Noah Benton, Titan Dynamics chief technology officer, prepares 3D-printed unmanned aerial system for flight during demonstration, April 25, 2024, at Eglin Air Force Base, Florida (U.S. Air Force/Samuel King, Jr.)

Fabrication at the Tactical Edge

By Aubry J. Eaton and Dustin T. Thomas

In 1945, General Henry "Hap" Arnold observed that in the future, "science and research will have the same relative importance as pilot training."[1] Recent conflicts, such as the Russian invasion of Ukraine, confirm this insight as combatants rapidly adapt weapons and tactics to dynamic battlefield conditions. Today, technological advances combining additive manufacturing (AM) and artificial intelligence (AI) make it possible to execute an acquisition observe, orient, decide, act (OODA) loop within 24 hours. If production is colocated with warfighters, the joint force can now design, produce, and deploy equipment as an integral part of operations. Mastery of managed innovation, alongside managed violence, will be critical to deterring and defeating aggression in this era. These devel-

Major Aubry J. Eaton, USAF, is Program Integrator at Defense Contract Management Agency (DCMA) Special Programs. Colonel Dustin T. Thomas, USAF, is Commander, DCMA Unmanned Systems.

opments have profound implications for both near-term deterrence and strategic competition with the People's Republic of China (PRC).

The Department of Defense—now the Department of War (DOW)—has traditionally relied on centralized procurement and manufacturing to supply and equip warfighters. While this model has historically served the United States extraordinarily well, it is mismatched to the demands of rapid-reaction warfare. Current requirements, resourcing, and acquisition processes were simply never intended to manage the production of expendable end items in the field. A new paradigm of Fabrication at the Tactical Edge (FATE) is needed to decentralize production by leveraging AM and AI to enable battlefield manufacturing. This paradigm shift could revolutionize operations by counteracting PRC anti-access/area-denial (A2/AD) capabilities by making U.S. forces unpredictable. Locating larger versions of FATE in allied and partner-nation territory contributes to a strategy of binding antihegemonic coalition members together. Most critically, the capability of FATE to generate mass prevents the PRC from seizing and holding the key territories of U.S. allies in what now–Under Secretary of War for Policy Elbridge Colby has termed a denial defense strategy.[2]

Blunting the Assassin's Mace

Existing acquisition decision support systems were optimized for managing high-cost programs with long service lives and exquisite technical requirements. They are ill-suited for dynamic, tactical-level adaptation—the near future of modern warfare. For example, a requirement for small unmanned aerial systems (sUASs) for Army Brigade Combat Teams that was approved in June 2023 resulted in a contract in September 2024.[3] While this instance was rightly considered a rapid acquisition by legacy standards, such a timeline is too slow for dynamic battlefield needs.

Reforms are already underway to streamline and accelerate capability acquisition. For instance, the Joint Capabilities Integration and Development System is being disestablished. In its place, the Joint Staff will publish an annual prioritized list of Key Operational Problems (KOPs), and DOW will align requirements and funding decisions through a new Requirements and Resourcing Alignment Board and Joint Acceleration Reserve.[4] These reforms shift the focus of management attention from document-heavy, front-loaded requirements to problem-driven, experimentation-led solutions with dedicated funding. The outcome is a viable policy framework to deploy rapidly iterating edge-driven capabilities like battlefield fabrication. Organizations such as the new Mission Engineering and Integration Activity will provide a formal venue to iterate FATE nodes against KOPs and accelerate fielding.

The urgency of these reforms is underscored by the PRC's People's Liberation Army (PLA) *shashoujian* ["assassin's mace"] strategy that seeks to exploit surprise and asymmetric advantages to neutralize the technological superiority of adversaries like the United States. Deeply rooted in Chinese views of history and culture, this approach leverages decisive unanticipated weapons or tactics to achieve a strategic breakthrough against a stronger opponent.[5] The sudden appearance of an assassin's mace on the battlefield, such as antisatellite weapons or swarm drones, could pose a severe threat to the joint force by targeting critical vulnerabilities in U.S. operations. Alongside the development of such asymmetric capabilities, the PLA has set a milestone to modernize the military of the PRC by 2027 in the areas of mechanization, information, and intelligence.[6] In contrast, key U.S. defense modernization programs are set to culminate in 2030 and beyond.[7] This disparity suggests a finite period of localized tactical PLA superiority against the United States and its allies. International relations scholars have hypothesized that a limited window of opportunity poses an especially dangerous threat of military conflict because of a perceived incentive to strike before the favorable military advantage is lost forever.[8] This dynamic significantly elevates the threat of military escalation in the Indo-Pacific region.

