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Final Report *Electronic Warfare*

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ELECTRONIC WARFARE (EW) 2020

Abstract: To regain and maintain the United States' competitive edge in a congested and contested Electromagnetic Spectrum, the Department of Defense and industry must seek radical change to existing Electronic Warfare paradigms. Both must let go of restrictive acquisition practices and platform-centric parochialism to focus on solving modern challenges, like modularity, supply-chain security, sustaining human capital, and persistent energy. With renewed focus, the Department of Defense and industry have the opportunity to transform, shifting to a flexible and resilient dynamic that will enable the United States to deliver spectrum superiority in support of Great Power Competition and national security.

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Introduction

Since the pivot to Great Power Competition in the 2018 National Defense Strategy, both the Department of Defense (DOD) and Congress have increased attention to Electronic Warfare (EW) and the Electromagnetic Spectrum (EMS). The Congressionally mandated National Defense Strategy Commission stated that “the United States is losing its advantages in electronic warfare, hindering the nation’s ability to conduct military operations against capable adversaries.” As a result, every Service Chief announced intent to “modernize” their approach to control and manipulation of the EMS.¹ To regain and maintain our competitive edge in the EMS, the DOD must commit to continuing and expanding the EW momentum and move out of its comfort zone with both industry and the warfighter.

Modernization of EW and the DOD’s use of the EMS is, and will continue to be, a challenge. The DOD struggles to define the concept and use of EW itself. Some subject matter experts in and out of the DOD passionately advocate for the EMS to be designated as a domain. Many others believe just as passionately that it is not a domain, but rather a cross-functional utility. Both groups believe that their way is the only path to EMS functionality receiving the attention it deserves. The concept of “modernization” is equally problematic, and in some cases has been limited to mitigating 20 years of neglect to EW strategies and systems. The DOD’s relationship with the EW industry is complicated by the fact that it is not an industry at all, but rather a sub-market for defense primes and smaller contractors who divide their attention with the commercial market.

The experiences of the academic year 2020 EW/EMS Industry Study serve as a metaphor for the fragility of long-held beliefs, established strategies, and “accepted truth.” While DOD priorities and industry strengths have always been subject to changes in leadership and priorities in both the legislative and executive branches, an exogenous event like the COVID-19 pandemic demonstrates just how quickly and immensely everything can change. It further highlights our weaknesses, such as limited domestic and restricted foreign supply-chains. For the United States to regain and maintain its advantage in the EMS in support of Great Power Competition, the DOD must commit to a unified and ambitious vision for EW. Both Defense and industry should shift their focus from decades-long commitments to exquisite weaponry to a balanced mix of platforms that will produce EW effects quickly and flexibly. All of our recommendations require consistent prioritization of the use of the EMS in and out of combat, even in the face of budget cuts. We believe that all of the Services must be open to radical modernization of EW, from the systems and weapons themselves to how the DOD communicates with industry.

While crisis reveals weakness, it also reveals strength. The EW/EMS Industry Study successfully completed its program despite curtailed travel, physical separation from colleagues, and limited virtual interaction with presenters and subject matter experts. That resilience represents the strength of our various services and agencies, as well as our collective ability to adapt. Should the EMS continue to receive the attention it deserves, the United States can discover a new enduring advantage in Great Power Competition.

Industry Defined – Moving Beyond EW to a Broader EMS Understanding

Despite its name, this EW Industry Study approached the topic from the more expansive umbrella of Electromagnetic Spectrum Operations (EMSO), which includes EW and Electromagnetic Spectrum Management (ESM) as subsets and reflects recent changes to joint doctrine. EW was once narrowly defined as “actions to attack and protect the electronic circuits associated with radios and radars,” including the subsets of electronic attack (EA), electronic protection (EP), and electronic support (ES).² However, the services and joint staff continue to update doctrine documents reflecting the expansive and integrative nature of the EMS as well as competition for its use. The Air Force published the most recent update, which this study found the most current and accurate, and it includes a redefinition of EW as *Electromagnetic Warfare*: “with expanded use of the [EMS] (e.g., infrared applications, lasers, microwave and satellite communications, computers) the broader term ‘electromagnetic’ is more technically accurate.” The Air Force EW/EMSO doctrine annex continues:

The EMS is a physical domain that exists regardless of human interaction and has physical and temporal properties, similar to the warfighting domains, which we interact with and influence. EMS-enabled capabilities are essential elements of military operations – critical enablers of multi-domain synergy... **Electromagnetic spectrum operations (EMSO)...refers to all actions taken in the EMS or involving the EMS regardless of their nature or adversary involvement. EW refers to military action in which forces use radiant and directed EM energy to obtain and maintain situational mastery of the EMS**, by protecting spectrum-dependent systems, networks and operations; tactically sensing the operational environment (OE); and attacking where necessary, at a time and place of their choice.³

The “EW Industry” is expanding, but not because of market forces – the increasing capability and cross-functional integration of systems operating in the EMS forced an expansion in the recognized umbrella of sellers and products. The increasing congestion and competition for use of the EMS created both the need and the capability for all users of the EMS to collectively attack, protect, manage, and support as part of joint EMS operations. So, while EW used to be the niche realm of jammers and countermeasure systems, now anything operating in the EMS, down to a soldier’s handheld tactical radio, not only requires EW functionality but also has the capability to perform cross-functional EW tasks in support of command objectives.

This study approached the “EW Industry” as the ecosystem of firms offering products and services that access or manage the EMS for defense applications. The products, services, and topics considered reflected the range of the EMS: from power generation, microchip fabrication, and radiofrequency (RF) transceivers, to directed energy and electromagnetic pulses. In this context, the universe of sellers is nearly as large as the defense industry itself, with access to the EMS as the defining characteristic as well as adherence to the rules and governing bodies for ESM, like the Federal Communications Commission, the National Telecommunications and Information Administration, and various foreign frequency authorization processes. Beyond these attributes, the EW industry and associated market characteristics resemble the broader defense context.

EW Industry Analysis – Diagnosing the Current Condition

To dominate in future Great Power Competition, the DOD will rely upon the EW ‘industry’ to provide sufficient capacity and appropriate cutting-edge capability. But is industry ready to meet that requirement?

The EW industry is not recognized by business analysts as a measurable entity; none of the major industry analysts publish a report on EW. Rather, the EW component market shares suppliers, buyers, and some individual firms with commercial electronics and communications industries and the larger defense industry. Primary firms within the United States include Raytheon, Lockheed Martin, Northrop Grumman, Boeing, General Dynamics, and L3Harris. Foreign-owned companies like Thales and BAE maintain a smaller, yet significant, portion of the market via their North American branches. Multiple barriers for new competitors to enter the EW market include high capital costs, extensive government regulation of technology development and sales, and a small, highly skilled workforce. Mergers and acquisitions are the only factor likely to change the current EW industry landscape.

Michael Porter theorized that firms deciding where, how, and when to compete on the Strategic Game Board, analyze national markets to determine if a competitive advantage exists.⁴ His Four Diamond framework⁵ (see Figure 1) posits that the following elements should be evaluated: “firm strategy, structure and rivalry; related supporting industries; demand conditions; and factor conditions.”

“Factor conditions” describe the external environment of an industry, and whether that environment encourages growth. Some of these factors are analogous to the “supplier’s power” within Porter’s Five Forces model.⁶ (See Figure 2.) They describe national conditions that support the development of a robust supplier network, such as an experienced labor force, public and private investments in innovation, and the infrastructure needed to support the industry. The United States developed and possesses all these factors – however, so do other near peer nations, including China.

“Related supporting industries” refers to the power of the supply chain. Firms design and produce complex subsystems such as antennas, sensors, power amplifiers, converters, and computers that are assembled and installed to receive data from the EMS, interpret it, and then recommend or execute actions in turn to change the EMS. Many of the necessary components, including specialized semiconductor chips, are produced outside the United States. The COVID-19 pandemic revealed the weaknesses of an international supply chain. EW firms are struggling to maintain their access to strategic suppliers, many of which are closed due to the pandemic or diverted their resources to crisis response. U.S. industry’s inability to maintain a domestic supply chain for EW components represents further vulnerability in great power competition.

“Demand conditions” in EW are analogous to the “Buyers’ Power” within Porter’s Five Forces. The EW market is restricted geographically and politically, with a small number of buyers. In the United States, the primary purchasers of EW capabilities are the three Title 10-empowered services. Normally, this would mean that the buyers maintained the majority of the power in the economic relationship. However, the services have a long list of priority

investments, regulations dictating which countries may and may not supply certain items, and prescribed funding. Thus, EW demand conditions are not constant, nor can they be reliably predicted to grow year over year.

The demand environment feeds the market's strategies. "Firm Strategy, Structure, and Rivalry" is the center of Porter's Five Forces because it affects the rest of the model. A rigorous and technical marketplace, specific and small industry growth rate, and limited product differentiation creates moderate rivalry in the EW market.⁷ Firms further manage their rivalry through cooperation and collaboration, as well as mergers and acquisitions. This renders the EW market small and clubby, effectively hindering DOD efforts at fair and open competition for contracts. EW systems in particular tend to be exactingly engineered to their host platforms. Without common hardware or software interfaces between the EW system and all other electronics and communications systems on a platform, the switching costs involved in changing from one vendor's product to another cannot overcome the benefits gained from changing systems. Thus, procurements of EW systems are often sole-source, and when not, are often run with a goal of purchasing all the needed systems over the life of a platform from one vendor. This "winner take all" aspect of EW procurement robs the services of much of their buying power.

