ARMING FOR THE AIR LITTORAL

The Defense Industrial Base and Future Air Warfare

Jennifer Kavanagh

To effectively contest the air littoral, the US Air Force will need to meet two requirements: production at scale and continuous innovation. First, operating in this subdomain against a major power adversary will require an incredible mass of small drones, loitering munitions, and counter-unmanned aerial systems that exceeds the limits of the US defense industrial base and commercial market. Second, rapid innovation beyond the current Department of Defense procurement model is needed. This article describes these challenges and their implications for Air Force operations. It recommends the development of a new paradigm with three lines of effort: a new business model focused on capabilities, not programs; investment in scaling cutting-edge technologies; and a workforce that continuously upgrades the subdomain's systems and software.

US Air Force Chief of Staff David W. Allvin recently reminded his service of adapting to the changing character of air warfare: "Do not get trapped in paradigms of the past." Key among these changes is the emergence of the air littoral—the space between the ground and the sky—as a critical new subdomain.[1] But just as operating in the air littoral will require a "paradigm change in American military thinking about verticality," so too arming for the air littoral will require such a shift in how the Department of Defense thinks about innovating, producing, and integrating the systems needed to operate in the new trans-domain.[2]

Russia's war in Ukraine has illustrated vividly both the peril and the promise of the air littoral for modern militaries.[3] Cheap drones operating at low altitudes over battlefields have allowed Ukraine at times to offset Russia's significant advantage in firepower

Dr. Jennifer Kavanagh is a senior fellow and director of military analysis at Defense Priorities.

1. Maximilian K. Bremer and Kelly A. Grieco, "To Reinvent Itself, the US Air Force Must Go Big on Small Drones," *Defense News*, April 2, 2024, https://www.defensenews.com/.
2. Maximilian K. Bremer and Kelly A. Grieco, "The Air Littoral: Another Look," *Parameters* 51, no. 4 (Winter 2021–22), https://press.armywarcollege.edu/.
3. Dominika Kunertova, "The War in Ukraine Shows the Game-Changing Effect of Drones Depends on the Game," *Bulletin of the Atomic Scientists* 79, no. 2 (2023).

but have complicated its efforts to advance along entrenched front lines.[4] Meanwhile, Russia has relied on large numbers of small drones to overwhelm Ukrainian air defenses but has been vulnerable to Ukraine's use of longer-range drones against oil refineries deep inside Russia.[5]

The war has also driven home the mass and technological requirements of operating in the air littoral. For example, the Ukrainian armed forces report using up to 50,000 "first person view" drones and burning through hundreds of air defense missiles each month.[6] Sustaining high rates of production and continually innovating to outsmart Russian defenses have challenged Ukraine's defense industry and surpassed the capacity of its Western partners, leaving Kyiv to rely on cheaper Chinese-made systems.[7] Russia has similarly struggled to meet its demand for small drones and munitions. In addition to investing in domestic drone manufacturing, Russia has purchased thousands of Shahed drones from Iran.[8] In a future war involving the United States and a major power adversary, the demands of the air littoral would likely be even greater.

The air littoral is best defined geographically as the space between the ground and 10,000 feet above it.[9] As one analysis asserts, going forward, the contest for air control will depend as much on what happens in this in-between space as it will on ground-based air defense or advanced fighter jets operating at high altitudes in the "blue sky."[10] "Air forces can now operate large numbers of small, relatively cheap drones in the air littoral," the analysis notes, arguing that "a single system cannot persist indefinitely in this airspace, but large numbers of them can achieve persistence indirectly, by continually rotating in and out."[11] The air littoral will be strategically and operationally important across theaters, with some variations. Drones and loitering munitions dominate the skies in Ukraine, making the air littoral nearly decisive to battlefield outcomes. In an East Asian contingency, standoff missile strikes, bombers, and fighters are likely to matter a great deal more, but even here

4. Maximilian K. Bremer and Kelly A. Grieco, "In Defense of Denial: Why Deterring China Requires New Airpower Thinking," *War on the Rocks*, April 3, 2023, https://warontherocks.com/.

5. Marcel Plichta, "Russia's Growing Kamikaze Drone Fleet Tests Ukraine's Limited Air Defenses," *Atlantic Council* (blog), May 14, 2024, https://www.atlanticcouncil.org/.

6. David Axe, "As the Ukrainians Fling 50,000 Drones a Month, the Russians Can't Get Their Drone-Jammers to Work," *Forbes*, February 16, 2024, https://www.forbes.com/.

7. Brett Forrest and Heather Somerville, "How American Drones Failed to Turn the Tide in Ukraine," *Wall Street Journal*, April 10, 2024, https://www.wsj.com/.

8. "How Are 'Kamikaze' Drones Being Used by Russia and Ukraine?," BBC News, December 29, 2023, https://www.bbc.com/.