To mitigate this risk, U.S. defense planners must carefully balance limited investment funds to maintain deterrence within this window while modernizing major systems for the long term. Under the current acquisition construct, the United States must largely rely on existing systems or those currently in production during this window of time. Given the long lead times for exquisite systems in the development phase, it is unlikely that they will be ready for combat in time to meet the elevated risk of this critical period. However, rapid and adaptable manufacturing methods are poised to fill this gap. By enabling battlefield improvisation, U.S. forces can rapidly counter unanticipated threats and blunt their impact.

A New Paradigm

Additive manufacturing is defined by the International Organization for Standardization as the "process of joining materials to make parts from 3D model data, usually layer upon layer."[9] Unlike traditional manufacturing in which material is removed, this process builds both parts and material simultaneously. AM can be used in a variety of media, including polymer, metal, ceramic, composite, electronic elements, energetics, and concrete.[10] It is an inherently digital endeavor, as it relies on 3D models to guide the process of manufacture. Concurrent growth in the capabilities of AI-enabled design tools allows operators of AM systems to quickly develop models to be printed. DOW has begun experimenting with AM in the field with initial use cases focused on enhancing sustainment. In 2022, the Marine Corps solidified a production specification for the Expeditionary Fabrication (XFab) system. It includes both polymer and metal printers as well as milling, drilling, and grinding tooling, all within an 8' x 8' x 20' standard container.[11] The USS *Somerset* has also been equipped with AM systems to conduct repairs while underway. During the 2024 Rim of the Pacific international maritime exercise, both naval and marine systems were utilized in operational conditions, resolving real-world parts failures.[12]

Through the Rapid Fabrication via Additive Manufacturing (R-FAB) program, the Army began piloting uses of AM for ground forces in the field, such as production of high-mobility multipurpose wheeled vehicle parts.[13] These use cases have demonstrated a compelling return on investment. Initial results reported by Naval Air Systems Command (NAVAIR) have demonstrated a 70-percent improvement in cost and 97-percent improvement in schedule when using AM over traditional procurement.[14]

FATE aims to decentralize production of spare parts to reduce the vulnerability arising from lengthy supply chains. The concept does require raw materials such as polymer and metal compounds to be shipped forward. However, FATE still confers a logistical advantage, since it vastly simplifies the variety of such materials. It is also more straightforward to include base materials in prepositioned stocks rather than thousands of individual spare parts. A key component of this approach is a digital library of certified and secure models.[15]

In addition to significantly improving sustainment, AM can be coupled with AI-enabled design to create entirely new end items. The Air Force has experimented with field production of new capabilities with the Black Phoenix sUAS initiative. This initiative proved out the combination of AM and AI–enabled design to go from tactical requirement to a fully operational sUAS within 24 hours while operating in mobile field conditions.[16] This capability ensures that U.S. forces can respond to evolving threats posed by PLA assassin's-mace systems with bespoke solutions, disrupting adversary expectations and maintaining operational superiority. These existing trends demonstrate the technological feasibility of the FATE paradigm of adaptable mission-specific systems produced within an operational planning cycle.

The DOW Replicator program seeks to acquire thousands of inexpensive sUASs using traditional streamlined procurement practices. FATE complements and enhances such efforts. For instance, a forward-deployed fabrication system could produce replacement parts for sUASs that are damaged during operations. It can also build sUASs that are adapted for specific missions, are designed to be expendable, and can serve to protect the sUASs acquired through Replicator. While Replicator focuses on centralized mass production of low-cost sUAS drones, FATE ensures that forces at the edge can customize, repair, or create mission-specific capabilities, providing a dual advantage in scale and adaptability.

Battlefield Production: Lessons From Ukraine

Rapid-reaction drone development in the Ukraine conflict highlights profound changes in the character of war and underscores the ability of warfighters to surge capability in less than a year. At the outset of the conflict, Ukrainian Bayraktar TB-2s served an important role, placing Ukraine's numerically superior enemy at a severe tactical disadvantage. The combat effectiveness of such an approach is revealed by data indicating that Ukrainian drones were responsible for destroying up to 57 percent of Russian armored combat vehicles.[17] However, within 4 months, Russian forces had adapted their own defenses and rendered the TB-2 obsolete as a frontline system.

