The Andrew W. Marshall Foundation

The Andrew W. Marshall Papers

The "AI RMA"

The Revolution Has Not Arrived (Yet)

OWEN J. DANIELS

Winner of the Inaugural Andrew W. Marshall Paper Prize on New Revolutions in Military Affairs

Foreword

What is the prospect for future revolutions in military affairs (RMAs), broadly defined? What are the implications for the national security and long-term competitions of the United States?

The notion of RMAs—periodic and dramatic changes in the way wars are fought—entered the public lexicon due in no small part to the work of Andrew Marshall. The beginning of his career, especially his time at the RAND Corporation at the outset of the Cold War, was defined by the advent of nuclear weapons. He spent more than two decades thinking through how these weapons revolutionized the character and conduct of both warfare and peacetime competition.

Over his subsequent four-decade career as director of the Office of Net Assessment in the Department of Defense, Marshall drew attention to another emerging revolution. Soviet military theoreticians believed rapid developments in microelectronics, significant qualitative improvements in conventional weapons, and the introduction of weapons systems based on new physical principles would soon lead to what they called a military-technical revolution (MTR). Inspired by their writing, Marshall dedicated years to examining the ways in which these technologies might bring about broader changes in the character of warfare. By the early 1990s, Marshall's office had completed an assessment of the MTR that confirmed the Soviet view that, "sooner or later, leading military powers will exploit available and emerging technologies, making major changes in the way they prepare and conduct operations in war, and realizing dramatic gains in military effectiveness."[i]

But technology was only part of the story for Marshall. Understanding how these revolutions came about and how they would unfold requires one to draw not only on technical fields but also on anthropology, economics, psychology, organizational theory, and other areas of inquiry. He read with interest histories of the European military revolution in the 17th century that suggested changes in organizational practices were at least as important as technology in driving that revolution. In his own assessment, Marshall wrote that "technology makes possible the revolution, but the revolution itself takes place only when new concepts of operation develop and, in many cases, new military organizations are created."[ii]

The "'AI RMA': The Revolution Has Not Arrived (Yet)," by Owen J. Daniels, the grand prize winner of the Andrew W. Marshall Paper Prize on New Revolutions in Military Affairs, is an outstanding, nuanced assessment of artificial intelligence and the extent to which it constitutes an RMA—or does not. It elaborates on the concept of an RMA and demonstrates understanding that an RMA is not solely a set of technological changes, but rather is something entirely more complex. We are proud to present this paper that begs us to temper our expectations, analyze carefully, and think critically about the technological-military competition between the United States and China.

The Andrew W. Marshall Foundation
October 2022

i. Office of the Secretary of Defense, "Assessment of the Military-Technical Revolution," July 15, 1992. Accessible via the George Washington University National Security Archive or in its republished form by the Center for Strategic and Budgetary Assessments (2002) at https://csbaonline.org/uploads/documents/2002.10.02-Military-Technical-Revolution.pdf.

ii. Andrew W. Marshall, "Some Thoughts on Military Revolutions – Second Version" (memorandum for record, August 23, 1993).

About the Author

Owen J. Daniels

Winner of the Andrew W. Marshall Paper Prize on New Revolutions in Military Affairs

Owen J. Daniels is a Policy Communications Specialist at Georgetown's Center for Security and Emerging Technology (CSET), shaping policy-relevant research across the organization's analytical portfolio and exploring emerging tech's defense implications in his writing. He sits on Young Professionals in Foreign Policy's global leadership team as Publications Fellow. Before CSET, he worked at the Institute for Defense Analyses' Joint Advanced Warfighting Division, researching AI and autonomous weapons norms and joint concepts. He has also worked in the Atlantic Council's Scowcroft Center and at Aviation Week. Owen majored in International Relations with minors in Arabic and Near Eastern Studies at Princeton University.

Table of Contents

List of Abbreviations

AI	Artificial intelligence
BUAER	U.S. Bureau of Aeronautics
C2	Command and control
CDAO	Chief Data and Artificial Intelligence Office
DARPA	Defense Advanced Research Projects Agency
DNN	Deep neural network
DOD	U.S. Department of Defense
IP	Intellectual property
ISR	Intelligence, reconnaissance, surveillance
JADC2	Joint All-Domain Command and Control
JAIC	Joint Artificial Intelligence Center
M&S	Modelling and simulation
MCF	Military–civil fusion
ML	Machine learning
ONA	Office of Net Assessment
PLA	People's Liberation Army
RMA	Revolution in military affairs
TEVV	Test, evaluation, verification, and validation

This paper examines the prospects for artificial intelligence (AI) applications initiating a new revolution in military affairs (RMA). It analyzes this issue by applying the lens of four RMA elements—technological change, military systems evolution, operational innovation, and organizational adaptation—to U.S. and Chinese military AI development. It finds that, in the near term, AI applications may be more likely to help fully realize the reconnaissance-strike RMA than to produce a new AI RMA altogether. However, understanding why AI has not yet sparked a new RMA can shape analysis of the potential trajectory of technological-military competition between the United States and China. The paper uses historical lessons from U.S.–Japanese interwar competition, which produced the carrier aviation RMA, to draw relevant insights for present day U.S.-China AI competition. It concludes by discussing potential frameworks for understanding a future AI RMA and areas for further study.

Introduction[1]

Geopolitical competition between the United States and China, two states with aspirations for global leadership but different visions for how to assert it, has emerged as a dominant characteristic of the international security environment. The countries hold fundamentally different perspectives on the nature of the global order, autocracy and democracy, human rights, and security flashpoints like Taiwan and islands in the South and East China Seas—disputes that carry broader implications for global norms.[2] China's economic strength and entanglement with the U.S. private sector distinguishes the current competition from challenges the United States faced during the Cold War. China, while seeking cooperation on certain pressing global issues like climate change,[3] views the United States as an obstacle to its rise to global hegemony; the United States sees China as a rising threat to the rules-based order established after World War II.[4] Official rhetoric on both sides increasingly reflects this, perhaps most notably in the 2018 U.S. National Security and National Defense Strategies, which identified China as a revisionist power and a competitor to the United States.[5]

Technological competition has emerged as an important overlay to these economic and security dynamics. Both countries aim to lead in developing and producing globally consumed, cutting-edge technologies and consumer products. China's technological pursuits match its global ambitions, and its government seeks to leverage centralized planning and its close relationships with major tech firms to spread its vision. The possibility that these firms' technological successes will be leveraged by China's military as part of China's military–civil fusion (MCF) policy, which looks to exploit advances in civilian and military technologies for mutual benefit, presents a growing concern for the U.S. defense establishment.

1 I would like to thank Clementine Starling, Dahlia Peterson, Emelia Probasco, Emily Weinstein, Jeff McKitrick, Joel Wuthnow, John Chen, Nathan Beauchamp-Mustafaga, Norah Bensahel, Samuel Klein, Thomas Greenwood, and Will Hunt for conversations on this topic in their respective areas of expertise. Any errors are my own.

2 Hal Brands and Michael Beckley, "China Is a Declining Power-and That's the Problem," Foreign Policy, September 24, 2021, https://foreignpolicy.com/2021/09/24/china-great-power-united-states/.

3 U.S. Department of State, "U.S.-China Joint Glasgow Declaration on Enhancing Climate Action in the 2020s," U.S. Department of State, November 10, 2021, https://www.state.gov/u-s-china-joint-glasgow-declaration-on-enhancing-climate-action-in-the-2020s/.

4 Benjamin Haas, "Xi Jinping Warns He Is Ready to 'Fight Bloody Battles' against China's Enemies," *The Guardian*, March 20, 2018, https://www.theguardian.com/world/2018/mar/20/xi-jinping-warns-fight-bloody-battles-chinas-enemies.

5 James Mattis, "Summary of the 2018 National Defense Strategy," U.S. Department of Defense, 2018, 2–5.

Artificial intelligence (AI) may be the most important area of U.S.-China tech competition. The United States and China are among many countries that see AI as potentially revolutionary in its civilian and military applications. AI attracts analogies to electricity in its ability to "enliven" machines, and some speculate that AI may spark longstanding societal changes akin to a new Industrial Revolution.[6] By 2021, 44 countries had released and were implementing national AI strategies;[7] however, the United States and China stand out as global leaders by several markers of success, including spending; academic publishing; granted patents and applications; and flourishing academic, private, and public sector AI research.[8] They are also key players in the semiconductor industry, where advances enable continued AI progress.

Most significantly for this paper, the United States and China are at the forefront of thinking about AI's military applications, which both see as potentially revolutionary. AI's transformative military potential is exciting but unassured. Its development trajectory is difficult to predict, historically prone to "winters" punctuated by rapid advances.[9] Yet some U.S. and Chinese analysts, strategists, and technologists believe it could fundamentally change the relationships between humans and machines, with effects on warfare ranging from limiting human involvement on the battlefield to destabilizing the calculus behind strategic nuclear deterrence.[10] Applications like computer vision, natural language processing, and recommender systems could help achieve strategic objectives by offering novel solutions to operational challenges in command and control, intelligence collection and aggregation, autonomy, and decision support.[11]

U.S. and Chinese national AI strategies accordingly acknowledge the importance of remaining at the leading edge of development.[12] The 2018 Department of Defense Artificial Intelligence Strategy posited AI is "poised to change the character of the future battlefield and the pace of threats we must face. We will harness the potential of AI to transform all functions of the Department positively."[13] Prioritizing AI lies at the heart of China's military modernization efforts.[14] Lt. Gen. Liu Guozhi, director of China's Central Military Commission for Science and Technology Commission, declared, "AI will accelerate the process of military transformation, ultimately leading to a profound Revolution in Military Affairs… The combination of artificial intelligence and human intelligence can achieve the optimum, and human-machine hybrid intelligence will be the highest form of future intelligence."[15] China's 2019 De-

6 Kevin Kelly, "The Three Breakthroughs that Have Finally Unleashed AI on the World," Wired, October 27, 2014, https://www.wired.com/2014/10/ future-of-artificial-intelligence/; Matthew Daniels and Ben Chang, *National Power After AI* (Washington, DC: Center for Security and Emerging Technology, 2021), iv.

7 Samar Fatima et al., "Winners and Losers in the Fulfillment of National Artificial Intelligence Aspirations," Brookings Institution, October 21, 2021, https://www.brookings.edu/blog/techtank/2021/10/21/winners-and-losers-in-the-fulfilment-of-national-artificial-intelligence-aspirations/.

8 Sachin Waikar, "AI Report: Competition Grows between China and the U.S.," Stanford HAI, March 3, 2021, https://hai.stanford.edu/news/ai-report-competition-grows-between-china-and-us; Neil Savage, "The Race to the Top among the World's Leaders in Artificial Intelligence," Nature News, December 9, 2020, https://www.nature.com/articles/d41586-020-03409-8; Autumn Toney and Melissa Flagg, *Comparing the United States' and China's Leading Roles in the Landscape of Science* (Washington, DC: Center for Security and Emerging Technology, June 2021): 1–12.

9 Marc Losito and John Anderson, "The Department of Defense's Looming AI Winter," War on the Rocks, May 10, 2021, https://warontherocks.com/2021/05/the-department-of-defenses-looming-ai-winter/.

10 Rafael Loss and Joseph Johnson, "Will Artificial Intelligence Imperil Nuclear Deterrence?", War on the Rocks, September 2019, https://warontherocks.com/2019/09/will-artificial-intelligence-imperil-nuclear-deterrence/.

11 Paul Scharre, "Debunking the AI Arms Race Theory," *Texas National Security Review* 4, no. 3 (Summer 2021): 123.

12 Gregory Allen, *Understanding China's AI Strategy* (Washington, DC: Center for a New American Security, February 6, 2019), https://www.cnas.org/publications/reports/understanding-chinas-ai-strategy.

13 U.S. Department of Defense, *Summary of the 2018 Department of Defense Artificial Intelligence Strategy* (Washington, DC: U.S. Department of Defense, February 2019), 4.

14 Dewey Murdick et al., *The Public AI Research Portfolio of China's Security Forces: A High-Level Analysis* (Washington, DC: Center for Security and Emerging Technology, March 2021): 3.

15 Elsa Kania, "Minds at War: China's Pursuit of Military Advantage through Cognitive Science and Biotechnology," *Prism* 8, No. 3 (January

"The RMA framework can help sidestep hyperbolic speculation about AI's potential and ground analysis in its effects on systems, operations, and organizations."

fense White Paper referenced AI as a critical component of the "Revolution in Military Affairs (RMA) with Chinese characteristics."[16]

But does AI truly augur a revolution in military affairs (RMA), and why does it matter? The RMA concept, whose elements include technological change, military systems evolution, operational innovation, and organizational adaptation, is a natural lens for assessing whether AI could transform the nature of warfare, given that AI's value currently lies in narrow applications.[17] RMAs may be driven by technology, but an RMA does not arise unless specific technological applications spur changes to operations and organizations that fuel military advancement. As Andrew W. Marshall, the former director of the Office of Net Assessment (ONA) who developed the intellectual concept of the RMA from the U.S. perspective, put it, "The main challenge in the RMA is an intellectual and not a technological one."[18] The RMA framework can help sidestep hyperbolic speculation about AI's potential and ground analysis in its effects on systems, operations, and organizations.

If AI is driving an RMA in either the U.S. or Chinese militaries, a combination of new technology and concepts could threaten either force's dominant way of operations. If it is not, understanding why and how it might in the future can help observers identify markers of progress and intellectual developments, such as combinations of military AI applications and new tactics and organizational structures that might make an AI RMA more likely to occur. Assessing whether AI might spark an RMA could therefore inform how the United States considers and shapes future strategic competition with China.

This paper's methodological approach uses the four elements of RMAs, identified in Andrew Krepinevich's seminal 1992 paper, as a lens for assessing AI as a revolutionary military technology. It defines RMAs for the purposes of the paper before examining AI applications; the degree to which they are sparking changes in U.S. and Chinese military systems, operations, and organizations; and the nature of that change. Drawing on interviews, scholarship, analysis, official documents, reporting, and historical examples, it finds that AI is not currently precipitating an RMA. The present state of AI technologies limits military applications, making it difficult for operational innovation and organizational adaptation to occur.

However, if the state of technology advances and the United States and China can more effectively grapple with the intellectual challenges of operational innovation and organizational adaptation, a medium- to long-term AI RMA appears more likely to emerge. Past RMAs, in particular the carrier aviation RMA that emerged from U.S.–Japan competition in the interwar period and World War II, offer insights for developments in U.S.–China competition that might contribute to or result in an AI RMA. The paper examines these insights and concludes by discussing frameworks for understanding a future AI RMA and areas for further study.

2020): 84.

16 Andrew S. Erickson, "Full Text of 2019 Defense White Paper: 'China's National Defense in the New Era' (English & Chinese Versions)," Andrew S. Erickson, July 24, 2019, https://www.andrewerickson.com/2019/07/full-text-of-defense-white-paper-chinas-national-defense-in-the-new-era-english-chinese-versions/.

17 Andrew Krepinevich, *The Military-Technical Revolution: A Preliminary Assessment* (Washington, DC: Center for Strategic and Budgetary Assessments, 2002), 3.

18 Dima Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the U.S., and Israel* (Stanford, CA: Stanford University Press, 2010), 2.

Defining and Identifying Revolutions in Military Affairs

To provide a framework for assessing whether AI is presently driving a new RMA, this section briefly defines and analyzes RMAs and contextualizes their unique characteristics amid military innovations. It identifies four key elements of RMAs that will provide the basis for subsequent assessment and analysis, as well as tools and methods for recognizing revolutionary developments.

Establishing Terms

An RMA "is a combination of new military organizational goals and structures with new operational practices on the battlefield that are sometimes but not always driven by new technologies."[19] Krepinevich, who worked at ONA to understand the framework with Marshall, noted that RMAs are typically composed of four elements: technological change, military systems evolution, operational innovation, and organizational adaptation.[20] An RMA is revolutionary not in the speed with which it occurs but rather in its impact on the nature of warfare. Its defining characteristic is its fundamental discontinuity from the previously dominant means and patterns of military operations, which the RMA renders obsolete.[21] RMAs can obviate one or more of the core competencies of a dominant military, create new core competencies in some domain for a military actor, or both. Hundley noted that combinations of technologies often precipitate RMAs; they do not always involve weapons; and changes to technology, systems, operations, and organization often occur simultaneously.[22]

While RMAs have usually been associated with system advances, such as tanks, aircraft carriers, nuclear weapons, and reconnaissance-strike complexes, technology alone cannot constitute an RMA. According to Marshall, "Innovations in technology make a military revolution possible, but the revolution itself takes place only when new concepts of operation develop and, in many cases, new military organizations are created."[23] Military organizations must also adopt new concepts and structures that serve novel military goals and create non-incremental advantages over opponents who are still operating in a previously dominant style.[24] If a technology does not help overturn a dominant military's core competency or create new core competencies, it cannot be part of an RMA.[25] That said, Carafano pointed out that it is difficult to imagine a future discontinuity in the nature of warfare without a major technological precursor.[26]

19 Michael Horowitz and Stephen Rosen, "Evolution or Revolution?" *Journal of Strategic Studies* 28, no. 3 (2007): 441.

20 Krepinevich, *Military-Technical Revolution*, 3.

21 Michael Vickers and Robert Martinage, *The Revolution in War* (Washington, DC: Center for Strategic and Budgetary Assessments, 2004), 2.

