25-T-2951

AY 2024-2025

SPRING 2025 INDUSTRY STUDY REPORT: ELECTROMAGNETIC WARFARE

15 MAY 2025

Word Count: 8,184

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Executive Summary

The United States faces a critical inflection point in the fight for electromagnetic spectrum (EMS) superiority. Historically treated as a supporting function, Electromagnetic Warfare (EW) is now a decisive warfighting capability. Adversaries like China and Russia have prioritized non-kinetic spectrum dominance, challenging decades of U.S. superiority. Without control of the EMS, precision capabilities fail, Joint operations falter, and deterrence erodes. U.S. policies, industrial base practices, and acquisition systems have not adapted at the pace of adversaries' integrated strategies. Regaining EMS superiority requires urgent, unified action across DoD, industry, and international partners.

This study identifies the fragmented authority, outdated export controls, rigid acquisition frameworks, and a lack of warfighter-informed innovation as root causes of the U.S. shortfall in Electromagnetic Spectrum Operations (EMSO). While the United States retains advantages in talent, allied relationships, and technology innovation, these assets remain under-leveraged. To regain spectrum superiority, this report proposes bold reforms. First, the United States must fix the foundation of domestic and international policy by establishing an office with centralized authority and budget oversight and overhauling export controls to enable seamless allied collaboration under frameworks like AUKUS. Second, accelerate the fight by integrating warfighters directly into capability development offices and leveraging adaptive acquisition pathways. Finally, sustain the advantage by strengthening industry-government partnerships to harness rapid innovation and by expanding and leveraging modeling and simulation tools for development, testing, training, and wargaming. Incremental reform is insufficient; a transformational shift in policy, acquisition, and mindset is essential to secure advantage in the increasingly contested electromagnetic battlespace of the 21st century.

I. Quoth the Strategy: 'Nevermore,' The End of Assumed EMS Superiority

The United States faces a critical juncture in the fight for electromagnetic spectrum (EMS) superiority. For decades, American strategy relied on developing advanced kinetic-forward platforms as the foundation of Western military power, while treating electromagnetic warfare (EW) as survivability and support. This approach shaped how the United States fights, its strategic thinking, its acquisition priorities, and how it fields new technology.[1] U.S. forces long enjoyed uncontested spectrum dominance, enabling a focus on kinetics and precision. However, in 2024, the congressionally mandated independent review of the 2022 National Defense Strategy stated that "the United States is losing its advantage in electronic warfare."[2] Adversaries and pacing threats, like Russia and China, are embracing a new paradigm, prioritizing EMS dominance and other non-kinetic operations, such as cyber and information, as primary tools to undermine U.S. strength before kinetic conflict begins.[3]

With the loss of EMS superiority, U.S. forces risk losing the ability to see, decide, and act across the competition continuum. Without spectrum control, advanced platforms cannot function, precision weapons turn into dumb bombs, offensive Electronic Attack (EA) is forfeited, situational awareness collapses, and Joint and allied operations become difficult to coordinate. This jeopardizes billions of dollars of investments and critically weakens allied confidence in

[1] Bryan Clark, Whitney McNamara, and Timothy Walton, "Winning the Invisible War: Gaining an Enduring U.S. Advantage in the Electromagnetic Spectrum" (Center for Strategic and Budgetary Assessments, 2019), ://efaidnbmnnnibpcajpcglclefindmkaj/https://csbaonline.org/uploads/documents/Winning_the_Invisible_War_WEB.pdf. pp 2-4.
[2] John Hoehn, "Defense Primer: Electronic Warfare," legislation, November 14, 2022, https://www.congress.gov/crs-product/IF11118.
[3] Alan Dayton, "Winning the Invisible Fight: The Need for Spectrum Superiority" (Defense360: Center for Strategic and International Studies, December 2016), www.defense360.csis.org.

U.S. commitments. DoD policy states: "the EMS is the connective tissue and battlespace, essential for sensing, communication, command and control, and precision engagement."[4] The U.S. military now recognizes that EMS superiority is not merely an enabler but a decisive warfighting requirement on par with other asymmetric capabilities.

Given the rapid advancements in EMS technologies, the United States is losing the technological edge to China and Russia. The absence of unified, empowered senior-level direction for industry and strategic operations, coupled with chronic under-resourcing and the persistent risk aversion in defense acquisition, created conditions unfavorable to U.S. EMS superiority. This failure to adapt and engage industry effectively threatens U.S. deterrence and its ability to prevail in future conflict.[5] However, the United States still has enduring strengths in a world-class technology sector, robust allies, and a competitive, innovative defense industrial base with deep ties to academia. These assets present opportunities to overcome current vulnerabilities if leveraged effectively. To regain and sustain EMS superiority against rapidly advancing adversaries, the United States must implement EMS advocacy at the highest DoD levels to drive a unified, industry-integrated EMSO strategy, reform acquisition and resourcing pathways, and transform its EMSO industrial base. With these reforms, the United States can secure technical overmatch and credible deterrence in the 21st-century battlespace and maintain our strategic position amidst great power competition.

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[4] "2020 Department of Defense Electromagnetic Spectrum Superiority Strategy," U.S. Department of Defense (Washington DC, October 2020), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/electromagnetic_spectrum_superiority_strategy.pdf.

[5] AnnMarie Anthony, "National Defense University Electromagnetic Spectrum Operations (EMSO) Professional Military Operations (PMO)" (Military, Maj Gen Anthony Presentation, National Defense University, February 26, 2025).

II. Surveying the Spectrum Battlespace: Current State of the Industrial Base and Strategic Environment

Situational Awareness: The Global EMSO Picture

Though the primary EW industry nations are the United States, China, Russia, the United Kingdom (UK), and Israel, countries worldwide recognize the importance of the EMS and are investing in nascent hardware and software capabilities to defend their assets.[6] Large multi-national defense firms focus on niche applications or regional defense needs, and many allied nations rely on U.S. technologies or subsystems, constrained by restrictive export regimes like the U.S. International Trafficking in Arms Regulations (ITAR).[7] Collaboration with allies and partners is a key force multiplier for the United States and sets it apart from its adversaries. Still, the ITAR, which were designed to secure sensitive technologies, often impede collaboration and market access for fielding EW capabilities.[8]

Traditionally, the United States held EW technological superiority thanks to the symbiotic relationship between the government, industry, and academia. However, recent studies show that U.S. EMSO Research, Development, Test & Evaluation (RDT&E) and procurement funding have stagnated while Chinese investments have surged. These studies also highlighted that the U.S. military has lost contested spectrum dominance in multiple recent exercises, and adversary EMSO R&D spending now rivals or exceeds the United States' levels in key areas.[9]

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[6] "Electronic Warfare [EW] Market By End User & By Technology 2032," accessed May 6, 2025, https://www.fortunebusinessinsights.com/electronic-warfare-market-103290.
[7] "Electronic Warfare Industry Worth $19.4 Billion by 2028," Markets and Markets, accessed May 4, 2025, https://www.marketsandmarkets.com/PressReleases/electronic-warfare.asp.
[8] Brandt Pasco, "The Case for Export Control Reform, and What It Means for America | Harvard National Security Journal," accessed May 4, 2025, https://harvardnsj.org/2014/10/19/the-case-for-export-control-reform-and-what-it-means-for-america/.
[9] "Military and Security Developments Involving the People's Republic of China 2024," Annual Report to Congress (Washington DC: Department of Defense, n.d.), https://media.defense.gov/2024/Dec/18/2003615520/-1/-1/0/MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA-2024.PDF.

Unlike the United States' federated system with separation of powers, the Chinese Communist Party (CCP) controls politics, industry, academia, and the military, which creates a streamlined approach to military modernization. The CCP's direction is explicit: the People's Liberation Army (PLA) seeks "information dominance" and "spectrum superiority," fielding large numbers of frequency-agile, low-cost EMSO systems designed to saturate and confuse U.S. forces.[10] This contrasts sharply with the United States' focus on fewer, more exquisite platforms.[11] China's concepts target critical nodes, sensors, and communication networks through non-kinetic means.[12] Russia has also invested heavily in EMSO, with conflict in Ukraine demonstrating the impact of EMSO in disrupting communications, jamming radar, and affecting GPS.[13] With similar goals to China, Russia has leveraged EW to blind and bypass Ukrainian defensive measures, enabling kinetic strikes on key supply routes and other valuable military targets. Russia is also credited as a "first-adopter," rapidly innovating and implementing new technologies like embedded artificial intelligence, and fiber optic and other alternative automation methods.[14]

Recognizing adversary actions, the Services made significant, though not always complementary, inroads in moving EMSO to the "pointy end of the spear" in the past few years. The U.S. Air Force (USAF) led the DoD in positioning EMSO as a warfighting requirement by

[10] "Military and Security Developments Involving the People's Republic of China 2024."
[11] *Ibid*.
[12] *Ibid*.
[13] Matthew Slusher, "Lessons from the Ukraine Conflict: Modern Warfare in the Age of Autonomy, Information, and Resilience," May 2, 2025, https://www.csis.org/analysis/lessons-ukraine-conflict-modern-warfare-age-autonomy-information-and-resilience.
[14] "Fighting the War in Ukraine on the Electromagnetic Spectrum," *The Economist*, February 5, 2025, https://www.economist.com/science-and-technology/2025/02/05/fighting-the-war-in-ukraine-on-the-electromagnetic-spectrum.

creating the 350th Spectrum Warfare Wing (SWW) in June 2021.[15][16] The Army Futures Command emphasizes that integrating cyberspace and EMSO is essential for successful Multi-Domain Operations (MDO), stating that they "provide the capability to process and manage operationally relevant actions across multiple domains, the EMS, and the information environment."[17] The Navy Information Warfighting Development Center (NIWDC) prioritized forming and developing shipboard EMSO teams to enhance fleet readiness in highly contested environments. NIWDC ensures warfighters are prepared to dominate the spectrum across all domains through integrated spectrum data applications and live-force exercises. This approach supports distributed maritime operations and improves interoperability across Joint and allied forces.[18]

Exercises like Bamboo Eagle, which provide a "combat representative environment" for most of the Joint Force (USAF, USSF, Navy, and Marine Corps) and allies (UK and Australia) in the Indo-Pacific region, are another step in the right direction for highlighting the importance of the EMS. The second iteration of Bamboo Eagle in 2024 included rapidly "reprogramming mission data files and transmitting them at the speed of relevance to and from the edge" under communication-degraded conditions.[19] Additionally, the DoD stood up the Joint Electromagnetic

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[15] Emili Koonce, "ACC Activates 350th Spectrum Warfare Wing," Air Force, June 28, 2021, https://www.af.mil/News/Article-Display/Article/2673019/acc-activates-350th-spectrum-warfare-wing/.
[16] Mark Pomerleau, "For the First Time, Air Force Integrates Spectrum Warfare Wing into Weapons School Capstone Event," *DefenseScoop* (blog), February 1, 2024, https://defensescoop.com/2024/02/01/350th-spectrum-warfare-wing-weapons-school-capstone/.
[17] "Army Futures Command Concept for Cyberspace and Electromagnetic Operations 2028" (Army Futures Command (AFC) Pamphlet 71-20-8, June 29, 2021), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://api.army.mil/e2/c/downloads/2021/07/08/fbd7fb76/20210629-afc-pam-71-20-8-cyberspace-and-electromagnetic-warfare-operations-approved.pdf.
[18] Jacquelynn Fisher, "Synergy Advances Interoperability - Strike Force Operators Collaborate," DVIDS, accessed May 8, 2025, https://www.dvidshub.net/news/420012/synergy-advances-interoperability-strike-force-operators-collaborate.
[19] Benjamin Aronson, "Crows 'ACE' Electromagnetic Spectrum Operations at Bamboo Eagle," 350th Spectrum Warfare Wing, February 12, 2024, https://www.350sww.af.mil/News/Display/Article/3674140/crows-ace-electromagnetic-spectrum-operations-at-bamboo-eagle/.