Many in industry believe that government regulations prevent firms from expanding the demand for their products through new markets in other countries. International Traffic in Arms Regulations (ITAR) restrict and control the export of U.S. EW systems to protect U.S. national security and further U.S. foreign policy. Others consider ITAR and its German and UK counterparts as discouragement to collaboration on such capability enhancers as open systems architecture standards.⁸ L3Harris believes that ITAR restrictions drive international customers to their overseas competitors, including end users like the Air Force and primes like Saab. This gives the United States less insight into the capabilities of both our international partners and competitors. For example, the government of Singapore bought a sonar system from Thales rather than L3Harris – they believe solely because of ITAR concerns. L3Harris further believes that ITAR negatively impacts coalition force interoperability and allows the company to export EW components only in platform participation.⁹ President Obama conducted the first major modernization of ITAR in 2013 and moved much of the heavily restricted U.S. Munitions List to the less regulated Export Administration Regulation list.¹⁰ Regulators at both the DOD and Department of State (DOS) believe industry complaints come from an outdated understanding of "old" ITAR and a lack of communication with regulators early in the process, when both the DOD and DOS can help them find "a way to yes."^{11 12}

According to Govini, an analytic firm supporting the DOD, the budget for EW programs has fluctuated between three and four billion dollars over the past five years and is projected to decline its lowest level (just above three billion dollars) through fiscal year 2024.¹³ Since many EW systems provide no dual-use commercial applicability, additional cuts to defense budgets could be catastrophic to the industry. Regulation and the uncertainty of budget priorities in both the DOD and Congress drive many defense firms to the commercial EMS market. In their 2019 10k report, L3Harris states:

We depend on U.S. Government customers for a significant portion of our revenue, and the loss of these relationships, a reduction in U.S. Government funding, or a change in U.S. Government spending priorities could have an adverse impact on our business, financial condition, results of operations, and cash flows.¹⁴

Of the four firms assigned to the EW/EMS Industry Study, two (L3Harris and Thales) increased focus on their commercial and civil product lines in recent years rather than continue to suffer the risks of being primarily a defense firm. Thales flipped the balance of the firm's portfolio in 2019 – 55 percent of its revenue now comes from commercial sales.¹⁵ L3Harris said it was diversifying specifically because of in the unpredictability in dealing with the United States Government in its 2019 annual report.¹⁶

Challenges to the EW Industry

The EW industry faces significant challenges. As discussed above, its limited participants and limited marketplace make it economically fragile in the face of reduced government defense spending. Second, in a field that is driven by novel innovation, the larger acquisition cycle struggles to keep pace. Third, lack of clear unifying direction leads to disjointed efforts. Fourth, current and projected EW equipment lacks flexibility and resilience and is difficult to scale due to costs and interoperability challenges. Finally, relying on innovation to maintain a competitive advantage, human capital is at a premium and the EW industry does not compete well for the best and the brightest engineers.

Although responsible for the greatest military in the world, it is no secret that the DOD Acquisition System (DAS) is a bureaucratic behemoth. Even as technology advances at an incredible pace, the DOD's newest fifth generation fighter, the F-35, has been in the works since the early 1990s. The strength, longevity, and natural tensions present in the Iron Triangle (see Figure 3) provide a number of benefits to the DAS, but speed is not one of them. Unfortunately, with the increasing rate of technology obsolescence, this will not work for maintaining effective EW capabilities in fielded systems, and the DOD must implement policies and processes to shorten acquisition timelines. The modular open system approach provides a promising way forward, as discussed in an essay below.

The debate of whether or not the EMS is its own domain continues, which highlights the lack of clear unifying direction and strategy for a near-peer conflict heavily reliant upon the EMS. Thus, in 2019, the Secretary of Defense established an EMS Operations Cross-Functional Team (EMSO CFT) per Section 1053 of the Fiscal Year 2019 National Defense Authorization Act. The Vice Chairman of the Joints Chiefs of Staff, General John Hyten, is the Designated Senior Official, and he is focused on “processes and procedures to develop, integrate, and enhance the electronic warfare mission area and the conduct of joint electromagnetic spectrum operations in all domains across the Department of Defense.”¹⁷ The strategic threat presented by adversary investments in asymmetric EW capabilities coupled with U.S. forces' over-reliance upon the EMS underlines the criticality of a clear, unified strategy with corresponding efforts that will protect U.S. advantages in this battlespace and evolve DOD towards a comprehensive and decisive strategic posture in the EMS.

EW equipment is historically designed for a single platform used for a specific purpose. Equipment designed by disparate manufacturers does not work well together and sometimes actually counters intended effects. In an era of great power competition, integrated network-based solutions will provide enhanced flexibility and resilience. Essays on a more flexible future force structure based on multifunction arrays, open system architecture, and small disaggregated, persistent, networked nodes present a compelling solution to this challenge.

Across the EW industry there is considerable competition for limited human capital. The mergers of L3 with Harris and Raytheon with United Technologies were due in part to securing an engineering talent pool. There is also effort across the industry to encourage potential young engineers to consider a career in EW. Relative to more widely known aerospace or computer engineering fields, EW is a little-known subset with no clear educational path. The essay on human capital further clarifies ways to expand the pool of capable engineers available nationwide.

Industry Outlook – Predicting the Health of the EW Industry

The EW industry should benefit from the nearly 10 percent increase in funding for research, development, test, and evaluation (RDT&E) in the President’s 2020 budget – a reflection of the Great Power Competition priorities established in the 2018 NDS. These are, of course, pre-pandemic numbers, and, as stated above, subject to changes in the U.S. economy and the will of Congress. However, the current Future Years Defense Plan (FYDP) for 2019-2024 anticipates that the DOD’s overall planned budget will remain relatively stable at approximately 700 billion dollars per year.¹⁸ Should it be correct, the Aerospace and Defense industry, including the EW market, would continue stable growth in revenue at or near the current Combined Aggregate Growth Rate (CAGR) of 3.5 percent.¹⁹ If the current DOD emphasis on EW and Secretary of Defense Mark Esper’s prioritization of Research and Development efforts are able to continue, it would mean a favorable near term outlook for the EW market. However, we must consider the potential cost to the DOD’s budget in post-pandemic America.

COVID-19

Estimates project that it will cost the U.S. Government more than four trillion dollars over the next five years to cope with the havoc of COVID-19. Pre-pandemic, the U.S. government deficit was increasing, discretionary spending was strained, and the DOD budget was projected to remain relatively flat.²⁰ Should COVID-19 cost projections prove to be correct the DOD will face budget cuts and hard choices. Secretary Esper’s prioritization of modernization could mitigate the effects on EW programs. In an April 2020 interview, he emphasized that planners should look to cut legacy programs to preserve funding for modernization.²¹ While the EW market would be negatively affected by reductions in Defense spending, those costs could be modest in comparison to other segments of the Aerospace and Defense market.

Long-Term Outlook for the EW Industry

While it is difficult to predict how an individual industry will perform 15 years in the future, the EW market should continue to hold strong in the defense sector. While EW cannot compete in

total dollar amounts or against large weapons platforms like ships and aircraft, there is little to no design, research, or production in the defense industrial complex that does not rely heavily on the EW ecosystem. However, as EW continues to evolve, the industry will have to evolve with it in order to grow. The seminar's industry interactions made it clear that the industry is learning to adapt and push past legacy platforms. We met with several companies that were not large defense contractors but were the innovators of the EW community. Startup companies like Anduril, a small, privately held defense company, represent the future of the EW industry. In an interview with an industry publication, Anduril's CEO Palmer Luckey said that, "I felt like there were not nearly enough high-tech companies working on defense problems in a way that was more similar to the Silicon Valley model of innovation rather than a traditional defense contract."²² Anduril believes that vanguard companies not only bring the most talented people to the research arena, they bring venture capital funding to defense.²³ Traditional defense contractors struggle to quickly design, build, and field EW effects. Larger companies are more risk adverse and comfortable with the long, slow acquisition process normally associated with the DOD. Funds spent to maintain EW superiority in the future will come from dual-use research and development. The EW industry's growing understanding of the capabilities and usefulness of cyber effects through the EMS will also enable it to grow over the long haul. When the EW industry invests in open architecture, computer programming will become a more prominent part of the ecosystem and the ability to lean on smaller, more agile companies will enable the United States to maintain its EW superiority.

U.S. Government Role in EW – Goals

Goal A: Reform EW Systems

The DOD should make a concerted effort to restructure all EW systems to conform to an interoperable standard between services and systems, reduce the size and cost of EW acquisitions, and increase automation and use of artificial intelligence.

Recommendation A1: Modular Open Systems Approach (MOSA) and Open Systems Architecture (OSA) allows for incremental additions and removal or replacement of subsystems and components through the lifecycle of a platform.²⁴ As EW systems continue to evolve, the DOD and Services EW leads need to continue the push for OSA through the SOSA Consortium and codify recommended requirements. This continued investment will benefit decades of program life-cycle maintenance and upgrades. The Joint Requirements Oversight Council (JROC) should increase its oversight of EW programs. The JROC Charter calls for "integrated architectures" but only requires National Geospatial Agency organizations to "evaluate open systems architectures, interoperability, and compatibility standards for geospatial intelligence related [information systems]."²⁵ The Services should bring forward requirements that are compliant with the MOSA memorandum signed by all the Service Secretaries, and the JROC provides the larger DOD perspective to ensure joint integration. However, the JROC should stop short of directing a specific solution.

Recommendation A2: The DOD should push for EW systems that optimize Size, Weight, Power and Cost (SWaP-C). Smaller, lighter, and more efficient systems allow for rapid manufacture and reduce overall costs. Smaller EW platform solutions tailored to threats and procured at a

lower rate would help to solve multiple concerns. Platforms based on current technology, which only need to remain valid for a couple of years, are far cheaper and faster to develop and field than those which must remain active for 40 or 50 years.