22 Richard Hundley, *Past Revolutions, Future Transformations: What Can the History of Revolutions in Military Affairs Tell Us About Transforming the U.S. Military?* (Santa Monica, CA: RAND Corporation, 1999), 9–17.

23 From a statement to the Senate Subcommittee on Acquisition and Technology. Andrew W. Marshall, "RMA Update," Memorandum, U.S. Department of Defense (Unpublished Collection, 1994), 4, cited in Thomas Skypek, "Evaluating Military Balances through the Lens of Net Assessment: History and Application," *Journal of Military and Strategic Studies* 12, no. 2 (2010): 19.

24 Horowitz and Rosen, "Evolution or Revolution?," 441.

25 Hundley, *Past Revolutions, Future Transformations*, 9–17.

26 James Carafano, "Carafano on Knox and Murray, 'The Dynamics of Military Revolution, 1300–2050'," H-Diplo, H-Net: Humanities & Social Sciences Online, 2002, 4, https://networks.h-net.org/node/28443/reviews/30214/carafano-knox-and-murray-dynamics-military-revolution-1300-2050.

RMAs can take many years to mature. They are often peacetime innovations that have benefitted from ample time and resources for theorization, concept development, and experimentation that peace offers.[27] However, they may require competition to be fully realized. For example, in 2009 Marshall felt that the United States had not advanced far in the reconnaissance-strike RMA. Drawing an analogy with the interwar period, he felt the U.S. military had not yet reached 1930 in its realization of that RMA because neither Desert Storm nor operations in Iraq and Afghanistan against weaker conventional opponents and insurgents had forced it to couple military systems advances with operational changes. Without facing a stronger conventional competitor, concepts and structures had not evolved and therefore the RMA's maturity was unknowable.[28] Peacetime development also means that a new RMA's enabling technologies may be greeted with skepticism, particularly by experts, until their effectiveness is demonstrated in combat.[29]

Cultural Influence

Defense establishments' abilities to cultivate, adopt, and realize an RMA vary. Adeptness at integrating and exploiting enabling technologies can differ across countries or even within a single military and can be highly dependent on cultural factors. RMAs are the products of technological, systems, operational, and structural changes, so culture can offer insight into a military's willingness to incorporate innovation and its methods of doing so. As such, countries that develop analogous technological capabilities can use them in dramatically different ways.[30] Several cultural characteristics may make militaries more likely to realize RMAs. Unmet military challenges can spark motivation and creativity, and organizational and leadership climates receptive to innovation and change are important. Experimentation in a single technical–operational area or a short list of them can provide focus. Organizational willingness and ability to use experimental results to shape concept development, doctrine, acquisition, and force structure are key.[31]

For example, cultural differences in the Soviet and American defense establishments informed their ability to realize the emerging reconnaissance-strike RMA in the 1980s. After studying the effective performance of Soviet integrated air defense systems in the Vietnam and Yom Kippur Wars, as well as antitank and other new Soviet capabilities that increased the lethality of land and air environments, the U.S. military recognized the need to develop qualitatively superior technologies that could help offset conventional Soviet advantages without massive attrition to air or ground forces. Standoff precision-strike capabilities that integrated target detection, recognition, and location with long-range guidance, navigation, and stealth emerged as promising nonnuclear solutions to this specific challenge.[32] Combining technological innovations in these areas with operational and organizational innovations for dominating maneuver through deep attack like AirLand Battle helped usher in the current reconnaissance-strike RMA, most notably during the Gulf War.[33] Adamsky contended that while the Americans solved the technological challenge of the RMA by developing precision weapons more quickly, they were slower to realize the intellec-

27 The nuclear RMA is a notable exception. James FitzSimonds and Jan M. Van Tol, "Revolutions in Military Affairs," *Joint Force Quarterly* 4 (1994): 26–27.

28 Barry Watts, *The Maturing Revolution in Military Affairs* (Washington, DC: Center for Strategic and Budgetary Assessments, 2011): 5–7.

29 Hundley, *Past Revolutions, Future Transformations*, 9–17.

30 Adamsky, *Culture of Military Innovation*, 5.

31 Hundley, *Past Revolutions, Future Transformations*, 59–73.

32 Joseph S. Doyle, *The Yom Kippur War and the Shaping of the United States Air Force*, The Drew Papers, no. 31, (Maxwell AFB, AL: Air University Press, 2019): 7–13, 27–33; Richard H. Van Atta et al., *Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs Volume 1—Overall Assessment*, IDA Paper P-3698 (Alexandria, VA: Institute for Defense Analyses, 2003), 6–17.

33 Michael L. Brown and Tammy M. Furrow, *"Revolution in Military Affairs Conference" Report on Conference Conducted at The Strategic Assessment Center*, November 12-13, 1996, (McLean, VA: Science Applications International Corporation, 2017), 17–19; Frederick Kagan, "Army Doctrine and Modern War: Notes Toward a New Edition of FM 100-5," *Parameters* 27, no. 1 (1997), https://doi.org/10.55540/0031-1723.1816.

tual side of the RMA given that conceptual and organizational innovations tended to develop bottom-up from the services rather than jointly from above. Conversely, the Soviet General Staff's culture of centralized military intellectualization at the operational level of war helped it accurately assess the discontinuous threat of the U.S. military-technical revolution for Soviet numerical superiority and force echelonment; yet the lack of a technological problem-solving culture left them unable to realize the RMA's technological side.[34]

Recognizing Emerging RMAs

Having identified RMAs' characteristics and the cultural factors that can influence how militaries realize them, this section turns to the challenge of recognizing one in the present. Generally, it is easier to recognize the complex interactions of RMA elements in hindsight, but exploring historical parallels and present trends may uncover developing RMAs. Historical studies offer examples of observable measures, including changes to force employments, territorial scope, and time to attack.[35]

Present-day observable factors include reporting, official statements, and new technological research. Technologies that could enable RMAs probably will attract press coverage. Dominant militaries may attempt to publicly discredit advances that challenge their superiority; less-dominant militaries may embrace innovation that threatens the existing order. Military research and development patterns and new operating concepts, doctrine, or experimentation could also suggest a new RMA.[36] Competitive asymmetries between adversaries and their respective concepts, doctrine, decision-making cultures, and philosophies of warfare might uncover areas for emerging RMAs.[37] Finally, because many potential RMAs fail, it is important to carefully assess a potential RMA's viability – acknowledge limitations of less likely scenarios while keeping an open mind. It is better to include a few seemingly far-fetched options than to be caught by surprise.[38]

If AI development in the United States or China is driving an RMA, one would expect that progress in AI technological applications would generate evolution in military systems, sparking operational innovations and organizational adaptations that challenge today's dominant warfare paradigms. Using the definitions and analytical methods described in this section, the next section examines AI's military impact through Krepinevich's four RMA elements and assesses whether an AI-driven revolution in military affairs is beginning.

34 Adamsky, *Culture of Military Innovation*, 79–90, 28–39.

35 Horowitz and Rosen, "Evolution or Revolution?," 441.

36 Hundley, *Past Revolutions, Future Transformations*, 37–39.

37 Eliot Cohen, *Net Assessment: An American Approach*, JCSS Memorandum 29 (Tel Aviv: Jaffee Center for Strategic Studies, 1990): 15–18.

38 Hundley, *Past Revolutions, Future Transformations*, 40–42.

Analyzing AI through the Lens of RMA Elements

Technological Change

Technical progress in specific AI techniques has been rapid and impressive over the past decade. Applications of AI techniques in areas like computer vision, natural language processing, and recommender systems have allowed machines to excel over humans at certain tasks, which has sparked creative thinking about military applications in the United States and China. However, AI applications presently have significant shortcomings that are likely to limit their battlefield usefulness for the foreseeable future. Additionally, consistent rapid progress is not assured: The history of AI is punctuated with winters of slow development, and some factors, like semiconductor access, could inhibit U.S. and Chinese advances. This section provides broad technological context about AI and its applications, recent advances, their strengths, and the significant near-term obstacles to enabling an AI RMA.

Technological background and relevant applications. Simply defining artificial intelligence can be challenging, given rapid technological and conceptual changes throughout the technology's history, its different and evolving subcategories and applications, and disagreements among experts.[39] For the purposes of this paper, *artificial intelligence* broadly refers to a constellation of technologies that enable computer systems to perform tasks that require human intelligence.[40] While AI has historically incorporated a range of decision-making systems, such as expert systems, the term's use in aspirational discussions about groundbreaking capabilities denotes machine learning (ML) systems that use computing power to complete tasks by executing data-driven algorithms. Algorithms, data, and computing power (collectively and hereafter, *compute*) are central components to advanced ML.[41]

Advances in these three elements have driven recent dramatic progress in AI, and they are accordingly valuable—and expensive. Experts, usually with advanced degrees, create cutting-edge algorithms. Ideally, these algorithms train on high-quality datasets that are sufficiently representative of a given problem set to increase algorithmic precision and robustness while limiting bias. Semiconductor manufacturing advances and chips optimized for ML have helped fuel AI breakthroughs by boosting compute: from 2012 to 2018, the compute used to train top AI projects increased by a factor of 300,000.[42]

Neural networks trained through deep-learning techniques are responsible for many recent strides in AI. Inspired by human neuron communication, neural nets are collections of algorithms with input, hidden, and output node layers. Weightings and thresholds assigned to different nodes in each layer help the model process data to achieve an objective, such as uncovering patterns or recognizing images.[43] Humans can train networks by providing feedback on

39 Dewey Murdick, James Dunham, and Jennifer Melot, *AI Definitions Affect Policymaking* (Washington, DC: Center for Security and Emerging Technology, June 2020): 3.

40 National Security Commission on Artificial Intelligence, *Final Report* (Washington, DC: National Security Commission on Artificial Intelligence, 2021), 20, 31.

41 Ben Buchanan, *The AI Triad and What It Means for National Security Strategy* (Washington, DC: Center for Security and Emerging Technology, August 2020), v–2.

42 This is partially due to increased willingness to fund these expensive breakthroughs. Ibid., 1–9.

43 IBM, "What Are Neural Networks?," IBM, August 17, 2020, https://www.ibm.com/cloud/learn/neural-networks.

their performances and fine tune models by calibrating weights in a generic model for specific tasks.[44] Deep neural nets (DNNs), which contain over three layers, have sparked strides in computer vision and language processing and can greatly outperform humans in many narrow applications like discerning insights from huge datasets.[45] However, DNNs, like brains, contain thousands of interconnected nodes whose interactions are highly complex and often impossible to meaningfully summarize. This limits the predictability and explainability of their outputs and thus their trustworthiness for sensitive tasks.[46]

ML advances like DNNs entered the public consciousness most notably in 2016, when the U.S. company DeepMind's AlphaGo system defeated the world's top-ranked human player at the Chinese strategy game Go.[47] AlphaGo developed strategies and moves that were unpredictable and incomprehensible to human players, hinting at ML's burgeoning potential to outperform humans at some tasks.[48] Its 2016 victory was widely cited as a Sputnik moment for China, one that resonated particularly deeply given the game's cultural significance and precipitated strategic concern and massive investment in AI research.[49]

Over a half-decade later, the United States and China see AI applications' civil and military potential as revolutionary, particularly in computer vision, natural language processing, big data analytics, and recommender systems. Increased computing power and reduced training times have sparked significant recent progress in *computer vision*, the ability of systems to detect, process, and recognize aspects of their environments.[50] Civil applications include medical imaging, real-time object detection to pick out significant details in complex environments, and social media image trawling.[51] Military applications include autonomous navigation, image-based intelligence collection and analysis, identifying individuals through facial or gait recognition, and target identification, among others.

Natural language processing models understand human language to perform tasks. Popularized by search engines and virtual assistants like Apple's Siri and Amazon's Alexa, models read existing texts to learn how words are used in context and subsequently "learn" to respond to open-ended queries, generate predictive text, translate, and perform chatbot functions.[52] Militaries may use this technology to scan collections of documents for specific information, translate foreign intelligence, or even generate textual disinformation.[53]

44 Since this is not a technical paper, this description of neural nets does not delve more deeply into different types (e.g., convolutional, feed forward, or recurrent neural nets) or the intricacies of supervised versus unsupervised learning. While these distinctions deserve attention, they are not necessary for linking technological applications to broader discussions of the relationships among technology, military AI applications, and RMAs.

45 Amy Webb, *The Big Nine: How the Tech Titans and Their Thinking Machines Could Warp Humanity* (New York: PublicAffairs, 2019), 40–50.

46 Recent research has made some progress on this black box problem by using methods that interpret what certain computer vision DNNs analyze in a given image, but easy explainability and transparency remain far off. Chris Olah et al., *The Building Blocks of Interpretability*, Distill, March 26, 2018, https://distill.pub/2018/building-blocks/.

47 "Google AI Defeats Human Go Champion," *BBC News*, May 25, 2017, https://www.bbc.com/news/technology-40042581. Experts had previously believed an AI would not be capable of beating a human at Go for one or two decades given the game's complexity, which features many possible moves and is comparatively unstructured. See Webb, *Big Nine*, 40–50.

48 Ibid., 48.

49 Ibid.

50 Michael Littman et al., Gathering Strength, *Gathering Storms: The One Hundred Year Study on Artificial Intelligence* (AI100) 2021 Study Panel Report (Stanford, CA: Stanford University, September 2021), https://ai100.stanford.edu/2021-report/standing-questions-and-responses/sq2-what-are-most-important-advances-ai#recommendation.

51 Ken Weiner, "Council Post: Computer Vision Is More than Just Image Recognition," *Forbes*, August 12, 2016, https://www.forbes.com/sites/forbestechcouncil/2016/08/12/computer-vision-is-more-than-just-image-recognition/?sh=4c8ddb816065.

52 IBM, "What Are Neural Networks?"

53 Ryan Fedasiuk, Jennifer Melot, and Ben Murphy, *Harnessed Lightning: How the Chinese Military is Adopting Artificial Intelligence* (Washington, DC: Center for Security and Emerging Technology, 2021), 9; 18–19.

AI also appears promising for decision support. Often fueled by big datasets—structured and unstructured data from amalgamated sources—decision-support algorithms can uncover insights that would be difficult or even impossible for humans to glean.[54] In keeping with their name, recommender systems offer decision support from aggregated data insights and user preferences. Spotify famously uses such algorithms to create playlists and suggest new music for users based on past listening behavior and community data.[55] Militaries see potential for decision support in fusing, analyzing, and deconflicting multisource sensor data from the battlefield and optimizing complicated logistics or maintenance operations.[56]

These are but a few recent promising AI advances that have military applications (others will be covered later in this section). However, enthusiasm about these applications must be tempered by an understanding of their current significant shortcomings.

Technological shortcomings. DNNs can be brittle outside of their training environments, meaning that small modifications to familiar inputs can lead to incorrect outputs. These issues can be exploited by adversaries. For example, researchers were able to thwart a state-of-the-art DNN image classifier from reading stop signs simply by placing black and white stickers on them.[57] Other researchers found that randomly distorting an image of a panda in a way that was imperceptible to humans caused a model to label the image a gibbon with over 99% accuracy.[58] Since models do not see the world as humans do and hidden layers are not transparent, humans can at best interpret why a model produces a certain output.[59] This makes validating a model's future performance on new data difficult, even with accurate past performance. Achieving trust and testing and evaluating systems for military purposes are therefore major weaknesses that could limit DNNs' near-term effectiveness in highly complex, dynamic combat environments.[60]

DNN datasets and training also can be costly and difficult, requiring high levels of compute or significant human effort to compile and label data. Even broadly representative training data may not eliminate issues with transitions to real-world applications.[61] Accessing usable data may be a problem: a U.S. Army initiative to leverage big data for predictive maintenance found that historical data was handwritten and not machine readable.[62] Adversaries can poison data in both training and real world environments.[63] Furthermore, datasets cultivated by humans can unintentionally incorporate their biases, raising deep ethical concerns about equity, algorithmic justice, and accuracy.[64]

54 Jason Miller, The Big Data Challenge Getting Smaller for Army, Air Force as CDOs Mature, Federal News Network, January 24, 2020, https://federalnewsnetwork.com/ask-the-cio/2020/01/the-big-data-challenge-getting-smaller-for-army-air-force-as-cdos-mature/.

