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Spring 2021 Industry Study

Final Report
Electronic Warfare

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Abstract
The U.S. military faces an inflection point in how it will develop, resource and field the capabilities it needs to effectively control electromagnetic spectrum operations (EMSO) in this era of great power competition (GPC). Notwithstanding the September 2020 release of its Electromagnetic Spectrum Superiority Strategy (ESSS) and other guidance, the U.S. remains challenged in integrating government, industry, academic, and foreign partner electromagnetic warfare (EW) efforts to achieve its national security objectives.[1] Disparate approaches have yielded significant EW advances among the military services, which have capitalized on research and development (R&D) within the field. However, to maximize its capabilities and counter adversaries' ability to use the electromagnetic spectrum (EMS) to the nation's detriment, the Department of Defense (DoD) must empower and resource a strategically positioned change agent to implement and integrate EW efforts. This agent must address doctrine, organization, training, materiel, leadership and education, personnel, facilities and policy (DOTMLPF-P), leveraging and building upon its strengths, and those of its strategic stakeholders and partners.

Industry Study Methodology
The EW industry study (IS) has completed its third year as an offering for Eisenhower School students. The focus of the IS was to expose a select group to the concepts, capabilities, challenges, and future planning for EW within the United States. Over a four-month period of study, the students were exposed to this community through a series of lessons, guest speaker interactions, industry and government expert briefs within the community, and site visits. Travel restrictions due to the COVID-19 pandemic limited IS travel to locations within the continental U.S. The semester concentration provided the understanding of the EMS, terminology, history, and EW fundamentals. Additionally, it provided a look into the industry ecosystem, covering the Triple Helix concept (industry, government and academia) interactions in a knowledge-based economy.[2]

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Introduction

Thirty years after EMS dominance enabled the U.S. and its coalition partners to rout Iraqi forces during Operation Desert Storm, this nation finds itself struggling to keep pace with its adversaries' technological and doctrinal advances in the global EW arena. These adversaries, most prominently the People's Republic of China (PRC) and the Russian Federation, understand and seek to exploit U.S. forces' dependence on the EMS. Today's character of war is heavily dependent on EMS and its ability to enable command, control and communications (C3), detection of enemy activities, targeting of weapons systems, and protection and disposition of its forces across all domains. Russian and Chinese use of passive sensors and jammers deny U.S. freedom of action within the EMS, while relying upon wired communications, multi-static and passive sensing, and their understanding of local conditions to gain an advantage in a highly contested electromagnetic (EM) environment.

Addressing challenges to U.S. EMSO will become more difficult as defense budgets come under pressure from competing demands for resources, including the projected costs of infrastructure improvements and other domestic initiatives, recovering from the economic recession, and servicing the growing national debt. Given the growing variety of adversary countermeasures and diverse demands for the commercial spectrum, both DoD and industry seek to modify or replace DoD EMS systems. The DoD has demonstrated a willingness to increase investment in new EW capabilities and upgrades to existing systems.[3] However, current approaches to managing resources and coordinating efforts are barely capable of bolstering current EW capabilities, let alone regaining EMS dominance. Absent significant, lasting changes in how the U.S. resources and integrates EW across all warfighting domains, and all relevant civil, military and foreign partnerships, U.S. forces will lack the capabilities they need to meet either the emerging threats from China and Russia or the pressures exerted by commercial entities for greater access to an already heavily congested EMS.

In particular, the lack of a common integrative change agent has enabled status quo – the perpetuation of EW systems acquisition and fielding that remain mired in the processes of the 20th century. Services and industry pursue efforts that address adversary capability-specific concerns without sufficient consideration of options for broader application or integration of efforts and technologies. Opportunities for collaboration abound, and while some show significant promise, the lack of a dedicated, empowered, driving force, ensuring that integration becomes the norm, not the exception, allows other prospects to slip away. Moreover, while the establishment of the EMSO Cross Functional Team (EMSO CFT) is a step in the right direction, its projected sunset, and the ensuing uncertainty regarding the continuation of its mandate to "take bold action across the Department to regain U.S. dominance in the Electromagnetic Spectrum," demands immediate attention.[4]

In recent remarks to The Aspen Institute, Deputy Secretary of Defense Kathleen Hicks provided guidance that resonates with the need for greater integration across a broad spectrum of DoD and industry initiatives within the EW field.

> "There is no single point solution or enabler that sparks innovation. This means that we are making department-wide, crosscutting adjustments relating to culture, people, systems and process…. The Department must leverage our unmatched test and lab

> infrastructure to spur both innovation and competition across the public and private sectors. *And we need to be sure that DoD's vast ecosystem of innovative organizations is sufficiently integrated and optimized. This means being able to share best practices and key findings focused on the most important national security challenges.*"[5] (emphasis added).

The U.S. has a healthy EW ecosystem that is producing pockets of success and innovation. To accelerate innovation and satisfy the ESSS's identified need "to develop new capabilities, new techniques, and better integration within DoD and with its partners," the DoD should embrace established theories of military innovation.[6] Common among the models of military innovation is the need for a change agent and the requirement for some form of top-down pressure.[7] The DoD must exert this high-level pressure by creating and resourcing a strong, empowered, central change agent to effectively implement and integrate industry innovations and service EW efforts to produce a joint EMSO capability sufficiently resilient and forward leaning to meet current and future threats.

This paper will explore the opportunities for integration by examining the health of the EW industry and the factors that influence it. The study will also assess EW industry in terms of strengths, weaknesses, opportunities, and threats, and will offer recommendations a change agent should implement, together with suggested priority actions DoD leadership should facilitate to better integrate efforts of industry and government to achieve EMSO superiority.

EW Defined

The North Atlantic Treaty Organization (NATO) definition of EW provides the essential understanding:

> The purpose of EW is to deny the opponent the advantage of, and ensure friendly unimpeded access to the electromagnetic spectrum. EW can be applied from air, sea, land, and space, and target communication and radar systems. It involves the use of electromagnetic energy to provide improved understanding of the operational environment as well as to achieve specific effects on the modern battlefield.[8]

Foundational to this industry study is an understanding of EM energy and how it moves through space in waves. This energy can be moved across the EMS at differing frequencies from radio waves to gamma rays. Radio waves are at the lower end of the EMS, with longer waves and lower energy, and gamma rays are at the higher end of the range, with shorter wavelengths and producing the most energy.[9]

Military uses of the EMS include support to terrestrial and celestial communications, global positioning, navigation, and timing, network connectivity, drones, and radar. These capabilities are integrated across the services and warfighting domains (air, sea, land, space, and cyber). The warfare concepts involved with EMS include the basics of jamming and spoofing. When jamming is employed, it can target a specific frequency or cover a band of the spectrum using high power transmitters. The technique of spoofing injects false data in the form of energy into systems creating conditions such as false air tracks. "In short, jamming causes the receiver to die, spoofing causes the receiver to lie."[10]

The capabilities invented, produced, and provided within the EW enterprise are divided into three main pillars. These are Electronic Attack (EA), Electronic Protection (EP), and Electronic Support (ES). These pillars define the domain and allow for clear lines of departure for the development and use of capabilities. Appendix A provides a listing of capabilities included under each pillar.[11] NATO considers the Electromagnetic Spectrum Environment (EME) as a maneuver space that the other domains are dependent upon for success, "the totality of electromagnetic phenomena existing at a given location."[12] As the DoD transitions from treating EW and spectrum management as separate specialty areas to a more inclusive view of all things EW and EMS as EMSO, the services will apply resources to each of the pillars based on national security objectives.[13] There are several "official" descriptions of each pillar. For this paper, Joint Publication 3-85, Joint Electromagnetic Spectrum Operations, definitions will be used:[14]

- Electronic Attack (EA) – Division of electromagnetic warfare involving electromagnetic energy, directed energy, or anti-radiation weapons to attack personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability and is considered a form of fires.
- Electronic Protection (EP) – Division of electromagnetic warfare involving actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability.
- Electronic Support (ES) – Division of electromagnetic warfare involving actions tasked by, or under the direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated electromagnetic energy for immediate threat recognition, targeting, planning, and conduct of future operations.

The primary challenges facing EMSO can be summed up in three main categories: congested, contested, and constrained.[15] These challenges are defined in the ESSS:

- Congested – Military and civilian EMS-dependent systems continue to crowd the spectrum and increase the amount of unintentional interference.
- Contested – Enemy activities detect, disrupt, exploit, degrade, deny, deceive, or destroy friendly EMS capabilities for the purpose of military advantage.
- Constrained – Domestic and international regulations cause the amount of spectrum available for military access to decrease.

This complexity is discussed in terms of shared spectrum use to support military necessity and economic growth as this concept is critical during conflict but is also integral during peacetime to provide realistic environments for testing, training, and operations.[16]

Strategic Environment

Assessment of Adversary Intentions

Great Power Competition (GPC) is being waged across many domains, regions, and nations. According to the Director of National Intelligence (DNI) annual threat assessment, "China and Russia are expanding cooperation with each other and through international bodies to shape global rules and standards to their benefit and present a counterweight to the United States and other

Western countries."[17] As such, they pose a significant threat to the U.S. as they seek to create a new global environment that challenges the full spectrum of U.S. and its allies' interests.

China. The DNI further assesses that Chinese leaders "will try to extend the country's global, economic political and military reach while using China's military capabilities, and overseas infrastructure and energy investments under the Belt and Road Initiative, to diminish U.S. influence."[18] When analyzing the PRC's "defensive" strategy, an underlying tenant can be summarized by a key concept from Mao Tse-Tung's statements in ***On Protracted War*** stating, "in order to achieve victory, we must as far as possible make the enemy blind and deaf by sealing his eyes and ears and drive his commanders to distraction by creating confusion in their minds."[19] China understands the power of cyber and EW. This core tenant is foundational in the PRC's plans for conflict in the multi-domain environment of the future.

Russia. Russia continues to challenge the U.S. and NATO leadership resulting in tension and a worsening bilateral relationship. The Kremlin maintains three strategic goals: reclaim and secure Russia's sphere of influence over former Soviet countries, regain worldwide recognition as a "great power" and portray itself as a reliable actor, powerbroker, and successful meditator to gain economic, military, and political influence of global affairs.[20] Russia continues to antagonize the U.S. through the annexation of Crimea, the ongoing war in southeastern Ukraine, support to Syria's Bashir al-Assad civil war, partnership with Venezuela's Nicolas Maduro, and interference in the 2016 U.S. election.[21] According to a 2019 Joint Staff White Paper, Russia is "adopting coercive strategies that involve the orchestrated employment of military and non-military means to deter and compel the U.S., its allies and partners to and after the outbreak of hostilities."[22] Further, Russia is pursuing a strategic objective to establish an uncontested sphere of influence in the post-Soviet region.[23] Russia will continue to look for opportunities to partner with adversaries of the U.S. to challenge U.S. supremacy while expanding their "success" supporting these three strategic goals.

Balance of Power on the International Stage

The United States has long enjoyed a superior fighting force in all aspects of military capability (air, space, land, and sea). Yet after 20 years of counterinsurgency-focused warfare, U.S. superiority has atrophied considerably in key areas of combat capability. The lack of superiority is especially striking when comparing U.S. air, space, and EW advanced capabilities against that of Russia and China. Of the two adversary nations, China is the greatest concern to military and civilian government leaders due to its rapidly improving and advanced capabilities.

DIA Director, Lt. Gen Scott Berrier, testified to Congress on April 29, 2021, that China's unique weapons development approach—which Berrier dubbed "military-civil-fusion"—purposefully combines civilian and military technology efforts into a single operation, allowing China the ability to swiftly advance technology without the stove-piped and regulated systems that continue to hinder U.S. advancement. According to Lt. Gen Berrier, China's efforts to blur the lines between civil and military environments poses "the greatest threat to U.S. technological superiority." In fact, Berrier stated China has "already achieved peer or near-peer levels in many research areas" and has targeted 57 specific technologies in which to outpace and out-field the U.S. military.[24]

U.S. efforts are already underway to address the increasing military capabilities of both Russia and China; however, even after three years of acknowledged concern, and subsequent attempts to increase both capacity and capability, there remains a concern that the U.S. would fare poorly in a fight with a peer adversary. Much of the concern is focused on the current plan to send a fleet of primarily 4th generation combat aircraft to fight in a highly contested environment full of integrated air defenses, advanced electronic jamming, and now even enemy 5th generation stealth aircraft. Congress has approved and allocated funds to produce replacements for 4th generation fighters and bombers, however, the costs to increase production of such advanced weapons systems make it difficult to continue operating legacy aircraft. The U.S. still needs to spend billions on operational costs associated with legacy airframes until the newest 5th generation fleet is fully airworthy. Yet, even with a predominantly 5th generation force, some experts argue it may not be sufficient to beat a peer competitor.

A 2019 report for Congress by the Center for Strategic and Budgetary Assessments (CSBA) identified a critical shortfall in the number of Air Force combat squadrons expected to be used by combatant commanders for major combat operations. In the study, CSBA sought to identify sufficient combat air forces to successfully defeat two peer competitors almost simultaneously. As an example, U.S. combat air forces would be required to defeat a "major Chinese military action in the South China Sea." Then, within two weeks, it would be required to defeat a second peer-competitor in an advanced battle such as "a Russian invasion of one or more Baltic states."[25] To accomplish two back-to-back victories, the study found that the Air Force, even with an advanced 5th generation fleet, would need to nearly triple its bomber presence from nine to 24 squadrons, increase its fighter squadrons from 55 to 65, and add 18 additional air-refueling squadrons. Additionally, the Air Force would need to increase the number of its remotely piloted aircraft squadrons from 25 to 43.

As noted below, similar concerns resonate in the U.S. ability to counter Russian and Chinese EW capabilities. Although the U.S. maintains a sophisticated portfolio of EW capabilities, the lack of overall EW capacity and its limited ability to integrate EW into its operational activities forces the U.S. into environments where it would be hard pressed to mount successful military operations against these peer competitors.

Importance of EW to National Security

Over the past thirty years, a very distinctive "American way of war" has emerged, first to guard against Cold War threats, and then to forward deploy forces abroad to defeat adversaries and shape the global environment suitable to U.S. national security objectives.[26] Large military assets such as carrier strike groups, brigade combat teams, and squadrons of aircraft all require tremendous logistics tails and full-size forward operating bases, all within close striking range of potential adversaries who lacked any form of overmatch to counter.[27] Additionally, the U.S. has created a complex web of intelligence, surveillance, and reconnaissance (ISR) capabilities that allow it to strike in a given time and place of its choosing, causing significant disruptions in an adversary's order of battle. The U.S. understands and trains against the many "forms" of war; however, those adversaries also understand how the U.S. prefers to fight, making it equally as important to know the extent of those adversaries' understandings and capabilities, creating a perpetual game of move and countermove.[28]

In its 2020 Annual Report to Congress regarding China, the DoD assessed that in 2000 "the PLA [People's Liberation Army] was slowly and unevenly adapting to the trends in modern warfare," however, by 2020 it noted that "the PLA's objective is to become a 'world-class' military by the end of 2049."[29] China's technological progress is not only fueled by its strong economy, but by its ability to move military capabilities through its acquisition processes, from concept to application, more quickly than the U.S.[30] This rapid acquisition and operationalization of advanced military weapons has rapidly allowed China to build up its presence in the South China Sea via man-made islands, and conduct all-domain exercises that train its forces in anti-access, area denial (A2/AD) capabilities, as well as in the use of hypersonic and EM weapons systems.[31]

Over the past two decades, Russia and China have been investing heavily in EW capabilities and techniques in an effort to undermine the U.S. technology advantage. As the U.S. pivots to engage them in GPC, as outlined in the 2017 National Security Strategy (NSS), the nation's investment priorities will need to align to the threats they pose.[32] In the event of a conflict, dominance within the EMS will be crucial to surveillance, intelligence, command and control, weapons engagement, navigation, and protecting the global economy.[33] As the ESSS states, "In modern warfare, EMS superiority is a leading indicator and fundamental component of achieving superiority in air, land, sea, space, or cyberspace."[34]

To prepare for potential conflict, the U.S. must regain its superiority in EW through investment and rapid development. This imperative is needed not just to protect military assets and capabilities but also commercial systems and capabilities supporting the global economy, which, due to the congested nature of the EMS, are also at risk. The shared nature of the spectrum will allow adversaries with basic EW capabilities to attack Internet satellite constellations, cellular services, commercial drones, and self-driving vehicles. Anything that relies on the EMS to operate is at risk. The congestion within the EMS is readily apparent in comparing the spectrum allocation charts from 1970 and 2016 as seen in Appendix B.[35] To better understand the focus of the 2017 National Defense Strategy (NDS), Congress directed a non-partisan, independent review of the strategy in the Nation Defense Authorization Act (NDAA) of 2017.[36] Within its final report, the review commission addressed EW:

> "Electronic warfare capabilities will be critical in any future conflict, especially those against major-power rivals. U.S. competitors have invested heavily in electronic warfare as a way of neutralizing U.S. advantages, undermining U.S. command, control, and communications, and weakening America's ability to project decisive military power in contested environments. Russia and China have made particularly significant strides in this area. DoD must enhance its electronic warfare capacity and capability to allow the United States to overcome adversary electronic warfare investments, and to degrade and defeat advanced anti-access/area denial capabilities and adversary command, control, and communications architectures."[37]

Of note, this IS addresses one of the ESSS objectives, namely to "Train and Sustain EMS Expertise." As its overarching intent, the ESSS seeks to ensure military and civilian leaders at all levels are "indoctrinated and trained at the appropriate level on EMS core concepts that enable an EMS maneuver mindset."[38] This objective will provide leaders with a baseline understanding of capabilities, deficiencies, and operational impacts as the department maneuvers to deepen and strengthen its EMS technical expertise.

Industry Status, Challenges, and Outlook

With this strategic environment as a backdrop, an assessment of the industry supporting the nation's EW efforts is in order. Several forces shape this complex, multi-billion dollar environment including competitive factors on the global stage, and market forces within the U.S. Appendix C provides additional information regarding the size and scope of the industry.

Industry Status: Porter's Diamond Analysis

The Porter's Diamond model of the competitive advantage of nations helps to address whether the U.S. EW industry's national advantage is sufficient to ensure development of national security systems at a level of capability and speed-to-market required to meet ESSS goals.[39] As shown in Appendix D, Porter's Diamond considers the relationships among several critical elements, including that between government and industry—the "catalyst" that a government can provide in its global position in economic competition—in explaining competitive advantages within a given global industry.[40] According to Michael Porter, the author of the Diamond, "In the sophisticated industries that form the backbone of any advanced economy, a nation does not inherit but instead creates the most important factors of production—such as skilled human resources or a scientific base."[41] The ESSS embraces this concept and identifies the need for the government to apply resources for research as the "springboard" for future EMS concept development, including investment in academia, laboratories, and industry to develop revolutionary capabilities.[42] Additionally, the DoD will need to continue its investments in developing its EMS workforce trained in "EMS core concepts that enable an EMS maneuver mindset."[43]

In the context of GPC, Porter's Diamond can be used to assess the relative competitiveness of Russia and China's EW industry as compared to that of the U.S. Factor conditions, demand conditions, supporting industries, and firm structure and rivalry all contribute to relative competitiveness and carry differing weights in employment and effectiveness in each of these nations.

The U.S. maintains the capacity to dominate the demand conditions element of Porter's Diamond. At over $700 billion, the U.S. defense budget is more than those of the next ten countries combined. Even more demonstrative, only 18 countries in the world (including the U.S.) have a gross domestic product (GDP) larger than the U.S. defense budget. Moreover, a significant portion of that budget retains a tie to EMSO, even if the actual amount spent on EW RDT&E and procurement (about $10 billion per year) is a small fraction of the total.[44] This spending level enables the U.S. to be a world leader in defense technology.

In addition, the sheer size of the U.S. defense budget, and by extension its defense industrial base (DIB) provides the U.S. with a nominal advantage in the element related and supporting industries. Moreover, the strength of the U.S. DIB is further augmented by hundreds of billions of dollars in foreign arms sales.[45] U.S. innovation in EW related technologies and dual-use technologies is world leading, with five U.S. firms accounting for one third of the total *global* sales of EW products in 2019.[46] The challenge for supporting industries within the U.S. DIB is that often, technology moves faster than the DoD acquisition process. The commercial and private sector, both within and outside of the U.S. often has more advanced technology, in specific areas, than DoD. However, that culture of innovation and ability is resident in the U.S.

Of the four elements of Porter's Diamond, this IS judged factor conditions, such as human capital in rough parity among GPC rivals, the U.S., Russia and China. According to the World Bank human capital index (HCI), "an international metric that benchmarks the key components of human capital across economies," the U.S., Russia, and China rank at 0.70, 0.68, and 0.65, respectively, revealing only a slight advantage for the U.S.[47] Other factor conditions such as capital resources, natural resources, and knowledge resources likely support similar ranking. All three nations have vast natural resources, sufficient capital to drive a military industrial base, and a knowledge base sufficient to pursue advances in EW technology. While one nation may rank slightly higher than another in each category, the advantage in factor conditions is not enough to be decisive, and can be offset by a disadvantage in another Diamond component. For example, while the U.S. may hold an advantage in human capital, China produces the vast majority of rare earth minerals essential to the manufacturing of EW equipment.

In contrast, this study found that firm structure, strategy, and rivalry constituted the most significant attribute of the Porter's Diamond model amongst these three nations—and from an EW industry perspective, the one in which the U.S. faces the greatest challenge. This attribute is heavily influenced by government intervention. As previously noted, the Chinese Communist Party (CCP) has established an aggressive "military-civil fusion" (MCF) strategy, systematically restructuring China's science, technology, mathematics, and engineering (STEM) enterprise to require all new commercial innovations to simultaneously advance military development.[48] The program is of massive importance to the PRC and is personally managed by President Xi Jingping.[49] Similarly, the Russian military industrial complex has the favor of President Vladimir Putin, to include support for acquiring new weapons systems and the cancellation of a significant portion of Russian military industrial debt.[50] The latter effort is designed to reinvigorate Russian defense industries, some of which had been saddled with high levels of toxic debt. In contrasting these two adversaries, it is clear that China maintains an edge vis-à-vis Russia due to its booming economy, which managed to grow in 2020, even in the face of the COVID-19 pandemic.[51]

In the U.S., the defense industrial base is driven by intense competition. Where China and Russia favor specific firms as national champions, U.S. EW firms are expected to compete for major defense contracts, following a business model that has existed since World War II (WW II). While this imperfect business model continues to yield productive and innovative solutions in every military sector including EW, adapting this model to incorporate more integrative and cooperative approaches can yield significant benefits. In short, the U.S. must continue to adapt and leverage this advantage in its pursuit of EMS dominance.