9. *Joint Maritime Operations*, Joint Publication (JP) 3-32 (Washington, DC: Chairman of the Joint Chiefs of Staff, 2023), I-5; and Bremer and Grieco, "Air Littoral."

10. Bremer and Grieco, "Small Drones"; and "Air Littoral."

11. Bremer and Grieco, "Small Drones."

the ability to contest the air littoral—for example with drone swarms—will be a necessary component of tactical offensive and defensive operations.[12]

To successfully contest the air littoral, the Air Force will need to meet two requirements: production at scale and continuous innovation. First, operating in this subdomain against a major power adversary will require an incredible mass of systems, likely surpassing the capacity of current US suppliers. Competing in the air littoral in East Asia against China, for example, would involve possibly hundreds of thousands of small drones, loitering munitions, and counterdrone systems along with man-portable air defense. "The fact of the matter is: we don't have an industrial base to do this," an expert in critical technologies assessed of meeting the demand for small drones in similar scenarios.[13]

Second, successful operations in the air littoral will require a procurement model that supports constant innovation and that is able to rapidly generate new systems able to overcome adversary defenses or disrupt adversary operations. As seen on the battlefields in Ukraine, adversaries can and will adapt quickly in this subdomain, developing defenses that can degrade, disrupt, or destroy small drones and loitering munitions, either kinetically or using electronic warfare and jamming, rendering any advantage only temporary.[14] As Georgii Dubynskyi, Ukraine's deputy minister of digital transformation, described, "What is flying today won't be able to fly tomorrow."[15]

Although the Department of Defense is often on the cutting edge of emerging technologies, the timeline for translating these into military hardware and software can be lengthy, far exceeding the rapid innovation cycles—days or weeks in length—necessary if the United States is to contest the air littoral with drone and counterdrone systems or other technologies in the future.

Taken together, the demands of operating in the air littoral will strain not only the physical capacity of the US defense industrial base (DIB) but also the Department of Defense's ability to innovate, field, and integrate new systems at scale. These challenges are not insurmountable, but a new business model, new technologies, and the right workforce will be required.

Dueling Dilemmas: Scale and Innovation

Arming for the air littoral will require the Department of Defense and the Air Force to find ways to meet two demanding requirements that are often in conflict: massive scale and rapid innovation. The current US DIB can produce large quantities of munitions if given sufficient time frames and simple designs. It can also innovate to

12. Evan Montgomery, Travis Sharp, and Taylor Hacker, "Quality Has a Quality All Its Own: The Virtual Attrition Value of Superior-Performance Weapons," *War on the Rocks*, June 19, 2024, https://warontherocks.com/.

13. Patrick Tucker, "Can Troops with 3D Printers Save the Pentagon's Mass-Drone Vision?," Defense One, November 22, 2023. https://www.defenseone.com/.

14. Forrest and Somerville, "American Drones."

15. Forrest and Somerville.

produce small numbers of advanced systems. But producing at scale and harnessing emerging technologies simultaneously can be difficult.

Production at Scale

To operate effectively in the air littoral, the United States must be able to produce large numbers of small unmanned aerial systems (UAS) and counter (c)-UAS systems quickly to saturate contested airspace and to replace systems lost to attrition.[16] This concept of operations is likely to significantly strain a US defense industrial base that suffers from limited production capacity, constrained access to key input parts and technologies, and workforce shortages that slow delivery of key systems.[17]

These pressures affect platforms of all kinds, from 155mm ammunition to F-35 fighter jets, but they have unique implications for the small-UAS and c-UAS market. Specifically, the large defense primes that have the capacity to ramp up production quickly are relatively less interested in the small drone market and its low profit margins.[18] This forces the Defense Department to turn to the commercial market, including established defense tech companies and smaller start-ups, to meet the scale demands of the air littoral, but the US commercial drone market is not currently up to the task.[19]

The commercial drone market is presently dominated by Chinese companies, both in terms of quality and quantity. Chinese-made drones continue to win out over those manufactured in the United States.[20] Chinese companies hold three of the top five spots in US drone sales, comprising 90 percent of the commercial market, despite rapid growth among US manufacturers.[21] Chinese firms also dominate the markets for drone components and inputs, so even some US-made drones end up including Chinese-made parts. These are off-limits to the Department of Defense, which is prevented from using drones or component parts made in China and forced to depend on a small number of domestic suppliers.[22]

16. Bremer and Grieco, "Small Drones."

17. Doug Cameron, "Pentagon Plan to Buy Thousands of Drones Faces Looming Snags," *Wall Street Journal*, September 25, 2023. https://www.wsj.com/.

18. Cameron.

19. Jonathan D. Caverley, "Horses, Nails, and Messages: Three Defense Industries of the Ukraine War," *Contemporary Security Policy* 44, no. 4 (2023); and Jacques S. Gansler and William Lucyshyn, *Commercial-Off-the-Shelf (COTS): Doing It Right* (College Park, MD: University of Maryland, School of Public Policy, Center for Public Policy and Private Enterprise, 2008), https://apps.dtic.mil/.