55 Priya Dialani, "Tech for Enjoying Music: Here's How Spotify Uses Big Data," Analytics Insight, April 19, 2021, https://www.analyticsinsight.net/tech-for-enjoying-music-heres-how-spotify-uses-big-data/.

56 Altwan Whitfield and Mike Crozier, "Sustainment Transformation: How Joint Artificial Intelligence Center Supports Army Logistics: An Interview with Mr. Nand Mulchandani," U.S. Army, December 16, 2021, https://www.army.mil/article/252657/sustainment_transformation_how_joint_artificial_intelligence_center_supports_army_logistics_an_interview_with_mr_nand_mulchandani.

57 Kevin Eykholt et al., "Robust Physical-World Attacks on Deep Learning Models," arXiv.org, April 10, 2018, https://arxiv.org/abs/1707.08945.

58 Robert Richbourg, "'It's Either a Panda or a Gibbon': AI Winters and the Limits of Deep Learning," War on the Rocks, May 10, 2018, https://warontherocks.com/2018/05/its-either-a-panda-or-a-gibbon-ai-winters-and-the-limits-of-deep-learning/.

59 Olah et al., *Building Blocks of Interpretability.*

60 Joshua Kroll, "Artificial Intelligence: Too Fragile to Fight?," U.S. Naval Institute, February 2022, https://www.usni.org/magazines/proceedings/2022/february/artificial-intelligence-too-fragile-fight?mc_cid=31b7a8c6db&mc_eid=cb69914e13.

61 Ben Dickson, "The Future of Deep Learning, According to Its Pioneers," VentureBeat, July 5, 2021, https://venturebeat.com/2021/07/05/the-future-of-deep-learning-according-to-its-pioneers/.

62 Whitfield and Crozier, "Sustainment Transformation."

63 Patrick Tucker, "Vulnerabilities May Slow Air Force's Adoption of Artificial Intelligence," Defense One, September 23, 2021, https://www.defenseone.com/threats/2021/09/vulnerabilities-may-slow-air-forces-adoption-artificial-intelligence/185592/.

64 Center for Naval Analyses, *AI Considerations for the Marine Corps,* (Arlington, VA: Center for Naval Analyses, 2021), 3.

"Battlefield problems posed by competitors are challenging enough for warfighters without introducing the complexity of immature algorithmic tools that perform best in constrained environments."

On top of these challenges, integrating teams of humans and machines is complicated and potentially dangerous. Battlefield problems posed by competitors are challenging enough for warfighters without introducing the complexity of immature algorithmic tools that perform best in constrained environments.[65] AI systems' decision-making speeds compared to humans, coupled with explainability challenges, could create scenarios where humans default to system judgment, which is called *automation bias*. This creates escalation risks if AI-enabled actions are uninterpretable by adversaries.[66] A 2020 RAND Corporation wargame found that rapid machine decision-making speeds contributed to quicker escalation, weaker deterrence, and decreased responses to de-escalatory signals, concluding: "Widespread AI and autonomous systems could lead to inadvertent escalation and crisis instability."[67]

U.S. and Chinese access to AI. In addition to the technological shortcomings discussed above, the respective abilities of the United States and China to access cutting-edge AI advances over the long term are not necessarily assured. This could threaten whether either country can realize an AI RMA. Securing access to talent, materials, and funding to advance military AI development will be necessary to sustain technological evolution, and each country navigates this challenge while carrying particular strengths and weaknesses.

U.S. advances in AI are largely driven by a flourishing private technology sector and academic research rather than by centralized government efforts. Mature U.S. tech hubs attract global firms and talent and create innovation ecosystems where they do not face the same legal pressures to transfer technology to the government as in China.[68] Yet relationships between the U.S. government and some tech companies, particularly those initiated by the Department of Defense (DoD), have been slow moving and occasionally mistrustful.[69] The DoD cannot shape private sector research priorities or access data held by private firms in the same ways China's authoritarian government can.[70] It has explored innovative ways to acquire technology, interacting more closely with Silicon Valley firms in addition to its traditional innovation hubs like the Defense Advanced Research Project Agency (DARPA), but DoD still struggles to fit firms into rigid defense procurement processes and to scale technological advancements.[71] The decentralized nature of U.S. AI innovation is mirrored by its national approach to AI education and training, which lacks a cohesive national vision or standards. While decentralization allows space for innovation in different educational programs, evaluating and scaling diverse efforts could prove difficult. The United States has struggled

65 Owen Daniels, "Speeding Up the OODA Loop with AI: A Helpful or Limiting Framework?," NATO Joint Air and Space Power Competency Centre, September 2021, https://www.japcc.org/speeding-up-the-ooda-loop-with-ai/.

66 Kroll, "Artificial Intelligence."

67 Yuna Wong et al., *Deterrence in the Age of Thinking Machines* (Santa Monica, CA: RAND Corporation, 2020), 44–58.

68 Peter Engelke and Robert A. Manning, *Keeping America's Innovative Edge: A Strategic Framework* (Washington, DC: Atlantic Council, April 2017), 13–20.

69 Billy Mitchell, "Google's Departure from Project Maven Was a 'Little Bit of a Canary in a Coal Mine'," FedScoop, November 5, 2019, https://www.fedscoop.com/google-project-maven-canary-coal-mine/; Richard P. Appelbaum et al., *Innovation in China: Challenging the Global Science and Technology System* (Cambridge: Polity Press, 2018).

70 Mitchell; Tom Upchurch, "How China Could Beat the West in the Deadly Race for AI Weapons," WIRED UK, August 8, 2018, https://www.wired.co.uk/article/artificial-intelligence-weapons-warfare-project-maven-google-china.

71 The Defense Innovation Unit (DIU) is one example of an office. Jon Harper, "Silicon Valley Takes on the 'Valley of Death,'" *National Defense Magazine*, January 26, 2022, https://www.nationaldefensemagazine.org/articles/2022/1/26/silicon-valley-takes-on-the-valley-of-death.

to develop domestic STEM talent, though it has enjoyed an advantage in attracting and retaining foreign talent at its higher education institutions, including from China.[72]

By contrast, China aims to highly centralize military AI procurement through its military–civil fusion strategy of exploiting dual-use technological advances. In 2017, Xi Jinping stated MCF's goal was ensuring "efforts to make our country prosperous and efforts to make our military strong go hand in hand."[73] China's New Generation Artificial Intelligence Development Plan invoked MCF to develop new AI for "command and decision-making, military deduction, defense equipment, and other applications."[74] The state views AI self-sufficiency as important to military modernization and as a shield against disruptions to foreign tech transfers.[75] To capitalize on innovations inside and out of the armed services, the Central Military Commission and People's Liberation Army (PLA) branches have even hosted public AI challenges to solve joint military problems.[76] Government-linked industry alliances among AI firms, which emulate the strengths of similar U.S., European, and Japanese programs, have also been tied to MCF.[77] However, MCF and China's reputation for intellectual property (IP) theft, government tech transfer pressures, and defiance of international norms can deter some foreign firms and lead some governments to impose sanctions on PLA-affiliated companies.[78]

That said, the Chinese tech sector has started to take on the characteristics of other advanced technological ecosystems. China hosts some of the world's largest AI firms, which work on cutting-edge applications, and is developing a more robust domestic patenting system and public-private investment funds.[79] Its science, technology, engineering, and mathematics (STEM) education growth rapidly outpaces the United States', suggesting it could enjoy a

72 Dahlia Peterson, Kayla Goode, and Diana Gehlhaus, *AI Education in China and the United States* (Washington, DC: Center for Security and Emerging Technology, September 2021), 38–40.

73 Xi made this point about MCF at the Nineteenth National Congress of the Communist Party of China in October 2017. Peter Wood and Robert Steward, *China's Aviation Industry: Lumbering Forward* (Montgomery, AL: China Aerospace Studies Institute, August 2019), 53–54.

74 Graham Webster et al., "Full Translation: China's 'New Generation Artificial Intelligence Development Plan' (2017)," New America, August 1, 2017, https://www.newamerica.org/cybersecurity-initiative/digichina/blog/full-translation-chinas-new-generation-artificial-intelligence-development-plan-2017/.

75 Ryan Fedasiuk, Emily Weinstein, and Anna Puglisi, *China's Foreign Technology Wish List*, CSET Issue Brief (Washington, DC: Center for Security and Emerging Technology, May 2021), 29; Eric Martin, "U.S. Blacklists Seven Chinese Supercomputing Firms," Bloomberg.com, April 9, 2021), https://www.bloomberg.com/news/articles/2021-04-08/u-s-adds-seven-chinese-supercomputing-firms-to-export-ban-list; Sebastian Moss, "TSMC Stops Supplying Chinese Supercomputing Company Phytium with New Chips," Data Center Dynamics, April 14, 2021, https://www.datacenterdynamics.com/en/news/tsmc-stops-supplying-chinese-supercomputing-company-phytium-with-new-chips/.

76 Sporting names like "Stratagem at Heart, Jointness to Win," "Intelligent Rocket and Fire Eyes," and "Unmanned Dominance," the competitions look to exploit AI advances in different scenarios, including a "joint island strike" emulating an attack on Taiwan. Marcus Clay, "The PLA's AI Competitions," The Diplomat, November 5, 2020. https://thediplomat.com/2020/11/the-plas-ai-competitions/.

77 Ngor Luong and Zachary Arnold, *China's Artificial Intelligence Industry Alliance* (Washington, DC: Center for Security and Emerging Technology, May 2021), 3–4.

78 Alex Rubin et al., *The Huawei Moment* (Washington, DC: Center for Security and Emerging Technology, May 2021), 39; Thomas Oriti, "China Is Still Stealing Intellectual Property—But that's not the Biggest Problem," ABC News, September 25, 2018, https://www.abc.net.au/news/2018-09-26/china-is-after-intellectual-property-not-always-illegally/10302424; NPR, "China and Intellectual Property," NPR, April 7, 2018, https://www.npr.org/2018/04/07/600482782/china-and-intellectual-property; Fedasiuk, Weinstein, and Puglisi, *China's Foreign Technology Wish List*, 2-10.

79 Shashank Jacob, "Chinese AI Research and Business Is Booming, but America Is Still King," Yahoo!, October 12, 2021, https://www.yahoo.com/video/chinese-ai-research-business-booming-135519057.html; Patrick Thomas and Dewey Murdick, "Patents and Artificial Intelligence" (Washington, DC: CSET Data Brief, September 2020), 12. See also: People's Republic of China Ministry of Education, China National Intellectual Property Administration, and People's Republic of China Ministry of Science and Technology, "Certain Opinions of the Ministry of Education, the China National Intellectual Property Administration, and the Ministry of Science and Technology on Improving the Quality of Patents at Institutes of Higher Education and Promoting [Patent] Conversion and Use," Center for Security and Emerging Technology, https://cset.georgetown.edu/wp-content/uploads/t0271_no_univ_patent_subsidies_EN.pdf; While the effectiveness of such funds appears unevenly distributed, they had still raised over 4.76 trillion yuan ($672 billion) by the first quarter of 2020. Ngor Luong, Zachary Arnold, and Ben Murphy, *Chinese Government Guidance Funds* (Washington, DC: Center for Security and Emerging Technology, March 2021), 3–9.

robust, competitive future talent pipeline; China will likely graduate nearly double the number of U.S. STEM PhDs by 2025.[80] Tracking programs like the Thousand Talents Plan aggressively recruit talent from academia in China and abroad.[81] Nonetheless, China struggles to attract foreign talent and is largely domestically reliant.[82]

Semiconductor access could affect both U.S. and Chinese pursuits of cutting-edge AI. The United States and its partners in leading-edge semiconductor supply chains maintain a collective edge over China in producing and controlling IP, design software, advanced semiconductor manufacturing equipment (SME), and leading-logic chip exports.[83] However, physical production of nearly all cutting-edge AI chips is located in Taiwan and South Korea, leaving U.S. access vulnerable to East Asian supply disruptions.[84] Meanwhile, though China will likely become the world's largest chipmaker by 2030, it remains a decade behind leading-edge AI chip production and largely depends on foreign imports for the most advanced chips.[85] The United States and its partners could feasibly block advanced chip and SME exports to PLA-affiliated firms.[86] China's future access to advanced semiconductors for military applications could therefore hinge on its efforts to indigenize its supply chain and SME development.[87]

In sum, an AI RMA would probably require significantly more robust and reliable technological capabilities at its foundation. In addition, the United States and China will need to maintain access to the technological cutting edge to secure more robust technology as it develops, and their respective decentralized and centralized approaches have advantages (e.g., the United States' ability to attract firms and talent and secure cutting-edge IP and the Chinese government's ability to plan and marshal resources and data) and drawbacks (e.g., difficulty setting relevant research agendas and working with the private sector and limited exposure to foreign talent and ideas). These technological limitations and challenges inform both countries' abilities to satisfy the other three RMA elements, as discussed in the following subsections.

80 STEM PhDs often spearhead AI research and development and serve as indicators of future AI competitiveness. The quality of Chinese PhDs appears to be rising. China develops its AI talent pipeline through centralized curricula planning across education levels, even collaborating with Microsoft on curricula development. While not all these PhDs will research AI, the estimated figures (77,000 Chinese to 40,000 U.S.) still carry overall national security implications. Remco Zwetsloot et al., *China is Fast Outpacing U.S. STEM PhD Growth* (Washington, DC: Center for Security and Emerging Technology, August 2021), 1–10; Peterson, Goode, and Gehlhaus, *AI Education*, 38–39.

81 This effort, one of many similar programs, was seen by the U.S. Justice Department as a potential threat to national security after university and government employees received research funding without declaring their involvement. James Jin Kang, "The Thousand Talents Plan Is Part of China's Long Quest to Become the Global Scientific Leader," The Conversation, August 31, 2020, https://theconversation.com/the-thousand-talents-plan-is-part-of-chinas-long-quest-to-become-the-global-scientific-leader-145100.

82 Graham Allison, "America Needs a 'Million Talents Program' Now," The Hill, September 28, 2021, https://thehill.com/opinion/technology/574160-america-needs-a-million-talents-program-now.

83 Will Hunt, *Sustaining U.S. Competitiveness in Semiconductor Manufacturing* (Washington, DC: Center for Security and Emerging Technology, January 2022): 20–21.

84 Leading-edge logic chips are considered to be at the 5nm node, while legacy logic is greater than 16nm. Taiwan produces 85% of leading-edge logic and South Korea 15%. Hunt, *Sustaining U.S. Competitiveness*, 2–8, 28.

85 Antonio Varas et al., *Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing* (Boston: Boston Consulting Group and Semiconductor Industry of America, September 2020), 7; Saif Khan, Dahlia Peterson, and Alexander Mann, *The Semiconductor Supply Chain: Assessing National Competitiveness* (Washington, DC: Center for Security and Emerging Technology, January 2021), 8.

86 The United States is already looking into banning exports to Chinese chip manufacturers associated with the PLA or other security forces. Reuters, "U.S. Considers Banning Key Exports to Chinese Chipmaker SMIC - WSJ," Reuters, December 10, 2021, https://www.reuters.com/technology/us-considers-banning-key-exports-chinese-chipmaker-smic-wsj-2021-12-10/. See Saif Khan and Carrick Flynn, *Maintaining China's Dependence on Democracies for Advanced Computer Chips* (Washington, DC: Brookings Institution, April 2020), 1–9.

87 Photolithography is a particular area of interest, with the National Integrated Circuit Industry Investment Fund investing $950 million into Chinese firms. Will Hunt, Saif Khan, and Dahlia Peterson, *China's Progress in Semiconductor Manufacturing Equipment: Accelerants and Policy Implications* (Washington, DC: Center for Security and Emerging Technology, March 2021), 18–30.

Military Systems Evolution

Technology must be effectively integrated into military systems, themselves components of system networks, to contribute to an RMA. The United States and China have taken trial steps toward AI systems integration, demonstrating how both countries intend to deploy military AI (though precise details can be vague). Systems in more advanced development are likely classified, meaning public statements from officials offer few details and publicly documented experimental efforts, like DARPA's, may not transition to programs of record.