Spectrum Operations Center (JEC) under the U.S. Strategic Command in July 2023. Its formation aimed to consolidate and streamline the DoD EMSO. The nascent JEC is intended to be the central hub for force management, planning, situational awareness, decision-making, and force direction within the EMS.[20] The Services have made progress. However, unification of effort across DoD, prioritization, and resourcing continues to vary, considering adversary progress and threats. DoD unity of effort and prioritization are critical to provide clear demand signals to industry partners to design and build the capabilities warfighters need at the pace required to meet and outmatch adversary threats.

The State of the (Dis)Union is Strong: The U.S. EW Industrial Base

The U.S. EW industry encompasses a complex ecosystem of key players, specifically large defense primes, small- and medium-sized start-ups, and government- and academia-sponsored research organizations. Established defense primes like Northrop Grumman, RTX, BAE Systems, Lockheed Martin, and L3Harris Technologies and their subsidiaries dominate the highly specialized global EW industry.[21] These large firms have significant market share due to substantial capital and historic R&D investments and intellectual property, focusing on developing and sustaining major platforms and specialized hardware systems with long lifecycles, creating long-term high-profit margins.[22]

Small- to medium-sized firms serve as technology drivers for advanced EMSO technologies, including: cognitive EW, the application of artificial intelligence and machine learning for signal processing and autonomous response, advanced integrated circuit (IC)

[20] "U.S. Strategic Command Stands Up Joint EMS Operations Center," U.S. Strategic Command, July 26, 2023, https://www.stratcom.mil/Media/News/News-Article-View/Article/3471149/us-strategic-command-stands-up-joint-ems-operations-center/.
[21] "Electronic Warfare [EW] Market By End User & By Technology 2032," Fortune Business Insights, April 28, 2025, https://www.fortunebusinessinsights.com/electronic-warfare-market-103290.
[22] Industry engagement, March 6, 2025.

components like gallium nitride (GaN) technology, networked EMSO concepts, passive sensing techniques, and modeling and simulation (M&S) tools. Some of the small-to-medium companies driving technology innovation in EMSO are: HawkEye 360, Mercury Systems, Vadum, and Anduril. Unlike the primes' focus areas, small- and medium-sized businesses and academic institutions focus on solutions to unique problem sets that require interoperability, adaptability, software, and other aspects of EW that require agility that some larger primes cannot provide. Smaller firms offer targeted, applied research, prototyping, experimentation, and innovation to advance EMSO capabilities. Smaller and newer firms are often less beholden to large boards and shareholders, allowing them greater flexibility to target niche capabilities and get after hard problems.

Academia is not profit-minded, is potentially more reliant on consistent government funding, and therefore can take risks by doing critical research to fill capability and technology gaps. However, it requires strong connections with warfighters to understand operational requirements.[23] Some examples of these academic, federally-funded, and non-profit organizations are: MITRE, MIT Lincoln Labs, and Georgia Tech.[24] There must still be a viable path to profit for industry to transition projects from universities and labs into deployable capabilities. In addition to technology development, academia also nurtures the next generation of human capital and technology that enter industry or government. The ability to combine industry, academia, and government into an "Industrial Commons" is a key lever for U.S.

[23] Warren du Plessis, "Challenges and Opportunities Associated with University Collaboration in Electronic Warfare Research," *XV Sige*, September 2013, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.sige.ita.br/edicoes-anteriores/2013/st/X_1.pdf.
[24] "MIT-Lincoln Lab & MITRE Industry Study Engagement" (Industry Engagement, Boston, MA, March 7, 2025).

strategic and national advantage and a source of continuous innovation.[25] Despite these strengths, the United States has critical disadvantages compared to its peers.

Diamonds Are Forever, Superiority Is Not: Porter's Diamond for National Advantage, Innovation, and Industry Trends

Capturing EMS superiority depends upon a global power's national competitive advantage and how well a state cultivates technological innovation, adaptability, and agility across the conflict continuum. Porter's Diamond examines national competitive advantage through factor conditions, demand conditions, related and supporting industries, and firm strategy, structure, and rivalry. It is a helpful tool to compare and assess how the United States and its pacing threat, China, are positioned and trending within this rapidly evolving industry. These elements collectively shape a nation's ability to compete in the global economy and provide a framework for businesses to assess investment opportunities and strategic positioning within different markets.[26] Table 1, on page 13, contains the comparative analysis between the United States and China through the lens of Porter's Diamond.

Regarding factor conditions, the United States benefits from a strong research and engineering workforce, world-class universities, and a proven technology industry that provides the industrial commons for civil and military technological advances. However, stringent environmental protection regulations drove much of the United States' mineral extraction and processing offshore, specifically to China.[27] China has significantly increased its educated workforce and improved its university system in the past few decades. Additionally, they are the

[25] Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (Columbia University Press, 1994).
[26] Michael Porter, *The Competitive Advantage of Nations* (Free Press, 1998).
[27] Emont, Jon. How China Beat Out the U.S. to Become the Top Player in Rare-Earths Refining; New York, N.Y.: Dow Jones & Company Inc, 2025. https://www.wsj.com/business/how-china-beat-out-the-u-s-to-become-the-top-player-in-rare-earths-refining-e84cc30d

world's leading supplier of rare earth minerals and a major hub for low-cost manufacturing in the tech sector.[28] Additionally, China has the advantage of geographic proximity to Southeast Asian nations that comprise most of the microelectronics supply chain. Regarding demand conditions in the EW industry, firms in the United States struggle with inconsistent DoD budget priorities, especially in the absence of any other customer for exquisite military technology. Conversely, China's highly centralized, strategically directed demand enables rapid alignment with military priorities.

Both nations possess strong related and supporting industries as described in factor conditions. However, China has a significant geographic advantage in access to raw materials and microelectronics manufacturing supply chains. Finally, regarding firm strategy and structure, the United States relies on a free-market system, even in the EW industry. However, the fickleness of government contracts and funding has led major defense primes to diversify beyond the EMSO sector to smooth out fluctuating demand. In contrast, China's centrally-coordinated model of state-owned enterprises, though still generally expected to be profitable, allows the government to override pure business interests when needed and supports scaling up for mobilization.[29]

[28] Melissa Pistilli, "Top 10 Countries by Rare Earth Metal Production," Investing News Network, March 25, 2025, https://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/rare-earth-metal-production/.
[29] International Monetary Fund Asia and Pacific Dept, "People's Republic of China: Selected Issues," January 15, 2021, https://www.elibrary.imf.org/view/journals/002/2021/012/article-A002-en.xml.

DIAMOND ELEMENTS	UNITED STATES	CHINA
Factor Conditions	Highly skilled engineering workforce (aging)	Massive STEM graduate output (6 x U.S.)
	World-class R&D institutions (Universities, DARPA, Lincoln Labs)	Heavy state subsidies and civil-military fusion directing civilian R&D to the PLA
	Advanced semiconductor and EW technologies	Rapid growth in chip manufacturing (Huawei, SMIC)
	Spectrum allocation and regulation responsibilities are shared between the military, the commercial sector, and civil agencies	CCP controls China's spectrum and has the freedom to allocate/redistribute bandwidth wherever needed
	Supply chain risks (rare earths, manufacturing erosion)	Dominance in rare earth mining and refining (controls major global supply)
Consumer Demand Conditions	Diverse (sometimes inconsistent) demand from the DoD and Congress; typically secondary to kinetic effects with slow acquisition and budget processes	Centralized state-driven demand aligned to PLA modernization goals reduced bottom-up feedback
	Innovation incentivized through market competition and operational feedback	Strategic direction from government eliminates commercial constraints on EW development
	Strong exportable demand from allies (NATO) but must consider ITAR and FMS restrictions	State-driven procurement bypasses traditional market forces
Related and Supporting Industries	Strong defense primes (Lockheed, Northrop, RTX, BAE) and emerging tech firms	Integrated telecom and tech giants (Huawei, ZTE) directly support military development
	Leadership in semiconductor, AI, and software sectors critical to EW advancement	Advanced internal manufacturing capabilities
	Collaboration across military, academia, and tech sectors	Heavy investment in 5G/6G, AI, and quantum technologies with military applications
Firm Strategy, Structure, Rivalry	Competitive, profit-driven market fosters innovation and agility	Centralized, top-down industrial strategy prioritizes rapid scaling of military capabilities
	Open architecture encouraging mid-tier and VC-backed entrants	Firms operate under direct government guidance (civil-military fusion)
	Slow to accept commercial innovation; Risk of oligopoly among primes stifling innovation	State-owned enterprises allow for efficient mobilization of resources toward national defense goals

Table 1: Porter's Diamond Comparison of the United States and PRC[30]

Beyond Porter's Diamond, additional capabilities that impact competitive advantage include the ability to master technological innovations. In EMS, this means applications that

[30]Bryan Clark, "Winning the Fight for Sensing and Sensemaking: Fielding Cyber and Electronic Warfare Capabilities at Scale | Hudson Institute" (Washington DC: Hudson Institute, December 20, 2024), https://www.hudson.org/national-security-defense/winning-fight-sensing-sensemaking-fielding-cyber-electronic-warfare-c5isr-bryan-clark; Clark; William Greenwalt and Dan Patt, "Competing in Time: Ensuring Capability Advantage and Mission Success through Adaptable Resource Allocation" (Washington DC: Hudson Institute, February 2021), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.aei.org/wp-content/uploads/2021/02/Greenwalt_Competing-in-Time.pdf; "National Defense Strategy" (Department of Defense, 2022), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.pdf; Deborah Rosenblum, "Progress Report: Securing Defense-Critical Supply Chains | Www.Dau.Edu," Defense Acquisition University, accessed May 6, 2025,

require highly technical, adaptable, and agile capabilities that scale rapidly from competition into conflict and crisis. Current trending technologies within the U.S. trifecta of academia, industry, and government include the development and integration of Artificial Intelligence/Machine Learning (AI/ML) for rapid signal processing, cognitive EW, software-defined EW, and adaptive EW response.[31] Supporting capabilities include rapid advances in edge computing, on-chip photonics and optical computing, neuromorphic chip architecture, quantum sensing, autonomous platforms, subcomponent plasma architecture, GaN-based semiconductors, and a host of other mature or near-mature technologies that are ready to integrate at scale.[32] U.S. government investment is critical to maturing these technologies to integrate into Joint Force capabilities while reinvigorating and reinforcing the government's relationships with industry.