Recommendation A3: The DOD must demand smaller, less costly unmanned EW systems allowing for increased numbers, greater coverage of manned platforms and personnel, and a larger capacity for data collection. Machine learning works best when learning from large data sets.²⁶ In EW, attaining these large, current data sets requires the dispersal of collection platforms from single-purpose EW and Signal Intelligence (SIGINT) platforms to every vehicle and as many personnel as possible.

Recommendation A4: Artificial intelligence (AI) is already improving the capabilities of EW tools. The Army has recently fielded and is continuing to develop its Tactical Electronic Warfare System (TEWS). TEWS incorporates AI and machine learning (ML) to assist in classifying signals of interest and depict the local EMS. The Defense Advanced Research Projects Agency (DARPA) describes this as the “first wave” AI system that makes use of open architectures and interchangeable modules to facilitate software and hardware configuration changes and upgrades. DARPA’s “Mosaic Warfare” concept improves on this model by utilizing networked AI to create a real-time, continually evolving representation of the EMS. Mosaic warfare enables the continual analysis of the EMS and individual programs and technologies will change and adapt as the portfolio grows and evolves.²⁷ The DOD must encourage development of these types of systems and move to more advanced systems in order to gain advantage over our adversaries.

Goal B: Prioritize EW Across the DOD Enterprise

In order to ensure EMSO superiority, the DOD must emphasize EW as a critical function of the war fighting domain.

Recommendation B1: The DOD should institute and support an ambitious joint EMSO/EW vision and associated capability roadmap, relying heavily on multifunction phased arrays, wideband access and maneuverability, and the MOSA. The roadmap should drive requirements for expandability and functional integration to meet the future vision and provide a standard for “best value” determinations.

Recommendation B2: The DOD should leverage current authority over service acquisitions and R&D requirements, particularly with cross-functional EMSO and all-domain Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) in mind. The current paradigm of service- and platform-specific budget authorizations perpetuates capabilities with insufficient multi-service and cross-domain integration. The JROC needs to enforce the current guidance, captured in DOD Instruction 5000.2 Change 2, codified in the MOSA and data rights, or Intellectual Property (IP), requirements in defense acquisition. Program managers are required to “identify where, why, and how a MOSA will or will not be in the program.”²⁸ Individual services have insufficient motivation or incentive to incorporate system capabilities and functionality beyond the scope of the service’s prominent domain. This leads to insufficient capacity for future integration and insufficient adaptability for

future innovative operational constructs. Top down driven requirements through the JROC will seed the required momentum to overcome service parochialism. The DOD should attain and exercise authority over the service's acquisition and R&D requirements to overcome these structural obstacles.

Recommendation B3: The DOD must allocate additional funding for EW R&D, training, and platforms for the services. This is consistent with the guidance provided by the 2019 NDAA which "identified EW as a critical capability."²⁹ Even considering the recent increases, current budget allocations for EW are insufficient to sustain future EMSO and drive innovation. The DOD must prioritize the most critical EW "crown jewels" and resource them appropriately in order to survive and defeat advanced Anti-Access Area Denial (A2AD) systems fielded by Russia and China.

Goal C: Enhance EW Supply Chain Resiliency

The United States should invest in state-of-the-art domestic capability as well as expand trusted/approved sourcing from domestic and offshore suppliers. Moreover, we need to improve and expand a qualified domestic workforce in order to control core technology development.

Recommendation C1: U.S. headquartered firms have the largest share of the global semiconductor market. In the advanced semiconductor segment, the American microelectronics industry leads the world in R&D and can provide the DOD the decisive hardware necessary to dominate the EMS. It is up to the DOD to provide far-sighted and integrated EMS hardware requirements. Government should incentivize domestic manufacturing of state-of-the-art semiconductors, including Defense Priorities and Allocation System (DPAS) ratings for microchip fabricators to supply defense firms with application-specific chips for high priority, low volume contracts.

Recommendation C2: Government should expand the Defense Microelectronics Activity (DMEA) Trusted Foundry Program beyond its current limit. The program lists only 75 suppliers – mainly domestic – and actually reduced the approved list in the past few years. We must utilize our most advanced researchers to find new ways to innovate. The Electronics Resurgence Initiative – Defense Applications (ERI-DA) project is a DARPA initiative with a goal to support domestic secure chip manufacturing processes that can help defense electronics systems integrators apply specialized circuits. It will also ensure that those electronic circuits can be trusted through the supply chain.³⁰ Beyond increasing internal capacity, we should look to develop relations with our allies that have capabilities. Building on existing relationships with technology powerhouses like Singapore, South Korea, and Japan will certainly improve technological capabilities. However, we may also want to partner with Western countries like the Netherlands, home to ASML – the world's only manufacturer of the most advanced modern chipmaking equipment.³¹ While there are certain risks with using foreign sourced microelectronics, advances in testing can provide mitigation.

Recommendation C3: U.S. EW systems firms are challenged with recruiting and retaining a qualified workforce. One mitigation is hiring foreign born engineers. However, restrictions on visas and Legal Permanent Residency can stretch the hiring process over years, or even make it

impossible, depending on the country of origin. This limits the labor pool and drives up development costs as our companies need to compete for U.S. engineers.³² The government should work in conjunction with the private sector to increase the domestic Science, Technology, Engineering, and Math (STEM) talent pool. Although there has been a concerted effort to increase attention in this area, Americans fall well behind our adversaries in earning STEM degrees. Essay 5 addresses STEM education recommendations in greater detail.

Goal D: Streamline the Acquisition of EW Technology

The DOD must simplify the procurement process to rapidly provide EW capabilities to the warfighter.

Recommendation D1: Advocate for relevant programming law and regulation changes. Program Executive Offices (PEOs) need quick access to operational system development funds (6.7 RDT&E) to allow for flexibility of reallocations at the portfolio level. Waiting for a two-year Program Objective Memorandum (POM) cycle does not support the technological advancements required to combat Great Power Competition.

Recommendation D2: The DOD must maintain professional memberships in consortiums like Sensors Open Systems Architecture (SOSA), become members of international standards organizations like VITA, and create dedicated open architecture liaison offices which are critical to ensuring needs for national defense integral to the MOSA conversation.

Recommendation D3: Leverage the Adaptive Acquisition Framework (AAF). The AAF provides the DOD increased flexibility to field modular and upgradable EW systems to the services once systems standards have been instituted. EW systems and platforms are reliant on sophisticated components and the AAF provides a pathway to accelerate the testing and fielding of this technology while simultaneously freeing the DOD from vendor lock.

Recommendation D4: Expand the use of Other Transaction Authority (OTAs). OTAs provide a pathway for acquisitions outside of the Federal Acquisition Rules (FAR), which stifles innovation and creates substantial delays. The DOD must leverage nontraditional processes to develop, test, and field EW platforms and enabling technologies at a more rapid pace.

Essays – Significant Issues in EW

Building a New Force for Flexibility and Resilience: Large Quantities of Low-cost, Multifunction, Persistent Nodes

To counter emerging threats in the A2AD environment, EW must shift to a force structure that enhances quantity through low cost systems, flexibility through multifunction apertures, and persistence through resilient energy logistics. Together these emerging technologies enable a future battlespace composed of a mix of high-end and low-end networked nodes in air, sea, undersea, land, and space transferring data and energy through established open system architecture protocols. Whenever possible common multifunction apertures will be used to establish both communication and energy links. This flexible network of EW nodes will ensure military advantage for U.S. combatant commanders by adapting within a chaotic, dynamic contested battlespace. The first three essays address elements of this vision.

Essay 1: Quantity Has A Quality of Its Own

Smaller, less expensive, EW platforms produced in large quantities offer enhanced mission effectiveness at a better price point in contested environments. To achieve this, smaller, rapidly procured EW platform solutions with shorter planned lifespans provide compelling advantages for military leaders. The current state of EW is a vicious cat and mouse game between aggressor and defender with ever-increasing stakes due to increased reliance on the spectrum for C4ISR and commercial use.³³ An increasing reliance on the EMS drives a requirement for deeper protection. Ensuring EMS operations against a near-peer competitor will require integrated EW capabilities across all services.

Reducing unit size without an increase in complexity decreases cost allowing for employment in larger quantities. This is enabled by a transition from analog to digital processing where modern systems can support multiple capabilities in the footprint of legacy systems that only had a single function. Achieving further reduction in size and cost may require removing or reducing the human footprint and trading unit survivability for mission survivability. Large numbers of unmanned units can accept some losses while effectively prosecuting missions. Each unit will prioritize ease of rapid manufacture and reduction in cost. These units are more able to surge in production as needed to respond to a new threat environment. A larger pool of commercial manufacturers can build these simpler designs to bolster production capacity. Likewise, for even greater horizontal expansion, simpler designs shorten the time required to completely retool or build new plants to manufacture the systems. Together these factors show that a push to simpler, repeatable, inexpensive designs greatly enhances surge responsiveness without sacrificing mission effectiveness.

The acquisition of current EW systems requires decades of planning to meet forecast operational threats. Relying on significant increases in technology that will remain viable for up to 50 years (i.e., the lifetime for the ALQ-99), requires an exquisite design which drives cost and schedule delays.³⁴ With the advent of increased digitization and implementation of Open Systems Architecture in EW systems, rapid iterative design emerges as a viable alternative. Designing systems that are only intended to provide overmatch for five to ten years is far cheaper and faster

to develop. Following the example of the Air Force's new Century Series aircraft concept, shortening the operational window and lowering cost allows for multiple concurrent or rapid succession projects. This, in turn, increases U.S. engineering experience and knowledge base at a lower price point than a single design for a complicated, piloted sixth generation fighter that must remain viable for decades to come.³⁵ The adaptation of open architecture software also helps by allowing for cross-pollination of the new standard of software to differentiate products in this industry between platforms.