This section therefore presents several illustrative examples of AI-enabled systems rather than exhaustively cataloguing known programs. It is worth noting the challenge of categorizing AI capabilities given the technology's wide-ranging applications in different environments. Several of the systems mentioned here incorporate different AI elements (e.g., autonomous navigation and computer vision).[88]

Autonomy and robotics. Both the United States and China are exploring AI-enabled autonomous systems across a range of applications. Military autonomy is appealing for its potential to limit casualty risks, execute dangerous or repetitive tasks, operate at faster-than-human analytical and decision-making speeds, and ultimately serve as a force multiplier. AI-enabled autonomous vehicles could support humans on missions, patrol areas in swarms, and engage in remote multitarget tracking. AI-enabled autonomous lethal systems that are able to act on targeting analysis remain highly controversial, but while lethal fully autonomous weapons systems have not been deployed (as far as is publicly known), states have not ruled out their future development. Some see the incorporation of lethal autonomy as inevitable.[89]

In the United States, most DoD investment in AI-related research efforts from Fiscal Years 2018–20 was tied to autonomy:[90] "All U.S. military services are working to incorporate AI into semiautonomous and autonomous vehicles, including fighter aircraft, drones, ground vehicles, and naval vessels."[91] The Army's Next Generation Combat Vehicle program incorporates ML to support autonomous navigation and maneuver in contested environments without the need for GPS.[92] The Air Force Loyal Wingman Program explores teaming a manned F-35 or F-22 with an unmanned F-16 fighter to assist the flight lead with tasks like jamming electronic threats and carrying weapons.[93] Sea Hunter is an autonomously navigating surface craft intended to conduct months-long submarine hunting and mine detection missions for the Navy.[94]

Chinese military strategists and scientists more frequently refer to autonomous weapons systems as "AI weapons" or "intelligentized weapons," seemingly emphasizing the role intelligence will play in target selection and engagement.[95]

88 Margarita Konaev et al., *U.S. Military Investments in Autonomy and AI: Costs, Benefits, and Strategic Effects* (Washington, DC: Center for Security and Emerging Technology, October 2020), 21.

89 Michael Klare, "Army of None: Autonomous Weapons and the Future of War," Arms Control Association, November 2018, https://www.armscontrol.org/act/2018-11/book-reviews/army-none-autonomous-weapons-future-war.

90 Konaev et al. estimated spending in this period across components on autonomy alone at about $15.5 billion, AI alone at 5.9 billion, and spending marked for both at roughly $4 billion. 48% of Army, 67% of Navy, 100% of Air Force, and 70% of DARPA funding allocated to AI research was also classified under autonomy. Konaev et al., *U.S. Military Investments,* 16–18.

91 Kelley Sayler, *Artificial Intelligence and National Security* (Washington, DC: Congressional Research Service, November 2020), 13.

92 Konaev et al., 22.

93 David Axe, "U.S. Air Force Sends Robotic F-16s into Mock Combat," The National Interest, May 16, 2017, https://nationalinterest.org/blog/the-buzz/us-air-force-sends-robotic-f-16s-mock-combat-20684; Sayler, *Artificial Intelligence and National Security,* 13–14.

94 Sayler, *Artificial Intelligence and National Security,* 14. The unmanned craft could likely operate at a cost of $15,000-$20,000 a day compared to the $700,000 of a comparable manned destroyer. Julian Turner, "Sea Hunter: inside the U.S. Navy's autonomous submarine tracking vessel," Naval Technology, May 3, 2018, https://www.naval-technology.com/features/sea-hunter-inside-us-navys-autonomous-submarine-tracking-vessel/.

95 Elsa Kania, *"AI Weapons" in China's Military Innovation* (Washington, DC: Brookings Institution, April 2020), 2.

Open-source analysis suggests that the Chinese security and defense establishment believes AI could augment intelligent munitions; unmanned vehicles; and intelligence, surveillance, and reconnaissance (ISR) software in ways that support potential operations against the United States.[96] The PLA and its branches have studied and published extensively on AI applications in multitarget tracking and targeting, as well as air, surface, and underwater autonomous systems.[97] The PLA Navy has tested the HN-1 unmanned undersea glider during exercises in South China Sea, and the Chinese defense industry has long attempted to augment the intelligence of cruise and ballistic missile targeting.[98] The JARI is an unmanned surface vehicle that could function autonomously via AI to provide fire support to manned craft or work in a swarm; the U.S. Navy has discussed similar concepts.[99]

Decision support. Decision support conveys different AI applications of models like recommender systems and computer vision that could help warfighters reason more quickly about battlefield or intelligence information. These applications could theoretically facilitate better and more rapid command and control (C2) and analysis stemming from ISR. Eventually, AI-enabled C2 assistants could even recommend courses of action to commanders.[100] The U.S. Joint All Domain Command and Control (JADC2) system, in development, intends to use AI to aggregate and prioritize data from across the services' systems and sensors into a common, deduplicated joint operating picture.[101] Project Maven uses computer vision to identify hostile behavior from drone footage, allowing human analysts to focus on decision making rather than sorting through data.[102] Recent PLA contracts for AI-enabled ISR systems include the GL-AI Speech Recognition System 001, which uses natural language processing to translate foreign texts into Chinese, as well as the GeoSide 1400, an unmanned subsurface craft that conducts seabed target detection.[103]

Maintenance, logistics, and sustainment. The United States and China both see AI as capable of helping fulfill maintenance, logistics, and sustainment needs in multiple ways. One is by using performance data to predict system maintenance. The U.S. Army's Logistics Support Activity contracted IBM's Watson to identify signs of engine trouble in its Stryker vehicles based on data from seventeen sensors, as well as to analyze incoming logistics requests from the field to make money-saving shipping decisions.[104] The Air Force has explored similar programs to anticipate aircraft maintenance.[105] The Army envisions combining predictive algorithms that anticipate force sustainment needs

96 Ibid. "Unmanned" and "autonomous" can be conflated in Chinese defense terminology, making it difficult to distinguish remotely piloted and self-directed capabilities in translated analysis: see Fedasiuk, Melot, and Murphy, *Harnessed Lightning*, 9; Ryan Fedasiuk, *Chinese Perspectives on AI and Future Military Capabilities* (Washington, DC: Center for Security and Emerging Technology, March 2020), 3.

97 Murdick, Dunham, Jennifer Melot, *AI Definitions*, 2.

98 Kania, *"AI Weapons,"* 4.

99 Dorian Archus, "Chinese Unmanned Mini-Destroyer 'Jari' in Sea Trials," Naval Post, January 23, 2020, https://navalpost.com/chinese-unmanned-mini-destroyer-jari-in-sea-trials/.

100 Sayler, *Artificial Intelligence and National Security*, 13.

101 Sydney Freedberg, "Building JADC2: Data, AI & Warfighter Insight," Breaking Defense, February 3, 2021, https://breakingdefense.com/2021/01/building-jadc2-data-ai-warfighter-insight/; Jay Coester, "JADC2 'Experiment 2' Provides Looking Glass into Future Experimentation," U.S. Army, April 23, 2020, https://www.army.mil/article/234900/jadc2_experiment_2_provides_looking_glass_into_future_experimentation

102 Maven's official name is the Algorithmic Warfare Cross Functional Team. Jack Corrigan, "Three-Star General Wants AI in Every New Weapon System," Defense One, November 3, 2017, https://www.defenseone.com/technology/2017/11/three-star-general-wants-artificial-intelligence-every-new-weapon-system/142239/.

103 Fedasiuk, Melot, and Murphy, Harnessed Lightning, 18–19.

104 Adam Stone, "Army Logistics Integrating New AI, Cloud Capabilities," C4ISRNet, September 7, 2017, https://www.c4isrnet.com/home/2017/09/07/army-logistics-integrating-new-ai-cloud-capabilities/

105 Marcus Weisgerber, "Defense Firms to Air Force: Want Your Planes' Data? Pay Up," Defense One, September 19, 2017, https://www.defenseone.com/technology/2017/09/military-planes-predictive-maintenance-technology/141133/. The F-35's Autonomic Logistics Information System uses engine and other onboard sensor data in an algorithm to predict when the aircraft needs part replacement inspections. Sayler, Artificial Intelligence and National Security, 11.

and use autonomous vehicles to deliver supplies to contested areas.[106] PLA branches and affiliates recently contracted for multiple AI-based predictive maintenance products, including software that diagnoses soldering faults and mechanical noise recognition equipment.[107]

Modeling and simulation. AI applications also support modeling and simulation (M&S), whose broad umbrella covers training, analysis to support new capability procurement, tactical analysis, and systems testing. AI appears to hold potential for data-heavy M&S applications.[108] Both China and the United States have used AI-enabled aerial simulators to test human pilots against AI emulations of adversary aircraft.[109] The DoD recently awarded a $500 million contract to an AI software company to provide services for AI-enabled M&S.[110] U.S. officials have also noted that China "is investing in all the enabling technologies needed for advanced modeling and simulation."[111]

Information operations and cyber. Beyond these battlefield, maintenance, and command support decisions, AI could augment information and offensive and defensive cyber operations (though gains in the latter area appear likely to be incremental for the near future).[112] Generative image and text AI applications could create convincing disinformation by producing high-quality fakes of pictures or intelligence. China has explored information operations and disinformation creation using ML techniques, as well as spearfishing cyberattacks. The PLA also recently contracted for firms to provide it with software that uses AI to conduct threat sensing.[113]

To conclude, AI systems' military applications are rampant across a range of areas. While the technology largely does not appear mature enough to drive major operational innovations for the U.S. or Chinese militaries, some more advanced applications like autonomous systems could likely (or may already) be integrated into their current patterns of operations. The next subsection will discuss whether and how AI systems could affect operational innovation amid U.S.-China competition.

"[D]espite public claims about AI's revolutionary impact and its mention in certain joint operational documents in both countries, neither military yet appears to be reshaping patterns of operations based on the technology."

106 Eric McCoy, "Sustainment Revolution: Implications of Artificial Intelligence for Army Sustainment," U.S. Army, July 22, 2020, https://www.army.mil/article/237343/sustainment_revolution_implications_of_artificial_intelligence_for_army_sustainment.

107 Fedasiuk, Melot, and Murphy, Harnessed Lightning, 19.

108 Yasmin Tadjdeh, "Big Data AI to Advance Modeling and Simulation," *National Defense Magazine*, January 3, 2018, https://www.nationaldefensemagazine.org/articles/2018/1/3/big-data-ai-to-advance-modeling-and-simulation.

109 Thomas Newdick, "Pilot in a Real Aircraft Just Fought an AI-Driven Virtual Enemy Jet for the First Time," The Drive, November 16, 2020, https://www.thedrive.com/the-war-zone/37647/pilot-in-a-real-aircraft-just-fought-an-ai-driven-virtual-enemy-jet-for-the-first-time; Ryan Pickrell, "China Says Its Fighter Pilots Are Battling Artificial-Intelligence Aircraft in Simulated Dogfights, and Humans Aren't the Only Ones Learning," Business Insider, June 15, 2021, https://www.businessinsider.com/china-pits-fighter-pilots-against-ai-aircraft-in-simulated-dogfights-2021-6.

110 Lamar John, "DOD Awards C3 AI $500M Software Contract for Modeling and Simulation," MeriTalk, December 14, 2021, https://www.meritalk.com/articles/dod-awards-c3-ai-500m-software-contract-for-modeling-and-simulation/.

111 Paul McLeary, "DOD Official Warns China Pulling Ahead in Data, Simulation Efforts," Breaking Defense, December 1, 2020, https://breakingdefense.com/2020/12/dod-official-warns-china-pulling-ahead-in-data-simulation-efforts/.

112 Micah Musser and Ashton Garriot, *Machine Learning and Cybersecurity: Hype and Reality* (Washington, DC: Center for Security and Emerging Technology, June 2021), 29.

113 Fedasiuk, Melot, and Murphy, *Harnessed Lightning*, 21–22.

Operational Innovation

Operational innovation is necessary for exploiting technological change and military systems evolution and creating the conditions for an RMA. If AI were fueling operational innovation, one would expect to find evidence that its applications were fundamentally changing the ways the United States or China design and conduct operations. But despite public claims about AI's revolutionary impact and its mention in certain joint operational documents in both countries, neither military yet appears to be reshaping patterns of operations based on the technology. Open sources suggest militaries are exploring using AI to augment systems and methods of conducting warfare in the current reconnaissance-strike RMA rather than introducing revolutionary changes.[114] Overall, these dynamics appear likely to continue to emphasize the competition between the hiders and seekers, as Krepinevich discussed in 1992, albeit with evolved methods. The United States and China do not yet appear to see AI as changing the rules of the game.[115]

Based on open-source documents and analysis, current and forward-looking U.S. approaches to operational concepts at the joint and service levels focus on several key elements. These include (a) the ability to harness long-range precision fires to achieve effects enabled by remote sensing, (b) distributed joint operations and maneuver across both geographical expanses and warfighting domains that create challenges for adversaries, (c) information dominance in using technology to exploit U.S. strengths in C2 and ISR for battle management, and (d) joint force projection ability into foreign theaters.[116] Recent discussions of new service-level operational concepts that would be used in a fight against China emphasize the importance of distributed operations, autonomous capabilities, and cross-domain integration as factors that distinguish them from older concepts.[117] These concepts incorporate AI through military applications as discussed in the previous subsection, including as an autonomous force multiplier, contributing to shared operating pictures, and boosting the ability to rapidly collect and analyze new data and intelligence for decision support.[118] However, these AI applications seem unlikely to immediately alter the nature of current operations.

Furthermore, according to findings from the House Armed Services Committee's Future of Defense Task Force Report, "The Pentagon's emerging operational concepts have the potential to provide the U.S. military a decisive advantage, but they are not yet fully viable...the Department of Defense must more aggressively test new operational concepts against emerging technologies."[119] The United States has only recently updated concepts from the current RMA for a near-peer challenge after decades of counterterrorism and counterinsurgency operations. As such, newer operational concepts combine tenets of older concepts with an appreciation for new competitors and

114 This analysis is limited to unclassified details about existing and future concepts under development, which may lack relevant details from classified sources. Theresa Hitchens, "The Joint Warfighting Concept Failed, until It Focused on Space and Cyber," Breaking Defense, July 26, 2021, https://breakingdefense.com/2021/07/the-joint-warfighting-concept-failed-until-it-focused-on-space-and-cyber/; Brent Eastwood, "A Smarter Battlefield?: PLA Concepts for 'Intelligent Operations' Begin to Take Shape," *China Brief* 19, no. 4, https://jamestown.org/program/a-smarter-battlefield-pla-concepts-for-intelligent-operations-begin-to-take-shape/.

115 Krepinevich, *Military-Technical Revolution*, 15-20.

116 U.S. Navy, U.S. Marine Corps, and U.S. Coast Guard, *Advantage at Sea: Prevailing with Integrated All-Domain Naval Power* (Washington, DC: Department of the Navy, December 2020); Andrew Feickert, "Defense Primer: Army Multi-Domain Operations (MDO)," Congressional Research Service, October 22, 2021; U.S. Air Force, *Air Force Future Operating Concept: A View of the Air Force in 2035* (Washington, DC: USAF, September 2015).

117 Recently developed or new service-level operational concepts include multidomain operations (MDO) for the Army and Air Force, agile combat employment for the Air Force, distributed maritime operations (DMO) for the Navy and Marine Corps, and expeditionary advanced base operations (EABO) for the Marine Corps. Ronald O'Rourke, *Renewed Great Power Competition: Implications for Defense—Issues for Congress* (Washington, DC: Congressional Research Service, March 10, 2022), 14–17.

118 The joint warfighting concept is the United States' forward looking joint operational concept, though it is still in development. Jane Edwards, "Gen. John Hyten Advances Joint Warfighting Concept with 4 'Strategic Directives,'" Executive Gov, June 25, 2021, https://executivegov.com/2021/06/gen-john-hyten-advances-joint-warfighting-concept-with-4-strategic-directives/.

119 House Armed Services Committee, *Future of Defense Task Force Report 2020* (Washington, DC: September 2020), 5, 71–76.

technologies. The RMA first operationalized in Desert Storm was characterized by combining information processing, stealth, long-range precision fire, and dominating maneuver; though technology has advanced, these elements also undergird new joint and service concepts.[120] AI is not yet dictating shifts, given the present state of the technology and its limited effectiveness in military environments. Current U.S. approaches suggest that AI is one of a range of enabling technologies that are evolving the reconnaissance-strike paradigm rather than creating an altogether new paradigm.