Beyond technological innovation, the United States must also optimize EW technological advances through interoperability across the Joint Force and with its allies. The DoD spurs industry and academia to improve interoperability through directives and advancements in software-defined systems and the adoption of open architecture (OA) frameworks like Modular Open Systems Approach (MOSA), Sensor Open System Architecture (SOSA), C5ISR Modular Open Suite of Standards (CMOSS). OA is crucial for enhancing flexibility, interoperability, faster integration of new technologies, and reducing vendor dependency.[33] Similarly, M&S are

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https://www.dau.edu/library/damag/january-february2023/securingdefensecriticalsupplychains; Steven Karl, "The Race to Resilience—Your Role in Securing Defense Supply Chains in a New Era of Great Power Competition | Www.Dau.Edu," Defense Acquisition University, February 2023, https://www.dau.edu/library/damag/january-february2023/theracetoresilience; Kimberly Martin, Keith E. Lee, and John Powell Hall, *Public Policy: Origins, Practice, and Analysis* (Dahlonega, Georgia: University of North Georgia Press, n.d.); Mike D. [R-AL-3 Rep. Rogers, "H.R.2670 - 118th Congress (2023-2024): National Defense Authorization Act for Fiscal Year 2024," legislation, December 22, 2023, 2023-04-18, https://www.congress.gov/bill/118th-congress/house-bill/2670.

[31] Stephanie Ricciardi and Cedric Souque, "Modern Electromagnetic Spectrum Battlefield: From EMS Global Supremacy to Local Superiority," *PRISM* 9, no. 3 (2021): 122–39.

[32] Reeshen Reddy and Saurabh Sinha, "State-of-the-Art Review: Electronic Warfare Against Radar Systems," *IEEE Access* 13 (2025): 57530–67, https://doi.org/10.1109/ACCESS.2025.3555493.

[33] "New MOSA-Enabling Standard in ASSIST," Defense Standardization Program, March 12, 2025, https://www.dsp.dla.mil/Publications/DSP-Journal/News-Display/Article/4117175/new-mosa-enabling-standard-in-assist/.

vital tools for replicating the complexity of the EMS environment for training, wargaming, capability development, and testing. The increasing demand for EMS requires advanced spectrum management techniques, including AI-driven spectrum sharing.[34]

In summary, China's advantages stem from its scale, centralized strategic alignment, and capacity for rapid mobilization. Its primary weakness is an over-reliance on top-down directives under the CCP, limiting organic innovation and long-term adaptability. By contrast, the strength of the U.S. EW industry lies in its entrepreneurial spirit, competitive market dynamics, and technological innovation; however, government bureaucracy and supply chain vulnerabilities present significant challenges. The United States should look to more modern conflicts between technologically capable adversaries and harness lessons learned to enhance its readiness.

Feathers to Factories: Ukraine's Lessons Learned for 21st Century U.S. Mobilization Preparedness

The ongoing war in Ukraine provides a powerful case study for assessing 21st-century defense industrial base (DIB) readiness for EMSO. Russian forces have employed sophisticated and adaptive EMSO tactics, including GPS jamming, communications denial, radar spoofing, and cyber-integrated electronic attacks. In response, Ukraine has leveraged rapid innovation pipelines, integrating commercial drones, satellite communications, agile software-defined radios, and other EW tools from non-traditional partners, all in timelines measured in weeks, not years.[35] This high-tempo adaptation is possible through decentralized innovation, rapid procurement, and close cooperation with non-traditional industry partners. The lesson is clear: EMSO superiority is happening at the edge, while in contact. It will not be secured solely

[34] *Cognitive Electronic Warfare: Using AI to Solve EW Problems* (USC Information Sciences Institute, 2023), https://www.youtube.com/watch?v=oO6piqNroiI.
[35] Slusher, "Lessons from the Ukraine Conflict."

through legacy acquisition systems or major primes building exquisite platforms on the DoD's five-year timelines. Instead, victory will go to those who can rapidly scale and field modular, software-adaptable, and interoperable EW solutions in response to evolving threats. For the United States, this means rethinking the structure, incentives, and responsiveness of its defense industrial base. A 21st-century-ready DIB must cultivate speed, flexibility, and resilience. Ukraine's example demonstrates that industrial agility and operational relevance are more decisive than scale in modern EMS conflict. The United States must heed this signal and close this gap to regain and sustain EMS superiority.

Forecast: Cloudy with a Chance of Jamming

As evidenced by the Russia-Ukraine conflict, the EMS is a constantly evolving battlespace. The industry is projected to grow significantly, from $16.7 billion (USD) in 2023 to $36.7 billion by 2032.[36] Evolution demands alignment between governments and industries to adopt agile solutions to counter consistently emerging threats quickly. Ensuring a secure and resilient supply chain for U.S. and allied EMSO components will become an increasingly critical concern for 21st-century mobilization preparedness as global uncertainties and disruptions to raw material availability persist.[37] Domestic manufacturing capacity is likely to expand in response to strategic competition timelines, with the government incentivizing the production of key EMSO technologies, such as chips, to reduce reliance on foreign suppliers and strengthen

[36] "Electronic Warfare [EW] Market By End User & By Technology 2032," April 28, 2025.
[37] Lukasz Bednarski et al., "Geopolitical Disruptions in Global Supply Chains: A State-of-the-Art Literature Review," *Production Planning & Control* 36, no. 4 (March 12, 2025): 536–62, https://doi.org/10.1080/09537287.2023.2286283.

national security.[38] However, without overcoming key systemic and bureaucratic challenges preventing EMS superiority, the United States will fall further behind its peers and adversaries.

III. Jammed Signals and Clipped Wings: Challenges and Barriers to U.S. EMS Dominance

Within the current strategic, geopolitical, and domestic environment, the United States lacks a clear and effective pathway to EMS superiority due to systemic challenges spanning the civil and commercial sectors, the DIB, the resourcing and acquisitions processes, DoD governance, and strict regulations limiting EMS domestically and cooperation and information sharing with allies.[39] Challenges are further compounded by the absence of a centralized authority to lay out a unified and enforceable U.S. EMSO policy that can effectively meet the needs of the combatant commands (CCMDs) and the Joint Force. Similarly, industry faces numerous challenges when participating in or breaking into the defense market. The DoD has created a market with high barriers to entry, inconsistent requirements and funding, and rigid standards and export processes limiting Foreign Military Sales and allied interoperability. As a result, there are too few participants, which negatively impacts competition, and participants must overcome these challenges to turn a profit, increase share value, and meet other business objectives.

No Room in the Roost: High Barriers to Entry

It is difficult for companies with little experience working with the DoD to break into the defense market.[40] Even DoD programs intended to help new firms, such as the Small Business

[38] "Biden-Harris Administration Announces CHIPS Incentives Awards with BAE Systems, Inc., and Rocket Lab to Expand Production of Chips Critical for U.S. National Security and Space Industry | U.S. Department of Commerce," November 25, 2024, https://www.commerce.gov/news/press-releases/2024/11/biden-harris-administration-announces-chips-incentives-awards-bae.
[39] U. S. Government Accountability Office, "Electromagnetic Spectrum Operations: DOD Needs to Take Action to Help Ensure Superiority | U.S. GAO," Government Accountability Office, March 19, 2021, https://www.gao.gov/products/gao-21-440t.
[40] "Global Electronic Warfare Market 2024-2028" (Infiniti Research Limited, 2024), www.technavio.com.

Innovation Research (SBIR) and Small Business Technology Transfer (STTR), can be difficult for a new firm to navigate. This is particularly true with EMSO systems, where significant upfront capital is often required to develop competitive prototypes that meet military security requirements before contract award.

The DoD's requirements, programming, budgeting, and acquisition systems favor developing and procuring hardware and platforms, like tanks, planes, ships.[41] EMSO capabilities are increasingly software-centric, which presents multiple challenges for the defense industry.[42] This drives companies to attempt business models that group software embedded with a hardware product, licenses, or software as a service. These different methods represent the industry's efforts to achieve viable revenues, as there is no one solid path for software profitability.[43] A Software Engineering Institute-Carnegie Mellon University report notes that sustainment costs account for 60 to 90 percent of the total software lifecycle effort, indicating high costs associated with the necessary continuous development to address everything from hidden bugs and security vulnerabilities to meeting new needs.[44] The software acquisition pathway in the Adaptive Acquisition Framework (AAF) attempts to assist the government in getting feedback from operators, software development, and updates to the field, but is still laden with bureaucracy, prompting software acquisition reform.[45]

Other software-based rules and regulations present a high barrier to entry for contractors seeking to enter the market and impact revenue potential for those in the market. One example is

[41] "Industry Engagement."
[42] *Ibid.*
[43] *Ibid.*
[44] Michael McLendon, Bill Scherlis, and Douglas Schmidt, "Addressing Software Sustainment Challenges for the DOD," *Crosstalk*, February 2014, 27–32.
[45] "'Directing Modern Software Acquisition to Maximize Lethality' Memo Background Briefing," U.S. Department of Defense, March 7, 2025, https://www.defense.gov/News/Transcripts/Transcript/Article/4113458/directing-modern-software-acquisition-to-maximize-lethality-memo-background-bri/.

achieving and maintaining the Cybersecurity Maturity Model Certification (CMMC).[46] Table 2 below outlines the number of requirements and costs for the different levels of CMMC. Despite the required effort and financial burden, a firm cannot compete for a defense contract without the proper level of CMMC.