Smaller, less costly, unmanned EW systems allow for employment in large quantities, which builds in flexibility and resilience. Larger quantities of platforms and sensors enable wider data collection, building the large data sets needed to effectively leverage Machine Learning.³⁶ In EW, attaining these large, current data sets requires increasing dispersion of collections platforms from low density, single-purpose EW and SIGINT platforms to every vehicle and the majority of personnel. As a first step, the Marine Corps has started this effort with their Intrepid Tiger II systems and Force Posture 2030, but significant future growth is imperative.³⁷ The use of unmanned systems and artificial intelligence to conduct warfare requires significant flexibility to maneuver in the EMS. A combination of software reprogrammable systems and multifunction arrays allow that now more so than ever in history.³⁸ Low-cost EW systems in large quantities provide benefits in surge capacity, acquisition responsiveness, mission effectiveness, and wide data-collection making quantity a core element of future force structures.

Essay 2: Flexibility through Multifunction Apertures

Multifunction apertures will give the proposed future network of EMSO nodes the requisite access, awareness, and maneuverability to more closely integrate a growing array of mission functions to meet the growing array of threats. Along with developments in advanced computing, component miniaturization, and modularity via open systems architectures, multifunction apertures promise not only to make more efficient use of resources but also bring broader and tighter integration to the family of EMSO functions. The parametric flexibility and wideband RF coverage of electronically steered arrays translates to vastly improved waveform flexibility to accomplish each EMSO function integrated into a system. Whether receiving GPS signals, datalinking via satellite, collecting SIGINT, or communicating via line-of-sight voice, integrating the functions within a system sharing one or multiple phased arrays means spatial discrimination for both transmitters and receivers, vastly increased RF available to avoid enemy intercept and interference, and maneuverability as agile as its software. For example, by bringing SIGINT collection and processing alongside radar, EA, and infrared imaging, a multifunction system achieves synergy in target identification, tracking, and the gamut of counter-effects like detection avoidance, jamming, and perhaps directed energy attack (despite inheriting the Title 10 versus Title 50 authorities conflict). By integrating missile warning with PNT, an aircraft can maintain both satellite track and inbound missile track regardless of its angle of bank or pitch. Multifunctionality promises great capability improvements and is a recognized trajectory for future EMSO systems, but there are several remaining technological challenges and related hardware tradeoffs that must be understood as broader functional integration becomes more prevalent.

Multifunction Arrays – One Challenge and Three Considerations

The main technological challenge stems from resource management – sharing resources (like an array) and data among an increasing number and diversity of supported functions drives an increasing complexity in resource management. That problem becomes exponentially more complex with distributed apertures or the integration of multiple, potentially non-homogenous antenna arrays. In support of this resource management and RF data handling challenge, the MITRE Corporation is developing a spectrum resource manager and a wideband adaptive spectrum server as part of DARPA’s CONverged Collaborative Elements for Radiofrequency (RF) Task Operations (CONCERTO) program, which aims to field a multifunction EMSO system on a Group 3 UAS (e.g., RQ-7 Shadow) in 2022.³⁹ While CONCERTO is an incremental step toward multifunction, further work toward broader functional (and perhaps networked) integration may incorporate cognitive computing or other AI applications to manage resources and data.

A related technology and integration challenge stems from different EMSO functions requiring different hardware attributes for maximum effectiveness. Multifunction arrays are not one-size-fits-all; different hardware configuration choices drive optimum pairings between certain arrays and functions, and acquisitions professionals must understand the tradeoffs involved. For example, EA and EP applications such as radar jamming require very low latency from signal detection to response transmission. As such, engineers must incorporate hardware and software configurations that limit the physical data pathways and processing time to a bare minimum, as the system’s overall effectiveness depends on the resultant latency. On the other hand, radar and SIGINT applications are less sensitive to latency, allowing for more design flexibility and processing time when integrating these functions.⁴⁰ Data throughput on the physical pathways is an additional challenge, particularly for data-heavy applications such as SIGINT and radar imagery.⁴¹

The limited availability of sophisticated microchip fabrication presents a challenge that affects latency in addition to overall SWaP requirements. Ideally, defense electronics firms would incorporate design efficiencies all the way down to the microchip scale, integrating the various programmable gate arrays, graphics processors, and central processors into a single die, which is referred to as an application-specific integrated circuit (ASIC). However, most defense-related firms do not command production scales worthy of fabricating ASICs. This restricts engineers to integrating field-programmable gate arrays with general-purpose graphics processing units and general-purpose central processing units, which increases software requirements, processing time, and circuit board real estate required.⁴² Wideband arrays reaching beyond K band (i.e., above about 30 GHz) involve additional engineering challenges like sophisticated RF transition design and the massive heat dissipation requirements associated with Gallium Nitride (GaN) amplifier circuits.⁴³

Another hardware tradeoff comes from digital versus analog (or hybrid) beamforming within phased arrays, which affects optimization of array agility versus spatial filtering (e.g., nulling out jamming signals or other noise), or a compromise between the two. While to the layperson, “digital” may sound more advanced than “analog,” both are solid-state hardware applications that incorporate different configurations of components

to balance competing performance features. Communications, electronic attack, and applications sensitive to high power consumption or standoff jamming are better suited to analog beamforming; whereas narrowband radar as well as applications in uncontested environments and other functions requiring high agility (in terms of multiple simultaneous beams) are better suited to digital beamforming. Hybrid beamforming can offer a compromise between the two.⁴⁴ Phased arrays can serve any EMSO function regardless of beamforming design, but the discussion illustrates that hardware design is an important consideration when integrating functions within a multifunction system. Again, there is no one-size-fits-all phased array for all functions, so broader functional integration will drive either performance tradeoffs or the need to integrate multiple arrays within a system. However, when implemented as part of an intelligent networked system, multifunction apertures will enable flexibility enhancing mission effectiveness.

Essay 3: Persistence Through Networked Energy

Former Deputy Secretary of Defense Robert Work proposed in his Third Offset Strategy in policy speeches in 2016⁴⁵ that networked human and machine teams in large quantities would be able to overwhelm A2AD environments. One vision of how this could be realized is presented in “DARPA Emerging Technologies”⁴⁶ and more recently is the basis of DARPA’s Mosaic warfare concept.⁴⁷ The key element in these strategies is that network effects provide flexibility and resilience by concentrating information through multiple paths to the needed consumer. One vulnerability of these strategies is that projecting and sustaining large quantities of platforms at long range requires a logistics network that does not yet exist. To produce platforms in large quantities, they must be inexpensive and therefore relatively small. Platforms with long range tend to be large and therefore expensive. Attempting to balance these factors results in a compromised solution that falls short in both areas. Flexible and resilient logistics are also needed to project persistent presence over long distances.

Military power projection within the current United States’ construct relies heavily on chemical energy stored in explosives and liquid hydrocarbon fuels. Both of these energy mediums were the best available for delivering military effects when introduced but have significant physical vulnerabilities. Emerging technologies now may enable the United States to harness network effects in energy logistics by leveraging the electromagnetic spectrum to deliver and cause military effects more flexibly and resiliently.

Energy Web Dominance (EWD) is a framework for optimizing network effects. Imagine a future battlespace as a region populated by energy nodes. A tanker is a node, an aircraft carrier is a node, an F-22 is a node; each participant consumes and delivers energy as needed to achieve military effects. Each of these energy transactions can be analyzed to ensure it is optimally delivering military effects. If these nodes are connected by physically transferring energy via liquid fuel, they accept limitations in flexibility since such a transaction is predictable and slow. Imagine instead that these nodes are connected remotely through the EMS. Such a network could flexibly concentrate energy, overwhelming an adversary’s ability to maneuver and respond. To destroy an enemy radar site in the current construct, one might store energy in a chemical warhead to cause that effect and burn fuel as energy to deliver that warhead in an F-22. If the F-22 has insufficient energy reserves to deliver that effect the full distance, it might have to refuel

from a tanker en route. If any part of this chain of subsequent energy transactions is broken, the military effect would not be delivered.

Imagine instead a web of energy nodes. These nodes might be Unmanned Aerial Vehicles (UAVs), ships, manned aircraft, preplaced hidden ground stations, space assets, undersea assets, or any number of multi-domain options. To deliver an effect, power generated from an aircraft carrier might be delivered to a satellite across thousands of miles to another satellite and then routed through a network of UAVs to focus directed microwaves at the radar site to destroy it. In this scenario, if any single element of the web were disrupted, other nodes would be used to deliver the energy. The energy web has built-in multipath resilience, so it degrades gracefully when under attack. These nodes can be small and persistent, being constantly recharged by the energy web while forcing cost imposition on an adversary. When a 300,000-dollar missile is needed to destroy a 50,000-dollar energy node UAV that would be immediately replaced by dozens of others, an adversary is faced with a cost and resources dilemma. Dominating the energy web will provide flexibility and resilience that will always beat an energy network that relies solely on legacy liquid hydrocarbons.

A number of technologies provide opportunities for creating energy linkages within the energy web as shown in Wireless Power Transfer Technologies Table (see Figure 4). The framework of Energy Web Dominance provides a novel perspective on the fundamental character of warfare revealing both a challenge and an opportunity. The current trend of buying fewer expensive, monolithic platforms that rely on hydrocarbon fuels is unsustainable and vulnerable. A2AD strategies imposed by American adversaries in great power competition force a new approach. Leveraging the EMS to transmit energy wirelessly could enable a new network of persistent, inexpensive platforms that are able to flexibly and resiliently focus military effects at a distance.

