Industrial Revolution and AI initiatives and is also prepared to back private-sector involvement where it knows such entrepreneurship might more easily be nurtured and spurred compared to the huge and often dysfunctional state corporations.[433]

China does not have a single dedicated AI sector. Related initiatives stretch across multiple sectors, including the high-tech, aerospace, defense, automotive, healthcare and communications industries, among others. But entrepreneurship in Fourth Industrial Revolution technologies generally and AI specifically are being encouraged within these sectors by promotion and application of reforms, investment, and cross-sector engagement as those being implemented in the aerospace and defense domains outlined in Chapter 2. These reforms, investment and incentivization can be regarded as the key conditions that are supporting entrepreneurship.

The end result is an environment in which, again according to Ng; "The velocity of work is much faster in China than in most of Silicon Valley. When you spot a business opportunity in China, the window of time you have to respond usually very short—shorter in China than in the United States."[434] Qiang Yang, a computer scientist at Hong Kong University of Science and Technology who collaborates with Tencent, elaborated on the opportunistic approaches in China's high-tech industry, noting that the cycle for product design, development and delivery is "very short" in China, meaning that once one company introduces AI, others must work to do the same. [435]

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[431] Jane's Implications and Recommendations Workshop, October 5, 2017, IHS Markit offices, Washington, D.C.
[432] Grevatt, Jon, "China to Accelerate Reforms Promoting Private Sector Industrial Growth," *Jane's*, March 14, 2016, https://janes.ihs.com/Janes/Display/jdin90127-jdin-2016.
[433] Watkins, Eli, "China Seeks Dominance of Global AI Industry," *Financial Times*, October 15, 2017, https://www.ft.com/content/856753d6-8d31-11e7-a352-e46f43c5825d.
[434] Zhang, Sarah, "China's Artificial Intelligence Boom," *The Atlantic*, February 16, 2017. https://www.theatlantic.com/technology/archive/2017/02/china-artificial-intelligence/516615/.
[435] Zhang, Sarah, "China's Artificial Intelligence Boom," *The Atlantic*, February 16, 2017. https://www.theatlantic.com/technology/archive/2017/02/china-artificial-intelligence/516615/.

This dynamic was evident over the first several months of 2017 as China's biggest technology and Internet I companies introduced digital assistants in January (Baidu's Xiaoyu Zaijia "Little Fish"), April (Tencent's DingDang) and July (Alibaba's Tmall Genie).[436]

"BAT" and China's Artificial Intelligence Industry

Baidu, Alibaba and Tencent dominate China's commercial AI industry. Each has been exceptionally active in AI research and application development in the last year.

Baidu

Baidu is the leading Chinese company for AI, investing 15% of its revenue (10 billion RMB or $1.5 billion) into R&D for AI.[437] In October 2016, Baidu launched a $200 million fund to focus on AI, AR and deep learning.[438] According to IHS Markit's Technology, Media and Telecommunications team, in February 2017, Baidu announced that it was working with the National Development and Reform Commission to develop a "Deep Learning Technology Lab."[439] The National Development and Reform Commission also commissioned China's first National Engineering Laboratory of Deep Learning Technology and Application in March 2017.[440] Baidu was chosen to lead the project, with support from Tsinghua and Beihang Universities, and a number of research institutes including the China Academy of Information and Communications Technology and the Beijing Electronics Standardization Institute.[441] The Beijing-based enterprise used its official WeChat account to state that the lab would focus on seven areas of research, including: "machine learning-based visual recognition, voice recognition, new types of human machine interaction and deep learning intellectual property." The overarching goal, it stated, was to "boost China's overall competence in artificial intelligence."[442]

There is a lack of public information available regarding the precise activities of the Deep Learning Lab since its inception. However, the following statement from Li Yanhong, Board Chairman and CEO of Baidu, provides additional clues regarding why Baidu was selected to drive the Lab:

> "Li added that technologists like himself are different from scientists. Scientists may try to figure out questions that only few can understand but technologists create things to benefit maybe 500 million or 5 billion people. As private enterprises focus on R&D that is based on the market prospect, they have evident advantage in technologies that benefit people's wellbeing, for instance AI."[443]

Considering the ambitious goals for China's AI development established in the Next Generation Artificial Intelligence Plan, Baidu is an understandable choice to lead the Deep Learning Lab. The search engine giant has wholeheartedly embraced AI technology, developing cutting edge speech recognition software (Deep Voice) and a highly-regarded machine-learning cloud-infrastructure team.

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436 Email interview with IHS Markit Technology, Media and Telecommunications team members on September 18, 2017.
437 Nusca, Andrew, "How Baidu Plans to Win the Artificial Intelligence Market," *Fortune,* October 18, 2017, http://fortune.com/2017/10/17/baidu-artificial-intelligence/.
438 "Baidu Names Former Microsoft Exec as COO in Artificial Intelligence Push," January 17, 2017, https://www.cnbc.com/2017/01/17/baidu-names-former-microsoft-exec-as-coo-in-artificial-intelligence-push.html.
439 Email interview with IHS Markit Technology, Media and Telecommunications team members on September 18, 2017.
440 He, Yujia, "How China Is Preparing for an AI-powered Future," *Wilson Center*, June 2017. https://www.wilsoncenter.org/sites/default/files/how_china_is_preparing_for_ai_powered_future.pdf.
441 Email interview with IHS Markit Technology, Media and Telecommunications team members on September 18, 2017.
442 Jing, Meng, "China's First 'Deep Learning Lab' Intensifies Challenge to US in Artificial Intelligence Race," *South China Morning Post*. http://www.scmp.com/tech/china-tech/article/2072692/chinas-first-deep-learning-lab-intensifies-challenge-us-artificial.
443 China Science and Technology Newsletter, No.7, April 15, 2017. http://www.cistc.gov.cn/upfile/874.pdf.

Baidu's DuerOS platform shows how the company seeks to use its AI capabilities to expand its market outside of China. The platform incorporates technology Baidu acquired through its purchase of U.S.-based chatbot developer Kitt.ai in mid-2017, making it available to English speaking users. The stated aim for the platform is to enable "everyone on this planet to build" services on its platform—which also incorporates the acquisition of China-based assistant developer RavenTech which it purchased in early 2017.[444]

Tencent
In February 2017, Tencent announced that it was working to launch an AI lab in Seattle with a main focus on speech recognition. It follows the launch of other labs in China, Baidu first launched an AI lab in the United States in 2014. Following its strong second quarter 2017 results, Tencent announced plans to focus on AI investments and product development.[445]

Alibaba
Members of IHS Markit's Technology, Media and Telecommunications team also note that Alibaba, which has stated that it seeks to "democratize" AI, is also interested in AI applications for the automotive industry.[446] In October 2017, Alibaba announced that it will invest over $15 billion over the next three years into its DAMO (discover, adventure, momentum and outlook) Academy, which will research topics such as data intelligence and the Internet of Things.[447]

AI Innovation Hubs
The BAT companies are not the only companies in China seeking to commercialize AI technologies. The Wilson Center notes that China has a vibrant industry centered around three Chinese cities: Beijing, Shanghai and Shenzhen.[448] Data published by the Center in June 2017 found that Beijing has 242 companies, Shanghai has 112 companies and Shenzhen is home to 93 AI companies, including two of the top 50 AI start-ups.[449]

Analysis of Shenzhen's "innovation ecosystem reveals the advantages"[450] that top-down government policy support can create for China's AI capability development. Notable innovation-facilitating characteristics include:

- Shenzhen is a financial center and its financial industry provides "ample private funding for local start-ups," which is on top of $1 million from the Shezhen municipal government for AI projects. Other municipal governments are providing funding for programs in their territory including $5 billion from the Tianjin municipal government for AI, $2 billion from the Xiantan

[444] Email interview with IHS Markit Technology, Media and Telecommunications team members on September 18, 2017.
[445] *Reuters*, "A Chinese Tech Giantis Setting up an A.I. Research Lab on Amazon's Home Turf," May 2, 2017, https://www.cnbc.com/2017/05/02/tencent-ai-research-lab-seattle.html.
[446] Erickson, Jim and Susan Wang, "Alibaba Cloud Wants to Democratize Artificial Intelligence Tech," *Alizila*, March 29, 2017, http://www.alizila.com/alibaba-cloud-wants-to-democratize-artificial-intelligence-technology/.
[447] Catherine Shu, "Alibaba Group Will Invest $15B into a New Global Research and Development Program," *TechCrunch*, October 10, 2017. https://techcrunch.com/2017/10/10/alibaba-group-will-invest-15b-into-a-new-global-research-and-development-program/.
[448] He, Yujia, "How China is Preparing for an AI-powered Future," *Wilson Briefs,* Wilson Center, June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.
[449] He, Yujia, "How China Is Preparing for an AI-Powered Future," *Wilson Briefs,* Wilson Center, June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.
[450] He, Yujia, "How China Is Preparing for an AI-Powered Future," *Wilson Briefs,* Wilson Center, June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.

government for robotics and AI and $800,000 from the Suzhou government for AI projects.[451]

- Shenzhen and the surrounding region have "formed a complete supply chain for AI-enabled applications."[452]

- The city and its industry have close collaborative ties with academia and research institutes that facilitate transfer of intellectual property and technology to local firms.

- The local government provides incentives for individuals to live in the city in order to attract talent. One such program has reportedly attracted in excess of 1,200 individuals including the founders of Intelli-Fusion, which has developed advanced applications in facial recognition.[453]

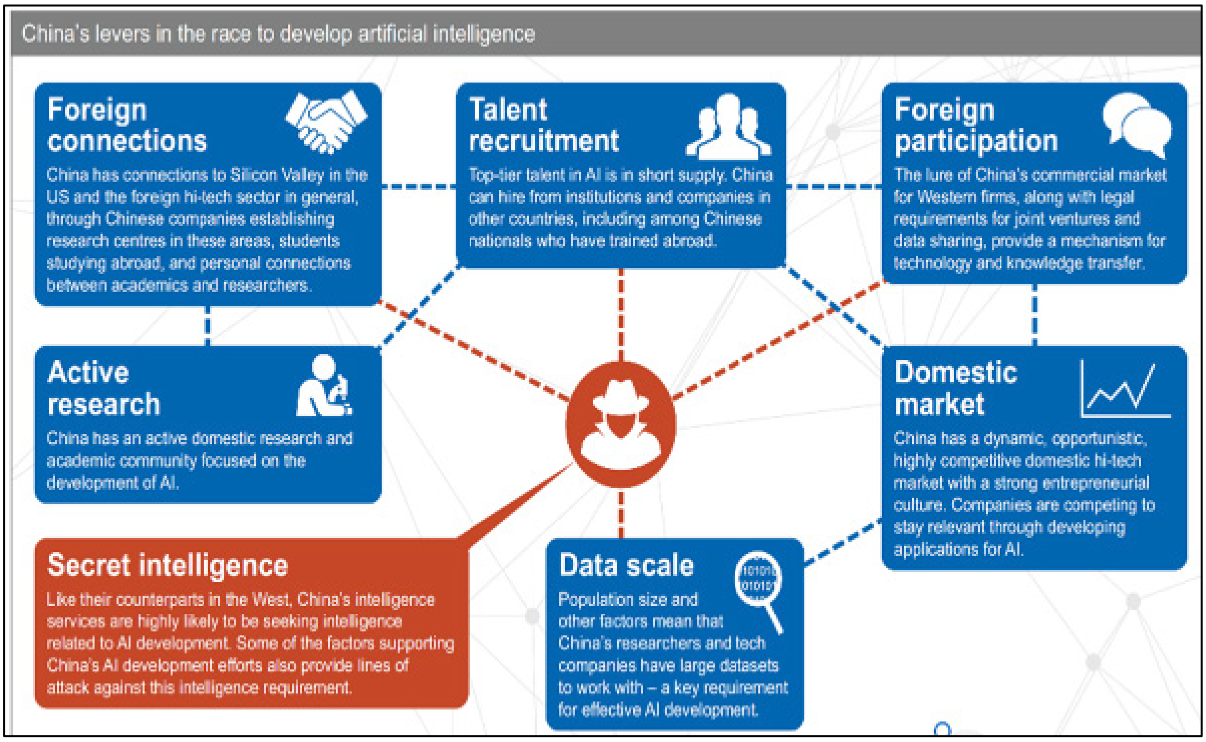
A Steep Upward Trajectory and Intensifying Competition
China's progress in both research and commercialization of AI over the past three to four years has been impressive and is likely to continue on a steep upward trajectory as the below components enable further volume and velocity of activity and innovation:

- Policy prioritization, high-levels of state funding and top-down direction
- Easy and essentially exclusive access to large sets of data
- An innovation model that isolates innovation centers, and enables them to develop
- Dynamic and highly competitive indigenous high-tech market environment, as well as an entrepreneurial culture that requires commercial enterprises to move quickly to meet market demand
- Growing volume of research on AI and connections
- Connections to Silicon Valley and the U.S. high-tech community, including "innovation labs" established by some of China's biggest technology and communications companies
- Size of the Chinese market
- Ability to leverage Chinese citizens operating in the United States and other countries, and increasingly recruit talent back to China to fill gaps between talent supply and demand

The graphic below lists several levers that China possesses that will accelerate its development of AI capabilities.

[451] Paul Mozur and John Markoff, "Is China Outsmarting America in A.I.?" *New York Times*, May 27, 2017. https://www.nytimes.com/2017/05/27/technology/china-us-ai-artificial-intelligence.html.
[452] He, Yujia, "How China Is Preparing for an AI-Powered Future," *Wilson Briefs,* Wilson Center, June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.
[453] He, Yujia, "How China Is Preparing for an AI-Powered Future," *Wilson Briefs,* Wilson Center, June 2017. https://www.wilsoncenter.org/publication/how-china-preparing-for-ai-powered-future.

Figure 15: A list of China's available levers in the development of its artificial intelligence program



Source: IHS Markit[454]

While some observers suggest that China exceeds the United States in some applications of AI, such as healthcare,[455] few credible assessments suggest China has an overall advantage in this space. Yet.

Maintaining U.S. advantage in this critical technology area—one with direct implications for advanced weapons systems and the future of military capabilities—will require vigilance, as well as enhanced direction and investment in the field and a reasonable caution toward technology transfer and Chinese investment in U.S. AI-related enterprises through either acquisition or limited partners in venture capital firms.

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[454] Nurkin, Tate, "China and US compete for AI dominance," *Jane's Intelligence Review,* March 2018, www.janes.com/images/assets/579/78579/China_and_US_compete_for_AI_dominance.pdf

[455] Zhou, Adelyn, "These 20 Leading Technologists are Driving China's AI Revolution," *Forbes,* June 21, 2017, https://www.forbes.com/sites/adelynzhou/2017/06/21/chinese-leaders-in-artificial-intelligence/2/#39ec77287568.

Jane's
By IHS Markit

Section 2

China's Advanced Weapons Systems

Chapter 4: Overview of China's Advanced Weapons Systems Industry

Chapter 4 Key Themes and Insights

- China's advanced weapons programs support its military modernization efforts to develop novel and asymmetric advantages over the United States and its Western Pacific allies.

- **Short Term (5 to 12 years):** China will focus on building power projection capabilities and enhance its A2/AD capabilities. It is our assessment that China's current priorities for development are: (1) counterspace; (2) unmanned systems; (3) MaRVs/HGVs; (4) directed energy weapons; and (5) EM railguns.

- **Long Term (early 2030s):** Autonomous unmanned systems and AI will switch with counterspace to become China's priority for advance weapons development as it seeks to compete in "intelligentized" warfare.

- **CASIC, CASC and State-owned Enterprises Dominate:** Industrial engagement in China's advanced weapons programs is channeled mainly through the academies and subsidiaries operated by state-owned enterprises CASIC and CASC, both of which maintain a presence in nearly all of the five programs.

- **China's Private Sector:** Private sector companies play a role in China's development of unmanned air and surface vehicles while academic and research institutes play a prominent role in the development of unmanned underwater vehicles and electromagnetic weapons.

Full Speed Ahead: Advanced Weapons Systems' Value to China's Military Modernization

China's advanced weapons systems programs, both as a group and as individual efforts, provide novel and enhanced capabilities and asymmetric advantages vis-à-vis the United States and its allies in the Western Pacific. Components of China's advanced weapons programs support all the objectives of China's military modernization discussed in Chapter 1 and listed below:

- Enhancing A2/AD capabilities, especially in the maritime domain and in the near seas
- Projecting power to protect China's growing international interests
- Supporting the transition to the "intelligentization" of warfare, mainly through AI-infused platforms and systems as well as the use of other Fourth Industrial Revolution technologies
- Disrupting balances and stabilizing imbalances across several domain area competitions
- Developing capabilities that project the image of a global power and leader in cutting-edge advanced technologies
- Complicating U.S. alliance management and geopolitical relationships and undermining the United States' defense export sales to Southeast, South and East Asia

Due to the breadth and extent of value that these weapons systems provide, our analysis strongly suggests that all the programs are moving forward at what one Australian expert interviewed for this effort termed "full speed."[456] While technical and engineering difficulties persist in each program area, "all programs are priorities given [China's] overarching emphasis on finding the vulnerability in the U.S. armor."[457]

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[456] Telephone interview with Australian network members on China's advanced weapons systems, September 2017.
[457] Telephone interview with Australian network members on China's advanced weapons systems, September 2017.

Prioritizing Systems

Our research clearly and repeatedly indicated that development in each of the five systems is a high priority for China's military modernization. Within this broader context of overall importance, our team was able to develop an assessment of how China prioritizes these programs relative to one another. This assessment is qualitative in nature. It is based on a methodology that queried Jane's and networks experts on:

- The level of possible and likely strategic and operational disruption presented by fully-operational advanced weapon capabilities for the overall U.S.-China competition and competition in each of the domains of interest to this study
- The level of maturity of specific systems and programs and nature of the technological challenges still to be addressed before each system reaches full maturity
- The ease or difficulty of other, adjacent innovations—in operational concepts or training, for example—required to go from a disruptive technology to an actually disruptive capability

These analyses were then compared to outputs from our secondary source research effort and, finally, vetted and filtered by our core team and lead author who determined the final rankings.

In the short-to-mid-term—the next five to 12 years—as the focus of China's ambitions is on enhancing A2/AD capabilities regionally and building more robust power projection capabilities, our assessment is that China's advanced weapons systems prioritization is:

1. Counter-space
2. Autonomous unmanned systems
3. MaRVs/HGVs
4. Directed energy
5. EM railguns

In the late 2020s, the transition to a more "intelligentized" battlefield will become more evident and tangible. China's Next Generation Artificial Intelligence Development Plan will enter its second and then third phase in the mid-to-late 2020s, both of which highlight the expansion of military applications of AI, autonomous systems and advanced manufacturing. In this environment, Jane's believes that the top two priorities will switch. Development of more highly-autonomous unmanned air, surface and undersea vehicles will supersede even counter-space as the lead priority of China's advanced weapons programs.

Also swaying our prioritization in the late 2020s and early 2030s is our assessment that demand for unmanned systems will increase as states recognize the asymmetric advantages that these systems confer. It is unlikely that middle and small powers in Asia will have immediate access in this time to the applied engineering of MaRVs—though this paper does investigate the potential for diffusion of hypersonic technologies in Chapters 10 and 11—but they will have growing access to the equalizing and asymmetrical impact of a large number of autonomous, potentially swarming, cheap drone airframes.

China is already a global leader in the export of unmanned aerial vehicles (UAVs), leveraging an over-arching business model that stresses low cost, good enough solutions, high degrees of technology transfer and even co-production. These are all tactics that U.S. providers are frequently unable to match. States unable to manufacture their own autonomous drone systems by the middle of the next decade will have a willing partner in China, opening up new commercial opportunities and also deepening geopolitical relationships in the region and beyond.

Program Overviews

The high-level summary tables below provide an overview of the primary value, motivation and technology challenges associated with each program of interest to this study.

Table 15: Summary of the primary value, motivation and technology challenges associated with each program of interest to this study

Weapons System Program	Function	Motivation	Technology Challenges
Counter-Space	• Deny/hold at risk adversary access to space-based C4ISTAR architecture • Asymmetric threat to highly-advanced and networked modern militaries	Supports A2/AD activities by ensuring modern militaries are unable to leverage advanced C4ISTAR capabilities. Holds at risk critical U.S. military assets, potentially limiting U.S. options during a crisis	Few. China has demonstrated core technologies effectively. Key development areas include further refinement and advancement of current generations of technologies and developing capabilities to address U.S. counter-counter-space measures, such as the use of microsatellites and disaggregation. Development of novel operational concepts is also a potential focus area.
Unmanned Systems/ Autonomous Systems	• Inexpensive and expendable capability to support China's A2/AD and Power Projection efforts by enhancing/ extending range and persistence of intelligence, surveillance and reconnaissance (ISR) and providing flexible, modular, multi-mission capabilities, including strike • Redress imbalances in undersea and maritime domain more broadly • Support maritime territorial claims • AI-infused unmanned systems are central to the future of warfare	Unmanned systems are important to the future of warfare. They also can support a growing range of missions from A2/AD to power projection.	Unmanned Systems • Persistence • Autonomy • Range • Communications (especially satellite communications that can help extend range) Swarms • Communications • Resilient/self-healing swarms • Keeping swarms in the air for longer periods of time
Maneuverable Reentry Vehicles (MaRVs)	• Provide high-speed and maneuverable strike capability to defeat advanced missile defense and deter adversaries from challenging China's interests in the region, initially and, eventually, perhaps across regions	Primarily the deployment of THAAD systems and continued development of advanced missile defense systems by the United States Maintain parity in hypersonics with the United States and Russia.	• Targeting, communication and maneuverability at high-speeds • Material sciences • For ASBMs: reconnaissance/strike complex
Directed Energy	• Close-in defense of platforms and installations • Counter-space operations	Proliferation of advanced unmanned systems and swarming tactics will mandate cost-effective means of dealing with close-in threats. Adding additional depth of counter-space capability.	• Energy/power capture and storage to reduce size and allow directed energy weapons to be deployed on smaller platforms and on naval vessels
Electromagnetic and Hyper-Velocity Weapons	• Missile defense • High-speed and long-range strike • Hand-held EM weapons • Salutary benefits of complementary research into EM science	Low cost capacity to deal with high-speed threats. Long-range strike on fixed targets.	• Energy capture and storage • Barrel wear, which is both a heat management and materials challenge

China's advanced weapons systems industry is varied across each system area and incorporates private sector companies (especially in China's UAV sector), academia and applied research institutes and, of course, state-owned enterprises, especially CASIC and CASC—two organizations that are deeply involved in nearly all of the programs of interest to this paper and are profiled in more depth below. Table 16 provides a list of key organizations and institutions identified through Jane's research supporting the full suite of China's advanced weapons programs.

Table 16: Key organizations involved in China's advanced weapons systems programs. Note how CASIC and CASC play a role in nearly all of the programs of interest

Organization	Advanced Weapon System				
	Directed Energy	EM Railguns	Counter-space	Hypersonics	Drones
1028th Research Institute	√				
Aero-Starloop					√
AVIC					√
Beijing University of Aeronautics and Astronautics					√
China Academy of Aerospace Aerodynamics				√	
China Academy of Engineering Physics	√				
China Aerospace Science and Industry Corporation (CASIC)		√	√	√	√
China Aerospace Science and Technology Company (CASC)		√	√	√	√
China Electronics Technology Corporation (CETC) International					√
China National Space Administration (operated by PLAAF)			√		
China Shipbuilding Industry Corporation (CSIC)					√
Chinese Academy of Sciences	√			√	
College of Maritime Studies					√
DJI					√
Jiuyuan Hi-Tech Equipment Corporation	√				
Jiangsu Automation Research Institute					√
NORINCO	√				√
Northwest Institute of Nuclear Technology	√				
Northwestern Polytechnical University of Xi'an					√
Poly Technologies	√				√
Naval University of Engineering	√	√			
Sifang Automation					√
Tengoen					√
Tianjin University					√
Tsinghua University		√		√	
University of Science and Technology of China					√
Xi'an ASN Tech Group					√
Yuneec					√
Ziyan UAV Co Ltd					√

Overview of CASIC and CASC

These two corporations were previously part of the former China Aerospace Corporation, which was established in 1956 as part of the Ministry of Defense but was split into two entities—the China Aerospace Machinery and Electronics Corporation (CAMEC) and CASC—in 1999. CAMEC was renamed CASIC in 2002. Much of the CASIC and CASC's activities overlap but are critical in China's efforts to develop advanced weapons.

The two corporations are split across two general sets of activities. CASIC is involved in producing air and missile defense systems, short- and medium-range ballistic missiles, cruise missiles, aerospace electronics, microsatellites and an array of related subsystems and components. CASC is mainly engaged in producing space launch vehicles (SLV) and satellites, as well as strategic and tactical ballistic missile systems and unmanned systems.

Both are also involved in commercial sectors, principally in the production of mechanical parts and components in other high-tech sectors related to electronics, security, transport and space.[458] The two corporations together employ more than 320,000 people.[459]

Their annual revenues are not publicized. CASIC revenues were reported at about $30.5 billion in 2016,[460] while CASC's most recently reported revenues were RMB 294.02 billion ($43.8 billion) in 2013.[461]

Both companies operate a series of business divisions, referred to as academies. These academies control numerous factories and research institutes that undertake research, development and production activities, as well as specialized companies, listed companies and numerous diversified subsidiaries. These academies are the main facilities in terms of advanced weapons development and production.[462]

CASIC and CASC academies that have major input in developing and manufacturing China's advanced weapons programs include those listed in Table 17 below:

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[458] Krolikowski, Alanna, "China's Civil and Commercial Space Activities and their Implications," Testimony before the U.S.-China Economic and Security Review Commission, May 11, 2011, https://www.uscc.gov/sites/default/files/5.11.11Krolikowski.pdf.
[459] "China Aerospace Science and Technology Corporation (CASC)," *Jane's*, December 12, 2016. https://janes.ihs.com/Janes/Display/jsd_3059-jsd; "China Aerospace Science and Industry Corporation (CASIC)," *Jane's,* December 4, 2017. https://janes.ihs.com/Janes/Display/jwdia226-jwdi._
[460] Fortune Global 500, http://fortune.com/global500/china-aerospace-science-industry/.
[461] CASC, "About Us," http://english.spacechina.com/n16421/n17138/n17229/c127066/content.html.
[462] "China Aerospace Science and Technology Corporation (CASC)," *Jane's*, December 12, 2016. https://janes.ihs.com/Janes/Display/jsd_3059-jsd_

Table 17: Key companies, research institutes and universities involved in China's Advanced Weapons Programs[463]

CASIC Academy	Focus Area
CASIC 1st Academy	• Microsatellites • Precision strike weapons
CASIC 2nd Academy	• Anti-missile interceptor systems
CAISC 3rd Academy	• Supersonic, ramjet-powered anti-ship missiles
CAISC 4th Academy	• Direct-ascent anti-satellite weapons (ASATs) • Re-entry vehicle warheads
CASIC 6th Academy	• Solid-fuel and hybrid liquid-solid engines
CASIC 9th Academy	• Ballistic missile systems
CASIC Base 061	• Missile components and software
CASIC Base 068	• Advanced materials
CASC Academy	**Focus Area**
CASC 1st Academy	• Ballistic missiles • Hypersonic glide vehicle sub-systems
CASC 4th Academy	• Ballistic missile systems • Hypersonic boost-glide vehicles
CASC 5th Academy	• Satellites • Remote sensing • Secure communications
CASC 6th Academy	• Liquid-fueled propulsion systems • Guidance systems for launch vehicles
CASC 7th Academy	• Missile and space systems • Laser-guidance
CASC 8th Academy	• Infrared-guided and semi-active radar missile systems • Satellites • Launch vehicles
CASC 9th Academy	• Main supplier to CASC 1st Academy for missile systems
CASC 11th Academy	• Advanced unmanned systems • Related control technologies • Hypersonic testing

Source: Compiled by Jane's

These academies can be regarded as Tier 1 enterprises, meaning that they are responsible for directly supplying the original equipment manufacturer or prime. CASIC or CASC then act as system integrators, integrating inputs from other Tier 1 suppliers to create the final platform or system. Many of the other major academies and their numerous subsidiaries are involved in supplying components, systems and sub-systems to these Tier 1 suppliers. There is also evidence of some limited private-sector involvement in these supply chains, suggesting these more dominant Tier 1 academies are increasingly acting as systems integrators as well.[464]

Many of these supply academies have duplicate capabilities, although in practice are likely dedicated to supporting specific programs and associated Tier 1 academies.

In recent years, CASIC and CASC have been looking for ways to enhance collaboration and maximize efficiencies.[465] In a 2014 agreement between CASIC and CASC, advanced weapons were not mentioned specifically, although the accord's focus on "strategic research, space [and] weaponry"

[463] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. pg. 18-20. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[464] This assessment is based on Jane's research and on insights provided in email interviews with Jon Grevatt, Jane's Defense Industry Reporter, on August 16, 2017 and November 23, 2017.
[465] Grevatt, Jon, "Chinese Aerospace Giants CASIC and CASC Sign Consolidation Agreement," *Jane's Defense Industry*, July 4, 2014, http://janes.ihs.com/Janes/Display/jdin87737-jdin-2014.

indicate that they might be. Given the duplication evident across some of CASIC and CASC's activities, there appear to be opportunities for consolidation, particularly in light of the Chinese government's efforts to support defense industrial efficiencies and innovation. As discussed in Chapter 2, meaningful consolidation of CASC and CASIC activities does not yet seem to have taken place, despite 2014 guidance to do so.

Further consolidation might also result from the two corporations' expanding efforts to engage with the private sector. While private sector involvement in major programs will remain limited for the foreseeable future, the government's increasing emphasis on promoting such engagement is likely to result in greater outsourcing of less sophisticated technologies, even those that are incorporated in more advanced weapons. This would also create opportunities for consolidation, with a view to gaining capability advancements.

Below is an outline of CASIC and CASC subsidiaries, and the some of the work they undertake in terms of advanced weapons:

China Aerospace Science and Industry Corporation (CASIC)

CASIC operates seven academies, two scientific R&D bases, six publicly-listed companies, and more than 620 other companies and institutes scattered across China.[466] It employs about 150,000 people; roughly 70% of which are described by CASIC as "technical personnel."[467]

The corporation states that it has nine key defense S&T laboratories, two national program centers, one national technology research center, three national enterprise technological centers, four defense technology study and application centers, seven enterprise technology centers and 23 provincial or municipal high-tech companies.[468]

CASIC describes itself as the "largest missile weapon designer and manufacturer in China" that specializes in the research, development and production of air defense and missile systems, cruise missile systems, solid rockets, space products, covering land, sea, air, space and electromagnetism. The corporation says it is aiming to become a "world-class aerospace defense corporation by 2020."[469] CASIC's export arm is the China Precision Machinery Import-Export Company.

Details about CASIC's various academies are below. Many of these divisions, most of which operate numerous factories and subsidiaries, are involved in space programs and in various commercial sectors, although details below primarily relate to their involvement in advanced weapons programs.

CASIC First Academy: Also known as the Academy of Information Technology, this institution is primarily involved in the production of responsive tactical microsatellites. It is also engaged in the research, development and production of capabilities and technologies needed for precision strike and advanced weapons. These include satellite applications and GPS/inertial guidance/navigation units. The First Academy's most prominent product is the Hangtian-Tsinghua-1 (HT-1) 50-kilogram microsatellite that operates in a sun synchronous orbit; and the 25-kilogram NS-1 microsatellite.[470]

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[466] CASIC, "About Us," http://english.casic.cn/n189298/n189314/index.html.
[467] CASIC, "About Us," http://english.casic.cn/n189298/n189314/index.html.
[468] CASIC, "About Us," http://english.casic.cn/n189298/n189314/index.html.
[469] CASIC, "About Us," http://english.casic.cn/n189298/n189314/index.html.
[470] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.

CASIC Second Academy: This academy—also known as the China Changfeng Mechanics and Electronics Technology Academy—is regarded as China's main designer, developer and manufacturer of air and space defense systems. The academy consists of a design department, 10 specialized research institutes, a simulation center, three factories and nine independent commercial enterprises.[471] Official state media reported in May 2017 that the CASIC Second Academy had developed a new type of "ultra-fast" anti-missile interceptor capable of engaging an incoming projectile flying "10 times faster than a bullet." CASIC was quoted as saying that its Second Academy had made a "new generation aerospace defense missile" that incorporates "top space technologies" and can intercept targets at an altitude of "tens of kilometers."[472] Jane's assessed that if the performance details about the Chinese anti-missile interceptor are accurate, then the new advanced weapon is likely to be part of an anti-ballistic missile system that it is likely to be used to intercept incoming missiles at altitudes between 10 km and 100 km, and at speeds of up to 12,000 kilometers per hour (km/h).[473]

CASIC Third Academy: This academy—also known as the HiWING Mechanical & Electrical Technology Corporation—is regarded as China's leading enterprise in the design, development and production of cruise missiles, other aerodynamic vehicles and propulsion systems and associated launchers. It has 10 research institutes and two factories.[474] In recent years, the academy has developed several major advanced weapons programs including the YJ-12 (Ying Ji; Eagle Strike), a supersonic, liquid-fueled ramjet-powered anti-ship missile. According to *Jane's Air-Launched Weapons*, the YJ-12 was designed as a ship-launched weapon but has also been fired (in development tests at least) from an aircraft. The CASIC Third Academy also developed a new optical precision-guided version of the CJ-10K/KD-20 land attack cruise missile, which first appeared in August 2017.[475]

CASIC Fourth Academy: The Fourth Academy specializes in developing and producing direct-ascent, co-orbital and other ASAT weapons. The academy is also said to engage with other CASIC and CASC affiliates in undertaking its programs, acting more as a systems integrator. Using this systems integrator strategy, the Fourth Academy was credited with the development and production of the DF-21 medium-range ballistic missile as well as the Kaitouzhe KT-2 solid-fuel launcher, which is based on the DF-31 Intercontinental Ballistic Missile (ICBM). According to *Jane's Space Systems and Industry*, a KT rocket is speculated to have carried the anti-satellite kill vehicle, on January 11, 2007, which destroyed an in-orbit Chinese Fengyun (FY-1C) meteorological satellite. It is also possible that the CASIC Fourth Academy is involved in the program to develop the DF-31AG ICBM, which might be armed with multiple independently targetable re-entry vehicle warheads.[476]

CASIC Sixth Academy: The Sixth Academy under CASIC—also known as the Hexi Machinery Corporation—is focused on the development and production of propulsion and motor systems

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[471] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[472] Lei, Zhao, "Ultrafast Missile Interceptor Developed," *China Daily*, May 27, 2017.
[473] Dominguez, Gabriel and Gibson, Neil, "Update: China Develops 'Ultra-Fast' Anti-Missile Interceptor, Says Report," *Jane's Defense Weekly*, June 1, 2017.
[474] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[475] Gibson, Neil and Fisher Jr., Richard D. "Images Indicate Possible Precision-Guided Version of China's KD-20 LACM," *Jane's Defense Weekly*, August 10, 2017, http://www.janes.com/article/73028/images-indicate-possible-precision-guided-version-of-china-s-kd-20-lacm.
[476] Fisher Jr, Richard D., "DF-31AG ICBM Can Carry Multiple Warheads, Claims China's State Media," *Jane's Defense Weekly*, August 8, 2017, http://janes.ihs.com/Janes/Display/FG_624634-JDW.

including solid-fuel propulsion systems and hybrid liquid-solid engines. The academy operates several subsidiaries. The academy's propulsion systems are used in many Chinese advanced weapon systems including the DF-21 and JL-1 medium-range ballistic missiles and the DF-21D ASBM.[477]

CASIC Ninth Academy: This academy—also known as Base 066 or the Sanjiang Space Group—is also a designer and producer of ballistic missile systems. According to *Jane's Strategic Weapon Systems*, Base 066 is believed to have designed and developed the DF-11 short-range, road-mobile, ballistic missile and its follow-on, the DF-11A.[478]

CASIC 061 Base: This institute, previously known as the Jiangnan Aerospace Group, has capabilities in producing missile components and software. Its products include many that are likely to have been integrated into China's advanced weapons programs undertaken by CASIC or CASC. These components include missile-related guidance, navigation and control software, composite materials, and a range of components, including aerospace-qualified fasteners, gyroscopes, autopilot systems, batteries, micromotors and fuel gauges.[479] According to *Jane's International Defense Directory,* 061 Base is also involved in producing telecommunications, batteries and power sources, electrical motors, metal wire drawing facilities, production machinery, engineering machines, molds, dies and tools.[480]

CASIC 068 Base: This institute is also known as the Hunan Space Bureau and, like the 061 Base, is positioned as Tier 2/3 supplier to other larger CASIC/CASC academies and subsidiaries. In this sense, the 068 Base is almost certainly involved in China's advanced weapons programs. The core capabilities of the 068 Base include advanced materials, electrical components, magnets, diamond coatings and antennas.[481]

China Aerospace Science and Technology Corporation (CASC)

CASC operates eight large research, development and production academies and 12 specialized companies and seven direct subordinate units. Its companies also operate numerous subsidiaries and affiliated entities.[482] At the end of 2013, CASC said it employed 170,000 people.[483]

According to CASC, it is mainly engaged in the research, design, manufacture and launch of space systems such as launch vehicles, satellites and manned spaceships as well as strategic and tactical missiles. The company also provides international commercial satellite launch services. The China Great Wall Industry Corporation is CASC's export arm for SLV products while its military marketing arm is the China Aerospace Long-March International Trade Co, Ltd.

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477 Stokes, Mark A. "China's Evolving Conventional Strategic Strike Capability: The Anti-Ship Ballistic Missile & Beyond," *Project 2049 Institute*, September 14, 2009, https://project2049.net/documents/chinese_anti_ship_ballistic_missile_asbm.pdf.
478 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), 26 April 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
479 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
480 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), 26 April 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
481 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), 26 April 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
482 CASC website, http://www.spacechina.com/n25/n142/n152/n12989/index.html (Accessed August 8, 2017).
483 CASC website, http://www.spacechina.com/n25/n142/n152/n12989/index.html (Accessed August 8, 2017).

Details about CASC's academies are below. Like CASIC, many of CASC's divisions operate numerous factories and subsidiaries and are involved in space programs and various commercial sectors. However, details below primarily relate to the academies' involvement in advanced weapons programs.

CASC First Academy: This academy—also known as the China Academy of Launch Technology—is China's largest developer and manufacturer of ballistic missile systems. Accordingly, it has led many major liquid-fueled surface-to-surface missiles programs and solid-fueled surface-to-surface and submarine-launched ballistic missiles programs. These include the DF-4, DF-5 ICBMs and solid-fueled systems such as the DF-15 short-range ballistic missile and DF-31/DF-31A ICBM.[484] In 2017, the First Academy also revealed its involvement in the rocket-boosted precision-guided glide bomb, the Fei Teng FT-12. In addition, the academy's Beijing Institute of Near Space Flight Vehicle Systems Engineering, which was established in 2008, is regarded as China's most prominent entity leading development of HGV sub-systems.[485]

CASC Fourth Academy: This academy—also known as the Academy of Aerospace Solid Propulsion Technology—has core capability in the development and production of high-thrust solid-fuel rocket motors and related technologies. Besides comprehensive involvement in China's space programs, the Fourth Academy is believed to have been involved in the development of propulsion systems for several major missile programs including the DF-31, DF-31A, JL-2 and DF-41.[486]

CASC Fifth Academy: Also known as the China Academy of Space Technology, this academy's capabilities are focused on the research, development and production of satellites. Through its various research institutes and factories, CAST is involved in the development and production of a wide range of systems and subsystems including jet propulsion and guidance, telecommunications, remote sensing, navigation, control, electro-optical systems, sensors, cryogenic technologies and antenna systems.[487] Despite its focus on space, many of CASTs products are involved in military programs. For instance, *Jane's Sentinel Security Assessment* notes that CAST's Fenghuo ('Beacon') series of satellites provide secure digital data and voice communications for the Chinese PLA, including a communications-on-the-move capability for land, sea and air assets.[488]

CASC Sixth Academy: This academy is also known as the Academy of Aerospace Propulsion Technology or 067 Base. Its capabilities are centered on the research, development and production of liquid-fueled propulsion systems, as well as other systems including inertial guidance systems for launch vehicles. According to *Jane's Space Systems and Industry*, 067 Base also led programs to develop the YF-100 and YF-115 engines that power the Long March 6 and 7 rockets. [489]

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[484] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[485] Stokes, Mark A., Prepared Statement Before The US-China Economic and Security Review Commission, February 23, 2017, https://www.uscc.gov/sites/default/files/Stokes_Testimony.pdf.
[486] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), 26 April 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[487] CAST, "Title," http://www.cast.cn/Item/list.asp?id=1665 (Accessed August 9, 2017).
[488] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), 26 April 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
[489] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.

CASC Seventh Academy: Also known as 062 Base or Sichuan Academy of Space Technology, this academy's primary capabilities are in producing components and systems for missile and space systems including navigation, guidance, fire control and engine control technologies. One of its subsidiaries, Sichuan Aerospace World Guidance, is also engaged in aerospace-related laser-guidance technologies. According to *Jane's Land Warfare Platforms: Artillery & Air Defense*, 062 Base also developed the WS-1 and WS-2 long-range multiple rocket launchers and is likely to be heavily involved in the development of the 400mm WS-3 multiple rocket weapon system.[490]

CASC Eighth Academy: Also known at the Shanghai Academy of Space Technology, this academy develops and produces specialized launch vehicles, satellites and other aerospace systems. The academy also has capabilities in areas related to advanced weapons. *Jane's Land Warfare Platforms: Artillery & Air Defense* reports that the Eighth Academy also specializes in infrared-guided and semi-active radar missile systems and is behind the development of the Lieying-60 surface-to-air missile system and its predecessor, the HQ-61 system.[491]

CASC Ninth Academy: Known as the China Academy of Aerospace Electronics Technology, this academy is a main supplier of components and systems to the CASC First Academy and has capabilities in producing a wide range of systems used in missile systems. These include navigation, control, tracking and telemetry, attitude control systems, radar signal processors, SATCOM modules and inertial guidance systems and components, including accelerometers.[492]

CASC Eleventh Academy: This academy is also known as the China Academy of Aerospace Aerodynamics. It is mainly engaged in producing flight vehicle aerodynamics: its specialisms include the development of UAVs. The academy is also involved in developing precision measurement and control technologies.[493] The Eleventh Academy has developed an app-based UAV management system specifically designed to reduce the complexities of operating larger, multirole air vehicles in the medium-altitude long-endurance (MALE) class.[494] The Eleventh Academy has also developed an anti-ship weapon/UAV system-centered on a wing-in-ground-effect optimized airframe known as the CH-T1.[495] As of July 2017, the Eleventh Academy was also preparing to mass produce the Cai Hong 5 strike-capable UAV. According to the company, the CH-5 is capable of carrying an airborne early warning system as well as electronic warfare instruments to collect electronic intelligence and jam enemy communications or radar.[496] Reporting in April 2017 suggests that the Eleventh Academy has also recently expanded its capabilities in testing hypersonic propulsion systems by the opening of a 556-foot-long wind tunnel dubbed the FD-21.[497]

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490 Kogan, Eugene. "A Profile of China's Public Gem: China's Aerospace Science and Technology Corporation," *The Jamestown Foundation*, September 24, 2009. https://jamestown.org/program/a-profile-of-chinas-public-gem-chinas-aerospace-science-and-technology-corporation/.
491 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
492 Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.
493 CAAA, "Title of Webpage," http://www.caaa-spacechina.com/n365/n366/index.html (Accessed August 9, 2017).
494 Wong, Kelvin, "China's CASC Plans App-based Control System for Cai Hong UAVs," *Jane's International Defense Review,* August 3, 2017.
495 Wong, Kelvin, "Details of Chinese Sea-Skimming Lethal Drone Prototype Emerge," *Jane's Missiles & Rockets*, July 28, 2017.
496 Dominguez, Gabriel, "China 'Ready to Mass Produce' Strike-Capable CH-5 UAV, Says Report," *Jane's Defense Weekly*, July 17, 2017.
497 Lin, Jeffrey and Singer, P.W. "A Look at China's Most Exciting Hypersonic Aerospace Programs," *Popular Science,* April 19, 2017.

Chapter 5: China's Counter-Space Capability

Chapter 5 Key Themes and Insights

- **High Stakes in Space:** Jane's assess that over the next decade, counter-space capabilities will be the most important to China of the five advanced weapons systems in this report. U.S. space-architecture is central to the exercise of American military power, and space as a domain is and will continue to be central to the operations and military capabilities of many U.S. allies as well. China's capacity to hold U.S. space infrastructure at risk constitutes a critical asymmetric capability that could have significant operational and strategic consequences during a crisis or conflict. There is already a growing sense among the U.S. military and analysts of U.S. space architecture that most, if not all, of the nodes within the U.S. space architectures are already vulnerable to China's counter-space capabilities.

- **A Diverse Program:** China's counter-space program is diverse, consisting of ASAT direct-ascent missiles, co-orbital "kamikaze" and "assassin" satellites and advancements in cyber and directed-energy ASAT capabilities. Significantly, China has tested or demonstrated each of these broad capability areas over the last decade, including a highly-controversial test of a direct ascent ASAT weapon against a defunct Chinese weather satellite in 2007.

- **An Iterative Competition: U.S. Counter-measures and Capabilities:** The United States has also developed and tested a range of counter-space capabilities that can hold China's expanding presence in space at risk as well. Moreover, the United States is also investing in and employing new counter-measures and concepts—such as disaggregation—to enhance the resilience of its space infrastructure against China's counter-space capabilities. The combination of U.S. capacity to hold China's assets at risk and its efforts to harden U.S. space architecture indicate both continued U.S. advantage and vulnerability in the dynamic and iterative space versus counter-space competition.

Overview

The modern "informatized" operational military environment is largely defined by the importance of networked forces being able to communicate with one another to enable C4ISTAR tasks. These communications can take place through many mechanisms and across many domains. Critical C4ISTAR functions are being facilitated by satellites based in space.

"Chinese military writings describe informationized warfare as an asymmetric way to weaken an adversary's ability to acquire, transmit, process, and use information during war, and discuss its use as a way to force an adversary to capitulate before the onset of conflict."

-Center for Strategic and International Studies

Consider:

- The U.S. military uses Global Positioning System satellites (GPS) to support navigation and targeting.
- It uses communications satellites to allow disparate forces to trade information and enhance situational awareness.
- It uses imagery satellites to surveil and monitor environments, identify changes in patterns or capture critical environmental information.

The United States has a resilient space-based infrastructure and relies on this infrastructure and the advantages it confers to bring to bear the full weight of its power projection and warfighting capabilities throughout the world.