20. Ben Jiang, "China's Drone Industry Crosses US$14-Billion Mark in Annual Output in 2022 amid Local Market Expansion into Low-Altitude Logistics," *South China Morning Post*, June 5, 2023, https://www.scmp.com/; and Dnyaneshwar Dhanawade, "U.S. Commercial Drone Market Size to Reach USD 14.11 Bn by 2033," LinkedIn, March 7, 2024, https://www.linkedin.com/.

21. Stacie Pettyjohn, "The US Can't Let China Dominate the Small-Drone Market," Center for a New American Security, April 1, 2024, https://www.cnas.org/.

22. Juan Plaza, "The Potential Impact of the 2024 National Defense Authorization Act on the Commercial UAV Industry," Commercial UAV News, January 8, 2024, https://www.commercialuavnews.com/.

In addition to being ubiquitous in the United States and across global markets, Chinese drones are also higher quality: they have more endurance and better cameras, can fly at faster speeds, and are less costly than US-made drones, which have been reported to be "glitchy" on the battlefields in Ukraine, easy to break and hard to maintain.[23] These differences in quality and price reflect the comparative robustness of China's domestic industrial base, bolstered by generous government subsidies, its civil-military fusion, and a high-tech workforce.[24] China's domestic drone production, for example, continues to grow at rates above the global curve.[25]

Notably, it is not only in small drone production where weak supply chains and lack of component parts are obstacles. Other systems needed in the air littoral are affected as well, including mobile air defense systems like the Javelin and Stinger. Low quantities of the motors and specialized semiconductors needed for these man-portable systems have kept Javelin production at just about 2,500 per year and Stinger production at a much lower 750 per year—rates that are far below what would be needed to support the air littoral in a future conflict.[26]

Even if a more robust commercial market for these systems and components existed, however, the Department of Defense is currently not well set up to make use of the additional production capacity. Historically, the United States has not been effective at integrating smaller defense contractors and commercial producers into its procurement cycle.[27] There are efforts to change this, led by the Defense Innovation Unit and others in the Pentagon, but the progress has been slow. In fiscal year 2023, for instance, contracts to defense tech start-ups made up only 1 percent of the total $411 billion in DoD procurement.[28] The Defense Innovation Unit's Blue UAS program aims to ease access for makers of small drones by certifying systems as meeting DoD security requirements, but according to suppliers, residual barriers—institutional and cultural—to commercial technologies remain.[29]

Working with many different types of contractors does come with challenges for the Defense Department, however, as each has its own incentive structures and levels

23. Forrest and Somerville, "American Drones."

24. Brad Howard, "Can U.S. Drone Makers Compete with Cheap, High-Quality Chinese Drones?," CNBC, October 11, 2023, https://www.cnbc.com/.

25. "China's Drone Industry Reports Robust Development: Data," State Council, People's Republic of China, March 30, 2024, https://english.www.gov.cn/.

26. "Ramping Up: Lockheed Martin Steadily Increasing Production of High-Demand Systems," Lockheed Martin (website), February 15, 2024, https://www.lockheedmartin.com/.

27. *Vital Signs 2024: The Health and Readiness of the Defense Industrial Base* (Arlington, VA: National Defense Industrial Association, April 2024), https://www.ndia.org/.

28. Heather Somerville, "Investors Are Betting on Defense Startups. The Pentagon Isn't," *Wall Street Journal*, January 25, 2024, https://www.wsj.com/.

29. Courtney Albon, "Defense Innovation Unit Eyes Partnerships for Drone-Vetting Effort," *C4ISRNET*, January 19, 2023, https://www.c4isrnet.com/.

of flexibility.[30] For instance, the Department of Defense will have much less leverage with a company whose sales are dominated by commercial buyers as compared to a defense tech firm that sells only to military clients.[31]

Given defense budgets, cost acts as a final constraint on achieving scale needed in the air littoral. Not just drones, but also c-UAS, air defense missiles, and loitering munitions manufactured in the United States remain far more costly than similar systems built and operated outside the United States. There are many reasons for this, including the US preference for advanced systems with many bespoke requirements and higher US labor costs.

For example, the Switchblade 600, the first recipient of contracts under the new Replicator Program—an initiative to rapidly procure large numbers of multidomain uncrewed systems, some of which would operate in the air littoral—costs $60,000 to $80,000. At this price, even if the entire $1 billion initially allocated to the program were put toward Switchblade drones, it would still amount to only 12,000 to 17,000 systems—out of a possible total required several hundred thousand.[32] Cost is an even greater challenge in the c-UAS market, where the high price of candidate systems has prevented the Pentagon from acquiring anywhere close to the number of systems it needs to defeat adversary threats.[33]

To sustainably achieve the scale needed to meet the demands of the air littoral, the US military must combine incentives aimed at rapidly increasing and harnessing the domestic commercial drone market for military ends with targeted investments in the DIB to relieve key bottlenecks.