Emerging technologies reveal a pathway to achieving this new vision based on flexibly transporting and employing energy to achieve desired military effects. Within this new framework, many legacy platforms and cumbersome forward infrastructure are no longer necessary. The linkages in the new energy web will be built using a combination of magnetic resonance, photonic beams, and electromagnetic beams enabled by a host of supporting developments. To foster such a disruptive change, DARPA is the appropriate research agency and should probe the necessary families of technologies to find niche markets such as High Value Airborne Asset (HVAA) defense where wireless power transfer provides an immediate advantage. From there, the proven technologies can be built out into a larger network to achieve transformative network effects.

The future of EW is even more broad and fundamental than most have recognized. Traditional stovepipes between logistics and tactics and kinetic and non-kinetic effects are a failure to abstract to a more basic level. Instead an integrated concept of delivering effects regardless of medium or pathway, enables a more flexible and resilient military power projection framework. Since the EMS is ubiquitous and pervasive, harnessing it effectively is critical to achieving this vision. This disruptive transformation will take investment in development, tactics, training, and procedures. By achieving Energy Web Dominance, the United States will seize the advantage in great power competition for decades to come.

Essay 4: Modular Open System Approach

Open systems, also referred to as systems engineering or system of systems, became a major focus area within the DOD in 1994, when Honorable Paul G. Kaminski, then Under Secretary of Defense for Acquisition and Technology, “directed Acquisition Executives in the DOD to use ‘open systems’ specifications and standards (electrical, mechanical, thermal, etc.) for acquisition of all weapon systems electronics to the greatest extent practical.”⁴⁸ Today’s current guidance, captured in DOD Instruction 5000.2 Change 2, codified the Modular Open Systems Approach (MOSA) and Intellectual Property (IP) requirements in defense acquisition. Program managers are now required to “identify where, why, and how a MOSA will or will not be in the program”⁴⁹ DOD’s twenty-five-year journey towards MOSA has generated examples of success; such as the Army’s C4ISR/EW Modular Open Suite of Standards or CMOSS. CMOSS reduced the SWaP in embedded military C4ISR systems on multiple platforms by using common software, hardware and network layers. Additionally, the Air Force initiated Sensors Open Systems Architecture (SOSA) consortium is comprised of government, industry, and academic partners working to develop an open technical standard “applicable to military and commercial sensor systems with a business model that balances stakeholder interests.”⁵⁰ These successes, as well as the efforts listed in the MOSA Standards Relevant to Electronic Warfare Table (see Figure 5), show momentum is building with MOSA which must be maintained. While positive gains towards achieving acquisitions utilizing MOSA have been realized; they have not dismantled the oligopoly nature of defense industry markets. MOSA is the key to reducing the cost of entry barrier to smaller defense firms which will drive both competition and innovation. Finally, MOSA initiatives provide a path forward to break free from vendor lock, enabling DOD to upgrade EW systems and components as technology matures or reaches obsolescence, without incurring significant switching costs.

The DOD faces three major challenges as it continues to work to incorporate MOSA into all levels of acquisition:

- MOSA is consensus-based and development takes time
- Program Managers (PMs) often lead programs for relatively short periods and are focused on minimizing risk to cost-schedule-performance (C-S-P)
- Striking balance between over-generalizing requirements to ensure openness, versus over-prescribing for specific DOD requirements

Achieving large group consensus on standards in the DOD is arduous and time consuming. Government and industry experts must agree on which standards to use and how to combine requirements across multiple system types.⁵¹ These rounds of discussions consume limited time and financial resources. It becomes more complicated when the DOD develops a prototype weapon system for the first time. Problems are bound to occur as a weapon system progresses through prototyping, engineering manufacturing and design, and into test and evaluation. “Architectural mismatches – conflicts between underlying architectures...– are hard to overcome and can result in serious system error.”⁵² The number of functions, each with its own components, subsystems, and interfaces, along with additional interfaces to weave the functions themselves into a cohesive weapon system are enormous, and therefore no single architecture supports everything. However, once achieved, these agreed upon standards will break vendor lock, and enable rapid acquisition of smaller subsystems.

Next, hesitation to embrace change at the PM level needs to be addressed. PMs are often only in the position for a few years, and their goal is to keep the project on track for C-S-P. Abrupt changes to the program or adding the difficulty of developing and implementing MOSA standards increases the risk to C-S-P. As a result, some have “opted to wait and leverage [MOSA] later.”⁵³ Ideally, PMs would include MOSA requirements during the Materiel Solution Analysis and Technology Maturation and Risk Reduction Phases to benefit the systems throughout its lifecycle. However, most PMs who develop the original requirement definition do not stay beyond Milestone B; and are very unlikely to still be PM in either Production and Deployment or Operations and Support when upgrades will be required.⁵⁴ It is difficult to incentivize long term life-cycle thinking by PMs when they are evaluated on short term program success. Additionally, PMs are leading staffs who are still adjusting to MOSA way of thinking.

Finally, as open architecture standards become more prevalent, the defense acquisitions enterprise must take care to preserve competitiveness within the defense industry, particularly by not over-prescribing requirements beyond reasonable lifecycle objectives. When the open architecture construct gained momentum following the 2017 NDAA, the general government reaction was to incorporate requirements for open standards that lacked specificity or purpose. Since then, requirements for open standards have become more specific and, in some cases, perhaps too much so. While the defense industry understands and embraces open architecture as the future standard, a persistent concern is that intrusive over-specification will lead to insufficient design leeway to innovate – basically a “commoditization” of hardware, where design and interface requirements are so specific that firms are unable to compete on product differentiation.⁵⁵

MOSA Recommendations

1. *Identify its EW “crown jewels” and resource them appropriately.* Architectural decisions for open systems must be made early in the conceptual process because they directly impact how hardware and software are built.
2. *Understand incentives.* Companies spend relatively little on independent R&D; recompeting contracts on subsystems offers a path to innovation through competition. Open architectures allow for upgrade and replacement of components and subsystems, rather than entire systems or platforms. This opens the door to smaller but more frequent competition and will drive increased independent R&D as they compete accordingly across both industry and academia.
3. *Recruit and retain appropriate workforce talent.* The Government needs the technical expertise to be an equal partner with industry when developing standards. It is also worth noting that all of the firms visited during this study specifically mentioned needing this same talent, and they compete accordingly across the entire industry and academia.
4. *Advocate for relevant programming law and regulation changes.* PEOs need quick access to operational system development funds (6.7 RDT&E) to allow for flexibility of reallocations at the portfolio level to capitalize technologies before they are irrelevant.
5. *Build critical mass and continue ensuring it has a vote.* Maintaining professional memberships in consortiums like SOSA, becoming sponsor members of international standards organizations like VITA, and creating dedicated open architecture liaison offices are critical to ensuring needs for national defense are part of the MOSA conversation.

6. *Stay the course and substantiate its position.* Continue to incorporate standards-based language into contract, acquisition and requirement efforts while routinely updating DOD 5000 Series Acquisition Policy.

Essay 5: Leveraging Human Capital for Electronic Warfare

Throughout this study's firm visits, engagements, and correspondence, the common leadership challenge of recruiting and retaining talent to work in EW became abundantly clear. To ensure the future talent of the defense industrial base on which national security relies, the U.S. government must follow through on strategies for STEM education and advanced manufacturing in addition to focused investment in internships, apprenticeships, and work-based learning.

In 2018, the current administration published multiple strategies through the National Science and Technology Council focused on educating the future workforce. The two most relevant to the EW ecosystem and the government's emphasis in growing said workforce are "Charting a Course For Success: America's Strategy for STEM Education" and the "Strategy for American Leadership in Advanced Manufacturing." The U.S. Goals for STEM Education Table (see Figure 6) lists the educational pathways and objectives under this strategic plan and the Federal departments and independent agencies that have STEM education programs, investments, and activities. The dots indicate the objectives each agency currently plans to contribute to through mission-specific actions, subject to budgetary constraints and other approvals.

Beyond these efforts, there are three main ways the federal government can best work with industry and focus its limited resources that will allow for the largest return on investment – internships, apprenticeships, and work-based learning. The U.S. government should develop a comprehensive STEM-centered education intervention as they did in the post-Sputnik space race, including providing best practices to educators and developing grant programs for educators and students. Efforts should target students from all socio-economic sectors at a young age and continue through university.

The federal government has the ability and the resources to chart a course that will produce the type of talent the EW industry needs to maintain its technological superiority over near-peer adversaries. Through a combination of private/public partnerships and renewed focus on comprehensive STEM education at the national level, the federal government can grow the domestic human capital the United States needs to dominate Great Power Competition.

Conclusion

For years, competing nations like Russia and China have invested in EW as part of an asymmetric strategy to counter the advanced and exquisite capabilities of U.S. forces, including stealth, precision strike, and power projection. As the U.S. emerges from the COVID-19 pandemic as well as decades of fighting insurgent conflicts, the DOD's excessive reliance on the EMS as well as parochial investment in EW have resulted in distinct access challenges in multiple domains. Decreasing the joint force's reliance and exposure in the EMS is a prudent task, but focused, collective investment toward an ambitious, joint EMSO capability vision is also required to fuel a leap-ahead in EW capabilities and secure future enduring advantages.

As the defense industry sees further consolidation, the EW industry stands to see an opposite trend, where more firms of various sizes and attributes can offer modular EW components that seamlessly integrate with fielded systems and architectures. Additionally, the technology trends of advanced computing and continued miniaturization of electronics are bringing multifunctionality, networked integration, and sophisticated EW capabilities to every combat system that accesses the EMS. This emerging breadth of the defense industry coupled with wide proliferation of EW capabilities across the joint force underscores the need for a unifying vision and capability roadmap to guide future procurement and development activities.