China's A2/AD modernization acknowledges the strength of the U.S. military and of its space-based architecture. It also understands that U.S. reliance on space assets constitutes a strategic and operational vulnerability.

If China was able to successfully deny U.S. access to its space-based assets or degrade or destroy those assets, it could have a potent effect on the operational effectiveness of the U.S. military. A particularly successful Chinese counter-space campaign could ensure U.S. forces could not effectively "see," "sense" or "hear," much less navigate, target and communicate.

PLA writings are clear about the importance of denying space to the United States: "space is the commanding point for the information battlefield" and "destroying or capturing satellites and other sensors … will deprive an opponent of initiative on the battlefield and [make it difficult] for [the United States] to bring their precision guided weapons into full play."[498] The 2013 *Science of Military Strategy* highlighted space:

> "The development of space force, particularly the military space force, has become a leading component of economic and technological developments, as well as an important foundation for protecting the safety of space assets. Moreover, it supports the effort in improving strategic deterrence capability and the expansion in national interests. It is extremely meaningful to build an informatized military force, win informatized wars, and push forward the strategic transformation of the army."[499]
>
> "In order to effectively deter other countries' unfriendly activities in the space and to prevent the damage and disruption of own space system, we should develop offensive capability in the space to a certain extent while keep improving defensive capability in the space. In case of necessary, we need to demonstrate the ability to incur fundamental damage and impacts to other's space system and our firm determination to utilize the capacity. In this way, we are creating psychological pressure and fear to the enemy, to force them not to initiate space operation and war against us."[500]

The 2013 *Science of Military Strategy* also stated:

> "[we should] insist using multiple methods in various domains including land, sea, air, space, cyberspace, and electromagnetic to disrupt the communication system which could cut the

[498] Cordesman, Anthony, Steven Colley and Michael Wang. *Chinese Strategy and Military Modernization in 2015: A Comparative Analysis.* Report. October 10, 2015, pg. 37. https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/150901_Chinese_Mil_Bal.pdf.
[499] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.179. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. pg.14-15. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.
[500] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.182. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf, pg.16

> connection between space and the earth. Thus, the enemy will not be able to operate its space system."[501]

The stakes in the U.S.-China space competition versus U.S.-China counter-space competition, then, are high and unlikely to diminish in coming years and decades. Even as cognitive capabilities grow more prominent in militaries around the world, the need to connect, communicate and target through space-based architecture will persist. This is why the Jane's project team ranked China's counter-space advanced weapons system program of most importance *to China*. Asymmetric denial of U.S. space assets is the ultimate game-changer and game-leveler, a sentiment that emerged in Jane's Implications and Recommendations Workshop.

China's counter-space advanced weapons system program also stands out among the other programs of interest to this paper in that it is not defined by a specific technology—as MaRVs, directed energy, EM weapons, autonomous unmanned systems are—but by an objective, an effect. As a result, there are several technologies/capabilities that contribute to a robust counter-space capability, ranging from highly provocative and escalatory measures such as ASAT missiles to more subtle approaches, such as using cyber-attacks, laser dazzlers and co-orbital satellites or space-craft. This section covers each of these areas of Chinese capability and also includes contextual analysis and background information on China's dual-use space program, which is one pathway through which China's counter-space capabilities are developed and deployed.

China's Dual-Use Space and Counter-Space Program

China has become a global space power after decades of investment.[502] According to the 2015 U.S. DoD Annual Report to Congress, China's progress in the development of its space program has been mirrored by developments in its counter-space program:

> "China possesses the most rapidly maturing space program in the world. In parallel with its space program, China continues to develop a variety of capabilities designed to limit or prevent the use of space-based assets by adversaries during a crisis or conflict, including the development of directed energy weapons and satellite jammers."[503]

While China's space program is dual-use, the PLA is thought to have strong influence.[504] The program's activities are leveraged for both military and civilian purposes. This arrangement is an important enabler of China's counter-space program growth in two ways. First, it allows the civilian China National Space Administration (CNSA) and supporting academic, research and industry infrastructure, including CASIC and CASC, to acquire technology and "know-how" from Western space programs without being constrained by arms embargoes. Through CMI and the dual-use nature of the program, this technology subsequently can be applied for military purposes.[505]

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[501] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.130-131. Translation from Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California, San Diego. September 2015, pg.21. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.
[502] Lambakis, Steve. *Foreign Space Capabilities: Implications for U.S. National Security.* Report. pg. 22. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.
[503] Malenic, Marina. "China's rapid Counterspace Capabilities Development Alarms Pentagon," *Jane's by IHS Markit*. May 11, 2015. https://janes.ihs.com/Janes/Display/jdw58586-jdw-2015.
[504] Koren, Marina, "China's Growing Ambitions in Space," January 23, 2017. https://www.theatlantic.com/science/archive/2017/01/china-space/497846/.
[505] Jane's by IHS Markit, "Strategic Weapon Systems," April 7, 2017. https://janes.ihs.com/Janes/Display/cnaa015-cna.

China is not shy about acknowledging the importance of these civilian collaborations, even with international firms, to catch-up and then surpass leading space powers. As Wang Chi of the National Space Science Center at the Chinese Academy of Sciences said in 2016: "International collaborations are the shortcut for China to catch up with the world."[506]

Second, the dual-use nature of the program means that China can develop novel space and counter-space military capabilities under the cover of a legitimate civil imperative. Rapid launch satellites, for example, are ostensibly developed to enhance natural disaster response, though they clearly can also be used to reconstitute or augment surveillance infrastructure in a time of conflict or crisis. Similarly, directed energy lasers have a scientific purpose and a counter-space one; lasers are used to locate space debris and satellites as well as calibrate telescopes, but they can also temporarily blind or permanently damage satellites. Co-orbital satellites and spacecraft can fix damaged satellites or damage working ones. The capability itself is neutral. It is the application that determines the intent.

China's Counter-Space Capabilities

China's counter-space capabilities overlap with other weapons systems explored in this report—particularly directed energy—and typically fall into one of four main categories:

1. Direct ascent ASAT weapons
2. Co-orbital ASAT weapons
3. Directed energy weapons
4. Cyber weapons

Key components of these programs and developments within them are discussed below:

Direct Ascent ASAT Weapons

Direct-ascent ASAT weapons are capable of being launched from the ground to hit and destroy a selected target satellite in space. They do not establish a presence in space nor do they go into orbit.

China's interest in direct ascent weapons dates back to at least 2000 and gained momentum in 2002 with the development of the Kaituozhe-1 (KT-1), seen as a likely candidate to deliver a kinetic kill vehicle into space. The KT-1 is a 16.1-meter-long, 1.7-meter diameter,[507] solid-propellant, three-stage space launch vehicle (SLV),[508] and may be a smaller version of the DF-31A.[509] Reportedly there were two tests of the KT-1 as an ASAT weapon: a July 2005 close fly-by of a Chinese satellite, and a February 2006 failed satellite interception.[510]

China infamously sparked international outrage in January 2007 when it launched a kill vehicle from the Xichang satellite launch center at a defunct Chinese weather satellite in orbit 500 miles above the earth.[511] Reportedly, the vehicle was the DF-21-based KT-1, which the U.S. Senate Armed Services Committee refers to as the "SC-19."[512] The impact generated thousands of pieces of debris

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506 Lambakis, Steve. *Foreign Space Capabilities: Implications for U.S. National Security.* Report. pg. 20. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.
507 Jane's by IHS Markit. "ASAT," September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
508 Jane's by IHS Markit. "ASAT," September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
509 Jane's by IHS Markit. "DF-31," February 29, 2016. https://janes.ihs.com/Janes/Display/jsws0415-jsws.
510 Jane's by IHS Markit. "ASAT." September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
511 Jane's by IHS Markit. "ASAT." September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
512 Jane's by IHS Markit. "Strategic Weapon Systems." April 7, 2017. https://janes.ihs.com/Janes/Display/cnaa015-cna.

into Earth's orbit, which continue to pose a serious threat to other satellites and spacecraft, including the International Space Station.[513]

The incident created international outrage, and China has not destroyed a satellite in space since. But it did not stop China's efforts to expand its direct-ascent ASAT capabilities. Additional tests and developments include:

- China may be looking to develop aircraft-launched ASAT missiles. In the April 2009 issue of *Aircraft Design*, Su Lian-dong of the 601 Institute stated that such an attack system is "feasible and reasonable…in the present stage." The Shenyang Aircraft Corporation may have been looking to modify its J-11 fighter into carry an ASAT weapon.[514]

- China tested the SC-19 again on January 11, 2010 with a ground-based mid-course missile interception test, using a kinetic kill vehicle.[515]

- China carried out an ASAT test in 2013 to an altitude above 30,000 km[516], almost reaching geosynchronous orbit.[517] The U.S. DoD reported that "analysis of the launch determined that the booster was not on the appropriate trajectory to place objects in orbit and that no new satellites were released," and the launch profile was inconsistent with traditional launch vehicles, ballistic missiles or scientific systems.[518] The vehicle launched may have been the KZ-1, a three-stage rocket based on the motor of the DF-21, which is able to launch to low earth orbit (LEO). The KZ-1 may be able to deliver a small nuclear warhead intercontinentally.[519]

- On May 13, 2013, a DN-2 missile conducted a near intercept in medium earth orbit.[520]

- On July 23, 2014, China conducted a non-destructive test of a missile designed to target satellites in LEO. Chinese officials said the test was for a missile defense system[521] but the launch "had a similar profile to the January 2007 test."[522]

- On October 30, 2015, the DN-3 vehicle was reportedly used in another ASAT test, launched from the Korla Missile Test Complex.[523] In July 2017, China tested the DN-3 a second time

[513] Jane's by IHS Markit. "Fengyun series," June 30, 2017. https://janes.ihs.com/Janes/Display/jsd_0475-jsd.
[514] Fisher, Richard and Sean O'Connor. "Space invaders – China's Space Warfare Capabilities," *Jane's by IHS Markit*. July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia.
[515] Jane's by IHS Markit. "Strategic Weapon Systems." April 7, 2017. https://janes.ihs.com/Janes/Display/cnaa015-cna.
[516] Malenic, Marina. "China's rapid counterspace capabilities development alarms Pentagon." Jane's by IHS Markit. May 11, 2015. https://janes.ihs.com/Janes/Display/jdw58586-jdw-2015.
[517] Lambakis, Steve. *Foreign Space Capabilities: Implications for U.S. National Security.* Report, pg. 42. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.
[518] Malenic, Marina. "China's Rapid Counterspace Capabilities Development Alarms Pentagon," Jane's by IHS Markit. May 11, 2015. https://janes.ihs.com/Janes/Display/jdw58586-jdw-2015.
[519] Fisher, Richard. "Chinese Dual-use Missiles and Satellites Point to Emerging 'Prompt Global Strike' Capability," *Jane's by IHS Markit*. November 12, 2015. https://janes.ihs.com/Janes/Display/jdw60294-jdw-2016.
[520] Fisher, Richard. "US sources: China tests new 'DN-3' interceptor missile," Jane's by IHS Markit. November 11, 2015. https://janes.ihs.com/Janes/Display/jdw60283-jdw-2016.
[521] Cordesman, Anthony, Steven Colley and Michael Wang,, *Chinese Strategy and Military Modernization in 2015: A Comparative Analysis.* Report. October 10, 2015. pg. 37. https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/150901_Chinese_Mil_Bal.pdf.
[522] Malenic, Marina. "China's rapid counterspace capabilities development alarms Pentagon," *Jane's by IHS Markit*, May 11, 2015. https://janes.ihs.com/Janes/Display/jdw58586-jdw-2015.
[523] Jane's by IHS Markit. "ASAT," September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.

from the Jiuquan Satellite Launch Center, though reports suggest that the test was not as successful as the October 2015 test.[524]

- In February 2016, Jane's reported on rumors of an ASAT version of the DF-31 (known as DF-31A), a 13-meter-long[525] three-stage solid-propellant rocket with a range of 11,200 kilometers.[526]

Directed Energy

Directed energy weapons include lasers, high-powered microwaves, radio frequency weapons and particle beam weapons. For counter-space purposes, they are designed to permanently or temporarily affect a satellite and its systems. A laser can "dazzle" or blind a satellite's sensors for a short-period of time or a higher-powered laser can completely destroy the satellite's capacity to function. Therefore, directed energy counter-space capabilities can be tailored or moderated to achieve specific effects and therefore can be less escalatory or provocative, depending on the context of their use, than direct ascent ASAT weapons. They can also be deployed on satellites in space or operated against adversary space assets from locations on the ground, offering a degree of flexibility and redundancy to directed energy counter-space operations.[527]

China's interest in directed energy as a counter-space weapon goes back to as early as December 1998. A report from that year stated that a Chinese deuterium fluoride chemical laser capable of damaging sensors on a satellite in LEO had become operational in mid-1998. [528]

More recent developments include:

- In September 2005, the U.S. Government reported that China "jammed" a U.S. satellite with lasers.[529] This report seemed to be confirmed by a 2013 journal article, where three Chinese researchers revealed that they had successfully used a laser to blind a satellite in 2005. The researchers wrote that from Xinjiang Province, they had used a laser with a capacity range of 50 to 100 kW and a beam only .6-meters-wide, to target a LEO satellite. [530]

- In 2006, China temporarily blinded a U.S. reconnaissance satellite with a laser. China claimed it was only testing the laser for range-finding, but the test proved that China could not only locate foreign satellites, it could disable them. China reportedly has five laser range-finders at fixed locations throughout the country.[531]

- In December 2013, the article that confirmed the 2005 satellite dazzling test was published. Written by three researchers from the Changchun Institute for Optics, a leading center for lasers, Gao Ming-hui, Zeng Yu-quang and Wang Zhi-hong discussed their proposal for a 5-ton

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[524] Jane's by IHS Markit. "ASAT," September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
[525] Jane's by IHS Markit. "DF-31," February 29, 2016. https://janes.ihs.com/Janes/Display/jsws0415-jsws.
[526] Jane's by IHS Markit. "DF-31," February 29, 2016. https://janes.ihs.com/Janes/Display/jsws0415-jsws.
[527] Fisher, Richard and Sean O'Connor, "Space invaders – China's Space Warfare Capabilities," *Jane's by IHS Markit*. July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia.
[528] Jane's by IHS Markit. "Laser weapons," March 3, 2017. https://janes.ihs.com/Janes/Display/jsws0514-jaad.
[529] Jane's by IHS Markit. "Strategic Weapon Systems," April 7, 2017. https://janes.ihs.com/Janes/Display/cnaa015-cna.
[530] Gertz, Bill. "How China's Mad Scientists Plan to Shock America's Military: Super Lasers, Railguns and Microwave Weapons." *National Interest*, March 10, 2017. http://nationalinterest.org/blog/the-buzz/how-chinas-mad-scientists-plan-shock-americas-military-super-19737.
[531] Lambakis, Steve. *Foreign Space Capabilities: Implications for U.S. National Security*. Report. pg. 24. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.

> chemical laser deployed in LEO, which could target other satellites. They theorized that the weapon could be ready by 2023.[532]
>
> The authors expounded on the necessity of this space-based ASAT laser: "In future wars, the development of ASAT 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."[533]

In addition to lasers, China is also developing radio frequency weapons. According to Kevin Pollpeter's February 2015 testimony to the U.S.-China Economic and Security Review Commission:

> "China is also researching radio frequency (RF) weapons that could be used against satellites. Radio frequency weapons using high power microwaves can be ground-based, space-based, or employed on missiles to temporarily or permanently disable electronic components through overheating or short-circuiting. RF weapons are thus useful in achieving a wide spectrum of effects against satellites in all orbits. Because RF weapons affect the electronics of satellites, evaluating the success of an attack may be difficult since no debris would be produced."[534]

Co-Orbital ASAT Weapons

Co-orbital weapons are weaponized satellites that are placed in orbit but can then be deployed in missions against specific targets. These satellites can be armed with explosives and directed energy weapons, among other payloads. Co-orbital satellites can also destroy target satellites by crashing into their targets ("suicide satellites") or by navigating close enough to the target to release a robotic arm that can be used to damage or destroy the target ("assassin satellites"). Assassin satellites, in particular, take advantage of the dual-use nature of China's space program as it is easy to claim that their primary purpose is to repair satellites rather than destroy them.

Notable recent co-orbital satellite activities include:

- In 2008, China navigated a nanosatellite close enough to the International Space Station to spark international alarm.[535] The small satellite was launched from China's Shenzhou 7 capsule, which had just housed three taikonauts for China's first successful spacewalk.[536] The SH-7 capsule was close to the International Space Station, but in a different orbit with no chance of collision. The nanosatellite, called the BX-1, drifted away from the SH-7, towards the International Space Station, reportedly to take photos of the Chinese capsule. While the BX-1 moved relatively close to the International Space Station, its camera was focused on

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532 Gertz, Bill. "How China's Mad Scientists Plan to Shock America's Military: Super Lasers, Railguns and Microwave Weapons." *National Interest*, March 10, 2017. http://nationalinterest.org/blog/the-buzz/how-chinas-mad-scientists-plan-shock-americas-military-super-19737.

533 Gertz, Bill, "Get Ready for China's Laser-Weapons Arsenal," *National Interest,* April 12, 2017, http://nationalinterest.org/blog/the-buzz/get-ready-chinas-laser-weapons-arsenal-20138.

534 Pollpeter, Kevin, "Testimony on China's Civilian / Dual–Use Military Space Program," U.S.-China Economic Security and Review Commission, Report on February 18, 2017 Hearing on China's Space and Counter-space Programs. https://uscc.gov/sites/default/files/Pollpeter_Testimony_0.pdf.

535 Lambakis, Steve. *Foreign Space Capabilities: Implications for U.S. National Security.* Report. pg. 23. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.

536 Weeden, Brian. "China's BX-1 Microsatellite: A Litmus Test for Space Weaponization," *Space Review*, October 20, 2008. http://www.thespacereview.com/article/1235/1.

the SH-7 capsule the entire time. It appears to have been a coincidence that the test occurred near the International Space Station, but the test still shows China's advancements in satellite maneuverability and satellite inspection (which could be used to plan out a space-based ASAT attack).[537]

- A November 21, 2009 report from the PLAAF expressed interest in co-orbital ASAT platforms such as "assassin satellites, laser interceptor satellites" and an "orbital bomber."[538]

- In August 2010, China appeared to test navigation capabilities of closely spaced objects when it navigated two satellites together and then apart.[539]

- In September 2013, China announced it had tested a co-orbital repair satellite with a robotic arm, most likely the Shiyan-7 or the SJ-15. The robotic arm could also be used to damage a satellite.[540]

- In June 2016, CASC launched its Aolong-1 or "roaming dragon" spacecraft. CASC said the Aolong-1 is an unmanned spacecraft with a civil government mission that will improve safety in space: the ship will use its robotic arm to clean up space debris in orbit by grabbing inactive satellites and other junk and throwing them out of orbit to burn up in the atmosphere. However, Beijing's National Astronomical Observatories said that it would be unrealistic for robots to remove the vast amount of trash in Earth's orbit. This statement suggests that the Aolong-1 has other purposes, including augmenting the diversity of China's co-orbital ASAT weapons.'[541]

  Later in June 2016 China launched its first satellite refueling system, the Tianyuan-1 which has been tested successfully.[542]

- In October 2016, China launched the Banxing-2 (BX-2), the next version of the 2008 satellite which will be used to co-orbit the Tiangong-2. Its 1.3-megapixel camera will be used to monitor the space station.[543] Just as with the BX-1, the BX-2 will be another test of China's co-orbiting capabilities.

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537 Weeden, Brian. "China's BX-1 Microsatellite: A Litmus Test for Space Weaponization," *Space Review*, October 20, 2008. http://www.thespacereview.com/article/1235/1.
538 Fisher, Richard and Sean O'Connor. "Space Invaders–China's Space Warfare Capabilities," *Jane's by IHS Markit*, July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia.
539 "ASAT." Jane's by IHS Markit. September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.
540 Fisher, Richard and Sean O'Connor. "Space invaders - China's space warfare capabilities." Jane's by IHS Markit. July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia.
541 Mizokami, Kyle. "Is China's Space Junk Collector a Weapon in Disguise?" *Popular Mechanics*. October 14, 2016. http://www.popularmechanics.com/military/weapons/a21627/china-space-junk-collector-potential-weapon/
542 Lin, Jeffery and P.W. Singer. "China's Largest Space Launch Vehicle, the Long March 7 Flies, with a Technological Triple Whammy." *Popular Science.* July 8, 2016. https://www.popsci.com/chinas-largest-space-launch-vehicle-long-march-7-flies-with-technological-triple-whammy.
543 *Space Flight 101,* "Companion Satellite released from Tiangong-2 Space Lab for Orbital Photo Shoot." October 23, 2016. http://spaceflight101.com/tiangong-2/companion-satellite-released-from-tiangong-2/.

- In November 2016, China launched the Shijian-17 which will use its optical-sensing payload to observe space debris from high orbit. The spacecraft could be used to approach and identify other spacecraft.[544] The Shijian-17 is also testing ion propulsion.[545]

Cyber ASAT Capabilities
China's 2015 Military Strategy White Paper states that space and cyber constitute the "commanding heights of warfare." China has clearly prioritized enhancing their capabilities and position in both domains. The intersection of the two domain areas—the use of cyber-capabilities in space—offers another opportunity for China to degrade, disable and destroy U.S. space-based assets and infrastructure without the attribution that necessarily accompanies ASAT missile strikes and, in most cases, other types of counter-space/ASAT attacks.

Attribution of cyber-attacks is exceptionally difficult, of course, but several cyber-attacks against U.S. space-assets have taken place since 2007. Previous reports by the U.S.-China Economic and Security Review Commission found that "Chinese hackers have likely been responsible" for these computer network operations, which have led to U.S. satellites being unable to operate for several minutes at a time.[546]

Other Space and Counter-Space Technology Developments

Hyper-spectral imaging satellite
China launched the world's most powerful hyperspectral imagining satellite at the start 2016. The satellite is able to simultaneously view hundreds of EM bands and creates a single layered image. This process can reveal objects concealed on one part of the spectrum, such as thermally shielded stealth aircraft. The process can also reveal hidden objects such as underground bunkers, tunnels and submarines. Hyperspectral imagers are used in crop measurement, oil prospecting, finding improvised explosive devices and discovering minerals underground. While the satellite will serve scientific and commercial purposes, it is also available for military use.[547]

Quantum satellite
On August 16, 2016, China was the first country to publicly launch a quantum communications satellite, the Quantum Experiments at Space Scale (QUESS), discussed in more detail in Chapter 2. The satellite has "a quantum key communicator, quantum entanglement emitter, entanglement source, processing unit, and a laser communicator." At an orbit of 1,000 kilometers above Earth, the satellite has been used to conduct groundbreaking quantum tests to include the first space-to-ground transmission of quantum decryption keys from the satellite to ground stations in China and Austria[548] and a quantum encrypted video call in September 2017.[549]

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[544] "China's Shijian-17 Satellite settles in Geostationary Orbit for Experimental Mission." *Space Flight 101*. November 24, 2016. https://spaceflight101.com/cz-5-maiden-flight/shijian-17-settles-in-geostationary-orbit/.
[545] Lin, Jeffery and P.W. Singer. "EmDrive: China claims success with this 'reactionless' engine for space travel." *Popular Science.* December 19, 2016. https://www.popsci.com/emdrive-engine-space-travel-china-success.
[546] U.S.-China Economic and Security Review Commission, "China's Space and Counterspace Programs," *2015 Report to Congress*, November 2015, http://origin.www.uscc.gov/sites/default/files/annual_reports/2015%20Annual%20Report%20to%20Congress.PDF.
[547] Lin, Jeffrey and P.W. Singer. "China to Launch Powerful Civilian Hyperspectral Satellite," *Popular Science*, January 25, 2016. http://www.popsci.com/china-to-launch-worlds-most-powerful-hyperspectral-satellite#page-4.
[548] Lin, Jeffrey and P.W. Singer. "China Launches Quantum Satellite in Search of Unhackable Communications." *Popular Science*, 17 August 2016. http://www.popsci.com/china-launches-quantum-satellite-in-search-for-unhackable-communications.
[549] Leary, Kyree. "Scientists Have Conducted the First Ever Quantum Video Call," *Futurism*, October 2, 2017. https://futurism.com/scientists-have-conducted-the-first-ever-quantum-video-call/.

Chinese scientists will also test "other quantum technologies such as photon teleportation, transmission error reduction and random number generators."[550] The QUESS program aims to build a quantum key distribution network by 2020 and a global quantum communication network by 2030.[551] China is almost certainly looking toward quantum encryption because of concerns about espionage and information security, especially after Edward Snowden revealed the NSA's widespread ability to monitor existing telecommunications.[552]

Both of these advancements show China's efforts to grow its space architecture as part of its "informationized" military modernization. Both programs also aim to make China a world leader in cutting edge technology, and to degrade U.S. advantage in stealth and communications.

U.S. Development Initiatives and Programs

Studies of ground-based ASATs began in 1988 under the U.S. Army's direction. The Kinetic Energy Anti-Satellite (KE-ASAT) program began in 1990 with a contract with Rockwell International (now Boeing). 150 KE-ASATs were expected to be ordered, but the project was zero funded in 1993 by the Clinton Administration. Testing began again in 1994, with a subsequent test in 1997 and possible flight tests of vehicles in 2006 and 2007.[553]

In 2004, the U.S. Air Force launched the XS-10 experimental satellite, which rendezvoused with old satellites in LEO. The XS-11 project followed with more testing of rendezvous. In 2005, NASA launched the Demonstrator of Autonomous Rendezvous Technologies system, but the program appears to have been simply for improving interception, not for any ASAT or counter-space purposes.[554]

It is believed that the DoD revisited ASAT programs after the 2007 Chinese ASAT test. In February 2008, a modified Raytheon Standard Missile-3 successfully intercepted a failing U.S. satellite at 247 kilometers above the Earth's surface. This test also led the United States to believe that modified THAAD interceptors could be used as ASAT weapons.[555]

In 2008, the Orbital Express and MiTEx Satellites demonstrated U.S. ability to reach and inspect satellites in geostationary orbit. The X-37B orbital test vehicle launched in 2010 and successfully navigated close enough to other satellites to conduct repairs or disable then returned to Earth. A second vehicle was launched in 2011 and stayed in space for a year. The first X-37B vehicle launched again for a third run in 2012 and a fourth test run launched in 2015. [556]

In August 2011, the U.S. Air Force began launching the Commercially Hosted Infrared Payload (CHIRP) on commercial communication satellites. CHIRP is a wide field-of-view infrared sensor that will maintain situational awareness for the satellite, tracking the activity of any other objects close to the asset.[557]

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[550] Lin, Jeffery, P.W. Singer and John Costello. "China's Quantum Satellite Could Change Cryptography Forever," *Popular Science*, March 3, 2016. http://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever.
[551] Lin, Jeffery, P.W. Singer and John Costello. "China's Quantum Satellite Could Change Cryptography Forever," *Popular Science*. March 3, 2016. http://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever.
[552] Lin, Jeffery, P.W. Singer and John Costello. "China's Quantum Satellite Could Change Cryptography Forever." *Popular Science*. March 3, 2016. http://www.popsci.com/chinas-quantum-satellite-could-change-cryptography-forever.
[553] *Jane's,* "KE-ASAT," September 15, 2017, https://janes.ihs.com/Janes/Display/jsws0541-jsws.
[554] *Jane's,* "KE-ASAT," September 15, 2017, https://janes.ihs.com/Janes/Display/jsws0541-jsws.
[555] *Jane's,* "KE-ASAT," September 15, 2017, https://janes.ihs.com/Janes/Display/jsws0541-jsws.
[556] *Jane's,* "KE-ASAT," September 15, 2017, https://janes.ihs.com/Janes/Display/jsws0541-jsws.
[557] Malenic, Marina, "US Eyes Collaboration to Maintain Strategic Advantage in space," *Jane's*, July 21, 2011, https://janes.ihs.com/Janes/Display/jdw46648-jdw-2011.

In July 2014, the Air Force launched two Geosynchronous Space Situational Awareness Program (GSSAP) satellites into orbit. The two satellites have advanced imaging capabilities and will be a "neighborhood watch" system that will monitor foreign assets for any "nefarious capability" in geosynchronous orbit.[558] Two more satellites in the program were launched in August 2016.[559]

Former National Security Advisor H.R. McMaster reported in early October 2017 that a new space strategic framework is in development and that greater counter-space threats are one of the major motivations for a new framework.[560] On June 30, 2017 President Trump revived the National Space Council and in March 2018, the White House released the "America First National Space Strategy" which includes four pillars that center on protecting U.S. space assets[561]:

1. "Transform to more resilient space architectures: We will accelerate the transformation of our space architecture to enhance resiliency, defenses, and our ability to reconstitute impaired capabilities

2. Strengthen deterrence and warfighting options: We will strengthen U.S. and allied options to deter potential adversaries from extending conflict into space and, if deterrence fails, to counter threats used by adversaries for hostile purposes

3. Improve foundational capabilities, structures, and processes: We will ensure effective space operations through improved situational awareness, intelligence, and acquisition processes

4. Foster conducive domestic and international environments: We will streamline regulatory frameworks, policies, and processes to better leverage and support U.S. commercial industry, and we will pursue bilateral and multilateral engagements to enable human exploration, promote burden sharing and marshal cooperative threat responses."

Implications for Future Competition with the United States

China's counter-space program is a central component of the space versus counter-space competition highlighted in the opening chapter of this report and poses a threat to U.S. space-based architecture. In the last decade, China has already demonstrated a functional capacity to hold at risk U.S. satellites and has reportedly used directed energy and cyber-capabilities against U.S. assets in space. China will work to make these capabilities more technically sophisticated and robust, given the priority ascribed to targeting perceived U.S. vulnerability in space. But the capability already exists and is already complicating U.S. efforts to deter conflict in space and secure critical space infrastructure.

Jane's contributor Richard D. Fisher Jr. and imagery intelligence analyst Sean O'Connor reported in 2014 that: "Imaging satellites in low earth orbit can currently be threatened by either direct-ascent ASATs such as the SC-19, or laser ASATs," and the DN-2 could target satellites in mid-earth and geosynchronous orbits.[562]

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[558] Malenic, Marina, "USAF to Place Two Situational Awareness Satellites into Orbit," *Jane's*, July 23, 2014, https://janes.ihs.com/Janes/Display/jdw56005-jdw-2014.

[559] "GSSAP (Geosynchronous Space Situational Awareness Program) Series," *Jane's*, September 13, 2016, https://janes.ihs.com/Janes/Display/jsd_a458-jsd.

[560] Host, Pat, "Blue Origin to Start BE-4 Engine Testing 'Soon'," *Jane's*, October 6, 2017.

[561] "President Donald J. Trump is Unveiling an America First National Space Strategy," White House Fact Sheet, March 23, 2018. https://www.whitehouse.gov/briefings-statements/president-donald-j-trump-unveiling-america-first-national-space-strategy/

[562] Fisher, Richard and Sean O'Connor. "Space Invaders – China's Space Warfare Capabilities," *Jane's by IHS Markit*. July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia.

But China's counter-space capabilities are broader than direct ascent weapons, which offer an inelegant capability that could, through the production of dangerous space debris and international outrage, end up being counter-productive. Few, if any analysts, doubt China's willingness to use direct ascent weapons in the context of an active or imminent conflict, but less attributable, less escalatory, less provocative capabilities are now available, complicating the U.S. mission of deterring China in space.

The combined result of these programs is summarized by Air Force Major General Nina Armagno who recently warned that "Russia and China, by the year 2025, will be able to hold at risk every one of (U.S.) satellites in any orbit."[563] Or, as a senior Air Force official offered in an October 2016 *National Interest* article, "there is no one node [in the U.S. military's spaced-based architecture] that is invulnerable to attack."[564]

But China's burgeoning capacity to hold at risk individual satellites does not necessarily mean that China's counter-space capabilities constitute a trump card for which there is no effective U.S. strategic or operational response.

Indeed, the U.S. Air Force is investing in both capabilities—some listed above—and concepts designed to enhance resilience and redundancy of the U.S. space architecture through disaggregation, a concept that focuses on "creating resiliency by spreading capabilities across diverse platforms."[565]

Manifestations/examples of disaggregation include:

- Enabling U.S. assets to operate using the European global navigation satellite system—GALILEO—if the U.S. GPS is compromised, degraded, diminished or disabled

- Investing in microsatellites—satellites weighing less than 300 kilograms—that can be launched cheaply and quickly into space. These satellites' small size enables for a large number to be put into orbit in an affordable way, ensuring both resilience and the capacity to rapidly reconstitute satellite infrastructure if it has already been compromised

- Placing multiple satellites into space responsible for carrying out a specific mission as the costs of space launch come down.

Further development of approaches to hardening individual satellites are also part of the suite of investments and solutions the U.S. Air Force and DoD are making to counter China's counter-space program. Specific hardening measures against electronic warfare/directed energy attacks and co-

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563 Lambakis, Steve, *Foreign Space Capabilities: Implications for U.S. National Security.* Report, pg. 43. http://www.nipp.org/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.
564 Osborn, Kris, "U.S. Air Force Has a Plan to Counter China's Super Lethal 'Satellite-Killer Weapons', *National Interest,* October 31, 2016, http://nationalinterest.org/blog/the-buzz/us-air-force-has-plan-counter-chinas-super-lethal-satellite-18247.
565 Wegner, Peter, Adang, Thomas, Rhemann, Maureen, "How to Make Disaggregation Work," *Air and Space Power Journal,* U.S. Air Force Air University, November-December 2015, http://www.airuniversity.af.mil/Portals/10/ASPJ/journals/Volume-29_Issue-6/C-Wegner_Adang_Rhemann.pdf.

orbital satellites range from the provision of counter-measures to more maneuverability to more classified means of building in resilience.[566]

The U.S. DoD is hedging its bet in space as well. Programs like the U.S. Defense Advanced Research Projects Agency's (DARPA') Micro-PNT (position, navigation and timing) is just one example of extant programs designed to allow U.S. platforms and systems to navigate in case U.S. space architecture is compromised. This program is developing high-performance miniature inertial sensors to enable self-contained inertial navigation for precise guidance in the absence of GPS.[567]

Moreover, China's continued investment in each of the three transitions of its military modernization has required China to build a more extensive space architecture as well. According to the Beidou global navigation satellite system website, Beidou's "space section contains five geostationary orbit satellites and 30 non-geostationary orbit satellite(s)."[568] It seeks to have global coverage by 2020.[569]

The presence of these satellites creates new capabilities and new vulnerabilities for China, highlighting at least one of the challenges associated with trying to keep up with the United States as well as with transitioning from a primarily A2/AD focus to growing emphasis on power projection capabilities. U.S. capacity to hold China's space-based infrastructure at risk could be used in a time of crisis to deter or dissuade Chinese counter-space activity against U.S. space systems. Survivability in space, then, can be enhanced by causing China to spend resources to defend their own space assets rather than target those of the United States and/or its allies.

Ultimately, though, the development of novel Chinese counter-space capabilities is part of an iterative competition to establish advantage, mitigate risk, exploit emerging competitor vulnerabilities and, where possible, force adversary trade-offs. The combination of spiraling measures and counter-measures ensures that as China's counter-space capabilities grow even more mature, the United States will still have opportunities to maintain longer-term strategic advantage.

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[566] Osborn, Kris, "U.S. Air Force Has a Plan to Counter China's Super Lethal 'Satellite-Killer Weapons'," *National Interest,* October 31, 2016, http://nationalinterest.org/blog/the-buzz/us-air-force-has-plan-counter-chinas-super-lethal-satellite-18247.
[567] DARPA. "Micro-Position, Navigation and Timing," https://www.darpa.mil/program/micro-technology-for-positioning-navigation-and-timing.
[568] Beidou Navigation Satellite System, "Survey," System Overview, http://www.beidou.gov.cn/2012/12/14/201212142e8f29c30e0d464c9b34d6828706f81a.html.
[569] Beidou Navigation Satellite System, "Development Plan," System Overview, http://www.beidou.gov.cn/2012/12/14/2012121481ba700d7ca84dfc9ab2ab9ff33d2772.html.

Chapter 6: China's Unmanned Systems

Chapter 6 Key Themes and Insights

- **Rapidly Growing Sector:** The unmanned systems sector is China's most rapidly growing of the five advanced weapon systems, especially in UAVs. China has become a major military drone exporter since 2010 and dominates the commercial and retail drone market, particularly UAVs and USVs by market volume and velocity. For example, over 50 UAV system designs were announced by Chinese companies in the summer of 2017, most are currently in marketing, so at an early stage of development.

- **From Imitation to Innovation:** Much of China's growth in the UAV market has been built upon a capacity to imitate Western designs and produce lower-end capabilities with Chinese characteristics. And while China's unmanned industry is still using Western intellectual property in many of its UAV and USV designs, China is developing both the technical competence and confidence to engage in more indigenous innovation in UAV and USV designs.

- **Supporting China's Military Modernization:** Unmanned systems are a critical capability supporting all three of China's military modernization objectives identified in Chapter 1 as well as supporting China's efforts to disrupt military competitions in the electromagnetic spectrum and undersea domain in particular. UAVs, USVs and UUVs will be used for a range of missions: ISR, mine countermeasure operations, strike missions, electronic warfare, environmental monitoring, installation and force protection and command, control and communications function. The future battlefield will be infested with relatively cheap and expendable unmanned systems.

- **Intersections with Artificial Intelligence:** AI-infused highly autonomous unmanned systems will be a central feature of the future of the intelligentized battlefield. Of particular interest, and constituting a particularly disruptive capability, are drone swarms; groups of networked unmanned drone systems capable of operating as a single body with separate mutually reinforcing roles in support of a pre-programmed mission. In June 2017, China crossed an important threshold in the development of an actual swarmed capability, testing a swarm of 119 drones. China's successful development of swarms could shift the operational parameters of the U.S.-China military-technological competition.

- **Private Sector and Academia Involvement:** China's defense private sector plays a more prominent role in China's unmanned systems industry than in other advanced weapons systems of interest to this paper, especially in UAV and USV development. China's UUV development centers around academic and research institutes as well as a small group of large state-owned enterprises.

- **Technology Challenges and Focus Areas:** Satellite connection, and thus range, is one constraining factor Jane's identified. However, Jane's experts believe this gap will be addressed within the next decade. China also seeks to develop technologies that will enable more efficient strength, weight and power and cost trade-offs, longer endurance and persistence, enhanced autonomy and greater modularity in unmanned systems development.

- **Implications for Strategic Competition with the United States:** Unmanned systems of all kinds will play an important role in changing the competitive dynamics in the undersea domain, the electromagnetic spectrum, as well as impacting the missile versus missile defense competition by contributing to improved C4ISTAR infrastructure. In conjunction with developments in AI, they also will be central to the transition to more cognitive kinds of military capabilities.

Overview on Unmanned Systems

Unmanned systems have been used in military contexts for over 100 years, initially as drone targets for testing and evaluation or training purposes. In the last twenty years, the use of UAVs (also frequently referred to as drones) has expanded and accelerated to the point where unmanned systems are a common—and for many missions, preferred—feature of the battlefield.

As a result, the UAV landscape is remarkably diverse with a growing number of individual systems—fixed wing, rotary wing and hybrid aircraft—in a range of categories of systems being developed and deployed. Discussion of UAVs as a single capability can be excessively broad and vague, given the diversity of missions, configurations, sizes and specifications of UAVs. U.S. military services previously defined UAV categories essentially by mission. Different services used slightly different categorization techniques, but all roughly aligned with the below categorization of the market:[570]

- **Close In/Personal:** Small and micro-UAVs that are typically able to be hand-held with little to no launch infrastructure
- **Tactical:** Small UAVs capable of low altitude, short-to-medium range tactical missions
- **Medium-Altitude Long Endurance (MALE):** UAVs typically with an altitude ceiling of 25,000-50,000 feet
- **High-Altitude Long Endurance (HALE):** UAVs capable of flying up to a ceiling of around 65,000 ft

In 2010, the U.S. DoD began the process of creating a common categorization system that groups unmanned aircraft into five groups or classes based on their maximum gross take-off weight (MGTOW, also abbreviated as MTOW), as demonstrated in the table below:

Table 18: Classes of Unmanned Systems[571]

UAS Group	Maximum weight (lbs) (MGTOW)	Nominal operating altitude (ft)	Speed (kilonewtons)	Representative UAS
Group 1	0-20	Up to 1,200	Max 100	RQ-11 Raven, WASP
Group 2	21-55	Up to 3,500	Up to 250	ScanEagle
Group 3	55-1,320	Up to 18,000	Up to 250	RQ-7B Shadow, RQ-21 Blackjack, RQ-23 Tigershark
Group 4	Up to 1,320	Up to 18,000	Any speed	MQ-8B Fire Scout, MQ-1A/B Predator, MQ-1C Gray Eagle
Group 5	Over 1,320	Over 18,000	Any speed	MQ-9 Reaper, RQ-4 Global Hawk, MQ-4C Triton

UAVs are by far the most mature and widely developed and dispersed form of unmanned systems, but they are not the only one. Unmanned ground vehicles (UGVs), unmanned surface vehicles (USVs)

570 Maple, Derrick, "Reign of the Persistent Warrior," *Jane's Intelligence Briefing Series,* November 15, 2016.
571 U.S. Army Unmanned Aerial System Center of Excellence, "Eyes of the Army: U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035," 2010, http://www.rucker.army.mil/usaace/uas/US%20Army%20UAS%20RoadMap%202010%202035.pdf.

and unmanned underwater vehicles (UUVs) are increasingly being developed by militaries and research institutes throughout the world.

This chapter focuses primarily on China's advances and efforts in UAVs, USVs—which are deployed on the surface of the sea or water—and UUVs—which perform an array of "dangerous and dirty" missions as well as surveillance and reconnaissance in the undersea domain.

UAVs can be armed with missiles, rockets, guns/sub-munitions and bombs, though not all are. Armed UAVs are referred to as Unmanned Combat Aerial Vehicles or UCAVs. A current trend in UAVs, in particular, is demand for UAVs to be able to carry out more than one of the below typical UAV missions, depending on the payload a specific system carries:

- ISTAR (intelligence, surveillance, target acquisition and reconnaissance)
- Armed missions
- Swarming
- Electronic warfare
- Logistics
- Security

Unmanned systems across all categories have several critical advantages that make them appealing to military and security communities (see Table 19 below).

Table 19: Advantages of Unmanned Systems

Advantage	Description
Cost	Even the most expensive unmanned systems are in the low tens of millions of dollars per platform, dramatically less than the tens to low hundreds of millions of dollars for the development or procurement of an advanced manned aircraft, submarine, ship or armored vehicle. Unmanned systems, then, offer a low cost, easily available way of building a versatile military capability that can operate in multiple environments. Also, because of their low cost, many unmanned systems can be viewed as expendable.
Safety	Unmanned systems are frequently incorporated because they can perform tasks that might otherwise put a human at risk.
Less Escalatory	Unmanned systems are typically seen, at least for now, as inherently less escalatory as expensive and manned military hardware. The incursion of a UAV, USV or UUV into a "gray zone" or tense and uncertain, but not necessarily conflict environment—for example, the South China Sea—will be more tolerable and less escalatory than the incursion of a destroyer or aircraft carrier.

Current development trends in drones are focused both on enhancing advantages of these platforms and on addressing some of the lingering technical challenges associated with unmanned systems (see Table 20 below).

Table 20: Areas of Focus of Development of Unmanned System Technologies

Attribute	Description
Autonomy	Broadly speaking, innovation in unmanned systems of all types is focused on enhancing the capacity of these vehicles to act autonomously; that is, to make decisions about the environment in which they are operating without having to, as one expert in UUVs noted, "phone home" to a human controller. Fully exploiting the value of unmanned systems across all domains through unmanned swarms or other operational concepts and mission requirements will require greatly-enhanced autonomy and AI.
Persistence	The ability to capture and store sufficient power for unmanned systems to operate for longer periods of time and at longer ranges is also an urgent priority of unmanned systems developed.
Modularity/Multi-Mission	Militaries and security communities are being asked to meet a broader range of threats and to carry out an expanded set of missions. Developing capabilities to meet specific threats or carry out specific missions is fiscally unrealistic, placing a premium on the development of capabilities, both manned and unmanned, that can meet multiple threats. The prominence of armed reconnaissance UAV development programs in China and elsewhere is one example of this trend. So, too, are modular "plug and play" designs that feature a central platform on which modular mission packages can be quickly fitted, depending on the mission requirement.
Latency/Communication	Unmanned systems are powerful tools for enhancing situational awareness for military commanders. However, at operational and tactical levels even a minimal delay of information collected by an unmanned system in its communication to the recipient can lead to a distorted understanding of the environment and less than optimal decisions, enhancing the value of improving the seamlessness and security of communications to and from unmanned systems.
Strength, Weight and Power-Cost	Building unmanned systems—particularly UAVs—that are able to effectively balance the need for more resilience, more payload, more persistence and low cost—one of the central advantages of unmanned systems and a discriminator in a highly competitive market—is a challenge for unmanned systems developers.

Overview of China and Unmanned Systems

According to Derrick Maple, Jane's Senior Principle Analyst for Unmanned Systems, since approximately 2010, China has become a "major power" in commercial and, increasingly, military unmanned systems development and sales.[572] China has also demonstrated a growing ambition and capability to develop more platforms and capabilities in USVs and UUVs. Increased focus on and investment in these capabilities is driven by strategic and operational factors that support each of the three transitions in China's military modernization plans:

1. **Near Seas Protection:** USVs and UUVs can serve as inexpensive force multipliers in deterring, dissuading, detecting, and defeating U.S. and allied naval assets and, most importantly, addressing U.S. superiority in the undersea domain. Greater numbers of more technologically advanced UAVs can also play a significant role in denying access to the Western Pacific through ISR missions, serving as remote sensors, carrying out electronic warfare missions, engaging enemy forces directly, and operating as part of broader networks of manned and unmanned systems across the land, air, sea, and undersea domains.