CMMC Level	Description	Number of Requirements	Initial Cost ($K)	Annual Cost ($K)
Level 1	Required for basic Federal Contract Information	15	$5 to $15	$5 to $30
Level 2	Protecting Controlled Unclassified Information	110	$63 to $200	$5 to $30
Level 3	Advanced requirements for highly sensitive or critical systems	134	$100 to $500	$5 to $30

Table 2: CMMC Level Requirement and Cost Breakdown[47]

Spectrum on a Shoestring: Inadequate Resourcing, Requirements, and Prioritization

The DoD signals demand to industry by validating operational requirements through the Joint Capabilities Integration and Development Systems (JCIDS) and resourcing requirements through the Future Years Defense Program (FYDP), part of the Planning, Programming, Budget, and Execution (PPBE) process.[48] However, the JCIDS process is designed to define requirements for long-term, large and exquisite, hardware-centric platforms. JCIDS is poorly suited for modern weapons platforms' dynamic, software-intensive nature.[49] The JCIDS process struggles

[46] Becki Johnson, "The Most Efficient CMMC Certification Process," Paramify, October 2024, https://www.paramify.com/blog/cmmc-certification-steps.
[47] Becki Johnson, "CMMC Certification Costs in 2025," Paramify, November 2024, https://www.paramify.com/blog/cmmc-cost.
[48] Brendan McGarry, "Defense Primer: Planning, Programming, Budgeting, and Execution (PPBE) Process," legislation, accessed May 5, 2025, https://www.congress.gov/crs-product/IF10429.
[49]"Defense Resourcing for the Future" (Washington DC: Commission on Planning, Programming, Budgeting, and Execution Reform, March 2024), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ppbereform.senate.gov/wp-content/uploads/2024/03/Commission-on-PPBE-Reform_Full-Report_6-March-2024_FINAL.pdf.[50]"21st Century Military Operations in a Complex Electromagnetic Environment," Department of Defense (Washington DC: Defense Science Board, July 2015), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://dsb.cto.mil/wp-content/uploads/reports/2010s/DSB_SS13--EW_Study.pdf.[51] *Ibid.*

to accommodate rapid threat evolution, repetitive development, or capabilities, like cognitive EW, designed to address unknown future signals rapidly, resulting in fielded EMSO systems based on outdated requirements.[50] Additionally, joint modeling and simulation environments, while showing promise, currently lack the interconnectivity and scalability to truly inform strategic wargaming and resourcing decisions. Requirements reform, however, is just one piece of the puzzle to accelerate capability development. The next layer, the budgeting process, also requires attention.

Calls to reform PPBE are frequent, and the most recent PPBE reform report made 28 recommendations, including multiple concerning resourcing guidance, reprogramming, and the difficulties caused by continuing resolutions.[51] These recommendations reflect how the current PPBE structure hurts the EMSO system demand signal by providing insufficient guidance on resources required to meet warfighter needs, the inability to make resource adjustments in the fast-moving threat environment that is the EMS, and the inability to enact changes or ramp up new and innovative programs from year to year under a continuing resolution. Without a strong understanding of the warfighter's validated operational and resource requirements, industry is unwilling to invest capital in researching and developing advanced capabilities. To get capability to the warfighter faster, the President recently ordered the Secretary of Defense to reform the DoD's acquisition and requirements systems, which "does not provide the speed and flexibility our Armed Forces need to have a decisive advantage in the future."[52]

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[50]"21st Century Military Operations in a Complex Electromagnetic Environment," Department of Defense (Washington DC: Defense Science Board, July 2015), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://dsb.cto.mil/wp-content/uploads/reports/2010s/DSB_SS13--EW_Study.pdf.[51] *Ibid.*

[51] *Ibid.*

[52] "Modernizing Defense Acquisitions and Spurring Innovation in the Defense Industrial Base," The White House, April 9, 2025, https://www.whitehouse.gov/presidential-actions/2025/04/modernizing-defense-acquisitions-and-spurring-innovation-in-the-defense-industrial-base/.

Who's Minding the Spectrum Gap(s)? A Lack of Senior-Level Advocacy and Coordination

While there are challenges with the acquisition system writ large, focused senior oversight is also lacking. The National Science Board's (NSB) *21st Century Military Operations in a Complex Electromagnetic Environment* report found that "little coordination, advocacy, and oversight for EW exist across the Department."[53] As a result, the Deputy Secretary of Defense established the EW Executive Committee (EXCOM) in 2015, co-chaired by the Undersecretary of Defense for Acquisition and Sustainment (USD A&S) and the Vice Chairman of the Joint Chiefs of Staff, and supported by a cross-functional team (CFT) of subject matter experts to provide the needed clout and technical expertise recommended by the NSB.[54]

The Government Accountability Office (GAO) found governance and oversight issues persisted, and a 2020 report found that the DoD was not on track to implement its EMS strategy.[55] Specifically, the GAO report concluded that the "DoD has not clearly assigned a Senior Official with appropriate authority and resources," nor had it "created oversight processes that ensure accountability" for strategy implementation.[56] In response, the FY24 National Defense Authorization Act (NDAA) mandated budgetary and capability reports from the Chairman of the Joint Chiefs of Staff (CJCS) and the Service Chiefs. Nevertheless, with the host of other non-EMS responsibilities borne by the members of the EW (now EMSO) EXCOM and Joint Chiefs, EMSO continues to fall by the wayside.

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[53] "21st Century Military Operations in a Complex Electromagnetic Environment."
[54] *Ibid.*
[55] "Electromagnetic Spectrum Operations: DOD Needs to Address Governance and Oversight Issues to Help Ensure Superiority," Government Accountability Office (GAO) (Washington DC: Government Accountability Office, December 2020), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.gao.gov/assets/gao-21-64.pdf.
[56] *Ibid.*

Grounded by Red Tape: Why the U.S. and Its Allies Cannot Operate on the Same Frequency

While a lack of centralized authority is problematic within DoD, the United States faces the opposite problem when it comes to technology sharing with close allies. The United States' 20th-century bureaucratic export control processes can no longer keep up with demand from allies or the speed of relevance, given the timelines required for effective EMSO fielding. ITAR, overseen by the State Department, serves to implement regulations for the Arms Export Control Act of 1976 and is the framework that controls the export of items specifically designed, developed, configured, adapted, or modified for military applications.[57] ITAR licensing and compliance is a notoriously lengthy and complex process, which sometimes takes months, especially if there is a jurisdictional disagreement within the executive branch. ITAR restricts the export of tangible defense articles on the U.S. Munitions List and the transfer of associated technical data, whether delivered formally or merely discussed.[58] The regulations' expansive scope creates a bureaucratic minefield that hinders collaboration even with the United States' closest allies.[59] Allied leaders and industry officials have voiced growing concerns that ITAR stifles meaningful collaboration. For example, the Australian Strategic Policy Institute and members of the UK Parliament have called for a significant overhaul of U.S. export controls, arguing that the current system undermines the very goals of cooperative agreements like AUKUS.[60]

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[57] *Export Control Challenges Associated with Homeland Security*, National Academies of Science, Engineering, Medicine (Washington, D.C.: National Academies Press, 2012), https://doi.org/10.17226/13369.
[58] Rajiv Shah, "US Export Rules Need Major Reform If AUKUS Is to Succeed," Australian Strategic Policy Institute (ASPI), February 13, 2023, https://www.aspistrategist.org.au/us-export-rules-need-major-reform-if-aukus-is-to-succeed/.
[59] Richard Wainwright, "AUKUS Is Supposed to Allow for Robust Technology Sharing. The US Will Need to Change Its Onerous Laws First," The Conversation, July 13, 2023, https://theconversation.com/aukus-is-supposed-to-allow-for-robust-technology-sharing-the-us-will-need-to-change-its-onerous-laws-first-206607.
[60] Luke Nicastro, "AUKUS Pillar 2 (Advanced Capabilities): Background and Issues for Congress" (Washington DC: Congressional Research Service, May 21, 2024), https://www.congress.gov/crs-product/R47599.

Lost In Transmission: Innovation and Crossing the "Valley of Death"

The difficulties associated with high barriers to entry, inadequate resourcing and prioritization, lack of senior-level advocacy and coordination, and export control barriers place enormous challenges on the DIB to adequately meet DoD EW requirements. This manifests through the inability of technologies to cross the "Valley of Death," or the gap between developing a promising technology and getting it into the hands of the warfighter. According to the Defense Innovation Board, the DoD still lacks a "repeatable, transparent process" for transitioning innovative technologies into fully funded programs, resulting in valuable EW systems failing to cross the valley.[61]

IV. Breaking the Jam: Recommendations to Secure the Spectrum

In order to address the challenges presented in the preceding sections of this paper and to regain spectrum superiority, this report proposes bold reforms detailed below. First, the United States must fix the foundation of domestic and international policy by establishing an office with centralized authority and budget oversight and overhauling export controls to enable seamless allied collaboration under frameworks like AUKUS. Second, accelerate the fight by integrating warfighters directly into capability development offices and leveraging adaptive acquisition pathways. Finally, sustain the advantage by strengthening industry-government partnerships to harness rapid innovation and by expanding and leveraging modeling and simulation tools for development, testing, training, and wargaming. Incremental reform is insufficient; a

[61] "Terraforming the Valley of Death: Making the Defense Market Navigable for Start-Ups" (Defense Innovation Board, July 18, 2023), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://innovation.defense.gov/Portals/63/DIB_Terraforming%20the%20Valley%20of%20Death_230717_1.pdf.

transformational shift in policy, acquisition, and mindset is essential to secure advantage in the increasingly contested electromagnetic battlespace of the 21st century.