In response, individual Ukrainian units began using AM to fabricate munition release mechanisms for commercial quadcopters.[18] In addition to procuring drones conventionally, Ukraine established over 200 hidden pop-up factories to decentralize production.[19] Defense companies even set up workshops in the trenches to enable rapid modification in direct response to combat results.[20] Further innovation included the use of intuitive first-person view (FPV) systems for navigation and targeting, which required little formal training.

Russian forces also adapted to the changing character of war. After Iranian-made Shahed drones were neutralized by Ukrainian defenses, the Russian industrial base pivoted to produce new designs. Within 10 months, Orlan-Lancet systems were deployed in hunter-killer pairs against Ukrainian forces.[21] By June 2024, an estimated 75 percent of battlefield drone losses were caused by electronic warfare.[22] In response, Russian forces began employing FPV drones that were controlled with fiber optics and immune from the effects of electronic warfare.[23] Such move-countermove developments in Ukraine demonstrate that rapid adaptability in battlefield production is a decisive necessity for modern battle. As one famous industrialist says, "The factory is the product." Today, this can be reformulated as "The factory is the weapon."

The Next Fight? Offsetting A2/AD

Harnessing the power of rapid adaptation holds the potential to offset the PRC's advantage of mass in the Indo-Pacific theater. The PLA's A2/AD doctrine and systems pose a significant threat due to its ability to target U.S.-enabling capabilities such as intelligence, surveillance, and reconnaissance (ISR) aircraft as well as command and control (C2) platforms. Additionally, the PLA Rocket Force seeks to target U.S. bases within the Indo-Pacific region. The dramatic expansion of the PLA Navy poses a further threat of precision strikes against U.S. maneuver forces and fixed bases.[24] By leveraging geographic advantages, such as shorter lines of communication and reduced logistics burdens, the PRC seeks to deter or prevent the United States from deploying forces to the decisive area of operations.[25]

A2/AD assumes that the PLA will have the ability to effectively find, fix, and finish the systems that enable and sustain U.S. forces. However, FATE dramatically complicates PLA targeting efforts through decentralization and distribution. Attempting to target battlefield production systems poses a significant tactical problem, since such capability may be indistinguishable from a standard shipping container, general-purpose truck, or other nondescript structure. Compared to geographically fixed-base or high-signature C2, ISR, and mobility platforms, FATE systems are inherently hard to target. Additionally, traditional models require the stockpiling of thousands of individual parts and end items.

Petty Officer 1st Class Tyler Vongphakdy of Southwest Regional Maintenance Center scrapes 3D-printed part during Joint Exercise Southern California 2025 in Coronado, California, May 8, 2025 (U.S. Navy/Antonio Gonzalez)

However, AM enables the fabrication of a thousand parts from a handful of base materials, vastly simplifying logistics.[26]

Rather than relying on the shipment of complete spare parts from the continental United States, FATE uses raw materials from prepositioned stocks, which reduces opportunities for the PLA to disrupt supply chains. While FATE systems are designed from the outset to be inexpensive and expendable, the A2/AD munitions used to defeat them are far more expensive to produce. For instance, a flight of four sUASs with C2, ISR, and homing-beacon payloads would cost a total of $30,000, based on experience with the Black Phoenix project.[27] In comparison, intercepting these sUASs with an S-300 class surface-to-air missile would likely cost approximately $1 million per shot.[28] Even if PLA forces target the FATE manufacturing systems instead of the end items, a brigade combat team–level system is projected to cost on the order of $200,000, significantly less than any munition expended against it. By employing systems at scale with an average 50x cost advantage, U.S. forces obviate a generation of investment by the PRC in A2/AD.

The PRC's reliance on state-owned enterprises and underinvestment in its professional acquisition corps limits its ability to emulate FATE.[29] FATE is designed to empower company grade officers (CGOs) and noncommissioned officers (NCOs) at the tactical level, fostering a decentralized command structure that allows for rapid decisionmaking and adaptability on the battlefield. Adversaries such as the PRC and the Russian Federation have historically resisted empowering their CGO and NCO corps to a similar degree. As acquisition professional and author Dan Ward states: "The tactical ability to rapidly deliver new capabilities is itself a strategic capability."[30] FATE offers the United States a transformative strategic advantage that will be difficult for the PRC to replicate.