Industry Status: Porter's Five Forces

Porter's five forces of industry competition are shown in Appendix E, and provide an additional, useful framework to analyze the current U.S. EW market, with DoD's reactive acquisition strategies strongly influencing how firms have participated in that market.[52] Two characteristics of this multibillion-dollar market should be highlighted.

First is the remarkably fierce rivalry amongst competitors. Within the U.S., the EW market is highly competitive, with five U.S. major defense firms dominating the market, and more than two dozen others providing niche products and components. Bargaining power in the EW market is consolidated with the sole consumer in this market, the DoD monopsony. Additionally, with five major market participants, the threat of substitute products is exceptionally high. To eliminate the threat of new entrants, defense firms vertically integrate their EW business units through mergers and acquisitions. In some cases, these business units can produce all of the significant hardware and software components for a given system. Conversely, the bargaining power of suppliers is somewhat mixed. Dozens of smaller companies compete with each other, and with the major producers as noted above, for a share of the EW component market; however, some smaller firms are able to leverage their unique product lines and/or capabilities to command advantageous price points and inroads into the DoD monopsony. Finally, the intense rivalry incentivizes firms to create proprietary connections to a given platform along with unique software and data formats.

The second notable characteristic is a byproduct of this vertical integration. Rivalry has effectively set the lowest sellable unit at the system level. Even though an EW system comes with hundreds of components, the unit of sale is a complete system, leaving the consumer at the mercy of its chosen manufacturer regarding the internal workings of a given EW system. For example, a final EW product may have broad-spectrum coverage, but poor receiver sensitivity, due to the sub-prime vendor chosen by the firm. The industry is entrenched in this paradigm and needs support in transitioning to any new approach in systems design, build, and integration to the EW market.

DoD Acquisition Challenges

DoD has managed the EW enterprise in a primarily reactive manner since the end of WW II.[53] This behavior has shaped the EW market and how industry participates in it. Procurements involve heroic engineering efforts whose high costs are justified by the warfighter's urgent need. However, during years between conflicts, demand drops sharply and acquisitions slow.[54] This results in sporadically produced systems that are stand-alone in nature, built for a narrow purpose, and not typically interoperable with other existing systems. After years of this practice, the defense industry's standard EW product line is now a suite of closed, proprietary subsystems.[55] For EW firms, this was a successful business model that grew from DoD's spending habits and created opportunities to secure and maintain market share.

DoD's erratic EW acquisition strategy stems from a flawed understanding of the EMS environment. The services have traditionally viewed the EMS as a utility, a commodity that would be available on demand.[56] While DoD has recently developed a better understanding of the EMS as a warfighting environment, where mass and maneuver function within the same space, the question remains whether that realization will translate into changes in behavior across all DOTMLPF-P processes and, if so, whether that change will occur in sufficient time to meet ever increasing GPC threats.

DoD has also struggled in adapting its approach to EW development and acquisition. In the past, DoD leadership focused on symptoms of the EW problem from the perspective of each service, rather than seeking the root causes of the department's inability to coherently maneuver in the EMS. DoD's focus is belatedly shifting towards a greater understanding of the EMS as an operational environment, instead of blindly trying to buy enhanced capabilities deemed necessary by a given service.[57] For years, DoD heavily invested in 3rd offset technologies as the 2nd offset was gradually being undone, however, the 2nd offset requires a foundation of EMS dominance. Position, navigation, and timing (PNT) capabilities, networking, and even stealth become ineffective without the ability to maneuver across the EMS. While DoD is making significant progress in adapting its approach, there is still much work to do.

For example, the practice of building a system to defeat a specific adversary capability will likely fail against adversaries like Russia and China. Consider the case of the Counter Radio Electronic Warfare (CREW) system developed to defeat remote-controlled improvised explosive devices (RCIEDs). Early versions also jammed blue force tactical radios while the system broadcast its protective jamming signal. When jamming was secured to enable communications, vehicles were vulnerable and, in some cases, RCIEDs detonated.[58] This was a complicated but solvable problem. DoD and industry responded by developing the Duke CREW system and U.S. forces kept pace with the threat presented by insurgents. These non-state actors are effective at adapting commercially available technologies into lethal capabilities, forcing the world's leading superpower to adapt and respond to groups that do not have a coherent industrial base or national innovation system.

By contrast, in a conflict with Russia or China, there is no opportunity to play catch up. This challenge pits the U.S. innovation base against great power competitors who understand that the while the U.S. defense industry has developed the world's most advanced weapons systems, those systems are inherently dependent upon the EMS. In today's complex EMOE, those dependencies will be ruthlessly exploited. We expect Russia and China to employ A2/AD strategies against the U.S. geared toward defeating 2nd offset technologies that rely upon on EMS dominance, like stealth, PNT, and long-range strike. Without freedom of maneuver in the EMS, U.S. military will fail to present a credible threat, and no longer provide conventional deterrence to great-power competitors.

Industry Outlook
The outlook for the EW industry is tied to the partnership between the DoD and the Defense Industrial Base (DIB). As the country moves to engage in GPC, significant investment is necessary to ensure our technology advantage outpaces that of our adversaries and overcomes capability gaps that have developed. Key areas for this investment include labor and infrastructure needed to drive innovation. For example, both industry and the U.S. government continue to focus on developing STEM talent, to include outreach to universities and other potential sources, to satisfy the technological demands facing their respective workforces. In addition to expanding their own facilities, industry also leverages DoD's extensive test and laboratory facilities to determine product viability and/or ability to meet government specified parameters.

In the U.S. EMS industry, the government is a significant driver of advantage, especially in segments specific to EW where it is the primary customer. However, absent a more integrative approach, one expects to see a continuation of service- and agency-specific competition for resources and solutions as drivers of innovation in the EW industry. Independent service efforts to develop joint all domain command and control (JADC2) capabilities, which have significant overlap and integration with EMSO and electromagnetic battle management (EMBM), bear this out, as do general public disagreements about specific mission sets such as long-range fires. And while service rivalries can be drivers of innovation, the department is best served in integrating efforts, sharing, as Deputy Defense Secretary Hicks notes, "best practices and key findings" that will maximize the return on investments in the EMS.

In addition, DoD must embrace civil agencies like the Federal Communication Commission (FCC) and Federal Aviation Administration (FAA), to leverage their interests in further maturing technologies and capabilities that enable better sharing, coordination and real-time deconfliction of the EMS. An integrated approach to spectrum management can drive innovation that supports not only dual-use for commercial and national security purposes in the U.S., but also in trade and military interoperability with partner nations. Consequently, in key emerging technologies like quantum radio, commercialization will require adroit government policy to ensure that the U.S. continues to support production, while concurrently ensuring that the transition to that commercial marketplace does not jeopardize national security interests.

As the majority consumer in the EW market, the DoD's improved understanding of and approach to the EMS is changing the nature of the marketplace and has sparked several notable industry trends. In response to operator demands for fully interoperable systems built with common architecture compliant with open standards, more recent EW products reflect a shift in DoD requirements that move away from unique, single-function units and towards units based upon modular open systems architecture (MOSA), which are multifunction, multi-spectral systems.[59]

In 2013 the U.S. Army created the C5ISR /EW module open suite of standards (CMOSS) initiative. In 2014, NAVAIR founded the hardware open systems technologies (HOST) standard. In 2015 the Air Force Lifecycle Management Center founded the open group sensor open systems architecture (SOSA) consortium standard. SOSA was conceived of with in the future airborne capability environment (FACE) consortium.[60] Similar initiatives like modular open radio frequency architecture (MORA) and vehicular integration for C4ISR/EW interoperability (VICTORY) pursue the same end goal.[61] These initiatives have existed for years but failed to yield any significant change in the EW market due to DoD's poor governance of the EMS enterprise and failure to account for free market forces, highlighting DoD's need for a centralized advocate to manage market trends and provide clear guidance to industry.

Industry must approach the new EW market in a way that provides multifunction, fully interoperable systems that meet open standards and open architecture concept of operations. This may result in several new developments, including a firm's EW business unit splintering into various individual hardware and software competitors, with open architecture requirements allowing a firm to win multiple bids inside a given system or win bids for a specific component across many systems and platforms. It may also open the door to increased competition beyond the "Big Six" defense firms (Boeing, Lockheed Martin, General Dynamics, BAE Systems Inc., Raytheon, and Northrop Grumman). Some firms may also seek to be the DoD's provider of user interfaces. Likewise, there are sub-prime vendors that excel in producing small form factor, high power RF generators. Open architecture would allow firms like these to design components and win contracts for EW systems across all services and platforms. This new model discourages firms from building a narrowly scoped system that defeats a specific adversary capability, and instead promotes robust EMS dependent systems that will be ready to compete in complex EMOEs.

Notwithstanding the nimble, proactive approach demanded within the new EW market environment, industry cannot instantaneously transition to open standards concepts, and there are several barriers to a wholehearted embrace by business. Chief Executive Officers (CEOs) will need time and incentives to change their business strategies to compete in the new market. Today, firms have no incentive to relinquish data rights and are reluctant to conform to yet another data standard. Firms create value by preserving their intellectual property (IP) rights through proprietary code and unique physical system interfaces, and the new EW market challenges this position. That said, this conundrum is not beyond resolution.

An expanded treatment of Porter's Diamond can explain how a transition could be achieved. Clusters, or hubs of industrial excellence, already exist throughout the U.S.[62] Take, for example, 'Infrared Valley' in Goleta, CA. Companies in this cluster could collaborate in creating a standardized data format that would enable them to share the risk associated with being a first mover in the new EW market, while also allowing all to benefit from the advantage that comes from cornering a new sector of a competitive market. They are uniquely positioned to develop an innovative solution due to their proximity to centers of industrial and technical excellence. Another business case for the new EW market can be made in terms of optimizing return on invested capital (ROIC). Defense firms stand to increase return on capital invested in EMS related R&D through open standard concepts. Using that approach, a firm only needs to invest in a component once and can then apply the technology across multiple platforms and applications.

Other EMS Factors

Given the complexities of the EW environment, additional in-depth discussion of selected topics identifying other challenges and opportunities impacting the EW industry are found at Appendix F.

Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis

"Adapt or die!" was the retort given by Oakland Athletics General Manager, Billy Beane, to an aging baseball scout in the movie, *Moneyball*.[63] While the Athletics still lost at the end of that 2002 season, the innovative adaptations undertaken by Beane changed the game of baseball, forcing all major league teams to adopt data analytics as a sine qua non for baseball success. As the DoD faces a revolutionary transition in military affairs, the National Defense Strategy acknowledges a similar requirement for the joint force to "adapt or die." Unlike the Athletics, however, the U.S. military is not afforded the luxury of approaching success and falling short. Today, the policies and decisions for force development and disposition must advance National Security objectives and position the joint force for decisive victory if deterrence should fail.

In the era of GPC, Russian and Chinese views of future warfare, and the extent to which they harness new capabilities, vary from the priorities and positions of the U.S. As such, a review of both adversaries' strengths, weaknesses, and other factors enables the U.S. to contextualize its own factors, enabling the U.S. to capitalize on the advantages afforded by pitting a U.S. strength against a Russian or Chinese weakness or mitigate the adverse consequences that may flow from the converse.

Russia

The Russian Armed Forces are developing multiple technologies and weapons platforms that further integrate their command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) capabilities, specifically incorporating the capabilities of their advanced EW platforms. For well over a decade, the Russian Armed Forces have embedded an EW presence within every service and subordinate element, such that EMS considerations are now organic and inherent in operations.[64] Analysts note that the extent and integration of Russia's EW capabilities play a major role in its success in Syria.

Strengths. Since 2008, Russian EW has modernized to support a more agile and contested EMS. Russia's EW modernization continues to improve and enable future concept development for the Russian Federation. Russia's primary strength is the integration of EW with cyber and information operations effects, causing the U.S. to expend resources to develop countermeasures, deceiving the U.S. and denying access to its networks, and increasing obfuscation of decision makers in both proxy wars and most recently in Ukraine's Crimea and Donbass regions.

Weaknesses. Conversely, Russia's supply chain remains limited, and ongoing sanctions restrict Russian ability to surge and/or sustain capabilities during intensified conflict. Russian central control over its EW industry through the integration of EW manufacturers under the umbrella of the Kontsern Radioelektronnye Tekhnologii (KRET) may improve procurement, but may weaken Russian EW innovation, enabling U.S. and NATO allies regain the initiative in countering Russian EW dominance.

Opportunities. Russian opportunities remain at the tactical level, to include supporting China, as China looks to modernize PLA EW capabilities. In addition, Russia has an opportunity to continue to layer EW capabilities across its military and Russian-controlled territories. This layered integration increases A2/AD protections and introduces new opportunities to test these non-kinetic systems against neighboring states or proxy areas of Africa and Nagorno Karabakh.

Threats. Currently, the primary threats to Russia are continued sanctions and self-isolation, which limit access to capital and markets. In addition, Russia's ability to effectively employ EW capabilities in a changing 5th generation EMOE and efforts to develop and utilize alternative PNT guided platforms may meet with increasing frustration as the U.S. and Russia's neighbors gain a better understanding of Russian activities, and apply countermeasures to thwart their desired affects.

Before their engagement in Syria, the Russian Armed Forces lacked the operational experience, training infrastructure, and synthetic environments necessary to test their modernized EW systems. However, as Russian forces gain operational experience, particularly in Syria, EW convergence and readiness within their ranks will continue to advance. In fact, by constructing a real-time and relevant environment, the Syrian 'training area' gave Russia an opportunity to target U.S. systems and weapons platforms in the region, evaluating its own EW effects against U.S. capabilities.[65]

China

Like Russia, C4ISR integration among PLA assets remains a priority, as China seeks to incorporate information technology and apply net-centric warfare in thwarting adversaries', primarily the U.S.'s, freedom of maneuver within its area of operations.

Strengths. Through modernization efforts, incorporating technologies that allow and facilitate information exchange among military services, individual military units, and weapon systems, network warfare attempts to enable cooperative target engagement in combat. This connectedness allows multiple platforms across all domains to mass and provide joint fires on the same target, accelerating the decision-making process and kill chain simultaneously. More concerning though, China is looking to integrate and command on an even grander scale. Already a significant challenge for U.S. planners looking at options to thwart China's A2/AD system, China's coastal radar and jamming capability could prove impenetrable if fully integrated into the PLA C4ISR frameworks, a present goal for the PLA.[66]

Weaknesses. China, unlike Russia, has the production capacity to sustain and increase agile developments for their EW operations and force structure. However, the PLA lacks operational experience in EW. China has not sufficiently matured its simulated environments or concepts to determine whether it has the right posture to achieve its desired operational affects within the EMS.

Opportunities. Given the progress that the PLA has made with its Strategic Support Force (SFF), the organization responsible for space, cyber, and EW missions across distinct parts of the PLA, and the tactical relationship it is building with Russia, the PLA is quickly moving towards EMS superiority.

Threats. Dampening China's revisionist goals are possible limitations imposed by semiconductor powerhouses (Taiwan and Korea), and the potential for constricted microchip supply chains impacting both its military and its commercial technology sector. In addition, the growing U.S. presence and sustained cyber electromagnetic activities (CEMA) modernization U.S. posits is assessed to stretch the limits of China's EW base and likely outpace overall PLA EW readiness.

Today, the PLA already has a national and redundant command-and-control system linking its senior leaders to the General Staff Department command center in Beijing as well as alternate command posts, military regions, and subordinate units that include air, land, maritime, and space assets. However, the SSF remains stove-piped, even as the PLA's strategic doctrine prioritizes integrating space and EW capabilities through a unified command.[67]

PLA and Beijing leaders acknowledge this gap in integrated EMSO functions and have made significant advancements in both application and education. While sustaining focus on coastal defenses, the PLA is also looking at broader applications across the EMS. For example, the PLA has developed the Electronic Countermeasure Institute, a school aligned with the National University of Defense Technology. This union has led to increased integration amongst cyber and EW capabilities supporting a warfighting concept within information warfare and converging the network and EMS space.[68]

U.S.

In contrast to its peer competitors, the U.S. Joint Force has taken a different direction in the EMSO arena. Instead of employing a single strategy, like Russia's tactical and regionally supported EW strategy or the PLAs integrated EMSO strategy, the U.S. has adopted an ad hoc, distributed approach to EMSO. This approach empowers each military branch and force employer to develop the warfighting concepts and tactics needed to fight within the relevant EMOE. However, as a result, U.S. EMSO functions are dispersed and lack standardized governance.

Strengths. Industry remains the driving factor behind EW capability development, acknowledging the value of the EMS space and demonstrating a willingness to invest its own capital in advancing the field. The U.S. also continues to lead the world in many areas of innovation, often centered in technology clusters, and retains an educated populace and academic institutions capable of producing the workforce it needs to meet current and future EW demands. Several of the industry partners engaged during this IS noted their efforts to forge ahead in this area, developing intern and scholarship relationships with universities to provide a pipeline for future STEM employees.

Weaknesses. Unfortunately, DIB developments and delivery of new and innovative EW systems remain aligned to overly bureaucratic acquisition processes, providing only incremental upgrades to weapon system capabilities. As evidence, the modernized capabilities integrating into the force today, such as software-defined radios, cognitive EW algorithms or digital radio frequency modulation systems, are evolutionary and not the revolutionary cloaking, stealth, or multi-PNT enablers requested by the Joint Force. Regrettably, this is the DOD's own doing. The DOD establishes requirements and acquisition programs in a move-countermove competition, mirror-imaging and establishing countermeasures rather than leapfrogging advantages.

In addition, both the DoD and industry partners would benefit from a new approach to writing and evaluating contracts. While Russia and China keep greater control over their defense industrial bases, U.S. contractual issues prevent fluid and rapid transitions in capability production and development, leaving industry more apprehensive to invest resources for EMS-centric systems. Currently, the EW DIB is largely reactive to DoD requirements for capabilities, knowing that meeting, but not necessarily exceeding those requirements will often be sufficient to win the contract award. As a result, the DIB is incentivized to be inherently inefficient.

Finally, as EW systems become more complex and integrated, they require more, and increasingly advanced semiconductors that the U.S. is challenged to provide. An in-depth treatment of this issue is found in Appendix F, Essay 2.

Opportunities. The Joint Force should redesign how they conduct Joint Warfighting Concepts and strategic plans to enable an integrated and layered system to circumvent adversary EW attacks, keep the integrity of weapons systems, and launch platform pathways and functionality. The DOD has an opportunity to revisit how funds are budgeted to support layered EW and look at how to capitalize on multifunction capabilities that include EW, such as flares with integrating jamming capability. The Joint Force also can identify the problem; given the increases in software-defined systems architecture, the largely incrementally adjusted hardware will sustain shape. Therefore, the more agile software designs and integration are not as time-sensitive or production restrictive.

Threats. Threats to the U.S. EW industry include a litany of challenges such as cluttered and burdensome acquisition processes that leave little room for redesign and competition. In contrast, Russia and China can test, employ, redesign, and employ much faster, achieving the agility requested in the ESSS.[69] Moreover, the lack of training and understanding of the problem leaves both U.S. services and warfighters in the awkward position of realizing the need to have EMSO superiority, but unable to show a coherent roadmap to achieve that objective against an agile and modernizing competitor.

If the Department fails to adapt, these threats will increase and the dollars thrown at the problem will not materialize as effective results creating an operational disadvantage. The understanding of human capital and lack of capacity and infrastructure in the semiconductor and software development and engineering arenas has several offshoots to form, but will require a system of systems beyond government, academia, and the DIB – and each of these three areas need to take greater risks.

Defense Industrial Policy Implications

Congress and the Department of Defense as Stakeholders in the success of Defense Firms

With a total annual market value exceeding $1.5 trillion, defense contractors have much at stake when considering the potential loss of revenue for a major weapons system contract. This incentivizes companies to do everything within their power to ensure they have access to markets (especially niche markets like EMSO systems), to understand the limitations (or the lack thereof) by the DoD, and ensure they have support and backing from congressional appropriators. Over time, leading defense companies have been careful to build portions of their major weapons systems in various parts of the country in order to maximize the parochial interests of congressional members.

Two recent examples include major weapons systems contracted by the Navy and the Air Force. The Ford-class aircraft carrier is constructed from parts hailing from 330 different congressional districts, representing nearly every state in the country. The F-35 is produced in a similar fashion, and also requires the input and assistance of nine foreign nations. The reality is that many (most) members of Congress feel the pressure of local voters who are employed by these multi-billion dollar "no fail" contracts, and, in the case of the F-35, it includes international pressure as well.[70]

These efforts highlight an important issue that has been identified and documented by the likes of Professor Richard Rumelt and Professor F. Edward Freeman, who argue that a firm's true success lies in satisfying all its stakeholders, not just those who might profit from its stock. Others argue even further that to achieve high performance, firms should adopt a broad strategy-making perspective that incorporates the needs and demands of multiple stakeholder groups.[71] This is an especially important concept in the defense industry since many of the most important stakeholders are also customers, defense officials, and congressional members.

As a result, in their roles as representatives of a state or district, members of Congress can pose a challenge to reforming unnecessary defense spending. Despite this, history has shown that members of the House and Senate Armed Services subcommittees tend to put such parochial interests aside to ensure the nation's best interests.[72] Often, the most difficult decision-making and in-depth analysis of service-specific needs is accomplished by professional committee staff members (not the elected officials) in the months leading up to committee hearings and votes for both the authorization bills and appropriation bills that the President eventually signs into law. These committee staffers are much less susceptible to the influence of defense lobbyists, and thankfully their expertise is often (not always) heeded by the actual members of the committees.[73]

This dual role of representing the best interests of each member's constituents, juxtaposed with simultaneously being responsible for the nation's best interests while in committee assignments, is what makes it possible to overcome the interests of the defense lobby and to reform the system. A recent example illustrates the power of the committees when faced with a challenge affecting defense readiness in the EMSO realm. In late 2019, key members of both the House and Senate Armed Services committees grew frustrated with DoD's lack of progress, especially in light of the serious peer-level threat posed by Russia and China, and chose to force DoD's hand using language that ultimately was passed in the FY21 National Defense Authorization Act (NDAA), officially dubbed H.R.6395.[74]

Section 152 of the act, in a much smaller and more focused way, resembles congressional mandates of the past like the National Security Act of 1947 and the Goldwater Nichols Act of 1986. Each of these congressional mandates created major shifts in ideology regarding how combat forces were structured as a result of past operational failures and the perceived needs of the future. And much like the previously passed acts, there are powerful defense officials who oppose the required changes, as well as others who believe the changes did not go far enough.