1. Consolidate EMS Authorities and Increase Budget Transparency

Many of the challenges highlighted throughout the preceding sections of this paper center on a lack of a centralized and resourced authority for creating and enforcing EMS policy and budgetary decisions. Congress took great pains to recognize the importance of EW by adding a new chapter to U.S. Code in the FY24 NDAA to consolidate and update EW provisions and ensure proper oversight.[62] The NDAA directed a data call to consolidate a list of all programs, projects, and activities and how they support DoD EMSO strategy as well as an annual report on whether the FY25-29 budget requests are sufficient for Electromagnetic Battle Management (EMBM) activities and Joint EMSO Cells in each fiscal year. Despite these efforts, EW programs across DoD still lack visibility and transparency, and perhaps adequate funding, because the current DoD budget lacks the ability to track EMS capability investments at the sub-system level. The FY24 NDAA also codified EXCOM membership to include individuals at the highest levels in the DoD, all of whom have vast portfolios and responsibilities, and are unlikely to prioritize EMS superiority over other needs of the Joint Force. The FY24 NDAA's efforts are a promising first step, but even once fully implemented, the NDAA provisions do not go far enough to bring about timely, meaningful change. Therefore, additional efforts to promote budget transparency and consolidation of authorities are needed.

Increasing budget transparency: Previous audits have criticized DoD's lack of unified budgeting and tracking mechanisms for EMSO, stating the need for a Major Force Program

[62] Mike D. Rogers, "Text - H.R.2670 - 118th Congress (2023-2024): National Defense Authorization Act for Fiscal Year 2024," legislation, Congress.gov, December 22, 2023, 2023-04-18, https://www.congress.gov/bill/118th-congress/house-bill/2670/text.

(MFP) or program-element-level tracking.[63] Expanding on the work done to comply with the FY24 NDAA's budgetary reporting, a broad portfolio review should be conducted to identify and standardize what the DoD considers EW capability and associated funds. Furthermore, it would highlight gaps across the Joint Force to enable more efficient and prioritized budget decisions in the future. The EW portfolio review can be modeled on the Space Policy Review conducted by the Assistant Secretary for Space Policy in 2023.[64] The EMSO EXCOM will review service Program Objective Memoranda (POM) and other PPBE products to ensure that EMSO capabilities are adequately resourced and on track to deliver to the warfighter.

Near-Term: The EMSO EXCOM sponsors a study in coordination with the Services, U.S. Strategic Command, U.S. Special Operations Command, U.S. Space Command, and U.S. Cyber Command to assess the effectiveness of the provisions of the FY24 NDAA as currently implemented and to identify gaps and seams. In addition to legal reporting requirements directed in the NDAA, the EMSO EXCOM must conduct the broad portfolio review highlighted above to adequately capture the totality of the EW budget and make recommendations to highlight transparency. The EMSO EXCOM will then coordinate with the OSD Comptroller and the Cost Assessment and Program Evaluation Office to establish methods to track EW funding within the PPBE process and ensure programs are adequately resourced throughout their lifecycle. This must be done through either a dedicated MFP, specific program elements, or both.

Mid-Long Term – Consolidation of Authorities: To find a solution to longer-term challenges regarding properly resourced authorities with the power to implement needed EMSO-related reforms, one can look to other mission areas that are force enablers, providing

[63] John Hoehn, "FY2022 Electronic Warfare Funding Trends," legislation, September 16, 2021, https://www.congress.gov/crs-product/IN11705; Office, "Electromagnetic Spectrum Operations."
[64] Sandra Erwin, "DoD Submits Congressionally Mandated Space Policy Report," *SpaceNews* (blog), September 14, 2023, https://spacenews.com/dod-submits-congressionally-mandated-space-policy-report/.

asymmetric advantages like space and cyber, which were largely taken for granted until U.S. superiority was threatened. Over the past 15 years, the United States shifted dramatically from a policy where space and cyber were seen as uncontested mission areas that supported the Joint Force but not a key warfighting capability to recognizing both as warfighting domains that all U.S. and allied operations rely upon. These domains benefited from additional attention and advocacy brought about by empowering and centralizing authorities as well as increased attention on the importance of the mission areas. To consolidate authorities and provide a centralized office overseeing the United States' EMS superiority policies, the DoD must work with Congress to create a high-level position or organization within the DoD who would have sole responsibility for managing, implementing, and advising the Secretary of Defense on all policy decisions germane to EMS superiority without the additional duties and responsibilities of the existing EMSO EXCOM members. This position could be a role like the ASD for Cyber Policy/Principal Cyber Advisor or the ASD for Space Policy. The goal of this new position or office would be to consolidate authorities currently scattered across various entities within the DoD to enable greater advocacy, resourcing and policy oversight, and reducing bureaucracy. The Secretary of Defense would grant the new office authorities to oversee cross-Service and cross-DoD EW architecture development, EW-related international agreements and legal issues, the requirements process, acquisition and budget decisions, and training authorities.[65] The office should be granted the authority to influence the acquisition of Joint EMSO capabilities, set OA and joint training standards, and oversee career path development. Fundamentally, the goal

[65] "DoD Directive 3100.10 Space Policy," DoD Directive (Office of the Under Secretary of Defense for Policy, August 30, 2022), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/310010p.PDF#:~:text=ASSISTANT%20SECRETARY%20OF%20DEFENSE%20FOR%20SPACE%20POLICY,space%2C%20pursuant%20to%20the%20October%2029%2C%202020.

would be to drive Service accountability to achieve the Secretary's and Joint Force's intent for EMSO and enable the CCMDs to achieve battlefield results.

2. Expand and Formalize International EMSO Collaboration

U.S. domestic export control policies, particularly ITAR, present persistent roadblocks in achieving the advanced technology and EW capability sharing called for by cooperative agreements like AUKUS. To retain its competitive edge, the United States must recalibrate its policy frameworks and export controls, which constrain innovation, stifle industrial integration, and weaken the competitive edge of the collective allied force and defense industrial base. An ideal export control end state would enable near-real-time, seamless collaboration with our closest allies to reduce duplication of efforts, share monetary and materiel resources, and increase interoperability. Growing and formalizing international partnerships in EMSO is essential to improving interoperability among allies and speeding up shared innovation. The DoS recently approved reforms to allow defense exports to Australia and the UK under the AUKUS partnership without individual licenses, designed to fast-track advanced military capabilities collaboration in some domains.[66] However, these reforms do not extend to key EMSO and EMSO-enabling technologies.[67] The United States must move to include EMSO capabilities and key enablers like communications systems into the reformed ITAR licensing frameworks, amended for AUKUS partners, and look to extend these exemptions to other international agreements, like close NATO allies, to improve collaboration and interoperability.

[66] "AUKUS Defense Trade Integration Determination," Government, *United States Department of State* (blog), August 15, 2024, https://2021-2025.state.gov/aukus-defense-trade-integration-determination/.
[67] , "On the Third AUKUS Anniversary, a Toast to ITAR Reform and a Call to Keep Going," *Atlantic Council* (blog), September 15, 2024, https://www.atlanticcouncil.org/blogs/new-atlanticist/on-the-third-aukus-anniversary-a-toast-to-itar-reform-and-a-call-to-keep-going/.

Pillar II of AUKUS highlights the value of joint research and development on advanced capabilities such as EMSO, AI, and hypersonics. It promotes shared innovation and combined efforts to develop technologies that help the coalition keep pace with emerging threats. One example is the trilateral work on collaborative autonomous systems and spectrum-sharing technologies. Australia, the UK, and the United States are exploring ways to integrate EMSO tools into unmanned platforms. This kind of joint development reflects the broader goal of Pillar II, creating interoperable capabilities that strengthen the coalition's edge in contested environments.[68] Establishing flexible, cross-border R&D pipelines synchronized with operational standards is essential for building EMSO systems that can operate across allied platforms to rapidly respond to evolving threats. Data sharing is the crux of EMSO interoperability but has been a perennial challenge. The F-35 Joint Program Office (JPO) has been working to overcome legacy policy barriers hindering data interoperability among coalition partners. A notable demonstration involved U.S. and allied F-35s operating with shared mission data and common Multifunction Advanced Data Link (MADL) keys. This initiative aims to ensure a unified common operating picture during coalition operations, reducing pilot confusion and enhancing decision-making, and is an area for immediate and impactful change.[69]

To operationalize these initiatives, senior military leaders should advocate for formalized multinational EMSO coordination agreements nested within frameworks like AUKUS or NATO to align capability development, classification guidance, and threat assessments across partner

[68] John Christianson, Sean Monaghan, and Di Cooke, "AUKUS Pillar Two: Advancing the Capabilities of the United States, United Kingdom, and Australia," *Center for Strategic and International Studies (CSIS)*, July 10, 2023, https://www.csis.org/analysis/aukus-pillar-two-advancing-capabilities-united-states-united-kingdom-and-australia.

[69] "F-35 Joint Strike Fighter Demonstrates Enhanced Interoperability with Initial Coalition Mission Data (CMDx) Flight Tests," DVIDS, accessed May 14, 2025, https://www.dvidshub.net/news/376510/f-35-joint-strike-fighter-demonstrates-enhanced-interoperability-with-initial-coalition-mission-data-cmdx-flight-tests.

nations. These structures can accelerate the integration of coalition EMSO systems, streamline EMS deconfliction, and prioritize shared investment areas.

Near Term: The DoD and State Department implement policy changes to include EMSO and EMSO-enabling capabilities under the ITAR exemptions for AUKUS members and other close allies while conducting a deep dive review of export control practices and providing recommendations for improvement. These policy changes include broadening the scope of exemptions to encompass core EMSO technologies restricted on the Excluded Technologies List. This will enable a streamlined transfer of essential capabilities to ensure EMS superiority in contested environments and reduce duplications of effort amongst U.S. allies. In addition to easing ITAR restrictions, the Department of State and Department of Defense must consider establishing a standing category of "pre-approved" AUKUS or other allied collaborative projects. These pre-approved projects would bypass traditional license-by-license processing and instead allow for blanket approvals based on pre-vetted security standards and programmatic oversight mechanisms. Additionally, DoD and DoS will consider developing an international cooperative program framework that permits cooperative development of a general technology area rather than a specific system. While security considerations would limit such agreements to small groups (likely no more than 3-5 partner nations), and establishing the agreement will take several years, the benefits realized will be considerable.

Mid-term and Long-term: DoD and DoS implement the recommended changes to their internal export control policies and work with Congress to change outdated legal restrictions that stymie international cooperation with trusted allies. In the long term, relevant agencies must implement and revisit policy and legal barriers related to export controls and global

collaboration, including reevaluating partners and technical areas for inclusion in cooperative agreements.