Rapid Innovation

Production at scale will be required to arm for the air littoral, but it alone will not be enough. In the air littoral and during a conflict with a well-armed adversary, the Air Force and the Department of Defense will need to innovate rapidly and continuously, evolving their systems, capabilities, and defenses as the adversary adapts—sometimes in just weeks or days.[34] The service and the Department must embrace a continuous innovation model that focuses both on upgrading military hardware and advancing software.[35]

---

30. Jonathan Caverley, Ethan Kapstein, and Jennifer Kavanagh, "One Size Fits None: The United States Needs a Grand Defense Industrial Strategy," *War on the Rocks*, November 16, 2023, https://warontherocks.com/.

31. Caverley, Kapstein, and Kavanagh.

32. Marc Selinger, "Stinger Missile Production to Rise 50% by 2025, US Army Says," Janes, January 25, 2023, https://www.janes.com/.

33. John Grady, "Pentagon to Industry: Build Drones Cheaper, Faster; Cost Per Unit Matters," *USNI News*, February 20, 2024, https://news.usni.org/.

34. Noah Robertson, "Replicator: An Inside Look at the Pentagon's Ambitious Drone Programming," *Defense News*, December 19, 2023, https://www.defensenews.com/.

35. Robert P. Bremner and Kathleen M. Eisenhardt, "Organizing Form, Experimentation, and Performance: Innovation in the Nascent Civilian Drone Industry," *Organization Science* 33, no. 4 (2022).

The current DoD innovation process—from idea generation to fielding—tends to be lengthy and onerous. Years typically pass during the research and development (R&D) phase, followed by prototypes, experimentation, and eventually fielding.[36] Initiatives run through the Defense Innovation Unit, including the Rapid Defense Experimentation Reserve (RDER), are intended to operate more quickly. RDER, for instance, employs "agile development methods" to cut two to four years off the typical development timeline for high demand emerging technologies.[37] These efforts may help address the peacetime innovation problem but will be insufficient in a contingency.

The United States does have some successes when it comes to rapid innovation during wartime. The best-known example is the Mine Resistant Ambush Protected (MRAP) vehicle program, which relied on a bespoke acquisition process to meet the urgent need for vehicles better able to protect against the improvised explosive devices killing American Soldiers in Iraq. Within 24 months of the need being identified in February 2005, the first MRAP vehicles began rolling of production lines. A little more than a year later, almost 7,000 vehicles had been delivered to Soldiers in the field.[38]

To achieve this rapid outcome, the Department of Defense relied only on proven technologies and commercially available products, specified minimal requirements, offered "indefinite delivery indefinite quantity" contracts to nine commercial sources, and used a concurrent testing approach. Notably, of the nine original indefinite-delivery-indefinite-quantity recipients, only one—General Dynamics—is among today's major defense primes.[39] Suppliers were encouraged to use nondevelopmental solutions—items already produced for other US government or Allied entities or commercial items in need of only minor modifications—to the extent possible. The program benefited from investment by contractors themselves, access to critical materials made possible when the Defense Department designated the program its "highest priority," and supplemental appropriations from Congress.[40]

Clearly, the Department of Defense can act outside of normal channels to innovate rapidly. The MRAP program had its shortcomings, however. First, while contractors were able to innovate quickly, they were less effective at innovating continuously, meaning that the MRAP did not evolve as conditions and needs of US Soldiers in Iraq and Afghanistan changed. Second, the program produced far more vehicles than the US military could use, an overcapacity problem that was written off as unavoidable

36. Peter Dombrowski and Andrew L. Ross, "The Revolution in Military Affairs, Transformation and the Defence Industry," *Security Challenges* 4, no. 4 (2008).

37. Jon Harper, "Pentagon Wants $450M for RDER Tech Experiments in Fiscal 2025," Defense Scoop, March 11, 2024, https://defensescoop.com/.

38. *Testimony before the House Armed Services Committee, Defense Acquisition Reform Panel, Defense Acquisitions: Rapid Acquisition of MRAP Vehicles, Statement of Michael J. Sullivan, Director Acquisition and Sourcing Management* (Washington, DC: US Government Accountability Office [GAO], October 8, 2009), https://www.gao.gov/.

39. Marine Corps Systems Command, "Marine Corps Announces Mine Resistant Ambush Protected Vehicle Contracts," US Marines (website), January 26, 2007, https://www.marcorsyscom.marines.mil/.

40. *Statement of Michael J. Sullivan*.

but that represented wasted resources.[41] Third, small defense suppliers were the winners in the initial round of contracts, but soon the larger defense primes swept up much of the MRAP production, crowding out the original innovators.[42]

This example provides positive and negative lessons when applied to the air littoral. Using many contractors simultaneously, relying on proven technologies and existing systems, and employing a concurrent testing approach were integral to the program's success and should be replicated in efforts to ramp up the production of small-UAS, c-UAS, and other air littoral capabilities. But multiyear contracts that did not incentivize continued innovation, together with inflated production targets, resulted in unnecessary expense, privileged large defense contractors, and ultimately left US military personnel vulnerable in the longer run.