2. **Power Projection**: The extended range and payload of hybrid armed reconnaissance UAVs, such as the Wing Loong II, offer China enhanced range and flexibility in meeting a broader range of missions within the Western Pacific and beyond. Unmanned systems of all types also provide deployed forces novel capabilities to maintain situational awareness and to carry out missions in the theaters they are in, including installation, asset, and force protection, that can support power projection and out-of-area missions. [573]

3. **"Intelligentized" Modernization:** Unmanned systems of all types are a lynchpin of China's transition from "informatized" to "intelligentized" warfare. Swarms of AI-infused systems, networked, and operating in conjunction with one another, are viewed as a particularly important element of the future of conflict, and are of interest to China's military modernization. As Vasily Kashin, a Russian expert on China's military modernization, noted, "Swarming is currently considered to be one of the most promising areas of defense technology development in the world. The Chinese are prioritizing it."[574] This is a view seconded by many, including Paul Scharre, Senior Fellow at the Center for New American Security, who stated "clearly, the United States and China are in some sort of weird swarm race."[575]

The industry supporting China's development of unmanned systems is broader than that supporting the development of other advanced weapons systems of interest to this project. China's state-owned enterprises are deeply involved in unmanned systems, especially in UAVs and USVs, as are research institutes. What sets the unmanned systems industry apart, though, is the relatively pronounced involvement of the private sector, not only through CMI technology diffusion activities, but also through the direct development of unmanned systems for military purpose for the PLA.

According to Tian Song, Chief Executive of Aero-Starloop, one of China's private unmanned systems companies, "the national strategy of integrating military and civilian sectors has opened up

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[572] Telephone interview with Derrick Maple, Senior Principal Analyst, Unmanned Systems, *Jane's Markets Forecast*, September 27, 2017.
[573] Maple, Derrick, "Unmanned Systems: Reign of the Persistent Warriors," *Jane's Intelligence Briefing Series,* November 15, 2017, https://janes.ihs.com/Janes/Display/jibr2622-jibr.
[574] Feng, Emily and Clover, Charles, "Drone Swarms vs Conventional Arms: China's Military Debate," *The Financial Times,* August 24, 2017, https://www.ft.com/content/302fc14a-66ef-11e7-8526-7b38dcaef614?mhq5j=e5.
[575]Feng, Emily and Clover, Charles, "Drone Swarms vs Conventional Arms: China's Military Debate," *The Financial Times,* August 24, 2017, https://www.ft.com/content/302fc14a-66ef-11e7-8526-7b38dcaef614?mhq5j=e5.

opportunities for private firms to invest in the aviation industry. [UAVs] are one of the fields where private investment can actively engage."[576]

As with China's research in AI, China's unmanned systems R&D is marked both by volume and velocity across an impressive variety of types of unmanned systems simultaneously.

In a late September 2017 discussion with Jane's research team, Maple noted that "in recent years, the number of [unmanned] projects has grown substantially and in the last two months alone China has released designs across" the following weight classes of UAVs:[577]

- Class I(b) 200 grams (g) to < 2 kg —3 programs—all in marketing phase
- Class I(c) 2 kg to < 20 kg —6 programs—all in marketing phase
- Class I(d) 20 kg to < 150kg —12 programs—3 in production, 9 in marketing
- Class II 150 kg to 600 kg —24 programs—3 in production, 21 in marketing
- Class III > 600 kg —17 programs—3 in production, 14 in marketing

This dynamic is also evident in the USV area. CASC outlined plans for a new family of four USVs during the International Ocean Science and Technology exhibition in Qingdao in September 2017.[578]

While indigenous innovation is frequently cited as a persistent issue for China's unmanned industry, some observers believe that China is at the start of a new era in which it is no longer only copying American designs. Instead, according to Maple, China has "actually transitioned to an environment in which there is a real commitment to unmanned and real capability being developed."[579] This necessary transition from reliance on foreign designs and technology to indigenous innovation is viewed by stakeholders within China as the industry's "biggest challenge as well as opportunity."[580]

China has also seen growing success in exporting its unmanned systems, especially its UAVs, to "about 10 countries," including Iraq, Kazakhstan, Egypt, Pakistan and the United Arab Emirates. In February 2017, AVIC announced a deal to export 300 Wing Loong II armed reconnaissance UAVs to a buyer later revealed to be Saudi Arabia.[581]

China's rise as a leader in the global export market is due in part to the "good enough" nature of its platforms, but also to its willingness to fill a gap left by U.S. unwillingness to sell sensitive UAVs and associated technologies in the broader defense market. These export efforts frequently include explicit agreements to transfer key technologies in order to deepen the political relationship and enable the importing country to further develop its own indigenous industry. For example, the month after AVIC signed its historic deal with Saudi Arabia, CASC signed an agreement with the King

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[576] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

[577] Email interview with Derrick Maple, September 27, 2017. Data derived from *Jane's Markets Forecast*.

[578] Wong, Kelvin, "China's CASC Unveils D3000 Unmanned Oceanic Combat Vessel Concept," *Jane's International Defense Review*, September 18, 2017, https://janes.ihs.com/Janes/Display/FG_645421-IDR; and Wong, Kelvin, "CASC unveils next generation USV concepts," *Jane's International Defense Review*, September 20, 2017, https://janes.ihs.com/Janes/Display/FG_646729-IDR.

[579] Telephone interview with Derrick Maple, September 27, 2017.

[580] *Jane's International Defense Review,* "Eastern Promise: China grows unmanned capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

[581] *Jane's,* "China Secures Its 'Biggest' Military Export Order for New UAV System," February 28, 2017, https://janes.ihs.com/Janes/Display/jdin91471-jdw-2017; Binnie, Jeremy "Saudi Arabia to Build Chinese UAVs," *Jane's*, 23 March 2017, https://janes.ihs.com/Janes/Display/jdw65111-jdw-2017.

Abdulaziz City for Science and Technology to establish a manufacturing plant for the CH-4 armed UAV.[582]

China's UAVs

China is considered the global leader in the commercial UAV market. According to Goldman Sachs, Chinese company DJI owned approximately a 70% market share in the commercial personal drone market in 2016.[583]

Seven of the top 10 personal drones ranked by *PC Magazine* were DJI models and an eighth, Yuneec's Typhoon, is also made by a Chinese company. The list is subjective, of course, but surveys of other similar industry magazines tracking the commercial drone market reveal starkly similar outcomes: DJI dominates, then other Chinese firms with a few Western suppliers scattered near the bottom of these rankings.[584]

Figure 16: The 10 best commercial drones as rated by PC Magazine

Source: *PC Magazine,* August 2017

So significant is DJI's penetration in this area that the company was actually selling to the U.S. Army. On August 2, 2017, an Army memo posted online and verified by Reuters ordered its members and units to "cease all use, uninstall all DJI applications, remove all batteries/storage media and secure equipment for follow-on direction." The order to stop using DJI drones was due to "cyber vulnerabilities." The Army acknowledged that DJI drones were the most widely used among Army purchased commercial off-the-shelf equipment.[585]

DJI's success is built on a blend of complementary capabilities and attributes that indicate how the high-speed entrepreneurial culture of China's high-tech industry is enabling real innovation and driving nearly unassailable competitive advantage in a high-growth market. Most important to DJI's success has been its reservoir of "1,500 people working on research and development" to bring new, technologically competitive products to market at a faster rate than its competition.[586] Partnerships and commercial arrangements with Sony and Apple also provide competitive advantages as does the fact that DJI has its own manufacturing facilities in Shenzhen.[587]

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[582] Binnie, Jeremy "Saudi Arabia to build Chinese UAVs," *Jane's*, March 23, 2017, https://janes.ihs.com/Janes/Display/jdw65111-jdw-2017.

[583] Scott, Alwyn, "US Army Halts Use of Chinese-made DJI Technology Co Drones over Cyber Concerns," *Sydney Morning Herald*, August 5, 2017, http://www.smh.com.au/world/us-army-halts-use-of-chinesemade-drones-over-cyber-concerns-20170805-gxpym7.html.

[584] Fisher, Jim, "The Best Drones of 2017," *PC Magazine,* August 28, 2017, https://www.pcmag.com/roundup/337251/the-best-drones.

[585] Mortimer, Gary, "US Army Calls for Units to Discontinue Use of DJI Equipment," *SUAS News*, August 4, 2017, https://www.suasnews.com/2017/08/us-army-calls-units-discontinue-use-dji-equipment/.

[586] Glasser, April, "DJI is Running Away with the Drone Market," *Recode*, April 14, 2017, https://www.recode.net/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast.

[587] Glasser, April, "DJI is Running Away with the Drone Market," *Recode*, April 14, 2017, https://www.recode.net/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast..

DJI's ability to cut prices has also helped drive competitors from the market. The Silicon Valley-based 3D Robotics, once valued at $360 million and seen as the next "big thing" in the commercial drone market reduced prices by as much as 70% in less than a year to stay competitive, ultimately leaving the drone manufacturing market in 2016 to sell software.[588]

Colin Guinn, 3D Robotics' former chief revenue officer, noted that DJI's vertical integration, technical competence and own manufacturing capability made it very difficult for Western companies to compete in the market. According to Guinn, "what we realized is that it's just going to be inherently much more difficult for a Silicon Valley-based, software-focused company to compete against vertically integrated powerhouse manufacturing company in China."[589] 3D Robotics CEO Chris Anderson was even more direct and complimentary, saying that "DJI is the best company [he has] ever encountered."[590]

China's burgeoning commercial UAV industry benefits its military UAV development, as there can be little separation between the two. As Tai Meung Cheung, professor at University of California-San Diego, noted about China's UAV industry, "It is increasingly blurred what is civilian and military."[591] These connections—and the broader prioritization of unmanned systems across the PLA and defense industrial base—have created a vibrant, active and fast-moving UAV development and, increasingly, innovation environment as demonstrated by the listing of the below named military/security UAV programs:[592]

Table 21: A list of Chinese Unmanned Aerial Vehicles by DoD Class

Chinese Unmanned Aerial Vehicles				
MTOW	Item Name	Primary Supplier	Platform Type	Item Life Cycle
Class I (b) 200g to < 2kg	Whirlwind Scout	AVIC	Helicopter	Marketing
	CH-902	CASC	Fixed-Wing	Marketing
	Lightweight UAV	Yintong Aviation	Helicopter	Marketing
Class I (c) 2kg to < 20kg	Grey Bee	Beijing University of Aeronautics and Astronautics	Fixed-Wing	Marketing
	CH-901	CASC	Fixed-Wing	Marketing
	CH-802	CASC	Fixed-Wing	Marketing
	CH-803	CASC	Fixed-Wing	Marketing

[588] Mac, Ryan, "Behind the Crash of 3D Robotics, North America's Most Promising Drone Company," *Forbes,* October 5, 2016, https://www.forbes.com/sites/ryanmac/2016/10/05/3d-robotics-solo-crash-chris-anderson/#5f72f0813ff5; Glasser, April, "DJI is Running Away with the Drone Market," *Recode*, April 14, 2017, https://www.recode.net/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast.
[589] Mac, Ryan, "Behind the Crash of 3D Robotics, North America's Most Promising Drone Company," *Forbes,* October 5, 2016, https://www.forbes.com/sites/ryanmac/2016/10/05/3d-robotics-solo-crash-chris-anderson/#5f72f0813ff5.
[590] Glasser, April, "DJI is Running Away with the Drone Market," *Recode*, April 14, 2017, https://www.recode.net/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast.
[591] Feng, Emily and Clover, Charles, "Drone Swarms Vs Conventional Arms: China's Military Debate," *The Financial Times*, August 24, 2017, https://www.ft.com/content/302fc14a-66ef-11e7-8526-7b38dcaef614?mhq5j=e5.
[592] *Jane's Markets Forecast* data.

	CETC54	CETC International	Helicopter	Marketing
	ASN-213	Xi'an ASN Tech Grp	Fixed-Wing	Marketing
	ASN-216	Xi'an ASN Tech Grp	Fixed-Wing	Marketing
Class I (d) 20kg to < 150kg	Z-5	60th Research Institute of the PLA Headquarters of the Central Staff	Helicopter	Marketing
	Nimble Loong	AVIC	Fixed-Wing	Marketing
	Night Eagle	AVIC	Fixed-Wing	Production (Past)
	TC	Beijing ZHZ Technology	Helicopter	Marketing
	Near-space UAV	CASIC	Fixed-Wing	Marketing
	Tianyi	Chengdu Aircraft Industry (Group) Company	Fixed-Wing	Marketing
	Dragonfly	CETC	Helicopter	Marketing
	Caihong Solar UAV	Chinese Academy of Aerospace Aerodynamic	Fixed-Wing	Marketing
	Z-3	Nanjing Research Institute on Simulation Technique	Helicopter	Marketing
	ASN-7	Xi'an ASN Tech Grp	Fixed-Wing	Production (Current)
	ASN-9	Xi'an ASN Tech Grp	Fixed-Wing	Production (Current)
	Small Multipurpose UAV	Zhuhai Xingyu	Helicopter	Marketing
Class II 150kg to 600kg	Sunshine	AVIC	Fixed-Wing	Marketing
	VD200	AVIC	Fixed-Wing	Marketing
	Blue Fox	AVIC	Fixed-Wing	Marketing
	AV500W	AVIC	Helicopter	Marketing
	U8E	AVIC	Helicopter	Marketing
	X200	Beijing Yotaisc Technology Development	Helicopter	Marketing
	M28	Beijing Youtaishuncheng Technology Development	Helicopter	Marketing
	TD220	Beijing ZHZ Technology	Helicopter	Marketing
	V750	CASC	Helicopter	Production (Past)
	Ptarmigan	CASC	Helicopter	Marketing
	CH-92	CASC	Fixed-Wing	Marketing
	CH-91	CASC	Fixed-Wing	Marketing
	QY-1	CASC	Helicopter	Marketing
	WJ-600	CASIC	Fixed-Wing	Production (Past)
	Hiwing	CASIC	Fixed-Wing	Marketing
	WJ-500	CASIC	Fixed-Wing	Marketing
	WZ-2000	Guizhou Aviation Ind	Fixed-Wing	Marketing
	China Helicopter UAV R&D	Jiangsu Tianyu Aviation Technology Co.	Helicopter	Research
	Sharp Eyes III	Norinco	Helicopter	Marketing
	PW-3	Poly Technologies	Fixed-Wing	Marketing

	SVU200	Sunward Tech.	Helicopter	Marketing
	HB001	Tengoen	Helicopter	Marketing
	HA001	Tengoen	Helicopter	Marketing
Class III > 600kg	Wing-Loong I	AVIC	Fixed-Wing	Production (Current)
	Yaoying II	AVIC	Fixed-Wing	Marketing
	Pterodactyl 1	AVIC	Fixed-Wing	Marketing
	Long Haul Eagle	AVIC	Fixed-Wing	Marketing
	BZK-005	Beijing University of Aeronautics and Astronautics with Hongdu Aircraft Industries Corporation	Fixed-Wing	Production (Current)
	T333	Beijing ZHZ Technology	Helicopter	Marketing
	CH-4A/B	CASC	Fixed-Wing	Production (Current)
	CH-5	CASC	Fixed-Wing	Marketing
	Long Endurance Stealth UAV	CASIC	Fixed-Wing	Marketing
	XY-1	AVIC	Fixed-Wing	Marketing
	Xianglong	Guizhou Aviation Industry	Fixed-Wing	Marketing
	LE300	Nanjing University of Aeronautics and Astronautics	Helicopter	Marketing
	Divine Eagle	Shenyang	Fixed-Wing	Marketing
	TA001	Tengoen	Fixed-Wing	Marketing
	TB001	Tengoen	Fixed-Wing	Marketing
	UVS-S100	UVSIS	Fixed-Wing	Marketing
	ASN-229A	Xi'an ASN Tech Grp	Fixed-Wing	Marketing

Source: Jane’s Markets Forecast, Derrick Maple

Indicative Sample of Key Fixed Wing UAVs

Key fixed wing aircraft from this extensive listing include:

Wing Loong I MALE UAV

The Wing Loong I was developed by AVIC’s Chengdu Aircraft Industry Company. It is 1,200 kilogram, measures approximately 9 meters long with a wingspan of 14 meters and can carry a payload of up to 200 kilograms split evenly between internal and external stores. It can stay aloft for approximately 20 hours. The Wing Loong is a strike-capable UAV that can be armed with NORINCO’s Hongjian 10 (HJ-10) air-to-surface anti-armor missiles mounted on two underwing hardpoints, as well as the Luoyang Opto-Electric Technology Development Center’s 50 kilogram LS-6-50 small diameter bomb, among other munitions.[593]

Figure 17: The Wing Loong II UAV (Kelvin Wong)

[593] *Jane’s International Defense Review,* “Eastern Promise: China Grows Unmanned Capabilities,” January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

Wing Loong II MALE UAV

The Wing Loong II is also an armed, strike-capable reconnaissance aircraft with twice the payload capacity (400 kilogram) and improved endurance (32 hours) over the Wing Loong I.

Compatible weapons include the 47-kilogram Blue Arrow 7 and a quad pack of 26.5-kilogram Blue Arrow 9 anti-armor missiles, as well as the 250 kilogram GB3 and 50 kg GB7 laser-guided bombs. According to Jane's, anti-surface missiles, such as the Blue Arrow 21 and TL-10 (also known by its export designation of YJ-9E) anti-ship missiles, hint at a maritime attack role for the air vehicle.[594]

Cloud Shadow

During the Airshow China in 2016, AVIC/CAC also unveiled the Cloud Shadow, which appears to be an export derivative of its domestic Tian Yi (Sky Wing) HALE UAV. AVIC is marketing the Cloud Shadow in two configurations:

Figure 18: The Cloud Shadow UAV (Kelvin Wong)

- An armed reconnaissance model, which has a maximum speed of 550 km/h and a payload capacity of 400 kg and six underwing hardpoints for external stores. The service ceiling for this variant is 45,931 ft.
- A dedicated ISR platform, which features a higher maximum speed of 620 km/h. The ISR variant is optimized with a suite of communication and radar surveillance equipment or high-altitude photo-reconnaissance systems. The service ceiling for the ISR variant is 49,212 ft.

Shared features of the two variants include:

- Synthetic aperture radar for improved moving-target tracking performance
- 9-meter-long and 3.66-meter tall airframe that appears "to draw some inspiration from the U.S.-made General Atomics Aeronautical Systems Predator C Avenger platform."
- V-tail surfaces and a dorsally mounted engine pod for its propulsion system—the WP11C turbo-engine, a "modernized and refined" version of the original WPCC system developed by the Beijing University of Aeronautics and Astronautics for unmanned aircraft applications.[595]

Cai Hong 4 and 5 (CH-4, CH-5)

CASC is the lead developer of the CH-4 armed MALE UAV, which has been used domestically and also exported, largely to the Middle East. CASC is currently developing the CH-5.

[594] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

[595] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

Figure 19: The CH-5 UAV (Kelvin Wong, Jane's)

The CH-5 has a lightweight all-composite airframe structure that is 11-meter-long with a wingspan of 21 meters. It has a MGWOT of 3,300 kg and can carry a 1,200-kg payload, with an internal mission bay capacity of 200 kg and the remainder of the payload capacity attributable to underwing stores.

CASC has specified an operating range of up to 250 km, though this can be extended to 2,000 km when SATCOM datalinks are available, highlighting one of the largest technical vulnerabilities facing China's UAV industry—using SATCOM links to extend the range of its platforms.

Most notably, the Ch-5 is capable of ***autonomous flight*** using pre-programmed waypoint navigation, with taxiing, take-off and landing maneuvers also fully automated.

Jane's has been told that the CH-5 has an endurance of up to 60 hours and a service ceiling of 30,000 ft. CASC notes that the CH-5 can loiter at speeds of 180-220 km/h while reaching maximum speeds in excess of 300 km/h.[596]

In July 2017, CASC's China Academy of Aerospace Aerodynamics—the country's largest exporter of military UAVs—announced that the CH-5 was ready for mass production, following a test flight of the first mass produced model.[597] The announcement came with expected braggadocio, designed for consumption mainly for potential customers in the export market, but also no doubt for the U.S. allies and partners in the region. According to Shu-Wen, chief designer of the CH series "the UAV is as good as the US-made General Atomics MQ-9 Reaper, a hunter-killer drone often deemed by Western analysts as the best of its kind."[598]

The mass production announcement was followed in September 2017 by live fire trials of the CH-5's capability to fire the 80 kg-class precision guided munitions—carrying a blast fragmentation warhead—via lock-on before launch targeting protocols from a production-model CH-5 at a launch altitude of 11,482 ft. A CASC spokesman told *Jane's*: "We demonstrate the CH-5's ability to win the initiative in any battlefield with its reconnaissance and strike ability, and our latest success exemplifies the maturity of our advanced products."[599]

Vertical Take-Off and Landing (VTOL) UAVs

While China's fixed-wing UAVs typically receive more attention due to their size, specifications, firepower and the nature of their capabilities and high-profile missions, China's UAV industry has also developed several VTOL designs for military or security purposes.

[596] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
[597] Dominguez, Gabriel, "China 'Ready to Mass Produce' Strike-Capable CH-5 UAV, Report Says," *Jane's Defense Weekly,* July 17, 2017, https://janes.ihs.com/Janes/Display/FG_569700-JDW.
[598] Dominguez, Gabriel, "China 'Ready to Mass Produce' Strike-Capable CH-5 UAV, Report Says," *Jane's Defense Weekly,* July 17, 2017, https://janes.ihs.com/Janes/Display/FG_569700-JDW.
[599] Wong, Kelvin, "China's CH-5 UAV Conducts Live-fire Trial with New Precision Weapon," *Jane's International Defense Review,* September 25, 2017, https://janes.ihs.com/Janes/Display/FG_648783-IDR.

Many of the VTOL platforms and concepts introduced over the last several years have been designed and produced by private companies, demonstrating the depth of China's unmanned systems industry.

BH-Series

Privately-owned Aero-Starloop High-tech Co. Ltd introduced the BH series VTOL in late 2016. The system is notable for its ***modular design*** that allows operators to modify or customize the vehicle to carry out various missions.

An Aero-Starloop company spokesman referenced the value of the design to end-users: "With our modular concept, we can develop new mission-specific payload modules that can be easily installed or swapped without compromising the basic performance and structural integrity of the UAV. Additionally, the modular sections greatly simplify maintenance processes, and therefore potentially increase its availability for missions."[600]

Figure 20: A standard BH Series VTOL UAV (Kelvin Wong)

Two variants of the BH-series are completed. The BH-90, which has a MWOT of 90 kg, and the BH-160 with a MWOT of 160 kg.[601]

AV500W

AVIC's China Helicopter Research and Development Institute is developing the rotary-wing armed reconnaissance AV500W. The UAV is a "weaponized variant of its civilian-model AV500 with improved performance."

Figure 21: The AV500W UAV (Kelvin Wong)

The AV500W can be configured to carry several air-to-ground weapons on stub wings mounted on either side of its fuselage. During the China Airshow 2016, the AV500W was shown carrying two 6 kg-class precision-guided munition mock-ups designed to engage static or slow-moving targets up to 5 km away.[602]

QY-1

CASC is currently developing a militarized variant of the civilian unmanned helicopter drone V750, which was originally developed by Shenzhen Tianxiang Aviation Industry Co Ltd (formerly Weifang Tianxiang Aviation Industry Co Ltd). The commercial version of the V750 is a highly-flexible multi-role vehicle that was used in support of civilian and commercial activities such as:[603]

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600 *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
601 *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
602 *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
603 V750, http://www.v750sky.com/.

- Marine monitoring and regulation
- Geo-information and mapping
- Power line patrolling inspection
- Emergency support during a geological disaster
- Ship monitoring and detection, target quick searching and locating and tracking

The QY-1 is optimized for reconnaissance, surveillance and battle damage assessment missions and can carry a range of lightweight munitions.[604]

Infiltrator

Ziyan UAV Co Ltd is another private company developing UAV solutions for military and security applications. The Infiltrator tactical VTOL UAV is designed "to perform anti-terrorism and special operations" with a focus "centered on its assault potential on the tactical level, and its ability to prepped and launched within two minutes."[605]

Figure 22: The Ziyan Infiltrator UAV (Kelvin Wong)

Special Design UAVs

According to Jane's, some Chinese firms are also "developing novel designs that cater to unique operational requirements."

AVIC's Sky Wing 6 (SW-6) is designed as a dedicated surveillance or electronic warfare UAV. It is a mini-UAV with a MGTOW of just 20 kg. It is designed to be deployed from a carrier aircraft at an altitude of around 6,560-9,840 feet in order to enable the aircraft to fully unfold its wings.[606]

Figure 23: The SW-6 and Mysterious Bee UAVs (Kelvin Wong)

CETC's Special Mission Aircraft System Engineering division is developing the Mysterious Bee fixed wing VTOL UAV. The UAV "appears to be modeled after comparable Western systems, such as the Arcturus JUMP family and Autel Kestrel."[607] But the Mysterious Bee does have a significantly larger airframe than these other versions.

The aircraft is designed for take-off and landing operations in austere environments and is fully capable of hovering under its own power, providing an "unprecedented" level of tactical flexibility for a UAV of

[604] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
[605] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
[606] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
[607] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.

its type. Most hybrid fixed-wing VTOL designs are capable of basic hovering maneuvers only before transitioning to or from conventional flight.[608]

Other Relevant UAVs

U650 Amphibious Drone

In September 2017, Chinese company UVS Intelligence Systems, a privately-owned drone-maker based in Shanghai, announced that mass production of its U650 seaplane had begun. The plane was described by *China Daily* as "the world's first unmanned, amphibious commercial aircraft."[609]

Beyond highlighting this "world's first" milestone, *China Daily's* report on the U650 reveals and reinforces two broader themes that are central to understanding China's UAV industry and broader innovation and development of advanced weapons.

First, UVS successfully leveraged foreign intellectual property to develop a new capability with Chinese characteristics, reflecting the continued importance and breadth of China's technology acquisition efforts—licit and otherwise. The U650 was reportedly developed "based on Spain's Colyaer Freedom S100 amphibious ultralight aircraft, *whose intellectual property rights were wholly acquired by the Shanghai company, according to UVS* [emphasis added]."[610]

In addition, the lines between commercial and military industry and uses for commercially developed platforms are blurring. For example, the U650's commercial and civil applications include a capacity to carry and deliver goods and transport supplies to islands that would not have access to "online shopping, which they are unable to do now because of the absence of delivery service."[611] But the *China Daily* article describing the U650 concludes on a conspicuous note with the curt and discordant mention that "the U650 is capable of carrying out reconnaissance and strikes for the military thanks to its ability to carry radar, sonar and missiles" and then quoting the founder of UVS as saying that "the drone can remain afloat at sea to tow sonar to detect submarines and move rapidly to other areas to continue the search."[612]

Ground Effect Unmanned Aerial Vehicle (GEUAV)

CASC's CAAA subsidiary has developed an unmanned ground effect vehicle, Jane's described in July 2017 as "a hitherto unseen anti-ship weapon/unmanned air vehicle (UAV)-like system."[613] CAA has given the vehicle the designation CH-T1, though it is also known as the GEUAV.

Ground effect designs allow vehicles to travel at high rates of speed at very low altitudes. China's GEUAV is estimated to have a maximum speed of Mach .65 and can cruise at altitudes of 1 to 6 meters. By flying so low, GEUAVs are more difficult to detect as their signal frequently gets mixed up

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[608] *Jane's International Defense Review,* "Eastern Promise: China Grows Unmanned Capabilities," January 20, 2017, https://janes.ihs.com/Janes/Display/idr19019-idr-2017.
[609] Zhao Lei, "World's First Amphibious Drone Made in Shanghai," *China Daily,* September 26, 2017, http://www.chinadaily.com.cn/business/tech/2017-09/26/content_32490302.htm.
[610] Zhao Lei, "World's First Amphibious Drone Made in Shanghai," *China Daily,* September 26, 2017, http://www.chinadaily.com.cn/business/tech/2017-09/26/content_32490302.htm.
[611] Zhao Lei, "World's First Amphibious Drone Made in Shanghai," *China Daily,* September 26, 2017, http://www.chinadaily.com.cn/business/tech/2017-09/26/content_32490302.htm.
[612] Zhao Lei, "World's First Amphibious Drone Made in Shanghai," *China Daily,* September 26, 2017, http://www.chinadaily.com.cn/business/tech/2017-09/26/content_32490302.htm.
[613] Wong, Kelvin, "Details of Chinese Sea-skimming Lethal Drone Prototype Emerge," *Jane's Missiles and Rockets*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_597138-JMR.

in the noise of undulating terrain and "constantly shifting waves."[614] The CAAA vehicle has a maximum payload capacity of 1,000 kg and can be used to carry a range of stores, including a blast fragmentation warhead for anti-capital ship (i.e., carriers, destroyers, etc.) or anti-structure missions. It can also be used as a recoverable dispenser system armed with sub-munitions for area denial.[615]

Jane's analyst Kevin Wong believes the GEUAV constitutes an "internal effort to explore a range of novel small aircraft aerodynamic designs as well as advanced flight control techniques."[616] Nonetheless, it is "difficult to discount the fact that the CH-T1 demonstrator appears to be for all intents and purposes a lethal drone system that blends UAV design and control with ground effect flight techniques to significantly enhance its potential range and load carrying capability over conventional subsonic cruise missiles."[617]

Implications of China's UAV Developments for Future Competition with the United States

Artificial Intelligence, Swarming and "Discounting the American Way of War": As impressive as China's rapid ascent as an unmanned power has been, the United States remains "by far, the world's leader in drone technology," benefitting not only from a world-class industry driving innovation in unmanned systems, but also from nearly a dozen years of using drones in high-tempo combat environments in Afghanistan, Iraq and elsewhere.[618] All U.S. services operate thousands of drones of impressive variety—from HALE and MALE configurations to tactical micro- and mini-UAVs.[619] In no other military have drones so thoroughly permeated across the enterprise than in the United States, and no other industrial base is developing the range and quality of systems as is that in the United States, despite the protestations of the Chief Designer of China's CH series that the CH-5 "is as good as the US-made General Atomics MQ-9 Reaper."[620]

But this advantage is coming under duress. More states, especially China and Israel, are building higher-quality drones and, as highlighted above, beginning to innovate in new technologies, designs and operational concepts. More fundamentally, though, the intensifying focus on autonomous UAV development is creating opportunities for states like China to build novel, game-changing capabilities that leverage good enough platforms and novel applications of AI to deliver the capacity to field drone swarms.

In a swarm, enhanced autonomy provides individual unmanned systems the ability to evaluate their environment, discern what is going on and decide on a course of action without having to be guided by a human being. This will be a capability in high demand on future crowded, complex, fast-moving and uncertain operating environments. Autonomous unmanned systems will be able to react quickly

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614 Wong, Kelvin, "Details of Chinese Sea-skimming Lethal Drone Prototype Emerge," *Jane's Missiles and Rockets*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_597138-JMR.
615 Wong, Kelvin, "Details of Chinese Sea-skimming Lethal Drone Prototype Emerge," *Jane's Missiles and Rockets*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_597138-JMR.
616 Wong, Kelvin, "Details of Chinese Sea-skimming Lethal Drone Prototype Emerge," *Jane's Missiles and Rockets*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_597138-JMR.
617 Wong, Kelvin, "Details of Chinese Sea-skimming Lethal Drone Prototype Emerge," *Jane's Missiles and Rockets*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_597138-JMR.
618 Farley, Robert, "The Five Most Deadly Drone Powers in the World," *The National Interest,* 16 February 2015, http://nationalinterest.org/feature/the-five-most-deadly-drone-powers-the-world-12255
619 Farley, Robert, "The Five Most Deadly Drone Powers in the World ," *The National Interest,* 16 February 2015, http://nationalinterest.org/feature/the-five-most-deadly-drone-powers-the-world-12255
620 Dominguez, Gabriel, "China 'Ready to Mass Produce' Strike-capable CH-5 UAV, Report says," *Jane's Defense Weekly,*17 July 2017, https://janes.ihs.com/Janes/Display/FG_569700-JDW

and take action not only without putting humans at risk, but also without the communications latency that comes with systems having to "phone home" to operators.

Swarms of AI-infused drones are likely to be a particularly prominent feature of the future battlefield. This critical capability will enable groups of linked and autonomous drones to communicate with one another—absent control from the ground—to carry out a specific mission. Each drone in the swarm may have different roles—for example, some may be equipped with surveillance payloads, others may carry weapons or electronic warfare capabilities, and others may be expendable, included in the swarm only to "light up" adversary air defenses so that they can be targeted by other drones in the swarm or by other assets launching stand-off weapons. Redundancy is built into the swarm allowing for self-healing and adaptation, complicating efforts to defend against them. As a CETC engineer noted to state-owned media after the test, UAV swarms will become "a disruptive force" that will "change the rules of the game."[621]

The U.S. DoD also understands the disruptive power of the intersection of unmanned systems and AI, and this intersection features in writings and discussion around the Third Offset Strategy, an approach to achieving and sustaining U.S. superiority in military technology and capabilities. Five types of AI–infused unmanned systems are referenced:[622]

- Autonomous deep learning systems
- Human-machine collaboration
- Assisted human operations
- Advanced human-machine combat teaming
- Network-enabled, cyber-hardened autonomous weapons

This capability and the combination of unmanned systems and AI technology that drives it is not yet operational, but it is in development by both the United States and China. In June 2017, China's CETC reportedly successfully tested a swarm of 119 UAVs, the largest drone swarm ever tested, beating the previous record of 103 set by the U.S. Air Force in October 2016.[623]

Drone swarms present multiple problems for military planners and—especially in conjunction with other advanced weapons systems capabilities—have the capacity to undermine U.S. military superiority. Because current operational concepts around drone swarms envision hundreds rather than dozens of individual systems in a swarm and because these swarms are resilient, redundant, self-healing and adaptive, capable of carrying out multiple missions or even altering the mission mid-flight, they present challenges to traditional challenges of air defense, in particular.

Participants in the Jane's Implications Workshop echoed this sentiment and identified unmanned swarms as one of the capabilities enabled by the combination of China's advanced weapons programs that are "discounting American advantage" and challenging long-held concepts of how Americans prepare for and fight wars.

Some of this disruption is at an operational level—meeting the dynamic and adaptive autonomous threat from a mass of drones that resemble a living organism will require new capabilities and operational concepts.

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[621] Tate, Andrew, "China Launches Record-Breaking UAV Swarm," *Jane's Defense Weekly,* 21 June 2017, https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017.
[622] Remarks by Deputy Secretary of Defense Robert Work at the Center for New American Security Defense Forum, December 14, 2015. https://www.cnas.org/publications/transcript/remarks-by-defense-deputy-secretary-robert-work-at-the-cnas-inaugural-national-security-forum.
[623] Tate, Andrew, "China Launches Record-Breaking UAV Swarm," *Jane's Defense Weekly,* 21 June 2017, https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017.

Some of the disruption will be strategic as well. For example, as more low-cost drones, including commercial drones, are made available to both state and non-state actors, the more that the cost curves of air defense will become even more skewed. According to *Popular Mechanics*, "a few $45,000 anti-air missiles are a cost-effective way to shoot down an $18 million Reaper, but firing that same anti-air missile at a smaller, commercial drone isn't as effective, especially when there are still 102 other drones flying the same mission at the same time."[624]

China's capacity to further develop swarming technologies will depend on solving several technical challenges related to:[625]

- Enhancing communication between a larger number of potentially different types of unmanned systems

- Ensuring resilient and self-healing swarms that can continue their mission even if a material number of individual drones are lost

- Keeping swarms in the air for longer periods of time.

Individuals interviewed for this project with expertise on all three topics of interest—China's AI capabilities, its defense industry and its unmanned systems—agreed that realistic development timelines for operationally relevant initial iterations swarming capabilities were relatively short, by the end of the next decade.

Exports and Deepening Geopolitical Relationships: China has become a viable defense exporter in many sectors in the last decade. In 2016, it was the ninth largest defense exporter in the world.[626] One area in which China has seen particularly impressive growth is in the export of its military UAVs, including the Wing Loong I, CH-3 and Ch-4.[627]

These efforts are continuing apace as China seeks to take advantage of:

- American unwillingness to sell weaponized or advanced platforms on the open market and to transfer technologies to end-users

- The desire of more export markets to use UAV purchases and technology transfers from these purchases as a platform for development of an indigenous defense industry

- Appetite for affordable, "good enough" technologies in many export markets, especially if accompanied by technology transfer, low cost, generous payment terms and even co-production

- A business model that makes few demands on trading partners, especially regarding human rights, democracy or specific policy measures

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624 Atherton, Kelsey D., "Pentagon's new drone swarm heralds a future of autonomous war machines," *Popular Science,* 10 January 2017, https://www.popsci.com/pentagon-drone-swarm-autonomous-war-machines.
625 Tate, Andrew, "China Launches Record-Breaking UAV Swarm," *Jane's Defense Weekly,* 21 June 2017, https://janes.ihs.com/Janes/Display/jdw66273-jdw-2017.
626 Jane's Defense Industry and Budgets, "Global Balance of Trade" press-release, April 2017
627 Grevatt, Jon, "Indonesia Looks to China for Combat UAVs," *Jane's Defense Weekly*, 28 July 2017, https://janes.ihs.com/Janes/Display/FG_600842-JDW.

Of course, the benefit of these export sales for China is only partially about funding streams. More significantly, China's UAV exports constitute a mechanism for expanding relationships with strategically important states around the globe; states that either sit atop of critical natural resources, primarily energy or are located in strategically critical locations or are in close proximity to, and can serve as a hedge against, India, as demonstrated in Table 22 below:

Table 22: Key export customers for China's military UAVs

Category	Customers
Energy Providers	Egypt, Iraq, Saudi Arabia, United Arab Emirates, Nigeria
Support for China's Interest in Central Asia and the Middle East	Kazakhstan, Turkmenistan and Jordan
Balancing India and Expanding Access to the Indian Ocean	Pakistan, Myanmar

Source: Jane's

China's export efforts are now also turning to Southeast Asia and to at least one nation with an active claim in the South China Sea. In late July 2017, *Jane's Defense Weekly* reported that Indonesian officials have outlined a program to procure UCAV from China. The exact requirement is still being finalized, but features six UCAV units each consisting of three batteries. In announcing the commitment, Laksda Leonardi, head of Indonesia's Ministry of Defense's Defense Facilities Agency stated that "Only China can sell the drones to us and the others cannot,"[628] highlighting one of China's main competitive advantages in the armed drone market.

Indonesian Defense Minister Ryamizard Ryacudu noted that the procurement was contingent on China transferring its technology to support Indonesia's on-going efforts to develop an indigenous UAV industry. This concern highlights a second key advantage China has over U.S. industry in meeting the demands of a rapidly growing market.[629]

Expansion of the variety and improvement in the quality of China's exportable UAVs will likely open up new UAV export opportunities as well as other equipment not just in these states, but potentially in new markets, some of which may currently seem unlikely. It is worth noting that China's presence at the 2017 IDEX show in UAE was considerably more pronounced and larger than in 2015 and that, in a much bigger surprise, the Wing Loong II was displayed at the sprawling 2017 Paris Airshow, the first time a Chinese UAV has been displayed at a Western airshow.[630]

China's Unmanned Surface Vehicles

China's UAV development is by far the most mature area of unmanned system investment and development. Nonetheless, recent investments in USVs demonstrates that China's interest in unmanned systems is more extensive than even what is discussed above. China has a small number of USVs currently operating, as demonstrated in the table below, all built by CETC Marine Equipment. What is most notable about China's USV program is the pace and scale of the current ambition to add an impressive array of new capabilities to its USV fleet (see Table 23 below).

[628] Grevatt, Jon, "Indonesia Looks to China for Combat UAVs," *Jane's Defense Weekly*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_600842-JDW.
[629] Grevatt, Jon, "Indonesia Looks to China for Combat UAVs," *Jane's Defense Weekly*, July 28, 2017, https://janes.ihs.com/Janes/Display/FG_600842-JDW.
[630] Nurkin, Tate, "IDEX 2017 – Analysis and Wrap-Up," *Jane's Aerospace, Defense and Security Blog,* February 24, 2017, http://blog.ihs.com/idex-2017-analysis-and-wrap-up.

Table 23: China's Military USVs

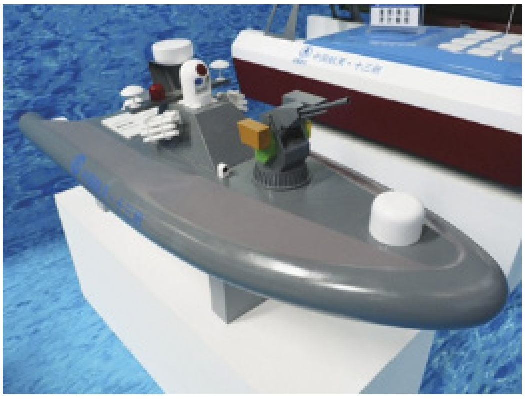
Item Name	Primary Supplier	Item Platform Type	Item Life Cycle
SeaFly-01	Beijing Sifang Automation	Ship	Marketing
C1500	CASC	Ship	Marketing
A1150	CASC	Ship	Marketing
D3000	CASC	Ship	Marketing
B850	CASC	Ship	Marketing
XG-2	CASIC	Ship	Production (Past)
31	CETC Marine Equipment	Ship	Production (Current)
71	CETC Marine Equipment	Ship	Production (Current)
101	CETC Marine Equipment	Ship	Production (Current)
M75	Yunzhou Tech	Ship	Production (Past)
L30	Yunzhou Tech	Ship	Marketing

Source: Jane's Market Forecast, Derrick Maple

At the 2017 International Ocean Science and Technology exhibition in Qingdao, CASC outlined its plans for a new family of USVs aimed at addressing a range of maritime security and naval requirements and gaps. The 13th Research Institute of CASC's Ninth Academy is leading development of the four new vessels. This division is China's primary developer of inertial measurement instruments with "a special focus on guidance systems." It has little experience in USV programs, but Jane's believes the organization should be able to leverage capabilities from across CASC's many technical enterprises.

B850 High Speed Patrol USV

Figure 24: The B850 USV (Kelvin Wong)



According to *Jane's International Defense Review,* The B850 is built on an 8.5-meter rigid hull inflatable boat sea frame outfitted with a diesel propulsion system with a proposed maximum speed of 40 knots (kt) and operational endurance in excess of 24 hours or out to a range of 107 nautical miles. The design is also expected to be capable of operating in conditions of up to Sea State 4 (refers to a 4 on the Beaufort scale which is wind speeds of 11 to 16 knots and waves at 3.5 to 6 feet high).

The B850 is armed with a forward mounted remote weapon system armed with a 7.62 mm or 12.7 mm machine gun. Other munitions, including anti-frogman rockets and an eight-tube launcher system have also been displayed on the B850.

The USV is expected to carry out maritime patrol, as well as force and installation protection missions. The B850 USV could potentially bolster China's protection of reclaimed islands in the South China Sea or support China's maritime territorial claims in other parts of the Western Pacific.[631]

[631] Wong, Kelvin, "CASC Unveils Next Generation USV Concepts," *Jane's International Defense Review*, 20 September 2017, https://janes.ihs.com/Janes/Display/FG_646729-IDR.

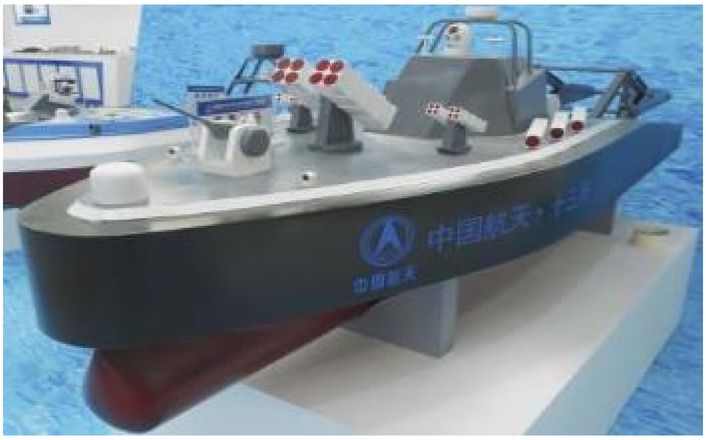
A1150

The second ship in CASC’s USV family is the A1150, which is designed for hydrographic survey missions and is equipped with a hybrid-electric propulsion system. The hybrid system provides endurance of 24-plus hours or out to a range of 130 nautical miles. The USV’s engineers traded speed and maneuverability for the capacity to capture and store the large amounts of energy required to run survey equipment over long periods of time. The A1150 can also operate in Sea State 4.[632]

C1500

The C1500’s main mission focus is ASW. Like the A1150, it uses a hybrid-electric propulsion system and has mission endurance in excess of 24 hours with a range of 270 nautical miles.[633]

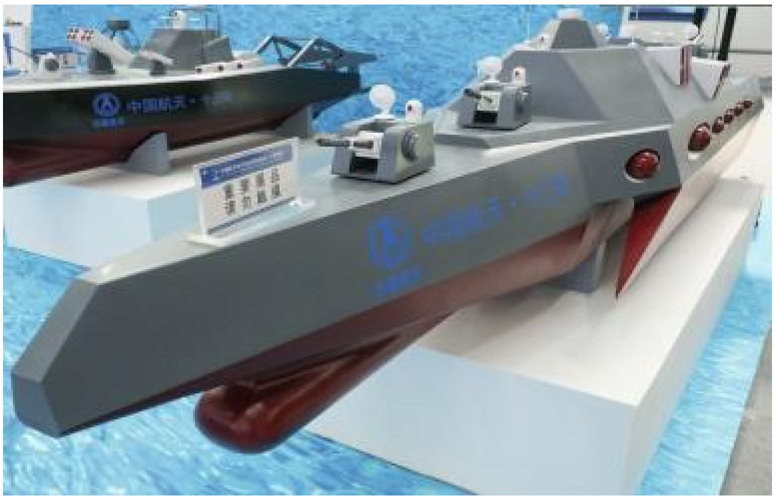
Figure 25: The C1500 USV (Kelvin Wong)



The C1500 will feature dipping sonar as well as a stern-mounted launch and recovery system for an autonomous underwater vehicle (AUV) or remotely operated vehicle (ROV). It will also be armed with lightweight torpedoes to deal with detected threats.

The C1500 can also be configured to fill short-range air defense, electronic warfare and mine-countermeasure missions.

Figure 26: The D3000 USV (Kelvin Wong)



D3000 Oceanic Combat Vessel Concept

Also, during the 2017 International Ocean Science and Technology Exhibition, CASC unveiled plans for its D3000 autonomous multirole surface vessel.

The boat is a 30-meter class USV, capable of operating out to a range of 540 nautical miles for up to 90 days in its base configuration. It can achieve maximum speeds of 40 knots and operate in seas up to Sea State 7 (winds at 28 to 33 knots and waves at 13 to 19 feet). The D3000 has a modular architecture that allows for the switching in and out of sensors, weapons and mission system payloads depending on the mission requirement. It can carry up to 10 tons of payload.

CASC envisions two variants of the D3000. The D3000A will be focused on fleet defense and surveillance and the D3000B will be configured for a surface combat role.

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[632] Wong, Kelvin, “CASC Unveils Next Generation USV Concepts,” *Jane’s International Defense Review*, 20 September 2017, https://janes.ihs.com/Janes/Display/FG_646729-IDR.