China's approach to operational concept development is more top-down than the American approach. It stems from elite political and military theory about warfare, which is in turn deeply influenced by science and technology.[121] Like the United States, however, China envisions a role for AI in its future operations. Its 2017 New Generation Artificial Intelligence Development Plan included objectives to "strengthen the use of AI in military applications that include command decision-making, military deductions, and defense equipment," and writing from Chinese military thinkers and analysts about future operations has been rhetorically consistent with these goals.[122] Chinese operational concepts lay out competitive strategies against the United States that try to undermine U.S. operational strengths through maritime area denial, cost imposition, and attacks on the political system.[123]

Informatized warfare is the present Chinese operational approach, and it may guide operations for the next decade.[124] According to Chinese defense analysts, information dominance is essential to supremacy in what they view as three of the most important domains: information, maritime, and air. These principles underpin the ideas in China's 2014 concept of Winning Informatized Local Wars, captured in its 2015 Defense White Paper, which entails defeating the enemy's entire operational system across domains through information dominance and precision strikes against strategic points.[125] This model jointly targets opponents' perceived weaknesses across domains and seeks war control through attacking adversary information networks like C2 nodes.[126] It envisions joint battlefield operations that combine China's highly sophisticated arsenal of precision-guided munitions, including antiship cruise missiles and ballistic missiles, with multilayered area denial capabilities that could exploit AI to dominate the cognitive space.[127] AI-enabled autonomy, munitions, and decision support could play critical roles in offsetting asymmetries with the United States and accelerating operations, which the PLA views as critical to information dominance. Yet, it is not clear that informatized warfare envisions AI as a tool that fundamentally changes the dominant operational paradigm. Rather, it appears aimed at offsetting U.S. qualitative advantages and preventing area access by using some AI to augment existing capabilities in precision munitions, maneuver, and information operations. Since informatized warfare will remain the likely approach for the next ten years, Chinese operational

120 FitzSimonds and van Tol, "Revolutions in Military Affairs," 27.

121 Edmund Burke et al., *People's Liberation Army Operational Concepts* (Santa Monica, CA: RAND Corporation, 2021), 1–5.

122 Kania, *"AI Weapons,"* 3.

123 Tai Ming Cheung et al., "Long-Term Strategic Competition between the United States and China in the Maritime Realm," in *The Gathering Pacific Storm: Emerging U.S.-China Strategic Competition in Defense Technological and Industrial Development*, ed. Tai Ming Cheung and Thomas G. Mahnken (Amherst, NY: Cambria Press, 2018), 129.

124 Burke et al., *People's Liberation Army Operational Concepts*, 21. It is worth noting that some Chinese writings have been known to be used to misestimate or misrepresent Chinese strategies, plans, or capabilities. See Bill Gertz, "China in Race to Overtake U.S. Military in AI Warfare," The National Interest, May 30, 2018, https://nationalinterest.org/blog/the-buzz/china-race-overtake-us-military-ai-warfare-26035.

125 Burke et al., *People's Liberation Army Operational Concepts*, 7–8; Fairbank Center for Chinese Studies at Harvard University, "China's Military Strategy in the New Era, with M. Taylor Fravel," YouTube Video, 1:16:00, April 25, 2021, https://www.youtube.com/watch?v=Am8l7uZ3UCk.

126 Burke et al., *People's Liberation Army Operational Concepts*, 9–13.

127 Tai Ming Cheung et al., "The U.S.-China Reconnaissance-Strike Competition," 95; Richard Uber, "Penetrating Artificial Intelligence–Enhanced AntiAccess/Area Denial: A Challenge for Tomorrow's Pacific Air Forces," *Journal of Indo-Pacific Affairs*, 3, no. 4 (November 24, 2020), https://www.airuniversity.af.edu/JIPA/Display/Article/2425748/penetrating-artificial-intelligenceenhanced-antiaccessarea-denial-a-challenge-f/.

“[E]ven if intelligentization does not occur on the ambitious timeline laid out by Chinese strategic thinkers, it demonstrates that they are thinking about the discontinuities that AI-enabled technologies could introduce to the battlefield.”

thinking does not augur a near-term AI RMA.

However, 2019 analysis suggested that Chinese military thinkers are anticipating a longer-term shift to “intelligentization” or “intelligentized” warfare.[128] This theoretical model refocuses from “systems confrontation” to “algorithm confrontation,” where the side that can better capitalize on AI-supported actions and decision making will retain the advantage. The PLA sees the intelligentization of joint operations as a way to move beyond playing catchup to the United States by targeting weaknesses in once-superior U.S. systems and seizing the lead with now-superior PLA systems.[129] Human absence from the battlefield may be a distinct feature of such operations.[130] Some PLA thinkers anticipate that integration between humans and machines could approach a battlefield singularity, with humans in command roles overseeing fully autonomous systems that make rapid, human-free decisions.[131] Intelligentized warfare will coincide with the development of better C2 architectures and modeling that ultimately contribute to a leap ahead of the present American military advantages.[132]

Intelligentized warfare appears to be at the center of claims Chinese military analysts have made that AI will usher in a new RMA.[133] Intelligentization is over the horizon, and its success will depend on China’s ability to advance its simultaneous efforts to modernize and progress in informatized warfare.[134] It will also depend on the military’s ability to marry innovative operational ideas to existing joint concepts and systems.[135] Despite calls to meet intelligentization milestones by 2027, integrating AI and other emerging technologies into operations is likely to be challenging, particularly for a force that lacks any recent combat experience.[136] Given attempts to assert increasingly tight political control over military decision making, it is also difficult to envision political or military figures ceding important decisions to AI-enabled systems.[137] Yet even if intelligentization does not occur on the ambitious timeline

128 Fedasiuk, Melot, and Murphy, *Harnessed Lightning*, 3–6.

129 Ben Noon and Chris Bassler, “Schrodinger’s Military? Challenges for China’s Military Modernization Ambitions,” War on the Rocks, 2021, https://warontherocks.com/2021/10/schrodingers-military-challenges-for-the-chinas-military-modernization-ambitions/.

130 Allen, *Understanding China’s AI Strategy.*

131 Elsa B. Kania, “China Is on a Whole-of-Nation Push for AI. The U.S. Must Match It,” Defense One, December 8, 2017, https://www.defenseone.com/ideas/2017/12/us-china-artificial-intelligence/144414/.

132 Elsa B. Kania, *Battlefield Singularity: Artificial Intelligence, Military Revolution, and China’s Future Military Power* (Washington, DC: Center for a New American Security, November 2017), https://www.cnas.org/publications/reports/battlefield-singularity-artificial-intelligence-military-revolution-and-chinas-future-military-power; Ben Noon and Chris Bassler, “How Chinese Strategists Think AI Will Power a Military Leap Ahead,” Defense One, September 17, 2021, https://www.defenseone.com/ideas/2021/09/how-chinese-strategists-think-ai-will-power-military-leap-ahead/185409/.

133 Noon and Bassler, “Schrodinger’s Military?”

134 Yuan-Chou Jing, “How Does China Aim to Use AI in Warfare?,” The Diplomat, December 28, 2021, https://thediplomat.com/2021/12/how-does-china-aim-to-use-ai-in-warfare/; Eastwood, “A Smarter Battlefield?”

135 Burke et al., *People’s Liberation Army Operational Concepts*, 22–23.

136 Michael C. Horowitz and Lauren A. Kahn, “DoD’s 2021 China Military Power Report: How Advances in AI and Emerging Technologies Will Shape China’s Military,” Council on Foreign Relations, November 4, 2021, https://www.cfr.org/blog/dods-2021-china-military-power-report-how-advances-ai-and-emerging-technologies-will-shape.

137 Phillip C. Saunders and Joel Wuthnow, “Large and In Charge: Civil-Military Relations under Xi Jinping,” in *Chairman Xi Remakes the PLA: Assessing Chinese Military Reforms*, ed. Phillip C. Saunders et al. (Washington, DC: National Defense University Press, 2019): 537–46.

laid out by Chinese strategic thinkers, it demonstrates that they are thinking about the discontinuities that AI-enabled technologies could introduce to the battlefield. Krepinevich's four RMA elements need not proceed sequentially (as this paper discusses in a subsequent section): Progress can be made against an RMA's intellectual challenges before technology catches up. PLA leadership appears to embrace thinking about intelligentization as the next stage in the evolution of warfare, even if they lack the technology or systems to realize it.[138] It will be important to better understand to what extent and in what ways China's future vision for military AI (perhaps elucidated in coming Defense White Papers) differs from that of the United States, whether it advances, and the implications for U.S.-China competition.

Organizational Adaptation

Viewing a potential RMA in organizational terms, Krepinevich noted, "For those states that intend to develop the capability to wage war effectively in a new era of conflict, it is important that they begin to organize themselves to promote the innovations—in terms of technologies, systems, and operational concepts—that will be required for a successful transition."[139] Solving the intellectual challenge presented by an RMA often requires new thinking about how to structure the force to most effectively capitalize on the potential of new systems and operations. For example, the German adoption of mechanized maneuver and emphasis on the importance of operational speed—hence decoupling tanks from infantry—led to the creation of the panzer divisions that executed the blitzkrieg.[140]

In this respect, U.S. and Chinese openness to the possibility that AI may change future warfare is evident in the statements of political and military leaders, who do not appear to need convincing about AI's future importance. Yet, AI has not impacted the structure of operational organizations, likely reflecting the technology's immaturity for battlefield operations. There is little or no publicly available evidence to support a belief that the United States or China has harnessed AI-enabled systems for warfighting goals in ways that alter the structures of their respective forces. If AI were ushering in an RMA, one might expect to see new warfighting structures that maximize the advantages provided by new systems and operational concepts. While China has recently developed its PLA Strategic Security Force for emerging technologies, it was not developed specifically for AI. Ultimately, this lack of new operational organizations supports the hypothesis that an AI RMA is not imminent.

Despite the lack of changes to operational organization, both the United States and China have made changes to bureaucratic structures to better acquire and integrate AI into their defense establishments. Through these bureaucratic reorganizations, both countries appear to acknowledge the importance of funding research and maintaining consistent access to the cutting edge of AI development. Krepinevich was not referring to this type of change when he wrote about organizational adaptation, yet it is worth briefly acknowledging how some of these bureaucratic changes reflect U.S. and Chinese understandings of AI as a strategically significant technology. Bureaucratic adaptation is discussed in a subsequent section.

138 Elsa B. Kania, Battlefield Singularity, 13.

139 Krepinevich, *Military-Technical Revolution*, 32.

140 Williamson Murray, "Armored Warfare: The British, French, and German Experiences," in *Military Innovation in the Interwar Period*, ed. Williamson Murray and Allan R. Millett (Cambridge: Cambridge University Press, 1996), 34–38. Murray notes that while these divisions offered the Germans operational freedom that they had not enjoyed during the First World War, mechanized units comprised less than 20% of the German force structure in 1940, and the German army remained a predominantly foot and horse-drawn force. Nonetheless, the Germans capitalized on mechanization in ways the British and French could not because of doctrinal and cultural differences.

A Prospective AI RMA: Assessment, Implications, and Historical Insights

AI is an umbrella term that encapsulates a wide variety of diverse applications. Blanket statements do not speak to the entirety of its potential: Some applications will mature more quickly than others, leading them to be more quickly adopted by militaries. Change may appear more evolutionary than revolutionary, and AI's historically nonlinear development trajectory makes it challenging to predict timelines for change. Nonetheless, this paper suggests there is not currently an AI RMA, and there probably will not be one for at least a decade.

To recap: Technologically, ML techniques like deep learning have made great strides in the past decade, but AI technology remains too immature for most military applications and is prone to a wide variety of failure modes. Computer vision and image and speech recognition models are brittle outside their training contexts, unreliable, and vulnerable to failure or adversarial manipulation. The possibility that datasets could be poisoned or introduce unhelpful bias into AI-enabled systems raises both ethical issues and questions about military performance reliability; difficulty with interpreting models with hidden layers compounds hesitancy to trust systems that deploy them.

As a result, U.S. and Chinese AI-enabled military systems generally appear to reflect the narrow uses that the current technology can support. These militaries are making some progress while exploring how best to augment proven AI capabilities, like incorporating fully autonomous navigation and sensing into unmanned vehicles. More conceptually ambitious and publicly acknowledged capabilities, like the U.S. JADC2 network, may face significant challenges to reliable implementation. AI's impact may be more immediately revolutionary in noncombat applications like predictive maintenance and logistics management, where it can reliably outperform humans at parsing vast datasets. Even then, defense establishments may struggle to collect machine-readable datasets of sufficient breadth and quality and to navigate new models' unforeseen challenges.

Despite their statements touting AI as revolutionary, AI does not appear to have inspired significant U.S. or Chinese operational innovation or organizational adaptation. Based on unclassified sources, AI technologies have not fundamentally changed how the United States and China conceptualize operations against one another. Those technologies will augment some capabilities but are not yet changing the character of operations. Both sides expect AI-enhanced autonomy to contribute to tactical effects within frameworks of distributed operations, perform duties that mitigate risks to human warfighters, and bolster their own C2 and ISR infrastructures while weakening those of their opponents. These applications are not operationally transformative. An apparent lack of change to military organizations further corroborates the absence of an AI RMA. The U.S. and Chinese militaries have made little progress against the intellectual crux of the problem. Barring unforeseen developments, revolutionary operational, organizational, and subsequent doctrinal changes appear far off.

So, if an AI RMA is neither underway nor imminent, how should its military significance be understood? Put differently, why should one care about the absence of an RMA if AI is unlikely to revolutionize some combination of systems, operations, and organizations soon?

One possibility is that AI could spark near-term evolutionary change. For example, AI could significantly augment

"An AI RMA may appear distant now, but it is possible."

existing capabilities and advance the current reconnaissance-strike RMA without revolutionizing operations or overturning dominant features of today's security environment. In the United States, public discussion of JADC2, including emphasis on the system's capacity to better connect "sensors to shooters," points to this conclusion – this aphorism has been used since reconnaissance-strike's operational debut in the Gulf War.[141] AI might help address specific challenges to U.S. dominance over China in areas like space, cyberspace, stealth, and power projection.[142] As speed becomes more important in operations, AI-enhanced decision support could help leaders make better decisions more quickly, and threat-warning systems that incorporate AI could help detect and neutralize emerging threats posed by area denial tactics intended to offset U.S. advantages. AI might be one of the advances that brings the systems of the reconnaissance-strike RMA from their 1918 equivalents closer to the context of a 1940 war.[143]

However, adopting only this mental model of evolutionary change while ignoring more disruptive possibilities presents inherent risks. Limiting considerations of how AI's future military significance will help reconnaissance-strike capabilities mature introduces the possibility that competitors may be quicker to incorporate rapid technological changes into new and innovative operational concepts.[144]

It is therefore important to also consider the longer term revolutionary potential of technological progress in AI, combined with new patterns of operations and force structures. An AI RMA may appear distant now, but it is possible. By acknowledging AI's game-changing potential and understanding its limitations through an RMA lens, we can broadly identify: (1) signs of technological progress toward a future RMA, (2) missing elements that could enable it, and (3) conditions that could help realize missing elements. Historical perspectives on RMAs can offer insights into these conditions. The subsections below address these points.

141 Krepinevich wrote in 1992, "Those competitors attempting to exploit these [extended-ranged fire] systems will move toward the coupling or integration of information systems to 'shooters.' When integrated, these systems would comprise what many Soviet writers have called a reconnaissance-strike complex". FitzSimonds and van Tol noted, "By reducing the strike timeline from target sensor-to-shooter by orders of magnitude while increasing the effectiveness of weapons in terms of range, target discrimination, and lethality, such systems conceivably could provide conventional forces the ability to rapidly destroy an opponent's critical military targets at minimal cost and with little collateral damage." Krepinevich, *Military-Technical Revolution*, 15; FitzSimonds and van Tol, "Revolutions in Military Affairs," 27. For use of similar phraseology around JADC2, see John Hoehn, "Joint All Domain Command and Control (JADC2)," Congressional Research Service, January 21, 2022, https://sgp.fas.org/crs/natsec/IF11493.pdf; Barry Rosenberg, "Is the Goal of JADC2 to Connect Sensors to Shooters or should it be command and control?" Breaking Defense, February 11, 2022, https://breakingdefense.com/2022/02/is-the-goal-of-jadc2-to-connect-sensors-to-shooters-or-should-it-be-command-and-control/; Pablo Kruger, Michael Molinari, and Benjamin Baumann, "The Future of Air-Ground Integration: Linking Sensor to Shooter in the Deep Fight," Air Land Sea Application Center, July 1, 2021, https://www.alsa.mil/News/Article/2667778/the-future-of-air-ground-integration-linking-sensor-to-shooter-in-the-deep-fight/; Kathryn Bailey, "Jointly Planning to Ensure Sensor, Shooter Technology Dominance," U.S. Army, March 18, 2020, https://www.army.mil/article/233762/jointly_planning_to_ensure_sensor_shooter_technology_dominance

142 Watts wrote that the possibility of conflict between the United States and a near-peer was likely to fundamentally change the conduct of warfare in the precision guided RMA more between 2011 and 2050 than it had since the 1990s. The U.S. military's ability to exercise cross-domain dominance in the Gulf War and afterward meant that potential conflicts challenging this dominance could create the need for new operational innovations and organizational structures. Watts, *The Maturing Revolution*, 14-39.