Section 152 requires the Secretary of Defense to transfer all authorities over EMSO from its temporary home under U.S. Strategic Command within two years to "an appropriate entity." This entity will be required to advocate for joint EW capabilities, provide EW support to geographic combatant commands, and support combatant command joint EW training.[75] In addition to this important (yet still vague) mandate, section 152 also requires each of the five service chiefs to provide a 5-year plan to address their respective service's ability to perform electromagnetic spectrum operations missions, as well as a requirement for three of the 11 Combatant Commanders to evaluate their respective manning, organizational alignment, Joint EMSO Cell effectiveness, EMSO exercises, force positioning, posture, and readiness.[76]

While this directive certainly was needed due to the DoD's inability to conduct analyses and planned changes on its own, it still falls short overall of what the United States needs in order to be ready for peer competition in a contested environment. The framers of the language found in section 152 provided the much-required beginning steps necessary to get the ball rolling, however, they stopped short of dictating to the Secretary of Defense what the "appropriate entity" should be, or what rank the senior leader should hold.

Industrial Security

The EMSO industrial and government sectors face a growing adversarial threat from foreign entities, specifically China, placing at risk the U.S.'s ability to maintain technological superiority. The DoD needs to expand its industrial security efforts in protecting critical infrastructure (CI). Many of the 16 CI sectors, noted in Appendix G, are critical to DoD mobilization efforts and these sectors will be targeted (kinetically or non-kinetically) by our adversaries. While the whole of government has made significant advancements in coordinating the protection of these sectors since the Homeland Security Act of 2002, vulnerabilities remain, directly threatening EMSO technological advantages. Recent cybersecurity studies indicate that PRC alone has been directly involved in cyber-attacks and espionage targeting 115 companies in the U.S. across 20 industries.[77] During one significant episode in 2010, PRC military hackers infiltrated the Pittsburgh location of QintiQ manufacturing stealing its proprietary chip and allowing the PRC to take control of or defeat U.S. military robots and aerial drones. This is but one of many examples of adversaries using cyber capabilities to set conditions to beat U.S. technology on the battlefield.

Of the 16 CI sectors identified in Presidential Policy Directive-21 (PPD-21), DoD is only responsible as the sector-specific agency (SSA) for the DIB.[78] However, in the event of a large conflict, two additional CI sectors, Communications and Information Technology, play a role in the DoD's ability to modernize and develop EMSO capabilities. If targeted non-kinetically through espionage or cyber-attack, damage to these three sectors would severely degrade DoD's EMSO capabilities.

There are three major industrial security initiatives an empowered DoD EW change agent could implement to protect EMSO across all the CI sectors, all of which entail greater integration of its efforts with those of other stakeholders. First, DoD could expand training and coordination with the Department of Homeland Security (DHS) and other SSAs, integrating into the intelligence and operations process established by PPD-21. PDD-21 established the SSA program and the partnering agencies created government coordinating councils (GCC) which work with the private sector and relevant stakeholders in the sector coordinating council (SCC).[79] DoD participation in the SCC will increase collaboration in the three relevant EMSO critical sectors. The DoD's training elements in the DHS National Infrastructure Protection Plan (NIPP) risk mitigation framework, ensure that the DoD can nest across the government using the same language as CI public and private sectors. Joint training would likely lead to a revision of Joint Publication (JP) 3-28, "Defense Support to Civil Authorities," which would transition from its current reactive guidance, to a more forward leaning, engaged approach toward civil-military relationships. Expanding the National Guard threat assessment program could also serve as a force multiplier for DHS in conducting additional CI risk assessments while improving DoD integration across sector lines. Moreover, supporting DHS exercises would ensure proper integration in preparation for an attack against one or more segments of the U.S. CI framework.

The second major effort for DoD would entail co-chairing SSAs with government elements to force better integration, in particular working with DHS to co-chair SSAs on Telecommunications and Information Technology. Relevant revisions to PPD-21 would force DoD into a more active role in managing the threats to and relationships among the three critical sectors supporting EMSO.

Finally, the DoD could increase intelligence support—specifically counterintelligence—to better protect the U.S. CI. DoD counterintelligence can expand its capabilities to support protecting these three additional CI sectors. Industries have consistently reported to the Government Accountability Office (GAO) that intelligence sharing on threats on a bi-monthly basis provides the most valuable benefit government has to offer regarding the threats they face.[80] And while increased intelligence interaction may increase the risk associated with potential violations of Executive Order (EO) 12333 and intelligence oversight infractions (notably collecting against U.S. persons or entities), leveraging existing DoD counterintelligence capabilities within appropriate legal boundaries would greatly improve early threat warnings and indicators.

A comprehensive DoD strategy to integrate its efforts with those of DHS and other SSAs will enable better coordination supporting U.S. CI and by extension will comprise a critical component of DoD's EMSO industrial security strategy in the face of any major conflict. It is in the DoD's interest to work across the three identified sectors for better integration in training and intelligence collaboration through the SCCs. There are significant capabilities that DoD can provide within the existing authorizations. Revising JP 3-28 would provide a culture shift from reactionary to pro-active engagement to better defense the Nation's Critical Infrastructure.

There are two primary barriers to increase support for protecting the U.S. 16 CIs. First, the DHS, DOT, and/or DOE may view increased DoD training and intelligence integration as an infringement on their mission as directed in existing authority documents. Second, existing *posse comitatus* and intelligence oversight regulations govern the use of DoD assets in support of domestic operations. These authorities must be closely followed or revised to enable significantly increased cooperation. While these lines of effort are not mutually exclusive, one can anticipate significant interagency push back if DoD seeks revisions in PPD-21 and the existing EO 12333, making the initial integrative approach the most likely to succeed in the short term.[81] Progress along any of these lines that can aid in the defense of these three CI sectors will assist in improving industrial security environment for U.S. EMSO suppliers, ensuring our future technological edge.

Trade Policy
Trade is generally considered a favorable activity in international markets, as it generates an efficient use of resources, greater competition (and therefore innovation), economies of scale, and lower prices and more choices for consumers. Due to their almost exclusively military application, however, trade in EW systems faces unique hurdles, including government regulations that restrict exports, a monopsonistic market in which governments can dictate demand, and potential competition from government-sponsored champions.

Nevertheless, analysts project that the global market for EW products will increase from just over $15 billion in 2019 to nearly $20 billion by 2026.[82] While the North American (primarily the U.S.) market will continue to account for the largest segment of this market, its overall share is likely to decrease due to increased demand in Asia. This dynamic presents both an opportunity and a challenge for U.S.-based firms as they compete with their global counterparts within the EW marketplace, an opportunity to strengthen the U.S.'s EW manufacturing base via expanded global sales, but with a need to do so in a manner that will preserve the U.S.'s technological advantages in the face of rising great power competition.

In addressing this dichotomous conundrum, it is worth noting that trade policy and industrial security policy are inextricably linked. Laws and regulations for both regimes limit the transfer of technology to non-U.S. nations or entities. However, trade policies are also designed to build bridges where needed and serve as more than a simple shield against the dilution of U.S. technology via unregulated sales of weapons systems or sharing of intellectual property. Moreover, the global proliferation of technology, particularly in Europe and Asia, has enabled many nations to develop technologies that were once dominated by the U.S., calling into question the efficacy of this shield, especially as it relates to the field of EW.

Export controls can also serve as an impediment to coordination with the U.S.'s closest allies—those whose support the U.S. needs to confront current and future adversaries. For example, the U.S. State Department's International Traffic in Arms Regulations (ITAR) restrictions impose a "cradle to grave" designation for U.S.-origin materials, such that purchasers seeking to re-export these materials must also traverse the same registration process as U.S. firms involved in their initial sale. The U.S.'s closest allies have often decried the chilling effect these export regulations have had on their ability to buy the weapons systems they need to upgrade their arsenals, even as the U.S. relies more heavily on allies and partners to maintain peace and stability and seeks to improve combat interoperability—including EW interoperability—with those partners.[83]

This is not to say that export controls should be abandoned as an element of EW trade policy. On the contrary, preserving current advances in innovation from across industry and academia, creating uncertainty on the part of adversaries and maintaining leverage within broader diplomatic initiatives all support the preservation of export controls as a valuable trade policy tool. However, a more nuanced approach, one that supports partners and thwarts adversaries, would create a more secure global environment without sacrificing the benefits that international commerce has to offer.

The Biden Administration's approach to arms exports suggests a greater emphasis on human rights rather than pure commerce. With that in mind, export of systems that are considered more defensive in nature, such as those that utilize the EMS to achieve their effects (communications equipment, radars, jammers, etc.) may receive more favorable consideration than their more lethal counterparts.[84]

Finally, these policies, which multiple departments within the government currently administer, also require additional harmonization and integration. From an EW industry perspective, establishing a primary DoD advocate capable of engaging the Departments of State and Commerce in reducing some of the regulatory burden would yield significant benefits and possibly forestall losses in global market share. The global market void created by current, complex regulatory regimes presents an opportunity for foreign EW technology firms to develop and produce products to meet the growing international demand. For example, several countries – both adversaries and strategic partners – have indicated a desire to purchase the Russia S-400 surface-to-air missile system, creating foreign policy complications for the U.S. and potentially inhibiting military partner interoperability.[85] An EW change agent capable of addressing trade policy concerns with State and Commerce may prevent future challenges of this nature.

Surge and Mobilization

Planning is the cornerstone of military contingency mobilization and should rely not on hindsight, but on foresight. JP 4-05, *Joint Mobilization Planning*, states, "A responsive mobilization capability is critical to our national security and the execution of the … NSS, NDS, and NMS."[86] This responsiveness stems from the synthesis of past, present, and recommended future mobilization efforts, and applying those TTP and best practices that secure and strengthen our global supply lines. The U.S. government cannot act unilaterally in these efforts; rather it must seek the active support and participation from the DIB. There is no greater need for this combined effort than in the EW supply chain.

The 2017 NSS makes a bold statement that nations like Russia and China are "[challenging] American power, influence, and interests."[87] One aspect of this challenge arises in the "Gray Zone" space, which lies just outside the threshold of armed conflict, where EMS attacks and espionage are the 'weapons' of choice.[88] To address this challenge and ensure that the U.S. is ready to bridge a transition between gray zone and enhanced conflict, the U.S. government and DIB must be prepared to leverage its advantages, to include the diversity of its supply chain, to include its relationships with allies and partners. Examples of current multi-nation acquisition programs, like the F-35 fighter, show the interconnectedness of the EW supply chain, which provides an enhanced surge and mobilization capability, but also increases the risks in meeting U.S. surge and mobilization needs.

Due to global outsourcing, the U.S. lacks full awareness, understanding, and end-to-end control over its EW supply chain, which puts at risk the security, survivability, and integrity of operational systems needed to mobilize. Viewed through the lens of the Cynefin framework, developed by management researcher David Snowden, mobilization is complicated and requires strategic leaders to synergize government, military, and civilian industrial base efforts in order to sense, analyze, and respond to supply chain issues in order to develop best practices for future problems. [89][90] The first step is to determine the health of the U.S. DIB.

Executive Order 13806 directed the DoD "to conduct a study evaluating the security and resiliency of the [DIB]." The study concluded that the U.S. DIB "is profitable overall," with the "Big Six" showing economic stability and growing market share.[91] However, a 2020 Industrial Capabilities Report To Congress highlighted the challenges the U.S. DIB faces when dealing with government contracts: "Conflict-driven procurements for [EMS] components make it difficult to maintain consistent and steady production demand. Steady demand enables industry to better plan for longer term stable production, negating the risk of the production line "going cold" (impacting readiness) and enabling greater surge capacity."[92]

The surge and mobilization challenges faced by the EW DIB demonstrate the need for a coordinated approach, to include the insights and guidance that a departmental EW lead could provide. However, while the EW DIB may be capable of meeting some of the increased industrial capacity needs demanded during surge periods—and notwithstanding the advantages an integrative change agent could provide—it faces continuing challenges to that capability as a result of ongoing instability in the area of semiconductor manufacturing.

Recommendations

As this study of the EW industry has illustrated, the U.S. is blessed with a robust ecosystem of organizations and firms dedicated to ensuring the U.S. achieves EMSO superiority in any future conflict. While that ecosystem certainly faces challenges, it also possesses great potential. To extract the maximum potential from this ecosystem, greater integration among the various nodes is needed. The overarching recommendation derived from the industry study is the need to establish a strong, empowered, central change agent to effectively integrate industry innovations and service EW efforts to produce a Joint EMSO capability. This recommendation is consistent with the established framework theories of how militaries innovate. The prominent theories (Posen's Civil-Military, Sapolsky's Inter-service Rivalry, or Rosen's Intra-service Rivalry) all share a common element in the need for a change agent to apply top-down, high-level pressure, to drive innovation.[93]

The establishment of a change agent can take many forms, and a careful analysis must take place before implementing statutory or regulatory changes. A comprehensive mission analysis of who this change agent should be, and how any supporting structures should be organized, while beyond the scope of this analysis of the EW industry, must occur. There are previous models worthy of consideration as DoD Senior leaders seek to establish a central integrator of the EMSO capability for the joint force. Previous joint efforts to integrate technology and warfighting capabilities, such as the Joint IED Defeat Organization or the Joint ISR Taskforce, bear examination for their applicability to the EMSO problem set. A promising model can be found in the department's approach to integration in another critical future technology – artificial intelligence (AI). The EMSO CFT should consider the efficacy of the Joint AI Center (JAIC) when drafting the implementation plan for the ESSS.[94]

To be effective, the change agent must be empowered. This will demand some direct influence over the individual services EW programs to achieve the level of joint integration the ESSS envisions. The control of resources is perhaps the most effective way to exert influence in the DoD. The Joint AI Center implementation plan again offers a method for consideration by the EMSO community. Enhanced authorities include, for example, the JAIC approval of service spending on AI projects in excess of $15 million.[95] Similar approval authority vested in an EMSO change agent would provide a means to ensure integration, open standards, interoperability, threat relevance, and deconfliction of redundant capabilities.

Although this analysis stops short of specifying who the empowered EMSO change agent should be, there are numerous recommendations on some priority actions that must be undertaken once they are established. The IS identified the following seven recommendations as its highest priority actions, however, a complete listing of recommendations gleaned from the submissions of the individual members of the IS can be found at Appendix H.

Recommended Priority Action 1: Increase investment in EMSO technology along with the infrastructure and capability to test and train with it.

In the Fiscal Year (FY) 2020 Industrial Capabilities Report to Congress, the OSD Office of Industrial Policy clearly stated the fiscal imperative: "if we are going to secure the future versus China, then far more investment is going to be required both by Federal authorities and the private sector."[96] Yet across the 93 program elements and 157 related projects associated with EW in the FY2021 budget request, funding was reduced by $104 million from FY2020, reducing EW research, development, testing and evaluation (RDT&E) funding from $5.6 billion in FY2020 to $5.5 billion in the FY2021 request.[97] RDT&E investment must be increased to ensure innovative technologies are developed. Additionally, a rebalancing of EW funding is in order. The Navy commands most EW funding while the OSD funding lines for modernization of infrastructure for training and testing are under resourced. The Test Resource Management Center (TRMC) concludes in the state of the Electronic Warfare Infrastructure Improvement Program (EWIIP) that the DoD infrastructure cannot support testing against advanced threats.[98] Additional RDT&E funding in the FY23-27 Fiscal Year Defense Program (FYDP) should be applied to the TRMC-identified test capability needs, ground facility and open-air range investments, data correlation between testing in each of EW test domains, realistic representation of existing and emerging threats, and improved distributed test capability.[99]

Recommended Priority Action 2: Drive a culture of embedded interoperability that begins with warfighting doctrine and establishes requirements for weapon system development.

Joint Force concepts derived from the ESSS should center on a layered aggregation of each service's EMSO capabilities to produce joint effects. In doing so, solutions to fill critical gaps may emerge; however, equal attention must be paid to the analysis of unnecessary redundancies and the removal of legacy concepts and models. In approving future EW system requirements, the JROC must force an un-waiverable interoperability requirement which includes data feeds that enable JADC2. Validated Capability Development Documents (CDDs) must also include key system attributes (KSAs) that drive EW systems towards more common and open standards for both hardware and software. Promising "one box with different cards" technologies exist throughout the EW industry.

Universal adoption by the services of this standard would serve to reduce cost, increase both prime and sub-prime industry contributions to innovation, and improve reliability.

Recommended Priority Action 3: Review trade barriers that burden effective EMSO integration with allies and partners and retard innovation through excessive export regulation.
Current export control restrictions limit our ability to effectively fight with allies and partners in the EMOE. This is especially true our closest allies, the "Five Eyes" partners (Canada, Australia, the United Kingdom (U.K.) and New Zealand), that will be essential to any effort to deter or defeat China. While the U.S. broadly shares highly classified intelligence with these partners, regulatory restrictions in the ITAR undercut needed synergies with the U.S.'s closest allies. The EW change agent must advocate for the selective relaxation of export controls for key partner nations within the National Technology Industrial Base (NTIB). As an initial change, Australia should immediately be afforded the broad exemptions from the licensing requirements under the EAR as Canada, given the Indo-Pacific focus of U.S National Security policy.[100] The breadth and complexity of sensitive defense export laws and regulations, while necessary to protect critical technologies, creates an environment where basic researchers are wary of engaging in the types of broad collaborations that fuel innovation for fear of unintentional violations. A more deliberate effort by government subject matter experts in export controls to facilitate training with industry and academic partners in the EW ecosystem is warranted. In support of this training effort, the designated change agent should initiate a thorough review of the specific critical technology worthy of heightened protection.

Recommended Priority Action 4: Reduce barriers to entry for new or smaller industry partners to the EW market and facilitate freedom of maneuver once they are in it.
The native complexity of EW technologies and the critical need to protect U.S. capabilities results in an industry that is capital intensive to enter and demands the strictest adherence to complex security protocols. Firms of various stages and sizes struggle to navigate both. EW technology development demands large infrastructure capacity and R&D. These firms have many innovative ideas yet do not have large cash reserves. The first concrete action would be to add EW technologies to the list of focus areas for both the DoD Trusted Capital fund and the Army Venture Capital Initiative, both of which could provide the necessary upfront funding.[101] Additionally, EW programs should review the structure of their contract vehicles and consider paying more upfront costs on R&D-type contracts to encourage startups to participate with the DoD. All firms involved in this IS expressed frustration with the complexity of navigating the necessary but burdensome security protocols surrounding EW technology. The DoD must also take a proactive approach to prioritize classified resource sharing. This includes everything from security clearances for critical sub-prime vendors to improved access to threat waveforms and sophisticated signal generators.[102] One method to overcome the security barrier would be the establishment of a joint EMSO lab. A physical laboratory, modeled after the Army PNT Open Innovation Lab (OIL), would serve as a secure facility where industry could access the physical hardware, open software standards, digital models, and latest threat data across the individual Services needed to develop EW solutions.[103] A joint EMSO lab would lower the barrier to entry for small and new EW solution providers and serve to both standardize and improve EW system development.

Recommended Priority Action 5: EMSO Superiority is a whole of government problem and will demand some national focus and deconfliction.

Clearly articulated executive branch responsibilities, especially in the area of commercial and military spectrum sharing is imperative.[104] As the commercial need for additional bandwidth and spectrum continues to increase, a balance will need to be negotiated to support economic interests while providing for military necessity.[105] Greater coordination and senior leader adjudication is necessary among the DoD CIO Office of Spectrum Policy, the FCC, and the National Telecommunications and Information Administration (NTIA) to effectively manage competing interests in the congested and constrained spectrum.[106]

Recommended Priority Action 6: The DoD must address its culture and incentives to both recruit and retain the requisite talent to achieve superiority in the contested, congested, and constrained EMOE.

Much has been authored in various defense strategies and policies about the criticality to our national security of a strong STEM skilled workforce. This is especially true in EMSO, where highly specialized skillsets in microelectronics development, fabrication, and packaging are in high demand, with a limited supply of trained and cleared personnel. While the DoD has a robust STEM outreach program that seeks to develop a "diverse and sustainable STEM talent pool ready to serve our Nation and evolve the Department of Defense's competitive edge," the DoD needs a more deliberate capture and retention effort.[107] Drawing the right STEM talent into the DoD EW mission space requires targeted outreach to holders of and candidates for advanced degrees through increased tuition assistance and/or student loan forgiveness for future enlisted, officer, and DoD civilian personnel.[108] Once these skilled EMSO personal are incorporated into the DoD, a strong retention effort is necessary to compete with similarly high demand from the commercial sector. The EW change agent should direct each service to implement a new Special Duty Assignment Pay (SDAP) and consider reclassification bonuses that would help build the EMSO force quickly to meet growing requirements.[109] No amount of financial compensation can overcome a culture that does not encourage innovation. The ESSS identifies the need "to create a long-lasting culture of innovation, empowerment, and improvement."[110] The strategy's pending implementation plan should demand each Service assign an EW champion to actively promote the desired culture. Strong consideration should be given to the DoD's development of culture promoting tools for EW professionals such as podcasts, virtual conferences, and training events.[111] These tools provide an avenue to remain updated on current EMS programs across and foster esprit-de-corps for EW professionals across the Joint Force.[112]

Recommended Priority Action 7: The EMSO change agent should advocate for legislative intervention to help break the service-oriented model and produce a truly integrated, joint EMSO capability.