To avoid these mistakes in the future, the Department of Defense will need to balance processes built to encourage rapid innovation and production at scale with contract mechanisms that favor caution, incrementalism, and risk aversion. Further, contract mechanisms must guarantee the ability to quickly surge, decrease, or reallocate production of specific systems as battlefield demand signals change.[43]

The MRAP example also provides several warnings about current Air Force and DoD approaches to arming for the air littoral. First, the success of the MRAP program relied fundamentally on the existence of a robust commercial market able to rapidly develop a new product and scale efficiently. This does not exist in the case of small drones—or other air littoral technologies such as c-UAS or loitering munitions.

Second, the MRAP program relied on special access to critical materials and supplemental funding. Thus far, efforts to arm for the air littoral have not had either but have instead faced supply constraints and relied on funding taken from elsewhere in the DoD budget.[44] Third, while the MRAP's timeline is impressive compared to other similar programs, the innovation cycle for drones and loitering munitions intended for the air littoral would need to be substantially faster and the Defense Department would need to field more systems—on the order of 10 times as many—and more diverse systems, for an extended period of time.

Finally, even with rapid innovation of new military hardware like that accomplished by the MRAP, air littoral operations can only be sustained if the lifespan of existing platforms can be extended with software updates, system upgrades, and rapid remote repairs to overcome adversary adaptation. Right now, this is not possible.[45]

---

41. Chris Rohlfs and Ryan Sullivan, "The MRAP Boondoggle," *Foreign Affairs*, July 26, 2012, https://www.foreignaffairs.com/.

42. *FY2010 Annual Report* (Washington, DC: Office of the Director, Operational Test and Evaluation, December 2010), "Mine Resistant Ambush Protected (MRAP) Family of Vehicles," 29–30, https://www.dote.osd.mil/.

43. Jerry McGinn, "How to Use the 'MRAP Mindset' to Get US Industrial Base on a Wartime Footing," Breaking Defense, January 3, 2024, https://breakingdefense.com/.

44. Matt Berg, " 'Disorganized and Confusing': Lawmakers, Industry, Rip Pentagon Plans for Drones," *Politico*, December 17, 2023, https://www.politico.com/.

45. Forrest and Somerville, "American Drones."

US drone manufacturers report that while they have the technical ability to update drone software to overcome Global Positioning System jamming and electronic warfare challenges, they are prevented from easily doing so by long DoD review processes, rendering US drones obsolete in Ukraine.[46] Delays are caused largely by institutional and workforce issues. Specifically, the software systems running small drones and other air littoral systems are managed by contractors, not in-house military personnel. This is largely a function of the limited number of skilled coders in uniform across the military services.

Some sort of safety review is required to guard against cyber threats and sabotage, but the current process can take weeks or months—far too long on an active battlefield. While the Defense Innovation Unit is working to reduce the timeline to a few days, even this may be too long in contested environments where the goal is persistent presence.[47]

While the Department of Defense tends to think of innovation as episodic, the air littoral will necessitate that the process is continuous. Achieving this end will require an evolution not just in military hardware but also, crucially, the software on which that hardware runs. Like efforts to achieve production at scale, this type of innovation will also lean heavily on the commercial sector, which has been on the cutting edge of drones and emerging technologies.

A New Paradigm

Meeting the dual challenges of achieving production at scale and maintaining continuous innovation to arm for the air littoral necessitates a change in paradigm. Neither spending more to expand production capacity nor leaning into new emerging technologies alone will suffice. Instead, the Department of Defense and Air Force will need a new approach: (1) Commercial suppliers must be the center of product development and procurement; (2) the Department and service must shift from a reliance on advanced technologies to commercially available and proven capabilities that can be scaled more rapidly; and (3) the Department and service must prioritize utility and versatility over complexity, seeking the good-enough rather than the perfect solution.

Three changes will jumpstart this transformation, namely, a new business model, new technologies, and a new workforce.

A New Business Model

The Defense Department and the Air Force will need to develop a new business model that can mobilize not just the defense industrial base but the broader US industrial base, to support rapid production at scale while supporting continuous innovation.

The elements of a new business model for the DIB to support the air littoral can be pulled from past rapid manufacturing and innovation successes. The MRAP program offers one model, best suited for areas where there are already commercially available

46. Forrest and Somerville.
47. Forrest and Somerville.

technologies and many available suppliers. Operation Warp Speed (OWS), used to rapidly develop and manufacture COVID-19 vaccines across the United States during the global pandemic, offers another case when there are no existing commercial solutions and where rapid innovation requires more significant R&D dollars.