The DOD must prioritize and balance department-wide EW requirements through a joint EMSO/EW concept, focused EW R&D, and streamlined acquisition processes to keep pace with technology advancements. To be effective in great power competition, EW systems must fundamentally shift from monolithic, single-use platforms and architectures to a network of disaggregated, modular systems with multifunction capabilities. Additionally, supporting small, inexpensive platforms with operationally relevant range and endurance will require a new concept of energy logistics, achieved by leveraging the EMS to beam power. Two threats to the industry are supply chain resiliency and maintaining a talented workforce. To counter these weaknesses, the DOD must further incentivize domestic manufacturing, expand the Trusted Foundry Program, and support industry's efforts to grow STEM capability in the United States.

To adapt and overcome in Great Power Competition, the DOD and industry together must seek radical change to past EW paradigms. Within the new paradigm, the EMS will be contested and systems must be designed with flexibility and resilience as their core attributes. With renewed focus, the EW industry has the opportunity to transform into the adaptive framework needed to address this new dynamic environment. By setting a clear vision, focusing development on modular networks, and integrating capabilities into a coherent effects-based strategy, the United States can dominate the EMS, ensuring security for decades to come.

APPENDIX

Appendix A: Graphics

Figure 1:

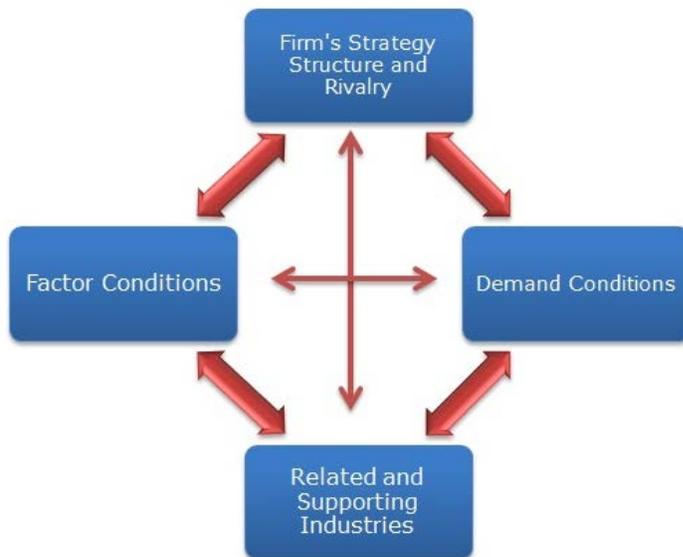


Figure 2:



Figure 3:

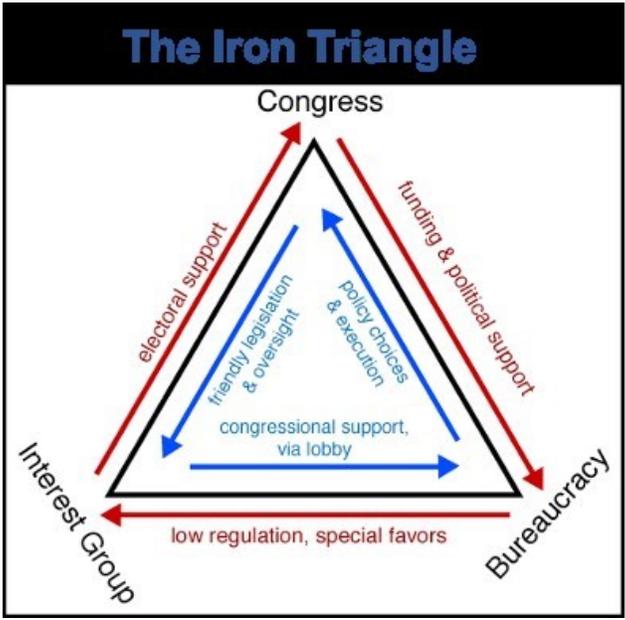


Figure 4:

Technology	Strengths	Challenges	Enabling Technologies
Magnetic Resonance —Near Field effect	<ul style="list-style-type: none"> • High efficiency (99%) • Simple • Low signature 	<ul style="list-style-type: none"> • Short Range (50 ft) • May interfere with existing electronics 	<ul style="list-style-type: none"> • Antenna Design • High 'Q' Resonators
Photonic Beams (Lasers) —Far Field effect	<ul style="list-style-type: none"> • Power dense beam • Low diffraction over distance • Small apertures 	<ul style="list-style-type: none"> • Atmospheric turbulence • Obscurants • Waste heat • Low PV efficiency (50%) 	<ul style="list-style-type: none"> • Adaptive Optics • Active Cooling
Electromagnetic Beams —Far Field effect	<ul style="list-style-type: none"> • Efficient conversion (85%) • Weather penetration • Flexible designs 	<ul style="list-style-type: none"> • Large antennas • Signal Synchronization • Signature management 	<ul style="list-style-type: none"> • Coherent Beamforming using distributed arrays • Network protocols

Figure 5:

STANDARD	CONSORTIUM OR EQUIVALENT	TARGETED PURPOSE
Sensor Open Systems Architecture (SOSA)*	The Open Group	Enable re-use of key sensor components across multiple platforms and services ⁹
Future Airborne Capability Environment (FACE)*	The Open Group	Enable standardized approach to reuse of applications across airborne platforms ¹⁰
C4ISR/EW Modular Open Suite of Standards (CMOSS)	US Army's Communications-Electronics Research, Development and Engineering Center (CERDEC) and Participants	Allow communication components of military vehicles to share a common platform ¹⁸
Vehicular Integration for C4ISR/EW Interoperability (VICTORY)*	VICTORY Participants	Provide phased set of standard specifications covering capabilities needed to integrate C4ISR/EW mission equipment and platform applications, and improve size, weight, and power-cooling (SWaP-C) burdens ¹¹
Modular Open Radio Frequency Architecture (MORA)	CERDEC	Enable development of true open standards-based RF and microwave modules as well as small form factor subsystem designs ¹²
Universal Armament Interface (UAI)	Air Force and Industry Participants	Standardize interfaces to support future weapon integration ¹³
Open Mission System / Universal Command and Control Interface (OMS/UCI)*	Government and Industry Participants	Develop industry consensus for non-proprietary mission system architectural standard / Establish set of messages for machine-to-machine, mission-level command and control for airborne systems ¹⁴
<u>OpenRFM</u>	Mercury Systems and Participants	Standardize electromechanical interfaces and control planes to within radio frequency (RF) / microwave domain ¹⁵

Figure 6:

GOALS FOR AMERICAN STEM EDUCATION ★ Build Strong Foundations for STEM Literacy ★ ★ Increase Diversity, Equity, and Inclusion in STEM ★ ★ Prepare the STEM Workforce for the Future ★																
Pathways	Objectives	DOC	DoD	DOE	DHS	DOI	DOL	DOS	DOT	ED	EPA	HHS	NASA	NSF	SI	USDA
Develop and Enrich Strategic Partnerships	Foster STEM Ecosystems that Unite Communities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Increase Work-Based Learning and Training through Educator-Employer Partnerships	●	●	●	●	●	●			●	●	●	●	●	●	●
	Blend Successful Practices from Across the Learning Landscape	●	●	●	●		●	●		●	●			●	●	●
Engage Students where Disciplines Converge	Advance Innovation and Entrepreneurship Education	●	●	●				●		●	●	●		●		●
	Make Mathematics a Magnet	●	●							●				●		●
	Encourage Transdisciplinary Learning	●	●	●	●	●		●		●	●	●	●	●	●	●
Build Computational Literacy	Promote Digital Literacy and Cyber Safety	●	●		●			●		●		●		●		●
	Make Computational Thinking An Integral Element of All Education	●	●	●	●	●				●		●		●	●	●
	Expand Digital Platforms for Teaching and Learning	●		●	●			●		●				●	●	●

Appendix B: Mobilization

EW systems and other high-technology weapons and sensors overlap so significantly in components, sub-systems, and functionality that the dividing lines between them have all but disappeared – at least from a manufacturing perspective. This commonality is a boon and a curse when considering capacities to expand or shift production priorities. Focused priority changes can benefit from commonality in parts and processes, but broad expansion will suffer from overlapping supply chains and critical materials. This annex explores the surge and mobilization capacities of the EW and related industries, beginning with definitions of key terms and government tools. The following section offers three mobilization scenarios as a baseline for analysis, and then an assessment concludes with recommendations for deep study of supply chains and limiting resources to inform balancing strategies of stockpiling, surge and mobilization planning, and force structure or posture changes.

Definitions and Tools

The key terms involved are surge, conversion, and mobilization, and all three can imply different meanings depending on context and scope. In general, surge is a temporary increase in productive capacity, while mobilization is a broad pooling and readying of national resources and has three main facets: the economy, the force fighting the battles, and the will of the people. In the context of economic mobilization, conversion involves changing the products a firm produces; these may be different products entirely or existing products modified to suit military applications. Scales of conversion and mobilization include partial, limited, or total. In dealing with the recent COVID-19 crisis, the press used the term mobilization loosely to refer to both temporary increases in productive capacity and to a limited conversion and surge to increase manufacturing of medical equipment and pharmaceuticals to meet national shortfalls.⁵⁶ Partial mobilization occurs far more often than total mobilization.

Surge. Surge capacity refers to the additional goods (or services) a firm, sector, or industry can produce in a transition from steady-state operations to full utilization of its resources.⁵⁷ The typical example involves extending existing shifts or adding shifts to operate production facilities 24 hours-a-day and through the weekends. The limit of this surge is 24-hour operations with the entire plant in use. Within a firm, a surge could also involve realigning resources (whether manpower, raw materials, or production facilities) toward the surge requirement. On an industry-wide basis, this might also include the use of other manufacturers in that industry to assist in or provide separate prime manufacturing capability.