Significant discussion in the EMSO mission space is directed toward the need for cohesive governance as a pre-requisite to achieve Joint effects and superiority. The GAO recently assessed the most glaring issue facing the department was "dispersed governance of the EMS" and identified eight separate entities within DoD who share disparate EMS responsibilities.[113] As the EMSO CFT recommends management, organizational, and operational reforms to the Sectary of Defense, it should advocate for specific EMSO directives in the next National Defense Authorization Act that would bolster future efforts.[114] The first legislative change should add the EMSO as a "covered mission area" under Sec. 855(b) of the 2017 NDAA that directs mission integration management and apply that designation to all EW programs irrespective of their acquisition category (ACAT).[115] This would enable the Under Secretary of Defense for Research and Engineering (USD (R&E)) to provide needed oversight and ensure both technical and mission joint interoperability. Congress should also emphasize and resource EMSO joint exercises. Earmarks to broaden and improve the virtual joint training environment would assist in ensuring joint readiness for a large force engagement while also concealing U.S. capabilities from adversary intelligence collection efforts.[116]

Conclusion

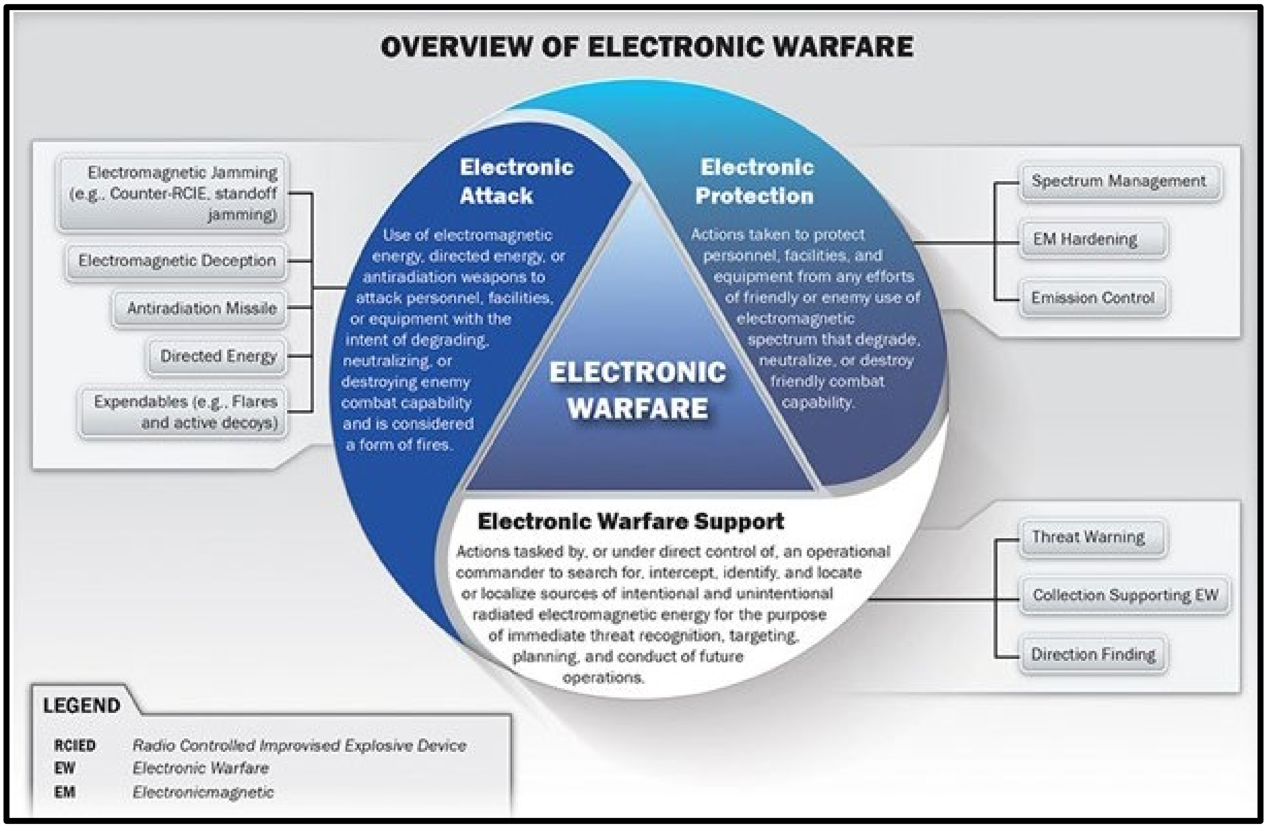
Repairing nearly thirty years of neglect in the EW arena will take time, effort, and resources. Challenges abound, spanning all aspects of DOTMLPF-P, as well as relationships between and among governmental agencies, industry, academia and the U.S.'s allies and partners. And while nearly everyone within DoD recognizes the significance of the task, the somewhat disjointed nature of the current Departmental response bodes ill for achieving the timely changes that are needed to forestall further decline in EMSO, relative to great power competitors China and Russia.

In forging an effective set of solutions to these challenges, the U.S. must first recognize that success will not occur without effective senior leadership capable of integrating efforts of all stakeholders across the entire EW enterprise. This includes the ability to implement enterprise-wide initiatives that will drive the change needed to close the EW gap with adversaries where the U.S. lags behind and expand the lead in those areas where the U.S. retains a dominant position. Essential to implementation is the capacity of this agent of change to direct resources, develop processes, share information and best practices, and establish and/or reinforce relationships that will be needed for the success of the enterprise.

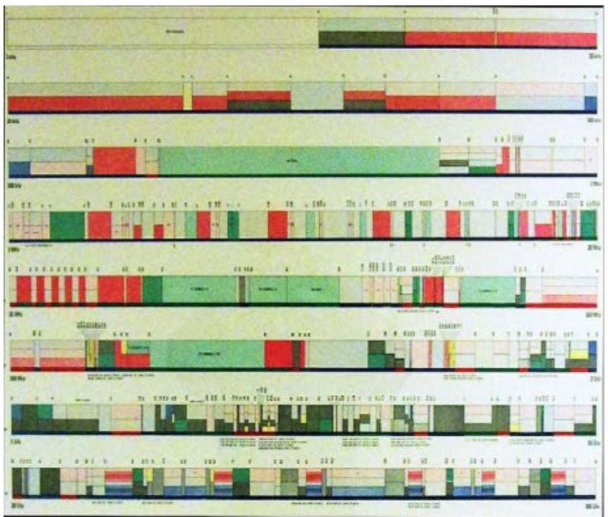
In moving forward with efforts to remedy its EW deficiencies and capitalize on its advantages in the EMS, the U.S. must also avoid the twin specters of inertia and hubris. Previous efforts to drive change in the EW arena have fallen short. In a 2021 Hudson Institute webinar, the co-chairs of the House of Representatives EW Caucus lamented the lack of implementation for previous strategies, published in 2013 [EMS] and 2017 [EW], as well as the lack of a single senior leader to manage the EMS enterprise, and called on Congress to force the issue.[117] In addition, the U.S. cannot assume that its advantages in innovation, its top-notch academic institutions, and its skilled workforce will be sufficient to regain EW dominance. Adversaries are also making great strides in these factors and seek to tilt the global competitive balance in their favor. The recent ransomware attack on a key CI sector demonstrates just how fragile elements of U.S. national power may be.

The time for change in managing the EW enterprise is upon us. We must rise to the occasion.

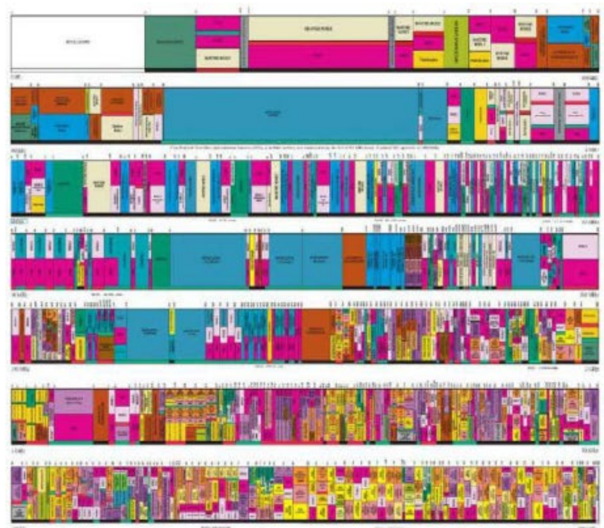
Appendix A: Overview of Electronic Warfare



Appendix B: Electromagnetic Spectrum Congestion



The Electromagnetic Spectrum, circa 1970



The Electromagnetic Spectrum, circa 2016

Appendix C: Industry Size, Structure, and Projected Emphasis[118]

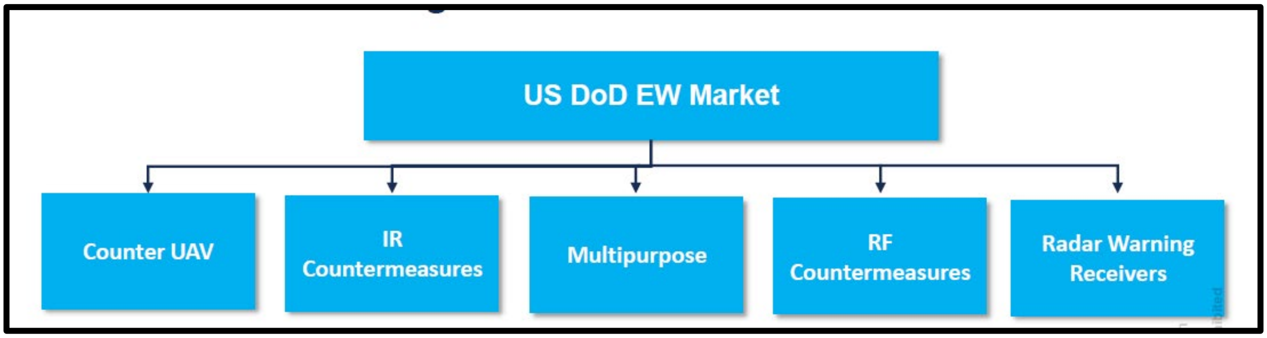


Figure C-1.

- $3+ billion market.
- Expected to grow 3% annually.
- 31 competitors; 90% of revenues captured by top 10 firms.
- All DoD military services show increased spending requests for 2021. The focus of RDT&E will be the airborne next-generation jammer and advanced radar warning receivers.
- EW procurement will focus primarily on shipboard EW systems, common infrared countermeasures, common missile warnings, torpedo defenses, and EW planning tools

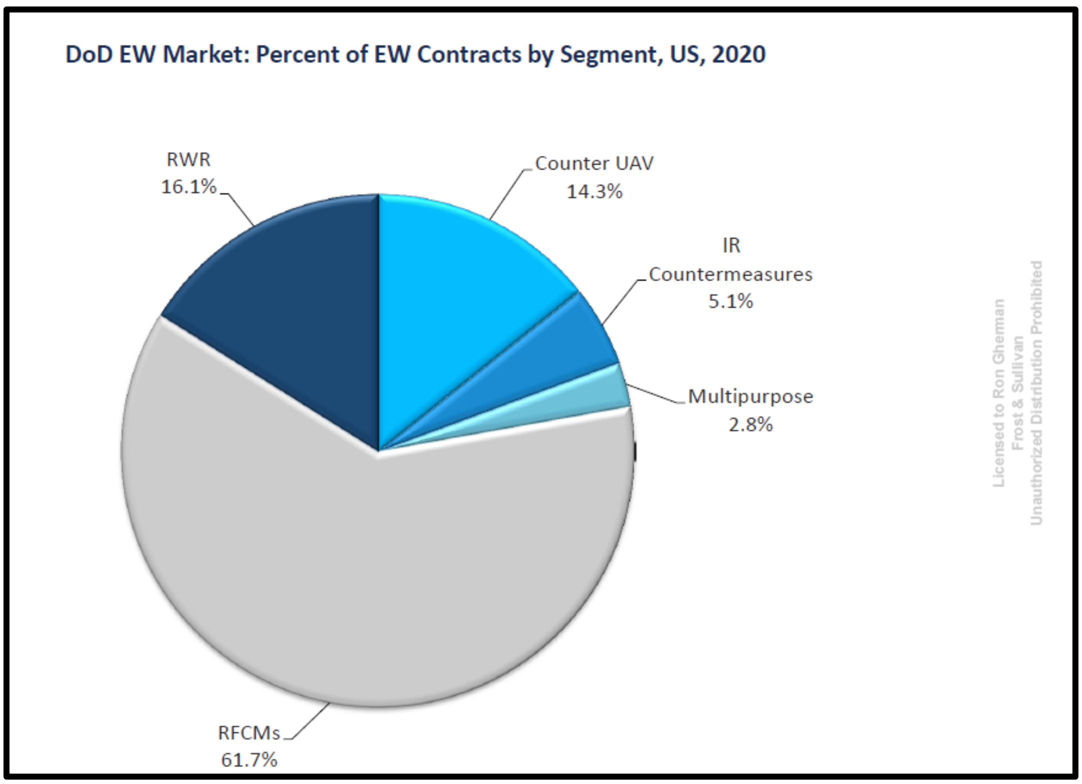


Figure C-2.

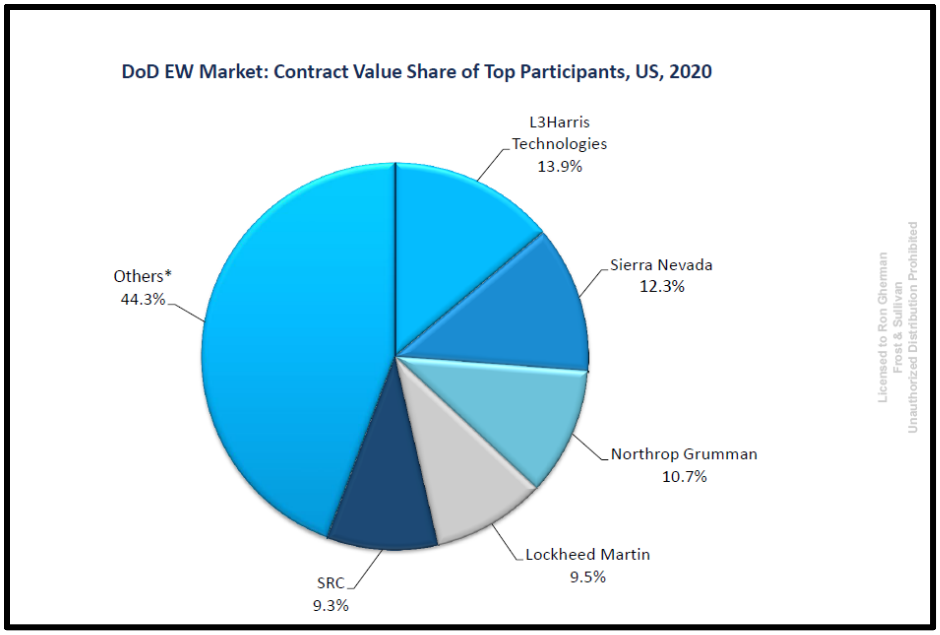


Figure C-3.

- Large systems integrators continue to dominate contract awards
- Non-competed contracts continue to gain ground- $3,690.9 million (63%)
- Firms tend to specialize- By Domain: Air- Sea- Ground- Space- Cyber
- And by Service: Navy (Air and Surface), USAF, USA &USMC

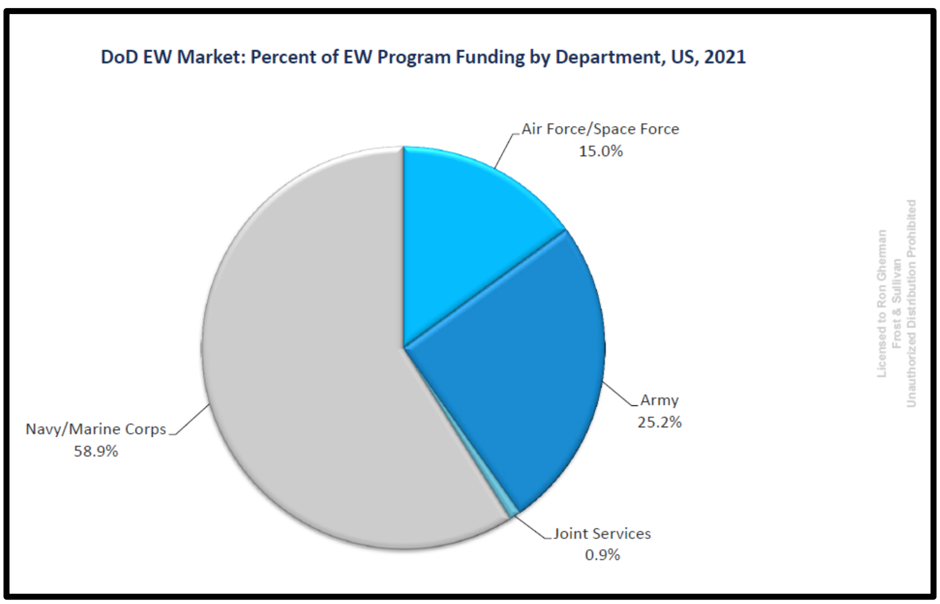


Figure C-4.

- The service budget parity "rule of one-thirds" does not apply to EW; USN has a disproportionally larger share of EW programs

Appendix D: Porter's Diamond

"Porter argues that any company's ability to compete in the international arena is based mainly on an interrelated set of location advantages that certain industries in different nations possess…. If these conditions are favorable, it forces domestic companies to continuously innovate and upgrade. The competitiveness that will result from this, is helpful and even necessary when going internationally and battling the world's largest competitors."[119]

Figure D-1 illustrates the factors identified by Porter in framing his diamond model, noting that in addition to location and competitive business factors, the role of governments also plays a significant role in shaping a business's (or industry's) competitive advantage.

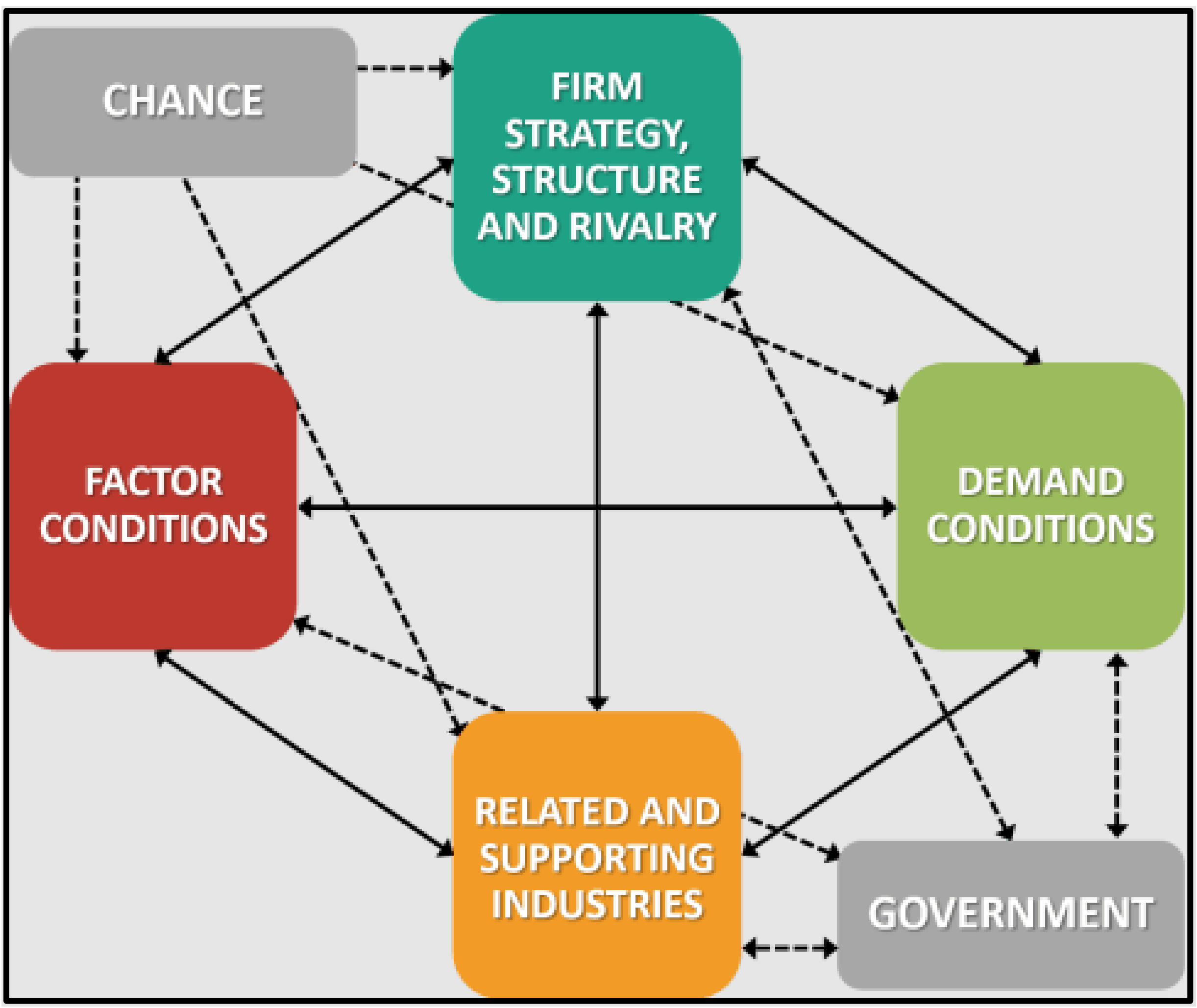


Figure D-1.

Appendix E: Porter's Five Forces

Porter's five forces "determine an industry structure and the level of competition in that industry."[120] Stronger competitive forces in the industry renders a firm less profitable.