143 FitzSimonds and van Tol wrote, "By 1918, systems like planes, tanks, and radios were considered state of the art and represented quantum leaps over 1914. Yet the combat power represented by these same systems in 1940 was orders of magnitude greater than in 1918. The promise they held in 1918 only became decisive after two decades of technical improvement, doctrinal development, and organizational adaptation. Could the modern systems such as stealth aircraft, cruise missiles, and smart weapons, the concepts of operations that employed them, and the military organizations of the Gulf War be the '1918' equivalents in the context of a future '1940' war?" FitzSimonds and van Tol, "Revolutions in Military Affairs," 27–28.

144 As a 1996 conference on RMAs prepared for ONA by Science Applications International Corporation (SAIC) found: "If the U.S. military determines that dominant battlespace awareness, precision strike, information, space or any other technology or combination of technologies provides the basis for the next RMA, they better be right. With the speed of technological change, it could be catastrophic to place the nation's faith in one set of operational concepts only to be outflanked by an adversary who waits either for the underlying technology to mature – allowing him to develop even newer and better concepts – or to adopt a different set of operational concepts that exploit an entirely different set of technologies." Brown and Furrow, "Revolution in Military Affairs Conference," 7.

Identifying Signs of Technological Progress and Missing RMA Elements

First, although AI development is hard to predict, signs of technological progress could indicate to policymakers and military innovators that an RMA is becoming more likely. Most major AI advances originate outside government institutions, so open-source monitoring of private sector and academic research could help uncover revolutionary developments in AI and complement other intelligence collection methods in identifying game-changing technological progress. China already relies on a well-established open-source monitoring capability to track global science and technology advancements.[145] Specific technological signposts could include advanced development of enabling computing technologies like quantum computing, which might spur advances in AI capabilities and algorithmic training.[146] New learning methods that are less compute heavy could drive AI progress even as breakthroughs requiring massive amounts of compute become more expensive and Moore's Law slows.[147] Progress in explainability and interpretability could help warfighters develop trust in previously opaque capabilities and use AI-enabled systems thoughtfully, rather than mistrusting them or accepting system judgments by default.[148]

Steps taken by governments could indicate advanced progress in AI development. Established AI assurance cases and dependable test, evaluation, verification, and validation (TEVV) frameworks and standards would suggest understanding of advanced systems and a need and ability to assess their performance at scale.[149] New doctrinal guidance incorporating AI, which would inform future training and force development, could also indicate significant progress. For example, examining new Chinese doctrine will help determine the importance the PLA sees for AI applications in its future force.[150] Passing these early- and late-stage signposts would indicate that AI technology is advancing beyond present shortcomings and making disruptions to military paradigms more likely.

Second, acknowledging that there is not yet an AI RMA allows one to identify which of Krepinevich's four elements are missing and would be needed to realize a future RMA. In this case, accounting for current technological constraints, the United States and China have made little progress on the intellectual aspects of an AI RMA, namely operational innovation and organizational adaptation. To paraphrase Marshall, an RMA's crux is an intellectual problem, not a technological one. A future AI RMA instigated by the United States or China will therefore require a more mature intellectualization of the military problem set each country faces. Until such maturation occurs, AI will likely remain a predominantly enabling technology.

Third, past RMAs can offer insights into conditions that might lead the United States or China to better address the

145 The state uses over 60,000 open-source science and technology intelligence collectors and a cadre of science and technology diplomats to seek information and access to foreign technological opportunities that help advance the Made in China 2025 plan and other strategic goals, many related to AI. William Hannas and Huey-Meei Chang, *China's STI Operations* (Washington, DC: Center for Security and Emerging Technology, January 2021). See also Tarun Chhabra et al., *Establishing a New Open-Source National Science and Technology Analysis Center* (Washington, DC: Center for Security and Emerging Technology, September 2020).

146 Tom Taulli, "Quantum Computing: What Does It Mean for AI (Artificial Intelligence)?" Forbes, August 14, 2020, https://www.forbes.com/sites/tomtaulli/2020/08/14/quantum-computing-what-does-it-mean-for-ai-artificial-intelligence/?sh=2dffee433b4c

147 Husanjot Chahal, Helen Toner, and Ilya Rahkovsky, *Small Data's Big AI Potential* (Washington, DC: Center for Security and Emerging Technology, September 2021), https://doi.org/10.51593/20200075.

148 Humans defaulting to acceptance of a system's decision-making is referred to as "automation bias." Michael C. Horowitz, "Trust, Confidence, and Organizational Decisions about AI Adoption: The Impact for U.S. Defense," Minerva Research Initiative, United States Department of Defense, August 28, 2020, https://minerva.defense.gov/Owl-In-the-Olive-Tree/Owl_View/Article/2328498/trust-confidence-and-organizational-decisions-about-ai-adoption-the-impact-for/.

149 Andrew Lohn, "Estimating the Brittleness of AI: Safety Integrity Levels and the Need for Testing out-of-Distribution Performance," arXiv.org, September 2, 2020, https://arxiv.org/abs/2009.00802.

150 Signs indicate China is in the process of developing new doctrine to be released within the next few years. Dean Cheng, "How China's Thinking About the Next War," Breaking Defense, May 19, 2021, https://breakingdefense.com/2021/05/how-chinas-thinking-about-the-next-war/.

intellectual side of a future AI RMA. The carrier aviation RMA that emerged from interwar U.S.–Japanese competition in the Pacific may offer particularly relevant insights for U.S.-China AI competition. The military problem sets of these periods feature several parallels, including similar geographic contexts, rapid paces of military and private sector innovation, and challenges with implementing new operational and organizational changes. While the analogy is imperfect, its insights may interest U.S. observers for another reason: the carrier aviation RMA was one of the few cases where the dominant actor with an arguable military advantage—the United States—realized an RMA without its advantage being overturned.[151]

Conditions for Fulfilling RMA Elements: The Carrier Aviation RMA's Insights for AI

For the U.S. and Imperial Japanese Navies, adopting the aircraft carrier was tied to perceptions about the future operating environment and the relative value of carrier-borne naval aviation fleets compared to battleship-borne artillery, which conventional wisdom placed at the center of the fleet. The interwar struggles of both sides to grapple with the intellectual implications of carrier aviation innovations informed their abilities to realize the RMA. The remarkable pace of change—carriers with planes delivering munitions by air replaced over five hundred years of gunship dominance at sea within a generation—was spurred by rapid advances in naval aviation technology.[152] Carrier and aircraft technologies developed simultaneously in the 1920s and 1930s, requiring continuously updated knowledge of emerging technologies to enable accurate experimentation and theorizing. Technological progress, driven by private sector and government innovation in the late 1930s and standing atop imaginative military intellectualization, eventually led to transformative operational and organizational changes.[153] Importantly, understanding of carrier aviation tactics, operations, and doctrine evolved in peacetime, but carriers did not fully displace the dominant battleship paradigm until the war, with circumstances and luck playing key roles.[154]

Brief descriptions of the U.S. and Japanese experiences follow, along with relevant insights for a future AI RMA. This section presents a nonlinear, necessarily messy process of innovation in a distilled, narrative fashion. As such, descriptions of the individual insights below generally proceed chronologically, but their presentation should not be interpreted sequentially because many relevant developments evolved simultaneously.

The importance of analytical focus and experimentation. *Identifying their likely adversary and theater of combat gave the United States and Japan a concrete military problem to innovate against.* The Americans and Japanese came to view carrier aviation as significant and worthy of future investment during World War I after seeing it pioneered by the British, who taught both navies flight operations and carrier design near the war's end and in the early interwar period.[155] The Americans and Japanese viewed one another as likely adversaries in a Pacific conflict as early as the first decade of the twentieth century.[156] Compared to multipolar Europe, a clear opponent

151 Thomas Wildenberg, "Midway: Sheer Luck or Better Doctrine?" U.S. Navy Naval History and Heritage, 2004, https://www.history.navy.mil/research/library/online-reading-room/title-list-alphabetically/m/midway-sheer-luck-or-better-doctrine.html; see Hundley, *Past Revolutions*, Future Transformations, 12.

152 Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics*, (Princeton, NJ: Princeton University Press, 2010), 67–68.

153 Thomas C. Hone and Mark D. Mandeles, "Interwar Innovation in Three Navies: U.S. Navy, Royal Navy, Imperial Japanese Navy," *Naval War College Review* 40, no. 2 (1987): 68–76, Jan M. van Tol, "Military Innovation and Carrier Aviation: An Analysis," Joint Forces Quarterly 17 (Autumn/Winter 1997-98): 108–09.

154 Hone and Mandeles, "Interwar Innovation," 68–76.

155 Hone and Mandeles, "Interwar Innovation," 64; Wildenberg noted that Anglo-American cooperation had cooled by the Washington Naval Treaty in 1922. Wildenberg, "Midway."

156 Kowner noted, "By the end of the Russo-Japanese War in 1905, the IJN was already the world's fifth-largest navy, but it now faced a bigger

in a contest for sea control focused U.S. and Japanese strategy and capability development.[157] While their early naval aviation doctrine followed British thought, emphasizing carrier aviation in support of battleship-led fleets, the confluence of American–Japanese competition, treaty-based fleet construction limits through the late 1930s, and geography led the U.S. and Japanese navies to seek and adopt innovations that eventually made sea control largely dependent on control of the air.[158]

In the case of U.S.–China AI competition, the idea of focusing on one adversary has value for scoping the military problem set and grounding strategy, planning, and experimentation in specific facts and a particular operating environment. An important divergence from the carrier analogy with respect to AI is the fact the latter technology will be used across a range of operational problems, from C2 to resupply to autonomous systems, unlike air and sea control. Even so, the insight still holds that focusing on one military problem could help determine which AI applications are more revolutionary than others in a particular operating context.

Considering the objectives of innovation from the competitor's perspective may also help mitigate risks of mirror imaging. For example, geography and the limited range of shore-based aircraft in the early interwar period dictated that the U.S. Navy, moving westward, could rely only on sea-based aircraft to attack the Japanese and protect its advancing fleet as the Americans sought territorial footholds. Aircraft launched from U.S. carriers needed to fulfill a range of missions, whereas Japanese proximity to South Pacific islands led them to initially envision using combinations of carrier aircraft, land-based aircraft, and other naval combatants to intercept and attrit U.S. forces before a decisive engagement dominated by Japanese battleships (although this strategy had changed by 1941).[159] Differing U.S. and Japanese views of the strategic problem informed their respective pathways toward innovation. For U.S.–China competition, where much cutting-edge AI progress is made in the public eye, considering the competitor's unique problem set in its specific operational context vis-à-vis one's own may help inform assessments of comparative strengths and weaknesses and how a competitor could deploy emerging military AI applications in different ways.

The U.S. and Imperial Japanese Navies framed experimentation around realistic scenarios, combining innovative thinking around technology, simulations, exercises, and real-world data to explore new roles, capabilities, and structures for carrier aviation. U.S. Naval War College simulations and Navy Fleet Problems used creativity, combined with real-world data and self-critical analysis, to explore new roles for carrier aviation in a war against

hurdle: the United States' larger and fast-expanding naval force. In just two years after the war's end, both the IJN and USN began to regard each other as their primary potential enemy and prepared for a future clash." Rotem Kowner, "Passing the Baton: World War II's Asian Theater and the Coming of Age of the Aircraft Carrier," *Education About Asia* 19, no. 2 (Fall 2014): 68; Yoichi Hirama, "Japanese Naval Preparations for World War II," *Naval War College Review* 44, no. 2, (1991): art. 6, https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=3664&context=nwc-review: 63.

157 Till wrote, "The American ability to point at the Japanese as a clear potential opponent was an asset in many ways; it provided a criterion against which they could judge their tactics and equipment." For the Japanese, "The manifest naval and industrial strengths of the United States made it clear that the challenge confronting the Japanese Nary was 'how to contend successfully against heavy odds.'" Geoffrey Till, "Adopting the Aircraft Carrier: The British, American, and Japanese Case Studies," in *Military Innovation in the Interwar Period*, ed. Williamson Murray and Allan R. Millett (Cambridge: Cambridge University Press, 1996), 203–04, 225.

158 Till, "Adopting the Aircraft Carrier," 225–26; Horowitz, *Diffusion of Military Power*, 84.

159 The Japanese initially believed South Pacific islands could serve as "unsinkable aircraft carriers" that would support superior land-based aircraft, obviating the need to produce carriers in numbers that might spur industrial competition with the United States. By 1941, the role of carrier aircraft had changed, becoming critical to Japan's offensive defense strategy to land decisive blows against the U.S. Navy and quickly bring the United States and Japan to the political negotiating table. This strategy itself was influenced by Japan's unique geographic constraints: its lack of access to natural resources and diminishing fuel supplies led it to seek conquest south and push quickly east to preempt the American response. Hirama, "Japanese Naval Preparations," 73-78; Katsuya Tsukamoto, "Naval Air Operation: The Development of Aircraft Carrier Operations during the Second World War," Paper presented at *International Forum on War History* 2014, International Forum on War History 2014 The 13th International Forum in War History, September 17, 2014, "*History of the Joint and Combined Operations*," 73; Till, "Adopting the Aircraft Carrier," 204, 220–21; Horowitz, *Diffusion of Military Power*, 74; Kowner, "Passing the Baton," 71.

Japan. The simulations tested carrier aviation force structures beyond the Navy's actual capabilities and challenged conventional wisdom that carrier aircraft were best suited for scouting, not fighting.[160] Simulations in the 1920s identified aircraft kept in the air as a critical measure of carrier effectiveness, which aviators tried to meet by quickening the pace of takeoffs and landings with innovative launch and land processes, deck parking, and crash barriers. These led to different U.S. carrier designs.[161] Through the 1920s and 1930s, fleet problems that incorporated ideas from the simulations allowed operators to test the viability of new tactics and concepts in large-scale maneuvers under real conditions, giving carrier commanders situational experience and uncovering essential characteristics of naval aviation.[162] In 1929, Fleet Problem IX, arguably the most important in the series, presaged the eventual innovation of the carrier task force by showcasing carriers' potential as independent strike platforms.[163] Critical analysis after each exercise was an essential part of the learning process. It highlighted areas for operational improvement, informed technical and operational assessments, and provided evidence to the broader U.S. Navy and other stakeholders of carrier aviation's potential.[164]

Japan also incorporated carriers and naval aircraft into interwar fleet maneuvers, similarly benefiting from cooperation between operational navy units and its Naval Staff College. Sengi combat training—the focused study of potential tactics, operations, and force mixes—allowed the Imperial Japanese Navy to explore different naval aircraft and carrier roles, with findings shared throughout the fleet.[165] Experimentation, coupled with experience and data from the Sino-Japanese War, led to operational and organizational innovations, including the world's first combined land- and carrier-based strike units.[166] They also led the Japanese to prioritize longer range aircraft that could harry approaching U.S. forces at the extreme range of Japanese surface ships' guns, pushing eastward the boundary of where Japanese interception-attrition tactics might begin.[167] By the 1930s, Japanese aviators recognized that aircraft could defeat battleship-led fleets and potentially offset U.S. quantitative advantages in military strength, resources, and industrial development.[168]

Accurate simulation and experimentation could be valuable for sparking innovative thinking about AI applications in the United States and China. As the carrier aviation RMA case illustrates, realism in wargaming and exercises is key to accurately conceptualizing the future operating environment and, coupled with rigorous analysis and critical

160 For example, in 1923, a simulation examined the impact of radical aircraft increases on naval warfare by employing a U.S. fleet with five carriers, more than any country actually possessed at that point. van Tol, "Military Innovation and Carrier Aviation—The Relevant History," *Joint Forces Quarterly* 16 (Summer 1997): 80–82; Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca: Cornell University Press, 1991): 69–71.

161 Jan van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 80–82; Rosen, *Winning the Next War*, 71; see Wildenberg, "Midway."

162 These included the ability to mass forces, payload capacity, and range. Jerry Hendrix, *Retreat from Range: The Rise and Fall of Carrier Aviation*. (Washington, DC: Center for a New American Security, 2015), 10.