The ability to "go to war with what you can build" rather than "go to war with what you have" fundamentally changes the calculus of strategic competition. By enabling U.S. forces to fabricate mission-specific capabilities at the tactical edge, FATE neutralizes decades of PRC investment in A2/AD systems. This capability not only renders A2/AD strategies less effective but also shifts the focus from preparing for a single large-scale conflict to maintaining a constant ability to innovate and adapt across a range of adversaries. The scalability of FATE ensures that its deployment remains reactive rather than escalatory. In essence,

Air ground equipment in U.S. military's war reserve materiel is stored at Warehouses Service Agency in Sanem, Luxembourg, February 8, 2024 (U.S. Air Force/Thomas Karol)

FATE allows the United States to adapt, build, and win in real time, keeping adversaries—whether the PLA or another emerging threat—on the defensive. This paradigm shift ensures that U.S. forces are not only ready to counter threats today but are also positioned to dominate the battlefields of tomorrow.

FATE at an Industrial Scale

As described in Arthur Herman's *Freedom's Forge*, General Motors established a striking historical precedent of forward-deployed production during World War II. The company discovered that a *Liberty*-class ship could transport 12 times as many trucks if they were disassembled rather than being shipped fully assembled. To realize this efficiency, GM established in-theater assembly plants at locations as far afield as Tunisia, Egypt, Burma, and Iran. These locations achieved incredible throughput and delivered a wide variety of vehicles. For instance, the plant at Andimeshk, Iran, supported Lend-Lease Program shipments to the Eastern Front. It employed 5,000 local nationals under U.S supervision and achieved a production rate of 2,500 vehicles a month.[31] This concept effectively extended the industrial reach of the United States to the tactical edge. As logistics once again become contested by the PLA, forward production reemerges as a solution for the United States and its allies.

Small-scale battlefield fabrication will focus initially on smaller-scale tactical systems, such as sUASs. The focus of these units will be on systems weighing less than 50 pounds that can be fabricated

with CONEX (container express) mobile production nodes. However, the FATE concept can scale beyond the immediate needs of the tactical battlespace. Located in theater, but not on the front lines, larger-scale fabrication hubs would produce more complex systems. These systems would be capable of providing larger UASs, loitering munitions, and unmanned undersea vehicles (UUVs).

Such larger hubs take advantage of the wide variety of base materials that modular AM platforms can provide, including concrete, metallics, and composites. Where appropriate, these systems could use host-nation personnel as operators, echoing the successful World War II approach. This two-tiered model—rapid CONEX-based battlefield production paired with larger forward-area manufacturing—provides scalable flexibility across the spectrum of conflict. It enables the United States to adapt to operational needs ranging from tactical swarming drones to operational-level autonomous systems while complicating adversary targeting and reducing logistical burdens.

One of the most powerful contributions of industrial-scale FATE is in effecting a binding strategy in the Western Pacific. Labor in this region has been driven largely by participation in global value chains with strong regional production networks.[32] By establishing forward-fabrication centers that leverage local national employees for both military and commercial production, the United States could strengthen economic and security ties simultaneously. These facilities could be rapidly retooled to manufacture UASs, UUVs, and subsurface vessels in times of conflict. During peacetime, the host nation may use the same systems to support the production of components for shipping, energy infrastructure, and disaster response.

In this way, FATE provides a military advantage as well as a mechanism to bind partner nations closer to the U.S. security architecture. Such a posture complicates PRC coercion and reinforces a resilient regional coalition well before any crisis begins. For the PLA to strike at FATE, it may be necessary to use force against otherwise neutral countries, diminishing the feasibility of a Chinese fait accompli.[33] Despite these advantages, it is important to consider how FATE would need to address barriers to a widescale deployment.

Structural and Procedural Consequences of Battlefield Fabrication

A straightforward thought experiment can provide a rough sense of the bulk lift effort required to support FATE at an industrial scale. Ukraine publicly states a loss rate of 10,000 sUASs per month during its conflict with Russia. Based on the experience of the Black Phoenix project, a standard intermodal CONEX could contain enough raw material for 500 to 1,000 unmanned mission-adaptable vehicles. A C-17 can carry a maximum of eight CONEX per sortie.[34] Assuming that a similar attrition rate would prevail in the U.S. Indo-Pacific area of responsibility during a widespread conventional conflict, FATE could be sustained by 10 to 20 dedicated C-17 loads per month. For comparison, a single Patriot battalion intertheater redeployment required 73 C-17 loads.[35] While these systems have different missions, they could provide similar impact at the operational level.