3. Develop EMSO Capabilities with Continuous Warfighter Integration and Revised Acquisition

Accelerating the acquisition of EMSO capabilities with warfighter input is key for EW systems to operate effectively in combat scenarios. Operational units need to be involved from the earliest stages of development through deployment. Warfighter-influenced design ensures the EMSO systems align with battlefield needs. Expanding the use of rapid acquisition tools such as OTA and MTAs can significantly shorten timelines and allow operators to shape prototypes that move swiftly from development to operational deployment. RAND research shows, "OT contracts and relaxed intellectual property restrictions are especially attractive to companies involved in early-stage technical developments because they provide flexibility for design iterations and can help suppliers identify military applications for their products," which directly supports faster and more adaptive acquisition cycles.[70] This flexibility allows technology iterations at combat-relevant timelines based on operator input by running acquisitions, developmental, and operational test concurrently. MITRE's AiDA website reinforces the need for specialized acquisition pathways, noting that MTA accelerates the fielding of capabilities to answer an operational need to leverage rapid prototyping without waiting for requirements to be complete.[71]

The convergence of acquisitions and warfighter collaboration must culminate in resource-informed budgeting. Auditing the resourcing of most EMSO capabilities is nearly impossible

[70] Jonathan P. Wong et al., "Improving Defense Acquisition: Insights from Three Decades of RAND Research" (RAND Corporation, June 16, 2022), https://www.rand.org/pubs/research_reports/RRA1670-1.html.
[71] "Middle Tier of Acquisition (Section 804) | AiDA," 2025, https://aida.mitre.org/middle-tier/.

because they are not represented as separate line items or projects in the PPBE process. EMSO capabilities are in each Service's POM and budgets. EMSO capabilities range from Major Defense Acquisition Programs (MDAPs), such as the Next Generation Jammer, to MTAs like the Army's Terrestrial Layer System, to subcomponents buried within larger programs like the F-35 EW suite. The DoD must take steps to better understand and assess how EMSO capabilities are resourced through the PPBE so that it can ensure they are properly prioritized. The Services have the flexibility within their budget to reprioritize funding away from EMSO toward token MDAPs, which may have more champions and visibility within senior leadership and Congress. However, EW capabilities require greater flexibility to allocate funds and adjust requirements within their portfolio based on evolving threats and technological opportunities, enabling faster adaptation than the current multi-year budget cycle allows.[72]Doing so aligns resources more directly with strategic needs like EMS superiority, allowing for faster adaptation than the rigid, platform-centric PPBE.

Near-term: Align acquisitions, developmental test, and operational test to run concurrently, led by the Joint Test and Evaluation (JT&E) program. JT&E enhances warfighter integration into early EMSO innovation by creating operationally relevant test environments incorporating user feedback during development.[73] Embed EMSO operators in 100% of new EMSO prototype efforts initiated by program offices, with at least three Indo-Pacific field tests conducted annually to drive early operator feedback and accelerate iteration. This iterative, field-focused approach not only improves the utility of emerging EW capabilities but also aligns

[72] Veritas Rei Group, "Adapting for Agility: How Flexible Funding in Defense Addresses Emerging Threats," Strategy Central, November 4, 2024, https://www.strategycentral.io/post/adapting-for-agility-how-flexible-funding-in-defense-addresses-emerging-threats.
[73] Department of Defense Joint Test and Evaluation Program Office. *JT&E Handbook.* Washington, DC: Office of the Secretary of Defense, 2022

closely with the AAF by supporting rapid prototyping and informed decision-making. By fostering early and sustained collaboration with program offices, Joint T&E ensures that test insights are directly fed into acquisition pathways, accelerating capability delivery, reducing risk, and better meeting the dynamic needs of the operational force.

Mid-term: Next, DoD will move beyond the one-off pilot program and establish permanent Joint EMSO development units that bring acquisition teams and operational units together across the Services. This ensures the warfighter can influence prototypes, requirements, and timelines, while acquisition reform shifts focus on speed and real-world utility. EMSO training pipelines should also be updated to produce operators who can provide meaningful system feedback, keeping the industrial base aligned with frontline needs and the pacing threat. Stimulate innovation in the defense industrial base through a Presidential Executive Order that prioritizes commercial solutions procured through optimization of OTA, MTA, and Software Acquisition Pathways.[74]

Long Term: In the long term, DoD will build operational relevance as a feature of EMSO development across the Joint Force and allied partners. Shared threat data, common reprogramming tools, and joint warfighters testing should shape EMSO systems before fielding. A formal process for real-time feedback from deployed units to developers will ensure EMSO capabilities remain responsive and ahead of the threat. This sustained integration supports adaptability and field utility to maintain EMS superiority.

[74] "Executive Order 14265—Modernizing Defense Acquisitions and Spurring Innovation in the Defense Industrial Base | The American Presidency Project," The American Presidency Project, April 9, 2025, https://www.presidency.ucsb.edu/documents/executive-order-14265-modernizing-defense-acquisitions-and-spurring-innovation-the-defense.

4. Enhance Realism and Interoperability of EMSO Training and Simulation

Enhancing EMSO training realism and interoperability is crucial for preparing military personnel facing complex, multi-domain threats. Integrating advanced M&S tools into Live, Virtual, Constructive (LVC) training environments creates comprehensive scenarios. The DoD developed the Joint Simulation Environment (JSE) to be the next-generation battlespace, supporting joint simulation and enabling cross-domain effects. Currently operational, the JSE supports numerous key programs, including the Air Force (AF) Operational Test and Evaluation Center (AFOTEC) at Edwards AFB, the Naval Air Warfare Center Aircraft Division (NAWCAD) at NAS Patuxent River, and the AF Air Combat Command and Warfare Center at Nellis AFB.[75] However, for JSE to meet warfighter needs, the DoD must accelerate its expansion and federation to ensure it is fully multi-domain and interoperable with other M&S platforms, including those in top-secret and special access required networks. The JSE focuses heavily on the end of the kill chain (shooters) but must evolve to incorporate high-fidelity EMSO battle simulations, integrated air defense systems (IADS), weapons systems modeling, and radio frequency (RF) signal interfacing. For example, incorporating Textron's Force-On-Force Reactive Tactical Readiness IADS Simulation (FORTRIS) into JSE better prepares service members for modern warfare.[76] FORTRIS simulates real-time IADS training with cognitive and autonomous behaviors across multiple command-and-control layers capable of integrating with other simulator environments to provide realistic, high-fidelity training.

Near-term: To address these challenges, the JSE must be resourced and governed consistently. The immediate need is consistent, ongoing funding for JSE expansion. Outlined in

[75] Lt Col Justin Bañez, "Add Special Operators to the Joint Simulation Environment," Defense One, April 1, 2025, https://www.defenseone.com/ideas/2025/04/add-special-operators-joint-simulation-environment/404213/.
[76] "FORTRIS: Force-On-Force Reactive Tactical Readiness IADS Simulator" (Textron Systems, 2024), chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.textronsystems.com/sites/default/files/_documents/FORTRIS%20Datasheet_0.pdf.

the DoD's Fiscal Year 2025 Budget Request as a Joint Training Requirement, future integration and technical upgrades necessitate consistent funding lines in the POM cycle.[77] Therefore, the JSE must be designated as a key enabler in POM guidance to establish joint-program funding streams. Concurrently, OSD must establish a JSE lead authority to streamline progression. Programs lacking strong champions or governance structures often lose momentum, even with funding. The Joint Staff J7 is best positioned to be the design lead, ensuring a joint, multi-domain perspective. As the lead, the J7 must also publish interoperability standards to facilitate seamless integration of current and future M&S tools across the defense enterprise.

Mid/Long-term: The JSE must be institutionalized across the Joint Force as a mission-essential tool. It must be entrenched in exercise design, training guidance, and experimentation campaigns, with the fidelity and breadth to inform resourcing decisions in the requirements process. Without consistent use and validated requirements, it will not be funded. Finally, the JSE must replace or phase out legacy M&S systems in the long term. Expanding JSE effects and accessibility across the Services and CCMDs will help standardize JEMSO training and support cross-domain exercises.

5. Foster Advanced Technologies with Modular OAs and AI Integration

To address evolving threats, the DoD must continue focusing on integrating advanced technologies into EW systems through modular OAs and AI. MOSA and SOSA enable fast and flexible software-based upgrades, helping integrate commercial tech into EW capabilities, ensuring quick adaptability to emerging threats. RAND describes MOSA as involving "systems

[77] "Defense Budget Review: FY25 Budget Request," Department of Defense (Washington DC: Office of the Under Secretary of Defense (Comptroller), March 2024), https://comptroller.defense.gov/Portals/45/Documents/defbudget/FY2025/FY2025_Budget_Request_Overview_Book.pdf?utm_.

of separately designed subcomponents that conform to widely adopted interface standards," upgraded on prescheduled timelines to support agility and future scalability.[78] In addition to OAs, prioritizing the development of cognitive EW systems and AI integration technologies is crucial for creating adaptable and scalable EW effects. AI-enabled systems can enhance responsiveness and reduce decision time in fast-moving operations, consequently advancing EW platforms that can detect and respond to novel electromagnetic threats in real time and provide a critical edge in contested environments. This autonomy is vital in EW, where speed and agility can determine tactical success.

Near-Term: Accelerate and remove policy and security bottlenecks. Many cognitive EW capabilities already exist in laboratory settings but are languishing in cybersecurity purgatory. The DoD maintains a cognitive capabilities library that is ready to field today, but issues such as outdated but issues such as outdated operating systems or rigid security scanning tools cause delays. The DoD must mandate that Approving Officials (AOs) adopt risk management (not risk aversion) when issuing Security Impact Assessments (SIA) and Certificates to Field (CTF). An SIA should have a maximum timeline of 30 days to be issued, and a CTF should take no more than two weeks. To further accelerate industry engagement, offer "fast-lane" SBIR and OTA pathways for companies that can meet these accelerated integration and fielding benchmarks that comply with OA.

Mid-Term: Scale integration and deployment of EW capabilities. Focus must shift to equipping current RF hardware with software capabilities, including software-defined radio for EW and embedding EMBM for offboard C2. Self-protection and communication suites need

[78] Wong et al., "Improving Defense Acquisition."

updates with CMOSS-compliant software enclaves for these capabilities. A dedicated System Program Office (SPO) with rapid acquisition powers must oversee platform-agnostic capabilities. The DoD should acknowledge and reward industry partners who quickly transition to fielded capabilities through contract bonuses, PPP opportunities, and expanded market access for vendors supporting cross-service and coalition interoperability.