163 Fleet Problem IX first introduced the carriers *USS Lexington* and *USS Saratoga*, loaded with over a hundred planes each, to U.S. fleet exercises. The *Saratoga's* success in the exercise, decisively striking its target of the Panama Canal unaccompanied by a battleship, indicated carriers' potential as independent strike platforms to naval aviators. Rosen, *Winning the Next War*, 69–71; Albert A. Nofi, *HM 18: To Train the Fleet for War: The U.S. Navy Fleet Problems, 1923-1940.* Historical Monographs 18 (Newport, RI: U.S. Naval War College, 2010), 109; Jan van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 83–86; Curtis Utz, "Fleet Problem IX January 1929," U.S. Navy Naval History and Heritage Command, January 1929, https://www.history.navy.mil/browse-by-topic/heritage/usn-lessons-learned/fleet-problem-ix.html.

164 Rosen, *Winning the Next War*, 69–71.

165 The Imperial Japanese Navy deployed all its seaplanes on a scouting mission as part of a 1919 maneuver. Hone and Mandeles, "Interwar Innovation," 68; Tsukamoto, "Naval Air Operation," 76–77.

166 Hirama, "Japanese Naval Preparations," 73; Wildenberg, "Midway."

167 Malcolm Muir, Jr., "Rearming in a Vacuum: United States Navy Intelligence and the Japanese Capital Ship Threat, 1936-1945," *The Journal of Military History*, 54, no. 4 (October 1990): 475; Hirama, "Japanese Naval Preparations," 74–78.

168 Hone and Mandeles, "Interwar Innovation," 70; Hirama, "Japanese Naval Preparations," 73–75.

"Accurate, realistic simulation can permit militaries to envision how they might use AI-enhanced capabilities beyond those currently at their disposal, while real-world exercises can link theory to operations and expose operational challenges that ultimately strengthen mental models of future combat."

insights after the fact, can help secure buy-in for innovative operational and organizational ideas. Accurate, realistic simulation can permit militaries to envision how they might use AI-enhanced capabilities beyond those currently at their disposal, while real-world exercises can link theory to operations and expose operational challenges that ultimately strengthen mental models of future combat. The U.S. and Chinese militaries may already be experimenting with military AI applications, but emphasizing rigor is critical if experimentation is to inform RMA elements like operational innovation and organizational adaptation. Questionable experimental results played a part in Commander-in-Chief of the Combined Japanese Fleet Admiral Yamamoto Isoruku's decision to shift from the decisive fleet battle strategy to the offensive defense strategy in January 1941. Although Yamamoto was a carrier proponent, the abrupt shift arguably left the Imperial Japanese Navy ill-prepared for new operations, including the disastrous carrier defeat at Midway.[169] In contrast, William Moffett, the first director of the U.S. Navy's Bureau of Aeronautics (BuAer), could rely on rigorous simulation results as evidence for his 1931 assertion to the Secretary of the Navy that a carrier's "offensive value is too great to permit it to be ordinarily devoted to scouting," and that its function "should be the same as that of a battleship."[170] While U.S. carriers did not evolve as a major operational weapon or overturn the battleship paradigm until the war, by 1939 Navy doctrinal guidance informed by the Fleet Problems envisioned carrier operations in many of the independent roles they eventually filled in wartime operations.[171] Realistic experimentation made the U.S. Navy better prepared to realize the carrier aviation RMA.

The effects of bureaucracy and culture on adapting mental models. *New bureaucratic structures in the United States and Japan during the interwar period centralized resources for innovative operational thought about carrier aviation, fostering experimentation and change*. The U.S. Congress authorized the Bureau of Aeronautics in 1921, which served as a bulwark for the Navy against external pressure to incorporate naval aviation into an independent air force. Throughout the interwar period, BuAer navigated toward change amid prevailing Navy and political winds, allowing aviators space and autonomy to innovate and advance their interests more strongly than their British and Japanese counterparts.[172] The bureau was an adjoining link between the Naval War College simulations and the Fleet Problems. It integrated naval aviators into the chain of command and enshrined appreciation for airpower among senior officers by incorporating aviation issues into mid-level professional education at the Naval War College.[173] BuAer secured funding for private research into game-changing aircraft designs and diversified its

169 "[Yamamoto] pointed out that in past wargames of such decisive battles the navy never achieved a convincing victory, and that the war games usually suspended when it appeared that Japanese forces would be gradually whittled away." Hirama, "Japanese Naval Preparations," 75–76.

170 Rosen, *Winning the Next War*, 70.

171 Thomas C. Hone, "Replacing Battleships with Aircraft Carriers in the Pacific in World War II," *Naval War College Review*, 66, no. 1 (2013): 58–59.

172 Till, "Adopting the Aircraft Carrier," 219–21.

173 Williams noted that Moffett inculcated in naval aviators the belief that they were naval officers first, aviators second. Rosen noted that from 1916–28, the number of U.S. Navy aviators who were officers grew from 2 to 11%, and by 1927 had sixty-nine officers from the commander level upward, including one vice admiral, receiving flight pay. Alison J. Williams, "Aircraft carriers and the Capacity to Mobilise U.S. Power Across the Pacific, 1919–1929," *Journal of Historical Geography*, 58 (2017): 74; Rosen, *Winning the Next War*, 99; van Tol, "Military Innovation and Carrier Aviation—An Analysis," 99–104; van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 80.

industry relationships. It cast a wide net to meet its own demanding technical aircraft requirements, which resulted in important innovations like radial engines and aeronautical streamlining.[174]

In 1928, the Imperial Japanese Navy created its own independent Aviation Bureau, which enabled the evolution of military capabilities by consolidating funding and research for airpower development.[175] Like BuAer, the Aviation Bureau enjoyed a close relationship with the Naval Staff College, which researched carrier operations and cooperated with real-world aviation units. It sponsored aircraft design competitions in the 1930s aimed at offsetting U.S. quantitative advantages with qualitative superiority and provided combat and exercise data to manufacturers like Mitsubishi.[176]

Even though both countries made bureaucratic adjustments that gave them advantages in carrier development over other navies, the ability to socialize ideas through the force and navigate civilian and military politics distinguished U.S. and Japanese abilities to adopt carrier innovations.[177] While naval aviators in both countries recognized carriers' offensive potential by the 1930s, their service branches were slower to embrace change due to entrenched interests, politics, and other factors.[178] How U.S. and Japanese naval aviators navigated these waters impacted their abilities to realize the RMA. The U.S. Navy eventually recognized carriers' disruptive potential and produced them in far greater numbers than the Japanese. Technological advancements were insufficient to advance the RMA without conducive organizational dynamics.

While Japan enjoyed an advantage over the United States at the outset of World War II in aircraft quality, its poor organizational dynamics and adherence to decisive fleet battle doctrine immediately prior to the war hamstrung its ability to realize the carrier aviation RMA.[179] The Imperial Japanese Navy faced fewer interservice or civilian external pressures than the U.S. Navy, which also left it with few reasons to question its assumptions about the relative values of carriers and battleships.[180] It struggled to train enough young officers as pilots and to put naval aviators into carrier command positions. This introduced elements of ineffective leadership in aviation command, negatively affecting carriers' development and operational effectiveness and leaving few to argue for a primary role for carrier aviation.[181] In addition, disconnects within the navy, including among operational fleet staff and a Navy General Staff that favored

174 Peter W. Singer, "Lessons on Defense Strategy from the Interwar Years," The Brookings Institution, August 7, 2013, https://www.brookings.edu/articles/lessons-on-defense-strategy-from-the-interwar-years/; van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 87.

175 As Till noted, "The revolution in [Japanese] naval administration... does much to justify the view that the bureaucratic/administrative environment is of decisive importance in the evolution of military capability and the process of innovation." Till, "Adopting the Aircraft Carrier," 212–213; Hone and Mandeles, "Interwar Innovation," 69–70.

176 In the late 1930s, the Japanese were able to test carrier aviation concepts in the Sino-Japanese War. Hone and Mandeles, "Interwar Innovation," 69–71.

177 For example, The United States and Japan did not consolidate their army and navy air assets into independent air forces, as the British had with the Royal Air Force (RAF) in 1918, thus allowing naval aviators to explore disruptive roles for carriers and naval aircraft more broadly during the interwar period. The successes of the U.S. Navy and Imperial Japanese Navy aviation bureaus stand in stark contrast to the British model, where the RAF's centralized control of air assets, administration, and purchasing power, coupled with the navy's lack of an experimentation-driven culture and weak senior leader support for carrier aviation, hampered the Royal Navy's potential to effectively develop carrier aviation. Till, "Adopting the Aircraft Carrier," 208–09. Hone and Mandeles, "Interwar Innovation," 64–66; ban Tol, "Military Innovation and Carrier Aviation—An Analysis," 109.

178 For example, President Franklin D. Roosevelt, as former Secretary of the Navy, and developed an admiration for the battleship and helped the navy procure more in the interwar period at the expense of new naval aircraft. William M. McBride, "The Unstable Dynamics of a Strategic Technology: Disarmament, Unemployment, and the Interwar Battleship," *Technology and Culture* 38, no. 2 (April 1997): 409.

179 Hone and Mandeles, "Interwar Innovation," 71, 80.

180 Tsukamoto, "Naval Air Operation," 75–76.

181 Compared to the U.S. Navy, where pilots were overwhelmingly drawn from the officer corps, noncommissioned officers comprised 90% of the navy's aviators by 1941. Transferred senior commanders were expected to learn about aviation through experience, rather than training. Tsukamoto, "Naval Air Operation," 75–80.

the decisive fleet battle, impeded the diffusion of technical and doctrinal carrier innovations throughout the force.[182] High-ranking officers and fleet planners still generally favored battleships to carriers, even after the success of carrier-launched attacks against the U.S. battleship fleet at Pearl Harbor.[183]

In contrast, BuAer, particularly under Moffett's leadership, savvily navigated civilian political and military pressures inside and outside the U.S. Navy to keep naval aviation separate from any independent U.S. air force. Moffett used 1925 legislation to establish a strong corps of pilots as officers and to provide nonpilot senior officers with aviation training, eventually enshrining high-level support for carrier aviation in the force.[184] For example, Admiral Ernest King, who became the Chief Naval Officer in 1942 and prioritized carrier procurement over battleships, retrained as a naval aviator after surface and submarine commands.[185] In the 1920s, Moffett amassed datapoints from exercises to justify his assertions to Navy leaders that carriers were mobile airfields that could support a range of operations, not just escort battleships.[186] While the Navy did not immediately envision the carrier displacing the battleship, leaders embraced analytical evidence about the value of carrier aviation and incorporated new ideas into doctrine. This generated new roles and force structures for carriers that were reinforced by wartime successes.[187] After Midway, Japan built seven new carriers between 1942 and 1943; the United States produced ninety, including nearly thirty fleet carriers.[188]

The importance of effectively navigating political and bureaucratic hurdles to harness military innovation may be one of the areas currently most relevant to U.S.–China competition, simply because bureaucratic reorganization around AI has proliferated in both countries. The United States and China are creating new bureaucratic organizations to incorporate AI into their military establishments; whether these organizations will be effective depends on their abilities to navigate cultural attitudes toward technological adoption, intra- and interorganizational interests, and political considerations.

The DoD and the services have created several new joint and service-level bureaucratic structures for AI. The newly created Chief Data and Artificial Intelligence Office (CDAO) will lead AI and data policy and strategy for the DoD and aim to incorporate AI technology and expertise throughout the department and workforce.[189] Situated within the Office of the Secretary of Defense, it will integrate the work of the Joint Artificial Intelligence Center (JAIC), the DoD Chief Data Officer, and the Defense Digital Service.[190] As the successor to the JAIC, CDAO will take on its

182 Hone and Mandeles, "Interwar Innovation," 80; Hirama, "Japanese Naval Preparations," 73–76.

183 Katsuya Tsukamoto, "Japan's 'Carrier Revolution' in the Interwar Period (doctoral dissertation, Fletcher School of Law and Diplomacy, Tufts University, 2016), 240–41. Tsukamoto also noted that class elements mirroring characteristics of the British gentrified officer corps came into play among noncommissioned officer pilots and naval officers.

184 van Tol, "Military Innovation and Carrier Aviation—An Analysis," 79; van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 80.

185 Manley R. Irwin, "Review of [Hone, Thomas C., Norman Friedman, and Mark D. Mandeles, American and British Aircraft Carrier Development, 1919-1941. Annapolis, MD: Naval Institute Press, 1999]" *Journal of Conflict Studies* 20, no. 1 (2000): 204–06; "King, Ernest J.: Fleet Admiral, USN (1878-1956), Chief of Naval Operations, 1942-1945," U.S. Navy Naval History and Heritage, https://www.history.navy.mil/our-collections/photography/us-people/k/king-ernest-j.html.

186 Rosen, *Winning the Next War*, 70.

187 Hone and Mandeles, "Interwar Innovation," 79; Hone, "Replacing Battleships," 57–74.

188 van Tol, "Military Innovation and Carrier Aviation—The Relevant History," 87, Tsukamoto, "Naval Air Operation," 80–82; P.M.H. Bell, *Twelve Turning Points of the Second World War* (New Haven, CT: Yale University Press, 2011), 92; Hirama, "Japanese Naval Preparations," 77.

189 U.S. Deputy Secretary of Defense, "Establishment of the Chief Digital and Artificial Intelligence Officer," Memorandum, Department of Defense, December 8, 2021, https://media.defense.gov/2021/Dec/08/2002906075/-1/-1/1/MEMORANDUM-ON-ESTABLISHMENT-OF-THE-CHIEF-DIGITAL-AND-ARTIFICIAL-INTELLIGENCE-OFFICER.PDF.

190 Brandi Vincent, "DOD to Hire First-Ever Chief Digital and Artificial Intelligence Officer, Form New Office," Nextgov.com, December 8, 2021, https://www.nextgov.com/emerging-tech/2021/12/dod-hire-first-ever-chief-digital-and-artificial-intelligence-officer-form-new-office/187399/.

"The successes and failures of the U.S. and Japanese navies in the carrier aviation RMA depended on senior officer buy-in to new technologies and concepts, and AI adoption will face these tests at a far more comprehensive, force-spanning scale."

missions of "strengthening current military advantages" and "accelerat[ing] the delivery of AI-enabled capabilities" in addition to joint scaling proven AI programs.[191] The services are also developing new or reimagined bureaucratic structures. The Army's Chief Data Officer, created within the last decade, received new responsibilities incorporating an AI focus.[192] Others, like the Army's AI Task Force and the Air Force's AI Accelerator, leverage relationships with universities to research AI applications and insights but are not connected to strategic or operational considerations.[193]

China has also adopted AI-specific and broad technology-related changes to bureaucratic and military institutions. Military–civil fusion, formally adopted with defense reforms in 2015–16 as a strategic approach to technology acquisition, has generated bureaucratic changes in China's defense-industrial sector aimed at easing military access to cutting-edge civilian dual-use technologies.[194] China has also developed new dual-use technological research institutions and adopted related reforms to existing bodies. The Ministry of National Defense established two AI-focused research organizations, the Unmanned Systems Research Center and the Artificial Intelligence Research Center, to conduct dual-use AI technology research under the National University of Defense Technology.[195] In 2019, China's Academy of Military Science incorporated science and technology research into its traditional emphasis on doctrinal development.[196] Its military-only staff was joined by civilian personnel with advanced technological degrees in 2020 to address research talent gaps.[197] Finally, since 2015 the government has established over thirty-five MCF funds dedicated to research investment; these are estimated to have raised over 447.16 billion yuan ($68.5 billion) as of 2021.[198]

191 U.S. Department of Defense, *Summary*, 8-9, U.S. Deputy Secretary of Defense, "Establishment of the Joint Artificial Intelligence Center," Memorandum, Department of Defense, June 27, 2018, https://admin.govexec.com/media/establishment_of_the_joint_artificial_intelligence_center_osd008412-18_r....pdf.

192 he Army's Deputy Chief Information Officer was dual hatted as Chief Data Officer in 2020. Jason Miller, "The Big Data Challenge Getting Smaller for Army, Air Force as CDOs Mature," Federal News Network, January 24, 2020, https://federalnewsnetwork.com/ask-the-cio/2020/01/the-big-data-challenge-getting-smaller-for-army-air-force-as-cdos-mature/.

193 Amanda Miller, "Turning up the Heat on AI," *Air Force Magazine* (January 19, 2022), https://www.airforcemag.com/article/turning-up-the-heat-on-ai/; Gary Sheftick, "AI Task Force Taking Giant Leaps Forward," US Army, October 7, 2019, https://www.army.mil/article/225642/ai_task_force_taking_giant_leaps_forward.

194 Tai Ming Cheung et al., "The Cinderella Transformation," in *The Gathering Pacific Storm: Emerging U.S.-China Strategic Competition in Defense Technological and Industrial Development*, ed. Tai Ming Cheung and Thomas G. Mahnken (Amherst, NY: Cambria Press, 2018), 61–67; Elsa B. Kania and Lorand Laskai, "Myths and Realities of China's Military-Civil Fusion Strategy," (Washington, DC: Center for a New American Security, January 2021), https://www.cnas.org/publications/reports/myths-and-realities-of-chinas-military-civil-fusion-strategy.