Realizing the benefits of industrial-scale application will require FATE to overcome numerous challenges. To overcome these barriers, the joint force should adopt a phased approach to FATE. The rapid prototyping phase is already well underway with systems such as XFab, R-FAB, NAVAIR's AM IPT, and Black Phoenix. One opportunity to garner additional early adopters during this phase is to use spare capacity at existing innovation cells within the joint force as FATE development centers. These initial experiments demonstrate the utility of developing two distinct variants of FATE: battlefield nodes and theater nodes. The smaller battlefield nodes would be optimized for field conditions to support immediate needs, while larger theater nodes are designed for enduring higher-capability needs. Each variant should be developed in parallel using existing technologies.

The next phase is rapid fielding. In this phase, training would begin in earnest, inclusive of both how to build with FATE and how to employ its end items operationally. Joint exercises are important to gather data and begin development of tactics, techniques, and procedures. Events focused on the Indo-Pacific, such as the Northern Edge or Northern Strike exercises, should be a priority for initial fielding. Additionally, this period would serve to validate functional requirements and elements of the product support strategy. Since FATE is a novel system, it is inevitable that it will encounter policy challenges. This phase

Army Private 1st Class Jimmy Roe, assigned to Bravo Company, 299th Battalion Support Brigade, Dagger Brigade, services Lulzbot Taz 2 Hard Plastic 3D Printer, part of Rapid Fabrication via Additive Manufacturing on the Battlefield, at Amberg Training Area, Amberg, Germany, May 4, 2018 (U.S. Army/Elliott Page)

of adoption provides an opportunity to resolve these bottlenecks prior to operations and sustainment.

As FATE ramps up nodes to reach its full operational capability, scalability concerns become paramount. Constraints such as unreliable power, lack of materials, and maintenance requirements are a fact of life in field expedient environments. Mitigations for these conditions include ruggedization, portable power systems, prepositioned stocks of base materials, and adequate organic maintenance training for operators. Using locally acquired material and prepositioned stocks could reduce FATE's logistical requirements. For sUAS capabilities, inexpensive plastic AM systems easily produce the required end items and can be set up within days, even in field conditions. More advanced capabilities to print metal or composite material require conditioned power and require months to establish at a theater node. However, the resulting end items provide greater capabilities.

Cybersecurity is an important concern that can be addressed by securing manufacturing systems on closed-loop networks or air-gapped systems, using encrypted design libraries to protect critical data. Keeping up with rapidly changing technologies requires integrating open architectures and modular designs into the manufacturing systems, allowing for fast upgrades and ease of maintenance by cross-trained personnel. Additionally, variable quality is a risk to the viability of delivering credible end items. Addressing doctrinal and cultural resistance to these changes will require strong advocacy from leadership across the joint force and demonstrable proofs of concept, like those achieved in the Black Phoenix project.

The Defense Logistics Agency (DLA) has made significant strides in establishing a supply chain for AM. For the first time, DLA has awarded a competitive commercial contract for AM production based on a data package including 3D drawings, print files, and quality assurance requirements.[36] Through its AM Integrated Product Team, DLA has also established a joint certification program for contractors as well as partnering with DOW organic manufacturers. While these efforts are still ongoing, they provide evidence that the logistics of FATE are manageable with modifications to current organizations and processes. These initiatives show that DOW is already beginning to lay the groundwork for integrating battlefield manufacturing.

An operationalized battlefield manufacturing capability is a profound paradigm shift for the joint force. Under the existing approach, uniformed services equip combat forces with end items in response to requirements derived from strategic guidance and validated primarily through Military Department processes with joint validations only where required by statute, and prioritized against the Joint Staff's annually ranked KOPs. With FATE, the acquisition community equips the joint force with a capability to produce a class of expendable end items, tailored to battlefield needs and delivered within the operational planning cycle. Fundamentally, this approach considers the ability to manufacture capability on demand in the field as an inherent element of employing military force.