Long-Term: Focus on autonomous, interoperable, networked EMSO systems to dominate the electromagnetic battlespace through intelligent, distributed action. This includes cognitive EMSO platforms operating with minimal human input, using edge AI, neuromorphic computing, and swarming logic to detect, deceive, and disrupt adversary emitters dynamically. Modular, MOSA-compliant systems will allow rapid upgrades and plug-and-play with allied architectures. Directed energy weapons will develop into high-power (1+ MW) scalable systems for strategic capabilities such as satellite defense, area denial, and integrated air and missile defense. The innovation infrastructure will produce capabilities that meet cybersecurity requirements and shorten administrative timelines. The United States must invest in a resilient industrial base with secure access to critical materials, next-gen photonics, and advanced semiconductors beyond GaN. A permanent innovation infrastructure (warfighter-informed development hubs, training range networks, and digital twin environments) will create capabilities that meet cyber requirements, reduce timelines, and ensure adaptation to evolving EMS threats. To sustain long-term industry commitment, DoD must establish enduring PPPs, guarantee competitive access to government test infrastructure, and offer milestone-aligned technology transition contracts for ongoing upgrades and interoperability.

6. Strengthen and Institutionalize Government-Industry Partnerships

To maintain its technological edge in EMSO, the DoD must build stronger, more structured partnerships with the private sector, which is essential to keeping pace with the speed of innovation seen in global commercial markets. Public-private partnerships (PPPs) are vital in bridging gaps between defense requirements and private-sector innovation. This is especially important for agile innovation organizations, like the Defense Innovation Unit (DIU), and expanding programs that reduce entry barriers for small firms and startups. These organizations are designed to interface with high-tech regions like Silicon Valley and "connect to the talent and technology resident there" while drawing on private industry's innovation talent and R&D infrastructure.[79]Additionally, creating regular forums for ongoing industry input can foster continuous collaboration and transparency. These forums offer smaller companies a platform to discuss emerging EMSO technologies directly with decision-makers, ensuring their innovations receive adequate exposure and funding opportunities. RAND highlights the importance of these interactions, stating that this kind of industrial base expansion "can be accomplished through improved DoD engagement with industry," which ensures alignment of defense priorities with commercial innovation cycles, benefiting national security and economic competitiveness.[80] Formal mechanisms to attract venture capital and private investment further solidify these partnerships to promote sustained technological advancement and a competitive advantage in EMSO capabilities.

Near-Term: DoD will launch quarterly regional EMSO innovation forums hosted by DIU, National Security Innovation Networks (NSIN), or Federally Funded Research and

[79] Andrew Philip Hunter and Ryan Crotty, "Keeping the Technological Edge," *Center for Strategic and International Studies (CSIS)*, September 25, 2015, 3.
[80] Wong et al., "Improving Defense Acquisition."

Development Centers (FFRDCs) to connect program managers, operators, and small firms to mitigate real capability gaps, to shorten contract timelines, and to move prototypes to testing within months. At the same time, acquisition policy updates like DoDI 5000.73 (Capability Portfolio Management) will enable earlier industry engagement under the AAF mandated in a Presidential EXORD and advocate for a dedicated EMSO innovation line in the DoD budget request, fully funded through the FYDP.[81] Early outreach to senior leaders and Congress should focus on how these public-private models deliver faster, lower-cost capability without structural overhaul.

Mid-Term: DoD must establish permanent EMSO acquisition channels modeled on SOCOM's speed and flexibility, bundling prototyping, integration, and testing into single efforts. An EMSO Industry Fellows program should embed commercial engineers into Service labs and program offices, while training tracks for acquisition professionals focus on open systems and nontraditional vendor tools. To grow the industrial base, DoD should expand EMSO supplier diversity using pre-competed contracts and consortia for second- and third-tier firms.

Long Term: In the long term, DoD must build a fully integrated defense-industry ecosystem by formalizing coalition industrial frameworks under agreements like AUKUS. The EMSO innovation budget line item could be transitioned to a standing EMSO Innovation Fund, and a national-scale EMSO talent pipeline anchored in technical schools, universities, startups, and DoD-industry training programs will sustain overmatch through continuous innovation with the end goal being a system that adapts faster than the adversary, cycle after cycle.

[81] "Executive Order 14265—Modernizing Defense Acquisitions and Spurring Innovation in the Defense Industrial Base | The American Presidency Project."

V. Conclusion: Reclaiming the Invisible High Ground

The United States cannot depend on old ways of doing business in the EMS, with scattered industry partnerships, restrictive regulations, or slow requirements and acquisition practices. China and Russia recognize the EMS as the next decisive domain, investing heavily in frequency-agile, AI-enabled, and mass-producible EW systems that have eroded decades of American technological advantage. If the United States fails to accelerate its own EMS transformation, it risks yielding the initiative and deterrence credibility to adversaries. Technological superiority in the EMS will hinge on modular open architectures, rapid adoption of AI/ML, and the ability to integrate and upgrade systems at the speed of relevance.

The U.S. EW industrial base contains world-class talent, innovation, and technological depth. Yet bureaucratic inertia within the acquisition system, compounded by a lack of unified senior-level advocacy, blocks the rapid translation of breakthrough technologies into fielded capabilities. Meanwhile, an inconsistent demand signal from DoD fails to incentivize bold private-sector investment. The United States must overhaul this status quo by consolidating EMS authorities under appropriately resourced and empowered leadership. By doing so, the United States can take critical steps to begin institutionalizing and exploiting existing agile acquisition pathways, breaking down barriers to entry for innovative firms and allied collaboration, and empowering public-private partnerships that harness the full creative power of our industrial commons. DoD must prioritize operationally relevant, “good enough” EMSO capabilities that can be rapidly fielded, integrated, and iterated based on warfighter feedback. Finally, the United States must elevate EMSO workforce development as a national priority, with clear career pathways, cross-sector mobility, and sustained investment in human capital.

The consequences of inaction are stark. The United States risks permanently ceding its EMS advantage, undermining deterrence, and facing peer adversaries who can neutralize our most exquisite platforms at will. The path to EMS superiority demands bold reform, relentless innovation, and unwavering unity of effort across government, industry, and allied partners. The time for incremental change has passed. The United States must seize this moment to lead, transform, and secure the invisible high ground, ensuring competitive advantage, credible deterrence, and victory in the electromagnetic battlespace of the 21st century.

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Appendices

A. Artificial Intelligence

The electromagnetic spectrum (EMS) has become a contested and congested environment, demanding increasingly complex systems and operations that will challenge the capabilities of Electromagnetic Warfare Operators (EWOs) and spectrum managers.[82] The advancement and military adoption of artificial intelligence (AI) are inextricably linked to the U.S. military's ability to maintain EMS superiority. Significant investments and policy changes are necessary to gain a critical advantage in spectrum sharing and battlefield EMS superiority. While the United States leads AI investment and technology development, resource superiority will not guarantee strategic victory over the People's Republic of China (PRC).[83] Instead, deep AI diffusion across defense sectors, particularly EMS operations, will create a competitive advantage.[84]

The DoD recognized the importance of AI, highlighting it multiple times in the 2020 EMS Superiority Strategy as essential to modernizing systems like Electromagnetic Battle Management (EMBM) and accelerating EMS information integration.[85] Traditional EW systems

[82] Richard Scott, "From the JED Archives: NATO Confronts the Challenge of a Congested and Contested Spectrum," Journal of Electromagnetic Dominance, accessed May 5, 2025, https://www.jedonline.com/2023/11/30/from-the-jed-archives-nato-confronts-the-challenge-of-a-congested-and-contested-spectrum/.
[83] Bill Tanner, "USA Leading the Charge on AI Investment – Intelligent CIO North America," *Intelligent CIO* (blog), August 8, 2024, https://www.intelligentcio.com/north-america/2024/08/08/usa-leading-the-charge-on-ai-investment/.
[84] "China and America Are Racing to Develop the Best AI. But Who Is Ahead in Using It?," *The Economist*, April 3, 2025, https://www.economist.com/business/2025/04/03/china-and-america-are-racing-to-develop-the-best-ai-but-who-is-ahead-in-using-it?utm_medium=cpc.adword.pd&utm_source=google&ppccampaignID=17210591673&ppcadID=&utm_campaign=a.22brand_pmax&utm_content=conversion.direct-response.anonymous&gad_source=1&gbraid=0AAAADBuq3JPFM1sFZ1ai8lW0ZsnvhNha&gclid=EAIaIQobChMIwq2ppvyLjQMVLm5HAR3nUBFEEAAYASAAEgLGbvD_BwE&gclsrc=aw.ds.
[85] "2020 Department of Defense Electromagnetic Spectrum Superiority Strategy."

reliant on static databases are insufficient against adaptable adversaries[86] While advancements like DARPA's Advanced Radar Countermeasures (ARC) program and other classified efforts may have occurred, true success demands broader AI diffusion in areas such as pilot decision aides, Cognitive Electronic Attack (EA) systems, and advanced spectrum sharing technologies.[87]

Looking at industry, closer ties between the EW industrial base and Silicon Valley AI start-ups would drive rapid EW-AI fusion, improving capabilities and workforce development.[88] AI would also enable the convergence of EW with cyber, space, and information warfare, while enhancing the quality of skilled personnel and automating tasks historically reliant on specialized analysts.

Cognitive Electromagnetic Warfare (EW) is critical for EMS superiority. As subject matter expert Dr. Karen Haigh explains, cognition in EW requires the ability to observe, decide, act, learn, and apply experience without human oversight.[89] Cognitive systems offer advantages in threat detection, classification, and adaptation to dynamic environments. Yet, much progress remains. Dr. Haigh emphasizes that data fusion—the ability to combine and learn from diverse sensor data—is still largely absent in EW systems, hampering true cognitive evolution.[90]

The growing demand for EMS access across commercial and military sectors further necessitates AI-driven spectrum sharing. Programs like DARPA's Spectrum Collaboration

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[86] Charlotte Adams, "Cognitive EW: RF Spectrum Meets Machine Learning," *Avionics Magazine*, September 2018, https://interactive.aviationtoday.com/avionicsmagazine/august-september-2018/cognitive-electronic-warfare-radio-frequency-spectrum-meets-machine-learning/.
[87] John Keller, "Leidos to Develop Electronic Warfare (EW) Adaptive Radar Countermeasures Software to Protect F/A-18 Aircraft," Military Aerospace, August 28, 2020, https://www.militaryaerospace.com/computers/article/14182542/electronic-warfare-ew-adaptive-radar-countermeasures-f-a-18.
[88] "Industry Engagement."
[89] Karen Zita Haigh and Julia Andrusenko, *Cognitive Electronic Warfare: An Artificial Intelligence Approach* (Artech House, 2021).
[90] *Cognitive Electronic Warfare*.