Conversion. Conversion refers to a change in the products (or services) a firm provides. The typical example is a change from a commercial application to a defense product, like the Rock-Ola Manufacturing Corporation transitioning from jukeboxes to M1 Carbine rifles to support World War II.⁵⁸ A more contemporary example is the General Motors Corporation manufacturing ventilators for the Department of Health and Human Services to support the COVID-19 response.⁵⁹ Conversion can also apply to firms within the defense industry changing products to support production priorities, like a communications systems manufacturer receiving a license and direction to produce radar antennas and circuit cards for another firm's cruise missile.

Mobilization. The term mobilization can have many applications, including the activation and preparation of military reserve components, but this analysis focuses on economic mobilization, and more specifically, industrial mobilization, or the production of war materiel needed to support the military.⁶⁰ Joint Publication 4-05, *Joint Mobilization Planning*, defines industrial mobilization as “the transformation of industry from its peacetime activity to the industrial program necessary to support the national military objectives.”⁶¹ Effectively mobilizing economic resources to support the war effort is a complex process, requiring superior coordination and productive capability on a national scale. The optimal amount of centralized control over an industry mobilizing balances a fine line between focus and overcontrol. Both over and under control provide less efficient results.

The Defense Production Act (DPA), provides authorities to assist the U.S. government in mobilizing private industry to address critical national security requirements. Specifically, DPA Title I provisions can require U.S. manufacturers to accept and prioritize government contracts critical for national defense. DPA Title III provides for the expansion of U.S. manufacturing capacities to support specific requirements through incentives and the conversion of other segments of the industry.⁶²

Examples of mobilization exist throughout U.S. history, with World War II providing the classic example and gold standard of total mobilization.⁶³ From start to peak mobilization it took approximately three years. More recent examples of mobilization include the production of Mine Resistant Armored Personnel (MRAP) vehicles to support Operation IRAQI FREEDOM and the production of ventilators and various protective equipment supporting the COVID-19 crisis.⁶⁴

Scenarios Driving Mobilization

This analysis considered plausible future conflict scenarios among the great powers to inform likely requirements for a future mobilization. The most likely scenarios involve a short-term (i.e., less than one year) mass surge with limited conversion to produce expendables and small, unmanned systems. While protracted conflict scenarios may involve increased production of platform-level systems, an increase in EW platforms, such as the EA-18G and EC-37B (plus any future unmanned variants), are the most likely needs across the spectrum because of their low density and already high demand. The next paragraphs describe three of the conflict scenarios envisioned.

Post-COVID Arms Race. As the world remains mired in global recession due to the COVID-19 Pandemic, the People’s Republic of China (PRC) sees an opening to replace U.S. influence throughout the first island chain. Sensing that the United States is economically and militarily vulnerable, the Chinese Communist Party (CCP) steps up the mass production and forward deployment of expendable weapons systems. Concerned the United States will fall behind, Congress authorizes additional funding for the DOD to procure weapons systems to counter these threats. In particular, the DOD plans to acquire and deploy multiple new MIM-104 Patriot batteries and Terminal High-Altitude Area Defense systems among partner nations across the

first island chain and stockpile long-range strike and anti-surface weapons such as the AGM-158 Joint Air-to-Surface Standoff Munition (Extended Range), the BGM-109 Tomahawk Land-Attack Missile, and the Army's new Precision Strike Missile.

Baltic Invasion. It is 2023 and President Vladimir Putin, reminiscent of actions in Ukraine, uses chicanery to cover movement of Russian military forces into neighboring Latvia.⁶⁵ The United States and NATO respond by massing forces in Lithuania, Poland, and Estonia to check Russian aggression. The tensions escalate into a high intensity conflict, and robust Russian air defense systems inflict unexpected heavy losses on U.S. and NATO aircraft. Calls to push back the Russian *fait accompli* along with moves by the PRC to capitalize on a bloodied and distracted United States result in calls for mass production of major weapon systems such as the EA-18G, the EC-37B, the F-35, the B-21, and Virginia- and Columbia-class submarines.

Taiwan Invasion. It is 2025 and the CCP, in a bid to divert the attention of the Chinese people from their faltering economy, increases interference in Taiwan.⁶⁶ The Chinese conduct cyber-attacks on critical infrastructure and step up military exercises off the Taiwanese coast.⁶⁷ The Taiwanese government pushes back by declaring independence and launching preemptive air strikes on selected Chinese targets in the Fujian Province.⁶⁸ A flash war begins, and the United States is compelled to side with Taiwan as the PLA invades.⁶⁹ Taiwanese and U.S. forward forces quickly deplete their magazines, and the fighting settles into protracted, insurgency-type warfare. The U.S. military requires immediate mass production of key expendable weapons, including the AIM-120 Advanced Medium-Range Air-to-Air Missile, the RIM-66/161/174 Standard Missile, the AGM-158 Joint Air-to-Surface Standoff Missile (JASSM) and its forthcoming anti-surface variant, the BGM-109 Tomahawk Land Attack Missile, and the ADM-160C Miniature Air-Launched Decoy.

Analysis - Need Supply Chain Mapping

The envisioned scenarios illuminate different weapon system needs in various levels of immediate urgency, and the DOD's depth of supply chain knowledge and its ability to prioritize and manage production will determine success in meeting materiel needs during conflict. Several themes emerge among the conflict scenarios: (1) the circumstances of the crisis can drive very different weapon systems needs and timelines; (2) these weapons are all high technology systems that rely on sophisticated microchips, amplifier circuits, and sensor apertures and arrays; (3) in a surge or mobilization, the demand for sophisticated components and sub-systems would likely outpace the availability of raw materials and the capacity of trusted fabrication and manufacturing facilities. Stockpiling and forward presence are alternatives to relying on surge production or mobilization; however, increasingly rapid technology obsolescence will challenge the affordability of building and maintaining sufficiently large stockpiles to support armed conflict among great powers. To enable both effective deterrence and also contingency execution, the DOD must fully understand surge and mobilization capacities and timelines to make the necessary assessments supporting a balance between stockpiling and crisis production via surge or mobilization. The following paragraphs further discuss considerations for industry capacity, surge, and mobilization.

Industry Capacity

The United States' ability to design and manufacture complex systems, whether electronics or ships or satellites, is the best in the world; however, over the last two decades, much of the high-volume manufacturing capacity for high-end electronic subassemblies has gone overseas. Although the United States maintains sufficient domestic capability to support the defense industry, the transition to a services-based economy and the associated loss of manufacturing capacity will have a limiting effect during a surge or mobilization. The amount of supply chain overlap and the identification of limiting resource factors are necessary areas for further study that will enable the timeline assessments and resource prioritizations that would prove critical in a crisis.

In the Aerospace and Defense market, the United States leads the world with revenues of 929 billion dollars in 2018 and an 89.6 billion dollar export surplus in the same year.⁷⁰ The United States aircraft industry is more capable than any other nation in providing support to the prime contractors of current fighter aircraft or taking over the duties of producing the aircraft themselves. Outside of the defense industry in 2017, the United States manufactured over 100 billion dollars-worth of motor vehicles and parts, fabricated metal products, and machinery. Similarly, U.S.-produced computer and electronic products garnered almost 300 billion dollars in the same year.⁷¹ This broad base provides the potential to provide significant assistance in supporting prime defense contractors in their efforts to surge.

Surge

For major platform systems like aircraft, program managers and defense contractors provide Congress annually with anticipated normal and surge capacity for their manufacturing lines. In studying the EA-18G, the F-35, and the F-16, the surge capacity of most production lines is between double and triple that of normal production. This increase normally comes from additional shifts on the same production line, but the circumstances driving the surge would determine the appropriate response, whether from organic surge capability, partial conversion of partner firms or competitors in the same industry, or full mobilization of other industries. Several of the EW firms the seminar visited as part of this study voiced the potential to rebalance their corporations internally to address increasing production requirements and achieve approximately 50 to 100 percent additional output. These options and assessments are likely reliable for narrowly defined need cases, but the broader the need across different weapon systems, the more likely that supply chain and resource conflicts will limit timelines and throughput. For planning purposes, the more that the DOD continues to rely on exquisite systems and monolithic platforms, the more it will experience competition for sophisticated components and highly skilled labor to produce them during a surge or mobilization scenario.

Mobilization

Moving beyond a firm's ability to surge, mobilization allows for further capacity expansion via conversion of private industry to meet defense needs. As an example of partial mobilization, a set of commercial electronics firms could assist in manufacturing components and subassemblies for system- and platform-level prime integrators. Alternatively, prime contractors may prefer to sub-contract various parts and processes selectively so as to protect more critical intellectual

property. Full mobilization brings the entirety of private industry to bear, as in the previous examples of Rock-Ola producing rifles during World War II and General Motors producing ventilators during the COVID-19 pandemic. Historically, this path requires additional time for retooling production lines, though this delay is dependent on the level of sophistication and automation employed by the original manufacturer. Increased simplicity and automation-friendly manufacturing may reduce the conversion timeline.