[633] Wong, Kelvin, “CASC Unveils Next Generation USV Concepts,” *Jane’s International Defense Review*, 20 September 2017, https://janes.ihs.com/Janes/Display/FG_646729-IDR.

The D3000s weapons stand out. While each variant is expected to have its own weapons package, the range of weapons that could be mounted on the D3000 is impressive. Models of the ship show four 30 mm caliber Type 730 close-in weapons systems (CIWS) as well as a pair of four cell box launchers containing anti-ship missiles mounted amidships. The D3000 also has four heavyweight torpedoes and eight lightweight torpedoes to meet undersea threats. It is capable of launching and recovering UAVs, "extending the vessel's detection and recovery range."

The D3000 will be able to operate beyond the horizon due to a SATCOMs suite linked to China Satellite Communications Co Ltd.'s ChinaSat constellation.

While CASC anticipates export opportunities, a CASC spokesperson also noted that the USV is currently being built to address a "potential PLAN requirement."[634] Jane's could find no definitive additional information about the specific nature of this requirement and believes the comment constitutes speculation by CASC, possibly rooted in the "unnerved"[635] response of China's strategy community to novel capabilities demonstrated by U.S. Sea Hunter USV.

SeaFly USV

China's private industry is also engaged in the development and production of next generation USVs. In August 2017, Beijing Sifang Automation (Sifang)—a research and manufacturing company specializing in power automation and generation, as well as transportation systems—announced that it plans to roll out a production-ready model of its SeaFly intelligent USV by the end of 2017.

Figure 27: Top: The SeaFly USV (Kelvin Wong), Bottom: MShip's Stiletto (U.S. Navy). Both ships have a "Double M" hull

The internally-funded Seafly program began in 2014, with the first prototype, SeaFly-01, successfully completing initial trials on Nanhu Lake in the central Chinese city of Wuhan on 27 October 2016.

Four SeaFly features demonstrate technical advancements in important capability areas that support China's advanced weapons systems and improvement of conventional capabilities.

First, the SeaFly has a "double M type" hullform of lightweight, all-carbon composite molded construction. Jane's reporting on the SeaFly notes that the hull "bears a striking resemblance to the M80 Stiletto stealth ship demonstrator built by U.S. naval architecture firm MShipCo." The Stiletto predated the SeaFly, and Jane's analysts believe that significant components of the design were "appropriated via business channels with the MShipCo," or through exploitation of available open sources on the Stiletto. One

[634] Wong, Kelvin, "China's CASC unveils D3000 unmanned oceanic combat vessel concept," *Jane's International Defense Review,* September 18, 2017, https://janes.ihs.com/Janes/Display/FG_645421-IDR.
[635] Goldstein, Lyle, "How China Sees the U.S. Sea Hunter Drone," *National Interest,* January 31, 2017, http://nationalinterest.org/feature/how-china-sees-the-us-navys-sea-hunter-drone-19264.

Jane's expert interviewed for the report assessed that the similarity is most likely due to "an exhaustive study of the many available images of the Stiletto."[636]

Second, the SeaFly incorporates low radar cross section design elements—such as a low-profile, faceted planform and radar-absorbent material—to increase the vehicle's stealthiness.

Third, Sifang has leveraged its expertise in intelligent ship-automation and power systems to incorporate advanced autonomy protocols into the SeaFly-01, enabling the vehicle to perform dynamic positioning and path planning, as well as obstacle avoidance and automatic return. In addition, multiple vessels can be networked to form a fleet.[637]

Fourth, the SeaFly is a versatile craft that can carry out a range of missions, including armed ISR and serving as a "mothership" for small UAVs to generate real-time aerial imagery intelligence and support beyond-line-of-sight (BLOS) communications. Sifang has stated that the USV is ideally suited for military missions such as area denial, surveillance and intelligence gathering, harbor and force protection and ASW as well as scientific missions. "We will develop [a range of] models for different application scenarios," Guo Tianyu, a key account manager at Sifang, told Jane's.[638]

Implications of China's USV Development for Future Competition with the United States

CASC's announcement of these new USV concepts is indicative of a growing recognition within the PLAN and broader Chinese military community that the nature of the maritime conflict is changing. As a CASC spokesman noted during the introduction of the D3000; "Over the next decade, we also expect to see the introduction of small to medium-sized USVs operating alongside manned platforms, particularly in leading navies, as the concept of mixed manned and unmanned fleets matures."[639] In this environment, demand for "autonomous ships, which offer a way to deliver increased operational capability without sending human crew into harm's way, while at the same time reducing operating and build costs"[640] will increase both within China and in the international market.

China's next generation of USVs will support China's attempt to better manage and control the maritime domain, particularly within the first and second island chains. The range of missions covered by these platforms will enhance:

- China's ability to compete in the undersea domain by providing more, relatively inexpensive assets to help monitor the undersea domain and meet the challenge of U.S. increased investment in UUVs. February 2016, then Secretary of Defense Ash Carter announced $600 million in spending on UUVs, a capability he noted the navy "will be seeing a lot more of."[641]

- China's USVs will also offer a novel capacity to secure and defend islands and installations, engage adversary surface combatants, carry out ISR missions and support important oceanographic missions. These capabilities will ultimately enhance China's navigation—

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[636] Email interview with Kelvin Wong, 20 November 2017.
[637] Wong, Kelvin, "China's Beijing Sifang automation readies SeaFly USV for production," *Jane's International Defense Review,* 14 August 2017, https://janes.ihs.com/Janes/Display/FG_625262-IDR.
[638] Wong, Kelvin, "China's Beijing Sifang Automation Readies SeaFly USV for Production," *Jane's International Defense Review,* August 14, 2017, https://janes.ihs.com/Janes/Display/FG_625262-IDR.
[639] Wong, Kelvin, "China's CASC unveils D3000 unmanned oceanic combat vessel concept," *Jane's International Defense Review,* September 18, 2017, https://janes.ihs.com/Janes/Display/FG_645421-IDR.
[640] Wong, Kelvin, "China's CASC unveils D3000 unmanned oceanic combat vessel concept," *Jane's International Defense Review,* 18 September 2017, https://janes.ihs.com/Janes/Display/FG_645421-IDR.
[641] Pomerleau, Mark, "DOD Plans to Invest $600M in Unmanned Underwater Vehicles," *Defense Systems*, February 4, 2016, https://defensesystems.com/articles/2016/02/04/dod-navy-uuv-investments.aspx.

through more complete knowledge of ocean environments—as well as surveillance and other maritime and naval activities.

Unmanned Underwater Vehicles

Multiple Jane's sources engaged for this project asserted that there is little public information about China's military use of UUVs. However, UUV development capabilities are clearly taking place at research institutes and universities and, given enhanced focus of CMI, it is widely assumed that as these capabilities mature, the military will exploit them to better meet the challenge posed by the United States and its allies and partners in the undersea domain.

Recent relevant activity includes:

Deep Sea Indian Ocean Exploration

In March 2016, China's unmanned submersible Qianlong 2 AUV completed its first exploration in the southwest Indian Ocean, reaching depths of 4,500 meters.[642] The 3.5 meter vessel dived 16 times during its first exploration from December 2015 to March 2016, covering an area of 216 square kilometers. The ship was designed by Shenyang Institute of Automation under the Chinese Academy of Sciences.[643]

The Qianlong 2 is expected to be used initially for deep-sea mineral resource investigation, though it does possess "forward looking sonar technology," which could certainly have relevant military applications in the undersea environment.[644]

Exploration of the Mariana Trench

China's Haidou-1 unmanned submersible dived to a depth of 10,767 meters in the Mariana Trench during a scientific expedition from June 22–August 12, setting a new record for the country according to the Chinese Academy of Sciences.[645] The scientific expedition and reportedly collected over 2,000 biological samples from 5,000–10,000 meters below sea level.[646]

During the trip, the submersible dived over 8,000 meters below the sea surface once, 9,000 meters twice and 10,000 meters twice. In its press release, the Chinese Academy of Sciences noted that China is now the third country after Japan and the United States to have built submersibles capable of reaching depths in excess of 10,000 meters.[647]

"It is another milestone in our maritime science journey after Jiaolong manned submersible," said Liu Xincheng, a scientist with CAS and head of the expedition. Jiaolong reached a depth of 7,062 meters in the Mariana Trench in June 2012.[648]

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[642] Xinhua, "China's 4,500-meter Submersible Finishes Indian Ocean Exploration," *Chinese Academy of Science Newsroom*, March 25, 2016, http://english.cas.cn/newsroom/news/201603/t20160325_160941.shtml.
[643] Xinhua, "China's 4,500-meter Submersible Finishes Indian Ocean Exploration," *Chinese Academy of Science Newsroom*, March 25, 2016, http://english.cas.cn/newsroom/news/201603/t20160325_160941.shtml.
[644] Xinhua, "China's 4,500-meter Submersible Finishes Indian Ocean Exploration," *Chinese Academy of Science Newsroom*, March 25, 2016, http://english.cas.cn/newsroom/news/201603/t20160325_160941.shtml.
[645] Xinhua, "10,767 Meters Below Sea Level: China's Submersible Sets New Record," *Chinese Academy of Science Newsroom*, August 24, 2016, http://english.cas.cn/newsroom/news/201608/t20160824_166691.shtml.
[646] Xinhua, "10,767 Meters Below Sea Level: China's Submersible Sets New Record," *Chinese Academy of Science Newsroom*, August 24, 2016, http://english.cas.cn/newsroom/news/201608/t20160824_166691.shtml.
[647] Xinhua, "10,767 Meters Below Sea Level: China's Submersible Sets New Record," *Chinese Academy of Science Newsroom*, August 24, 2016, http://english.cas.cn/newsroom/news/201608/t20160824_166691.shtml.
[648] Xinhua, "10,767 Meters Below Sea Level: China's Submersible Sets New Record," *Chinese Academy of Science Newsroom*, August 24, 2016, http://english.cas.cn/newsroom/news/201608/t20160824_166691.shtml.

Underwater "Real-Time" Communications Testing

In late July 2017, China deployed 12 Haiyi sea gliders—a type of UUV that uses the natural buoyancy of the water to "glide" forward, moving up and down through the water—in the South China Sea as part of what were billed as scientific experiments led by the Chinese Academy of Sciences.[649] The AUVs were set to roam for one month and collect detailed information on the ocean temperature, salinity, cleanliness, oxygen level and sea current speed and direction. A second objective of the experiment was to test China's capacity to relay this information back to a land-based laboratory in "real-time."[650]

As noted by Yin Jingwei, Dean of the College of Underwater Acoustic Engineering at Harbin Engineering University, if real time communications from an undersea vessel are, in fact, achieved, it would constitute a "breakthrough."[651] Undersea communication is notoriously slowed because the density (or thickness and pressure) of the ocean limits the speed at which signals travel. Along with relatively limited persistence—the ability of systems to stay underwater for extended periods of time—and the need for better autonomy, communications challenges constitute the main constraints facing all militaries, research institutes and industry leaders to more efficient and effective UUV operations for military, civilian or commercial purposes.

Observers of the tests—which took place in one of the tautest maritime security environments in the world—assess that the tests also signal at least two less scientific purposes. At a geopolitical level, the deployment of twelve AUVs in the South China Sea is a form of capability demonstration, a way of expressing both intent and a new capability to project power to and patrol disputed maritime areas in the South China Sea to all those watching, especially the United States, without explicitly escalating tensions. According to Margaret Kosal, an associate professor at Georgia Tech, the deployment is a "clear attempt to signal a capability associated with leading powers in terms of technology, which often translates to prestige."[652]

There are other operational benefits to these tests as well. They will gather data and refine AUV capability that could support China's efforts to further develop its undersea and anti-submarine capabilities. Swee Lean, a research fellow at Singapore-based Nanyang Technological University, stated that "information about underwater terrain, salinity and thermal layers are extremely useful for planning and executive submarine and anti-submarine operations."[653]

More generally, an extrapolation of an advanced PLAN UUV capability has the capacity to diminish the United States' most effective deterrent—its undersea advantage—and, as with many of the other weapons systems of interest to this effort, compromise current foundational assumptions about how the United States prepares for, deters and fights conflicts. Sylvia Mishra, a junior fellow at New Delhi-based think tank Observer Research Foundation captures this sentiment, succinctly: "the

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[649] Chen, Stephen, "Why Beijing is speeding up underwater drone tests in the South China Sea," *South China Morning Post*, 26 July 2017, http://www.scmp.com/news/china/policies-politics/article/2103941/why-beijing-speeding-underwater-drone-tests-south-china.
[650] Chen, Stephen, "Why Beijing is speeding up underwater drone tests in the South China Sea," *South China Morning Post*, 26 July 2017, http://www.scmp.com/news/china/policies-politics/article/2103941/why-beijing-speeding-underwater-drone-tests-south-china.
[651] Chen, Stephen, "Why Beijing is speeding up underwater drone tests in the South China Sea," *South China Morning Post*, 26 July 2017, http://www.scmp.com/news/china/policies-politics/article/2103941/why-beijing-speeding-underwater-drone-tests-south-china.
[652] Chandran, Nyshka, "Beijing is using underwater drones in the South China Sea to show off its might," *CNBC*, 12 August 2017, https://www.cnbc.com/2017/08/12/china-uses-underwater-drones-in-south-china-sea.html.
[653] Chandran, Nyshka, "Beijing is using underwater drones in the South China Sea to show off its might," *CNBC*, 12 August 2017, https://www.cnbc.com/2017/08/12/china-uses-underwater-drones-in-south-china-sea.html.

ability of UUVs to detect and hunt submarines . . . potentially changes the way of warfare. It is precisely why Beijing has been investing in a burgeoning underwater drones industry."[654]

Implications of China's Unmanned Underwater Vehicles for Strategic Competition with the United States

China has focused considerable attention over the last decade on enhancing its undersea capacity in order to achieve a number of national priorities and objectives and redress a critical strategic military vulnerability relative to the United States and its allies and partners in the region.

China's UUV and USV development will offer a new means of enhancing China's ASW and even, over time, potentially offering a new offensive capacity as well. They will also likely play a role in the future development of China's Great Undersea Wall of sensors in the Western Pacific being developed by China State Shipbuilding Corporation (CSSC).

Details of the network of surface ships (manned and unmanned) and sub-surface sensors were revealed in a CSSC booth at a public exhibition in China in late 2015.[655] Multiple analysts tracking China's military modernization have drawn a direct parallel between the Great Undersea Wall and the U.S. Sound Surveillance System deployed against Soviet submarines in the Atlantic during the Cold War that, for a time, provided the United States a significant advantage in countering Soviet submarines.[656] The Great Undersea Wall likely constitutes a first iteration of efforts to create a net of robust detection that can provide a similar advantage to Chinese forces in the Pacific Ocean.

Figure 28: At the 2016 Defense Services Asia exhibition in Kuala Lumpur CETC offered a "Reef Defense" system that may use many elements of CSSC's proposed "Underwater Great Wall Project". (Richard D Fisher via CETC)

CSSC says that one of its objectives is to provide customers with "a package solution in terms of underwater environment monitoring and collection, real-time location, tracing of surface and underwater targets, warning of seaquakes, tsunamis and other disasters as well as marine scientific research."[657] Specific components of CSSC's surveillance system include surface ships, sonar systems, underwater security

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[654] Chandran, Nyshka, "Beijing is using underwater drones in the South China Sea to show off its might," *CNBC*, 12 August 2017, https://www.cnbc.com/2017/08/12/china-uses-underwater-drones-in-south-china-sea.html.

[655] Fisher, Jr., Richard D., "China proposes 'Undersea Great Wall' that could erode US, Russian submarine advantage," *Jane's Defense Weekly*, 17 May 2016, https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016

[656] Fisher, Jr., Richard D., "China proposes 'Undersea Great Wall' that could erode US, Russian submarine advantage," *Jane's Defense Weekly*, 17 May 2016, https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016 and Lin, Jeffrey and Singer, P.W., "The Great Underwater Wall of Robots: Chinese Exhibit Shows Off Sea Drones," *Popular Science,* 22 June 2016, https://www.popsci.com/great-underwater-wall-robots-chinese-exhibit-shows-off-sea-drones

[657] Fisher, Jr., Richard D., "China Proposes 'Undersea Great Wall' that Could Erode US, Russian Submarine Advantage," *Jane's Defense Weekly*, 17 May 2016, https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016.

equipment, marine oil and gas exploration equipment, underwater unmanned equipment and marine instrument electronic equipment.

Richard Fisher noted in an article published by *Jane's Defense Weekly* in May 2016 that:

> "It is likely that the 'Underwater Great Wall' would also receive data from towed array sonars, unmanned undersea vessels, anti-submarine aircraft, plus ship and shore-based electronic intelligence systems, and satellites. Data processing by onshore supercomputers would greatly assist the location of undersea targets."[658]

Fisher also asserts:

> "If successful a Chinese 'Underwater Great Wall' could significantly shift the naval balance of power against the United States and Russia and undermine the 'extended deterrent' element that Washington offers its Asian allies and friends. If built near Taiwan, such a network of ship sonar and stationary underwater sensors could help the PLAN to deny access to U.S. submarines if China decided to coerce or attack the island."[659]

In addition to assuaging military concerns about the undersea domain, China's investment in UUVs and USVs also furthers economic and strategic interest, particularly regarding the mining of raw materials and minerals found predominantly in the very deep sea.

President Xi commented on the importance of this mission for China, telling attendees at a national science conference in May 2016 that accessing raw materials found at great oceanic depths was of utmost importance to the nation and its economic prospects and global standing, stating: "The deep sea contains treasures that remain undiscovered and undeveloped, and in order to obtain these treasures we have to control key technologies in getting into the deep sea, discovering the deep sea, and developing the deep sea." In support of this and its strategic objectives, China announced plans to build a laboratory 10,000 feet undersea near the disputed Spratly Islands. [660]

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[658] Fisher, Jr., Richard D., "China Proposes 'Undersea Great Wall' that Could Erode US, Russian Submarine Advantage," *Jane's Defense Weekly*, 17 May 2016, https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016.
[659] Fisher, Jr., Richard D., "China Proposes 'Undersea Great Wall' that Could Erode US, Russian Submarine Advantage," *Jane's Defense Weekly*, 17 May 2016, https://janes.ihs.com/Janes/Display/jdw61882-jdw-2016.
[660] *Bloomberg News*, "China is Planning a Massive Sea Lab 10,000 Feet Underwater," June 7, 2016, https://www.bloomberg.com/news/articles/2016-06-07/china-pushes-plan-for-oceanic-space-station-in-south-china-sea.

Chapter 7: China's Maneuverable Re-entry Vehicles (MaRVs)

Chapter 7 Key Themes and Insights

- **A Multi-faceted and Successful Program:** China's MaRV program—at least as assessed in this paper—includes both its development of ASBMs (the DF-21D and DF-26) and HGVs. While considerable uncertainty exists about the status of both programs—especially of the capacity of these systems to maneuver on re-entry (in the case of the ASBMs) and glide phase (HGVs)—Jane's assesses the ASBM capability to be viable, but vulnerable, and that the HGV capability is steadily progressing.

- **MaRV Motivation and Iterative Missile versus Missile Defense Competitions:** China is developing HGVs for three main reasons. First, China seeks to counter-act the diminishing effect it believes ever-advancing U.S. missile defense capabilities, especially THAAD, are having on its strategic and conventional deterrent. Second, China seeks to match U.S. development of hypersonic weapons being made through the U.S. Prompt Global Strike program. Third, there is evidence that China believes HGVs could serve in an A2/AD strike mission. In addition to these motivations, China's continued development of HGVs has the effect of reinforcing U.S. development of advanced weapons systems—especially hyper-velocity weapons—some of which are part of the original motivation for China's HGV program.

- **WU-14 / DF-ZF:** China's main HGV research program is known as the Wu-14 or, alternatively, DF-ZF. The DF-ZF has been tested seven times since early 2014. Six of these tests have been deemed to be "successful," though U.S. and Western analysts are careful to caveat this normative assessment by saying that the U.S. does not know exactly what China's objectives were for each test.

- **A Massively Destabilizing Weapon:** Jane's believes that HGVs, in particular, are massively destabilizing and confer enormous strategic and operational advantages for the states that possess them. The combination of extremely high-speed and maneuverability make HGVs a particularly difficult missile and air defense problem. Those threatened by HGVs may feel the need to take pre-emptive action as the only means of protecting themselves against this daunting threat, especially during times of crisis.

- **Ancillary Programs:** HGVs are just one manifestation of hypersonic weapons. China is also developing ramjet and scramjet engine technology to support development of a hypersonic cruise missile, which does not qualify as a MaRV, but can be a highly-effective A2/AD weapon. China has also developed the world's largest known hypersonic wind tunnel, indicating deep expertise on the topic of hypersonics and hypersonic flight.

- **U.S. HGV Development:** U.S. development of HGVs has previously lacked urgency, focus and a cohering strategic vision of how HGVs might be used. In the last 12-18 months, though, the success of China's DF-ZF tests as well as Russia's growing HGV program have inspired increased focus on HGVs as well as ramjet and scramjet engines within the U.S. Air Force, Army and broader DoD as well as U.S. defense primes.

- **Technical Challenges:** China's HGV program is advancing, but there remain technical challenges across both ASBMs and HGVs. For ASBMs, the need to improve its reconnaissance/strike complex is the most glaring gap in capability. For HGVs, a mature capability will turn on the ability to develop new materials, enhanced maneuverability, and communications with sensors and other C4ISTAR infrastructure.

Overview of Maneuverable Re-entry Vehicles

MARVs are warheads on missiles that leave the earth's atmosphere and are able to adjust their flight path when re-entering the earth's atmosphere and moving toward a target.[661] MaRV-equipped ballistic missiles provide many advantages over traditional ballistic missiles, which typically are relatively easy to detect and whose conventional warheads coast on a set and predictable ballistic curve once they re-enter the atmosphere, making them easier targets for missile defense systems. MaRVs, on the other hand, are able to maneuver toward their target, potentially taking an irregular or unpredictable path and providing the missile a better opportunity to defeat even the most advanced missile defense systems. In addition, the maneuverability of the warhead enables MaRV-equipped ballistic missiles to hit moving targets.

China has learned from U.S. development of MaRVs and began research and development efforts to create its own systems starting around 2002.[662] The most mature of China's MaRV-related capabilities is its ASBMs, which are thought to be equipped with MaRVs (though open-source information on characteristics and capabilities is limited).[663] The development of MaRVs for use on ASBMs demonstrates China's ambitions to improve A2/AD capabilities against enemy naval assets and disrupt the missile versus missile defense competition by forcing new investments in concepts and capabilities to protect U.S. carrier battle groups, in particular.

The discussion of MaRVs has expanded in the last decade as the United States, China and Russia have all advanced HGV programs. HGVs are weapons that are launched toward the atmosphere as payload on ballistic missiles. However, unlike ballistic missiles, most HGV concepts and designs include the HGV separating from the ballistic missile at the edge of the atmosphere, about 100 km above earth.[664] As the HGV separates it transitions from the "boost" phase to the "glide" phase, which enables the HGV, in theory, not only to maneuver aerodynamically—performing evasive actions and evading interception—but also extending the range of the missile. During the glide phase, HGVs accelerate to speeds in excess of Mach 5, before entering a dive towards the final target.[665]

HGV weapons are still in development and not expected to come into service for several more years. However, many military experts consider HGVs to be a highly destabilizing weapon. As *Breaking Defense's* Robbin Laird noted, the combination of their high speeds and likely maneuverability makes them "unstoppable."[666] Tom Brussing, Vice President of Raytheon's Advanced Missile Systems, suggests they could "hold an entire region at risk."[667] Existing defense systems, both area and point, offer limited protection against the threat posed by HGVs, increasing their appeal as a delivery system for conventional or possibly nuclear weapons. Jane's research shows that U.S. and Chinese development of HGVs are used by the other as a justification for a) further development of HGVs and b) other advanced weapons systems, such as EM railguns that can better cope with the speed and maneuverability of HGVs.

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[661] Boffey, Philip M. "New Generation of Warheads Just Around the Bend," *New York Times*, February 14, 1983.
[662] Stokes, Mark "Prepared Statement on Chinese Advanced Weapons Development," Testimony before the U.S.-China Economic and Security Review Commission, February 23, 2017, pg. 2. https://uscc.gov/sites/default/files/Stokes_Testimony.pdf.
[663] Erickson, Andrew, "Chinese Anti-Ship Ballistic Missile Development and Counter-intervention Efforts," Testimony before the U.S.-China Economic and Security Review Commission, 23 February 2017, pg. 4.
[664] Gady, Franz-Stefan, "China tests new hypersonic vehicle," *China Defense Observation*, 2, November 2015. http://www.chinadefenseobservation.com/?p=1506
[665] Ballistic And Cruise Missile Threat," Defense Intelligence Ballistic Missile Analysis Committee, June 30, 2017, p.8, http://www.nasic.af.mil/LinkClick.aspx?fileticket=F2VLcKSmCTE%3D&portalid=19
[666] Freedberg, Sydney J. "Speed Kills: The Case for Hypersonic Weapons," *Breaking Defense*. June 3, 2014.
[667] Norris, Guy. "Raytheon Invests in Technology to Meet Hypersonic Threats," *Aviation Week Network*. June 20, 2017.

HGVs are the primary focus of this section, given the capabilities they provide to the countries that successfully develop and deploy them. China's ASBMs (the DF-21D medium-range ballistic missile and DF-26 intermediate-range ballistic missile) are also of interest to this chapter. They are strategically significant to several domain area competitions between China and the United States and allies and reportedly also incorporate MaRVs that facilitate hitting moving ships at sea.[668]

Open-source evidence suggests that development of HGVs and improving the supporting infrastructure and delivery systems for hypersonic weapons is a strategic priority for China. Government programs to support development of the requisite technology have provided funding and guided R&D efforts at defense industrial and academic institutions, while reorganization of China's strategic missile capability under the PLA Rocket Force (PLARF) gives more institutional weight to these weapons capabilities within the wider PLA organization. This comes at a time when the influence of the PLARF is increasing under the guidance of President Xi Jinping.[669]

Several critical technological challenges must be solved before the PLA gains a reliable threat with MaRV or HGV based weapons. These weapons require an extensive network of support infrastructure to identify and track targets; reliable data networks and communications systems to relay targeting information; and sophisticated navigation technologies to guide them to target—a particularly critical component for moving targets such as surface vessels. China must combine these capabilities with a refined HGV or other MaRV system, and missile on which to deliver it, to have a fully functional weapons system.[670]

Should China be able to combine these capabilities, it will have a weapons system with the potential to destabilize and arguably reshape regional and global security dynamics. An ASBM equipped with an HGV will provide a leap forward in regional defense and increase the range of the missile, allowing mainland PLA forces to threaten surface vessels out to the Second Island Chain. The potential for air-launched missiles or those positioned on reclaimed island features in the South China Sea would expand this area-denial capability even further. Furthermore, if China seeks to fit HGVs with nuclear weapons for delivery via ICBM, it would give China an exceptional strategic deterrence capability that could escalate the arms race between development of strategic weapons and ballistic missile defense (BMD) systems.

This section also includes some discussion of China's hypersonic cruise missile program, but only in the context of China's broader hypersonic weapons research and A2/AD objectives rather than as a system that could be categorized as a MaRV.

Summary of China's Anti-Ship Ballistic Missiles

China's ASBM program is an integral component of its efforts to develop hypersonic weapons systems, and a critical piece of larger strategic deterrence and A2/AD efforts. The DF-21D and DF-26 ASBMs are both relatively new, and many uncertainties exist regarding their present capabilities and operational limitations, including range, accuracy and current arsenal size.

However, Jane's assesses that these missile programs are viable, though vulnerable, and that China continues to refine the requisite technologies for targeting to make them reliable weapons systems and a centerpiece of China's regional defense capabilities. Furthermore, the PLA's clear development

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[668] Kazainis, Harry, "Is China's 'Carrier Killer' Really a Threat to U.S. Navy," *National Interest,* September 2, 2015, http://nationalinterest.org/blog/the-buzz/chinas-carrier-killer-really-threat-the-us-navy-13765.
[669] Yang, Zi, "Rocket Force Gaining Power in China's Army-dominated PLA," *Asia Times*, September 23, 2017, http://www.atimes.com/article/rocket-force-gaining-power-chinas-army-dominated-pla/.
[670] Erickson, Andrew, "Raining Down: Assessing the Emergent ASBM Threat," *Jane's*, March 16, 2016. http://janes.ihs.com/Janes/Display/1765057.

strategy for ASBM systems demonstrate Chinese strategic intent to acquire destabilizing weapons capabilities that challenge U.S. strengths—namely the U.S. Navy's surface fleet—and provide insight to the development trajectory for associated technologies, including HGVs.

Early Development Efforts and Strategy
According to Mark Stokes, Executive Director of the Project 2049 Institute, China established a rough timeline for ASBM and broad global strike capabilities from 2006–2025, broken into four stages and in line with Five Year Plans:

- *11th Five-Year Plan:* Develop a rudimentary ASBM capability with a range of 1,500–2,000 km by 2010
- *12th Five Year Plan*: Extend ASBM range to 3,000 km by 2015, including of advanced technologies such as solid motors and boost-glide trajectories to counter mid-course missile defenses
- *13th Five-Year Plan:* Extend conventional strike capabilities to 8,000 km by 2020
- *14th Five-Year Plan:* Achieve global precision strike capabilities by 2025[671]

Developments since Mr. Stokes published this timeline in 2009 suggest that China's global strike capabilities and its ASBM capabilities are indeed steadily progressing in this direction. The fielding of the two missile systems examined here—the DF-26 and the DF-21D—are part of this overall effort and form a critical piece of China's deterrence and A2/AD capabilities.

DF-21D
Derived from CASIC's DF-21 medium range ballistic missile, the DF-21D was first delivered to the PLASAF in 2006 and is believed to be designed for use against ships, with a particular emphasis on U.S. carrier strike groups. Jane's estimates the missile to be 15 meters in length and 1.4 meters in diameter, with an overall weight of approximately 15,000 kg and an estimated range of between 1,550 and 2,000 km, although some Chinese sources suggest a maximum range is 2,700 km. The total number in service is unclear, although Jane's assesses that between 20 and 40 are produced annually. Reports suggest that the DF-21D may be deployed in southeastern China near either Shaoguan or Qingyuan.[672]

The DF-21D is a two-stage, solid fuel missile featuring an RV and has synthetic aperture radar and optical sensors which enable it to hit moving targets. It is believed to carry a sufficiently powerful warhead to disable ships the size of U.S. aircraft carriers.[673] Jane's notes that the DF-21D was reportedly tested against a target of 200–300 meters in length in April 2013, although it is unclear if the target was stationary or moving.[674] Although the precise capabilities of the DF-21D to evade or defeat existing BMD systems are unknown, its potential to increase China's A2/AD capacities in the Pacific Ocean are clear, as its estimated range allows the missile to threaten ships in the East and South China Seas.

DF-26
Developed by CASC, the DF-26 was unveiled in September 2015 and is a second-generation ASBM, building on the DF-21D. Little information has been revealed about the DF-26, but it is reportedly

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671 Stokes, Mark "China's Evolving Conventional Strategic Strike Capability," *Project 2049 Institute*, September 14, 2009, pg. 1–2. https://project2049.net/documents/chinese_anti_ship_ballistic_missile_asbm.pdf.
672 Jane's Strategic Weapon Systems, "DF-21," February 22, 2016.
673 Kreisher, Otto, "China's Carrier Killer: Threat and Theatrics," *Air Force Magazine*, December 13, 2013, http://www.airforcemag.com/MagazineArchive/Pages/2013/December%202013/1213china.aspx.
674 Jane's Strategic Weapon Systems, "DF-21," February 22, 2016.

capable of carrying both nuclear and conventional warheads. The DF-26 is also capable of both land-based/surface-to-surface and anti-ship operations, with an anti-ship focus for the conventional variant,[675] and its range may be up to 4,000 km—double that of the DF-21D.[676]

Jane's reports that the DF-26 was test-fired over the Bohai Sea in April 2017, and photographs posted on Chinese online forums show what appear to be a ballistic missile motor stage jettisoned over the Siziwang area in China's autonomous region of Inner Mongolia. Provisional analysis suggests that the motor stage appeared to have dimensions broadly similar to those attributed to the DF-21D.[677] The operational status of the missile is unclear at this stage, but its increased range over the DF-21D—if matched with sufficient targeting capabilities—would expand China's A2/AD capabilities to the Second Island Chain.

Intended Role and Development Questions

The role of the DF-21D and DF-26 to increase the PLA's A2/AD capabilities and threaten the U.S. Navy and other allied assets in the East and South China Seas appears clear, contributing to their being titled as "carrier killers."[678] But their actual capacity to do so in a combat scenario remains questionable. Jane's noted when the DF-26 was unveiled, actual threat level would "hinge on the PLA's ability to sustain a chain of ISR systems necessary to assure long-range targeting [and the] vulnerability of this ISR network will also pose the most serious threat to the success of the DF-26 ASBM."[679]

Targeting capabilities are critical to ASBM success, as these missiles require "over-the-horizon" targeting support, which integrates information from multiple sources to guide the missile to target. China is rapidly expanding the requisite C4ISR infrastructure for this task and improving information integration.

China may be able to accurately target ships on the shorter end of the range spectrum with the DF-21D, but it is unlikely that it has sufficient coverage to make use of the full range of the DF-26. Fully meeting this challenge will require not only greater coverage from satellites and radar systems but for sensor-to-shooter inputs to work seamlessly and in real-time.[680] However, Jane's notes that the absence of high-profile tests against moving targets by either the DF-21 or DF-26 do not necessarily suggest shortcomings in targeting capabilities. Indeed, speculation and uncertainty among foreign observers regarding the precise capabilities of these missiles may be preferable to China.

China will also have to consider strategic concerns regarding use of these systems. The dual nuclear/conventional capabilities of the DF-26 introduces risk of escalation, as a first-strike intended

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[675] Jane's Strategic Weapons Systems, "DF-26," June 1, 2017; Rogoway, Tyler, "Is This China's DF-21D Air Launched Anti-Ship Ballistic Missile Toting Bomber?," *The Drive*, August 15, 2017, http://www.thedrive.com/the-war-zone/13511/is-this-chinas-df-21d-air-launched-anti-ship-ballistic-missile-toting-bomber; Tian, Fang, "Dongfeng-26 Can Strike Large Moving Targets within 4,000 Kilometers: Expert," *People's Daily*, August 2, 2017, http://en.people.cn/n3/2017/0802/c90000-9249992.html.

[676] Jane's Strategic Weapons Systems, "DF-26," June 1, 2017.

[677] Jane's Strategic Weapons Systems, "DF-26," June 1, 2017.

[678] Majumdar, Dave, "How the U.S. Navy is Trying to Make China's 'Carrier-Killer' Missiles Obsolete," *National Interest*, 16 December 2016, http://nationalinterest.org/blog/the-buzz/how-the-us-navy-trying-make-chinas-carrier-killer-missiles-18766.

[679] Fisher, Richard D, "DF-26 IRBM May Have ASM Variant, China Reveals at 3 September Parade," *Jane's Defense Weekly*, September 3, 2016.

[680] Erickson, Andrew, "Raining Down: Assessing the Emergent ASBM Threat," *Jane's*, March 16, 2016. http://janes.ihs.com/Janes/Display/1765057.

to destroy conventional Chinese ballistic missiles could end up destroying some nuclear-armed missiles instead, in turn raising the chance of counter-escalation by China.[681]

In spite of potential escalation risks, China will continue to seek solutions to infrastructure limitations and technology gaps, and other ways of extending its deterrence capability beyond land-based ASBMs. In an August 2017 presentation, former PLAN Rear Admiral Zhao Dengping illustrated possible PLAN objectives to include depictions of a ship-launched ASBM flight profile, suggesting ambitions for a naval ASBM capacity.[682] China's H-6 strategic bomber may also be modernized to carry ASBMs, as the new H-6N model, which features an in-flight refueling capacity, may be used to carry the DF-21D. The capacity of the H-6N to carry an ASBM is unclear,[683] but an air-launched DF-21D might be sufficiently reduced in weight by removing the initial boost phase, and could extend China's A2/AD capabilities up to 3,000 miles from the Chinese mainland, and potentially allow for deployment from anywhere in China.[684]

Potential Employment of ASBM Programs

China's progress in developing ASBM systems is illustrative of its A2/AD ambitions and demonstrative of its ability to overcome technical challenges and field increasingly sophisticated weapons. As noted by Dr. Erickson, China is now the world leader in ballistic missile development, and it appears to hold a financial and tactical advantage over the United States in an ASBM/BMD arms race.[685] The true capacity of the DF-21D and DF-26 to threaten U.S. Navy carrier strike groups remains uncertain, and without further testing of these systems and improvements in the aforementioned C4ISTAR infrastructure, it will be difficult to ascertain their actual wartime capabilities.

However, efforts to date suggest China will continue prioritizing ASBM development and perfecting these weapons to support its regional A2/AD goals.[686] Many analysts believe the DF-21D and DF-26 are or will be armed with maneuverable warheads or with a maneuverable hypersonic warhead—perhaps based on the WU-14 HGV or lessons learned from that program—which will increase the threat of these systems.[687] Furthermore, the future deployment of ASBMs on ships and aircraft is representative of Chinese efforts to make these weapons more adaptable and deployable.[688] Jane's anticipates that ASBM development will continue to play a central role in Chinese A2/AD strategy, with advances in HGV design and application creating increasingly lethal systems to challenge the U.S. naval presence in the Pacific.

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[681] Gomez, Eric "Meet the DF-31AG and the DF-26: The Big Ballistic Missiles at China's Military Anniversary Parade," *The Diplomat*, August 8, 2017, http://thediplomat.com/2017/08/meet-the-df-31ag-and-the-df-26-the-big-ballistic-missiles-at-chinas-military-anniversary-parade/.

[682] Fisher, Richard D., "PLAN Plans: Former Admiral Details Potential Modernization Efforts of Chinese Navy," *Jane's Defense Weekly*, August 25, 2017.

[683] Jane's estimates that the standard internal capacity of the H-6 is up to 9,000 kg—significantly less than the estimated 15,000kg weight of the DF-21D, sees Jane's All The World's Aircraft, "H-6," June 28, 2017.

[684] Rogoway, "Is This China's DF-21D Air Launched Anti-Ship Ballistic Missile Toting Bomber?"August 15, 2017, http://www.thedrive.com/the-war-zone/13511/is-this-chinas-df-21d-air-launched-anti-ship-ballistic-missile-toting-bomber.

[685] Erickson, Andrew, "Raining Down: Assessing the Emergent ASBM Threat," *Jane's*, March 16, 2016. http://janes.ihs.com/Janes/Display/1765057.

[686] Kazianis, Harry J, "Is China's "Carrier-Killer" Really a Threat to the U.S. Navy?" *The National Interest*, September 2, 2015, http://nationalinterest.org/blog/the-buzz/chinas-carrier-killer-really-threat-the-us-navy-13765.

[687] Fisher, Richard D, "US Officials Confirm Sixth Chinese Hypersonic Maneuvering Strike Vehicle Test," Jane's Defense Weekly, November 26, 2015.

[688] Fisher, "PLAN plans: Former Admiral Details Potential Modernization Efforts of Chinese Navy," August 25, 2017.

Summary of China's Hypersonic Glide Vehicle Program

China's development of hypersonic systems has attracted significant attention during the last decade. Official government publications such as the 2013 Science of Military Strategy and 2015 White Paper do not directly discuss hypersonic weapons, though both do emphasize the need for enhanced ability of strategic weapons to penetrate adversary missile defenses as part of broader deterrence and nuclear counter-attack efforts. Chapter 10 of the 2013 *Science of Military Strategy* discusses the need for the Second Artilleries' Corps' nuclear force to develop "key points of survivability and penetration ability" for missiles such as "rapid maneuver and launch, gliding, and MIRVing [Multiple Independent Reentry Vehicle] technology."[689]

The 2015 Defense White Paper calls for the PLA Rocket Force to "strengthen its capabilities for strategic deterrence and nuclear counterattack."[690] These comments, taken with the proliferation of academic studies and research programs on hypersonics and MaRVs, suggests a concerted effort to establish military capabilities with hypersonic systems that meet or exceed those of the United States to strengthen China's nuclear deterrence.[691] Furthermore, the development of new systems and investment in R&D facilities offers insight on the potential application of these systems and how they may support China's overall geopolitical and military strategies.

China is prioritizing the development of hypersonic systems primarily for purposes of strategic deterrence, with an aim to develop systems that can defeat BMD systems such as THAAD. Secondarily, China is interested in HGVs in order to develop a capability similar to the United States' Prompt Global Strike system, which provides the United States with an option for hitting high-value targets with a conventional weapon within a matter of minutes.[692] Such a capability would increase the survivability of China's conventional strike capabilities.

China's HGV development, if not exclusively framed against U.S. ambitions and activities, explicitly consider them, due to China's ambition to develop a weapons system which can provide an asymmetrical advantage over the United States—particularly in an area where China may be able to position itself as the technological leader. Publications and statements from Chinese military institutions and leadership reflect continued concern with the strategic threat posed by U.S. capabilities and the continued U.S. HGV program in particular. The lack of an apparent breakthrough by the United States in its own HGV development, and the challenges of sustained funding for the U.S. program amid defense budgetary constraints, may push China to prioritize HGV development over the near-term in order to create an advantage.

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[689] Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, 233-234. Translation from Chase, Michael and Arthur Chan, "China's Evolving Approach to 'Integrated Strategic Deterrence". RAND Corporation. 2016. https://www.rand.org/content/dam/rand/pubs/research_reports/RR1300/RR1366/RAND_RR1366.pdf P.53

[689] China's Military Strategy, The State Council Information Office of the People's Republic of China, May 26, 2015, http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm

[690] China's Military Strategy, The State Council Information Office of the People's Republic of China, May 26, 2015, http://english.gov.cn/archive/white_paper/2015/05/27/content_281475115610833.htm

[691] The 2013 *Science of Military Strategy* states on page 233: "The expansion of national security interests and development and transformation of the pattern of warfare, are making struggles and confrontations that utilize the fields of space and the Internet more and more intense, and this raises new requirements for military capability development. Having a foothold in and relying on the special points and advantages of guided missile weaponry, developing new types of operations methods, and taking PLASAF operations capabilities into space and other new domains of development, are important directions in PLASAF construction and development." Shou Xiaosong, ed., The Science of Military Strategy, Military Science Press, 2013, P.233. Translation from Chase, Michael and Arthur Chan, "China's Evolving Approach to 'Integrated Strategic Deterrence". RAND Corporation. 2016. https://www.rand.org/content/dam/rand/pubs/research_reports/RR1300/RR1366/RAND_RR1366.pdf. p.53

[692] Woolf, Amy F., "Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues," *Congressional Research Service*, July 7, 2017, p. 6, 11.

Hypersonic systems may also play a more tactical military role, extending the range and improving the survivability of missile systems in support of China's ambition to improve A2/AD capabilities and win regional conflicts in contested areas such as the South China Sea. HGVs could also provide rapid strike in support of assets and personnel deployed as part of China's power projection activities.

Jane's therefore anticipates that development of hypersonic weapons systems will remain a long-term strategic priority for China as it seeks to develop a greater non-nuclear deterrence capability. Progress may not be linear, and the precise nature of ultimate objectives may not be clear due to the opacity of China's development efforts, but steady improvements—and potentially large-scale advances—should be anticipated as research, development and testing of various systems progresses.

The key hypersonic weapons program in China is the Wu-14/DF-ZF HGV. Regular testing of the system and advances in missiles equipped with ramjet/scramjets can support China's strategic goals of deterrence, regional A2/AD efforts, and engaging the United States in a technology/arms race that China may believe that it can effectively win.

There have also been rumors of tests of a Chinese hypersonic drone. In September 2015, AVIC published an article online announcing the successful test of a hypersonic aircraft in the north-east of China. Very little detail was given and the article has since been removed from their site, but Henri Kenhmann of *East Pendulum*'s analysis of Notices to Airmen (NOTAMs) found that the test was on September 9, 2015. Kenhmann found satellite images of an unidentified UAV sitting on the tarmac of AVIC's Chengdu Aircraft Industrial Group's Factory 132 hanger right before the 9th. Kenhmann has also found patents for a "high-speed cruising vehicle in near space" filed by researchers of AVIC's 611 Institute in Chengdu. The patents indicate that the drone would be launched by another aircraft, hooking underneath. It is not clear from the patents if the vehicle would be capable of hypersonic flight, Kenhmann's analysis finds that it would likely be limited to Mach 5 (supersonic, a step below hypersonic). However, Chinese documents continually refer to the vehicle as hypersonic and the patents and testing show a clear effort to develop a hypersonic drone.[693]

Relatively rapid development of hypersonic systems has been facilitated by China's move away from a compartmentalized modernization process towards a more integrated model in which R&D efforts draw from both foreign and domestic designs. This "has significant implications for the speed with which military systems are researched, developed, operationalized, and deployed within China."[694]

Industry and Organizations Involved in HGV Development

Several state-owned enterprises and academic institutions are involved in China's development of hypersonic systems, driven by what Lora Saalman, Director of the China and Global Security Program at the Stockholm International Pearce Research Institute (SIPRI), describes as "an interlocking set of academic, industrial, and military research institutes."[695]

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693 Kenhmann, Henri, "Exclusif: Le Drone Hypersonique Chinois Enfin Révélé? [Exclusive: the Chinese Hypersonic Drone Finally Revealed?]," East Pendulum, October 6, 2016. http://www.eastpendulum.com/exclusif-drone-hypersonique-chinois-revele

694 Saalman, "Prompt Global Strick: China and the Spear," *Asia-Pacific Center for Security Studies*, April 2014, pg. 16 http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf.

695 Saalman, Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," *Stockholm International Peace Research Institute*, SIPRI Insights on Peace and Security, No. 17, Vol. 1, January 2017, p.3. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles

Industry

On the industrial side, R&D efforts for military applications are largely shaped by CASC and CASIC, with individual academies within each organization leading specific initiatives.