Although the existing Acquisition Decision Support Systems are intended to support the procurement of end items, these processes can be adapted to field FATE. For instance, conventional key performance parameters for a UAS might include threshold requirements such as required operating altitude, loiter time, and payload capacity. In contrast, the most essential attribute of a FATE system is its ability to fabricate effective military capabilities on an operationally relevant timeframe. A program of record that is itself capable of creating other systems is a revolutionary requirement. However, when reduced to its most fundamental attributes, FATE can be designed, procured, and sustained through established acquisition processes.

Cost and budget concerns can be alleviated by emphasizing long-term savings through lower production costs, as seen with systems like Black Phoenix. The potential trade-off between speed and quality in rapid manufacturing cycles is mitigated by focusing on mission-specific requirements, thus producing low-cost expendable systems that meet the immediate needs of the battlefield without requiring high durability. Operational risks such as making manufacturing systems targets for the enemy can be countered by ensuring they are mobile, easily concealed, and rugged enough to withstand harsh environments, a lesson learned from early tests at Eglin Air Force Base, Florida. While FATE poses implementation challenges, effective mitigation strategies ensure the capability remains scalable and operationally viable. When FATE is implemented across the joint force, its benefits far outweigh its costs and enable the rapid technological development as a form of maneuver, allowing the U.S. military to outpace adversaries in innovation, adaptability, and operational resilience.

Successful battlefield innovation is characterized by a well-defined combat need; a willingness to deploy immature capability; iteration; and a direct connection between developers and operators.[37] The technological developments underlying FATE enable a novel approach of empowering end users to become developers themselves. By reducing the barriers to decision and action, this approach has the potential to eliminate seams and dramatically shorten the acquisition OODA loop so significantly that technological adaptability becomes a decisive form of military maneuver. This concept, called Technology Maneuver Warfare (TMW), treats technological adaptation as a deliberate and decisive battlefield action. In TMW, capabilities are produced at the tactical edge that minimize sustainment needs and are highly adaptive to adversary developments and countermeasures. Although FATE presents numerous challenges, each comes with a feasible solution that makes battlefield manufacturing both practical and essential. Providing operators with a maneuverable manufacturing capability, in both physical and technological dimensions, represents the culmination of trends toward decentralized innovation and rapid adaptation in modern warfare.

Conclusion and Recommendations

FATE is a transformative approach to modern warfare that will significantly reduce U.S. dependence on vulnerable supply chains and fixed bases. By dispersing production capabilities across the battlefield, FATE complicates adversarial targeting, making it harder for the PRC to neutralize U.S. forces. Most critically, FATE allows for rapid adaptation to evolving tactical and operational needs, enabling U.S. forces to stay ahead of threats, iterate solutions quickly, and impose asymmetric costs on opponents. This flexibility positions the United States for success in future conflicts, ensuring battlefield dominance through innovation and speed.

The time to act is now. With current technology and sufficient resources, limited FATE capabilities can be fielded within 2 years. Between 2027 and 2030, the FATE capability could provide essential battlefield manufacturing, such as rapidly producing sUASs and mission-specific tools using 3D printing, AI-driven design, and open architectures. These mobile units at the tactical edge would enable decentralized production, thus reducing supply chain vulnerabilities and enhancing agility—critical enablers for agile combat employment in contested environments.

Beyond 2030, FATE has the potential to expand to more complex systems, such as Group 3 or Group 4 UASs and loitering munitions, as well as autonomous land and sea vehicles. With modular production technologies, FATE may fabricate autonomous vehicles, ISR platforms, and munitions, optimizing designs in real-time via AI. However, the United States must not wait to achieve these higher levels of complexity. Immediate investment in training, deployment, and field testing will ensure FATE becomes an operational capability before the critical window of 2027 to 2030 opens. **JFQ**

Notes

[1] Quoted in Gabriel Almodovar, "Igniting a Cultural Insurgency in the Acquisition Community: Part I," *Over the Horizon Journal*, August 20, 2018, https://othjournal.com/2018/08/20/igniting-a-cultural-insurgency-in-the-acquisition-community-part-i/.

[2] Elbridge Colby, "A Strategy of Denial for the Western Pacific," U.S. Naval Institute *Proceedings* 149 no. 3 (2023), https://www.usni.org/magazines/proceedings/2023/march/strategy-denial-western-pacific.