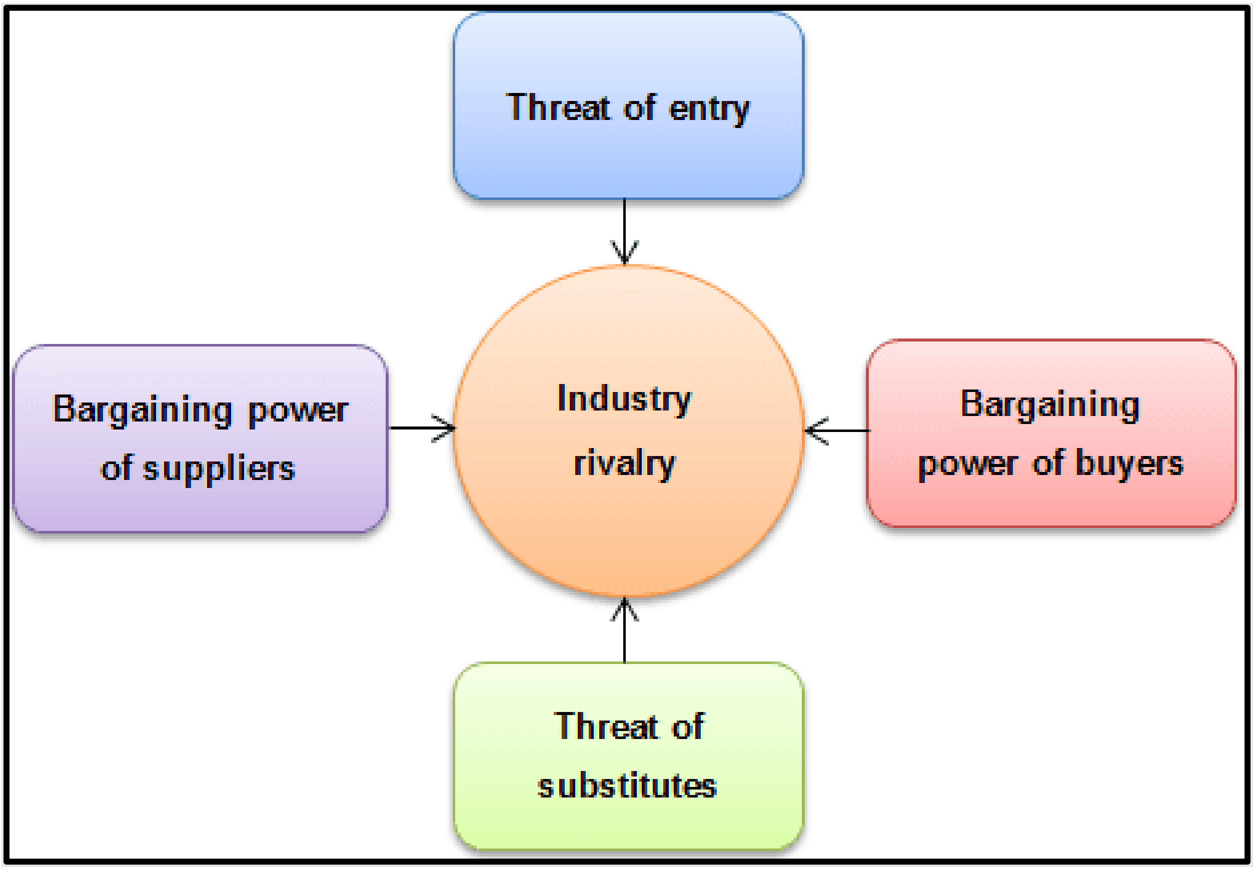


Figure E-1.

Appendix F: Essays Regarding Significant Issues in EW

Essay 1: Innovation in the Quantum Age

We are on the verge of a quantum telecommunications transformation. While quantum information science (QIS) has promised paradigm-changing breakthroughs for well over a decade, quantum radio (QR) is finally on the cusp of revolutionizing our use of the EMS in military and civil applications. Arriving more slowly than desired but holding the potential for even more transformative effects than expected, these revolutionary systems are finally emerging from the realm of the theoretically possible, and into laboratory testing and experimentation, with full-scale production of deployable models on the horizon. While QR systems are currently too big and power-hungry to be deployable on current platforms, they could have initial utility at fixed sites and await, as we have seen repeatedly, commercialization of related systems that will enable them to shrink with continued development.

U.S. companies are in the midst of that commercialization. Articles have shifted from the gloom of two years ago to the seeming inevitability of U.S. commercialization of QIS. In his article in *Forbes*, "Quantum's Road to Commercialization," Jeremy Hilton writes, "The shift from prototype to commercialization has been a historical 'make or break' moment for many emerging technologies. Innovations either pass through this inflection point unscathed or fall victim to a combination of overhyped promises and immature tech."[121] Quantum computers, clocks, radio, and remote sensing are all in early stages of adaptation and commercialization, the success of which will drive other factors in the industry. As noted in the Porter's Diamond model, government can, and often does, serve as a catalyst in bolstering the development of an industry. With respect to QIS, the U.S. government not only provides funding to continue R&D, but also provide funding to academic institutions to educate a QIS literate workforce industry will need in the coming decades.

Just because we develop QR here doesn't mean that we will produce it here. "The devil is in the details of fielding such technology."[122] American history is replete with tales of technologies developed here and commercialized elsewhere—the most famous being transistors and the integrated circuit. The inverse is also true. Exactly how far along, how well developed is the coming quantum revolution? Is it a revolution or another bubble? How concerned should the U.S. Government be in developing industrial policy regarding the quantum revolution? In an insightful article, Rhea Moutafis of the Sorbonne University asks, "Will We See a Quantum Computing Revolution?" While her article's title specifically refers to quantum computing, her answer, "As a trained physicist, I have no doubt that quantum is the future, but it might be too early to invest in it in these early stages,"[123] is broadly applicable to other aspects of QIS, and precisely identifies where government can step in to nurture a nascent technological ecosystem.

From a developmental perspective, it doesn't matter how far we progress in advancing the field if the regulatory environment doesn't support the capability. For example, it seems theoretically possible to allocate band usage to smaller, more tightly focused segments of the spectrum using QR. While greater sensitivity of radio receivers provides the opportunity for slicing the spectrum into tighter bands and novel off-band uses may increase the golden zone of the spectrum, it will ultimately be the responsiveness of the regulatory framework that determines the commercialization success of the coming quantum revolution. However, the regulatory system to support these actions is often slower than the development of the technology itself. While the transition from analog to digital television provides an excellent example of how long the regulatory process can be, it also proved to be precedent-setting, with subsequent actions taking less time and recouping greater funds for the treasury. The regulatory agencies making spectrum allocations must consider the implications of greater sensitivity from QR in their future spectrum allocation decisions, and swiftly take actions to ensure the U.S. remains competitive.

Our most likely potential adversaries take this revolution seriously, hoping for a decisive advantage by leapfrogging current capability. Quantum Radio has the potential to revolutionize our use of the electromagnetic spectrum and must be seriously considered in any plans for future systems production. As we are at the bow-wave of miniaturization and commercialization of QR, with the fruits of that revolution yet to be fully realized, to include its impact on issues such as the current crowding within the EMS, we must make sure that we do not continue to invest in dead-end technologies, ignoring the revolutionary change that is happening now.

Finally, although there is minimal English language reporting on either Russian or Chinese QR efforts, there are signs that both nations are taking this area of quantum physics research seriously. Although they appear to be following different technical solutions, they both see the potential for revolutionary developments within the field.

CHINA: In his book, *The Hundred-Year Marathon*, Michael Pillsbury uses lessons from the Warring States period of Chinese history to explain their asymmetric approach to challenging the U.S., seen by China as the global hegemon. In the scenario of a rising power attempting to confront the hegemon, the underdog must mask their true power while either bankrupting their opponent or maneuvering to bring the hegemon to a battlefield of their choosing. He says -

> Instead of trying to match America plane for plane and ship for ship, China has invested heavily in asymmetric systems designed to get the biggest bang for the buck. The Chinese have pioneered antisatellite technology, developed the means to counter stealth bombers, invested heavily in cyber intrusion, and built missiles costing a few million dollars that can sink a $4 billion American aircraft carrier.[124]

The Chinese approach to QR fits neatly into this paradigm. In his article "Where Quantum Satellites Fit in PLA Strategy," Michael Raska of the Australian Lowy Institute explains that with their terrestrial quantum communications backbone and Micius quantum communications satellite experiments, the Chinese are attempting to leapfrog over the whole electromagnetic spectrum.[125] Success with these efforts would enable the Chinese to sidestep the main thrust of the U.S.'s current EW efforts, while at the same time providing the secure communications necessary to prevail in a modern conflict.

RUSSIA: The Russians are taking QR seriously as well. The National Research Institute at the Moscow Institute of Physics and Technology even has a degree specifically in QR Physics.[126] They also have an active and current scientific journal dedicated to "Radio Physics and Quantum Electronics" sponsored by the Institute of Applied Physics of the Russian Academy of Sciences.[127] Although the approaches are different, the Americans[128] and the Russians appear to be researching the THz area of the EMS as useable communications space. The Russian effort focuses on the unique effects of quantum tunneling in graphene to make sensors orders of magnitude more sensitive than current devices.[129]

Essay 2: Supply Chain Challenges
Semiconductors are the lifeblood of today's technologically oriented society. Media coverage of the inability of large U.S. automakers to produce automobiles at the rate demanded by U.S. consumers has highlighted the current shortage of semiconductors as the principal culprit. Moreover, the matter is not merely an automobile concern. Semiconductors are tiny operating brains inside nearly all modern devices, from smart phones and defense weapon systems. The pandemic has sent chip demand soaring unexpectedly for everyday commercial items, but it has also underscored a national security gap in homegrown semiconductor production. Despite the demand for semiconductors, and notwithstanding IBM's recent development of a 2nm microchip, U.S. advances in semiconductor fabrication is slowing and rapidly becoming dated.

Currently, 75% of semiconductor manufacturing occurs in Asia. This represents a substantial change from 25 years ago, when the United States was producing 37% of the world's semiconductors. Today, U.S. semiconductor production accounts for just 12% of the world's total and – at least until the IBM chip reaches production capacity – is third in chip size and capability. Taiwan, specifically the Taiwan Semiconductor Manufacturing Company (TSMC), produces the world's most advanced chips, which are 30% faster and more powerful than the U.S.'s largest semiconductor producer, Intel Corp.

Intel Corporation is the largest U.S. semiconductor manufacturer, operating some of the most advanced production plants in the nation. However, even Intel's CEO has acknowledged critical shortfalls in chip production capacity as well as capability. To make up for these shortfalls, Intel wants to increase its production capacity and is seeking changes to government policies and resourcing to increase advanced semiconductor production. While Intel is looking to double the size of its current chip production within the next decade, it plans to tandem that long term approach with a continued focus on current critical manufacturing shortfalls in the automotive and defense production industries. Moreover, given heightened Sino-U.S tensions, a shift toward trusted domestic sources for advanced semiconductor fabrication mitigates a portion of the risk inherent in relying upon TSMC for those components.

In contrast to the efforts of TSMC and Intel, China's attempts to develop its own advanced chip industry have, to date, largely failed, and it has become increasingly reliant on imported chips to meet the soaring demands for semiconductors from its technology sector, particularly in the growing cities surrounding Shenzhen – China's Silicon Valley. This reliance poses risks for both Taiwan and the West—not that China will seek to leverage its economic muscle to secure other sources for chips, but that China will make good on its historic "One China" posture and invade Taiwan to gain control of TSMC and the Taiwanese chip industry.

China's President, Xi Jinping, has intensified his long-time threat to seize Taiwan, a strategic move that Beijing sees as critical to securing its regional position and control. Moreover, recent belligerent action by the PLA, including naval and air force intrusions into Taiwanese air space and claimed coastal waters, highlight the fragility of TSMC as a global source for microchips. As global demand for advanced semiconductors continues to rise, an invasion or other successful coercive initiative (perhaps a series of gray zone activities) that allowed China to seize control of the Taiwanese semiconductor industry would provide Beijing with a strategic advantage over the Washington and other Western nations.

That said, Taiwan and TSMC also maintain strategic options, potentially mitigating a portion of that security risk. TSMC has announced the development of fabrication plants in the U.S., sending a message to Beijing that Taiwan holds security advantages of its own. In addition, increased diplomatic engagement with the U.S. designed to bolster U.S. policy against a forced unification of Taiwan under Beijing rule could result in a U.S. military defense of Taiwan in which no one benefits. But while some argue that the chip business today is what keeps Taiwan safe from invasion, it does not keep Beijing from leveraging other tactics—espionage, trade sanctions, intellectual property theft, political subversion—to potentially coopt or gain control of TSMC's and Taiwan's fabrication processing capabilities.

Instability in the semiconductor market directly impacts global weapons development, to include EW systems. Advanced manufacturing is leading great power competitors and other toward the creation of a new generation of smaller, smarter, and cheaper weapons. However, these systems, which continue to increase in complexity and technological innovation, almost invariably rely on semiconductors to achieve their affects. In addition to this new breed of weapons systems, the U.S. and Russia continue to pursue exquisite, high-end systems such as fifth-generation fighters, heavy bombers, and aircraft carriers. These too rely on microchips, perhaps even more so, as systems such as the F-35 incorporate an almost bewildering number of electronic subsystems, such as jammers, radars, and other sensors.

As manufacturing continues to rapidly change in the era of GPC, a key question arises: will shortages in the semiconductor sector accelerate deglobalization? If so, and the U.S. embraces the impulse to "re-shore" semiconductor and other manufacturing, how can the U.S. sustain necessary partner capacity, as it pursues additive manufacturing efforts while imposing increased security protocols on its production activities? The U.S. is concerned, and rightly so, regarding its partners' abilities to produce semiconductors and other technologically oriented products the U.S. currently needs to support economic and military growth. However, without a path for accelerating domestic manufacturing, as COVID-19 demonstrated, the U.S. will move at its competitors' desired pace, putting the U.S. at an operational disadvantage.[130]

Essay 3: Directed Energy (High Energy Laser)

From 1947 to 1991, the Cold War reigned supreme as the global "status quo" with nuclear destruction as the sine qua non for its end. High energy laser/directed energy (HEL/DE) weapons were seen by the U.S. as an offensive weapon that could change the status quo, providing the means to shoot down Soviet nuclear missiles while still in orbit, and just before reentry. Utilizing EM wavelengths from the ultraviolet to the infrared regions of the spectrum, defense scientists envisioned lasers in space performing this task, an undertaking as complex at its inception as sending a person to the moon would be at the launch of Sputnik in 1957.[131] However, as enticing a vision of this capability might be, early laser technology was based primarily on chemical reactions and neutral particle beam accelerators which, according to a 1987 American Physical Society report, were one or two orders of magnitude lower in power output than what was mathematically necessary for a destructive beam emittance.[132]

The limited power output available from then extant technology meant limited (approaching zero) viability for a working HEL/DE weapon; hence, early attempts by the U.S. to develop such technology into weapons would remain in the realm of science fiction. The overall cost of the program, when it was canceled in 1993, was thirty billion dollars (over $55 billion in today's dollars). Given this low return on [government] investment, politicians raised objections to the costs associated with the continued exploration of HEL/DE as a viable weapons system, noting what they viewed as the immaturity of the underlying technology. However, in their 1987 report, members of the American Physical Society stated that given enough time, HEL/DE R&D would mature to a point capable of producing a feasible HEL/DE weapon.

More than two decades later, developments in technology have proven them correct. As HEL/DE R&D advanced, DoD programs like the Navy's Laser Weapon System (LaWS)—an active program of record, and the DoD's first ever laser weapon system approved for operational use—provide proof positive that HEL/DE weapons no longer reside only in science fiction books and films.[133]

The miniaturization of key components of HEL/DE weapon systems made their use on board ships and tactical vehicles feasible while still maintaining the required optimal EM output to detect, disrupt, and destroy threats to the fleet and ground forces. Reducing the size, weight, and power (SWaP) of optical refraction and batteries enables the increase, by an order of magnitude, the power needed for an effective, efficient destructive EM beam.[134] The Army's Tactical HEL system shows how the reduction in size requirements of components has lowered the costs associated with HEL/DE weapon technology by altering and reducing the attendant support equipment and personnel needed to run, operate, and maintain it.[135] A key enabler in advancing U.S. HEL/DE weapon system technology beyond its current programmatic parameters comes from the DIB and its ability to operationalize science & technology (S&T) by coordinating efforts between and among the DoD, academia, and the various government research labs.

Large DIB companies like Raytheon, Northrop Grumman, and Lockheed Martin, continue to work with the U.S. government and the DoD on advancing HEL/DE weapons technology. However, the DIB faces challenges that make continued HEL/DE weapons R&D less attractive. The cost of building "one off" systems, which may lack any commercial use, disproportionately places the risks and related cost on the DIB, rather than the government. In interviews with several large and small U.S. DIB companies, a clear picture emerged that commercial EW industry partners desire more direct government involvement, via procurement dollars and policy changes, to keep the U.S. DIB incentivized in continuing HEL/DE weapon R&D.

This realization is critical, because just as the U.S. has made significant R&D and operational advancements in HEL/DE weapons, so too have Russia and China. The U.S. does not enjoy a monopoly on DE weapons development; its GPC adversaries have well-established HEL/DE weapons ecosystems that, in some cases, are on par or even surpass those under development by DoD.[136] The following recommendations require an innovative look at how America, as a whole-of-government, engages, mobilizes, and incentivizes its DIB ecosystem within the HEL weapons development line-of-effort, as well as the leadership needed to move from following the "as is" to leading the "to be" in HEL/DE weapons technology:

#1 - Reduce barriers to entry into the DoD acquisition system. U.S. acquisitions "is a large and complex enterprise" that has evolved over time and has "a tendency to add rules but not take them away."[137] Regulations that favor economy of scale or capital requirements, such as large infrastructure capacity and Research and Development (R&D) outlays, should take into account the size of a company vice a "one size fits all" approach. Although large U.S. DIB companies are actively performing R&D into HEL/DE weapons, more may be accomplished if an ecosystem of smaller companies were able participate, on their own, like a "prime" contractor. There are, however, risks and opportunities associated with this approach. The government assumes a higher level of risk on advanced technology that may or may not fail while in the development stage. This may pose too large a risk for Congress to take when managing the public's money. If coordinated and articulated properly, these risks may also be viewed as key opportunities. Failing fast and early may reduce long-term costs typically associated with "new technology" that is pressed into tight requirements as shown in previous large, CAT I, acquisition endeavors.[138] If "failing" is spread across a large, more diverse pool of large and small companies within a DIB ecosystem, then the multiple decades it took to move from the SDI/"Star Wars" program to the current HEL DE technology may be reduced to a single DoD Five Year Development Plan (FYDP).

#2 - Incentivizing DIB startup companies to work with the DoD. Startups, like Anduril Industries, a small defense company, are often best positioned to "solve a lot of these defense problems [but] are refusing to work on them."[139] However, they frequently lack the cash reserves to continue their advancements in technology. Government procurement contracts typically disburse incremental payments, either periodically, or as a system successfully transitions from one developmental milestone to the next. This approach may work for larger DIB companies whose resources enable them to continue operations while awaiting payment for millions or billions of dollars in contractual backlog. However, most DIB startup companies, especially those not backed by investment groups, do not have large cash reserves. By paying more upfront costs on R&D-type contracts, the U.S. government would revitalize the startup ecosystem and encourage its participation with the DoD. Additionally, allowing startups to actively partner with and utilize government R&D facilities, labs, and ranges, at significantly reduced costs, would provide access to best equipment and while reducing costly overhead. I adopting this recommendation, the DoD would embrace some degree of risk. Return on investment (ROI) may be low if startups receive more cash up-front, but do not deliver as expected. However, even if the ROI remained low, the lessons-learned and intellectual property garnered through shared access would "pay it forward" for future advanced technologies and close the gap between concept development and acquisition procurement. Both recommendations impose more risks on the government, risks that some lawmakers are hesitant to take.

The 2017 NSS makes a bold statement that nations like China and Russia actively seek to challenge "American power, influence, and interests."[140] This challenge takes the form of low-level conflicts, in the "Gray Zone" space, which lies just outside the threshold of total war, where low "cost-per-shot" swarms of drones are the weapons of choice.[141] Shifting U.S. policy towards lowering the cost-per-shot ratio of future military weapons does not exclude continued HEL/DE R&D or weapons procurement as the current technology possesses the potential of meeting or exceeding the requisite lower ratio thresholds. Given these factors, DoD should continue to pursue further research into HEL/DE weapons, as related threats change and mature over time, and adversaries become more emboldened in their use.

Essay 4: Human Capital Considerations

The 2017 National Security Strategy identifies the importance of growing and retaining STEM professionals, along with a renewed focus on ensuring the U.S. maintains an industrial manufacturing workforce of skilled laborers as a national priority.[142] "A healthy defense industrial base is a critical element of U.S. power. The ability of the military to surge in response to an emergency depends on the nation's ability to produce needed parts and systems, healthy and secure supply chains, and a skilled U.S. workforce."[143]

The health of the EW workforce impacts the innovative capability of the EW industry and future military capability. The following section discusses EW human capital in the military and in industry starting with top-down guidance from National Security Strategy. The DoD must prioritize human capital initiatives that focus on EW training, recruitment, and retention to encourage growth and innovation in EW. Moreover, STEM investment now is essential to safeguarding the human capital necessary to fill future capability gaps in the EW workforce and the larger defense sector.

Current literature on the U.S. workforce suggests numerous critical labor shortages in the lower-skilled, blue-collar labor force and higher-skilled STEM careers, specifically in software development. In a report published by The Conference Board, a non-profit organization dedicated to addressing business challenges, the authors report an extreme downward trend in labor market conditions, resulting in a future workforce that is insufficient to meet projected needs. This insight is especially alarming as it reveals a labor shortage under nominal, peacetime conditions. The report attributes decreased labor supply to several long-term trends, including: a decrease in working-age population growth due to the retirement of "baby boomers;" a decrease in the working-age population of noncollege graduates; an increase in disability rates; and finally, a large drop in labor force participation for young men between 16-24 years of age coupled with a trend that young men without a college degree are less likely to be in the labor force.[144] It is also significant to note that these trends predate the 2020 COVID-19 pandemic. Forecasters and decision-makers will need to assess the pandemic's impact on the U.S. workforce to understand how the events of 2020 will either exacerbate current labor force trends or alleviate pressure on a potentially tight labor market.[145]

Notwithstanding current demographic and participation trends, DoD retains a vested interest in maintaining a robust and innovative workforce capable of transformative technical advances and applying those advancements to further workforce productivity. In meeting these objectives, personnel will require a strong foundation in STEM expertise.[146] The NSS explicitly highlights the necessity of investing in STEM education and the defense of the National Security Innovation Base as critical to America's competitive advantage, security, and prosperity.[147]

Currently, the national STEM strategy, "Charting a Course for Success: America's Strategy for STEM education," provides a vision and selective pathways to incentivize students, increase diversity in STEM, and further STEM collaboration throughout America. The next crucial step, however, requires the translation of that vision into action, furthering STEM investment and creating the national workforce that can affect positive change in the military and industry EW environment of the future.