CASC First Academy: China's R&D efforts on HGV's are almost entirely focused within the First Academy's 10th Research Institute—also known as the Near Space Flight Vehicle Research Institute. The First Academy has specialized in developing flight vehicles transiting the upper atmosphere (20-100 km) on a sub-orbital trajectory rather than a ballistic flight path. Research by Mark Stokes and Dean Cheng found that "the establishment of such a separate research institute—one that focuses on a single capability—within China's premier launch vehicle and ballistic missile academy serves as a prominent indicator of the priority that senior civilian and military leaders place on new generation long-range precision strike vehicles."[696] The consolidation of R&D efforts for the HGV program appears to have helped China achieve quick results in the Wu-14/DF-ZF program.[697]

CASC Fourth Academy: CASC's 4th Research Institute conducts R&D efforts on ramjet/scramjet technologies and has researched solid-fueled ramjets since at least 2000.[698] Other agencies that have supported ramjet/scramjet R&D efforts include the CASIC's Third Academy; CASIC's 31st Research Institute; and the Chinese Academy of Engineering.[699]

Academia

China's university system is an active supporter in advanced military technologies development. Many of China's leading technical universities have schools focused on aerospace and/or aeronautics that have helped drive research efforts and key programs, publishing studies on topics ranging from trajectory optimization to re-entry.[700]

Students and faculty from these institutions contribute regularly to the growing body of academic research that addresses key challenges in the development and application of hypersonic technologies. Some collaborate directly with CASC and CASIC on these programs, while others have direct ties to the PLA. Table 24 provides a partial list of key universities that have contributed through direct R&D support or by publishing research papers.

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[696] Stokes, Mark A. with Cheng, Dean, "China's Evolving Space Capabilities: Implications for US Interests." *Project 2049*, (prepared for the U.S.-China Economic and Security Review Commission), April 26, 2012. https://www.uscc.gov/sites/default/files/Research/USCC_China-Space-Program-Report_April-2012.pdf.

[697] Solem, Erika; Karen Montague, "Updated – Chinese Hypersonic Weapons Development," Jamestown Foundation China Brief, Volume 16 Issue 7, April 16, 2016, https://jamestown.org/program/updated-chinese-hypersonic-weapons-development/.

[698] Lin, Jeffrey, P.W. Singer, "This New Ramjet Engine Could Triple the Range of Chinese Missiles," *Popular Science*, June 12, 2017, http://www.popsci.com/chinas-new-ramjet-engine-triple-range-missiles; Xiaoci, Deng, "China's New Ramjet Engine to Enhance Firing Range of Missiles, Combat Ability of J20," *Global Times*, June 5, 2017, http://www.globaltimes.cn/content/1050098.shtml.

[699] Gibson, Neil, "China Reveals Details of a New Ramjet-powered ATGM," *Jane's Defense Weekly*, January 8, 2008.

[700] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," *SIPRI*, January 2017, pg.4. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

Table 24: Research institutes and academic institutions contributing to China's hypersonic weapons programs

Institution	Location	Hypersonic Weapons Program Activities
The Harbin Institute of Technology (HIT)	Harbin	HIT's School of Astronautics has close relations with both CASC and CASIC, as well as the PLA General Armament's Department and PLA Rocket Force.
Northwest Polytechnic University	Xi'an	Both the School of Astronautics and the School of Aeronautics have contributed extensively to China's growing body of academic research on development challenges for HGVs and ramjets.
The National University of Defense Technology (NUDT)	Changsha	Reporting directly to the Central Military Commission (CMC), the NUDT is a leading contributor to China's space program and supports research efforts on a wide range of hypersonics technology challenges.
Beihang University	Beijing	The National Laboratory for Aeronautics and Astronautics was established in 2006 to help support national strategic objectives and offers advanced degrees in topics such as Hypersonic Aerodynamics.
Tsinghua University	Beijing	One of China's most prestigious universities, Tsinghua's School of Aerospace Engineering was founded in 2004 and has ongoing research initiatives which support hypersonics R&D, including the Institutes of Dynamics and Control.
Beijing Institute of Technology (BIT)	Beijing	The BIT's School of Aerospace Engineering has focused on flight vehicle engineering since 1961 and supports hypersonics programs through research on key areas including flight vehicle design, control and dynamics for flight vehicle, hypersonic fluid mechanics and aerospace launching engineering.

Military Structure

In addition to support from industry and academia, the PLA plays a direct role in R&D efforts for advanced weapons systems, and the establishment of the Scientific Research Steering Committee in 2017 to fulfill a role within the Chinese military establishment similar to the one the U.S. Defense Advanced Research Projects Agency (DARPA) plays in order to help further the design and application of hypersonic weapons systems.[701] The Scientific Research Steering Committee is housed under the Central Military Commission (CMC) and will coordinate with the CMC's Science and Technology Commission. While its precise scope and authority are not yet clear, the move is part of a broader effort to reorganize China's fragmented defense R&D organizations to improve efficiency and promote new technology advances.[702]

Structural changes within the PLA may also reflect increasing emphasis on the development of hypersonic weapons systems as an integral part of the PLA's capabilities. The PLARF—formerly known as the PLA Second Artillery Corps—was established as an independent service branch in January 2016, giving it the same organizational stature as the Army, Navy and Air Force. PLARF's responsibilities include command of all three legs of China's nuclear triad and the PLARF works with the CMC and Ministry of National Defense on the doctrinal level to determine how the technological

[701] Chan, Minnie, "Chinese Military Sets up Hi-tech Weapons Research Agency Modelled on US body," *South China Morning Post*, July 27, 2017, http://www.scmp.com/news/china/diplomacy-defence/article/2104070/chinese-military-sets-hi-tech-weapons-research-agency.
[702] Grevatt, Jon "China Sets up Agency to Lead Military R&D," *Jane's Defense Weekly*, 27 July 2017.

advances in hypersonic boost-glide can be integrated into policy and posture. It is noteworthy that the change gives China's military a similar structure to that of Russia, with the PLARF serving a similar function to Russia's Strategic Rocket Forces. This may provide some insight in to China's strategic defensive concerns and its objectives for hypersonic technologies.[703]

Current Programs and Technologies

The R&D efforts of these organizations and academic institutions have helped produce multiple programs. Precise goals of these programs remain unclear, but solid progress demonstrates continued Chinese commitment to addressing technical issues.

Wu-14/DF-ZF

The Wu-14 (also known as the DF-ZF) is an HGV, the first known test of which was conducted in January 2014. The Ministry of National Defense publicly confirmed that a "new ultra-high-speed missile delivery vehicle" had been tested, but offered little additional information on the secretive program, stating only that "it is not directed against any other country,"[704] and has not confirmed that the vehicle in question is in fact an HGV.[705] To date, the Wu-14 has been tested on seven occasions, with dates, ranges and known results of these tests listed below in Table 25:

Table 25: List of known Wu-14/DF-ZF tests.

Date	Range (km)	Notes
January 9, 2014	1,750	Presumed success. Launched from Taiyun Space Center. "Keep out" zone declared near Ningxia. Believed to have reached speed of Mach 10.
August 7, 2014	1,750	Suspected failure. Images showed debris at a presumed crash site near the Bulong Hu Hot Springs Resort in Mongolia, with large volumes of red smoke or vapor suggesting the release of unburned nitrogen tetroxide and unsymmetrical dimethylhydrazine rocket propellants. Eastern and western keep out zones were declared, suggesting a similar intended flight path to the January 9th launch.
December 1, 2014	1,750	Presumed success. Suspected similar flight path to two previous tests, although no keep out zones were declared. But the precise range of this test is unknown.
June 7, 2015	1,750	Presumed success. Similar flight path to failed August 2014 test.
August 20, 2015	2,100	Presumed success. Enlarged keep out zones suggest possible plans for maneuvering; unclear if attempted, or successful, as precise objectives remain unknown.
November 23, 2015	1,250	Presumed success. Same keep out zones as previous test.
April 22, 2016	1,250	Presumed success. Identical flight path to previous test.

Sources: Acton, "China's Advanced Weapons;" various IHS Jane's Defense Weekly reports.

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[703] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 3. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

[704] Fisher, Richard, "China Confirms Hypersonic Vehicle Test," *Jane's Defense Weekly*, 15 January 2014.

[705] Acton, James, "China's Advanced Weapons," written testimony before the U.S.-China Economic and Security Review Commission, February 23, 2017, http://carnegieendowment.org/2017/02/23/china-s-advanced-weapons-pub-68095.

The capabilities of the Wu-14 have been the subject of considerable coverage—and to some degree speculation—in Chinese and international media. A December 2014 article in *Popular Science* states:

> "The Wu-14 uses a large rocket booster to fly into the boundary between space and Earth's atmosphere, over 100 km above the ground, before gliding in a relatively flat trajectory, at up to speeds of Mach 10, to accurately hit a strategic target, whether an aircraft carrier or command bunker. The flat trajectory of the Wu-14 and other HGVs makes it harder for missile defense systems to defend against them. The Wu-14 is likely to be carried by DF-21 intermediate range ballistic missiles in the short term, but HGVs boosted by ICBMs such as the DF-31A would have the range to strike at the continental US."[706]

However, numerous details regarding the program and its tests are still unknown, meaning that uncertainties regarding the technical capabilities of the Wu-14 program persist. Co-Director and Senior Fellow of the Nuclear Policy Program at the Carnegie Endowment for International Peace James Acton noted in his testimony before the U.S.-China Economic and Security Review Commission in February 2017 that re-entry speeds, lift-to-drag ratio, guidance systems, accuracy and the degree of indigenous development versus foreign assistance related to the Wu-14 program are all unclear.[707]

Acton also noted that the nature of China's specific test objectives is also uncertain, stating that the designated "keep-out zones" in each test reflect flight plans only and do not provide any evidence as to whether a test was actually successful, as the objectives for the tests remain unknown. This includes efforts to test the maneuverability of the Wu-14, which would present a significant technical challenge, but greatly increase the value of the program as a test bed for future designs.[708]

Regardless of the outcomes of these tests, Jane's noted at the time of the first launch in January 2014 that it represented a key step towards China's ambition of developing various long-range hypersonic strike systems that include scramjet-powered vehicles, space planes and post-boost vehicle weapons based on HGVs.[709]

Related Technology Developments

HGV developments have attracted the majority of attention in China's quest to develop hypersonic systems, but other programs—both confirmed and conceptual—illustrate the breadth and depth of R&D efforts and offer some insight into potential objectives.

Ramjets/Scramjets

Ramjets and scramjet are a key technology for developing broader sets of hypersonic weapons, particularly hypersonic cruise missiles, which constitute a different capability than that of HGVs and MaRVs. Nonetheless, research in this area still supports China's overall hypersonics program and therefore can intersect with HGV programs. China has reportedly made breakthroughs in ramjet and

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[706] Lin, Jeffrey, P.W. Singer, "Offset This! China's Hypersonic Glider Flies for the Third Time This Year," *Popular Science*, 9 December 2014, http://www.popsci.com/offset-chinas-hypersonic-glider-flies-third-time-year.
[707] Acton, James, "China's Advanced Weapons," written testimony before the U.S.-China Economic and Security Review Commission, 23 February 2017, http://carnegieendowment.org/2017/02/23/china-s-advanced-weapons-pub-68095.
[708] Acton, James, "China's Advanced Weapons," Carnegie Endowment for International Peace, 23 February 2017, http://carnegieendowment.org/2017/02/23/china-s-advanced-weapons-pub-68095
[709] Fisher, Richard, "China Confirms Hypersonic Vehicle Test," *Jane's Defense Weekly*, 15 January 2014.

scramjets in the last two years.[710] In fact, China's apparent tests with scramjets in 2015 make it only the second country in the world to achieve this milestone.[711]

Wind Tunnels
China's commitment to hypersonics R&D is further demonstrated by its investment in supporting infrastructure, including some of the world's most capable wind tunnels. China's JF-12 wind tunnel—the world's largest hypersonic wind tunnel—began operations in March 2014 and can produce speeds of Mach 5 to Mach 9. This wind tunnel provides scientists with the ability to monitor airflow over different scramjet configurations while testing material durability in laboratory conditions.[712] The JF-12 has been joined by the FD-21, a 556-ft-long tunnel that became operational in late 2016 and can produce speeds of Mach 10 to Mach 15. Built by the China Academy of Aerospace Aerodynamics, it is capable of accommodating full-sized components of hypersonic propulsion, including HGVs and scramjets.[713]

Concept aircraft
Public announcements offer some insight in to the potential direction of future research efforts and operational usage of hypersonic vehicles to include:

- **Teng Yun**: A hypersonic two-stage carrier platform designed by CASIC, which it intends to deliver by 2030. The first stage will be able to reach altitudes of 18 to 25 miles and speeds of up to Mach 6, while the second stage will be a 10-15 ton spaceplane equipped with rocket engines and capable of carrying up two tons of cargo or five passengers. Both stages are reusable, and the system could be employed in either strike or reconnaissance missions. CASIC Vice President Liu Shiquan said that company has finished demonstration of key flight technologies as part of a $16 billion research effort, and its combination with speed and near-space flight altitude could fill a PLAAF need for global bomber platform that is nearly impervious to current air defense systems.[714]

- **SSTO**: CASC announced the development of a hypersonic single-stage-to-orbit spaceplane in August 2016 and plans to fly a full-scale model by 2030. This timeframe matches that of a scramjet being developed by the Beijing Power Machinery Research Institute, which is slated to begin full-scale testing of the technology demonstrator in 2020, followed by the flight of a full scale afterward. This R&D effort may lead to a scramjet engine powerful enough to enable an SSTO spaceplane to re-enter orbit on multiple occasions during the same flight and travel at faster speeds than a near-space-only hypersonic aircraft.[715]

Prioritization and Objectives
Defense strategy documents such as the 2013 Science of Military Strategy and 2015 Military Strategy White Paper do not contain direct comment on future development trajectories for hypersonic

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710 Wang, Brian, "China reveals hypersonic scramjet developments and plans," *Next Big Future*, 14 April 2017, https://www.nextbigfuture.com/2017/04/china-reveals-hypersonic-scramjet-developments-and-plans.html.
711 Norris, Guy, "China Reveals Key Test Progress On Hypersonic Combined-Cycle Engine," *Aviation Week*, 10 April 2017, http://aviationweek.com/technology/china-reveals-key-test-progress-hypersonic-combined-cycle-engine.
712 Lin, Jeffrey, P.W. Singer, "Chinese Hypersonic Engine Wins Award, Reshapes Speed Race?," *Popular Science,* 8 October 2015, http://www.popsci.com/chinese-hypersonic-engine-wins-award-reshapes-speed-race.
713 Lin, Jeffrey, P.W. Singer, "A look at China's most exciting hypersonic aerospace programs," *Popular Science,* 18 April 2017, http://www.popsci.com/chinas-hypersonic-technology.
714 Lin, Jeffrey, P.W. Singer, "American and Chinese aircraft could be flying 4,000 miles per hour by 2030," *Popular Science*, 16 June 2017, http://www.popsci.com/hypersonic-arms-race-china-united-states.
715 Lin, Jeffrey, P.W. Singer, "American and Chinese aircraft could be flying 4,000 miles per hour by 2030," *Popular Science*, 16 June 2017, http://www.popsci.com/hypersonic-arms-race-china-united-states.

systems or how they might be employed. However, they do provide clues regarding evolution in thinking that could influence the use of hypersonics as strategic weapons systems.

The 2013 Science of Military Strategy discusses the PLA's approach to long range strike capabilities, emphasizing "mid- and long-range accuracy strike as the determining method of operation," and the "unification of information and artillery" to help achieve overall goals of deterrence. The document further notes that:

> "Brand-new methods of deterrence, based on…new technology, could effectively create more uncertainty when the adversary is evaluating the two sides' military capabilities, and affect the adversary's original strategic plan. In this way, the credibility of deterrence is enhanced."[716]

Hypersonic systems can certainly support this strategy by fulfilling a deterrence role, and present an asymmetric threat for most potential adversaries, as even the most sophisticated defensive systems are ill-equipped to defend against threats moving at speeds of Mach 5 or more.

The 2015 Military Strategy White Paper builds on themes introduced in the 2013 book, noting that "revolutionary changes in military technologies and the form of war have not only had a significant impact on the international political and military landscapes, but also posed new and severe challenges to China's military security." It also notes that the Second Artillery Corps—the predecessor of the PLARF—will:

> "Press forward with independent innovations in weaponry and equipment by reliance on science and technology, enhance the safety, reliability and effectiveness of missile systems, and improve the force structure featuring a combination of both nuclear and conventional capabilities. The [PLA Rocket Force] will strengthen its capabilities for strategic deterrence and nuclear counterattack, and medium- and long-range precision strikes."[717]

Potential Employment of HGV Programs

Based on R&D activities to date, testing programs, public statements and other open-source evidence, China's hypersonic programs appear to be driven by several factors. Notably:

- The perceived necessity of improving deterrence capabilities, particularly against U.S. nuclear and conventional forces
- The ambition to improve A2/AD capabilities to support regional defensive efforts
- The desire to match U.S. technological developments and achieve a degree of strategic parity

These factors are listed in rough order of priority, as assessed by Jane's. China's concern with threats posed by the U.S. military and its long-range strike capabilities continues to appear in Chinese throughout "gray" literature and appears to be a key, long-term driver of China's overall military modernization and effort to improve deterrence capabilities. Jane's assesses the concern with regional A2/AD capabilities to be another key factor, which supports China's ambition to improve the security of the mainland against both conventional and nuclear threats, while also improving its

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[716] PLA Research Department of Military Strategy, "The Science of Military Strategy," Military Science Press, 2013. https://fas.org/nuke/guide/china/sms-2013.pdf. Excerpts used in this paper draw from an English-language analysis by Qiu, Mingda, "China's Science of Military Strategy: Cross-Domain Concepts in the 2013 Edition," University of California San Diego, September 2015. http://deterrence.ucsd.edu/_files/Chinas%20Science%20of%20Military%20Strategy%20Cross-Domain%20Concepts%20in%20the%202013%20Edition%20Qiu2015.pdf.

[717] State Council Information Office of the People's Republic of China, "China's Military Strategy," May 2015, http://eng.mod.gov.cn/Database/WhitePapers/index.htm.

own ability to project power out to the Second Island Chain at a minimum. Finally, China may view the development of HGV technology as an area in which it can not only match the United States but perhaps surpass it, and thus achieve a degree of strategic parity without resorting to methods such as increasing the size of its nuclear arsenal.

Deterrence and the Missile versus Missile Defense Competition

The pursuit of improved deterrence capabilities has long been a foundation of China's advanced defense programs, having guided its nuclear weapons development and shaped its "no first-use" policy.[718] China's military sees deterrence as encompassing capabilities across various domains and geographies, and the 2013 *Science of Military Strategy* notes that "military deterrence can be categorized as conventional or nuclear, space or nuclear, direct or indirect, regular or contingent, operational or non-operational, and local or global."[719]

Chinese writings express strong and enduring concern over U.S. BMD systems, with one 2011 study noting that the DoD "has spared no expense in its missile defense program" in an effort to achieve complete security and render the theory of mutually assured destruction obsolete.[720] China sees U.S. BMD as dangerous in the absence of a U.S. "no first-use" policy, and its objections to the deployment of the THAAD system to South Korea and the X-Band radar system in Japan further illustrate its concern with the potential of an U.S. BMD to erode or eliminate China's potential deterrent threat.[721] These deployments are not a driver of China's development of hypersonic weapons, but support its perception that these systems can pose a threat to its own offensive capabilities.

The development of HGVs capable of defeating U.S. BMD systems would alter this perception of a strategic imbalance in the missile versus missile defense competition. It would provide China with a technological advantage that could improve the survivability of its numerically inferior nuclear arsenal and, at least plausibly, re-establish the calculus of mutually assured destruction.[722]

Although it is unclear what, if any, maneuvering attempts were made during the Wu-14 tests from 2014 through 2016, lessons learned from the program appear to have influenced subsequent R&D efforts. A January 2017 SIPRI study notes that academic studies and publications in Chinese scientific journals include simulations that leverage near space and heat reduction to facilitate successful re-entry; research on more powerful engines; and improved trajectory optimization to expand range.[723]

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718 Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 16-17. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf.

719 PLA Research Department of Military Strategy, "The Science of Military Strategy," Military Science Press, 2013. https://fas.org/nuke/guide/china/sms-2013.pdf.

720 Ceng Huafeng, Shi Haiming and Chen Haiping, "Hypersonic Weapons: The New "Triad" Deterrence Sword," *Science and Technology Daily*, 20 December 2011. For further details, see Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 9. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

721 Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 6. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles,

722 Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 8-9. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf.

723 Examples cited in Saalman, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," include Zhang Xiangyu, Wang Guohong, Zhang Jing and Liu Yuan, who are affiliated with the Institute for Information Fusion at the Naval Aeronautical and Astronautical University, "Tracking hypersonic boost-glide trajectory targets in near space," Journal of Astronautics, No. 10, October 2015, p.1125-1132; Qiu, X. "Re-entry-glide near space vehicle flight attitude control systems," Master's Thesis, School of Information and Control, Nanjing University of Information Engineering, May 2013; Li, Qiang, "Study on re-entry guidance and control method for hypersonic glide vehicle," Doctoral Thesis, School of Aerospace Engineering, Beijing Institute of Technology, January 2015; Meng, L. "Optimization of leap trajectory for near space vehicles

These efforts, and close observation of the capabilities—and limitations—of U.S. BMD will likely drive Chinese efforts to improve the maneuverability of HGVs and thus regain the strategic advantage of its nuclear deterrent.

HGVs could also play a strategic role by fulfilling a similar function to the U.S. Prompt Global Strike program. China views the U.S. Prompt Global Strike as designed towards first-strike and potentially more dangerous than nuclear weapons. Articles in Chinese technical and strategic journals express doubt that Chinese defensive systems are capable of detecting and intercepting U.S. Prompt Global Strike weapons.[724] Researchers from the Beijing Institute of Structural and Environmental Engineering suggest that Prompt Global Strike systems are more likely to be used than nuclear weapons, stating that the United States:

> "Is developing these new conventional weapons, with high combat accuracy, controlled damage range, flexible time use, and hypersonic flight… [in other words] strategic conventional weapons that are easy to use and able to be used... Currently, the U.S. is facing a transition from a nuclear to a conventional strategic strike force and will not give up just because a few test flights 'fell into the Pacific'."[725]

This concern is further illustrated in another article written by experts from China's Third Engineering Army, which argues that:

> "With continuous improvement of its organizational mechanisms, command structure, and equipment systems, actual deployment of prompt global strike is not distant. Prompt global strike capabilities are an important part of providing the United States with an offensive combat capability and will in the future provide the U.S. military with more options for its 'pre-emptive strike' strategy. With its extreme long-range precision strike, immediate arrival, mobile penetration capabilities, prompt global strike will have a significant impact on the combat theory and style of future wars, posing a new threat to international peace and regional stability."[726]

China's interest in the speed and flexibility offered by Prompt Global Strike is reflected in Chinese technical studies on HGVs and related technologies emulating what China calls "rapid response" programs. In addition, approximately 25% of the studies reviewed in the 2017 SIPRI study discuss the concept of rapid response.[727] Despite the prevailing Chinese view of Prompt Global Strike as detrimental to global stability, it is possible that China may seek to develop its own equivalent Prompt Global Strike capability with HGVs out of a perception of near existential vulnerability.

Lora Saalman, Director and Senior Researcher at SIPRI, noted in a 2014 study that with:

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at hypersonic speed," Master's Thesis, Harbin Institute of Technology, June 2009; Chen, F. "Rapid trajectory planning for hypersonic glide vehicles, Master's Thesis, National University of Defense Technology, January 2012.

[724] Saalman, Lora, "Prompt Global Strike: China And The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf, p.2, 10.

[725] Wang Zhijun, "On U.S. 'Absolute Security' Political Theology and Obama's 'Nuclear Free World' Thought," International Forum), Issue 1, 1 January 2010, p. 17-18; Li Qingyuan and Shi Junhong, "Overview of Hypersonic Technology Development," Structure and Environment Engineering, Issue 5, October 2012, p. 55-64.

[726] Dang Aiguo, Li Xiaojun and Xu Bao, "Foreign Military Prompt Global Strike Prompt Global Strike Capabilities Dynamic Developments," Winged Missiles Journal, Issue 7, July 2012: 51-54.

[727] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles, p.8.

> "Development of such systems as the DF-21D and the Wu-14, this is exactly what China has done. Thus, for all of the concerns over China's potential nuclear 'sprint to parity,' advanced conventional high-speed, high-precision weaponry constitutes a more likely and contemporary venue for arms racing."[728]

Salmaan also noted:

> "Chinese strategic and technical experts tend to frame hypersonic, boost-glide weaponry as inherently pre-emptive. If this view crosses from the conventional to the strategic realm, then Beijing's 'strategic conventional weaponry' and posture is likely to become more proactive and less 'reactive'."[729]

Nuclear or Conventional Weapon

There is also the outstanding question of whether HGVs will carry conventional or nuclear payloads. The January 2017 SIPRI study of Chinese literature notes that HGVs are described in a more "utilitarian" manner than nuclear weapons systems; this view of HGVs as a practical tool rather than a pure deterrence weapon suggests a conventional weapons application, and thus increases the risk of their use.[730]

However, the study also notes that approximately half of the surveyed Chinese studies focus on technologies related to longer-range systems, including space planes, which suggest focus on strategic rather than regional use, creating the potential "to erode the nuclear taboo, increasing the likelihood of their use even if mounted with nuclear payloads…If China's DF-ZF system is launched in response to what has been deemed a 'first-use' attack on a co-mingled facility, there is a chance of nuclear escalation."[731] Furthermore, Saalman notes "the nuclear potential of these systems is never far off. Whether in strategic journals or in technical journals, both the development of and the purpose for hypersonic, precision-guidance and boost-glide systems are merging within Chinese discourse."[732]

The strategic deterrence application for hypersonics thus centers on China's concern over a U.S. strike designed to incapacitate China's conventional and nuclear weapons arsenals and render it unable to effectively retaliate because of U.S. BMD systems.[733] This concern will drive Chinese development of hypersonic weapons systems for strategic purposes. Regardless of whether China seeks to develop HGVs with the intention of carrying nuclear weapons, their ability to do so will give China a degree of parity with the United States despite its smaller arsenal of nuclear weapons. This capability will also allow China to maintain an international posture of peaceful growth that would be undermined by increasing the size of its nuclear arsenal.

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[728] Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 14. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf,
[729] Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 17. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf.
[730] Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf, p.14
[731] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles, p.7.
[732] Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg.14. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf,
[733] Saalman, Lora, "Prompt Global Strike: China and The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 2. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf,

A2/AD

China has a strong interest in strengthening its A2/AD capabilities and has dedicated significant resources to increase its ability to control access to areas such as the South China Sea. Both HGVs and ramjet/scramjet-powered missiles could improve existing capabilities. Indeed, despite the aforementioned strategic uses, some analysts suggest that China's development of hypersonic weapons systems are designed primarily to support conventional A2/AD strategies.[734]

As noted in the overview of current programs, China has pursued use of ramjets on a variety of munitions, suggesting interest in a wide range of tactical battlefield applications. Through sheer speed, missiles equipped with ramjet/scramjets will challenge even the most robust defensive systems of opposing naval and land assets, and the relatively low production costs (once the technology is developed to an adequate level) could allow China to field a vast array of air and ground launched weapons against aerial, naval and land targets.

HGVs also have the potential to improve A2/AD capabilities—for example, by increasing China's ability to threaten distant naval forces from an inland launch site without risking alternative assets such as aircraft. As a result, they offer low and relatively flat trajectories, which make them less vulnerable than ballistic missile systems such as the DF-21D.[735] However, the primary development driver for HGVs appears to be strategic in nature, and the escalation risk with systems such as HGVs arguably reduces their value as a more tactical weapons system.[736]

Matching U.S. Development

For a range of economic and political reasons, China has avoided entering a direct arms race with the United States, particularly with strategic systems such as nuclear weapons. China's leadership may wish to avoid any similar escalation with hypersonic systems, but does not want to see United States develop an outright lead that would place China at technological disadvantage. China may thus seek to develop its own programs beyond those of existing U.S. capabilities to ensure parity at the very least, and possibly to "leap-frog" into a position of technological superiority.[737] Therefore, Jane's assesses that some competition—either through an effort to achieve superiority or merely maintain parity—may drive development.

While China has not sought to achieve true parity with the United States and Russia through expansion of its nuclear arsenal,[738] having a sophisticated delivery system may negate that deficit by rendering it irrelevant. This would elevate China to an effective status of parity and provide greater leverage in arms limitation talks—possibly a key strategic goal in and of itself, according to Dr. Saalman.[739] By limiting the growth of its nuclear arsenal while improving a delivery system in which R&D efforts also support China's civilian space program, China can also help maintain its image of pursuing peaceful development and providing world economic leadership rather than through military power.

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[734] Ekmektsioglou, Eleni "Hypersonic Weapons and Escalation Control in East Asia," *Strategic Studies Quarterly*, Summer 2015, 9:2, pg. 51. http://www.airuniversity.af.mil/Portals/10/SSQ/documents/Volume-09_Issue-2/ekmektsioglou.pdf.
[735] Ekmektsioglou, Eleni "Hypersonic Weapons and Escalation Control in East Asia," *Strategic Studies Quarterly*, Summer 2015, 9:2, pg. 51. http://www.airuniversity.af.mil/Portals/10/SSQ/documents/Volume-09_Issue-2/ekmektsioglou.pdf.
[736] Ekmektsioglou, Eleni "Hypersonic Weapons and Escalation Control in East Asia," *Strategic Studies Quarterly*, Summer 2015, 9:2, pg. 58. http://www.airuniversity.af.mil/Portals/10/SSQ/documents/Volume-09_Issue-2/ekmektsioglou.pdf.
[737] Saalman, Lora, "Prompt Global Strike: China And The Spear," Daniel K. Inouye Asia-Pacific Center for Security Studies, April 2014, pg. 5, 16. http://apcss.org/wp-content/uploads/2014/04/APCSS_Saalman_PGS_China_Apr2014.pdf.
[738] Hanham, Melissa, "China's Happy to Sit Out the Nuclear Arms Race," *Foreign Policy*, 30 January 2017, http://foreignpolicy.com/2017/01/30/chinas-happy-to-sit-out-the-nuclear-arms-race/.
[739] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 10–11. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

China's intentions vis-à-vis the United States can also be established by examining parallels with Russia's development of hypersonic weapons systems, which appear to provide a strong technical influence on China's own development programs. A January 2017 SIPRI report reviewed contemporary Chinese literature on HGVs and found that 872 articles (approximately 52% of the total number of studies examined) mention Russian development programs and technologies. The report notes that Chinese research on the effects of high-speeds on aerodynamic properties, maneuverability and the G-forces provide assessment of Russian programs, including the Yu-70, Yu-71 and Yu-74 HGVs. Furthermore, this analysis found the majority of Chinese literature focused on U.S.-Russian relations, suggesting that they are seen as an emerging element in strategic arms control dialogue between the United States and Russia.[740]

Other ties between Russia's and China's programs indicate possible similarities and their approach to hypersonic systems. Neither Russia nor China distinguish between regional and global missile defense and make similar objections to the U.S. deployment of BMD systems such as THAAD in their respective regions.[741] Like China, Russia views the U.S. Prompt Global Strike program as inherently pre-emptive and destabilizing and may also see hypersonic systems as providing a deterrent effect. Furthermore, Jane's assessment is that China and Russia hold similar views on the threat posed by U.S. military activities in their respective regions of influence and may seek to counter the perceived U.S. threat through weapons systems that can negate superior U.S. strength in numbers or otherwise offset superior U.S. firepower through an asymmetric threat.

"We, the United States, do not want to be the second country to understand how to control hypersonics."

-Former U.S. Acting Assistant Secretary of Defense Alan Shaffer

U.S. Development Initiatives and Programs

U.S. interest and activity in hypersonic weapons is long-standing, but has, until very recently, lacked a sense of urgency or articulation of cohering strategic concepts associated with U.S. hypersonic weapons R&D. This inattention—a point made earlier in this paper about other capability areas, especially U.S. investment in and urgency regarding electronic warfare capabilities—is a central theme of a 2016 U.S. Air Force Studies Board report entitled "A Threat to America's Global Vigilance, Reach, and Power High-Speed, Maneuvering Weapons" (HSMWs). This report assessed that there are technical, conceptual and prioritization challenges that need to be addressed and overcome:

> "The technical challenges posed by HSMWs are compounded. The committee could find no formal strategic operational concept or organizational sense of urgency. Further, the committee believes there is a lack of leadership coordination to provide efficiency and

[740] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 1–3. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

[741] Saalman, Lora, "China's calculus on hypersonic glide," *Stockholm International Peace Research Institute*, 15 August 2017, https://www.sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide

> direction for the development of possible countermeasures and defensive solutions across the Department of Defense."[742]

Todd Harrison, Director of the Aerospace Security Project and Director of Defense Budget Analysis at the Center for Strategic and International Studies, seconded this conclusion, assessing that research on hypersonic weapons has been on-going for decades "at a relatively low level."[743]

However, China's advancing program (as well as Russia's HGV) has inspired this long-absent sense of urgency in across the U.S. defense enterprise and a growing sense of the destabilizing and disruptive nature of these weapons. As former Acting Assistant Secretary of Defense Alan Shaffer noted in July 2017, "We, the United States, do not want to be the second country to understand how to control hypersonics."[744]

This urgency seems particularly prominent in the U.S. Air Force. In May 2017, then Acting Secretary of the U.S. Air Force, Lisa S. Disbrow stated the Air Force is "accelerating our research in this area" while Dr. Greg Zacharias, the Air Force Chief Scientist noted that the U.S. Air Force has "a real sense of urgency."[745]

And this renewed urgency is embedded in the 2017 National Defense Authorization Act, including funding to establish a defense against hypersonics. In 2012, the U.S. Air Force requested under $79 million for hypersonics, compared to $92 million for the 2018 presidential budget request, $90 million of which is for prototyping. "It seems like now, based on whatever intelligence assessments they are receiving, the military seems to be getting very serious," Harrison commented.[746]

This urgency appears to be translating into dramatically increased funding in FY2017 and FY2018, as indicated in Figure 28 below.

Figure 28: Air Force funding requests for hypersonics research and development programs from 2012 through the FY2018 budget request. The information indicates swings in funding from FY14, but the highest two years are the last two, FY2017 and FY2018

Fiscal Year	FY12	FY13	FY14	FY15	FY16	FY17	FY18 (REQ)	FY12-FY17 TOTAL
Hypersonics S&T Investment ($US millions)	78.8	72.9	161.7	221.4	108.8	378.1	292.5	1,021.5

Note: This total funding includes hypersonics S&T efforts across the Air Force's aerospace systems, materials and munitions portfolios.
Source: U.S. Air Force.

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[742] Committee on Future Air Force Needs for Defense Against High-Speed Weapon Systems Air Force Studies Board Division on Engineering and Physical Sciences, "A Threat to America's Global Vigilance, Reach, and Power—High-Speed, Maneuvering Weapons: Unclassified Summary," The National Academies Press, Washington, D.C., 2016, pg. 21.
[743] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.
[744] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.
[745] Evans, Lt. Colonel Sharon, "Accelerating Hypersonics Development," *U.S. Air Force website, News*, 9 May 2017, http://www.af.mil/News/Article-Display/Article/1177338/accelerating-hypersonics-development/.
[746] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.

Key hypersonic weapons programs from the DoD and defense contractors include:

- The Air Force Research Laboratory (AFRL) has partnered with DARPA and NASA and defense companies on developing air-breathing and boost glide hypersonics. Lockheed Martin is a partner for the hypersonic air-breathing weapon concept (HAWC) which would use a ramjet or scramjet, while Raytheon is assisting with boost gliding technology that would use a launch from a rocket into the atmosphere and rapid descent. [747]

- Between 2010 and 2013, the AFRL conducted several tests of hypersonic flights with a scramjet aircraft developed by the lab with NASA, DARPA, Boeing and Aerojet Rocketdyne, called the X-51 Waverider. The 2013 flight set the current world record for longest air-breathing hypersonic flight. [748]

- In 2011, the U.S. Army tested a long-range glide vehicle titled the "advanced hypersonic weapon," but there has been no comment from the service on other developments. [749]

- In 2006, the AFRL began partnering with Australia's Defense Science and Technology Group and NASA on the hypersonic international flight research experimentation (HiFIRE) program. In July 2017, the program successfully tested a Mach 8 missile.[750] The program is scheduled to run through 2018, but is currently expected to be extended. [751]

The 2016 Air Force Science Board report also highlighted technical challenges and, indeed, the S&T associated with hypersonic weapons remains a principal interest of the U.S. Air Force Acquisition professionals and the U.S. Air Force Research Laboratory. "We simply can't get where we need to go without continued S&T investment to bring these supporting technologies to a readiness level that can meet our timelines for an operational capability," said Lt. Gen. Arnold Bunch, the military deputy with the Office of the Assistant Secretary of the Air Force for Acquisition.[752] As a result, the U.S. Air Force Research Laboratory has active research and development efforts in foundational hypersonic technology maturation, including work in ordnance, tactical boosters, airframe and structures, guidance, navigation, and control and materials and manufacturing, according to the U.S. Air Force

[747] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.
[748] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.
[749] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research
[750] Wang, Brian, "US-Australia had a successful Mach 8 HiFire 4 hypersonic missile test last week," *Next Big Future,* 15 July 2017, https://www.nextbigfuture.com/2017/07/us-australia-had-a-successful-mach-8-hifire-4-hypersonic-missile-test-last-week.html
[751] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research
[752] Evans, Lt. Colonel Sharon, "Accelerating Hypersonics Development," *U.S. Air Force website, News*, 9 May 2017, http://www.af.mil/News/Article-Display/Article/1177338/accelerating-hypersonics-development/

website.[753] Despite these successes, experts believe the United States is several years away from a hypersonic weapon in the field. [754]

Implications for Future Competition with the United States

The U.S remains committed to the development of hypersonic weapons system, despite previous testing failures and funding limitations.[755] DARPA's 2016 contracts with Lockheed Martin and Raytheon for the HAWC, and the U.S. Air Force's July 2017 notice regarding development of an air-launched hypersonic weapon demonstrate continued U.S. interest in developing offensive capabilities.[756] In addition, the $75.3 million included in the 2018 Presidential Budget Request for hypersonic missile defense illustrates the sustained focus on defense.[757] China will continue to respond in kind with development of equivalent systems in order to prevent the United States from developing an insurmountable technological advantage.

These systems have the potential to alter the regional strategic balance by giving the PLA a long-range strike capability that can potentially overwhelm existing defensive measures. This capability has direct implications for confrontations in contested areas including the East and South China Seas, and could facilitate more aggressive Chinese A2/AD efforts with the first and second island chains. The global strategic implications of a sophisticated HGV threat also pose a direct challenge to the United States if they can feasibly defeat U.S. or allied missile defense systems, although the potential risk of escalation may discourage the assumption of an overly aggressive posture with these systems.

Unless China makes concerted efforts to rein in hypersonic development by using it as a means of entry in to the global arms control dialogue, the possibility of an arms race—even one broadening beyond the United States, China and Russia—remains real. This trend may already be underway, and the speed of progress in China's HGV and ramjet programs indicate that it has the appropriate R&D structures and funding to maintain momentum in technological development, and possibly drive the global direction of research, testing and employment of hypersonics weapons.[758]

In fact, the combination of United States under-investment and rapid advancement of and heavy investment in hypersonics programs in China (and Russia) has undermined and potentially usurped U.S. advantage in hypersonic weapons. In January 2018, Air Force General Paul Selva, the Vice Chairman of the Joint Chiefs of Staff claimed that "We have lost our technical advantage in hypersonics. We haven't lost the hypersonics fight. The Russians and Chinese have moved out pretty

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[753] Evans, Lt. Colonel Sharon, "Accelerating Hypersonics Development," *U.S. Air Force website, News*, 9 May 2017, http://www.af.mil/News/Article-Display/Article/1177338/accelerating-hypersonics-development/.

[754] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, 26 June 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.

[755] Ekmektsioglou, Eleni "Hypersonic Weapons and Escalation Control in East Asia," *Strategic Studies Quarterly*, Summer 2015, 9:2, pg. 48. http://www.airuniversity.af.mil/Portals/10/SSQ/documents/Volume-09_Issue-2/ekmektsioglou.pdf.

[756] Carey, Bill, "U.S. Air Force Aims To Speed Hypersonic Weapon Development," AIN Online, 26 July 2017, https://www.ainonline.com/aviation-news/defense/2017-07-26/us-air-force-aims-speed-hypersonic-weapon-development.

[757] "RDT&E PROGRAMS (R-1)," US Undersecretary of Defense Comptroller, November 2017, last accessed 14 November 2017, pg. D-33A.
http://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2018/November2017Amended/fy2018_r1a.pdf.

[758] Saalman Lora, "Factoring Russia into the US-Chinese Equation on Hypersonic Glide Vehicles," SIPRI, January 2017, pg. 10. https://www.sipri.org/publications/2017/sipri-insights-peace-and-security/factoring-russia-us-chinese-equation-hypersonic-glide-vehicles.

smartly" on hypersonics. China, in particular, has been "willing to spend tens to hundreds of billions of dollars on its program."[759]

Jane's has identified the following key issues that will drive further Chinese development of ASBMs, HGVs and other MARV technologies.

1. China will continue its effort to develop an improved ISR network to identify and track targets, with a focus on developing comprehensive coverage out to at least the Second Island Chain. This will feature improved coverage from satellites, fixed sensors such as those envisioned in the Underwater Great Wall and the proliferation of unmanned systems (particularly UUVs) which can locate and track high-value targets. This supporting infrastructure is critical in transforming hypersonic weapons from a novel technology to a truly destabilizing weapons capability that can shift regional power balances and help China realize its A2/AD ambitions.

2. Developing the capability to gather this information is likely a matter of time and investment, as China largely possesses the technology required. Key technology gaps remain in developing the network to relay this information, particularly in challenging environments (e.g. deep sea), where the reliability and speed of information transmission is still challenged, and sensors and datalinks could be subject to jamming or other counter-measures. As noted by Erickson, a more seamless "sensor-to-shooter" network is required for China's ISR assets to effectively feed targeting information to decision makers and input to weapons systems, enabling their use against moving targets (e.g. surface vessels, aircraft).[760] However, China is improving these capabilities, and the launch of an ultra-secure quantum communications satellite in August 2016 is expected to help with directing HGVs and developing their flight paths.[761]

3. In tandem with improving the sensor-to-shooter network, China will seek to improve the navigation technology for MaRVs so that they can remain on course for identified targets. China is pursuing the development of reliable, hardened navigation technologies both through organic R&D efforts and from foreign sources (including industrial espionage) and will seek to employ these on ASBM delivery vehicles.

4. The Wu-14 likely provided valuable technical insight in the development of future HGVs, particularly in regard to maneuvering. It is unclear from open source information what China's objectives were in testing the maneuverability of the vehicle during these tests, and therefore difficult to establish if test objectives were met. Lessons learned in key areas, including regarding vehicle design and construction, launch trajectories and flight paths, will guide R&D efforts for China's next generation HGV. The development of supporting infrastructure (e.g. wind tunnels) will facilitate testing and refinement of designs.

5. China will seek to maintain, at a minimum, technological parity with the United States in the development of HGVs, and will thus closely follow U.S. developments in hypersonic technologies and hypersonic weapons defense, and evaluate what this means for China's own programs. China likely does not have an apparent interest in arms limitation talks at this

[759] Morgan, Wesley, "Selva: We have lost our technical advantage in hypersonics", *Politico,* January 30, 2018, https://www.politicopro.com/defense/whiteboard/2018/01/selva-we-have-lost-our-technical-advantage-in-hypersonics-503866.
[760] Erickson, Andrew, "Raining Down: Assessing the Emergent ASBM Threat," *Jane's*, 16 March 2016. http://janes.ihs.com/Janes/Display/1765057.
[761] Gibson, Neil, Andrew Tate "China launches world's first ultra-secure quantum communications satellite," Jane's Defense Weekly, 17 August 2016.

stage, but should this become a priority for China, it could attempt to use its technological advantage in HGVs and other hypersonic weapons to negotiate from a position of relative strength. Given the apparent advances China has made in the development of HGVs thus far, the resources provided to future R&D (e.g. supporting infrastructure, funding through S&T programs), and the dramatic advantage they could provide in facilitating China's A2/AD objectives, Jane's anticipates China will place a high-priority on hypersonic technologies over the next decade.

Chapter 8: China's Directed-Energy Weapons

Chapter 8 Key Themes and Insights

- **An Advanced Capability:** Directed energy weapons are already being fielded by China—and offered for export—meaning that this category of advanced weapons system joins both counter-space and unmanned systems as relatively mature systems with on-going, as opposed to distant, future operational relevance. China has demonstrated a range of laser weapons in multiple settings:
    - **Counter-space:** China used a ground-based laser to dazzle a U.S. satellite in 2005 and reportedly again in 2006. Space-based jamming and dazzling satellites are also thought to be under development. The effects of counter-space directed energy weapons can be moderated to disable satellites for finite periods of time or to destroy satellites, offering China a flexible and potentially less provocative means of engaging adversary and competitor space-based architecture than direct ascent ASAT missiles.
    - **Counter-drone/electronic warfare:** Police in China have used hand-held laser rifles to jam signals of drones, forcing the small crafts to land.
    - **Close-in defense**: China has also successfully developed a series of truck mounted close-in defense weapons, primarily focused on meeting the threat of masses of slow-moving drones at relatively close range. The Silent Hunter laser protection system is the most recent version of this capability and is currently available for export.
    - **Non-lethal weapons:** The WB-1 is a truck-mounted microwave, non-lethal weapon that can be used in crowd-control functions.
- **Naval Applications:** China will continue to scale up the power of its directed energy systems while attempting to scale down their size. Interest has already been shown in deploying directed energy weapons on ships for close-in defense—as the U.S. has already demonstrated on the *U.S.S. Ponce*—and as a local A2/AD weapon, potentially chasing adversary ships disputed waters, such as the South China Sea.
- **Technology Challenges:** China continues to struggle with capturing and storing energy for more powerful beams, scaling powerful systems down for mounting on vehicles, maneuverability and mitigating the effects of environmental conditions on the weapons' operation. Fog and smoke can dissipate lasers and microwaves, rendering the weapons useless.

Overview on Directed Energy Weapons

Directed energy weapons concentrate and direct energy at a specific target. Lasers and microwave weapons are the most commonly mentioned types of direct-energy weapons and are the focus of this section.