[3] Jen Judson, "Army Picks Two Companies to Get Small Drones for Brigade Combat Teams," *Defense News*, September 12, 2024, https://www.defensenews.com/land/2024/09/12/army-picks-two-companies-to-get-small-drones-to-brigade-combat-teams/.

[4] Memorandum for Senior Pentagon Leadership, Commanders of Combatant

Commands, and Defense Agency and DOD Field Activity Directors, *Reforming the Joint Requirements Process to Accelerate Fielding of Warfighting Capabilities* (Washington, DC: Office of the Secretary of Defense, August 20, 2025), https://www.dau.edu/cop/rqmt/documents/memo-osd-reforming-joint-requirements-signed-20-aug-2025.

[5] Andrew Scobell and Larry M. Wortzel, *Civil-Military Change in China: Elites, Institutes, and Ideas after the 16th Party Congress* (Carlisle Barracks, PA: U.S. Army War College Press, 2004), 334–5, https://press.armywarcollege.edu/monographs/33/.

[6] *Military and Security Developments Involving the People's Republic of China 2022: Annual Report to Congress* (Washington, DC: Office of the Secretary of Defense, 2022), https://media.defense.gov/2022/nov/29/2003122279/-1/-1/1/2022-military-and-security-developments-involving-the-peoples-republic-of-china.pdf.

[7] Enterprise Capability Collaboration Team, *Air Superiority 2030 Flight Plan* (Washington, DC: Headquarters Department of the Air Force, May 2016), https://www.af.mil/portals/1/documents/airpower/air%20superiority%202030%20flight%20plan.pdf.

[8] 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/.

[9] International Organization for Standardization, ISO/ASTM52900-15, *Standard Terminology for Additive Manufacturing—General Principles—Terminology* (West Conshohocken, PA: ASTM International, 2021).

[10] *Department of Defense Additive Manufacturing Strategy* (Washington, DC: Office of the Under Secretary of Defense for Research and Engineering, January 2021), 4, https://www.cto.mil/wp-content/uploads/2021/01/dod-additive-manufacturing-strategy.pdf.

[11] Peter Zelinski, "Where Does a Hybrid Metal AM Machine Tool Make Sense? Ask the Marines," *Modern Machine Shop*, February 4, 2019, https://www.mmsonline.com/articles/metal-am-in-a-machine-shop-ask-the-marines.

[12] Wyatt Olson, "RIMPAC Exercise Tests Bounds of 3D Printing of Crucial Parts in Real Time," *Stars and Stripes*, July 5, 2024, https://www.stripes.com/theaters/asia_pacific/2024-07-05/rimpac-3-d-printing-navy-hawaii-14398425.html.

[13] Martin Egnash, "Soldiers Needed Humvee Parts and Rifle Grips During an Exercise—So They Printed Them," *Stars and Stripes*, May 9, 2018, https://www.stripes.com/news/2018-05-09/soldiers-needed-humvee-parts-and-rifle-grips-during-an-exercise-so-they-printed-them-1507448.html.

[14] Craig Collins, "Additive Manufacturing," *Defense Media Network*, October 2, 2019, https://www.defensemedianetwork.com/stories/additive-manufacturing-department-of-defense-3d-printing-military-logistics/.

[15] Beth Reece, "Parts on Demand," Defense Logistics Agency, April 20, 2016, https://www.dla.mil/About-DLA/News/News-Article-View/Article/744030/parts-on-demand/.

[16] Nicholas Slayton, "Air Force Team Designs, 3D Prints, Launches New Drone in Under 24 Hours," *Task and Purpose*, May 4, 2024, https://taskandpurpose.com/news/air-force-designs-drone-24-hours/.

[17] Jack Detsch, "Ukraine's Cheap Drones Are Decimating Russia's Tanks," *Foreign Policy*, April 9, 2024, https://foreignpolicy.com/2024/04/09/drones-russia-tanks-ukraine-war-fpv-artillery/.

[18] David Kirichenko, "Analysis: Future of Drones on Ukraine Battlefield," *Kyiv Post*, May 11, 2024, https://www.kyivpost.com/analysis/32482.

[19] David Kirichenko, "Ukraine's Innovative Drone Industry Helps Counter Putin's War Machine," *UkraineAlert* (blog), Atlantic Council, June 26, 2024, https://www.atlanticcouncil.org/blogs/ukrainealert/ukraines-innovative-drone-industry-helps-counter-putins-war-machine/.