The critical shortfalls in today's EW industry are organic fabrication of cutting-edge hardware subassemblies and the talent to design and produce them.⁷² As the leading edge of microchip fabrication continues beyond 10 nm transistors, the United States has only three trusted foundries, and two of them are located within striking range of the PLA's conventional weapons. With continued globalization of manufacturing, the United States must ensure that defense supply chains remain viable throughout the spectrum of conflict, particularly avoiding loss from political fallout such as experienced with Turkey and the F-35. Developing incentives (perhaps using DPA Title III authorities) supporting feasible business models to expand sub-10 nm foundries in the United States would better support the defense industry's myriad microelectronics needs and mobilization capacity. At the time of this writing, the Taiwan Semiconductor Manufacturing Company (TSMC) is considering building a foundry in the United States based on USG pressure.⁷³

We have already discussed the human capital challenge of engineering expertise in this report, but the issue carries further restrictions to capacity expansions associated with mobilization. The EW firms visited as part of this study consistently reported challenges with recruiting and retaining engineers for their steady state operations. Surging those operations and also incorporated converted suppliers and expanded production lines could spread the limited engineering expertise beyond capacity. As discussed, the STEM challenge goes beyond college programs; USG policies and programs should promote competitive STEM education beginning in primary and secondary education.

Assessment

Should a conflict escalate in scale or time so as to require surge and mobilization, the U.S. industrial base can and will respond; however, deep knowledge of supply chains and resource limitations would prove critical to manage such a feat in an effective and timely manner. None of the material or manufacturing processes used to produce EW systems is exclusive to one manufacturer. Moreover, collaborations between defense manufacturers and the use of sub-primes continually increase the scope of knowledge across the industry. Finally, with software being the new hardware that differentiates defense systems, increased use of and dependence on open architecture standards reduces a new manufacturer's barrier to entry or support.

EW and EMSO systems have become so ubiquitous and integral to high technology weapon systems that supply chains as well as manufacturing tools and techniques have also become quite common. This has two important implications: (1) the commonality is likely to restrict the ability to expand capacity on short notice, and (2) the defense industry as a whole has significant surge capacity if given focused priorities. Sophisticated expendables, including weapons and sensors, are likely top priorities early in a conflict, and the whole of the defense industry,

including facilities producing EW systems, can be focused toward those weapons, provided deep knowledge of the supply chains and the capabilities of the manufacturing ecosystem.

Based on the previous examination of the defense aerospace industry, mobilization within three years, the timeline for World War II, is possible. Probably timelines for modern and future war will be far shorter. In this instance, manufacturers can initially surge their production. As proposed by Mark Cancian, while these manufacturers achieve maximum capacity on their lines, EW systems from the reserves potentially augmented by those repurchased from foreign military sales and pulled from long term preservation will commit to the fight.⁷⁴

Alternatives

There are also alternatives to building exquisite and expensive systems to attain and maintain EMSO superiority, particularly in unmanned systems and manned-unmanned teaming. One current initiative is the next generation Miniature Air-Launched Decoy (MALD-X), an air-launched, networked EW decoy with a 500 NM range and inflight reprogrammable flight and electronic attack profiles.⁷⁵ Near future examples of this teaming include the “loyal wingman” program, which pairs a stealthy XQ-58 UAS with an F-35 to provide additional weapons, range, sensors in a high threat environment.⁷⁶ The far future with increased AI and computing power may well reduce or remove the servicemembers from the battlefield in order to allow for more maneuverable, cheaper, and rapidly adapting systems to lead the fight.

Modern cutting-edge EW systems aircraft such as the EA-18G, F-16, and F-35 are complex weapons systems that incorporate integrated computers and sensors, requiring thousands of lines of software code to operate.⁷⁷ They can accomplish a multitude of missions in threat environments that would result in significant losses for previous generations. They rely on stealth, electronic warfare, and connectivity with other platforms in order to destroy enemy forces without incurring significant friendly losses. The use of technology overmatch to defeat near peers eventually results in a transfer of advantage between peers, which requires a high economic cost to regain. The F-35C current flyaway cost is 123 million dollars per aircraft.⁷⁸ Maximum production for both lines would result in 130 combat aircraft in one year with a nominal cost of 15.8 billion dollars. To contrast, the Russian S-400 air defense system costs 500 million dollars per battery.⁷⁹ Outside of a minor skirmish, the economic math on this type of warfare is prohibitive.

Today is an inflection point, much like President Eisenhower faced in 1953 when he commissioned Project Solarium in order to guide the creation of a new grand strategy to face the new Soviet nuclear threat.⁸⁰ The United States can continue to invest in evolutionary increases of the same types of technology and order of battle or choose a revolutionary change in the strategy of our military’s support to our grand strategy. An example of such a revolutionary change would be the adoption of large volumes of inexpensive mid to long-range UEMSO platforms. These platforms can either strike high-payoff targets through the first several phases of a military operation or cause the enemy to deplete their more expensive precision A2AD weapons and lower the threat to friendly forces while attaining EMS superiority. Both options result in success for the United States.

Conclusion

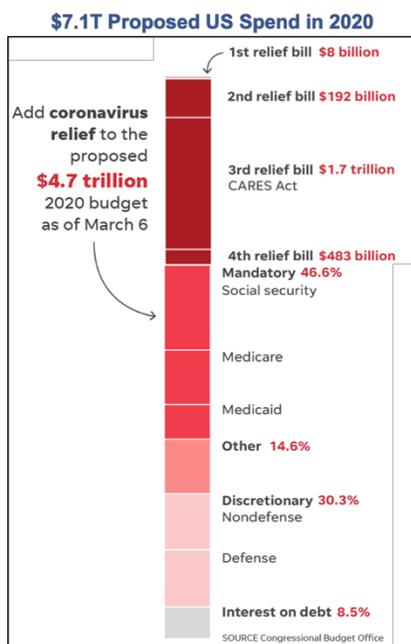
Full-scale combat between the United States and its near-peer adversaries will require significant additional EW assets beyond those forward deployed. The United States must have a surge and mobilization plan based on deep knowledge of supply chains, resource limitations, and manufacturing capabilities and capacities. The plan should then hedge gaps with stockpiling, changes in force structure or posture, or other risk mitigation strategies. In all cases, industry and the DOD alike must move forward into the age of increasing automation, in manufacturing as well as integration in war machines. Barring attacks on CONUS facilities, the U.S. EW industrial base has a significant capacity to surge manufacturing and lesser capacity to mobilize if required due to an exogenous threat. The current lack of optimization, digitization, and automation of manufacturing processes limits the ability to expand rapidly beyond a surge. Mobilization to produce additional high cost EW systems requires detailed analysis before execution due to the limited microprocessor resources available to EW and other supporting defense industries. Unmanned technology potentially brings a new offset to both surge and mobilization in the economics and technological advantage afforded by current and future systems. It must remain prioritized in development and incorporation by the U.S. defense industries to maintain advantage over our peers.

Appendix C: Budget Realities

As many years of conflict and war in the Middle East fade, the United States continues its troop withdrawals from established conflicts and further concentrates on Great Power Competition. These wars have come at great costs in both blood and treasure, and between 2001 and 2016 the United States spent more than 3.6 trillion dollars in war appropriations and war-related efforts, to include homeland security and interest on borrowed money for the wars.⁸¹ Additionally, this conservative total does not include other economic factors such as opportunity costs, future medical and disability costs, or future interest on the war-related debt, which all linger long past when victory is declared or troops are fully withdrawn.

Currently, the United States is coping with a new threat: the worldwide COVID-19 pandemic.

This extraordinary “war” against a biological agent has no cure, limited treatments, and no obvious end in sight⁸² As of May 12, 2020, just under 4.1

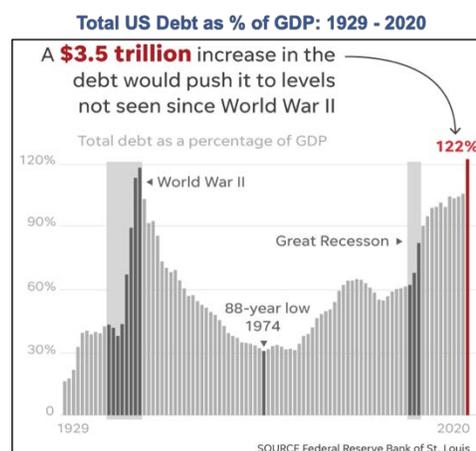


million people had been reported as infected, with more than 280,000 reported deaths.⁸³ There are more than 80,000 reported deaths COVID-19 in the United States,⁸⁴ compared with the National Archives’ figure of 58,220 deaths from the Vietnam War, which lasted more than a decade.⁸⁵ Due to the infection rate, incubation time, and limited testing, the primary strategy in combatting COVID-19 in the United States to date is the self-isolation of everyone not in critical industries – effectively shutting down the economy.⁸⁶ In April 2020, unemployment soared to almost 15 percent⁸⁷ as many Americans continue to isolate themselves and undertake social distancing measures. In response, Congress passed four relief packages totaling 2.4 trillion dollars.⁸⁸

The combination of the COVID-19 relief packages and the fiscal year 2020 4.7 trillion budget results in a whopping 7.1 trillion dollars appropriated in 2020. Mandatory entitlements

and the interest on national debt comprise more than half of the annual budget. Moreover, even before the pandemic hit U.S. soil, the federal government was on track to add another 1.1 trillion dollars to the national debt by the end of September 2020. The Congressional Budget Office estimates that COVID-19 stimulus will more than triple that projection to 3.5 trillion dollars.⁸⁹ This increase creates a debt level at 122 percent of U.S. GDP, a level not seen since near the end of World War II.

If history is a reliable indicator, such economic fragility is a sure sign that future discretionary defense budgets will either remain flat or be reduced. Thus, the notion that the DOD can continue to invest in the most exquisite, all-encompassing, and expensive weapons systems is unrealistic. Instead, the DOD should shift to a strategic mix of platforms that leverages capabilities across the EMS. By capitalizing on EW technologies and capabilities as discussed throughout this paper, the DOD



can realize lower cost alternatives that not only produce more lethality, speed, flexibility, and resiliency in the battlespace but also reduce acquisition, implementation, and modernization timelines.

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