Operation Warp Speed, a public-private partnership, allocated substantial government funds to support first the research and development of multiple different vaccine candidates and then to rapidly manufacture the most promising technologies while testing was still ongoing. By allocating funding across many candidate technologies and vaccines, the US government was able to reduce risk while also benefitting from competition between candidate pharmaceutical firms. Upfront government funding and use of simultaneous testing sped manufacturing processes while ensuring the efficacy and safety of vaccines. Even as first rounds of doses were still being delivered, pharmaceutical firms were already hard at work on new vaccines tuned to the latest virus variants.[48]

A new business model to support the production of the UAS, c-UAS, air defense, and loitering munitions needed for the air littoral could draw from both the MRAP and the OWS examples. The Department of Defense would offer upfront R&D dollars to a consortium of contractors, including primes, smaller defense tech suppliers, and commercial entities, to support the development of prototypes. It would offer indefinite-delivery-indefinite-quantity contracts to the most promising prototypes, as was done with the MRAP, prioritizing—at least at first—commercial suppliers with proven capacity and mature technologies that can be scaled quickly. Prototypes would then enter experimentation and initial manufacturing simultaneously. Subsequent rounds of contracting could allocate a portion of available funds to big bets on new emerging technologies or to new products from nontraditional defense suppliers more akin to the OWS model.

By continuing to incentivize new product lines and technological breakthroughs, even as it funds longer-term programs, the Department of Defense can avoid some of the rigidity and calcification that affected the MRAP in its later phases. Key to the success of this approach would be ensuring rapid growth in the commercial drone market even outside of DoD initiatives. The Defense Department and Air Force might encourage joint ventures to take advantage of economies of scale and fully utilize production capacity. Working more closely with Allies and partners in the commercial drone market, much as the United States has started to do with shipbuilding and repair with Allies such as South Korea and Japan, is another avenue to pursue.[49]

48. *Report to Congressional Addresses, Operation Warp Speed: Accelerated COVID-19 Vaccine Development Status and Efforts to Address Manufacturing Challenges* (Washington, DC: GAO, February 11, 2021), https://www.gao.gov/.

49. John Geddie and Tim Kelly, "U.S. Wants Japanese Shipyards to Help Keep Warships Ready to Fight in Asia," Reuters, January 19, 2024, https://www.reuters.com/; and Choi Kang and Peter K. Lee, "Why U.S. Naval Power Needs Asian Allies," *War on the Rocks*, January 12, 2024, https://warontherocks.com/.

Such a model would require Congress to fund UAS and c-UAS development in a more open-ended way than is done currently, attaching money to a capability rather than specific programs.[50] With money attached to air littoral capabilities like UAS or c-UAS, for example, it would be up to the Department of Defense to allocate funding across relevant lines of effort, adapting the set of funded programs as the threat on the battlefield evolves to ensure a steady stream of new technologies even as it worked to accumulate the required mass of systems.

In addition, although multiyear funding has typically been reserved for large platforms such as planes and ships and more recently munitions, there is an argument to be made that the development and manufacturing of UAS and c-UAS capabilities would be most effective and responsive if multiyear funding streams were attached to these capabilities—though not necessarily to specific systems—to allow for long-term acquisition strategies.[51]

Beyond a new funding model, some additional money will likely be required to meet the needs of the air littoral. Both OWS and the MRAP program required large amounts of supplemental funding that is not currently available for efforts to arm for the air littoral.[52] Subsidies of some kind will likely be required to push the commercial drone market forward, just as the Biden administration has done for other key tech sectors central to US national security.[53] Given tight defense budgets, increases in funding for the air littoral will also likely require cuts elsewhere, creating hard choices for Air Force leaders between advanced fighters, long-range drones, and smaller attritable systems.[54]

New Technologies

Adopting this new business model would support efforts to achieve production at scale without simply falling back on larger defense budgets, but this may not be enough on its own to overcome physical limitations. Leveraging cutting-edge technological advances could also help address these constraints and speed innovation, potentially at lower cost in the long run. A few areas warrant particular mention, though in all cases the challenge will be producing the new technology at scale.

First, 3D printing and other additive manufacturing techniques can speed up production and innovation cycles and reduce costs. For example, 3D printing can be employed to produce component and replacement parts—especially useful where there are currently few secondary suppliers—or to rapidly create prototypes to test the

50. Lauren C. Williams, "Don't Call It a Slush Fund: Pentagon's Top Buyer Says Looser Pursestrings Will Foster Innovation," Defense One, February 12, 2024, https://www.defenseone.com/.

51. Ronald O'Rourke, *Multiyear Procurement (MYP) and Block Buy Contracting in Defense Acquisition: Background and Issues for Congress*, R41909 (Washington, DC: Congressional Research Service [CRS], April 29, 2024), https://sgp.fas.org/

52. *Operation Warp Speed*.

53. "FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China" (Washington, DC: White House, August 9, 2022), https://www.whitehouse.gov/.