[20] Kateryna Bondar, "Closing the Loop: Enhancing U.S. Drone Capabilities Through Real-World Testing," Center for Strategic and International Studies, August 21, 2024, https://www.csis.org/analysis/closing-loop-enhancing-us-drone-capabilities-through-real-world-testing.

[21] Ben Aris, "Long Read: Ukraine Is Losing the Drone War," *bne IntelliNews,* May 27, 2024, https://www.intellinews.com/long-read-ukraine-is-losing-the-drone-war-323020/.

[22] Rudy Ruitenberg, "Small Drones Will Soon Lose Combat Advantage, French Army Chief Says," *Defense News*, June 19, 2024, https://www.defensenews.com/global/europe/2024/06/19/small-drones-will-soon-lose-combat-advantage-french-army-chief-says/.

[23] David Hambling, "Ukraine Fields Unjammable Fiber Optic FPV Attack Drone," *Forbes*, November 7, 2024, https://www.forbes.com/sites/davidhambling/2024/11/07/ukraine-fields-reboff-unjammable-fiber-optic-fpv-attack-drone/.

[24] *Military and Security Developments Involving the People's Republic of China 2023: Annual Report to Congress* (Washington, DC: Office of the Secretary of Defense, 2023), https://media.defense.gov/2023/oct/19/2003323409/-1/-1/1/2023-military-and-security-developments-involving-the-peoples-republic-of-china.pdf.

[25] Norman Friedman, "American Sea Power Project: Geography Plays an Ocean-Sized Role," U.S. Naval Institute *Proceedings* 148, no. 6 (2022), https://www.usni.org/magazines/proceedings/2022/june/american-sea-power-project-geography-plays-ocean-sized-role.

[26] Jen Judson, "U.S. Army Inches Closer to 3D-Printing Spare Parts Under Fire," *Defense News*, October 14, 2024, https://www.defensenews.com/land/2024/10/14/us-army-inches-closer-to-3d-printing-spare-parts-under-fire.

[27] Author's direct experience with the Black Phoenix program.

[28] "Missile Interceptors by Cost," Missile Defense Advocacy Alliance, February 2024, https://missiledefenseadvocacy.org/missile-defense-systems-2/missile-defense-systems/missile-interceptors-by-cost/.

[29] Christian Curriden, *The Chinese Acquisition Process* (Santa Monica, CA: RAND, 2023), https://www.rand.org/pubs/testimonies/CTA2691-1.html.

[30] Dan Ward, *F.I.R.E.: How Fast, Inexpensive, Restrained, and Elegant Methods Ignite Innovation* (New York: HarperCollins, 2014), 20.

[31] Arthur Herman, *Freedom's Forge: How American Business Produced Victory in World War II* (New York: Random House, 2012), 249–50.

[32] Elisabetta Gentile, "Skill Flows and the Fourth Industrial Revolution: Future Questions and Directions for the ASEAN Economic Community," in *Skilled Labor Mobility and Migration: Challenges and Opportunities for the ASEAN Economic Community*, ed. Elisabetta Gentile (Cheltenham, UK: Edward Elgar Publishing, Ltd., 2019), 271, https://www.adb.org/sites/default/files/publication/517601/skilled-labor-mobility-migration-asean.pdf.

[33] Colby, "A Strategy of Denial for the Western Pacific," 207–9.

[34] Carl D. Sullivan, *C-17 Container Study* (Washington, DC: Air Force Center for Studies & Analyses, January 1987), https://apps.dtic.mil/sti/tr/pdf/ADA362578.pdf.

[35] Howard Altman, "It Took 73 C-17 Loads to Move Patriot Battalion From Pacific to Middle East," *TWZ*, April 10, 2025, https://www.twz.com/air/it-took-73-c-17-loads-to-move-patriot-battalion-from-pacific-to-middle-east.

[36] Beth Reece, "DLA Awards First Competitive Contract for Additive Manufacturing," Defense Logistics Agency, November 18, 2024, https://www.dla.mil/About-DLA/News/News-Article-View/Article/3967178/dla-awards-first-competitive-contract-for-additive-manufacturing/.

[37] Mykhaylo Lopatin, "Bind Ukraine's Military-Technology Revolution to Rapid Capability Development," *War on the Rocks*, January 23, 2024, https://warontherocks.com/2024/01/bind-ukraines-military-technology-revolution-to-rapid-capability-development/.