Directed-energy weapons are of interest to modern militaries for many reasons, but their appeal is heightened due to their "deep magazine/low cost of shot" nature. This makes lasers especially interesting for the U.S. Navy as its current ways to defend against anti-ship cruise and ballistic missiles are limited in shallow depth of magazine and high cost per shot weapons such as kinetic kill vehicles. In a combat situation infested with large numbers of UAVs and cruise and ballistic missiles fired from different axes or domains (land, air, sea, undersea), using kinetic kill vehicles to meet and defeat all threats is unaffordable and maybe technically unfeasible.[762]

The U.S. Navy's Laser Weapon System (LaWS) costs under $1 to fire for 10 seconds, which is the amount of time it takes for the laser to burn through an engine in a 50 meter vessel.[763] Moreover, laser weapons rely only on an energy supply to continue to fire and can therefore fire as many rounds as the power source can generate. Laser weapons allow rapid engagement as the shot is as fast as the speed of light; they are also scalable and highly focused, limiting collateral damage.[764]

Technical and operational challenges slowing laser weapon development and deployment are that it is limited by line of sight: targets can only be hit if they can be seen and the beam must stay focused on the target. This limits lasers weapons' use against swarms by constraining how fast they can move from target to target. In addition, it makes laser weapons vulnerable to countermeasures; Reflective surfaces can deflect beams and rapid movements, such as rapid rotation, will make it very difficult for the beam to stay on the target and inflict damage.[765] "Thermal blooming" in which the heat of lasers distorts the air around it, making the beam unstable, is another vulnerability of the use of lasers, especially against targets heading straight towards the weapon as the laser would not move enough to mitigate thermal blooming.[766]

Lasers have been proposed to counter many threats of the modern and future battlefield, though each type of threat requires a different range of power. Missiles will need to be targeted by lasers in the 500 kilowatt (kW) to 1 megawatt (MW) range. Power constraints and limits on cooling systems' abilities hinder current development of lasers up to 500 kW. 1 MW lasers are believed to be beyond current technical capacities.[767]

Table 26: Ranges of power needed for lasers to destroy certain targets[768]

<table>
<tr><th colspan="5">Power in Watts</th></tr>
<tr><th>~10 kW</th><th>10-90 kW</th><th>100 kW</th><th>500–999 kW</th><th>1 MW</th></tr>
<tr><td colspan="3">UAVs</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Rockets, artillery and mortars</td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Small boats/Trucks</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="2">Missiles</td></tr>
</table>

[762] O'Rouke, Ronald, "Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, 17 October 2017, pg. 3. https://fas.org/sgp/crs/weapons/R44175.pdf.
[763] Mcguirk, Rod. "US admiral Praises Laser and Electromagnetic Guns on Costs," *Phys.org*, February 10, 2015. https://phys.org/news/2015-02-laser-electromagnetic-guns.html.
[764] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," *Jane's Intelligence Briefings*, 21 April 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[765] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," *Jane's Intelligence Briefings*, 21 April 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[766] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, 21 April 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[767] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," *Jane's Intelligence Briefings*, 21 April 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[768] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," *Jane's Intelligence Briefings*, 21 April 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.

Several different types of lasers exist. The most commonly mentioned for military use are:

- Solid-state, which use a solid mass, such as a ruby, as the energy conductor
- Gas, which use noble gases or carbon dioxide as the energy conductor
- Chemical, which use a chemical reaction to generate the beam[769]

Microwave weapons

Microwave weapons use an antenna to direct invisible, high frequency radio waves at a target. When the beam hits human skin, it is absorbed in the top 1/64th of an inch, "about three sheets of paper" deep, right where nerve endings are. The microwaves work the same on human skin as they do on food: generating heat by exciting the water molecules inside. The result is a burning sensation that disappears as soon as the individual moves out of the beam. Microwave weapons are effective non-lethal crowd control systems, people instinctively flee the sensation and, allegedly, it leaves no lasting damage to the body (though U.S. trials found that a very small number of people developed pea-sized welts on the skin).[770]

Technical challenges to directed energy development include:

- Energy capture and storage
- Size and maneuverability of the systems
- Capacity of systems to operate in bad weather (which reduces line of sight and can distort the path of the directed energy).

In addition, ethical questions remain over the use of directed energy weapons, especially the use of high-powered microwaves and lasers as non-lethal weapons against humans. A crowd control non-lethal laser could startle and temporarily blind humans at low levels but at the wrong setting it could easily permanently blind the crowd members.

Summary of China's Directed Energy Activities

China's interest in directed energy goes back to the 1960s with the launch of Program 640, which researched lasers to combat ballistic missiles.[771] Chinese industry, academia and research institutes have been successful in fielding directed energy systems since the mid-to-late 1990s. Historic and current systems typically fall into the following categories of capability:

- Counter-space, including capabilities to "dazzle" or blind satellites
- Non-lethal weapons for crowd control or operations in which excessive civilian casualties could be avoided
- Close-in defense against threats such as unmanned systems, mortars and fast attack boats, similar to the capability demonstrated on the *USS Ponce* in 2016
- Electronic warfare to jam transmissions of adversary platforms and systems.

Poly Technologies and NORINCO are the most prominent industry players involved in directed energy development. The China Academy of Engineering Physics and the China Academy of Science are the main research institutes on directed energy followed by the Northwest Institute of Nuclear Technologies, Changchun Institute for Optics and the Jiuyuan Hi-Tech Equipment Corporation.

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769 AZoOptics. "Gas and Chemical Lasers - Introduction and Applications of Gas and Chemical Lasers," *AZoOptics.com*. October 14, 2007. https://www.azooptics.com/Article.aspx?ArticleID=45.

770 Martin, David. "The Pentagon's Ray Gun," *CBS News*, February 29, 2008. https://www.cbsnews.com/news/the-pentagons-ray-gun.

771 Fisher, Richard. "Space invaders - China's space warfare capabilities," Jane's by IHS Markit. https://janes.ihs.com/Janes/Display/jir11780-jir-2014.

China's directed energy systems are increasingly appearing at defense and law enforcement exhibitions throughout the world, indicating a capability mature enough to be exported. For example, the Silent Hunter directed energy system was prominently displayed in the "Defense China" pavilion at the February 2017 IDEX show in Abu Dhabi.

Current Programs and Technologies

China has had a long-standing interest in developing lasers, at least since the 1960s for anti-ballistic missiles with an increased effort on lasers for ASAT capabilities in the 1980s.[772] These efforts have delivered an array of advanced systems capable of carrying out at least four broad mission areas.

Jamming and Blinding Weapons

The ZM-87 by NORINCO was first publicly revealed at an exhibition in the Philippines in 1995 and was a laser designed to damage electro-optical sensors and human eyes up to 10 km away. The system was lightweight, portable and able to be mounted on Type 98 tanks and possibly ships. However, production reportedly ceased after China signed the United Nations 2000 Protocol on Blinding Laser Weapons, which prohibited use of lasers that can blind humans.[773] Despite signing this protocol, as early as 2004, reports emerged that the PLA was outfitting the Type 63A light amphibious tank with a roof-mounted laser that would locate and then blind hostile optical devices. Reportedly, the device could blind humans at full power, constituting a violation of the United Nations protocol.[774]

Figure 29: The reportedly $19,000 gun that forced an unmanned system down during a recent soccer game in China (Weibo)

China displayed four laser rifles at a December 2015 police exhibition: the PY131A, PY132A, WJG-2002 and BBQ-905.[775] The rifles were advertised as being able to blind drones, thermal imagers or security cameras. The lasers were also advertised as being able to pick up encrypted communications and stealth aircraft.[776]

Chinese police in Wuhan used a rifle that looked very similar to the PY131A on March 11, 2017 to jam a drone as it flew over a soccer game. By jamming the signal to its operator, the rifle forced the drone to switch to its automatic landing sequence. The jammer gun reportedly has a range of 1 km.[777] The PLA reported that these rifles are already being provided to PLA troops and Chinese police as a means of dealing with potential threats arising from the proliferation of commercial drones.[778] The

[772] Fisher, Richard. "Space invaders - China's space warfare capabilities," Jane's by IHS Markit. https://janes.ihs.com/Janes/Display/jir11780-jir-2014.
[773] "Laser Weapons." Jane's by IHS Markit. March 3, 2017. https://janes.ihs.com/Janes/Display/jsws0514-jaad.
[774] "NORINCO Type 63A light amphibious tank," Jane's by IHS Markit. May 9, 2016. https://janes.ihs.com/Janes/Display/jaa_1272-jafv.
[775] Jianing, Yao. "In Pics: China's blinding laser weapons." China Military Online. December 9, 2015. http://english.chinamil.com.cn/news-channels/photo-reports/2015-12/09/content_6808116_6.htm.
[776] General, Ryan. "The Chinese Military Now Has Laser Weapons," *NextShark*. December 19, 2016. https://nextshark.com/the-chinese-military-now-have-laser-weapons/.
[777] Lin, Jeffrey and P.W. Singer. "Here's how China is battling drones," *Popular Science*. March 28, 2017. http://www.popsci.com/chinas-new-anti-drone-weapons-jammers-and-lasers#page-2.
[778] Gertz, Bill. "Chinese Military Using Blinding Laser Weapons," *Washington Free Beacon*, December 22, 2015. http://freebeacon.com/national-security/chinese-military-using-blinding-laser-weapons/.

United States has a comparable jamming rifle, the Battle Drone Defender, which has been used by coalition forces in Iraq against Islamic State drones.[779]

In addition, in January 2017, a team at the Northwest Institute of Nuclear Technology in Xi'an announced they had developed a microwave weapon that can kill electronics. Open source information on the system was limited, but apparently the weapon is small enough to fit on a lab work bench and could be mounted onto vehicles, aircrafts, missiles and even drones.[780]

The PLA appears confident in its lasers and their ability to blind a radar system, including, potentially, radars attached to the U.S. THAAD system. A strategist at the PLA Academy of Military Science, Peng Guangqian, said that it would be "easy" to blind THAAD's radars with electronic interference or feigned military activities.[781]

Counter-Space/ASAT Lasers

There have been multiple incidents in which China has used lasers to blind satellites. In September 2005, a U.S. Government source reported that China "jammed" satellites with lasers.[782] This report was confirmed by a 2013 journal article, where three Chinese researchers revealed that they had successfully used a laser to blind a satellite in 2005. The researchers wrote that they had used a laser in the Xinjiang province with a capacity range of 50 to 100 kW and a beam only .6 meters wide, to target a LEO satellite.[783]

On September 28, 2006, *Defense News* reported that China had blinded a U.S. spy satellite with a high-powered laser. China tried to write it off as a mistake, arguing the laser was simply an astronomical range finder, but range finders by their very purpose can be used to locate objects in orbit and China had already proved it could intentionally dazzle satellites.[784] There are reportedly five laser range finders at fixed locations throughout China.[785]

> ***"In 2005, we have successfully conducted [sic] a satellite-blinding experiment using a 50-100 kilowatt capacity mounted laser gun in Xinjiang province"***
>
> -Gao Ming-Hui, Zeng Yu-Quang And Wang Zhi-Hong Of Changchun Institute for Optics

In addition to these demonstrated capabilities, researchers within China are also exploring laser systems concepts—including concepts with scientific applications—that could also theoretically be deployed in a jamming role.

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779 Lin, Jeffery and P.W. Singer, "Here's how China is battling drones," *Popular Science*. March 28, 2017. http://www.popsci.com/chinas-new-anti-drone-weapons-jammers-and-lasers#page-2.
780 Lin, Jeffrey and P.W. Singer. "China's new microwave weapon can disable missiles and paralyze tanks," *Popular Science*, January 26, 2017. http://www.popsci.com/china-microwave-weapon-electronic-warfare.
781 Torode, Greg and Michael Martina, "Chinese Wary About U.S. Missile System Because Capabilities Unknown: Experts," U.S. News & World Report. April 03, 2017. *https://www.usnews.com/news/world/articles/2017-04-03/chinese-wary-about-us-missile-system-because-capabilities-unknown-experts.*
782 "Strategic Weapon Systems." Jane's by IHS Markit. April 7, 2017. https://janes.ihs.com/Janes/Display/cnaa015-cna.
783 Gertz, Bill. "How China's Mad Scientists Plan to Shock America's Military: Super Lasers, Railguns and Microwave Weapons," *National Interest*, March 10, 2017. http://nationalinterest.org/blog/the-buzz/how-chinas-mad-scientists-plan-shock-americas-military-super-19737.
784 Fisher, Richard and Sean O'Connor. "Space invaders - China's space warfare capabilities." Jane's by IHS Markit. July 28, 2014. https://janes.ihs.com/Janes/Display/jsia0102-jsia
785 Lambakis, Steve. *Foreign space capabilities: implications for U.S. national security.* Report. pg. 24. http://www.nipporg/wp-content/uploads/2017/09/Foreign-Space-Capabilities-pub-2017.pdf.

In December 2013, Changchun Institute for Optics researchers Gao Ming-hui, Zeng Yu-quang and Wang Zhi-hong published an article in the *Chinese Optics* journal about their proposal for a 5-ton chemical laser deployed in LEO. They theorized that the weapon could target other satellites and be ready by 2023, a fast timeline indicating a high level of confidence in China's laser technology.[786]

The Chinese Academy of Sciences developed an astronomical laser used in a test for calibrating the international Thirty Meter Telescope.[787] The laser was fired out of Mianyang, China in December 2014. Reportedly it can reach 90 km into space with an accuracy of within 2 trillionths of a meter.[788] Lasers are used to calibrate telescopes by using their powerful beam to make artificial stars in the atmosphere. Telescopes can then focus on the fake star and use it as a reference to correct for distortion from the atmosphere.[789] While its alleged purpose was scientific, the Mianyang laser is theoretically capable of targeting satellites or missiles and strong enough to blind them.[790]

Close-in/Counter-Drone Defense

In 1999, the 1028th Research Institute reportedly tested a laser weapon and successfully destroyed a drone.[791] Since then, China has focused on developing directed energy systems to defeat CIWS, particularly drones.

The Low Altitude Guard I (LAG I): The LAG I was first revealed in late 2013.[792] The system is a joint venture between the Chinese Academy of Engineering Physics and Jiuyuan Hi-Tech Equipment Corporation, marketed by Poly Technologies.[793] The LAG I uses a 10-kW laser to engage and defeat low flying drones at speeds up to 180 km/h, up to 2 km away at a 50 meters altitude.[794] The system is able to track targets on its own but needs a human operator to allow it to fire. LAG I is especially suited for urban environments; it is small, cheap to fire, easy to place on buildings and can take out drones with little collateral damage.[795] LAG I reportedly shot down over 30 drones in a single test run.[796]

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[786] Gertz, Bill. "How China's Mad Scientists Plan to Shock America's Military: Super Lasers, Railguns and Microwave Weapons," *National Interest*, March 10, 2017. http://nationalinterest.org/blog/the-buzz/how-chinas-mad-scientists-plan-shock-americas-military-super-19737. Article can be found here (second one down): http://www.chineseoptics.net.cn/CN/volumn/volumn_1165.shtml.

[787] Zhang Yueliang [张岳良], Wu Qirong [伍其荣] and Zhu Dan [朱丹], "An Analysis of the 'All-Domain Access' Concept of the US Navy" [美国海军"全域进入"概念探析], China Military Science [中国军事科学], no. 4 (2015): 138.

[788] National Astronomical Observatory of China."TMT laser guide star joint experiment at the National Astronomical Observatory Xinglong Observatory" [神光一阳指， 造星耀银河"—TMT 激光导星联合实验在国家天文台兴隆观测站成功进行], December 30, 2014. http://www.bao.ac.cn/xwzx/zhxw/201412/t20141230_4285067.html; Lin, Jeffrey and P.W. Singer. "Chinese Laser Zaps Space, for World Peace," *Popular Science*, December 24, 2014. https://www.popsci.com/chinese-laser-zaps-space-world-peace.

[789] Moskvitch, Katia. "Laser Guide Star at VLT to shine brighter light on stars," *BBC News*. June 11, 2012. http://www.bbc.com/news/technology-18341684.

[790] Lin, Jeffrey and P.W. Singer. "Chinese Laser Zaps Space, for World Peace," *Popular Science*. December 24, 2014. https://www.popsci.com/chinese-laser-zaps-space-world-peace.

[791] "Laser Weapons," Jane's by IHS Markit. March 3, 2017. https://janes.ihs.com/Janes/Display/jsws0514-jaad.

[792] Pagliery, Jose. "China Claims New Laser Cannon Shoots Down Drones," *CNN*, December 29, 2014. http://money.cnn.com/2014/11/03/technology/security/china-laser-drone/index.html.

[793] Lin, Jeffrey and P.W. Singer. "China Sells a New Laser Gun," *Popular Science*. September 22, 2016. https://www.popsci.com/china-sells-new-laser-gun?utm_content=buffer51ebb&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer.

[794] Lin, Jeffrey and P.W. Singer. "China's New Laser Zaps Drones," *Popular Science*, November 3, 2014. https://www.popsci.com/blog-network/eastern-arsenal/chinas-new-laser-zaps-drones#page-2.

[795] Lin, Jeffrey and P.W. Singer. "China Joins the Laser Arms Race," *Popular Science*, July 30, 2015. https://www.popsci.com/china-joins-laser-arms-race#page-3.

[796] Lin, Jeffrey and P.W. Singer. "China's New Laser Zaps Drones," *Popular Science*, November 03, 2014. https://www.popsci.com/blog-network/eastern-arsenal/chinas-new-laser-zaps-drones#page-3.

Low Altitude Sentinel: The China Academy of Engineering Physics first revealed its Low Altitude Sentinel system in November 2014. The Sentinel is reportedly able to detect small drones within 2 km, up to 500 meters, at max speeds of 180 km/h and destroy them within 5 seconds. The system destroyed up to 30 targets in one test. The Sentinel's development was completed by late 2014.[797]

Low Altitude Laser Defending System (LASS): In September 2016, Poly Technologies showed off its LASS at a defense show in South Africa. The LASS has a max power of 30 kW and a range of 4 km. It is best suited for combating slow, large UAVs. Poly Technologies said it has been working on the LASS and other laser systems since 2011. [798]

Low Altitude Guard II: The Low Altitude Guard II, a truck mounted version of the anti-drone laser system, was also on display at the September 2016 South African defense show. The laser had been upgraded to a max power of 30 kW and range of 4 km. Reportedly, LAG II is capable of shooting down more than drones, such as aircraft, missiles and artillery shells. [799] The platform has been advertised for law enforcement and counterterrorism missions.[800]

Silent Hunter: Poly Technologies used the February 2017 IDEX show in Abu Dhabi to reveal its latest anti-drone laser system: The Silent Hunter. It is a more advanced version of LASS, with a power level between 30 to 100 kW. Poly Technologies said the laser can cut through five layers of 2 millimeters (mm) steel at 800 meters away or 5 mm of steel at 1 km. The display had two plates of steel that the system had reportedly cut through. There is a fixed and mobile version of the Silent Hunter, but both require a medium-truck sized power unit along with the laser unit.[801]

Figure 30: The Silent Hunter system as displayed at IDEX in February 2017 (Tate Nurkin)

Poly officials said they are also working on integrating a millimeter radar for better targeting and developing a more powerful version that would be able to defend against mortar shells and small artillery. Currently the system is too heavy to be developed as an aircraft mounted laser. Poly Technologies is advertising the laser weapon for international buyers, which could indicate China has a stronger laser weapon it is not exporting. While Poly officials reported no orders from foreign buyers yet, they said they have had "active interest." When asked if they were working on a space-based laser, Poly officials responded: "no, that would be another department."[802]

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797 Jane's by IHS Markit. "Sentinel," March 3, 2017. https://janes.ihs.com/Janes/Display/jaad0560-jaad
798 Fisher, Richard. "IDEX 2017: Poly reveals Silent Hunter fibre-optic laser system," Jane's by IHS Markit. February 2, 2017.https://janes.ihs.com/Janes/Display/jdw64717-jdw-2017.
799 Lin, Jeffrey and P.W. Singer. "China Joins the Laser Arms Race," *Popular Science*. July 30, 2015. https://www.popsci.com/china-joins-laser-arms-race#page-3
800 Lin, Jeffrey and P.W. Singer. "New Chinese Laser Weapon Stars On TV," *Popular Science*. November 25, 2015. http://www.popsci.com/new-chinese-laser-weapon-stars-on-tv#page-2.
801 Fisher, Richard. "IDEX 2017: Poly reveals Silent Hunter fibre-optic laser system," *Jane's by IHS Markit*. February 2, 2017. https://janes.ihs.com/Janes/Display/jdw64717-jdw-2017.
802 Fisher, Richard. "IDEX 2017: Poly reveals Silent Hunter fibre-optic laser system," *Jane's by IHS Markit*. February 2, 2017. https://janes.ihs.com/Janes/Display/jdw64717-jdw-2017.

Chinese academic sources have documented a longstanding interest by the PLAN in developing ship-based lasers and microwave weapons. In an August 2017 presentation, former rear admiral and former director of the PLAN's Equipment Department, Zhao Dengping, gave a PowerPoint presentation on modernization where several slides implied plans to outfit Type 055 Destroyers (DDGs) with laser/kinetic energy weapons and railguns (explored in the next chapter of this report).[803]

Non-Lethal Weapons

China's industry has also developed and demonstrated non-lethal weapons designed to support peacekeeping deployments and internal security missions in crowded and complex environments in which potential threat actors are co-mingled with civilians. This category of weapons could also be useful in efforts to prevent domestic protests in China from escalating to a more violent and dangerous situation without the use of deadly force. Jane's assesses that the requirement for "non-lethals" will expand both for use in internal security applications as well as in support of China's expanding economic and military/security presence abroad.

China has also developed these weapons for export. At the November 2014 Airshow China, NORINCO showed off its Safeguard RWS, which combines lethal and non-lethal capabilities for peacekeeping and anti-terrorism missions. Safeguard features a diode-based laser dazzler and an acoustic device to temporarily disorient targets.[804]

Figure 31: The WB-1 system (via Top 81 webpage, as published in *Jane's Defense Weekly*

At the same 2014 Airshow China, Poly Technologies revealed its WB-1 non-lethal crowd control system, which is similar to the U.S. Active Denial System, developed by Raytheon (see Figure 31). Both use microwaves to create a burning sensation in human skin. The Active Denial System was deployed to Afghanistan in 2011 but never used due to concerns of the strategic communications challenges that could be associated with the use of a microwave weapon against local populations, along with a long boot up time and high fuel use.[805] China's WB-1 reportedly has a range up to 1 km[806] and Poly Technologies is reportedly developing the WB-1 weapon for naval applications, such as close-in defense against unmanned systems, adversary small and fast attack boats and/or to chase foreign commercial and fishing ships out of contested maritime areas.[807]

Related technology developments

A major hindrance to developing lasers for combat has been the size of the systems, which can be logistically cumbersome and difficult to incorporate onto ships or other platforms that are not trucks.

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[803] *Jane's by IHS Markit*. "PLAN plans: former admiral details potential modernization efforts of Chinese navy," August 25, 2017. https://janes.ihs.com/Janes/Display/FG_631670-JDW.
[804] *Jane's by IHS Markit*. "Mob busters: Non-lethal weapons seek prime time," April 30, 2015. https://janes.ihs.com/Janes/Display/idr17603-idr-2015.
[805] Fisher, Richard, "China's Poly Group unveils WB-1 directed-energy crowd-control weapon," *Jane's Defense Weekly,* 27 November 2014, https://janes.ihs.com/Janes/Display/jdw57135-jdw-2015.
[806] *Jane's by IHS Markit*. "Mob busters: Non-lethal weapons seek prime time," April 30, 2015. https://janes.ihs.com/Janes/Display/idr17603-idr-2015.
[807] Fisher, Richard, "China's Poly Group unveils WB-1 directed-energy crowd-control weapon," *Jane's Defense Weekly,* 27 November 2014, https://janes.ihs.com/Janes/Display/jdw57135-jdw-2015.

The Chinese Academy of Sciences achieved an important breakthrough in September 2015 with the development of a new type of crystal, capable of channeling a regular laser beam into high-frequency waves. Before this development, multiple crystals were needed to do so. With the new crystal, the system was shrunk to the size of a hand bag.[808] This advancement was key to developing the aforementioned handheld laser rifles.[809]

Integrated electrical power systems (IEPS): IEPS is the process of powering everything on a platform (usually referring to ships) with the same source. By eliminating separation of power for propulsion and power for electrical systems, energy can be quickly redirected to different tasks. This capability will be important for energy-heavy weapon systems such as direct-energy lasers and microwaves, and railguns. Using electrical propulsion also reduces noise, making IEPS a significant upgrade for submarines. In June 2017, Rear Admiral Ma Weiming claimed that China had leap-frogged Western IEPS using DC power distribution systems instead of Western AC systems.[810] According to Rear Admiral Ma Weiming, "China now has a significant lead over U.S. and Western navies in the development of integrated electrical power systems."[811] The claim is, at best, bold, and at worst not credible, but it does reflect the emphasis China is placing on developing leading technologies in this critical area.

"China now has a significant lead over U.S. and Western navies in the development of integrated electrical power systems."

-Rear Admiral Ma Weiming

Potential Employment of Directed-Energy Weapons

Counter-space: Lasers do have civil, scientific and dual-use applications, a fact that enables China's research institutes to develop capabilities that could also be deployed in support of military or security missions. China's development of directed energy capabilities that can hold at risk U.S. space assets is likely the most strategically significant component of China's directed energy development program. As discussed in Chapter 5, China has leveraged its directed energy capabilities for counter-space testing activities for a dozen years—successfully blinding satellites as early as 2005.

A2/AD: In addition to the A2/AD capabilities referenced above, China is also interested in using directed energy weapons to support to China's maritime territorial claims. For example, a naval version of the WB-1 microwave weapon could potentially be used as a weapon in the East China and South China Seas to stop foreign militaries and civilians from entering the waters in an effective but less escalatory manner as more lethal weapons.

Close-in Defense: China's ability to use its directed energy weapons to meet close-in threats from fast attack craft and drones offers a potentially effective means of countering asymmetric

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808 Binglin, Chen. "Chinese military could soon disable sensors on enemy missiles using suitcase-sized device after 'groundbreaking' study on ultrafast lasers," *South China Morning Post*. September 23, 2015. http://www.scmp.com/tech/science-research/article/1860336/chinese-military-could-soon-disable-sensors-enemy-missiles.

809 Laguipo, Angela. "Chinese Scientists Develop Star Wars-Like Laser Guns," *Tech Times*. January 10, 2016. http://www.techtimes.com/articles/122731/20160110/chinese-scientists-develop-star-wars-like-laser-guns.htm.

810 Jane's by IHS Markit. "Chinese navy claims lead in IEPS development," June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.

811 Jane's by IHS Markit. "Chinese navy claims lead in IEPS development," June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.

capabilities of the future, such as drone swarms. Directed energy weapons could be targeted against the United States and its technologically advanced allies to engage intelligent drone swarms. They could also be targeted against regional or non-state actors that view the likely future proliferation of autonomous drones as an asymmetric means of challenging stronger actors, including a more assertive China.

Air and Missile Defense: China's directed energy program was originally developed in order to address ballistic missile threats. However, none of the directed energy systems discussed in this paper are able to target missiles or larger aircraft. Nonetheless, directed energy for missile defense does appear to be an important capability for China, again in part due to the iterative and mutually reinforcing competition of U.S. and China advanced weapons production.

U.S. Development Initiatives and Programs

The U.S. DoD became interested in directed-energy weapons in the 1960s.[812] The U.S. Navy has been developing the Laser Weapon System (LaWS) since 2007, which was first tested at sea in 2012 on the *U.S.S. Dewey* against UAVs. The system uses six solid state lasers to produce a 34 kW beam. LaWS was subsequently tested on the *USS Ponce* and successfully engaged UAVs and a rocket propelled grenade (RPG) launcher. A 500 kW generator had to be added to the ship to support the laser.[813] The project has been relatively low cost, only $40 million thanks to the use of existing and commercially available hardware.[814]

Existing U.S. platforms are able to support 35 kW laser, but to integrate lasers above 200 kW they will have to undergo modifications, including freeing up extra space for cooling systems. Current technology is not capable of generating a 1 MW laser, and even if possible, existing platforms would not be able to generate the immense power needed to support it.[815]

The U.S. Navy has also researched free electron lasers (FELs), currently believed to be the only way to generate a 1 MW laser. FELs accelerate electrons to nearly the speed of light and then convert their energy into light.[816] FELs will be able to vary their frequencies in response to different atmospheric conditions, a major improvement on current lasers. But FEL technology is not yet mature.[817]

The U.S. Navy has also fast tracked a plan, named the Seasaber, to deploy a 60 kW laser with counter-ISR dazzling capability on a DDG-51 Flight IIA Arleigh Burke-class guided missile destroyer by 2020.[818] The new DDG 1000 destroyer will have an Integrated Power System that will be able to power future directed-energy weapons and EM railguns.[819]

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[812] Scott, Richard, "Bright lights: High-Energy Laser Weapons Approach the Front Line," *Jane's,* November 28, 2016, https://janes.ihs.com/Janes/Display/jni77894-jni-2016.
[813] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[814] Scott, Richard, "Bright lights: High-Energy Laser Weapons Approach the Front Line," *Jane's,* November 28, 2016, https://janes.ihs.com/Janes/Display/jni77894-jni-2016.
[815] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[816] Scott, Richard, "Bright lights: High-Energy Laser Weapons Approach the Front Line," *Jane's,* November 28, 2016, https://janes.ihs.com/Janes/Display/jni77894-jni-2016.
[817] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[818] Scott, Richard, "USN Plans Accelerated Laser Weapon Fit on DDG 51 Flight IIA destroyer," *Jane's*, March 8, 2017, https://janes.ihs.com/Janes/Display/jni77999-jni-2017.
[819] Osborn, Kris, "The U.S. Navy's Hyper Velocity Projectile: A Mach 7.5 Super Bullet," *National Interest*, 11 September 2017, http://nationalinterest.org/blog/the-buzz/the-us-navys-hyper-velocity-projectile-mach-75-super-bullet-22253.

Boeing has developed the 50 kW High Energy Laser Mobile Test Truck, which engaged more than 150 UAV and mortar targets during testing in 2014. The laser was able to operate in fog. Current plans are the scale the project up to a 60 kW laser and even potentially a 100 kW laser. Northrop Grumman is working on a high power 150 kW fiber solid state laser.[820]

The U.S. Army launched the Robust Electric Laser Initiative (RELI) to develop more efficient 10 kW modules which could be combined for 30 and 60 kW lasers. Lockheed Martin was awarded a contract for the project and developed the 30 kW ATHENA laser, which successfully destroyed the engine of a truck 1 mile away during testing in 2014. Lockheed Martin finished developing a 60 kW version of the weapon for the U.S. Army in March 2017. [821]

For microwave weapons, while the United States has had the Active Denial System ready since 2008, it has yet to see combat use. The system had a 16-hour boot time and massive fuel use, making it ineffective for rapid response to crowds.[822]

Deployment of lasers on U.S. Air Force platforms comes with a set of difficult engineering challenges, most notably managing and mitigating disruptions to laser system targeting from vibrations of the aircraft and general turbulence. The Self-Protect High Energy Laser Demonstrator project is developing a 100+ kW laser for fighter jets that can fit inside an external pod and protect against incoming missiles. The RFI was released in February 2016 and a demonstrator is planned for 2022. The challenges will be balancing size with power, weight with the plane's mobility, as well as building a system that can survive combat maneuvers. Finally, there are several questions that remain about placing lasers on fighter jets; vibration remains a challenge, and most critically, thermal blooming will hinder the system's effectiveness against missiles heading straight for it.[823] In addition to this program, the High Energy Liquid Laser Demonstrator began as a DARPA project in 2001. The goal is a light weight 150 kW electrically pumped laser (instead of fiber or solid) for mounting on an AC-130.[824]

The DoD reported in early March 2017 that it anticipates a directed energy roadmap to be finished in early 2018.[825]

Implications for Future Competition with the United States

China's laser capabilities are currently best suited for combating slow drones and dazzling satellites and China has focused on these functions in its efforts to export directed energy systems at airshows and exhibitions.

In terms of integration, China has developed handheld, rifle lasers meant for blinding sensors, missiles and drones that are already being used by PLA troops and Chinese police. Jane's expects the laser rifles to continue to mature. The other systems do not appear to have been as well integrated. These systems still require advancements in size reduction and energy efficiency to be integrated on

[820] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[821] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[822] Martin, David. "The Pentagon's Ray Gun." CBS News. February 29, 2008. https://www.cbsnews.com/news/the-pentagons-ray-gun/.
[823] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[824] Goodlad, Ben, "Star Wars: High Energy Laser Weapons Awakening," Jane's Intelligence Briefings, April 21, 2016, https://janes.ihs.com/Janes/Display/jibr2260-jibr.
[825] O'Rouke, Ronald, "Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, October 17, 2017, pg. 15. https://fas.org/sgp/crs/weapons/R44175.pdf.

ships, aircraft and land vehicles. China will likely continue to develop its laser systems to target faster moving objects such as missiles and even aircraft. Researchers will also want to make the platforms lighter and smaller so they can be mounted on ships and aircraft.

In the 1990s, the Second Artillery Corps (renamed to the PLA Rocket Force in 2016) was believed to be developing a ground-based chemical laser system called the "Shen Huo" and other reports indicate that there is another program to develop lasers with outputs up to 300 kW to damage satellites.[826] China is likely already working on, if not already deploying, a space-based laser ASAT system, given the short timeline proposed by leading researchers in their article on such a system.

There has not been as much of a focus on microwave weapons, but the WB-1 and reports of a naval version of the weapon indicate a desire to develop non-lethal weapons for the South China Sea and East China Sea that can keep other militaries away without escalation. Assuming that China is able to mitigate the slow boot time and massive fuel costs of such a system, it would be unsurprising to see such a weapon be used in the next several years, especially as tensions continue to rise in the seas.

[826] Jane's by IHS Markit. "Laser Weapons," March 3, 2017. https://janes.ihs.com/Janes/Display/jsws0514-jaad.

Chapter 9: China's Electromagnetic Railguns and Hyper-Velocity Weapons

Chapter 9 Key Themes and Insights

- **Least Developed:** EM railguns are the least mature of the five weapons systems investigated in this paper. While China's S&T and research community has performed considerable research on railguns and electromagnetic science more broadly, China has yet to develop a confirmed railgun prototype, though there are unconfirmed reports of hyper-velocity weapons tests going back to 2006. On February 1, 2018, *Popular Science* reported on images on Twitter of a Chinese ship with a new turret that is 2 to 3 times larger than a conventional artillery barrel and similar in size to the BAE railgun. There is no other information to confirm or deny if it is a working prototype railgun.

- **Persistent Interest:** China has clear interest in developing the technology, as evidence by the many researchers publishing work in international journals and the rise of participation by Chinese scientists, and even PLA figures, in international electromagnetic academic and scientific conferences. China has also hosted a series of electromagnetic conferences, including the 18th EML Symposium, held in Wuhan in October 2016. BAE Systems served as one of the event's main sponsors, demonstrating the relative influence of the event in the international electromagnetic research community.

- **Adjacent Development:** While EM railgun development has lagged behind—and is certainly less mature than the U.S. development program—China has leveraged its growing interest and competence in electromagnetic science and technology to advance development of electromagnetic launch capabilities for aircraft. This capability is to be built into a future iteration of China's indigenous aircraft carriers, allowing for the launch of heavier (and more heavily armed) aircraft from carrier decks than the current ski jump configuration enables.

- **MAHEM Reverse Engineered:** The most advanced railgun prototype seen from China is what appears to be a reverse engineering of the MAHEM shoulder-mounted railgun originally designed by DARPA. Classified material on the system was potentially compromised among other weapons in a 2013 hacking of DoD.

- **Technology Challenges:** Railgun development is typically slowed by two main technical challenges:

  - **Power generation and storage:** Railguns require a tremendous amount of energy to generate the launch of hyper-velocity projectiles (HVPs) and must be able to store this energy in order to fire on demand.

  - **Managing the heat created by use of railguns:** In addition, the process of launching the projectile rips the railgun's rails apart. The plasma generated from immense heat of the reaction is "material from the rails and [round] being vaporized" into molten gas. Managing that intense heat, its consequences and developing materials capable of mitigating these risks is another critical area of electromagnetic research in China.

- **Future Railgun Development:** Jane's expects continued investment in China's railgun efforts, though it is clearly the least developed of the advanced weapons systems considered by this paper. Current estimates place an initial operating capability in the late 2020s. Jane's estimates similar maturity for a U.S. railgun, if the U.S. chooses to continue developing it, in the early 2020s. Motivation for developing EM railguns are tied largely to the complex and cascading dynamics shaping the future of the missile-versus-missile defense competition, though clearly handheld weapons will have a different mission in mind, perhaps counter-drone or anti-tank. Continued Chinese development of HGVs and other advanced missiles is driving U.S. development of hypervelocity weapons—including railguns and the use of HVPs fired from naval powder guns—to meet that threat, which, in turn, is driving China's continued interest in railguns. China may also view the weapons as a possible A2/AD long-range strike capacity as well.

Overview on Electromagnetic Railguns

EM railguns are a type of hypervelocity weapon that propels projectiles at exceptionally high rates of speed and are seen as being particularly useful in meeting the threat of other high-speed projectiles, such as MaRVs and HGVs, discussed earlier. They can also provide long-range strike on fixed or, plausibly, moving targets.[827]

According to the U.S. Office of Naval Research, what distinguishes railguns from conventional artillery is that they use electricity instead of chemical propellants to launch projectiles. Magnetic fields created by high electrical currents accelerate a sliding metal conductor, or armature, between two oppositely charged rails to launch projectiles at 4,500 miles per hour, approximately Mach 6—or six times the speed of sound.[828]

The process of firing a rail gun typically comprises of three stages. First, electricity generated by a connected source is stored over several seconds. Many rail gun concepts feature variants that fire from ships—in which case, electricity generated by the ship is stored over several seconds in the railgun's pulsed power system. Other concepts include land-based railguns, which will draw power from a ground-based source.[829]

Once sufficient energy is stored, an electric pulse is sent to the railgun, creating an EM force, which sends the projectile (called the sabot) racing down the rails at speeds up to Mach 6.[830] EM projectiles do not carry explosive warheads. Instead, they use their extreme speed on impact to destroy targets. In addition to a railgun's capacity to deal with extremely high-speed missiles and strike distant targets quickly, the kinetic energy—rather than explosive—warhead "eliminates the hazards of high explosives in the ships [that use railguns] and unexploded ordnance on the battlefield."[831]

> ***"The real limit is how much energy per shot you can deliver to the projectile and sabot without destroying the rails too fast. All that plasma that you see when the gun erupts, that's material from the rails and sabot being vaporized at the sliding contact."***
>
> -Physicist Mark Gubrud of University of North Carolina

The U.S. Navy is developing resistant electronics that could go inside the projectile and aim it using GPS. With this technology, railguns could be used for missile-defense.[832]

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[827] "Blitzer EM Railgun Takes Step Forward for Air Defense Role," *Jane's,* November 25, 2009. http://janes.ihs.com/Janes/Display/idr12657-idr-2009; LaGrone, Sam. "Navy Wants Rail Guns to Fight Ballistic and Supersonic Missiles Says RFI," USNI, January 5, 2015. https://news.usni.org/2015/01/05/navy-wants-rail-guns-fight-ballistic-supersonic-missiles-says-rfi.

[828] Department of Defense, Office of Naval Research, "Electromagnetic Railguns," https://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Electromagnetic-Railgun.

[829] Department of Defense, Office of Naval Research, "Electromagnetic Railguns," Office of Naval Research, https://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Electromagnetic-Railgun.

[830] Bennett, Jay. "The Future of the Navy's Electromagnetic Railgun Could Be a Big Step Backwards," *Popular Mechanics*. April 2, 2017. http://www.popularmechanics.com/military/weapons/a21174/navy-electromagnetic-railgun/.

[831] Department of Defense, Office of Naval Research, "Electromagnetic Railguns," Office of Naval Research, https://www.onr.navy.mil/en/Media-Center/Fact-Sheets/Electromagnetic-Railgun.

[832] Bennett, Jay. "The Future of the Navy's Electromagnetic Railgun Could Be a Big Step Backwards," Popular Mechanics. April 2, 2017. http://www.popularmechanics.com/military/weapons/a21174/navy-electromagnetic-railgun/.

Most railgun projectiles are shells of aluminum that cover a tungsten metal projectile, and fall away after launch.[833] China is the global leader in tungsten production, accounting for over 80% of the world's tungsten output. China began limiting exports of tungsten in 2017, claiming the move is part of the country's efforts to close down polluting mines. As a result, the price of the metal jumped 50% from July-September in 2017.[834] Current railgun concepts use projectiles of approximately 25 kilograms.[835]

EM railgun development is focused on addressing two main technical challenges:

- *Energy/power capture and storage*: Railguns require a tremendous amount of energy to operate and need to store this energy to be able to fire on-demand. According to a June 2016 *Popular Mechanics* article, "The problem [with railguns] is that the only ships that will be able to generate the gargantuan 25 megawatts of power (enough to power almost 19,000 homes) required to fire the railgun are the Zumwalt-class destroyers, which will use Rolls-Royce turbine generators to produce as much as 78 megawatts of power for the ship." [836] New ways of generating and storing power for both ground and, especially, ship-based railguns are critical to the deployment of these potentially disruptive advanced weapons systems.

- *Durability:* In addition, the process of launching the projectile rips the railgun's rails apart. Plasma radiates from the EM railgun as the immense heat of the reaction vaporizes "material from the rails and sabot" into molten gas, explains University of North Carolina physicist Mark Gubrud.[837] Other parts of the railgun may melt and the repulsive force generated from the rails being oppositely magnetically charged pushes them apart. The combined effects of these forces can damage or destroy a railgun after even a few uses.[838]

Summary of China's EM Railgun and Hyper-Velocity Weapon Development Activities

Railgun development in China is not as mature as several of the other advanced weapons systems programs discussed in this paper. China's interest in railguns reportedly began in the mid-1980s as the China Academy of Engineering Physics and the Institute of Particle Physics began researching coil guns, electrothermal guns and railguns. There are reportedly two programs, one to develop surface-to-surface anti-tank and anti-armor guns and another to develop surface-to air guns.[839]

Based on the limited open source information available on China's R&D of EM railguns, China has prioritized these weapons and demonstrated progress toward developing a more robust capability, though a workable prototype is not imminent.[840] Academic researchers have published dozens of

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[833] Tucker, Patrick. "Can the Navy's Electric Cannon Be Saved?" *Defense One*. June 2, 2016. http://www.defenseone.com/technology/2016/06/can-navys-electric-cannon-be-saved/128793/
[834] Biesheuvel, Thomas. "China Sends One of the West's Most Critical Materials Soaring," Bloomberg. September 10, 2017. https://www.bloomberg.com/news/articles/2017-09-10/china-sends-one-of-the-west-s-most-critical-materials-soaring.
[835] *Jane's Land Warfare Platforms: Artillery and Air Defense*, "Hypervelocity Guns," March 17, 2017, https://janes.ihs.com/Janes/Display/jsws9074-jaad.
[836] Bennett, Jay. "The Future of the Navy's Electromagnetic Railgun Could Be a Big Step Backwards," Popular Mechanics. April 2, 2017. http://www.popularmechanics.com/military/weapons/a21174/navy-electromagnetic-railgun/.
[837] Tucker, Patrick. "Can the Navy's Electric Cannon Be Saved?" *Defense One*. June 2, 2016. http://www.defenseone.com/technology/2016/06/can-navys-electric-cannon-be-saved/128793/.
[838] Harris, William. "How Rail Guns Work," *HowStuffWorks Science*. October 11, 2005. http://science.howstuffworks.com/rail-gun2.htm.
[839] *Jane's Land Warfare Platforms: Artillery and Defense*, "Hypervelocity Guns," March 1, 2017, https://janes.ihs.com/Janes/Display/jsws9074-jaad.
[840] *Jane's Land Warfare Platforms: Artillery and Defense*, "Hypervelocity Guns," *Jane's*, July 24, 2015; *Jane's Land Warfare Platforms: Artillery and Defense*, "Hypervelocity Guns," March 1, 2017, https://janes.ihs.com/Janes/Display/jsws9074-jaad.

papers for international EM conferences over the past two years on railguns, other hyper-velocity weapons and military applications of EM energy.[841]

China has made advances in other areas of EM research, such as EM catapults to enable the launch of heavier and more capable aircraft off China's growing fleet of aircraft carriers. China has also demonstrated depth and breadth of research interest on EM technologies. In 2016 and 2017, China hosted nine conferences for international EM research societies. Chinese academics, military personnel and researchers have delivered several keynote presentations at other international conferences on EM technologies.[842]

Jane's research also found that 31.9% of the papers submitted in support of the 24 international EM conferences held between 2016 and September 2017 were given by Chinese researchers. Many of these papers were on topics relevant to the military sector, such as:

- Radar detection of stealth vehicles
- Metamaterials and other cloaking advancements
- Remote sensing and imaging
- Reducing radio interference on military vehicles
- Quantum communications
- Electromagnetic launch (EML), especially of aircraft

The PIERS 2016 conference in Singapore included several Chinese presenters from the Air Force Engineering University who presented on designing metamaterials for absorbing and reflecting radar waves.[843]

China hosted the 18th EML Symposium in Wuhan in October 2016. The EML Symposium is "a biennial event that serves the principal forum for the discussion, interchange and presentation of research on critical technologies for accelerating macroscopic objects or projectiles to hypervelocity using EM or electrothermochemical launchers." The event's "Platinum Sponsor" was listed as BAE Systems, indicating both the extensive international involvement in the event and the strong defense, space and security focus to conference discussions[844] as BAE is a principal contractor supporting U.S. Navy efforts to develop EM railguns.[845]

According to the welcome statement on the 18th EML website:

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841 A search on the Institute of Electrical and Electronics Engineers (IEEE)'s digital library for articles on electromagnetic railguns from Chinese authors finds 235 results as of January 17, 2018. 113 of which were published at conferences. Jane's further analyzed the results to identify the top institutes and authors, discussed below. http://ieeexplore.ieee.org/search/searchresult.jsp?queryText=%22Index%20Terms%22:.QT.Railguns.QT.&matchBoolean=true&searchWithin=China.

842 "Keynote Speeches," AMPEC 2017. http://apemc2017.org/keynote-speeches; "List of Confirmed Keynote Speakers," PIERS 2017 in Singapore. http://www.piers.org/piers2017Singapore/keynotelist.php; "List of Confirmed Keynote Speakers," PIERS 2017 in St. Petersburg. http://www.piers.org/piers2017StPetersburg/keynotelist.php; "Keynotes," IEEE International Symposium on Personal, Indoor and Mobile Radio Communications 08-13 October 2017 – Montreal, QC, Canada. http://pimrc2017.ieee-pimrc.org/program/keynotes.

843 "List of Confirmed Keynote Speakers," PIERS 2017 in Singapore. http://www.piers.org/piers2017Singapore/keynotelist.php.

844 "18th EML Symposium Agenda," http://www.emlsymposium.com/schedules/agenda.html.

845 "Electromagnetic (EM) Railgun," BAE Systems. https://www.baesystems.com/en-us/product/electromagnetic--em--railgun.