The services face significant human capital challenges in the ability to build and retain the EMSO force of the future. These highly technical career fields require an innovative talent management approach to recruit and retain quality specialists, technicians, and engineers. For example, the Army's current strength for enlisted Electronic Warfare Specialists according to Human Resources Command is the following: 17E (Electronic Warfare Specialist) – 824 authorized and 755 On Hand (92%) with projected On Hand of 634 (77%) by FY22.[148] The projected loss of these technical subject matter experts is primarily due to lucrative contractor positions within the industry—a good news story because this talent is retained in the relevant defense industry, but a challenge for military professional retention. Industry is not without similar human capital challenges as well. One challenge for the defense industry is the draw of talent away from defense (government) to more lucrative commercial careers in social media and application building. Young talent is enticed with the prospect of building something now, selling it, and making a quick fortune. To offset this trend, defense leaders must improve recruitment efforts targeting a generation of talent unfamiliar with the defense industry, confidently sharing the importance of their products to U.S. national security, and the role they could play in supporting that vital effort. In addition to recruiting new talent, defense leaders must also establish targeted professional development and human capital retention strategies, critical to building EW professionals and the EMSO workforce.

DoD and industry must also take an even longer view of workforce development and sustainment, planting the seeds of the next generation of STEM leaders as an essential first step. DoD and industry leader must seize opportunities to invest in education at all levels in the United States, piquing interest at the elementary and middle school levels, and incentivizing continued interest, engagement, and recruitment of STEM students at the high school and collegiate levels through scholarship and internship programs. U.S. government leadership must be unified in shaping a human capital strategy that incentivizes career paths to fill future gaps in the workforce, to include a more robust focus on the EMS and EW, and create the necessary milestones for a healthy, reliable U.S. EW workforce.

The military services, as a major 'consumer' of EW talent must adopt three major steps to address these challenges and meet the requirements of the future. First, the services need to implement an EW retention program. Modeled after programs within the DHS, the service-wide Special Duty Assignment Pay (SDAP) program needs to be overhauled. The services currently pay SDAP 2/3/4 to any servicemember meeting the service determined requirements.[149] The current SDAP rates include SDAP-1 ($75 per month), SDAP-2 ($150 per month), and SDAP-3 ($225), which are inadequate to financially reward these specialists.[150] A more appropriate level of compensation for the skills the services seek to retain would require modifications to current policies to increase SDAP for EW officers, enlisted specialists and DoD civilian employees. A flat monthly bonus of 15-25% of base pay, based on skill level (SDAP 1 at 15% of base pay, SDAP 2 at 20% and SDAP 3 at 25%) would change the fiscal calculus for most DoD personnel, providing a powerful incentive for them to continue their contributions to national defense. For example, an E3 with three years of experience would receive SDAP-1 (15%) resulting in payment of an additional $345 per month. An E8 with 20 years of service at SDAP 3 (25%) would receive an additional $1385 per month.[151] This approach mirrors the DHS's Cyber Pay Retention Program. Although this financial incentive may not completely offset what these specialists could make with industry, it will assist the services in recruiting and retaining personnel who are critical to the future EMSO fight.

Second, the services must expand targeted outreach of advanced degrees through increased tuition assistance for enlisted, officer, and DoD civilian personnel. Many service members want to preserve their Post 9/11 GI Bill benefits for their dependents. By targeting individuals who want to pursue advanced degrees supporting EMSO, DoD can help further develop a workforce capable of outpacing technological changes. Finally, adding a reclassification bonus to entice servicemembers from other specialties to join the EMSO cadre would help build the EMSO force quickly (in under 5 years) enabling the services to meet growing EW requirements. For example, as previously noted, the Army EW MOS (17E) is facing significant shortfalls in the coming years, and a reclassification bonus could serve to quickly bolster their ranks. These three major changes to DoD policy will enable the recruitment and retention of the technical specialists required to dominate the EMSO in future conflicts.

Appendix G: U.S. Critical Infrastructure Sectors

Sector	U.S. Government Lead
Chemical Sector	Department of Homeland Security
Commercial Facilities Sector	Department of Homeland Security
Communications Sector	Department of Homeland Security
Critical Manufacturing Sector	Department of Homeland Security
Dams Sector	Department of Homeland Security
Defense Industrial Base Sector	Department of Defense
Emergency Services Sector	Department of Homeland Security
Energy Sector	Department of Energy
Financial Services Sector	Department of the Treasury
Food and Agriculture Sector	Department of Agriculture and the Department of Health and Human Services
Government Facilities Sector	Department of Homeland Security and the General Services Administration
Healthcare and Public Health Sector	Department of Health and Human Services
Information Technology Sector	Department of Homeland Security
Nuclear Reactors, Materials, and Waste Sector	Department of Homeland Security
Transportation Systems Sector	Department of Homeland Security and the Department of Transportation
Water and Wastewater Systems Sector	Environmental Protection Agency

Appendix H: Consolidated Recommendations Contained in IS Individual Papers

Pursuant to course work during the Academic Year 2020-2021 at National Defense University's Dwight D. Eisenhower School for National Security and Resource Strategy, fifteen students in the Electronic Warfare Industry Study authored individual Industry Study issue papers. These papers covered various topics relevant to the EMSO space with a focus on industry impacts and government policy. While only abbreviated versions of select individual papers have been included in this report in Appendix F, all the individual research produced insightful recommendations that are worthy of consideration by senior leaders as they shape and execute the ESSS Implementation Plan.

A consolidated listing of EMSO related recommendations follows, categorized by: General Policy; Fiscal; Material and Technology; STEM and Human Capital; Doctrine and Force Structure; Training; and Governance, Legislation, and Acquisition Reform. Readers who desire more information or insight into the research supporting a recommendation of interest may contact the individual author (listed in parentheses following the recommendations) at the email address listed at the end of this Appendix.

General Policy Recommendations

1. The U.S. needs a microelectronics strategy that includes a comprehensive, multi-faceted package of policy solutions to reassert the U.S. position in this industry. A more thoughtful, organized approach with clearly articulated executive branch responsibilities is imperative. (Callow)
2. The DoD should stress a layered and decisive framework to move the Joint Warfighters into an EMS postured force, stay ahead of relevant offsets, and increase readiness. (Caplin)
3. Export laws and regulations protecting U.S. EW capabilities require revision to more effectively address threats from adversaries, relationships with partners, and an increasingly complex global technological environment. (Danner)
4. Prioritize and fund shared spectrum initiatives. As the commercial need for additional bandwidth and spectrum continues to increase, a balance will need to be negotiated to support economic interests while providing for military necessity. (Wright)
5. Allow startups to actively partner with and utilize government R&D facilities, labs, and ranges, at significantly reduced costs. This would provide access to best equipment and reduce costly overhead. (Westphall)
6. The Secretary of Defense should expand the scope of DoDI 5000.88 and direct Mission Engineering to be applied to all EW programs irrespective of ACAT and establish the EW Executive Committee (EW EXCOM) co-chaired by the USD (R&E) and the VCJCS as the approving body for all EW system engineering plans (SEPs). This will serve as a forcing function to ensure that the benefits of ME are applied to the formal DoD acquisition process for all EW systems and ensure ME actives are adequately resourced. (Strauss)
7. The DoD should establish an EMSO Center of Excellence that would serve to validate the foundational Joint mission threads for ME activities, and both integrate and curate the EMOE data required for models and simulations. (Strauss)

8. The DoD needs to set policies that balance defense industry concerns with exposing their intellectual property with the requirements of a global system-of-systems. (Herron)
9. The services must increase engagement and work with industry and academia to maintain EMS advantage. (Pitman)
10. While progress has been made, the services must increase the pace, and eliminate inefficient processes to refocus resources and personnel toward creating the experts and capabilities needed to maintain EMS superiority. (Pitman)
11. The DoD must prioritize classified resource sharing. This includes everything from security clearances for critical sub-prime vendors to improved access to threat waveforms and sophisticated signal generators. (Roa)
12. The DoD's EMSO Implementation plan must be a balance of sustaining innovation and disruptive innovation as both are required for enduring military innovation. (Roa)
13. The EMSO CFT, should revisit the ESSS with the DIB in mind. Considerations should include leveraging the DIB's strengths to include domain expertise and innovative capacity and talent in concept and solution development. Likewise, the revisit should consider options for mitigating industry's most burdensome risks and shortcomings in the market, such as subcontractor and supplier constraints and concerns and uncertainty in defense spending. (Webb)
14. Rather than pursuing a solution for every capability gap, the ESSS should instead prioritize critical needs and provide industry with an actionable vector for internal research and development. (Webb)
15. The U.S. must continue to nurture and strengthen relationships with its allies, and a key aspect of those partnerships should be the protection of Intellectual Property. (Callow)
16. Protection of intellectual property (IP) must also be addressed in the microelectronics policy package. The U.S. government should continue to publicly market all aspects of the Chinese Communist Party's (CCP's) IP theft strategy to ensure that U.S. firms have insight into how they should protect themselves from this vulnerability. In addition, firms that reside outside of the U.S. should be considered key foreign partners, and the U.S. government needs to ensure that these partners are aligned with U.S. interests about China. (Callow)

Fiscal Recommendations

17. A package of subsidies for the construction of fabrication and assembly, testing and packaging (ATP) facilities along with tax incentives aimed at retention over the long term are desperately needed to attract semiconductor investment and retain market share in the future. These incentives should be granted to all firms, not just U.S. firms, to encourage on-shore fabrication and ATP migration as soon as possible, which would mitigate the potential supply threat posed by a Chinese invasion of Taiwan. (Callow)
18. If spectrum dominance is a priority, and the need to develop expertise is key to that dominance, the department should consider significant realignment of funding to support regaining our technology advantage. This is highlighted in the Fiscal Year 2020 Industrial Capabilities Report to Congress: The bottom line is: if we are going to secure the future

versus China, then far more investment is going to be required both by Federal authorities and the private sector. That includes funding to ensure that research, development, and resulting products are safe and secure from adversary influence and manipulation. (Wright)

19. To effectively prepare to win in the Pacific against China, the USMC must be equipped with offensive and defense EMSO technologies. Long-term commitment to the Futures Years Defense Plan (FYDP) is challenging. Therefore, to avoid wasteful and avoidable costs across several platforms, the capability should platform agnostic. (Feltham)
20. Sufficient funds must be applied to the National Quantum Initiative intended to ensure that we build these new technologies at home. (Hagadorn)
21. The Office of the Secretary of Defense must earmark EW resources and push prioritization of EMS capabilities, training, and equipment down to the services. (Pitman)

Material and Technology Recommendations

22. The Joint Force should focus procurement and acquisition on cheaper, scalable, and expendable EW systems vice extensive and manpower intensive. (Caplin)
23. To defeat the EW capabilities of our adversaries, the DoD must continue to invest and acquire more secure products that will assist in assuring communications across the battlefield. (Afeku)
24. All future EW systems need to be interoperable. Future JROC validated requirements need to include an interoperability requirement which includes a data feed to the Joint All Domain Command and Control (JADC2) system. (Bowers)
25. The DoD must embrace Open architectures for systems to keep pace with the technological changes the enemy employs and rapidly adjust. Open architectures will enable primes and sub-primes to develop innovative advancements in antenna, software, and "one box" with different card technology. Failure to implement these requirements will ensure our adversary outpaces the DOD with technological advancement. (Roa)
26. The Intelligence Community (IC) needs to do a better job securing and exploiting foreign military systems and disseminating the capabilities of those systems to the Joint Force to inform RDT&E. (Bowers)
27. The Army EMSO system at the Corps level needs to have a very long-range operating across a much broader segment of the EMSO. This capability is critical to the Corps' "deep fight" and the employment of the future Multi-Domain Task Force (MDTF) long-range precision fires (LRPF). Additionally, the Army needs to develop JROC validated requirements at echelon instead of one TLS system to meet the needs of the Corps, Division, and Brigade—whose requirements vary greatly. (Bowers)
28. The Army needs to develop a comprehensive blended strategy of low-cost and high-cost EA capabilities to clutter the EMSO to confuse the enemy. A low-cost Vertical Take-Off and Landing (VTOL) UAS with GPS spoofing and beam focus jamming should be considered. (Bowers)
29. To win the potential Indo-Pacific fight against the Chinese Communist Party (CCP) the CMC must invest in EMSO technologies necessary to control the spectrum in unmanned systems, communications, and air defense capabilities. (Feltham)

30. To gain access in A2AD the DoD will need to develop technologies that provide freedom of movement in the spectrum. (Feltham)
31. The “cost-per-shot” ratio of future military weapons should be considered. High Energy Lasers and Directed Energy (HEL DE) R&D technology has the potential of meeting or exceeding lower ratio thresholds and further research into HEL DE weapons is needed. (Westphall)
32. The DoD needs to establish an open and accessible Joint EMSO lab. A physical laboratory modeled after the Army Positioning, Navigation & Timing (PNT) Open Innovation Lab (OIL) should be considered. The lab would serve as a secure facility where industry could access the physical hardware and digital models needed to develop EW solutions. An open and accessible Joint EMSO lab would lower the barrier to entry for small and new EW solution providers and serve to both standardize and integrate system modeling. This laboratory will also host the multiple open architecture standards that have developed across the individual Services and seek ways to integrate those disparate standards. (Strauss)
33. The Department of Defense must pursue full development of Quantum Radio in our portfolio of capability, including support to fielding initial capability and future support to commercialization efforts. (Hagadorn)
34. Incentives should be applied to elements of the national innovation system to develop the algorithms necessary for AI- enabled EMBM and JADC2. In the short term the Services should continue fielding and modernization of their EMBM solutions. DISA DSO and STRATCOM JEWC must begin collaboration on a capstone solution that supports Joint Electromagnetic Spectrum Operations (JEMSO) at a CCMD or JTF level. (Herron)
35. As DoD moves forward, EMSO and JADO concepts must evolve together and development of EMBM and JADC2 capabilities must occur in tandem. The nature of these concepts and enabling technologies will require significant integration between products and services across the spectrum of the defense industry. (Herron)
36. EW acquisition contracts must be written to account for the rapid pace at which EMS related technology advances. This is achievable though processes like continuous capability development and delivery (C2D2). This allows incremental improvements to software and hardware throughout the acquisitions processes. (Roa)
37. Future open standards initiatives must include ownership and accountability, a significant shortcoming of past efforts. The program executive office (PEO) must be the one enforcing adherence to open standards in the acquisitions process while accounting for fundamental economics and industry incentives (protection of competitive advantage proprietary information) to be successful. (Roa)
38. DoD must implement a faster approach to adopting current commercial IC technologies in weapons systems. In its assessment of DoD’s trusted microelectronics policies, DARPA has concluded that newer technologies are more secure. To mitigate security threats associated with using vendors outside of the trusted supplier program, DoD must work with the DIB to find a workable solution that incorporates current technologies into weapons systems at a more rapid pace. (Callow)

39. Quantum Radio's applicability to Wideband Jamming needs greater scientific exploration. There is potential to see through the noise and the possibility of jamming certain thresholds that allow your receivers to function while drowning out adversarial systems. (Hagadorn)
40. The DoD needs to commit to a pilot program to demonstrate proof of concept for MOSA. Airborne tactical radios are an excellent candidate as they are ubiquitous across services. This will build confidence in the new EW market and show that programs acquired with multifunction, common architecture, and open standards can work as a business model and produce superior EMS dependent systems. (Roa)
41. Industry must adapt to keep pace with the dynamics of the new EW market that demands products be multifunction, broad spectrum, fully interoperable systems that are developed with a modular, open system approach (MOSA). For its part, DoD must provide governance in the transition from the old model to the new, carefully balancing sustaining and disruptive innovation. (Roa)

STEM and Human Capital Recommendations

42. A successful microelectronics strategy must include a comprehensive approach to addressing the STEM shortage as well as other skill sets that are needed for fabrication and ATP. The U.S. needs a centralized, mobilization-type effort, to increase the labor supply in key areas – a national labor supply strategy that complements the microelectronics strategy. (Callow)
43. Continue the policy of the Trump Administration to provide more oversight and restrictions on Chinese students attending American universities. There is no way of knowing if these students are under the control of China's Communist Party and will be used to export leading-edge research to China and steal federally funded university research. (Wright)
44. Modeled after programs within the Department of Homeland Security, a new Special Duty Assignment Pay (SDAP) needs to be created. (Bowers)
45. The Army needs to expand its targeting outreach of advanced degrees through increased tuition assistance for enlisted, officer, and DAC personnel. (Bowers)
46. Adding a reclassification bonus would help build the EMSO force quickly (<5 years) to meet the growing requirements. Along with other initiatives it will enable the recruitment and retention of the technical specialists required to dominate the EMSO in future conflicts. (Bowers)
47. The DoD must incorporate a fast-paced, innovative culture to modernize EW training and the development and acquisition of EMS capabilities by applying the theory of cultural hierarchy. (Pitman)
48. A new generation of EW specialists must be resourced and supported by leadership at all levels if the United States hopes to maintain EMS superiority across each domain. (Pitman)

Doctrine and Force Structure Recommendations

49. Instead of increasing EMSO force structure, considerations for retooling and retraining the current EW and signal forces may lead to increased value and cost savings. EMS-focused

professionals should enable the development and integration of needed long-range jamming and future EMSO concepts. (Caplin)

50. The Joint Force concepts should center on layered and agile aggregation to prevent unnecessary redundancies, fill appropriate gaps, and remove legacy concepts and models. (Caplin)
51. The Joint Force should relook at their layered approaches across all domains to challenge Service modernization and concept development for EMS maneuver and a path to leapfrog advantages to sustain superiority. (Caplin)
52. The ARCYBER Center of Excellence in coordination with TRADOC needs to develop convergence doctrine in coordination with all three functional areas (EW/CYBER/INTEL). (Bowers)
53. The DoD, with congressional approval and resourcing, should establish an EMSO Combatant Commander with control and authority over all EMSO acquisitions to ensure a common operating environment. (Folks)
54. The new EMSO Combatant Commander will need the ability to:1) overcome unnecessary proprietary data delays in RDT&E and production of advanced and evolving EMS technologies, and 2) be able to direct (at minimum) bi-annual joint training exercises in a virtual environment. (Folks)

Training Recommendations

55. The Department must ensure all personnel train at the appropriate skill levels on EMS maneuver at the appropriate echelon. Forces should understand the EMS impacts on their capabilities, operations, and plans- from EMS Common Operating Pictures (COP) to jamming, targeting data, and sensing. (Caplin)
56. The U.S. government should partner with industry and academia to flag critical technologies being targeted by adversaries and highlight the severe criminal and civil penalties that apply to violations of the ECA and AECA. (Danner)
57. The DoD must modernize infrastructure for training and testing of EW systems. Particular attention should be paid to addressing the shortfalls in the 2015 Defense Test Resource Management Center State of the Electronic Warfare Infrastructure Improvement Program (EWIIP). The report concluded that the DoD infrastructure could not support testing against advanced radar threats. They also outlined four test capability needs, ground facility and open-air range investments, data correlation between testing in each of EW test domains, realistic representation of existing and emerging threats, and improved distributed test capability. (Wright)
58. All EMSO related service specialties need to understand the capabilities of the Joint Force. This would be demand cross-training on other services systems in addition to service-specific training requirements. (Bowers)
59. The intelligence and CEMA professionals need rehearsals and training of coordination measures to mitigate any Title 50 vs Title 10 friction. (Bowers)
60. The Army must develop and implement home station training of SIGINT and CEMA simulation trainers to assist in realistic training for a future MDO. (Bowers)

61. Military installations need to be exempt from FCC regulation to improve "live fire" training capabilities. There will need to be mitigation measures emplaced to ensure training does not impact civilian infrastructure or communications systems. (Bowers)
62. To improve convergence, recommend establishing one training location for all three Army EMSO related MOS at Fort Gordon. (Bowers)
63. Services should evaluate possible conflicts between missions as they integrate EW capabilities into the force. As the services fight for state-of-the-art facilities and new simulated test and training environments, it is critically important to have leaders singularly devoted to providing their service with the best EW capabilities in the world. (Pitman)

Recommendations on Legislation, Acquisition Reform, and EMSO Governance

64. Government and industry proponents should explore the development of a registry to assist prospective exporters of EW products and technologies in appropriately classifying materials destined for sale and educating firms regarding restrictions that might apply. (Danner)
65. Lawmakers must consider the advancement of the EW market when developing our national policies. (Afeku)
66. Congress should add EMSO as a "covered mission area" under Sec. 855(b) of the 2017 NDAA that directs mission integration management. Additionally, Congress should authorize discrete funding for ME activities to the USD (R&E) rather than rely on an under-resourced Rapid Prototyping Fund as currently directed in public law. Both these legislative actions would empower the USD (R&E) to provide needed oversight and ME tools to the greater EMSO enterprise. (Strauss)
67. Key members of the House and Senate must take the next step in the FY22 NDAA to ensure that the Department of Defense and the individual services have more specific direction on how to create an effective EMSO force. Congress must mandate not only the rank, but also the organizational structure needed to be effective in creating an entity that will be responsible for ALL future joint EMSO resources and training. To avoid wasting any more critical time, rather than using such language as "an appropriate entity", legislative language must additionally mandate a four-star general officer who reports directly to the Secretary of Defense with both operational and functional authority over all aspects of EMSO acquisitions, training, and operations. (Folks)
68. Congress should consider the creation of a Unified Combatant Command responsible for both functional and operational EMSO requirements (*A precedent already exists to justify the creation of a new unified combatant command. Like the current state of EMSO responsibilities, United States Cyber Command's original disparate authorities also fell under USSTRATCOM*). (Folks)
69. While the analysis of where governance should reside develops and groups such as the EMSO CFT and EW EXCOM play an important role the Services must embrace the EMS as a native maneuver space, not as someone else's responsibility. (Roa)
70. Each service should assign an EW champion responsible for educating the force on the value of service-wide EMS expertise. Service champions should seek out organizations

that can capture a new generation of EW professionals to increase networking and professional development for EW personnel. (Pitman)