54. Bremer and Grieco, "In Defense of Denial."

viability of new design ideas. Small drones have also been successfully manufactured using 3D printing, and some hope the technology could serve as another way to increase production capacity.[55]

Ukrainian forces have relied on 3D printed drones to help overcome their limited munitions stockpiles, and US forces in the Middle East are also experimenting with 3D printed drones that could be armed with explosives or electronic jammers to serve in a c-UAS capacity.[56] Currently, however, when it comes to military applications, the technology is still in the "interim phase" and cannot produce systems at scale.[57]

A second area, nanotechnology, can support the development of lighter, smaller drones, munitions, and c-UAS systems that can fly farther and faster.[58] This is especially important for East Asia scenarios where occupying the air littoral will mean covering longer distances. Nano-drones can be used for gaining intelligence and conducting surveillance of adversary defenses, as they have done in Ukraine. Production of nano-drones at scale can also open new delivery options for systems into the air littoral, including a mothership drone that releases large numbers of miniature systems or uncrewed underwater systems that release aerial drones.

Advances in areas such as robotics and quantum mechanics will also be essential to effective operations in the air littoral. Quantum technologies will allow for more secure encrypted communications and coordination between UAS and c-UAS of different types and from different suppliers.[59] Robotics and artificial intelligence (AI) can create UAS and c-UAS systems that will respond to their environment, adapt, and learn, potentially without manual system upgrades.[60]

In the c-UAS space, the US military is currently experimenting with several technologies, including nonkinetic capabilities—such as directed and microwave energy and jamming—and kinetic effects.[61] Although some systems have been fielded in small numbers, the big challenge remains achieving production at sufficient scale and low unit cost. Scaling systems that rely on directed and microwave energy has proven difficult thus far due to technical complexity and because these weapons require scarce inputs.

55. Tucker, "Troops with 3D Printers."

56. J. P. Lawrence, "Air Force Tech Squad in Middle East Expands Mission into 3D-Printed Drones," Aviation Pros, October 25, 2023, https://www.aviationpros.com/.

57. Noah Robertson and Megan Eckstein, "Why the Pentagon's Use Of 3D Printing Is 'Not Quite There Yet,' " *Defense News*, April 10, 2024, https://www.defensenews.com/.

58. Rory Jackson, "Small Is Beautiful: Nano Drone Tech Is Advancing," Defence IQ, July 20, 2017, https://www.defenceiq.com/.

59. Ishveena Singh, "US is Developing Drones with 'Unhackable' Quantum Communication Technology," DroneDJ, May 26, 2022, https://dronedj.com/.

60. Noah Bressner, "Pentagon Stares Down 'Drone Swarm' Threat," Axios, March 15, 2024, https://www.axios.com/.

61. Ashley Roque, "Spurred by Ukraine Conflict, US Army Conducts New Tests of Kinetic, Microwave Counter-UAS Systems," Breaking Defense, July 13, 2023, https://breakingdefense.com/.

Current systems using these technologies have a unit cost of $100,000 or more, 10 times what the Pentagon says would be needed to acquire systems in sufficient numbers.[62]

Achieving the necessary breakthroughs in these technologies to speed production, increase capacity, and accelerate integration and innovation in a cost-effective way is not guaranteed. In addition to investing in research and development, the Air Force should further expand partnerships with science, technology, engineering, and mathematics (STEM) programs at research universities much as the Department of Defense has already done in the area of AI.[63] Incentives provided to commercial manufacturers could speed development of these technologies as well, and hiring authorities that bring in highly qualified experts can jumpstart new lines of research within the Department of Defense and aid in the integration of new capabilities.

Finally, the United States should also make technologies relevant to the air littoral a central part of defense industrial cooperation with Allies and partners. Some emerging technologies—autonomy and quantum—are included in Pillar 2 of the Australia-United Kingdom-United States (AUKUS) agreement, for example, but the United States should seek to collaborate more with NATO and other Allies such as Japan and South Korea.[64] New technologies will not be a cure-all for speed, mass, innovation, or obsolescence challenges, but they can serve as multipliers.

A New Workforce

Arming for the air littoral will also require a new military and civilian defense tech workforce. All the advanced technology in the world cannot alter the outcomes on the battlefield without the right personnel to build, repair, and manage that technology.[65] The current DIB workforce is insufficient for the air littoral for two reasons. First, it lacks enough skilled workers across key supply chains to produce necessary input components and for later stage manufacturing of relevant military hardware.[66]

This is a problem across the DIB, not one specific to the drones, munitions, and c-UAS systems needed in the air littoral. Investments in technical training programs and colleges, apprenticeship programs, and efforts to make better use of AI and robotics in manufacturing are just some of the promising strategies to build the necessary capacity. Workforce also receives attention in the DoD's *National Defense Industrial Strategy*.[67]

62. Colin Demarest, "Drone-Killing Costs Must Come Down, Says Pentagon's Chief Weapons Buyer," *C4ISRNET*, April 25, 2024, https://www.c4isrnet.com/.