> "The technology for using electromagnetic energy pulses to accelerate materials to extremely high speeds is only now sufficiently advanced that it is being exploited to evaluate the survivability of space structures and the survivability and lethality of military weapons systems. Electromagnetic launchers are now capable of accelerating objects to such high-speeds that projectiles are capable of travelling many hundreds of kilometers or penetrating the most advanced modern armors, and there is a renewed and growing interest in using electromagnetic launchers to reach sufficiently high speeds to put objects in orbit around the earth."[846]

The event included three Chinese keynote speakers:[847]

- Weiming Ma, National Key Laboratory for Ship Integrated Power System, *Thinking and Study of Electromagnetic Launch Technology*
- Shaopeng Wu, Harbin Institute of Technology, *Pulsed Alternators*
- Xinjie Yu, Tsinghua University, *Summary of Meat Grinder*

Weiming Ma is a Rear Admiral at the PLAN Naval University of Engineering and considered to be a driving force behind the Chinese EM aircraft catapult. His efforts are discussed later in this chapter.[848]

Shaopeng Wu has multiple publications on pulsed alternators, or generators of pulsed power.[849] Pulsed power is the process of accumulating energy and then quickly releasing it, and is central to propelling EM railgun projectiles at incredible rates of speed.[850]

Xinjie Yu and his team at Tsinghau University lead the University's "meat grinder" project.[851] The "meat grinder concept," is a type of circuit for generating pulsed power, and "meat grinder" circuits have been a proposed source of power for a railgun for 30 years. Xinjie Yu and his team have been exploring the next iteration of the concept, called the "STRETCH meat grinder," which has been successfully used in railgun tests. While their work is "still conceptual," there has been an "increasing number of papers and involved personnel" emanating from and engaged in their work.[852]

Institutions and Organizations

CASIC has led industry involvement in China's R&D in EM launch for missiles and close-in air defense.[853] There are several Chinese researchers have authored or co-authored between 20 to 40

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[846] "18th EML Symposium-Wuhan Home Page," http://www.emlsymposium.com/.
[847] "18th EML Symposium Agenda," http://www.emlsymposium.com/docs/18th%20EML%20Agenda%2010162016.pdf.
[848] "The Top Engineer with the Key to China's Dream of Having the World's Most Powerful Navy," *South China Morning Post,* July 5, 2017. http://www.scmp.com/news/china/diplomacy-defence/article/2099006/top-engineer-key-chinas-dream-having-worlds-most.
[849] Weldon, William F., Mircea D. Driga and Herbert H. Woodson. Compensated pulsed alternator. US Patent US 4200831 A, filed August 3, 1978. https://www.google.com/patents/US4200831.
[850] Rodriguez-Achach, Manuel. "Pulsed Power and its Applications," *Hackaday*. January 12, 2017. https://hackaday.com/2017/01/11/pulsed-power-and-its-applications/.
[851] Yu, Xinjie, Hui Liu, Jun Li, Zhen Li and Peizhu Liu. "Study on the collaborative triggering of multiple STRETCH meat grinder with ICCOS modules." *2014 17th International Symposium on Electromagnetic Launch Technology (EML)*, October 13, 2014. http://ieeexplore.ieee.org/document/6920631/.
[852] Liebfried, Oliver. "Review of Inductive Pulsed Power Generators for Railguns," *IEEE Transactions on Plasma Science*, March 2017. pg. 3. https://arxiv.org/pdf/1701.07063.pdf.
[853] Wang, Brian. "China May Have Made Breakthroughs with Aircraft Carrier Electromagnetic Launch and Railgun Technology," *NextBigFuture.com*. November 24, 2015. https://www.nextbigfuture.com/2015/11/china-may-have-made-breakthroughs-with.html.

conference articles about railguns from 2016 to 2017. Research institutes associated with the most published experts are:[854]

- Beijing Institute of Special Electromechanical Technology
- Tsinghua University
- Huazhong University of Science and Technology
- Shenyang Aerospace University
- Harbin Institute of Technology
- Changsha University of Science and Technology
- The Institute of Electrical Engineering

In addition, several universities, research organizations and industry institutes have been involved in sponsoring the nine EM-focused conferences in China:[855]

- 41st Institute of CETC
- Antenna and Microwave lab China
- AVIC
- Beijing E-town
- CEMEE Lab China
- CASIC
- CASC
- China Electrotechnical Society
- China National Electric Engineering Company
- China National Investment and Guaranty Corporation
- China National Nuclear Corporation
- China Shipbuilding Industry Corporation
- China State Shipbuilding Corporation
- Chinese Institute of Electronics
- Dalian Dongshin Microwave Absorbers Co. Ltd
- Development & Research Academy for Global Optical Neo-technology (DRAGON)
- Guangdong Shengyi Sci. Tech Co., Ltd
- Hebei University of Technology
- Huawei
- JORCEP (Sino-Swedish Joint Research Center of Photonics) **Includes Zhejiang University
- Mitron
- MWRF.net (Chinese microwave news site)
- Nanjing University
- National University of Defense Technology or People's Liberation Army National University of Defense Science and Technology
- Rflight Communication Electronic Co., Ltd
- Science and Technology on Electromagnetic Scattering Laboratory
- Shanghai Key Laboratory of Electromagnetic Environmental Effects for Aerospace Vehicle
- South University of Science and Technology of China
- Tongji University
- YSL Photonics
- Zhejiang University

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[854] List is derived from Jane's research on participation in and paper lists/programs for several electromagnetic conferences in China and elsewhere.
[855] List derived from Jane's examination of several electromagnetic science and technology conferences held in China and elsewhere.

Zhejiang University also sponsored several of the conferences outside of China.

Current Programs and Technologies

China's research on EM launchers started in the 1960s.[856] Open source reporting on the program is not as extensive as other advanced systems covered by this paper and, indeed, some of the reporting on both EM railguns and broader hypervelocity weapons programs are difficult to confirm. For example, according to Jane's, there was an "unconfirmed report from India in January 2008" that the PLA had tested a railgun firing 25 kg projectiles up to 250 km in 2006.[857]

Some programs and developments of interest to China's development of railguns include:

Hand-Held Railgun: MAHEM Reverse Engineering: Researchers at Nanjing University of Science and Technology published an article in 2013 in the *Applied Mechanics and Materials* journal that includes an exceptionally detailed breakdown of how DARPA's handheld railgun, the Magneto Hydrodynamic Explosive Munition (MAHEM) weapon, works.

MAHEM is a program developed by DARPA in the 2000s, though there has been little, if any mention of the shoulder-fired railgun in open sources since 2008. It was designed to use electrical energy to accelerate metal, potentially shrapnel or an explosively formed projectile. The weapon is notable because it can accelerate a projectile to a higher speed, or accelerate a greater weight, than existing warheads.[858]

"This is more information than you can get from any U.S. source, and appears to be based on the reverse-engineering MAHEM by a team with a very detailed knowledge of magnetohydrodynamics and munitions."

- David Hambling of *Popular Mechanics*

The article includes "more information than you can get from any U.S. source, and appears to be based on the reverse-engineering MAHEM by a team with a very detailed knowledge of magnetohydrodynamics and munitions."[859] This report is especially concerning given that railgun designs were in the list the *Washington Post* published in May 2013 of DoD weapon systems compromised by hackers.[860]

[856] Sohu, "China Aerospace Science and Industry Group issued a document on the development of electromagnetic guns [中国航天科工集团发文透露已进军电磁炮研制]," November 17, 2015. http://business.sohu.com/20151117/n426768823.shtml.
[857] *Jane's Land Warfare Platforms: Artillery and Air Defense*, "Hypervelocity Guns," March 17, 2017, https://janes.ihs.com/Janes/Display/jsws9074-jaad.
[858] Hambling, David. "China May Be Reverse-Engineering the Handheld Railgun," *Popular Mechanics*. December 2, 2015. http://www.popularmechanics.com/military/a18386/china-mahem-railgun-darpa/.
[859] Hambling, David. "China May Be Reverse-Engineering the Handheld Railgun," *Popular Mechanics*. December 2, 2015. http://www.popularmechanics.com/military/a18386/china-mahem-railgun-darpa/.
[860] "A list of the U.S. Weapons Designs and Technologies Compromised by Hackers." *The Washington Post*. May 27, 2013. Accessed October 12, 2017. https://www.washingtonpost.com/world/national-security/a-list-of-the-us-weapons-designs-and-technologies-compromised-by-hackers/2013/05/27/a95b2b12-c483-11e2-9fe2-6ee52d0eb7c1_story.html.

CASIC "Breakthrough": In late 2015, CASIC reported that its 206 Institute had a breakthrough in EM missiles and railguns, though few details were provided.[861] The 206 Institute had just played a key role in hosting the 7th Chinese Electromagnetic Technology Conference in October 2016. Reporting on that event indicated progress in the development of materials to reduce barrel wear.[862] In its broadcast of this news, the Hong Kong-owned channel Phoenix Television, reported that the PLAN hopes to test a railgun "in a few years."[863]

Railguns and Next Generation Type 055 Destroyers: On August 21 and 22, 2017, collections of presentation slides found on multiple Chinese military-issue websites confirmed plans to equip the next generation Type 055 destroyer with railguns and/or lasers. The slides were apparently from a Northwestern Polytechnical University lecture given by former Rear Admiral Zhao Dengping. Rear Admiral Zhao is a former director of the PLAN's Equipment Department. Several slides in his presentation implied the Type 055 Destroyers (DDGs) would have railguns, as well as directed-energy lasers.[864] The PLAN's modernization plans assume that railguns will be ready in the next decade.

Figure 32: A photo of China's possible EM rail gun

Possible Naval Prototype: On February 11, 2018, *Popular Science* reported on new images appearing on Twitter of a Chinese Type 072III landing ship tank, an amphibious platform,[865] with a new turret that is too large to be a conventional artillery barrel and is similar in size to the BAE 32 megajoule railgun being tested by the U.S. Navy. This led the authors, Jeffery Lin and P.W. Singer, to conclude that it may be a prototype railgun.

This would be a surprising development given Jane's assessment of China's railgun efforts. The authors note that questions still remain on how well the prototype functions, if at all: "Engineers for this test, as with all other railgun work, will have to overcome formidable challenges in material durability, power storage, and projectile guidance."[866]

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[861] "China's Electromagnetic Launch Technology Breakthrough," [中国电磁发射技术获突破性进展 杀伤力具革命性], China News Network. November 17, 2015. Accessed October 12, 2017. http://www.chinanews.com/m/mil/2015/11-17/7626923.shtml.
[862] Lin, Jeffrey and P.W. Singer. "An Electromagnetic Arms Race Has Begun: China Is Making Railguns Too," *Popular Science*. November 23, 2015. https://www.popsci.com/an-electromagnetic-arms-race-has-begun-china-is-making-railguns-too#page-5.
[863] Lin, Jeffrey and P.W. Singer. "An Electromagnetic Arms Race Has Begun: China Is Making Railguns Too," *Popular Science*. November 23, 2015. https://www.popsci.com/an-electromagnetic-arms-race-has-begun-china-is-making-railguns-too#page-5.
[864] Fisher, Richard. "PLAN plans: Former Admiral Details Potential Modernization Efforts of Chinese Navy." *Jane's by IHS Markit*. August 25, 2017. https://janes.ihs.com/Janes/Display/FG_631670-JDW.
[865] Clover, Charles, "China Developing Naval Rail Gun Technology, Say Experts," *Financial Times,* February 7, 2018. https://www.ft.com/content/e111bfe0-0bc2-11e8-8eb7-42f857ea9f09.
[866] Lin, Jeffery and P.W. Singer, "Looks like China Just Installed a Railgun on a Warship, Beating the U.S. Navy to the Punch," *Popular Science*, February 1, 2018. https://www.popsci.com/china-navy-railgun-warship?dom=rss-default&src=synhttps://www.popsci.com/china-navy-railgun-warship?dom=rss-default&src=syn.

Chad Ohlandt, a senior engineer at the RAND Corporation, commented that, "Based on the pictures, a rail gun is a plausible explanation, but it's not conclusive." There are three shipping containers on the bow, which could indicate that it is a railgun as they could be storing the generators such a system would need. But Ohlandt was doubtful that the containers are large enough for the immense power the railgun would need. He did concede that there may be a capacitor bank below deck and, "It's also possible that the above-deck stuff is just enough to fire one shot, then wait minutes or hours until they recharge for the next test." [867]

However, there is also a chance that the gun is just a large conventional naval gun with additional power equipment to test such an oversized turret. [868]

Related technology developments

China's R&D on EM weapons has been augmented by notable developments in two other technologies that respectively enable enhanced operational effectiveness of railguns and offer another important military application of China's research in electromagnetic launch (EML).

Integrated electrical power systems (IEPS): Discussed in the Direct Energy Chapter 8, China's claims to be the global leader in this area may be dubious, but progress in IEPS could support deployment of railguns on Chinese ships—for example the Type 055 destroyer.[869]

Aircraft catapults: The U.S. Navy has sought to replace its steam-driven aircraft launchers with EM launchers on aircraft carriers.[870] EM launchers provide many advantages to aircraft carriers: [871]

- EM launchers would eliminate the need for pipes carrying steam around the ship
- They are gentler on aircraft with a steadier acceleration
- EM catapults are also more controllable, reducing the risk of launch mishaps, such as overpowering aircraft or under-powering aircraft at launch, both of which put at risk the pilots and equipment

China has also prioritized EM catapult systems for its indigenously-built aircraft carriers. Jane's first reported on China's development of an EM catapult system in 2012, but noted that it would be a long and costly undertaking. Jane's Richard Scott estimated that the capability would not be ready before 2025.[872] Yet, in 2015, Rear Admiral Ma Weiming told the press that China's EM launch technology is more advanced than that of the United States and implied that China's indigenously-built aircraft carriers would have EM catapults. [873]

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[867] Clover, Charles, "China Developing Naval Rail Gun Technology, Say Experts," *Financial Times,* February 7, 2018. https://www.ft.com/content/e111bfe0-0bc2-11e8-8eb7-42f857ea9f09.
[868] C Clover, Charles, "China Developing Naval Rail Gun Technology, Say Experts," *Financial Times,* February 7, 2018. https://www.ft.com/content/e111bfe0-0bc2-11e8-8eb7-42f857ea9f09.
[869] Tate, Andrew. "Chinese navy claims lead in IEPS development." Jane's by IHS Markit. June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.
[870] General Atomics & Affiliated Companies, "EMALS," http://www.ga.com/emals.
[871] Paisley. "EMALS: Next Gen Catapult," *Defensetech*. April 5, 2007. https://www.defensetech.org/2007/04/05/emals-next-gen-catapult/.
[872] Scott, Richard. "China 'Developing EMALS-type System'," *Jane's by IHS Markit*. May 1, 2012. https://janes.ihs.com/Janes/Display/jdw48926-jdw-2012.
[873] Tate, Andrew, "China Navy Claims Lead in IEPS Development," *Jane's Defense Weekly,* June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.

In November 2016, unsubstantiated reports of a successful test of the catapult emerged.[874] In March 2017, Jane's reported that the PLAN's Naval University of Engineering had finished developing an EM catapult for future aircraft carriers, and in July 2017, *Aviation International News* reported that several photos released on the Chinese Internet seem to show the PLAN testing an EM catapult system against a steam system. Satellite photos show the two systems set up side-by-side at the Huangdichun airbase.[875]

Admiral Ma told the press that the EM catapult will be on the "No.3 carrier"—the Type 002 indigenously built carrier, expected to enter service in the mid-2020s—and that construction of the carrier was delayed due to the testing of launch systems, but the decision on which catapult to use was imminent.[876] In November 2017, Yin Zhou, a senior researcher at the PLA Naval Equipment Research Center was interviewed by China Central Television and reported that the PLA has run "hundreds" of tests of the EM system. The PLAN also confirmed at that time that the Type 002 aircraft carrier will likely be fitted with the EM catapult.[877]

Potential Employment of Electromagnetic Launch

Missile Defense: One of the biggest advantages of EM railguns is the cost. Firing a railgun would cost less than three percent of firing current missile systems, according to U.S. Rear Admiral Matthew Klunder, former chief of the Office of Naval Research.[878] A railgun projectile is estimated to cost only $25,000, compared to $1 million per cruise missile.[879]

Anti-ICBM/HGV: Ground-based EM railguns could launch projectiles fast enough to intercept HGVs. Railguns would be even more effective in space without an atmosphere to slow the projectile down. The DoD has toyed with the concept of a space-based railgun to destroy nuclear warheads.[880]

Satellite/Shuttle Launch/Counter-space: EM railguns could potentially launch satellites and shuttles into the upper atmosphere, cutting down on use of expensive fuel. The vehicle would need to still have rockets to augment the EM launch, but would use far less fuel than conventional launches.[881] Such a system could also be repurposed to launch kill vehicles at enemy satellites.

Nuclear Fusion: Scientists have proposed using railguns to jump start fusion reactions. For fusion to happen, nuclei must be traveling at high velocity. Railguns could potentially launch pellets of fusible

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[874] Chuanren, Chen. "China Explores Electromagnetic Carrier Launch System." *Aviation International News*, July 6, 2017. http://www.ainonline.com/aviation-news/defense/2017-07-06/china-explores-electromagnetic-carrier-launch-system.
[875] Chuanren, Chen. "China Explores Electromagnetic Carrier Launch System." *Aviation International News*, July 6, 2017. http://www.ainonline.com/aviation-news/defense/2017-07-06/china-explores-electromagnetic-carrier-launch-system.
[876] Chuanren, Chen. "China Explores Electromagnetic Carrier Launch System." *Aviation International News*, July 6, 2017. http://www.ainonline.com/aviation-news/defense/2017-07-06/china-explores-electromagnetic-carrier-launch-system.
[877] Gady, Franz-Stefan. "China's New Aircraft Carrier to Use Advanced Jet Launch System," *The Diplomat,* November 6, 2017. https://thediplomat.com/2017/11/chinas-new-aircraft-carrier-to-use-advanced-jet-launch-system/.
[878] Lendon, Brad. "Navy's Future: Electric Guns, Lasers, Water as Fuel," CNN. April 10, 2014. http://www.cnn.com/2014/04/10/tech/innovation/navy-new-technology/index.html.
[879] Mcguirk, Rod. "US Admiral Praises Laser and Electromagnetic Guns on Costs." Phys.org - News and Articles on Science and Technology. February 10, 2015. https://phys.org/news/2015-02-laser-electromagnetic-guns.html.
[880] Harris, William. "How Rail Guns Work." HowStuffWorks Science. October 11, 2005. http://science.howstuffworks.com/rail-gun3.htm.
[881] Harris, William. "How Rail Guns Work." HowStuffWorks Science. October 11, 2005. http://science.howstuffworks.com/rail-gun3.htm.

materials at each other and create enough heat and pressure to form plasma.[882] The plasma then generates electricity.[883] Nuclear fusion could be controlled to generate an immense amount of energy or it could be weaponized. Thermonuclear bombs or hydrogen bombs use nuclear fission to kick off nuclear fusion, creating a bomb 1,000 times more powerful than that dropped on Hiroshima. EM railguns could bypass the costly process of building a hydrogen bomb by simply colliding fusible material over a targeted area.[884]

A2/AD: While railguns are often depicted as anti-missile defense weapons, they can be powerful offensive weapons against surface ships, land vehicles and enemy installations.[885] EM railguns could become a key anti-ship platform for China in the East China and South China Seas.

U.S. Development Initiatives and Programs

Development of DARPA's MAHEM hand-held EM gun started in 2008 but there has been little update on the weapon as virtually everything about it is now classified.[886] The U.S. Navy has been working on EM railguns since 2005, industry-built prototypes were evaluated in 2012. In September 2013, BAE Systems was awarded a $34.5 million contract to carry out Phase 2 of the EM railgun program. General Atomics, a competitor for the contract, retained its prototype and has continued testing and developing other models, thanks to private funding. In 2016, the U.S. Navy ran at-sea trials of a railgun on the *USS Trenton*.[887]

Current projections from the U.S. Navy estimate that a platform that can fire 10 rounds per minute at 32 megajoules should be ready by FY2019.[888] It will likely be 10 years until railguns are placed on new ships and 30 years after that the Navy transitions completely from powdered weapons to directed-energy weapons.[889] The new DDG 1000 destroyer will have an Integrated Power System that will be able to power future directed-energy weapons and EM railguns.[890]

The United States has already spent half a billion dollars trying to develop the railgun, and the DoD investment in EM railguns is now facing competition for resources from other hyper-velocity weapons systems concepts, such as firing the railgun's hyper-velocity projectiles (HVPs) from existing powder naval guns.[891] Powder gun-launched HPVs can reach speeds up to Mach 3, roughly twice as fast as a normal explosive round fired from a powder gun, but also approximately half as fast as an HPV fired from a railgun.[892] As former Deputy Defense Secretary Robert Work said in 2016:

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[882] Harris, William. "How Rail Guns Work." HowStuffWorks Science. October 11, 005. http://science.howstuffworks.com/rail-gun3.htm.
[883] MacDonald, Fiona. "The UK Just Switched on an Ambitious Fusion Reactor - And It Works," *ScienceAlert*, May 1, 2017. https://www.sciencealert.com/the-uk-has-just-switch-on-its-tokamak-nuclear-fusion-reactor.
[884] Buckley, Chris. "What's the Difference between a Hydrogen Bomb and a Regular Atomic Bomb?" *New York Times*. September 3, 2017. https://www.nytimes.com/2017/09/03/world/asia/north-korea-hydrogen-bomb.html.
[885] Haffa, Robert and Anand Datla. *Hypersonic Weapons Appraising the "Third Offset."* Report. April 2017. Pg. 10. https://www.aei.org/wp-content/uploads/2017/04/Hypersonic-Weapons.pdf.
[886] Hambling, David, "China May Be Reverse-Engineering MAHEM, the Pentagon's Handheld Railgun," *Popular Mechanics*, 2 December 2015, http://www.popularmechanics.com/military/a18386/china-mahem-railgun-darpa/
[887] "Electromagnetic naval railgun system (EMRG)," *Jane's*, June 6, 2017, https://janes.ihs.com/Janes/Display/jnwsa057-jnw
[888] O'Rouke, Ronald, "Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, October 17, 2017, pg. 15-17. https://fas.org/sgp/crs/weapons/R44175.pdf.
[889] O'Rouke, Ronald, "Navy Lasers, Railgun, and Hypervelocity Projectile: Background and Issues for Congress," Congressional Research Service, October 17, 2017, pg. 29. https://fas.org/sgp/crs/weapons/R44175.pdf,
[890] Osborn, Kris, "The U.S. Navy's Hyper Velocity Projectile: A Mach 7.5 Super Bullet," *National Interest*, September 11, 2017, http://nationalinterest.org/blog/the-buzz/the-us-navys-hyper-velocity-projectile-mach-75-super-bullet-22253.
[891] Barnes, Julian E., "A First Look at America's Supergun," *Wall Street Journal,* May 30, 2016, https://www.wsj.com/articles/a-first-look-at-americas-supergun-1464359194.
[892] Tucker, Patrick. "Can the Navy's Electric Cannon Be Saved?" Defense One. June 2, 2016. http://www.defenseone.com/technology/2016/06/can-navys-electric-cannon-be-saved/128793/.

> "We thought railguns were something we were really going to go after, but it turns out that powder guns firing the same hypervelocity projectiles gets you almost as much as you would get out of the EM rail gun, but it is something we can do much faster."[893]

In October 2017, the U.S. Navy's Future Naval Capability program announced it will be exploring HVPs for ships' deck-mounted 5-inch guns. The rate of fire will be 10 rounds per minute, on par with the EM railgun. The office also announced in July 2017 a solicitation for new 5-inch guided projectiles compatible with the MK 34 5-inch Gun Weapon System found on Cruisers and Destroyers. Responses were due by August 28th, and the project has an 18- to 24-month timeline.[894] The U.S. Army is currently test firing HVPs from a Howitzer, reaching Mach 6.5. The Howitzer's muzzle breach catches some of the propellant, making it safer for by-standing troops.[895]

Still, reports of the railgun's death do seem to be premature. The U.S. Navy's $175 billion 2018 budget request included $2 billion in funding for railguns in order to have it deployed on guided-missile destroyers and cruisers in the next 10 years.[896] The focus for now has shifted towards building a defensive version (which will have a shorter range) and adapting existing guns to shoot railgun projectiles.[897] Both BAE and General Atomics plan to have a prototype for testing as early as 2018.[898]

Implications for Future Competition with the United States

China's investment in railguns appears to be linked with perceptions of advancing U.S. development of HGVs, just as the United States is developing railguns to deal with China's advanced missile programs, including China's HGVs and ASBMs. A race to develop any of these advanced weapons systems, then, is also a race to build counter technologies, railguns being one example. The recent images of the supposed EM railgun prototype are a very interesting and very new development. Time will tell whether the prototype is functioning and mature enough to demonstrate that China has successfully advanced its EM railgun program.

The rumored prototype aside, China's progress has primarily been conceptual with fewer indicative successes similar to the seven rounds of testing of the Wu-14/DF-ZF HGV or extensive counter-space and unmanned developments. Estimates of a viable Chinese railgun capability uncovered in Jane's research tend to focus on the late 2020s, though investment in EM railguns could accelerate depending on how the U.S. Prompt Global Strike program and other hypersonic weapons systems efforts progress.

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[893] Tucker, Patrick. "Can the Navy's Electric Cannon Be Saved?" *Defense One*, June 2, 2016. http://www.defenseone.com/technology/2016/06/can-navys-electric-cannon-be-saved/128793/.
[894] Federal Contract Opportunity N00178-17-R-3001," GovTribe. https://govtribe.com/project/live-fire-demonstration-of-technologies-related-to-qualifying-and-fielding-a-mature-design-for-a-naval-surface-fire-support-nsfs-5-inch-guided-projectile-compatible-with-the-mk-34-5-inch-gun-weapon-system-gws
[895] Osborn, Kris, "The U.S. Army's New Super Weapon: 5,000 Mile Per Hour 'Big' Guns," *National Interest*, September 27, 2017, http://nationalinterest.org/blog/the-buzz/the-us-armys-new-super-weapon-5000-mile-per-hour-big-guns-22495?page=3.
[896] Keller, Jared. "The Electromagnetic Railgun May Not See Action the Way the Navy Originally Planned." *Task & Purpose*, June 27, 2017. http://taskandpurpose.com/navy-electromagnetic-railgun-ship-defense/.
[897] Tucker, Patrick. "Can the Navy's Electric Cannon Be Saved?" *Defense One*. June 2, 2016. http://www.defenseone.com/technology/2016/06/can-navys-electric-cannon-be-saved/128793/.

Section 3

Implications and Recommendations

Chapter 10: Implications

Several overarching themes and implications emerged from our secondary source research, network engagement, and collaborative forums. Jane's has collected these implications into two broad categories: Context and Capability.

Context

China's Advanced Weapons and Regional Geopolitical Competition

China is developing its advanced weapons systems in the context of accelerating and intensifying competition across the Western Pacific and Indian Ocean.

At the basic level, both American and Chinese analysts tend to view this technological competition in "binary" terms, depicting it as an across-the-board exercise either to maintain existing technical and innovative supremacy or to challenge it. For China, the challenge lies in further eroding U.S. hegemony in economic, political and strategic systems created and codified in the post-Second World War and, especially, post-Cold War global architecture.

Each of the weapons systems under review fits into this aspiration for supremacy (or at least parity status). It's an easily understood competitive model in which, as geopolitical tectonics grind more frequently, the stakes assume a progressively greater importance. But this often becomes a one-size-fits-all, beggar thy neighbor approach, irrespective of the particular weapons system being developed or researched. The two countries' intelligence services take this mindset as axiomatic.[899]

This vision of binary great power competition frequently leads to the view that the U.S.-China competition of the 21st century is a "Cold War Redux"—a winner-take-all, zero-sum game governed by familiar concepts of deterrence and dissuasion and "clean line-ups" of allies and adversaries aligning behind the two competing powers. But the fused perception of a binary, Cold War Redux is too narrow and misses important differences. Notably, unlike the Cold War, the U.S.-China competition is not rooted in two clashing ideologies. China's vision of a post-unipolar world has little overarching "glue," beyond a more fulsome expression of Chinese power and influence and deemphasizing existing norms and rules, especially those focused on democracy and human rights.

More fundamentally, though, the Cold War Redux model ignores the complexity of the geopolitics of the Indo-Pacific region in the 21st century. Many actors with not always overlapping interests are developing robust capabilities, sometimes in conjunction with the United States or regional partners, but also outside of these frameworks. North Korea stands as a stark and worrying example.

Heightened investment in undersea assets by states across Southeast Asia is another example. Singapore, Indonesia, and Malaysia have all announced requirements over the last three years for expansion of their submarine fleets. Vietnam's investment in upgrading its submarine fleet actually began in 2009 with an order of six KILO-class submarines from Russia. The last boat in the order was received in February 2017.[900] Even the Philippines, which does not currently operate submarines, has considered adding three submarines as part of its ambitious "fleet desired force mix" initiative.[901]

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[899] U.S.-China Economic and Security Review Commission, "2016 Report to Congress of the U.S.-China Economic and Security Review Commission," November 2016, pg. 289-303. https://www.uscc.gov/sites/default/files/annual_reports/Executive%20Summary%202016.pdf.

[900] "IHS Jane's Navigating the Emerging Markets- Vietnam," *Jane's Industry Quarterly,* January 18, 2018. https://janes.ihs.com/Janes/Display/jiq0136-jiq.

[901] "Philippines- Navy," *Jane's World Navies*, January 23, 2018. https://janes.ihs.com/Janes/Display/1322748.

These investments are adding real capability, some of which may be used to support regional maritime security initiatives, but, in Jane's estimation, are more likely being procured out of a sense of a need to keep up with regional neighbors in the complex sub-regional security dynamics of Southeast Asia. As *Jane's World Navies* emphasized in January 2018 about Indonesia's submarine procurement efforts: "The fact that various other Southeast Asian countries are in the process of acquiring submarines appears to have sufficiently politicized the issue to persuade the government to press ahead with" planned submarine acquisitions.[902]

In addition to the development of independent military capabilities, deepening economic relationships between some U.S. allies and partners (Australia, Singapore) and China, and developing geopolitical relationships between China and two U.S. partners (the Philippines and Indonesia) reflect a layered geopolitical environment that was only an incidental feature of the 20th century Cold War Europe. Complexity is also revealed in the virulence of the competition between China and Japan, nearly independent of the U.S.-China competition or U.S.-Japan alliance. Chinese disdain for core Japanese interests in and near the disputed Senkaku island chain has become pronounced.

The risk of the binary interpretation for U.S. analysts and decision-makers, then, is that the framework ignores the relevance of allied capability and the increasingly complementary nature of defense R&D among allies. U.S.-led joint projects once took a condescending view of partner capabilities, an approach that should be amended to more completely incorporate partner areas of strength—for example, the Japanese economy's enormous technical competence—into a defensive arc constraining Chinese assertiveness.

The "quad" (quadrilateral liaison between Australia, India, Japan and the United States)—periodically)—mooted in the 2000-2008 Bush presidencies and again during the 2008-2016 Obama period—can serve as a platform for emergent collaboration between often disparate but improving technical capabilities. This concept is explored in more detail in Chapter 11 below.

Advanced Weapons Systems and China's Opportunistic Business Culture

China's centralized political system and economy offers opportunities to focus the energies of China's defense industrial base and high-tech industry through specific policy initiatives and funding mechanisms. This assessment generates visions of a defense industrial base and broader economy, all collaboratively and patriotically advancing China's interests and national development without concern for their own commercial prospects. This is the vision that Lee Ronghuai, the Vice Chairman of AECC, reflected when he told the *People's Daily* in September 2017 that "Related enterprises are sparing no efforts to support us. They are supporting us *even at their own losses* when we need specific steels in very limited amounts"[903] (emphasis added).

But this nationalist-inspired altruism is not always the guiding principal in China's highly opportunistic political economy. Intense competitions for funding programs, corporate success, and even personal advancement do exist as part of what one contributor to this project believed was a complex, multi-layered and often overlapping set of motivations for corporate actions and funding decisions. Its strands include personal/familial/educational cohort/and corporate and bureaucratic loyalties.

The implications for China's military modernization effort and, more specifically for the weapons systems of interest to this paper, are significant. Separate motivations, such as those tied to competitive dynamics within the large state-funded defense entities, are likely to manifest

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[902] "Indonesia- Navy," *Jane's World Navies,* January 23, 2018. https://janes.ihs.com/Janes/Display/jwna0071-jwna.

[903] Wenyu, Sun, "China Plans to Catch up with Advanced Aero Engine Producers in 20 Years," *People's Daily*, September 11, 2017, http://en.people.cn/n3/2017/0911/c90000-9267418.html.

themselves in defense development in ways that the United States does not currently fully appreciate or understand. Recall CASIC and CASC's apparent dragging of their respective feet in responding to SASTIND's demand for collaboration and elimination of redundancies or CASIC's decision to expand its space-launch product portfolio into new areas already occupied by CASC.

To be clear, top-down directives remain a powerful driver of China's S&T success. However, it is equally clear that understanding key personal and corporate networks and motivations will be important to capturing potential constraints on and accelerators of innovation on a specific program. This tactical intelligence could be crucial—though possibly difficult to acquire and cultivate—in informing competitive strategies designed to slow the development of China's advanced weapons systems.

The Rapidly Changing Technology and Innovation Environment

The global defense technology and innovation landscape has become more crowded, complex, and difficult to monitor. Many militarily-relevant technologies—such as AI, big data analytics, VR and AR, advanced sensors, semiconductors, advanced manufacturing, smart materials—have moved their manufacturing locus beyond the once tightly defined boundaries of the global defense industry. Real innovation in these technologies is taking place in—and in some cases, is being driven by—the commercial sector and applied research centers in addition to the traditional defense industry.

The dual-use nature of the technology diffusion environment has benefitted China enormously. Lured by the pull of the country's gigantic market, high-tech firms from throughout the world have located to China and, as a result, must accommodate themselves to the favoritism given to China's national champions and requirements for the transfer of technologies from Western commercial partners.

China's investment in programs such as the "Made in China 2025" and the "Next Generation Artificial Intelligence Development Plan" campaigns show clear, top-down intention to become a leader in industries and technologies that will shape and dominate the future of the global economy *as well as* the future battlefield. This applies notably to unmanned systems and to AI, two of the technologies of interest to this paper. The United States, without comparable policy initiatives, could lose its leading position in both the concepts behind AI and in its ability to conceptualize and progress military applications of AI and, critically, the governance models behind autonomous military systems.

The possibility of being "out-algorithm-ed" on the battlefield is a growing preoccupation for DoD. As highlighted in Chapter 3's discussion of AI and national security, former Deputy Secretary of Defense Robert Work touched on this risk in May 2017, arguing that "a lot of the advances that the other people are doing on their weapons systems, we won't see until we fight them. And if they have artificial intelligence then that's better than ours, that's going to be a bad day."[904]

In this environment, the "Third Offset strategy"[905] may offer an opportunity for U.S. manufacturers to gain an advantage in emerging technologies and the novel capabilities they enable, *especially* AI.

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[904] Freedberg, Sydney J., "War Without Fear: DEPSECDEF Work on How AI Changes Conflict," *Breaking Defense,* May 31, 2017. https://breakingdefense.com/2017/05/killer-robots-arent-the-problem-its-unpredictable-ai/.

[905] The "offset" concept derives from the so-called "first offset" in which possession of deployable nuclear weapons conferred upon the United States an advantage in the early cold war – albeit an advantage of only a few years. The so-called "second offset" conferred the advantages of long-range precision strike and C4ISR technologies from the late 1980s. These proved more long-lasting. Only in the last decade has the U.S. conventional military supremacy based on the second offset effectively been challenged, though asymmetric conflict with non-state actors have in many ways required the development of additional capabilities not envisioned at the start of the second offset.

The Third Offset Strategy is characterized as seeking asymmetric advantages in, and has recently increased focused on, five technological components: deep-learning systems, human-machine collaboration, assisted human operations (wearable electronic and exoskeletons), network-enabled and cyber-hardened weapons, and human-machine combat teaming.[906] However, it is uncertain how durable the U.S. advantage will be in emerging technologies gained through Third Offset Strategy investments.

China is already challenging long-standing assumptions about U.S. advantage in key domain and capability areas, including in advanced weapons systems, causing the U.S. Defense Community to reevaluate many of its most strongly-held truths about U.S. innovation and military superiority. Claims cited in this paper that China has surpassed the United States in IEPS[907] are likely overstated, but reflect a growing sense of China's confidence in its industrial outputs (or at least some of them) and a willingness to publicly call into question U.S. technological superiority in a key technology area.

What is considerably more worrying, though are a series of recent statements made by senior members of the U.S. Defense Community that suggest persistent U.S. inattention to key capability areas has created openings and new vulnerabilities for China to exploit. Dr. Conley's and General Silva's comments referenced in this paper (about U.S. electronic warfare and hypersonic weapons developments respectively) both suggest that China has either closed the gap or inched ahead in key technology areas. These comments are rooted in the perception that the U.S. has "sat on its lead" in these areas, only regaining focus after the full scope of China and Russia's advancement was revealed. Indeed, Dr. Conley's exact comment was that "the foot is fully on the gas pedal"[908] within DoD to make up for "twenty-five years of inattention" to electronic warfare.[909]

Jane's believes that these challenges will be amplified and accelerated in the next decade by the expansive, multi-dimensional innovation and defense technology environment that is facilitating widespread technology diffusion. Maintaining U.S. technological and military advantage in this environment will require "improvisation and creativity" in proactively developing means of enhancing U.S. technological advantage and denying or degrading China's development of advanced weapons. Approaches to achieving this improvisation and creativity must feature shifts in U.S. export control policies as well as how the U.S. DoD effectively engages with, invests in, and procures from the U.S. high-tech industry as well as traditional defense suppliers.

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[906] Lange, Katie, "3rd Offset Strategy 101: What It Is, What the Tech Focuses Are," *DoD Live*, March 30, 2016, http://www.dodlive.mil/2016/03/30/3rd-offset-strategy-101-what-it-is-what-the-tech-focuses-are/.
[907] Jane's by IHS Markit. "Chinese Navy Claims Lead in IEPS Development," June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.
[908] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.
[909] Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.

Beyond Technology: Building the Flexibility to Meet Novel Threats
Of course, development of the most exquisite and expensive applications of advanced technologies is not always required in order to achieve a disruptive effect on the battlefield, a point demonstrated emphatically by capabilities like the improvised explosive device (IED). IEDs contained few, if any, difficult to access or develop technologies, but were employed in a way in the mid-to-late 2000s that took the U.S. and coalition militaries in Iraq and then Afghanistan by surprise. In the process, insurgents posed an asymmetric challenge to the most powerful military on earth. Insurgents were able to exploit U.S. tactics, techniques, procedures, and ways of fighting that were no longer relevant for the operational environment that the U.S. military faced.

The same dynamic is likely to unfold in the Asia-Pacific region. China will seek to leverage the dual advantages of the sheer numbers of platforms and systems it is able to build and deploy and the simple geographic reality that much of the military competition is playing out *in the Western Pacific*, roughly-speaking, China's "home field." Together these advantages will allow China to field some systems that are less advanced or sophisticated than those the United States deploys to the region. For example, China's Great Undersea Wall ASW sensor net may not require the use of the most advanced UUVs capable of long-range operations, given that they will be used in environments relatively close to shore.

China's savvy use of its Maritime Militia is a good example of how novel operational concepts, scale, and presence combine to create an effective force multiplier for the PLAN, not to mention a difficult to address tool for pushing China's interests in the many gray zones of territorial dispute in the South China Sea.

China's use of its large and capable Maritime Militia to support the PLAN in asserting territorial claims enables a Chinese presence in flashpoint areas as crises break out, or certainly soon thereafter. This capability can provide forward ISR and even block and harass adversary ships from passage to, through, or within crisis zones. Losing the initiative in fast-moving Western Pacific crises to Chinese scale and presence will mean a reduction of options for decision-makers seeking to avoid escalation and/or pursuing U.S. and allied security interests. Dislodging Chinese assets—either Maritime Militia or PLAN—after a crisis begins may or may not be operationally complex depending on the specific context, but it will almost certainly be strategically risky and potentially escalatory in ways that may not support U.S. security interests in the region.

Ultimately, China's military modernization is particularly problematic for the United States because, as discussed at the start of this paper, it is proceeding along multiple levels simultaneously. Each of these dimensions poses different threats to the U.S. military's ability to project power and pursue U.S. security objectives in East Asia and the Pacific.

Significantly, China's unmanned weapons systems support each of these levels of threat and also reinforce China's advantages in presence and scale both in independent operations and alongside advanced manned platforms. The United States, then, must become more agile in its efforts to compete with China's capacity to simultaneously develop highly-disruptive advanced weapons systems and affecting A2/AD capabilities that leverage less-escalatory capabilities in imaginative and aggressive ways.

The required agility can be driven by intelligence, policy, strategy and capabilities or all of the above, but it can only be achieved if these measures are accompanied by "extreme vigilance." That is, an instinct to not just monitor developments related to China, but also to create structures and mechanisms to iteratively challenge U.S. assumptions about itself, China and the competition between the two. Alternative analysis techniques such as red teaming, wargaming, and scenario planning are particularly useful to building the sort of hedging strategies and indicators and warnings constructs required to operationalize this vigilance. They are also discussed further in Chapter 11.

Vulnerability and Ambition

Both the PLA and the industrial base that supports it are pursuing multiple and disparate objectives, simultaneously inspired by an acknowledgement of China's own military vulnerability as well as a focused and self-assured ambition driving it to pursue new approaches and grander objectives.

The A2/AD element of China's military modernization is rooted in a sense of insecurity and vulnerability. Unable to match the sophistication of U.S. conventional military platforms and systems, China has prioritized targeting asymmetric vulnerabilities in space, the information domain, and the EM spectrum. It has also effectively exploited cost curves in the air and missile defense competition to create new asymmetric vulnerabilities stemming from multi-axis saturation attacks.

However, China's advancing industry and power projection effort are stimulating investments in precisely the sort of advanced military capabilities and infrastructure it is targeting through its A2/AD effort. Its ambition here is impressive: to reach parity (or superiority) with the United States in the next two to three decades in order to protect what it views as growing overseas assets and interests.

Similarly, China's defense industrial base reforms, technology acquisition efforts, and investment in Fourth Industrial Revolution technologies are all balancing an effort to (1) acquire technologies to ameliorate vulnerabilities and fill gaps in the domestic S&T technology and (2) develop novel technologies that will allow China to fundamentally change the nature of the competition and establish a durable advantage.

So long as funding levels are high and government interventions and direction enables cross-industry focus on all of the varied modernization objectives, the tensions between the dual guiding forces of vulnerability and ambition can be managed. However, if and as China is forced to make difficult decisions, it is unclear whether it will prioritize the development of A2/AD capabilities or a potential transformation from informatized to intelligentized warfare.

For the United States and its allies, there is a growing sense that competitive strategies should prey on China's sense of vulnerability and desire to compete with the United States in advanced military capabilities, rather than try to push it to move too far, too fast down the road of developing transformative capabilities. In both Jane's workshops and in multiple interviews, experts mentioned that the United States should seek to encourage China in subtle ways to continue investment in advanced conventional military capabilities, such as aircraft carriers, because these are competitions in which the United States is more likely to retain advantage.

Capabilities

China's advanced weapons systems programs are a highly-prioritized component of China's military modernization effort with the capability to upset military and geopolitical balances in the Asia-Pacific. If deployed, the weapons systems considered in this paper should not be viewed solely as six discrete capabilities. Intersections between several of these systems exist and will amplify and reinforce their strategic and operational utility for China.

"Game-Changer and Game-Leveler"

Effective development and deployment of China's advanced weapons systems would constitute what one Asia-Pacific-based expert called "both a game-changer and game-leveler". It will stress U.S. alliances in the short-term, undermining American objectives in several cascading ways.

First, at an operational level, deployment of disruptive new capabilities will offer asymmetric advantages for China if its development of these systems moves faster than that of the United States and/or its allies or than effective counter-measures. This could reduce China's sense of military vulnerability to and awe at American military power, yielding instead to an ambitious sense that China can, and *should*, take more risks and pursue interests more aggressively in disputed maritime regions and other regional hotspots.

The use of clusters of linked and potentially swarmed UAVs, USVs and UUVs is well-suited to capitalize on the grey zone dynamics particularly evident in maritime territorial disputes in the South and East China Seas. Deploying assets such as these has a less immediately escalatory impact than moving more conventional manned assets to, or through, these contested waters.

This assessment rests on visceral perceptions of inimical intent and the escalatory optics associated with the deployment of manned surface combatants to a contested area. Escalation typically results from the sense that one's adversary has committed to a result and will risk meaningful loss—frequently *human* loss—to achieve it; by comparison, unmanned systems, even if armed and swarmed, lacks the same impact. As one interviewed expert noted, "possessing and even deploying UAV, USV or UUV assets simply doesn't have the same gravitas as committing an aircraft carrier battle group."[910]

Over time, of course, the less fraught emotional response to unmanned systems will alter as forward positions experience the menacing presence of and operational effects of clustered and/or numerous unmanned systems operating together to achieve a mission. A steep curve of increased appreciation of the capability's potential danger will result. But a deliberate act of escalation, or of escalatory miscalculation, will still be more effectively signaled when committing human combatants rather than unmanned systems at least in the next five-–plus years. The result enables a less urgent need, in the tactician's mind, to make counter moves vis-à-vis unmanned systems and creates opportunities for large numbers of present unmanned systems to change the strategic, operational, and tactical situation in contested areas or crisis zones. Within these dynamics, China, the United States, and even small or middle powers in the region can now pursue objectives in ways which, though not without risk, have a less threatening albeit still effective optic.

Nonetheless, once in theatre these assets can establish networks to find, track, and threaten kinetic, electronic warfare, or cyber disruptions against foreign vessels or naval assets. Such maneuvers would warrant a U.S. and potentially allied response. The existence of these advanced weapons

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[910] Email interview with network expert, January 28, 2018.

systems capabilities (and others) will spur enhanced risk-taking that could drive fast-moving crises and conflict with highly uncertain (and potentially unintended) outcomes.

Second, development of advanced weapons systems could lead states across the region to question the superiority of U.S. technological and military capabilities, a result flowing from a gathering sense that hitherto hard and fast certitudes about American power—and its deterrent effect—can no longer be taken at face value.

The most likely outcome and the one most frequently cited in Jane's workshops and interviews with regional experts is that traditional U.S. allies and partner states will seek to hedge by developing more robust relationships with China. For some partner states, this may include deeper defense industrial ties such as those mentioned in Chapter 6 on Unmanned Systems.