71. Reduce barriers to entry into the DoD acquisition system by revising regulations that favor economy of scale or capital requirements, such as large infrastructure capacity and Research and Development (R&D) outlays typical of large firms in the defense industry. Although large U.S. DIB companies are actively performing R&D more may be accomplished if an ecosystem of smaller companies were able participate, on their own, like a 'prime' contractor. (Westphall)
72. Incentivize DIB startup companies to work with the DoD by adapting government procurement contracts that typically payout incrementally or as the system successfully transitions from through each milestone of development. This may work for larger DIB companies that can financially handle millions or billions of dollars in contractual 'backlog'. However, most DIB startup companies, especially those not backed by investment groups, do not have large cash reserves. By paying more upfront costs on R&D-type contracts the U.S. government would revitalize the startup ecosystem and encourage participation with the DoD. (Westphall)
73. The regulatory agencies making spectrum allocations must consider the implications of greater sensitivity from Quantum Radio in their future spectrum allocation decisions and swiftly take actions to keep the United States competitive. (Hagadorn)
74. The Departments of Defense, State, and Commerce should finalize the consolidation of the CCL and USML and create a public-private forum to develop and maintain an EMS/EW export registry. The continued existence of both the CCL and USML perpetuates an overly complex export system for EW and other military products and technologies. (Danner)

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BAE SYSTEMS

Firm Brief

April 2, 2021

TEAM

Jeremy Folks, Nicholas Roa, Sam Pitman, "Hags" Hagadorn

Overview

- Firm Profile and Strategy
- Firm Financials and Value Assessment
- Competition and Porter's Forces
- Innovation / Research and Development (R&D)
- Challenges
- Recommendations

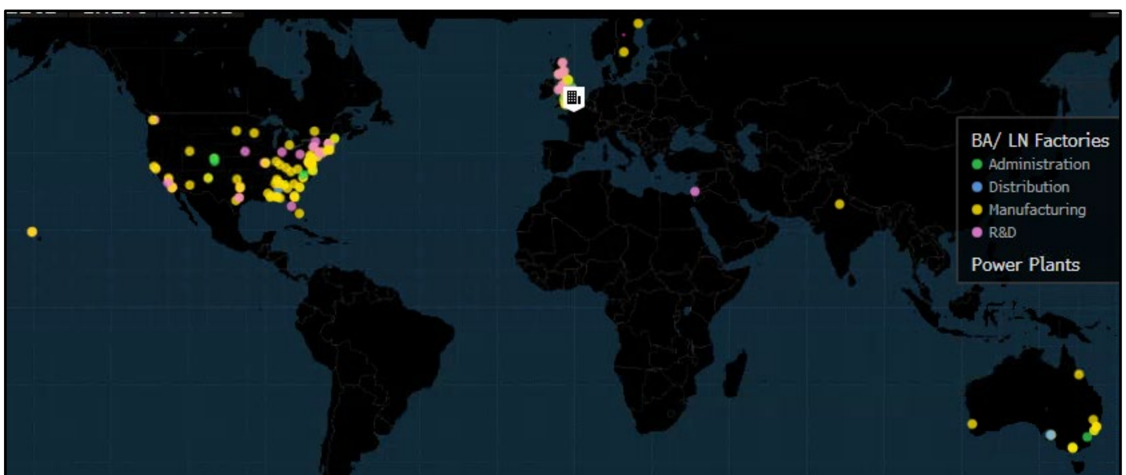
BAE Systems PLC Profile

<u>Headquarter (Founded 1999)</u>

- United Kingdom: London & Farnborough
- United States: BAE Systems Inc. a subsidiary of BAE Systems PLC operates in the U.S., Sweden, and Israel.
- Special Security Agreement

<u>Primary Market</u>

- US, UK, Australia, and Saudi Arabia
- BAE PLC – 87,800 Total Workforce
    - BAE Inc. – 35,100 People Workforce
- Operating in 40 Countries Worldwide



<u>Segments</u>

- Air
- Electronic Systems
- Cyber and Intelligence
- Maritime
- Platforms and Services

BAE PLC Corporate Strategy

Strategy

- Maintain & grow defense business
- Develop and expand international business
- Continue to grow defense business in adjacent markets
- Inspire and develop a diverse workforce to drive success
- Enhance financial performance and deliver sustainable growth in shareholder value

Mission: *To provide a vital advantage to help customers to protect what really matters*

Strategic Priorities

- Drive Operational Excellence
- Advance and further leverage our technology
- Continuously improve competitiveness and efficiency

Vision: *To be the premier int'l defense aerospace & security company*

BAE PLC Strategy

Corporate Strategy:

- Focus on the **design, development, delivery** of products/services
- Employ **technology** to improve efficiency and competitiveness
  - Invest in tech & infrastructure by focusing on customer needs
- Develop & **expand relationships** in Asia-Pacific & the Middle East
- **Smart Acquisition** – Targeted toward future high-tech investment
  - *Collins Aerospace GPS receivers*
  - *Raytheon's Tactical Airborne Radios*
  - *BAE FastLabs acquisition of Riptide Autonomous Solutions*
- Continued **investment in R&D** and **innovation**

Business Strategies:

- Dependent on **large order backlog** with established positions in **long-term defense programs** in **US, UK, Saudi Arabia, India, & Australia**
  - **Strong US portfolio** aligned to National Defense Strategy
  - US Electronics business focused on **key growth sectors in high-tech**: electronic warfare, precision guided munitions, ISR, & electro-optics
  - **FastLabs**

Focused on ***sustainability*** *and* ***shareholder value*** *executing strong order book,* ***reinforcing a strong position*** *in the* ***higher growth markets*** *of business,* ***investing*** *in* ***new products*** *and* ***technologies****….*

2019 Annual Report

Strategic Game Board Decisions

Where: Defense and Adjacent Markets

- Product: Electronic Warfare Capabilities (Electronic Systems)
- Customer: Governments and other defense companies
- Channel(s): Direct to government or major program’s prime contractors
- Location: U.S., U.K., and Israel

How: Customer Value

- Dependable delivery, reliable network of suppliers, & tech design expertise
  - Excellence in complex engineering, developing cutting-edge tech & seeking innovative solutions for greater agility & global reach
  - Set performance & innovation standards across a wide range of platforms

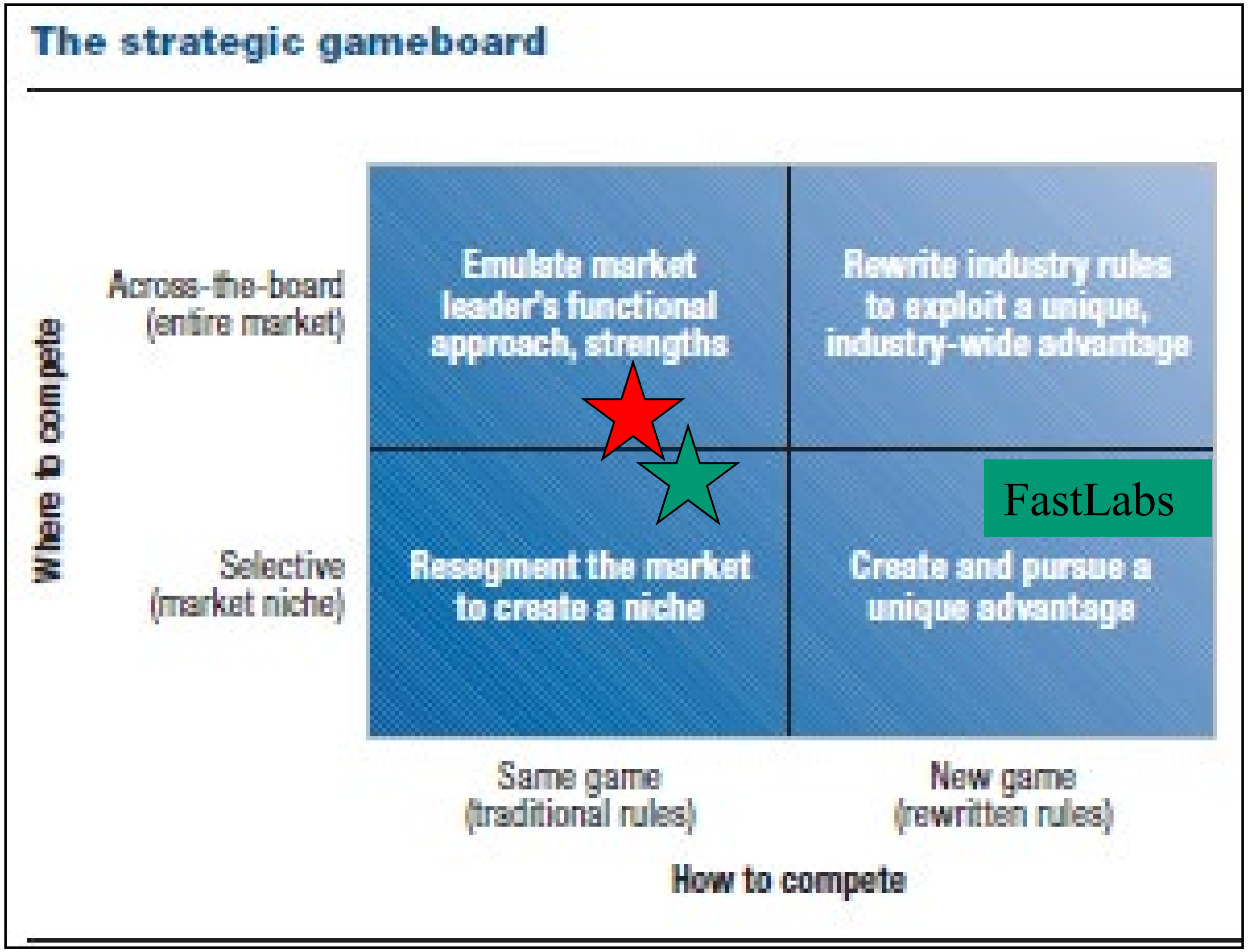
When to Compete

- Unique in broad capability and diverse geographic presence
- Example – Purchased Collins Aerospace GPS receivers and Raytheon's tac airborne radios to provide broad range of GPS products for 2021 -2025 investment strategy

The Strategic Gameboard

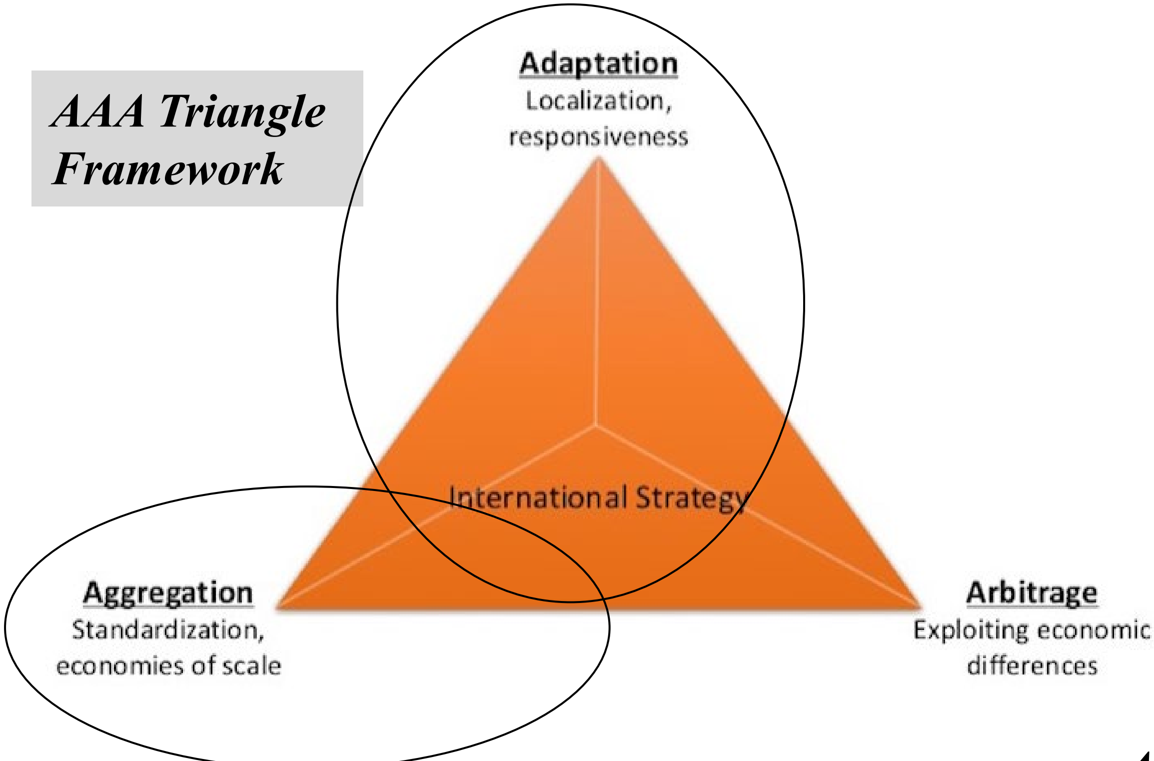
- **Emulates vs Market Niche**
  - Geography
  - New Markets
  - Strong presence and supply chains in US and UK

- Pursues **new technology, innovation** with strong **R&D investment**



Internationalization & Strategy

AAA Triangle Framework



Adaptation: Optimize product or service offering for local markets to maximize a firm's local relevance and responsiveness

- BAE Systems Inc.

- Diverse geographic focus on platforms versus electronic capabilities

Aggregation: Standardize product offerings to deliver economies of scale via regional or global operations

- Government contracts increased production

- Centralized R&D investment

Arbitrage: Exploit differences between markets.

- Locate parts of the supply/value chain in different locations

- Limited ability to maximize costs with government requirements

BAE Creates Value from R&D

Research and Development (R&D)
Return on Invested Capital (ROIC)
Weighted Average Cost of Capital (WACC)
British Pound (GBP)

Value Creation Metrics

- ROIC vs. WACC - 9.42% vs 7.03%
  - (Dec 2020 Annualized)
  - Comparable performance with pre-COVID numbers
  - Revenue growth - 8.8% increase from 2018 to 2019

Individual Business Units

- Electronic Systems vs. Cyber & Intel
- 15.4% (↑) vs. 5.2% (↓)

Net Cash Flow

- Electronic Systems vs. Cyber & Intel
- 833mGBP (↑) vs. 99mGBP (↑)

BAE produces technology no one else can make; <u>not</u> the cheapest technology

Recent Sources of Risk

Electronic Warfare (EW) Acquisitions Early COVID:

- ***Collins Aerospace military GPS division***
- Previously owned by United Technologies Corp.
    - UTC had to sell Collins' GPS business in order to clear the antitrust regulatory requirements of its merger with Raytheon.

- ***Raytheon Airborne Tactical Radios***
    - Good fit for "BAE Inc." EW Business Unit
    - Expected to yield increases profits and cash flows in the near future

SPACENEWS

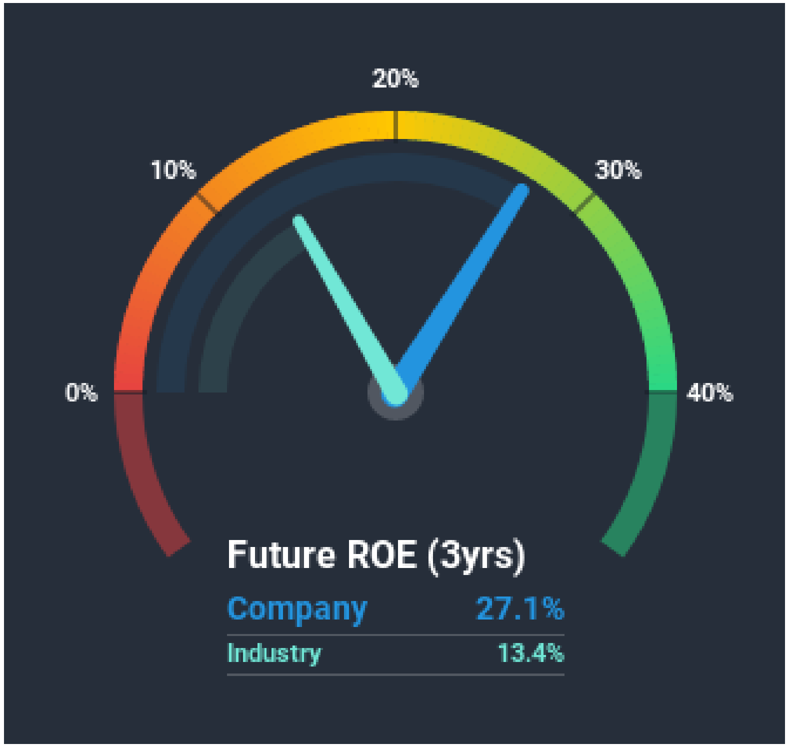
BAE Systems positioning for growth in military GPS following Collins acquisition

The Space Force is buying advanced GPS receivers that can take advantage of a jam-resistant signal known as M-code.

Major 2019-2020 investments show promising returns in the next 5 years

BAE's Recent Debit Numbers

- **Liquidity Ratio** (Current)
  - Current ratio is 1 (last 4 yrs)
  - Lower than biggest competitors
  - (LM 1.3, GD 1.2)
- **Solvency Risk** (Long term)
  - Debt/equity ratio is 1.44
  - Nearly doubled since last year
  - 2020 debt increase ~400%



https://uk.finance.yahoo.com/news/bae-systems-plc-lon-ba

Although debt increased significantly BAE still stands to create value in coming years

BAE Debt Numbers

Search | International | Providing defence for business | Multimedia | Contact us

BAE SYSTEMS

Home | What We Do | Our Company | Investors | News & Events | Careers

Five Year Summary

Investors > Financial information > Five Year Summary

Movement in net debt for the year ended 31 December

	2020 £m	2019 £m	2018 £m	2017 £m	2016 £m
Movement in net debt	**(1,975)**	161	(152)	790	(120)
Opening net debt	**(743)**	(904)	(752)	(1,542)	(1,422)
Closing net debt	**(2,718)**	(743)	(904)	(752)	(1,542)

COVID Impact: Outlook for 2021

Key take away's from the past year:

- Dividend payments: Commitment to shareholders
- BAE stock 'oversold' during the past year[1]
- Hedging bets: Liquidity and Solvency

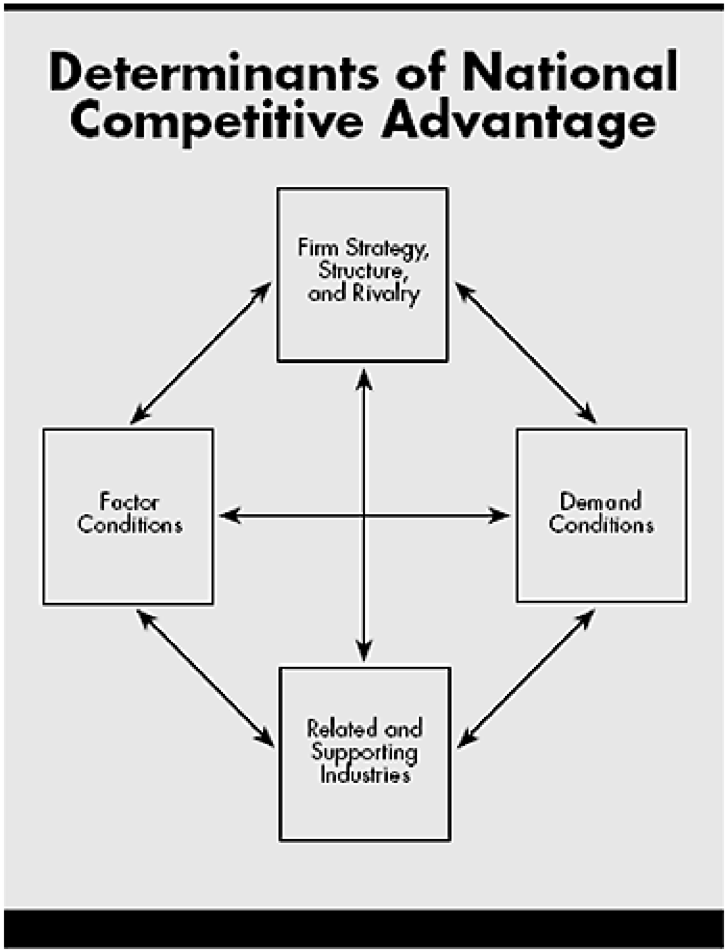
Future action:

- Move cash back into current contracts
- Invest in future projects

1 https://www.afr.com/wealth/personal-finance/bae-systems-oversold-in-pandemic-and-biden-fears-20201112-p56dy3

BAE successfully weathered the storm and is now positioned to grow

National Advantage (Porters D)



- BAE PLC (UK)
- BAE Inc. (US)

Porter's Five Forces – Competitive Advantage

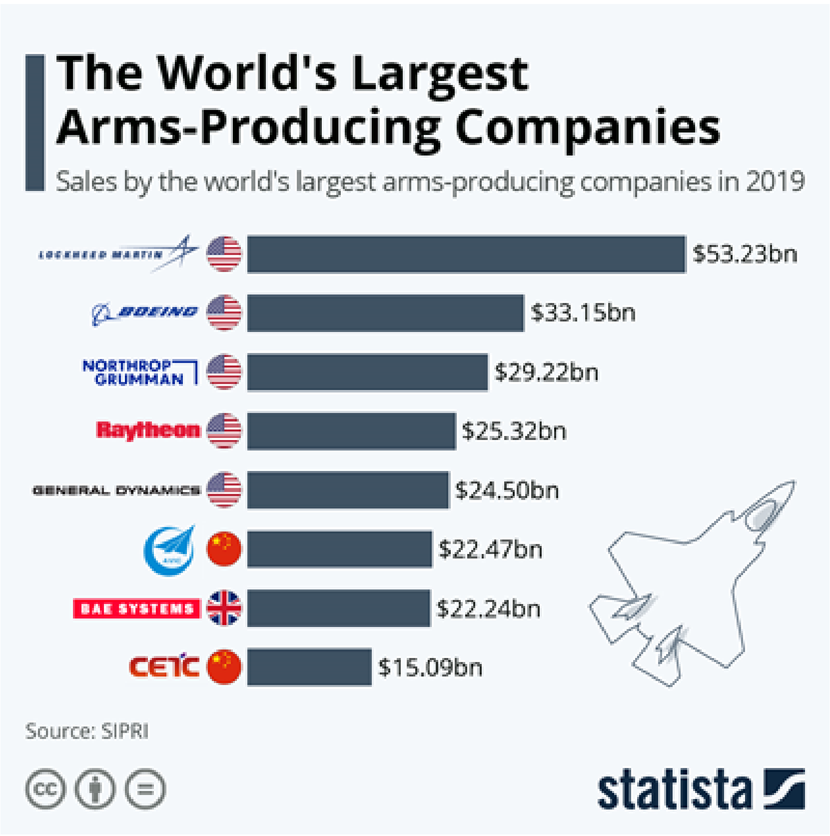
- Buyers - "The Outsider"
- Suppliers - Coopetition
- New Entrants
  - Scale/Experience
  - Fast Labs
  - China
- Substitutes - When only the best will do