63. "AI Collaboration Supports U.S. Army Operations," Carnegie Mellon University, 2020, https://www.sei.cmu.edu/.

64. Patrick Parrish and Luke A. Nicastro, *AUKUS Pillar 2: Background and Issues for Congress*, R47599 (Washington, DC: CRS, June 20, 2023), https://crsreports.congress.gov/.

65. Antonio Calcara et al., "Why Drones Have Not Revolutionized War: The Enduring Hider-Finder Competition in Air Warfare," *International Security* 46, no. 4 (2022).

66. John A. Tirpak, "New Report: Defense Industrial Readiness 'Going in the Wrong Direction,' " *Air & Space Forces Magazine*, February 9, 2023, https://www.airandspaceforces.com/.

67. *The National Defense Industrial Strategy (NDIS)* (Washington, DC: Department of Defense, 2022), https://www.businessdefense.gov/.

The second workforce challenge—more specific to the air littoral—is what some have called the need for an "army of coders." The United States must build a cadre of skilled technologists in and out of uniform able to program, integrate, update, command, and protect the small drones and c-UAS systems, loitering munitions, and man-portable air defense that will occupy or operate in the air littoral.[68] These workers will be essential to achieving the continuous innovation required by operations in the air littoral, especially when it comes to the crucial software that will power and protect UAS and c-UAS systems.

Building a corps of computer scientists and AI professionals will be a joint effort between the Air Force and other services and the civilian sector. Efforts on the civilian side are well underway, though there are still shortages. Initiatives to grow university and high school STEM programs and to fund internship programs, on-the-job training, and hiring incentives can work to expand this career field, like others.

Building a military counterpart to this civilian tech workforce will be more challenging. While it makes little sense for it to duplicate civilian capabilities exactly, the Air Force will need a group of uniformed professionals able to lead and manage future battles in the air littoral. To operate with agility and speed, the Air Force will need experienced coders integrated into forward-deployed units, reprogramming drones and munitions in real-time, and generating new ideas and operational concepts as fighting continues. Uniformed personnel will need to be able to directly manipulate the software on which their air littoral's UAS and c-UAS systems run, both for faster upgrades and troubleshooting and to stimulate bottom-up innovation.[69]

The Air Force should make use of the advantages provided by its large pool of trainable workers and an effective career-spanning training system. It could incorporate coding into all levels of training and education while also cycling high performers through specialized software development and coding courses. Creating data science career fields and offering retraining or cross-training incentives could also be beneficial. Retaining highly trained computer and data scientists against a private sector that will be able to offer higher salaries and more stability may be difficult. Sending military personnel to outside training programs, use of retention bonuses, and greater use of lateral hires can help overcome these obstacles.

Conclusion

While some military analysts argue future wars will be shaped primarily by breakthrough technologies that give the United States a decisive military advantage—hypersonics, for example—others argue that wars will only be won by mass and attrition

68. John Ferrari and Charles Rahr, "Army of Coders Needed to Make Replicator Drone Initiative a Success," *C4ISRNET*, September 14, 2023, https://www.c4isrnet.com/; and Jon Lindsay, " 'War upon the Map': User Innovation in American Military Software," *Technology and Culture* 51, no. 3 (2010).

69. Nina Kollars, "Military Innovation's Dialectic: Gun Trucks and Rapid Acquisition," *Security Studies* 23, no. 4 (2014).

as seen in Ukraine.[70] Future battles in the air littoral will require both. Arming for the air littoral requires leveraging and integrating new technologies at scale and producing and employing large numbers of systems. In addition to necessary investments in manufacturing capacity and technology, the Department of Defense and the Air Force will need a fundamentally new paradigm that aims to build a suite of capabilities that is constantly evolving and adapting to the threat environment.

A new business model is needed, one that focuses on capabilities, not programs. This model would incentivize rapid innovation and production, cutting-edge technologies, and a workforce able to continually transform systems for the air littoral in response to changes in threats and operational concepts. This will require developing new procedures and processes, working with Congress to develop new funding models, building new public-private partnerships, investing in STEM education and training, and leveraging the complementary expertise of key Allies and partners.

The changes recommended here will also have spillover benefits across the defense industrial base. The need for a new DIB paradigm likely extends across domains and platforms, and efforts to arm for the air littoral can lead the way to a more resilient US DIB with more production and innovation capacity and a more robust workforce. The Air Force should start what could be a lengthy transition now with an eye toward creating future leaders primed to arm and operate in the air littoral. Æ

70. Paul Lushenko, "AI and the Future of Warfare: US Military Officers Can Approve the Use of AI-Enhanced Military Technologies That They Don't Trust. That's a Serious Problem," *Bulletin of the Atomic Scientists*, November 29, 2023, https://thebulletin.org/; and *Testimony from Outside Experts on Recommendations for a Future National Defense Strategy: Hearing before the Committee on Armed Services, US Senate, Day 1*, 115th Cong. 231 (2002), https://www.govinfo.gov/.