195 Xi has called the AMS the "fist" driving PLA military science research. Allen, *Understanding China's AI Strategy*; Cheung et al., "Cinderella Transformation," 68.

196 Kai Lin Tay, "China's Military Looks to Civilians to Boost Innovation," International Institute for Strategic Studies, May 7, 2020, https://www.iiss.org/blogs/analysis/2020/05/china-civil-military-innovation; Joel Wuthnow, "China's 'New' Academy of Military Science: A Revolution in Theoretical Affairs?" *China Brief* 19, no. 2 (January 18, 2019), https://jamestown.org/program/chinas-new-academy-of-military-science-a-revolution-in-theoretical-affairs/.

197 Kai Lin Tay, "China's Military."

198 Kania and Laskai, "Myths and Realities."

Both the U.S. and Chinese militaries have indicated in public statements that they view AI adoption as critical to military advancement. Yet the successes and failures of the U.S. and Japanese navies in the carrier aviation RMA depended on senior officer buy-in to new technologies and concepts, and AI adoption will face these tests at a far more comprehensive, force-spanning scale. The United States and China could confront similar overarching challenges to AI technology adoption, though there are nuanced differences.

The level of AI literacy among both countries' policymakers and senior military officials is unclear. Few AI training programs exist for U.S. policy- and decisionmakers, despite evidence elites view AI as a revolutionary technology.[199] U.S service culture may create its own disincentives to AI adoption in the force: incorporating enlisted servicemembers and officers with AI talent and knowledge into regular patterns of operations is difficult, and promotion policies and rotation cycles that do not prize AI literacy may fail to reward officers with relevant skills. A 2021 report found that individuals at DoD with AI experience who are in positions to enact relevant policy changes succeed "in spite, not because of, their organizations' incentives."[200] Jointly focused civilian coordination offices like the CDAO may help influence department priorities, policy, and strategic thinking about integrating AI, data, and security, but they could struggle to gain traction given budget and manpower imbalances with the services.[201] Attracting talent to civilian and military AI roles will also be challenging given fierce competition with the private sector.[202] These obstacles sit atop the DoD technology procurement challenges discussed earlier.

There is little public research or commentary about Chinese AI literacy among civilian or military leaders, and uncertainty muddles assessments of whether the PLA will succeed in adopting AI throughout the force. Public articles in the *PLA Daily* and elsewhere have called for additional training on AI for C2 and highlighted shortages of highly skilled tech workers in AI industries.[203] Siloes are a pronounced feature of the Chinese military career system, possibly making it difficult for officers not trained or literate in AI to adapt; joint assignment opportunities have only developed since 2016, which could impede joint thinking among officers about AI's potential.[204] Given its importance in Chinese politics, the PLA may face pressure to achieve AI advances—or allege such progress—by politically significant deadlines, such as the 2027 intelligentization strategy milestone, so its actual success at incorporating science and technology into doctrine may be unclear. The PLA's lack of recent combat experience could make adopting AI military capabilities at scale difficult, but it could also leave leaders less attached to past concepts. Chinese assessments appear sanguine about the military's ability to incorporate AI into operations and to match and

199 Michael C. Horowitz and Lauren Kahn, "The AI Literacy Gap Hobbling American Officialdom," War on the Rocks, January 14, 2020, https://warontherocks.com/2020/01/the-ai-literacy-gap-hobbling-american-officialdom/.

200 Diana Gehlhaus et al., "The DOD's Hidden Artificial Intelligence Workforce" (Washington, DC: Center for Security and Emerging Technology, September 2021), 30–46.

201 For example, the CDAO's budget will be roughly $500 million with two to three hundred employees, while the U.S. Army's Fiscal Year 2023 budget request will be $177.5 billion to support nearly one million soldiers alone. Lauren Kahn and Michael C. Horowitz, "Two Cheers for the Department of Defense's New Data and Artificial Intelligence Leadership Initiative," Council on Foreign Relations, December 1, 2021, https://www.cfr.org/blog/two-cheers-department-defenses-new-data-and-artificial-intelligence-leadership-initiative; Jaspreet Gill, "Pentagon's New Data And AI Office Hits IOC Milestone, Gets $500M Budget," Breaking Defense, February 2, 2022, https://breakingdefense.com/2022/02/pentagons-new-data-and-ai-office-hits-ioc-milestone-gets-500m-budget/; U.S. Army Public Affairs, "Army Releases Fiscal Year 2023 Presidential Budget Request," U.S. Army, March 28, 2022, https://www.army.mil/article/255122/army_releases_fiscal_year_2023_presidential_budget_request.

202 Sam Drub, "How the Defense Department's AI center Recruits Top Tech Talent Without Top Salary Offers," HR Brew, March 17, 2022, https://www.hr-brew.com/stories/2022/03/17/how-the-defense-department-s-ai-center-recruits-top-tech-talent-without-top-salary-offers.

203 Center for Naval Analyses, "The China AI And Autonomy Report," Issue 5, Center for Naval Analyses December 16, 2021, https://www.cna.org/archive/CNA_Files/centers/cna/cip/china/ai-newsletters/chinaai-autonomy-report-issue-5.pdf

204 Roderick Lee, "Building the Next Generation of Chinese Military Leaders," *Air University Journal of Indo-Pacific Affairs* 3, no. 3 (August 31, 2020), https://www.airuniversity.af.edu/JIPA/Display/Article/2331143/building-the-next-generation-of-chinese-military-leaders/.

overtake U.S. capabilities.[205] Ultimately, it is unclear whether U.S. or Chinese bureaucratic or service-level policies are particularly well-suited to accommodate revolutionary AI applications.

The roles of circumstances and luck. *Finally, circumstances and luck play roles in realizing RMAs.* Not all developments can be foreseen or accounted for. BuAer was fortunate to benefit from strong leaders, like Moffett, who valued experimentation and analysis and protected nascent innovation.[206] Some historians believe that the destruction of American battleships at Pearl Harbor made carriers the U.S. Navy's preeminent strike unit by default, not choice.[207] At Midway, where U.S. carrier warfare came of age, U.S. doctrine that aimed to establish air supremacy as quickly as possible, scout bombers, and quick aircraft recovery times helped capitalize on Japanese weaknesses, but chance belied a significant lack of operational polish.[208]

For the United States and China, circumstances and luck could influence an emerging AI RMA in numerous ways. A game-changing technological application may emerge from one country's private sector, one state may have a set of leaders particularly suited to encouraging and adopting innovation, or one military may be forced to rely on a new AI application they otherwise may not have. Culture, training, and norms influence these three examples, and luck realizing an AI RMA could result from preparation meeting opportunity.

In sum, an RMA could emerge from closer examinations of AI's applications to specific military problems facing the United States and China. For example, numerous insights could be uncovered by analysis, modeling and simulation, and experimentation about how AI-enabled capabilities could be used by both sides in contingency scenarios like a Taiwan-related conflict. These could include differences in how the United States and China might develop military AI capabilities based on their respective needs for power projection versus fighting local wars and how each side might use certain AI technologies to disrupt what it sees as the other's advantages in conducting maritime or area denial operations. From a U.S. perspective, considering Chinese intellectual styles and organizational dynamics against a specific military problem will be crucial to avoiding cultural blind spots, mitigating risks from mirror imaging, and developing a grounded, realistic assessment of Chinese capabilities.

205 Michael Dahm, "Chinese Debates on the Military Utility of Artificial Intelligence," War on the Rocks, June 5, 2020, https://warontherocks.com/2020/06/chinese-debates-on-the-military-utility-of-artificial-intelligence/.

206 Hone and Mandeles acknowledged that "naval aviation also benefitted from the Navy's commitment to a rational examination of doctrine through analysis. Officers who did not like aviation, but who nonetheless were good professionals, had to accept the evidence that aircraft spotting was essential to very long-range daytime gunner, that carrier aircraft were growing more powerful and effective from year to year, and that long-range seaplanes were a great aid to fleet reconnaissance." Hone and Mandeles, "Interwar Innovation," 75–79; Singer, "Lessons on Defense Strategy."

207 Andrew Krepinevich, "Cavalry to Computer: The Pattern of Military Revolutions," *The National Interest 37*, (Fall 1994): 39–40; Wildenberg, "Midway;" Kowner, "Passing the Baton," 71; Irwin, "Review," 204–06.

208 Japanese weaknesses included the Imperial Japanese Navy's risky four carrier task group design, which massed all its carriers in one area with insufficient protection, and hangar parking that slowed launch and recovery times for aircraft. The Japanese decision to operate without scout aircraft also meant that when attack aircraft could not locate U.S. carrier task forces, they had to return to their carriers to refuel before sortieing out again. Wildenberg, "Midway;" Horowitz, *Diffusion of Military Power*, 69–71.

Conclusion and Issues for Future Research

An AI RMA is not presently underway. Acknowledging this reality allows one to examine RMA elements that are missing from current military thinking about AI (such as operational innovation and organizational adaptation), why they are missing, and the conditions that could make them possible.

If U.S.–China AI competition is going to produce an RMA, history suggests much focused experimentation against real-world military problems remains to be done. Developing new technologies will be insufficient to spark revolutionary change: Military leaders will also need to embrace new ideas and innovation, up and down the ranks. Technology development may occur more quickly than technology adoption throughout the force. In addition, bureaucratic components will need to secure ongoing access to the cutting edge in AI semiconductors, talent and algorithms, and computing power.

The relative abilities of the United States and China to intellectualize AI's value for operations and the characteristics of the security environment it could overturn may offer one side important advantages in strategic competition. The different ways in which U.S. and Chinese political and military leaders and technologists see the world will impact the development and application of new technologies. RMAs emerge from particular cultural contexts, and more studies should be done on how differing perspectives on various military problems and contingencies might affect AI development. From a U.S. perspective, it will remain important to closely follow Chinese thought on both AI development and future patterns of operations across a range of scenarios. This will help identify where China might deploy AI-enabled capabilities to exploit perceived competitive advantages against the United States and avoid potential mirror imaging by U.S. strategists, policymakers, concept developers, and others.

Futures analysis could aid framework development for what an emerging RMA might look like. Assessing the least, middling, and most disruptive potential alternative futures for AI capability development could help measure progress toward an RMA. AI applications might be more immediately transformative in some areas than others, which could affect whether and how different AI-influenced RMAs emerge. Such analysis should draw on close monitoring of the academic and private sectors, where most technological progress will likely emerge, and should explore military AI implications of varying plausibility.

"Because narrow AI applications seem to hold the most promise for military purposes, it is possible there might not be a single AI RMA but rather several hyphenated ones: for example, an AI-cyber, AI-autonomy, or even AI-nuclear RMA."

Because narrow AI applications seem to hold the most promise for military purposes, it is possible there might not be a single AI RMA but rather several hyphenated ones: for example, an AI-cyber, AI-autonomy, or even AI-nuclear RMA. Combinations of AI and cyber applications could increase the importance of taking an adversary's physical capabilities offline before force-on-force clashes begin. Virtual battles to control and secure datasets that train AI algorithms could influence the security and performance of algorithmic military capabilities. Generative AI models could create or amplify disinformation, eroding confidence in political leadership—especially in democratic states—and perhaps even hampering the creation of accurate operating pictures for warfighters. The evolution of current approaches to deploying AI-enabled autonomous capabilities could gradually evolve to incorporate new combat and noncombat roles for autonomy with less human supervision.

In addition to futures that may seem related or adjacent to current capabilities, assessments should consider more radically disruptive changes to the nature of warfare that AI might enable. For example, a less gradual, punctuated-equilibrium evolution of the application of AI-enabled autonomy might result in a sudden, drastic reduction in the number of soldiers on the battlefield. Increasing operational speed, whether from AI or other capabilities like hypersonic weapons, could lead militaries to call into question the effectiveness of human-centric decision making. Assuming sufficient technical progress, some militaries might prefer to cede many tactical decision-making responsibilities to speedier, AI-enabled machines with less human supervision. The possibility of different types of fully autonomous systems working together could lead to new autonomous units and patterns of operations with limited human involvement; as mentioned earlier, the implications of such developments for conventional deterrence and crisis de-escalation should be carefully analyzed.

Some believe that AI could have a transformative effect on nuclear deterrence, which would amount to an even more disruptive change. Current nuclear deterrence incorporates elements like human rationality, perception, and signaling, so any application of AI that challenges the existing paradigm could be game changing and carry far-reaching consequences.[209] AI could theoretically be used both offensively and defensively in a nuclear context. Competitors like Russia and China could use AI to augment nuclear strike early-warning systems, and AI-enabled autonomous vehicles could serve as strike platforms.[210] Some have posited that AI could be used to help locate an adversary's nuclear weapons launchers or serve as a decision aid to humans in a nuclear crisis.[211] Crucially, human perceptions of the threats these systems pose to first- and second-strike capabilities, perhaps even regardless of the performance of the systems themselves, create risks as AI evolves. In other words, AI could challenge nuclear deterrence "not because it works too well but because it works just well enough to feed uncertainty."[212] This topic and its implications for nuclear arms control, modernization, and international security in general will remain crucially important to study, for obvious reasons.

209 James Johnson, "Rethinking Nuclear Deterrence in the Age of Artificial Intelligence," Modern Warfare Institute, January 28, 2021, https://mwi.usma.edu/rethinking-nuclear-deterrence-in-the-age-of-artificial-intelligence/.

210 Lora Saalman, "The Impact of AI on Nuclear Deterrence: China, Russia, and the United States," East-West Center, April 14, 2020, https://www.eastwestcenter.org/news-center/east-west-wire/the-impact-ai-nuclear-deterrence-china-russia-and-the-united-states.

211 Edward Geist and Andrew J. Lohn, *How Might Artificial Intelligence Affect the Risk of Nuclear War?* (Santa Monica, CA: RAND Corporation, 2018), 1–6, 20–22.

212 Ibid., 15.

More generally, further research could explore how AI's broader societal and economic effects may strengthen or weaken U.S. national security in the short and long terms. As Scharre noted, "Although AI can increase military capabilities, the more consequential advantages over the long term may come from non-military AI applications across society" like improved health-care outcomes, economic productivity and growth, and the augmentation of other instruments of national power.[213] Some experts argue AI could prove transformative on the scale of the Industrial Revolution in the magnitude of change it instigates economically and socially by displacing human cognitive labor.[214] Future research could examine parallel historical periods of revolutionary social and economic change and correlated changes to the international security environment.

Finally, the relationship between humans, technology, and warfare as AI progresses is a deeply important subject that merits contemplation and research beyond the scope of this paper. Philosophical questions about the suitability of AI and autonomy for military applications—ground well-trodden elsewhere—deserve careful consideration.[215] The extent to which nations may be willing to cede decision-making responsibility to AI will differ, and policymakers, strategists, and warfighters must weigh the costs and benefits of further incorporating AI into the conduct of warfare among humans. The vociferous debate around lethal autonomous weapons systems at the United Nations among states and nongovernmental organizations illustrates the complex mixture of factors that states could incorporate into decisions to deploy such systems. Comparisons between ethical concerns raised by AI-enabled military systems and by other historically controversial platforms and capabilities could expose helpful insights. Addressing such concerns will be paramount to thoughtfully and responsibly harnessing AI's revolutionary potential.

213 Scharre, "Debunking the AI Arms Race Theory," 123.

214 Daniels and Chang, *National Power after AI*, iv.

215 The concept of establishing meaningful human control over autonomous and AI-enabled weapons systems, for example, has generated academic and policy discussion and debate about the relative roles of humans and machines in warfare. Santoni de Sio and van den Hoven neatly summarized different facets of these discussions in their literature review. Filippo Santoni de Sio and Jeroen van den Hoven, "Meaningful Human Control over Autonomous Systems: A Philosophical Account," *Frontiers in Robotics and AI 5*, no. 15 (February 2018): 1–3.

The Andrew W. Marshall Foundation

Founded by Andrew W. Marshall and Jaymie Durnan, with the continued support of generations of people who worked for, worked with, or were mentored by Andy Marshall, the Andrew W. Marshall Foundation is a 501(c)(3) tax-exempt organization. The people and work it supports are impartial and intellectually fearless.

Designed by: Selena Robleto, Red Velvet Creative

Edited by: Thomas Mowle, Rampart Professional Solutions

The Andrew W. Marshall
FOUNDATION

The Andrew W. Marshall Foundation
1 Woodbury Hill Road
Jaffrey, NH 03452
www.andrewwmarshallfoundation.org