Challenge and MITRE's National Radio Dynamic Zones (NRDZ) highlight early progress toward dynamic, AI-enabled spectrum management.[91] The Advanced Dynamic Spectrum Sharing Program, mandated for 2025 by the National Spectrum Strategy (NSS), represents a critical "moonshot" effort to ensure adaptable spectrum access.[92] AI-driven systems will enable real-time sensing and intelligent spectrum reallocation, essential for avoiding congestion and ensuring mission success.

However, the implementation of AI-enabled EMSO systems faces significant challenges. Military testing frameworks must adapt to account for AI's learning and evolving nature, where traditional repeatability is impossible.[93] Resource constraints, particularly the processing of vast EMS data collections, further complicate AI development. Political obstacles, especially surrounding spectrum control between military and commercial interests, add complexity.[94] Finally, ethical concerns regarding autonomous EW systems highlight the need for careful operational planning that aligns with international norms.

The DoD must accelerate AI diffusion through partnerships with industry, academia, and key allies to succeed. Improving data management and streamlining data sharing is a critical first step. In the future, EMS superiority will depend on technological superiority and the United States' ability to rapidly and intelligently integrate AI into every facet of EMSO.

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[91] George Seffers, "Smarter AI for Electronic Warfare | AFCEA International," The Cyber Edge, November 1, 2017, https://www.afcea.org/signal-media/cyber-edge/smarter-ai-electronic-warfare.
[92] "Advanced Dynamic Spectrum Sharing Demonstration in the National Spectrum Strategy | National Telecommunications and Information Administration," Government, National Telecommunications and Information Administration, June 28, 2024, https://www.ntia.gov/issues/national-spectrum-strategy/advanced-dynamic-spectrum-sharing-demonstration-in-the-national-spectrum-strategy.
[93] "Industry Engagement," April 6, 2025.
[94] "Pentagon Engagement" (Academic Engagement, Department of Defense, Pentagon, January 2025).

B. Wargaming

Due to its increased importance in conflict, Electronic Warfare (EW) is increasingly being wargamed, trained, and exercised at multiple levels across the DoD, focusing on degraded/denied spectrum environments, Joint All-Domain Command and Control (JADC2), offensive versus defensive EW, CIV/MIL spectrum conflict, and the impact of autonomous systems.

From single-point experiments to integrated simulation, integrating Electromagnetic Spectrum Operations (EMSO) into live and virtual wargaming increasingly affects all facets of operations, allowing a greater understanding of how EMSO can set conditions leading to operational and strategic success. Field trials, like the Army-led Project Convergence, are experiments that test concepts and innovative technologies in live and simulated environments to gather data on emerging operational concepts. For example, Project Convergence 2025 will focus on four primary warfighting operational constructs, including layered electromagnetic protection and electromagnetic spectrum operations.[95]

A key enabler for advancing EW wargaming is the effective use of modeling and simulation (M&S), which replicates the complexity of the Electromagnetic Spectrum within closed-loop and limited open-loop virtual, live-virtual, training, and exercise environments.[96] While numerous tools create discrete spectrum effects, federating multiple tools and effects into a coherent environment poses significant challenges. For example, integrating multi-domain EW effects at the operational and strategic levels into component and joint-level efforts such as Warfighters Simulation (WARSIM) and the Joint Simulation Environment (JSE) has proved

[95] Mark Pomerleau, "Project Convergence Headed to Indo-Pacific Command in April," *DefenseScoop* (blog), March 11, 2025, https://defensescoop.com/2025/03/11/project-convergence-capstone-5-indo-pacific-command-army/.
[96] "Joint Publication 3-85: Joint Electromagnetic Spectrum Operations" (Joint Chiefs of Staff, May 22, 2020), https://crows.org/download/cjcs-joint-publication-3-85-joint-electromagnetic-spectrum-operations-jemso/.

problematic. This gap weakens EW readiness and informed decision-making, necessitating urgent attention from senior leaders to develop more realistic, integrated training and simulation environments.

Defense contractors have developed several M&S tools; however, given EW's technical complexity, no tool replicates all multi-domain EW effects and operational requirements. As a result, both DoD and its industry partners have developed mission-specific tools designed for specific EW applications. The challenge remains the federation of these disparate systems. In response, the Joint Force developed the Joint Simulation Environment (JSE) as a government-owned, multi-domain simulation tool that enhances joint interoperability [97]

Incorporating additional EW effects into JSE-based CCMD (Tier One) and Joint Staff (Tier Zero) exercises and wargames remains challenging. Obstacles include multi-domain COP integration, restrictive classification levels, intelligence stovepipes, and barriers to working with allies and partners. During his Senate confirmation hearing, General Dan Caine addressed challenges related to EW and EMSO in Tier One exercises. He noted that current M&S tools are inadequate for evolving RED and BLUE force play. He also highlighted shortcomings in the JSE, noting that it remains fragmented with other systems and cannot support the development of new joint EW concepts.[98] This shortfall limits the Joint Force's ability to effectively experiment, refine, and fully operationalize EW and EMSO capabilities.

To advance EW readiness, the DoD must establish precise training, simulation, and wargaming requirements, particularly at the operational and strategic levels. Of particular importance is enabling the federation of EW information and data from operational-level

[97] "Joint Simulation Environment | NAWCAD," accessed April 20, 2025, https://www.navair.navy.mil/nawcad/jse.
[98] John Tirpak, "Caine: US Has Lost Electronic Warfare Skills, Needs to Up Training," Air & Space Forces Magazine, April 3, 2025, https://www.airandspaceforces.com/caine-us-electronic-warfare-skills/.

environments to coherent strategic-level simulation platforms. Accelerating the integration and expansion of the JSE is critical beyond shooters and the end-game kill chain. It must be fully interoperable with other M&S platforms, including those operating within top-secret and SAP environments. This effort includes federating specialized EW tools into the JSE, such as the Force-On-Force Reactive Tactical Readiness Integrated Air Defense System (FORTRIS). FORTRIS enables real-time, high-fidelity EW battle simulations and features integrated air defense systems (IADS), weapons systems modeling, and radio frequency (RF) signal interfacing.[99] Successful integration into the JSE hinges on stringent security protocols and compatibility requirements.

In addition to augmenting the JSE, the DoD must address classification barriers and enhance coordination with the defense industry. The government will help the industry develop more technically advanced and operationally relevant M&S tools by clearly articulating EW training objectives, capability gaps, and system requirements.

[99] "FORTRIS: Force-On-Force Reactive Tactical Readiness IADS Simulator."

C. Meet the Crows

The AY 2025 Electromagnetic Warfare Industry Study comprised thirteen U.S. students and three faculty members. The Crows represent a diverse joint and interagency group with a wide range of backgrounds and experience across the U.S. government. The group comprised professionals from the U.S. Department of State, U.S. Army, U.S. Navy, U.S. Air Force, U.S. Space Force, and the Defense Threat Reduction Agency (DTRA).

Faculty
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COL Jeremy Gwinn, USA (Co-Industry Study Lead, IA)

Students
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Mr. John Burghardt, USCYBERCOM
LTC Elizabeth "Betsy" DeSitter, USA
Col Ajay "Ramrod" Giri, USAF
LTC Melissa "Mel" Hoaglin, USA
COL Eric "Counselor" Husby, USA
CDR Brian "BMow" Mowry, USN
LTC Richard "Bird" Peacock, USA
Ms. Megan Piersol, DAF
Lt Col Carri "ELF" Salas, USAF
Lt Col Leslie "Nilla" Woll, USAF
LtCol Joshua "Walleye" Wort, USMC
Mr. Matthew "Token" Wright, DoS

D. Field Study Visit Locations, Agencies, and Companies

From December 2024 to May 2025, the EWIS engaged across the U.S. Government, academia, the domestic and Australian industrial base, and key partners in the Australian Department of Defence to gain a broad understanding of Electromagnetic Warfare strategy and policy, technological advances, and the challenges and opportunities faced by the Department of Defense, the military services, key allies and partners, and the Defense Industrial Base.

Government

350th Spectrum Warfare Wing at Eglin Air Force Base [Virtual]
479th Operations Support Squadron at Naval Air Station, Pensacola [Virtual]
Australian Defence Force (ADF)
Cyber and EW Ops Division, Joint Staff J39
Defense Advanced Research Projects Agency (DARPA)
Defense Information Systems Agency (DISA)
Defense Security Cooperation Agency (DSCA)
Defense Technology Security Administration (DTSA)
Deputy Director for Electromagnetic Warfare, OUSD(R&E)
DoD CIO Electromagnetic Spectrum Enterprise Policy & Programs
DoD CIO Electromagnetic Spectrum Enterprise Governance and Strategy
EMS Superiority Directorate, HAF A2/6L
Federal Communications Commission (FCC)
Force Application Division, Joint Staff J8
Former Director of Electronic Warfare, OUSD(A&S)
Joint Electromagnetic Spectrum Operations Center (JEMSOC), INDOPACOM
National Reconnaissance Office (NRO)
National Security Agency (NSA)
National Telecommunications & Information Administration (NTIA)
Naval Research Laboratories (NRL)
Naval Air Warfare Center – Weapons Division
PEO, Intelligence, Electronic Warfare and Sensors (IEW&S), Army

Academia, FFRDCs, and Non-Profit Organizations

Georgia Tech Research Institute [Virtual]
Hudson Institute
Massachusetts Institute of Technology Lincoln Labs
MITRE Corporation
RAND Corporation
SRC, Inc

Industry

Anduril Industries
BAE Systems, Inc
Consunet (Australia)
Epirus, Inc
HawkEye 360
IAI
L3Harris
Mercury Systems
RF Technologies (Australia)
RTX
Solinnov (Australia)
Sypaq Systems (Australia)
Vadum, Inc

Field Study Locations

Greater Boston, MA
Greater Los Angeles, CA
Honolulu, Hawaii
Canberra, ACT, Australia
Adelaide, SA, Australia