Ultimately, Jane's research indicates that even among the closest allies of the United States, the impact of a demonstrable second-best U.S. outcome in the competition to develop advanced weapons systems could contribute to a reevaluation of old paradigms and frameworks for security and deterrence in the Asia-Pacific.

Third, the presence of these weapons could incentivize other states in the region to develop or procure similar weapons, which could drive a destabilizing arms race across the region.

Unmanned weapons systems are the weapons systems most immediately likely to be diffused broadly, a process that is supported by prevailing trend toward technology transfer as part of export deals across the global defense market. As highlighted in Chapter 6, Indonesia's decision in July 2017 to buy six unmanned combat aerial vehicles (UCAVs) from China was due in large part to China's willingness to transfer technology to support Indonesia's efforts to build an indigenous UAV industry. This is an approach that China has been willing to pursue with other UAV customers.

In November 2013, the Pakistani Air Force announced the induction of its first two indigenously developed UAVs, the Burraq and the Shahpar. Jane's assessment of the Shahpar at the time was that it had "more than a passing resemblance to the China Aerospace Science and Technology Corporation (CASC) CH-3." The resemblance was not coincidental. Jane's had previously reported in 2010 that China was preparing to deliver 20 systems, along with the CASC FT-5 65 kg-class "small diameter bomb", to Pakistan in 2011.[911] So, in the span of approximately two years Pakistan was able to take Chinese UCAV technology and develop an indigenous version, presumably with Pakistani characteristics.

More recently, in May 2017, CASC signed an agreement with the King Abdulaziz City for Science and Technology to establish a plant for local manufacture of the CH-4 armed UAV.[912] The agreement will necessarily include the transfer of technology and know-how that will support Saudi Arabia's objective of developing a more robust domestic defense industry. It will also serve China's goal of deepening geopolitical connections to a strategically valuable energy provider.

In light of these examples and given the low-cost nature of UAV production, five to 10 year forecasts of considerably more states across the Indo-Pacific capable of developing effective unmanned system seem realistic. This dynamic could be accelerated by diffusion of technology from Western suppliers trying to compete with Chinese (among others) business practices. Indeed, the current U.S.

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[911] Bokhari, Farhan and Hardy, James, "Pakistan Inducts First 'Indigenous' UAV," *Jane's Defense Weekly,* November 28, 2013, https://janes.ihs.com/Janes/Display/jdw53971-jdw-2014.
[912] Binnie, Jeremy "Saudi Arabia to Build Chinese UAVs," *Jane's*, March 23, 2017, https://janes.ihs.com/Janes/Display/jdw65111-jdw-2017.

Administration's April 2018 decision to loosen export regulations for unmanned combat aerial vehicles (UCAVs) as a means of levelling the playing field with China in a market that is poised for short and long-term growth. The decision will enhance U.S. industry competitiveness, but does carry with it risks of unintentional diffusion.

The proliferation of large numbers of more advanced unmanned systems in the Western Pacific could confer asymmetric advantage to regional actors, who, in turn, may feel more compelled to take risks in local or regional competitions. China's on-going efforts to export directed energy weapons—Silent Hunter was prominently displayed at the IDEX exhibition in Abu Dhabi in February 2017—indicates that these weapons, in a counter-drone role, could proliferate across the region as well.

Of more intense concern is the prospect of proliferation of hypersonic weapons. A 2017 RAND report entitled "Hypersonic Missile Non-Proliferation" noted that hypersonic technologies have applications beyond hypersonic weapons—e.g., hypersonic flight—and could therefore proliferate to actors as part of sales or co-development of commercial applications of hypersonic technologies. The report warns, however, that "proliferation [of hypersonic weapons] beyond" China, the United States and Russia "could result in lesser powers setting their strategic forces on hair-trigger states of readiness and more credibly being able to threaten attacks on major powers."[913] And while the list of states that could immediately incorporate hypersonic technology to create HGVs is shorter than the list of states able to meet the relatively low threshold of indigenous unmanned systems development, the report makes a compelling case that over the coming two decades of innovation the threat of hypersonic weapons proliferation is greater than zero.

Amplifying Capabilities
Three developments and intersections will serve to amplify the disruptive effects of China's advanced weapons systems.

First, the use of multiple advanced weapons systems in conjunction with one another is likely to generate more complicated and intense challenges to U.S. military superiority. Simultaneous development and effective use of AI for military purposes, counter-space weapons and cyber-capabilities could serve to "discount not only U.S. military advantage, but also the way Americans prepare for and fight wars," particularly the way Americans ensure "air defense."[914]

Providing air defense in an environment in which HGVs are operating in conjunction with ASBMs, AI-infused unmanned swarms, semi-autonomous missiles and more robust and subtle/less-attributable counter-space capabilities requires layers of capabilities and accompanying concepts that the United States does not currently deploy and in many cases would need to develop. Hyper-velocity weapons, directed energy, cyber and electronic warfare weapons are all seen as central to the U.S. response.

Second, the simultaneous development of several enabling technologies will help optimize the transformative promise of several of China's advanced weapons systems. Two enabling technologies were highlighted frequently in our research:

- **AI:** AI will be a central feature of the future battlefield, not to mention military and security community efforts at greatly improved perception, intelligence processing, cognition and decision making. This paper focuses largely on the powerful intersections between unmanned systems and AI, but its applications are much broader—ranging from, among

[913] Speier, Richard H., Nacouzi, George, Lee, Carrie A., Moore, Richard M, "Hypersonic Missile Nonproliferation," *RAND Corporation*, September 2017, https://www.rand.org/pubs/research_reports/RR2137.html
[914] Jane's Implications and recommendations Workshop, IHS Markit offices, Washington, D.C., 5 October 2017.

many others, enhancing intelligence processing and commander decision-making to assisting tank drivers and helicopter pilots focus on critical tasks, to ensuring missiles are able to effectively locate and strike (or not) targets in a complex and fast-moving operational environment. China's AI eco-system and policy guidance indicates a capacity and compulsion to compete with the United States and others to become the leader in AI-infused military capabilities over the next decade.

- **IEPS:** IEPS are capable of capturing, storing and distributing energy across a platform, such as a ship, in more efficient ways, potentially remedying one of the technological challenges associated with directed energy and EM systems: the enormous amounts of power required to operate them. In June 2017, China claimed that it had "leap-frogged" the West in developing IEPS by using DC power distribution rather than AC power distribution. The claim, while excessive and dubious, should not overshadow the broader points of continued progress and interest in this technology.[915]

Third, China's advanced weapons systems both drive and are significantly affected by the iterative competitive geopolitical, military and security dynamics unfolding in the Indo-Pacific. Motivations of the development of capabilities such as HGVs and EM railguns are closely tied to U.S. development of similar technologies as well as THAAD missile defense systems.

Just as the United States views EM railguns and hyper-velocity weapons as a potential means of addressing HGV threats from China and Russia, China sees its EM railgun weapons program, at least in part, as a hedge against U.S. development of hypersonic weapons. The "fist over fist" nature of these exchanges mean that the mere existence, much less deployment, of China's advanced weapons systems programs already are shaping the types of capabilities being developed by the United States, other regional actors, and, in turn, China itself.

Adjacent Innovations

Much of this paper is focused on the acquisition, diffusion, development and potential deployment of novel technologies and the capabilities they enable. However, the development of novel, disruptive technology does not, in-and-of itself, constitute novel, disruptive capability. In order to move from technology to capability, China's defense community and industry—and subsequently the U.S. defense community and industry in response—must be able to innovate in several other areas (see Figure 33 below).

[915] Jane's by IHS Markit. "Chinese navy claims lead in IEPS development," June 5, 2017. https://janes.ihs.com/Janes/Display/jdw66061-jdw-2017.

Figure 33: Six areas of innovation required to develop a disruptive capability.

Achieving New Possibles: Technology and Design	**Conceptualization of Demand and Use:** Doctrine, Applications, Narratives, CONOPs, Strategies	**Building Supporting Infrastructure:** Education, Infrastructure, Logistics
Comfort of Use: Moral, Ethical, Psychological Concerns	**Business Case:** Affordability, Profitability, Market Creation	**Facilitating Adoption:** Legal, Regulatory and Procurement Shifts

Source: Jane's Strategic Assessments and Futures Studies Center

- **Conceptualization of Demand and Use:** The development of effective doctrine and savvy operational concepts is a critical component of capability development, especially in an environment in which innovation in Fourth Industrial Revolution technologies will happen quickly and individual technologies will have multiple military applications. Militaries—not just the PLA—will be stretched to build, test, refine and communicate operational concepts that keep up with the pace of technological innovation.

- **Building Supporting Infrastructure:** Operational efficacy of China's advanced weapons systems will require development of the physical infrastructure and maintenance, repair and overhaul capabilities to sustain advanced weapons systems and their counter-measures. This category of adjacent innovation also includes development of new training protocols, organizational structures, and career pathways for individuals working with new technologies and capabilities.

- **Comfort of Use:** Some technologies come with moral or ethical concerns that need to be explored and resolved. Autonomous strike—the use of unmanned systems or other autonomous weapons that make battlefield decisions to take human life without a human in the loop—are a contemporary example of ethical concerns associated with China's advanced weapons systems. Direct ascent ASAT weapons are another. China has already demonstrated its willingness to destroy a satellite in space, though the reported surprise of China's leadership at the backlash to that action may have constrained the range of scenarios in which China uses these weapons.

- **Business Case:** Establishing ways for manufacturers to make money off new technologies is less of a concern for China's advanced weapons programs, which are well-funded by China's government. However, China's on-going domestically-focused reforms do indicate that there are compelling structural issues and intra-industry competitions that could affect the pace of development of China's advanced weapons programs.

- **Facilitating Adoption:** China's Next Generation Artificial Intelligence Development Plan notably includes a plan for the development of legal and regulatory governance of a new and transformative technology. Similarly, among Jane's recommendations below is the suggestion that China, the United States and Russia develop protocols around the development and deployment of HGVs in order to avoid miscalculation and pre-emption related to these destabilizing weapons systems. Establishment of these regulatory frameworks, as well as refinement of the ways in which new capabilities (some of which will be developed outside of the traditional defense industrial base), are critical to the successful incorporation and use of novel technologies and advanced weapons systems.

Concluding Thoughts

This report’s major thrust and sense of concern are unambiguous. The five (plus AI) major advanced weapons systems under review do not have fixed, limited utility to China’s expansion of its military R&D base. Nor do they necessarily point to full weaponization and operational deployment within the Chinese armory. But past history and existing potential point fairly clearly to the likelihood that these systems will become a feature of the strategic landscape in a decade. Or less.

The report’s authors have sought to identify which among these systems presents both destabilizing asymmetrical power potential (AI-managed swarm or cluster deployments of UAVs, UUVs and other robotic vehicles), and destabilizing potential for the management of strategic weapons (hypersonic glide vehicles). We have repeatedly stressed that the overall strategic environment in the Western Pacific rests not only on unchallenged offshore American ascendancy since the Second World War but also on pooled effort by American treaty allies (Japan and Australia) and, increasingly, by an emerging defense partner, India. China’s advanced weapons systems development challenges these allies’ and partners’ security as much if not more so, given existing imbalances in capabilities, than the United States.

The appropriate response must gather these overlapping interests and bundle them to American and allied advantage, notably via deliberate plans to understand and counter China’s destabilizing moves. China does not stand ten feet tall. It remains vulnerable to internal stresses and discord. Adversaries can play on China’s anxieties and phobias.

More important, the lifting of U.S. competitive performance in this area of military R&D promises not only parity and continued ascendancy but also, if adroitly managed, a chance to cap China’s destabilizing moves with bilateral limitation agreements. The United States should never forget that China’s ostensible friends, notably Russia, harbor deep if quiet reservations about China’s developing the capabilities we have described. They have an interest in slowing the momentum too. The challenge—further explored in Chapter 11—is to pull these strands together in a clear if variegated response.

Chapter 11: Recommendations

Our recommendations are grouped into three categories.

Figure 34: The three categories of Jane's recommendations

Upping the Competitive Game	Military and Operational	Strategic Intelligence and Competitive Strategies
• Prioritize countering Chinese defense R&D in our Indo-Asian alliances/partnerships • Quietly engage with western defense firms on strategies to frustrate de-stabilizing Chinese defense R&D • Identify possible leverage and pressure points in the non-migrant visa system enabling PRC nationals to maximize work/study in US • Position senior people in government, research and corporate realms to monitor competitive dynamics	• Special emphasis on competing with, or heading off, advanced weapons system advances with strategically destabilizing impact -- e.g., hypersonics • Extra effort to retain mastery and control of air and space domains • Deepen U.S. understanding about which advanced weapons system, *or combination of systems*, have game-changing potential - and plan for offsets	• Inculcating within the intelligence community (IC) the parameters of the technology acquisition intelligence challenge • Introduce standalone sections on 'destabilizing Chinese weapons systems' in China NET Assessments and in the congresionally mandated annual DOD report on Chinese Military Power.

Recommendations for "Upping the Competitive Game"

The United States must "up its competitive game" to effectively slow China's research momentum and its emerging and consequential geopolitical advantages. Specifically, this means:

Expanding the definition of "alliance management" (a term applied to both the statecraft and the special collaborative arrangements the United States has developed with the closest of its allies).

China's competitive and destabilizing intent in one or any combination of the five (plus AI) advanced weapons systems examined in this study points to an immediate need to confer with allied and partner states in the region and harmonize perspectives about the impact on their respective national security of China's programs *and* on the credibility of the American deterrent. Discussions with Japan, South Korea, Australia, India, and Singapore are especially urgent.

The United States' approach to Asia and to its Asian partners reflects a long and remarkably consistent vein of security statecraft, the so-called system of "hub [the United States] and spokes [the other security partners or allies]" in which open multilateral trading systems augmented a web of bilateral treaties.

The common need to counter destabilizing weapons systems offers a new rallying point for an updated defensive security community grounded in a focused rejoinder to China's plans. Beyond the readjusting of global geopolitics of 2017-18, continued development of China's advanced weapons systems will further erode confidence in the absolute military-technical advantage of the United States, affecting alliance dynamics and introducing new openings for Chinese opportunism.

This new dimension to alliance management emerges from **a technologically defensive posture** and a determination to master analytical and technical trends shaping China's development of these programs. Soliciting and incorporating national expertise and national strategic perspectives of U.S. allies and partners is central to this task. They have exceptionally valuable filters that can validate and inform U.S. perspective and even challenge and expose unhelpful U.S. biases (e.g. China is systemically unable to innovate).

The objective of this new technology focused security community should be to create mechanisms aimed unambiguously at stemming technology acquisition with the onus being on those acquiring it to show the absence of destabilizing impact or intent

In a reimagined alliance management approach, "Father Knows Best" detachment and/or excessively and unnecessarily provocative approaches will no longer deliver results.

Accordingly, modern engagement with U.S. alliances in the Asia-Pacific must rest on a common understanding of the unambiguous threat of China's geopolitical and military rise, especially its development of the destabilizing and competition-shifting weapons discussed in this paper.

The objective of this new technology-focused security community should be to create mechanisms aimed unambiguously at stemming technology acquisition with the onus being on those acquiring it to show the absence of destabilizing impact or intent.

Taking alliance management in this direction means an intention to agree on **joint projects**, grounded in common interests and interlocking technical capabilities. Little noticed by the U.S. public, the announcement in November of "quadrilateral" security talks—four-way talks between Australia, India, Japan and the United States—creates the right forum to produce techno-competitive joint products and enhance America's security linkages in the Asia-Pacific.[916]

For example, China's HGV weapons development plus sharply rising concern about air control and local defense postures provides a solid foundation for deeper collaboration between the United States and Japan on new "air defense" solutions. The U.S. approach to joint development of a layered missile defense system in Israel could serve as a model, with outputs potentially including *something like* the Stunner low-cost interceptor, co-developed by Raytheon and Rafael,[917] or the SkyCeptor low-cost interceptor Raytheon is planning to co-develop with the Polish defense industry.[918]

Shared anxiety about destabilizing trends in the undersea domain could easily elicit a "quad working group" aimed at solutions to problems that traditional ASW collaboration can no longer address. The EM spectrum is another domain in which joint projects could have an outsized value for the United States and its allies. Dr. William Conley, the Deputy Director of Electronic Warfare in the Office of the Undersecretary of Defense for Acquisitions, Technology and Logistics, stressed this point during his June 2017 speech. Dr. Conley noted that ignoring allies in this domain or becoming overly concerned with "need to know" and secrecy could be disastrous for U.S. operations: "If allies don't have the same systems, or don't know about U.S. capabilities, some electronic warfare weapons may have to

[916] Panda, Ankit, "U.S., Japan, India and Australia Hold Working Level Quadrilateral Talks Over Regional Cooperation," *The Diplomat,* November 13, 2017, https://thediplomat.com/2017/11/us-japan-india-and-australia-hold-working-level-quadrilateral-meeting-on-regional-cooperation/.
[917] Stunner Air and Missile Defense Low-Cost Interceptor Brochure, Raytheon and Rafael.
[918] Raytheon, "Raytheon to Offer Low – Cost Patriot Interceptor," June 19, 2017, https://www.raytheon.com/news/feature/skyceptor.html.

be switched off, or risk being mistaken as an attacking adversary."[919]

Of course, there are potential drawbacks to joint projects and deepening industry collaboration that will need to first be understood and then effectively managed both by the U.S. government and by U.S. defense industry organizations. Most notably, multi-national development efforts can bring engineering and integration challenges as defense industrial bases with varying cultures, areas of expertise, processes, standards, and resources seek to collaborate on frequently sophisticated engineering problems. Recent experience with the Lockheed Martin-led F-35 fifth generation fighter program highlights some of these integration challenges[920] and the knock-on implications for cost, timeline, and program optics that can result. Another drawback is the potential loss of future revenue for the U.S. defense industry as foreign suppliers feature in development activities and supply chains that could be filled by U.S. suppliers.

China will also seek to use these programs to support a narrative of U.S. aggressiveness in the region that may resonate with some regional actors, depending in part on the nature of U.S. leadership at the time of the joint program. China will feign outrage over a "destabilizing" move – when it is on China's decision to upend the strategic equilibrium that the blame should fall. It would be a replay of the accusation that the past administration's decision to "rebalance" America's posture in the Asia-Pacific was in itself destabilizing—whereas the United States has been a status-quo power in the region since the end of the Second World War. As both Republican and Democratic administrations have emphasized since 2008, "the United States is a resident power in Asia."[921]

Even taking into account these risks, Jane's believes that these programs' potential advantages outweigh the conceivably counter-productive political, geopolitical, and financial outcomes associated with frayed or failed joint programs. Joint programs, then, should be a pillar of U.S. efforts to up its alliance management efforts. At the least, they offer an important opportunity for confidence building and sustained engagement and collaboration on the military and technology threat emanating from China and how to address it. If programs are successful, they can provide enhanced military capabilities and geopolitical alignment, which will help buttress the U.S. position in the Asia-Pacific.

There is nothing novel about this suggestion of an enhanced engagement with allies, which can be and most policymakers say *should* be an area of particular advantage for the United States. The United States knows how to play a multilateral game, especially vis-à-vis China. On the other hand, China has a historical tradition of viewing regional neighbors as tributaries. "We have done this before and done it well," offered one Implications Workshop participant, "China still struggles with these types of tasks, especially in Asia."[922]

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[919] Magnuson, Stew, "DoD Puts 'Foot on Gas Pedal' to Catch Up on Electronic Warfare," *National Defense,* July 14, 2017, http://www.nationaldefensemagazine.org/articles/2017/7/14/dod-puts-foot-on-gas-pedal-to-catch-up-on-electronic-warfare; and Conley, Dr. William, "State of Electronic Warfare in the DoD," speech at the Mitchell Institute of Aerospace Studies, June 22, 2017, https://www.youtube.com/watch?v=qR_PPGDnejo.

[920] According to Lockheed Martin, the F-35 program has suppliers in nine countries outside of the United States. "The Centerpiece of 21st Century Global Security," F-35 Lightning II webpage, Global Partners page, https://www.f35.com/global.

[921] This phrase was used by then Secretary of Defense Robert Gates at the Shangri-La Dialogue in Singapore during prepared remarks on 31 May 2008. A summary of Secretary Gates' comments, including the reference to being a "resident power" is found in the Shangri-La Dialogue Report 2008, International Institute of Strategic Studies, http://www.iiss.org/en/publications/conference%20proceedings/sections/shangri-la-aa36/the-shangri-la-dialogue-2008-deba/sld08-04-chapter-02-7ca7.

[922] Jane's Implications and Recommendations Workshop, IHS Markit Offices, Washington, D.C., October 5, 2017.

An important dimension to this re-invented model of alliance management lies in the need for streamlining collaborative mechanisms within the Five Eyes intelligence alliance between Australia, Canada, New Zealand, the United Kingdom, and the United States. This alliance needs new operating guidelines for focusing on the competitive dynamic with China. Their knowledge about and concern over continuing technology proliferation into China must be mobilized to give direction to the task. While different states may see China's technology acquisition with varying grades of concern, this core group of allies could offer a strong starting part for multilateral efforts to deny technology transfer to China and to work together to track China's massive (and growing) technology acquisition efforts.

Industry Engagement

A decision to up the United States' competitive game requires more alignment and collaboration between the U.S. government and several critical industries, as well as within the industries themselves.

At the government level, this requires adroit handling of industry sensitivities and market pressures, notably from China. No fanfare should attend efforts to deepen collaboration and coordination on technology protection or implementation of any belated American effort to "up its competitive game." For commercial, diplomatic and strategic reasons, the Chinese government and many of China's commercial entities will seek to frustrate this attempt to "rebalance" the technological terrain. But confidential and collaborative mechanisms alert to sensitivities should ensure a better understanding of the dimensions and dynamics of China's technology acquisition program while better positioning the American response.

China's competitive behavior and strategy and its links to China's exclusionary industrial policy are best answered using like-with-like approaches – i.e., coordinated government/industry responses based on reciprocity of action – plus quiet but unambiguous signaling of US intent and priority. U.S. technology protection efforts therefore cannot replicate other cross-sectoral initiatives involving businesses and government. U.S. firms know in great and useful specificity how China rigs its commercial space, but there is still room for U.S. government action to address two persistent challenges.

First, in many cases, U.S. businesses outside of the U.S. defense and security industry lack a robust perspective on the rapidly evolving military, security and technology competitions between the U.S. and China. At an intuitive level, these companies understand that there is a competition, but this competition is frequently seen through the narrow lens of immediate corporate interest rather than the broader aperture of the accretive national security effects of the bleeding of individual technologies.

The second challenge is related to transparency. Getting U.S. corporates to share deep experience or to identify specific Chinese actions requiring countermoves is difficult – whether this is in the open, or even in the ostensibly "closed" space of a public/private dialogue. This reticence results from a strong desire to prevent commercially confidential information or experience from reaching other Western competitors. Overall, the Chinese commercial system works on a pragmatic basis in which the divide between enforceable legal/contractual space and other business activity is blurred. U.S. industries remain leery of sharing their experience in a common forum—for fear of alerting competitors or jeopardizing already tenuous positions if the U.S. government takes an inelegant approach without regard to on-the-ground sensitivities.

The U.S. government must recognize the near- and immediate-term conundrum into which the Chinese market's guardians have put American firms. There is not, in our assessment, an even remotely level playing field.

A carefully selected task force from the congressional and executive branches should begin working closely with the private sector, establishing collaborative forums and cross-industry working groups that would bring together the U.S. defense, high-tech, automotive, financial, commercial aerospace and maritime and energy industries as well as relevant academia and applied research representatives. *There is no better way to acquire a full understanding of China's technology acquisition efforts and their implications – or to devise a set of best practices for combating them*, in Jane's view. The task force will have three main functions.

- **Trusted Agent and Clearinghouse:** A central function of the task force will be to assuage corporate concerns about transparency (even in closed forums) and offer a confidential channel through which corporates can share concerns about and indications of China's technology acquisition efforts. The task force will also need to serve as a clearinghouse and "launderer" of this information in order to ensure safe distribution of confidential reports to a relevant network of U.S. companies operating in similar industries or trading in similar technology areas.

- **Special Representatives: Advocacy and Engagement:** The task force approach also involves identifying and appointing various point-persons who carry messages from the top of the U.S. political system. These "Special Representatives" should have the confidence of senior members of Congress and work in conjunction with the U.S. Trade Representative while enjoying executive branch confidence. They will also work with the taskforce to prioritize issues where U.S. pushback is needed.

  In addition to being an instrument through which pushback and advocacy can take place, Jane's also envisions three additional Special Representative roles. First, Special Representatives will be critical to operationalizing meaningful engagement with China on the most de-stabilizing technology development and acquisition issues, such HGVs.

  Second, they will also need to win allied/defense partner country sign-on to technology retention and technology innovation collectively in response to Chinese acquisitiveness. And finally, the roles will take the lead in establishing and chairing an industry working group in the five most pressing areas of Chinese technology acquisition (to be determined by nominated special reps of leading info-tech CEOs).

- **Education and Facilitation:** U.S. companies are highly unlikely to simply forego the promise of China's market in these industries of interest, just as U.S. universities and applied research labs will be unlikely to completely pass on qualified Chinese students and researchers. Therefore, this initiative should establish a common understanding of the dimensions and implications of technology acquisition challenge and seek to assess and communicate:

  - The technologies of most interest to China's efforts to advance its economic, national development, and military objectives
  - Implications for U.S. national security of China's technology acquisition program
  - How China is acquiring this technology
  - Best practices for monitoring technology diffusion

- The scale of China's illicit technology acquisitions to include IP theft, pilfering of proprietary information, and outright espionage for three decades
- The risks and difficulty associated with doing business in China

Industry Engagement II: Specific Engagement with U.S. High-Tech Industry
None of the intended collaboration should be treated as something *ab initio*: engagement between the U.S. DoD and the U.S. high-tech industry reflects decades of close collaboration. Informal systems exist today for exchanging information and for devising ways to preserve American advantages in the fast-moving world of AI, big data analytics, advanced manufacturing, and novel materials, among many others.

The U.S. DoD's Defense Innovation Unit (Experimental), DIU(x), provides one model of facilitating contact and aligning focus areas between DoD and U.S. high-tech centers such as Silicon Valley, CA, Austin, TX and Boston, MA. In addition, there is growing ecosystem of small companies, particularly in Washington, D.C., that are assisting small non-defense companies with no experience managing the complexities of defense procurements navigate the frequently byzantine (and equally as frequently frustrating) process required to bring novel capabilities to defense end-users as quickly as possible.[923]

Even as this engagement accelerates and expands, there is still a broadly-held consensus among those interviewed in this research and open sources on this topic that significant barriers to engagement exist as do dynamics that undermine its ultimate objective: enhancing the ability of the U.S. government to procure advanced technologies in a timely manner.

From the high-tech industry perspective, the federal acquisition process—with timelines of twelve months or more—is too slow and too bureaucratic. Government acquisition and research and development models are not nimble and adaptable enough to keep pace with the near fluid nature of technological change in many of the key technology areas relevant to modern and future warfare.

As a result, the U.S. is missing opportunities to utilize one of its most compelling national advantages: its dynamic and innovative high-tech industry and start-up ecosystem. Efforts to reduce procurement timelines—namely, "other transactional authorities"—have sought to expedite research and development, technology demonstration and procurement and have had some initial success. Jane's recommends that these procurement methods—which add a high degree of flexibility and adaptability to capabilities development and acquisition—be protected and expanded and that next generation means of incentivizing experimentation, rapid prototyping and speeding up procurement all be implemented to reduce the number of years' or decades'-long development programs that currently risk fielding outmoded capabilities.

Of course, traditional defense industry—which occasionally and rightly bristles at the idea that innovation only takes place in Silicon Valley—has a prominent role to play in both shaping and participating in these new approaches to technology development and procurement and in maintaining U.S. technological advantage vis-à-vis China. But this community will also need to design ways – incentivized by U.S. DoD assistance—to balance its instinct to compete with new industry actors with an equally compelling need to accommodate, and partner with, high-tech companies where appropriate in order to best serve U.S. warfighters.

[923] Jane's research team spoke to two of these companies during our research for this effort. Representatives from both organizations believed that these types of facilitation services will be in increased demand in the coming five years as DoD and other defense and security enterprises intensify engagement with non-traditional defense providers.

The recommendation here is not for a complete abandonment of large and complex procurements. There will still be programs that will require this deliberate approach. Rather the recommendation is to ensure that the DoD develops a sufficiently broad variety of procurement mechanisms to be able to run a "horses for courses" approach based on urgency of demand and complexity of requirement, to include expansion of sole source, expedited awards, and IDIQ vehicles that facilitate rapid acquisition of novel technologies.

Policy Tools

Export controls, visas, and the appointment of a special envoy to China are three policy tools that could be implemented to slow or stop the diffusion of sensitive U.S. intellectual property and technology to firms (particularly China) who work in a world where technologies have long since become dual-use. Frequent review and, if necessary, revision of existing **export control policies,** nearly all grounded in the perpetuation of Cold War strictures after 1990, must be pursued in order to balance multiple pressures and challenges and allow for more flexible approaches to technology protection and dissemination.

Pressure for change to that regime comes first from U.S. defense firms' determination to enter new markets and secure existing clientele in response to the prevailing trend in the global defense industry. Export markets in Asia, the Middle East, and Eastern Europe are exercising their leverage and demanding transfers of technology and know-how to support indigenous defense industry development. The days of captive U.S. markets are coming to an end and simple contracts involving payment for the delivery of finished platforms and systems are on the decline. Export markets are making trade-offs between needing the highest quality equipment and the need for lower costs, higher work-share and co-development opportunities, more technology transfers, and more forgiving payment terms.

This places U.S. firms in a competitive quandary. Export sales are seen as important to achieving resilience against increasingly unpredictable U.S budget dynamics. They also contribute to economies of scale and the margins necessary for investment in new systems. However, U.S. companies that are responsible to shareholders and constrained by concerns over exporting the most advanced military technologies in the world have fewer direct and obvious levers to pull in order to compete with heavily subsidized or state-owned enterprises who are able to share "good enough" technologies with export markets.

Change is also required to "keep up" with the high-velocity of innovation in technologies from commercial and research sectors that have demonstrable defense and security applications, a dynamic highlighted throughout this paper.

In response to these sometimes competing pressures, Jane's recommends exploration and adoption of mechanisms that enable more regular review and dissemination of guidelines on controlled technologies that support the development of capabilities of most intense concern to the U.S. DoD and the U.S. government. The intent of this policy recommendation is not necessarily to liberalize export controls in aid of private defense firms' eagerness to conquer new markets—though the U.S. suppliers have found themselves at a competitive disadvantage in some markets, including the UAV market, as a result of strictures on the export of sensitive technologies. Rather, it is to enhance "flexibility and adaptability," the qualities identified in Chapter 10 as being critical to dealing with China's advanced weapons and military modernization challenge in the current technology diffusion and military capabilities development environment.

The intent of these reforms should be to enable the streamlining of efforts to expand joint or mutual projects by advanced partner countries—Australia and Japan come readily to mind. Focused proliferation of technologies of this type can even enable, as part of overall project implementation, improved control over technology diffusion, as partner countries have the same goal, especially as efforts at alliance management referenced above produce a common understanding of the risks of technology diffusion. This requires new approaches to the rules affecting defense joint ventures and collaborative commercial arrangements.

Charting a more flexible way ahead presents many challenges, especially in communicating and enforcing *too frequently* reviewed and refined policies, but persisting with rigid strictures ignores the rapidity with which technology innovation is moving across defense and adjacent sectors.

The provision of **visas** is another tool which, if used quietly and with finesse, can put pressure on China and reduce intellectual property theft by Chinese post-doctorate and graduate students. Migration into the United States has become a vexed and rightfully sensitive area of concern to those worrying about the ease with which technology is acquired by smart technical personnel and full fee-paying students. Prior to 9/11, the U.S. Embassy's head of mission had the authority to use visa-granting powers in ways that furthered overall U.S. policy. The criteria for the DHS to apply the brakes now to visa-applicants rests on protecting the homeland from extremist violence—not for monitoring, let alone regulating, migration which has the effect of steepening the techno-competitive odds. Denial of visas or, more practically, instituting a program to reduce the number of visas and better vet candidates would be a useful, if evident, first step. Also discussed in our workshops was evaluating policies on H1-B visas. Current efforts to restrict these visas incentivize Chinese students to return home. Reform should also extend to the H1-B visa program, but with the opposite intention, to have the capacity to selectively ease the ability of American-educated Chinese graduates to stay.

One additional suggestion from an expert based in the Asia-Pacific region is for the United States to think about technology theft in the United States as a "two-way street" that also includes a counter-intelligence opportunity to "turn" individuals engaged in technology theft within the United States.

A useful analogue: China's Beidou global navigation satellite system poses a challenge to the U.S. ability to project power, but it also creates new vulnerabilities for China as more satellites in space give the United States more opportunities to disrupt critical Chinese networks. Similarly, the threat of technology diffusion and theft via foreign students and skilled laborers is real and affecting. However, so too, might be the opportunity to learn more about the scale, motivations, focus areas and methods of China's technology acquisition strategy and how pilfered technologies play into China's broader military modernization efforts.

Military and Operational Recommendations

Continued—let alone accelerated—development of China's advanced weapons systems amounts to a "game-changer and game leveler" at both the strategic and operational levels.

On the basis of China's development-to-deployment experience this century, we can expect little time lag to impede the introduction of these weapons into China's armory. Given the operational intent of China's security establishment, those planning U.S. countermeasures have little choice but to assume full operational introduction into the inventory of many of the capabilities in question by the end of the next decade, if not before. China already has deployed advanced counter-space capabilities, and its unmanned systems industry is one of the fastest maturing in the world with exports to states in Southeast, South and Central Asia as well as the Middle East and North Africa. China is also using and even seeking to export directed energy weapons, meaning that three of the five weapons systems of interest to this report are active and operational—if still maturing. Add in the DF-21D and DF-26 ASBMs—assessed by Jane's to be vulnerable, but viable weapons systems—

and an argument can be made that four of the five categories are systems are operationally relevant in 2018.

Further development of these already operational weapons systems is inevitable as are efforts to field an HGV. As these more advanced manifestations of these systems come online, they will create new vulnerabilities, especially for allied countries' security and for the U.S. forward position in the Asia-Pacific. Chinese deployment of operationally coherent advanced weapons systems will also, if managed well by the United States, potentially create collaborative and alliance-tightening opportunities as third-party governments seek to offset perceived Chinese tactical ascendancy in adjacent, local sea, undersea, air, and space domains. But if the United States fails in its alliance management efforts, the deployment of these weapons will serve as another wedge between the United States and its allies and partners in the region.

Recommendations to counter China's development and deployment of these capabilities and to mitigate risks to U.S. and allied assets, interests and personnel include:

Directly Engaging China on Hypersonic Weapons

HGVs are a particularly destabilizing weapon that upset traditional expectations of both nuclear and conventional deterrence. Hypersonic weapons create inducements and incentives for preemptive strikes, an anxiety in times of heightened bilateral U.S.-China tension coupled, as has happened since the mid-2000s, with Chinese assertiveness along its Asian periphery.

Given the progress in China's hypersonic research, and an expectation of future production and deployment by late in the next decade, the United States and its technologically competent defense partners, have little choice but to regain superiority in hypersonic glide vehicle capability. As former Acting Assistant Secretary of Defense Alan Shaffer noted, "We, the United States, do not want to be the second country to understand how to control hypersonics."[924]

Because hypersonics "set the pace" in advanced weapons systems development, this will prompt new efforts to intercept, i.e., new investment in other advanced systems, such as EM railguns and missile defense.

Discussion of HGVs in both workshops reflected an opinion among experts contacted for this study that engagement with China and with other regional actors (Russia) should occur soon. Beginning initially between academics and policy centers/think tanks, the aim of engagement should be the identification of ways to diminish and degrade the destabilizing effects of HGVs. One participant summed up the prevailing perspective on these weapons in the initial Framing Workshop by asking: "Not to sound like an arms control enthusiast, but why aren't we talking to China about these things?"[925]

Prioritizing the need for restraint in R&D for these advanced weapons systems should figure in the talking points of our senior most officials in their interaction with equivalent Chinese officials—who may be insufficiently aware of the negative trends that follow their researchers' enthusiasm. It is useful to remember the apparent surprise of the CCP Politburo in January 2007 regarding the consequences of the Chinese ASAT, which spewed debris from a kinetically destroyed Chinese satellite into space, complicating global orbital management.[926]

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[924] Machi, Vivienne, "Future Weapons: Rivals Push Pentagon to Boost Funding for Hypersonics Research," *National Defense*, June 26, 2017, http://www.nationaldefensemagazine.org/articles/2017/6/26/future-weapons-rivals-push-pentagon-to-boost-funding-for-hypersonics-research.
[925] Jane's Framing Workshop, IHS Markit offices, Washington, D.C., August 8, 2017.
[926] Jane's by IHS Markit. "ASAT," September 27, 2017. https://janes.ihs.com/Janes/Display/jsws9047-jsws.

The first objective of these bilateral forums would be to develop enhanced understanding of these weapons, their destabilizing potential and their "inevitability." The United States would augment this bilateral link with parallel liaison with allied and defense partners—notably (but not exclusively) the other members of the so-called "quadrilateral" talks. Thus, an indirect multilateral dynamic would be created, mitigating Chinese insistence (on this and other security issues) on addressing problems bilaterally. The "quad" would have an anticipatory role in fashioning common positions and consensus about the pace of technological development, and the tactical/strategic consequences. This forum would lead, in the Sino-American bilateral context, to steadily more sophisticated discussion about possible protocols to mitigate the escalatory and destabilizing risks associated with these weapons.

Frequent consultation among the quads requires the United States to be especially attentive to the diplomatic sensitivities each country faces vis-à-vis Beijing. In particular, extra attentiveness must occur regarding (a) respecting our defense partners' national security anxieties in the face of destabilizing Chinese advanced weapons R&D and (b) involving them in fashioning development programs reciprocal to the Chinese moves. Thus prepared, U.S. engagement with China on hypersonic weapons should focus on preventing diffusion of hypersonic technologies to other states within the region and beyond.

To emphasize how pressing an issue "hypersonic restraint" has become, a 2017 RAND report, "Hypersonic Missile Non-Proliferation," warned that "proliferation [of hypersonic weapons] beyond" China, the United States and Russia "could result in lesser powers setting their strategic forces on hair-trigger states of readiness and more credibly being able to threaten attacks on major powers."[927] Coordinating a common position among U.S. allies and defense partners for achieving this restraint will not be easy. The distance between full technical awareness of the hypersonic potential, and actual possession of the vehicles themselves, could be problematic for some quad states, notably India—which sees China as its peer competitor, a perception not shared by the Chinese.

New Capabilities and Concepts

China's counter-space, HGV and cyber capabilities, plus its UUVs, USVs and AI-infused platforms and the integrated systems development all threaten current U.S. and allied military advantages. These have accrued after decades building a networked, high-tech force and the supporting infrastructure.

Beyond the specter of lost advantage comes another worry: Chinese gains in recent years threaten to undercut what has been described as the "American way of war." The United States has a small window, only a decade at most, in which to develop new capabilities and concepts for countering the cascading disruption of China's advanced weapons programs.

How might we best prepare to optimize this narrow window of time? Our research and Workshops pointed to the following recommendations for development and investment:

- **Selecting and Winning the Critical Competitions.** Continued investment in novel weapon systems and the underlying concepts behind their operational integration will enable the United States to retain and even expand its advantages. The question is, *which* systems development promise the most competitive advantage? There are neither facile nor simple choices, but the authors opt for concentrating on the **undersea domain,** on **missile versus missile defense** and on retaining our pre-eminence in the **space domain and EM spectrum**.

[927] Speier, Richard H., Nacouzi, George, Lee, Carrie A., Moore, Richard M, "Hypersonic Missile Nonproliferation," *RAND Corporation*, September 2017, https://www.rand.org/pubs/research_reports/RR2137.html.

This is not an either/or list. It's a matter of relative emphasis. The two workshops and associated research within the U.S. public domain and among our defense partners abroad also emphasized how disruptive weapons like EM railguns and weapons employing directed energy can shift the nature of the missile versus missile defense competition. New approaches to missile defense will come to dominate policy response to China, as will concepts such as "left-of-launch" interventions. While potentially destabilizing in its own right, the concept of using difficult to detect cyber or EW weapons to stop a missile launch before it happens could offer a powerful preemptive and prescriptive tool and a hedge against failed diplomacy and HGVs.

UUVs (and radically new concepts for using them) will parallel new SSN capabilities, all seen as critical for maintaining the extant stabilizing imbalance of undersea capabilities in Asia. New investments in electronic warfare capabilities are also required—especially cognitive electronic warfare systems able to enter into any environment with no information about adversarial systems and independently and rapidly identify, understand and formulate countermeasures. Effective and rapid development of cognitive electronic warfare "will provide the United States with a decisive advantage within the critical EW [electronic warfare] domain."[928]

Our recommendations in this area also include an enhanced emphasis on wargaming to assess second and third order consequences of decisions and of how the introduction of new technologies and capabilities might drive these competitions along new trajectories. We also believe that more emphasis on operational red teaming—understanding how China will think, act, decide, and ultimately actually employ advanced weapons systems—will be a critical input into determining the appropriate balance of investment across these competition areas. We recommend a standing red team made up of a multi-disciplinary set of experts and analysts on China, its military modernization, defense industrial base, high-tech industry, and cultural proclivities to provide a fluid and dynamic understanding of how China is thinking about these weapons and their employment both as isolated systems and in conjunction with other advanced weapons systems.

- **Revisiting the Future of Space.** Some experts interviewed for this report took the view that the United States must re-evaluate its current approach to the weaponization of space. In light of China's capacity to deploy a range of ASAT weapons—cyber, co-orbital satellites, directed energy and even direct ascent missiles—frequently under the guise of "dual-use" civilian missions.

  This conduct puts the United States and its defense partners at a potentially serious disadvantage in this critical domain area. One specialist noted that the space domain today has similarities to the undersea domain during the 20th century's inter-war period. While actual undersea domain hostilities ran counter to settled international law, this did not prevent the major naval powers from preparing for a time when conflict would dominate this domain.

  Space resilience by the United States and its partners will result from a combination of investments in hardening existing satellites, developing micro-satellites and other capabilities to quickly reconstitute architecture, and concepts of operation that stress disaggregation and extreme redundancy of systems and capabilities. U.S. counter-counter-space approaches will also include enhancing the ability to *operate independent of space-*

[928] Jane's C4ISR Systems team analysis included in primer papers submitted to SAFS on May 20, 2017.

based architecture. If China believes that degrading U.S. space architectures will not fundamentally cripple U.S. operational efficacy, perhaps it will take a different (and plausibly costlier) approach to A2/AD.

Rising to the Intelligence Challenge and Developing Competitive Counter-Strategies Recommendations

Our final recommendations call for more complete and nuanced intelligence about China's intentions and capabilities. What does this mean in practice?

Bounding China's Technology Acquisition Effort. The intelligence challenge associated with the wide scope and daunting complexity of China's technology acquisition efforts is enormous. Bounding it, assessing it, monitoring it, and anticipating diffusion of critical technologies to China will require a centralized system and the evolution of collaborative mechanisms within the United States and allied country defense, intelligence, and law enforcement communities.

The minimal prerequisite is an active, focused capability, perpetually monitoring issues and questions such as:

- **China's Motivations and its Prioritized Targets for Acquisition**: What technologies are prioritized and why? How might target prioritization change based on shifts in the strategic and operating environment?

- **Assets, Resources, Relationships and Methods**: What tools does China have and which does it employ with little or no pushback from the United States and its partners? What gaps does the United States have in its knowledge about how China leverages these assets? What gaps in China's knowledge about the technology and innovation does China confront? For example, two knotty issues that emerged in Jane's discussions with experts were:

    - How can the U.S. inter-agency process deepen their grasp of the modalities of raising capital in Hong Kong or other capital markets for Chinese high-tech ventures?

    - How does China use venture capital firms to invest directly or indirectly in U.S. technology firms, especially those being invested in by DoD?

- **Opportunities and Approaches:** How does the United States anticipate and interdict/stop/slow core technology loss?

- **Implications:** How do technology acquisition strategies, many rooted in informal ethnic Chinese networks, affect regional inter-state competition in the Asia Pacific? Is there a high degree of dependence on it by China's defense industrial base and its broader S&T community?

Developing this system will require effective integration of traditional intelligence tradecraft, automation/machine learning, pattern detection software, and alternative analysis techniques designed to expand thinking and challenge assumptions about the U.S. – China competition.

A Comprehensive China Technology Assessment Process: One Australian expert engaged for this project was asked "what's missed about China's advanced weapons systems in DoD and related agencies assessment of these programs?" His response echoed a perception that both Australia and the United States still have persistent gaps in their knowledge about China and, particularly, the nature of its strengths and vulnerabilities, despite having a robust group of very knowledgeable

China experts assessing China and advising decision-makers on China policy. Without that deeper knowledge, the two allies cannot fully assess China's vulnerabilities and strengths. Most importantly, they do not know *how to exploit them.* "We suspect we are missing many weaknesses and therefore losing opportunities to exploit PRC vulnerabilities,"[929] said the expert.

One idea from the project's Implications Workshop addressed enhancing U.S. strategic understanding of China's technology acquisition effort, its competencies and possible implications of future investments for the U.S.-China military competition. The workshop recommendation urged mandating appropriate Defense and/or Intelligence Community agencies to run a comprehensive technology assessment process that would examine China's defense industrial base and broader S&T capability and assess the future of the technology acquisition competition.

Specifically, the process would seek to challenge assumptions about, expand thinking on and deepen understanding of:

- The nature and sensitivity of China's vulnerabilities and strengths relative to the United States (and U.S. allies and partners) with a particular focus on strengths and vulnerabilities that could accelerate or slow the pace of China's technology acquisition and development or change the nature of China's prioritized technology focus areas

- Identification of competitive asymmetries that could be exploited or need to be mitigated against

- The range of scenarios for the future of the technology and capability development competition unfolding across multiple domains, with a particular focus on identifying how new technologies and competitive strategies might introduce new competitive dynamics that could either benefit or challenge the capacity of the United States to pursue its interests in the Indo-Pacific and maintain technological, economic and military advantage

- Scenarios and strategies to be wargamed—to include a "red teaming" component—in order to better understand pressure points, consequences, risks, and opportunities inherent in various competitive strategies

- Recommendations to enhance competitive strategies for slowing China's advanced weapons systems, military modernization, technology acquisition and regional ambitions as well as hedging strategies to deal with disruptive developments

[929] Interview with Australian expert on China's advanced weapons systems, September 2017.