Porter's Competitive Advantage

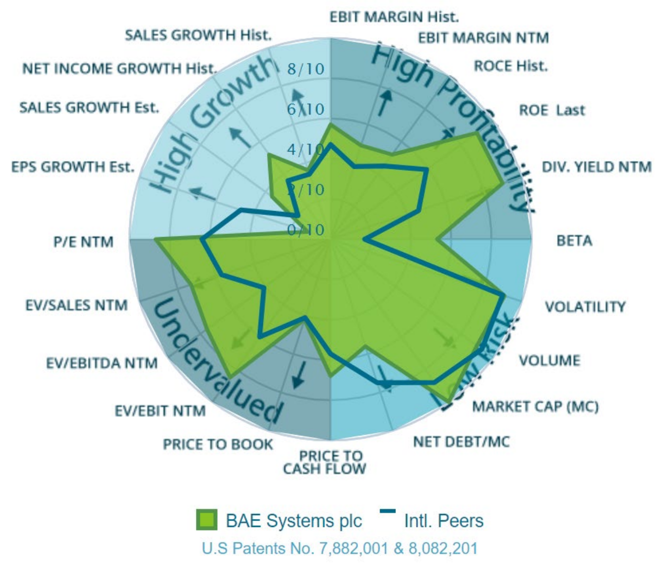
- Defense – Niche Market
  - High Barriers to Entry
  - Exquisite Capabilities
  - Low Volume
  - Cost Not Driver
  - Monopsony

BAE produces technology no one else can make; not the cheapest technology

Competition



GPRV Analysis



Competition II

DoD EW Market: Competitive Environment, US, 2020

Number of Companies in the Market	31, with a prime contract value of $5.85 billion
Competitive Factors	Cost, performance, schedule, support, technology, reliability, contractor relationships, and customer relationships Out of 82 contract actions totaling $5.85 billion, 13 contracts valued at $2,163.3 million or 37% were competitively bid, and 69 contracts valued at $3,690.9 million or 63% were non-competitive. The contracts are classified as follows: • 14 cost contracts: $1,890.3 million or 32.3% • 26 fixed-price contracts: $2,622.3 million or 44.8% • 4 IDIQ* contracts: $209.9 million or 3.6% • 38 modified contracts: $1,131.7 million or 19.3%
Major Market Participants	L3Harris Tech, Sierra Nevada, Northrop Grumman, Lockheed Martin, and SRC
Market Share of Top 5 Market Participants	$3.26 billion or 55.7%
Other Notable Market Participants	Elbit, Leonardo, Boeing, Terma North America, and American EW Associates
Key End Users	US Air Force/Space Force, Army, Navy/Marines, and Joint Service organizations
Notable Acquisitions and Mergers	BAE acquired Raytheon's (Collins) GPS unit, and Ansys acquired Analytical Graphics

*IDIQ = Indefinite Delivery/Indefinite Quantity

Source: Frost & Sullivan

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Frost & Sullivan
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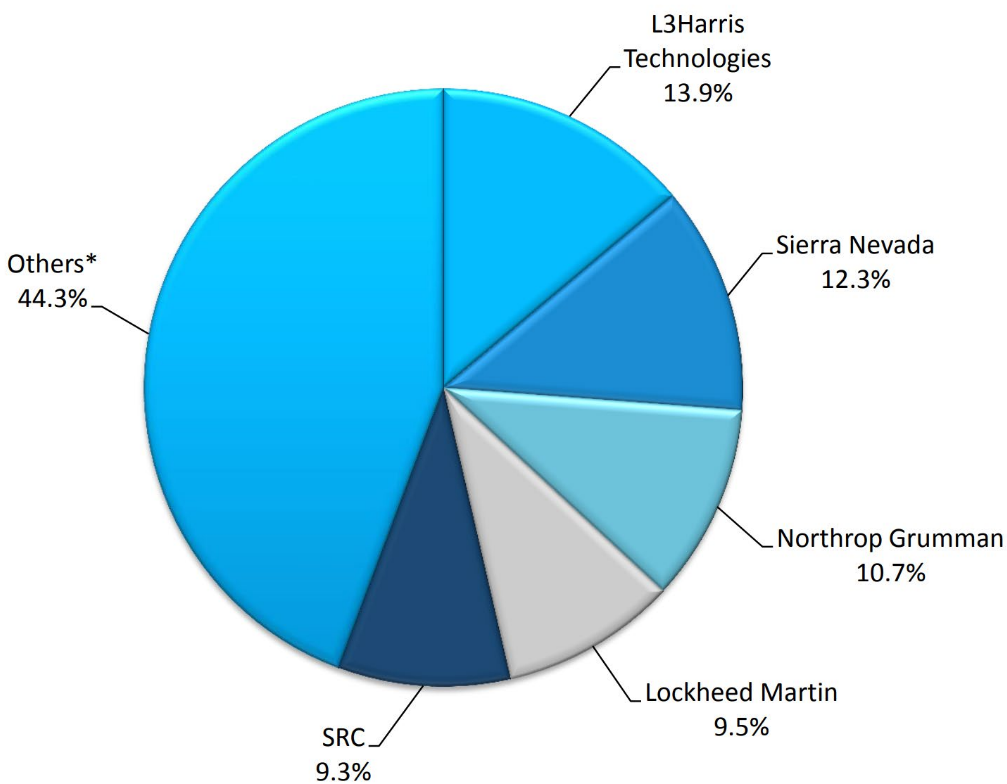
Competition III

DoD EW Market: Contract Value Share of Top Participants, US, 2020



Company	Contract Value ($ Million)
L3Harris Technologies	812.3
Sierra Nevada	722.0
Northrop Grumman	623.5
Lockheed Martin	553.8
SRC	547.0
Others*	2,595.6
Total	**5,854.2**

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*Others includes 26 companies. Total is $5.85 billion

Source: Frost & Sullivan

Competition IV

DoD EW Market: Top 10 Contractors, US, 2020

Contractor	Value ($ Million)	Major Awards
L3Harris Technologies	812.3	EA-18G aircraft NGJ-LB, Aircraft IDECM, B1-B aircraft/electronic countermeasures
Sierra Nevada	722.0	USSOCOM RFCM for AC-130J Ghostrider and MC-130J Commando II aircraft, Marine MODI multi-function EW systems
Northrop Grumman	623.5	Navy Large Aircraft IR Countermeasures system, Surface EW Improvement Program, supply chain management AN/ALQ-155/161/184/ systems
Lockheed Martin	553.8	Surface EW Improvement Program, F-35 EW/Counter Measures Aperture Electronics Module (EW/CM AEM), ASQ-239 EW/countermeasures
SRC	547.0	Expeditionary-Low, Slow, Small Unmanned Aircraft System Integrated Defeat System (E-LIDS), Counter-small Unmanned Aerial System (C-sUAS) with Medusa sustainment
Elbit	471.6	Air Force pylon-based IR missile warning system for the F-16 aircraft
Leonardo	331.4	Army Mobile-Low, Slow, Small Unmanned Aircraft System Integrated Defeat System, Navy components for the AN/AAQ-45 Distributed Aperture IR Countermeasure
Boeing	316.7	F-15 aircraft Passive Active Warning and Survivability System (EPAWSS), test and evaluation support for Next Generation Jammer integration on the EA-18G aircraft
Terma North America	306.4	Air Force production, repair, and engineering support of various types of aircraft electronic countermeasure systems
American EW Associates	218.0	Integrated Battlespace Simulation and Test department, advanced RDT&E, integrated combat environment capabilities
Others	951.5	High Endurance EW Jet (HEEWJ) airborne threat simulation, EW aircrew tactics, EW combat training, equipment and EW range infrastructure maintenance
Total	**5,854.2**	

Others include the 21 other prime contractors for 2020. Source: DoD Comptroller, DoD Contract Newsroom

Source: Frost & Sullivan

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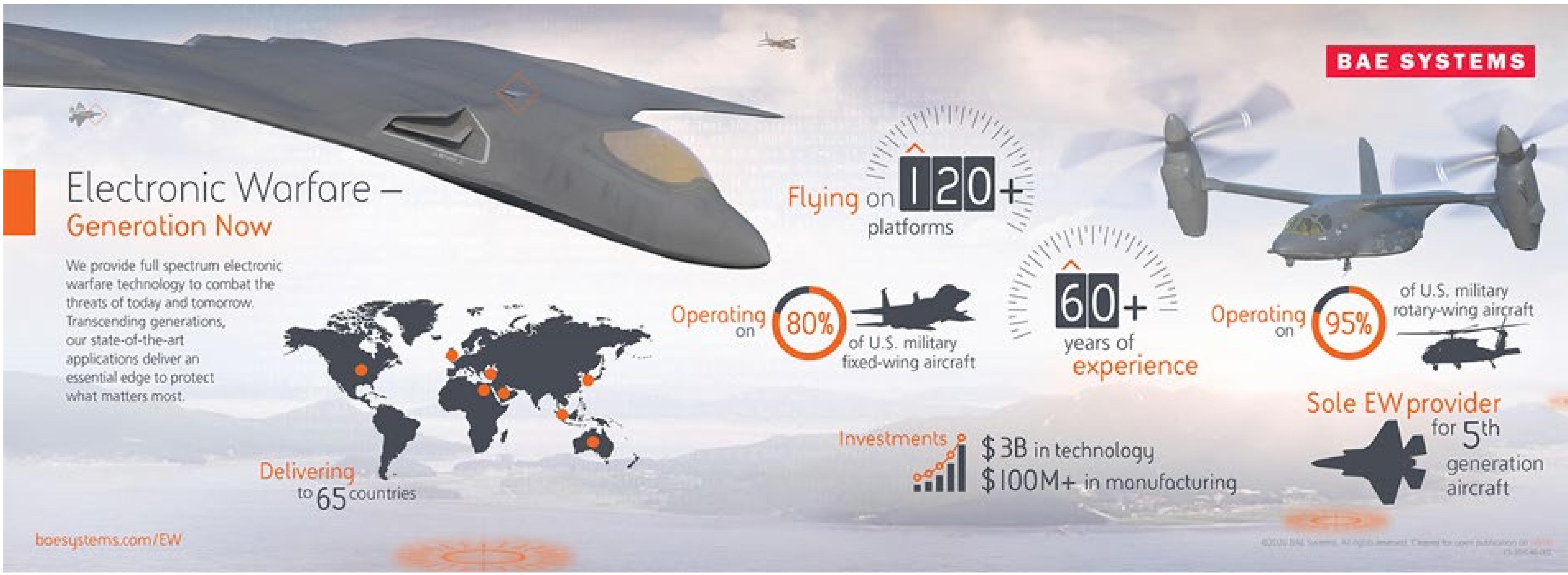
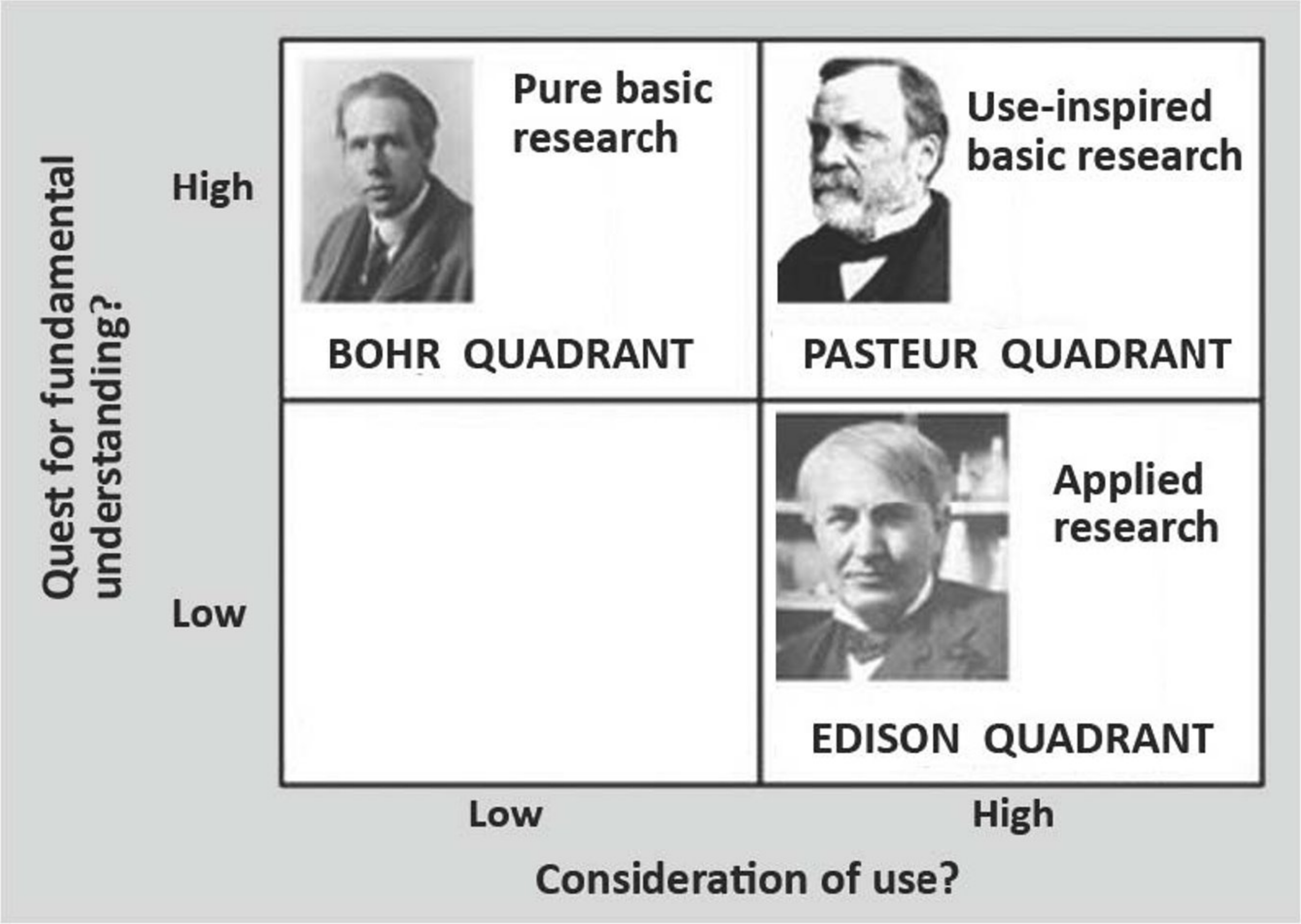
BAE's View



BAE SYSTEMS
Electronic Warfare –
Generation Now
We provide full spectrum electronic warfare technology to combat the threats of today and tomorrow. Transcending generations, our state-of-the-art applications deliver an essential edge to protect what matters most.
Delivering to 65 countries
Flying on 120+ platforms
Operating on 80% of U.S. military fixed-wing aircraft
60+ years of experience
Operating on 95% of U.S. military rotary-wing aircraft
Sole EW provider for 5th generation aircraft
Investments
$3B in technology
$100M+ in manufacturing
baesystems.com/EW

National Innovation System



Future: Innovation / R&D

Challenges


BARGAINING POWER OF BUYERS
BARGAINING POWER OF SUPPLIERS
INDUSTRY RIVALRY
THREAT OF NEW ENTRANTS
THREAT OF SUBSTITUTES

Organizational Challenges

Workforce of the Future:

- "Grey Tsunami"...the experts are all retiring
- New workers must have advanced training
- Clearance Capable!

Acquisitions:

- Integrating proprietary tech into existing BAE systems (Raytheon & Collins)
- Bond Burden
- Pension Payouts

International Challenges

US & UK Domestic Politics:

- Higher debt/lower revenue from COVID
- Both nations considering lower defense spending to ease debt burden & increase domestic spending

Uncertainty with Allies/Partners:

- ITAR Restrictions
- Turkey and the S-400
- Saudi Arabia's war in Yemen
- BAE Systems PLC (UK) vs BAE Systems INC (US)

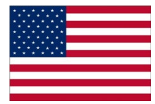
Innovation Challenges

Future Positioning: Navigating the Defense Industry during Great Power Competition

- Reliance on foreign suppliers for semiconductors
  - *Already a shortage due to COVID supply disruptions*

- Unmanned AI weapons vs. traditional platforms
  - *Where and how much to invest in old vs. New?*

Policy Recommendations

1. Flexibility
   – BAE Inc Vs. PLC  
     • Need better collaboration with our most trusted allies
   – Flexibility in R&D
     • Move beyond the DARPA model
2. Culture Change
   – Remotely Piloted Aircraft vs manned, Open Architecture, workforce
3. Budget (2yr cycle) and predictability in procurement

Questions

Industry Analysis : Firm Brief

NORTHROP GRUMMAN

AY 2020-2021

Jeff Strauss
Jennifer Webb
Ingemar Westphall
Dayle Wright

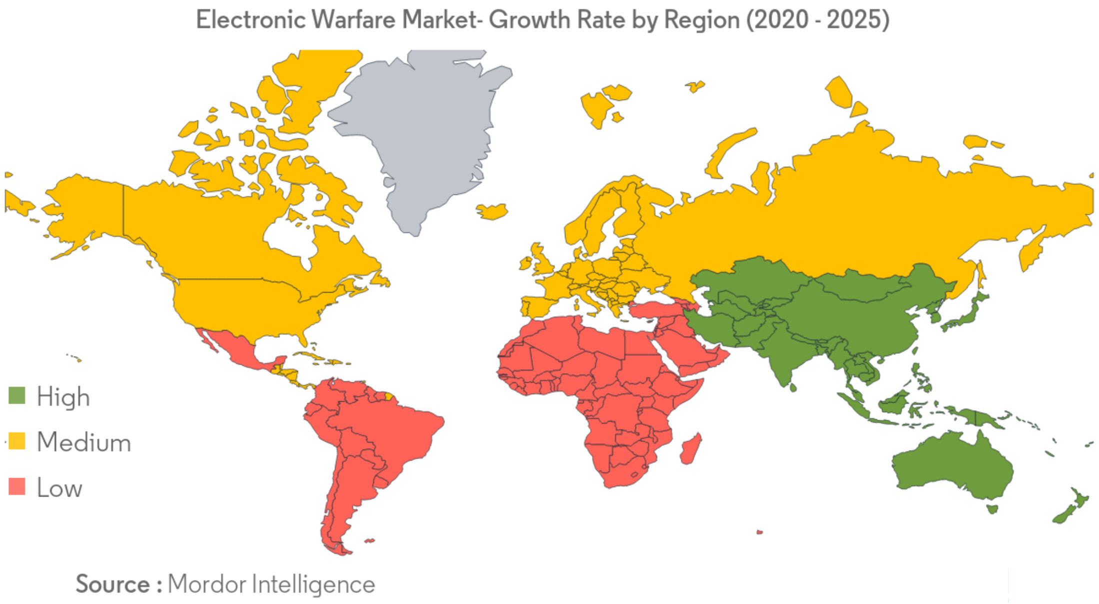
Agenda

The purpose of this brief is to provide an analysis of Northrup Grumman's structure and performance in the wider Defense and specific Electronic Warfare (EW) market to gain an understanding of how the firm's conduct impacts National Security policy. The S-C-P-P model

- Structure
  - Introduction of NGC
  - Of Industry
  - Of Market
  - 5 Forces
- Performance
  - Finical performance
  - Health
  - Value Creation
- Conduct
  - Strategy
  - Alignment
  - M&A
  - Global
- Policy
  - National Dimond
  - Innovation
  - Supply chain, exports, risks
  - National Security Considerations
- Recommendations
- Conclusion

Structure

Global EW Market - “Thirty Thousand Feet”



Iggy

NG Today

- Leading Global Defense Company
- $36.8B in sales, 2020
    - 86% U.S. / 14% International
- $81B Total Backlog (as of Dec 31, 2020)
- ~97K Employees
- Leading Capabilities
    - Space
    - Missiles
    - Advanced Weapons
    - Aeronautics
    - Mission Systems

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NG Operating Sectors

Aeronautics Systems


Autonomous Systems

Aerospace Structures

Advanced Technologies and Concepts

Aircraft Design, Integration and Manufacturing

Long-range Strike

Multi-Domain Integration and Operations

Intelligence, Surveillance and Reconnaissance

Battle Management

Defense Systems


Integrated Air & Missile Defense

Defensive Cyber and Information Operations

Platform Modernization and Fleet Operations Support

Advanced Weapons

Precision Munitions

Software Systems Modernization and Sustainment

Training and Simulation

Propulsion Systems

Mission Systems


Airborne Sensors and Networks

Artificial Intelligence/Machine Learning

Cyber and Intelligence Mission Solutions

Navigation, Targeting and Survivability

Maritime/Land Systems and Sensors

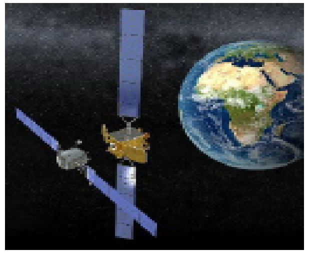
Engineering & Sciences

Emerging Concepts Development

Multi-domain C2

Agile/DevSecOps Systems

Space Systems

Launch Vehicles

Propulsion Systems

Commercial Satellites

Military and Civil Space Systems

Science and National Security Satellites

Human Space and Advanced Systems

Space Components

Missile Defense

Space Exploration

Space ISR Systems

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Where Does NG Sit within the EW *market* structure …

- Market consists of three categories: electronic protection (EP), electronic warfare support (EWS) and electronic attack (EA)
- Market expected to be dominated by EP
  - Will account for 59% of the market; followed by EWS and EA, 32% and 9% respectively
- North America forecasted to dominate the sector with a share of 45%
  - Asia Pacific, 27%
  - Europe, 20%

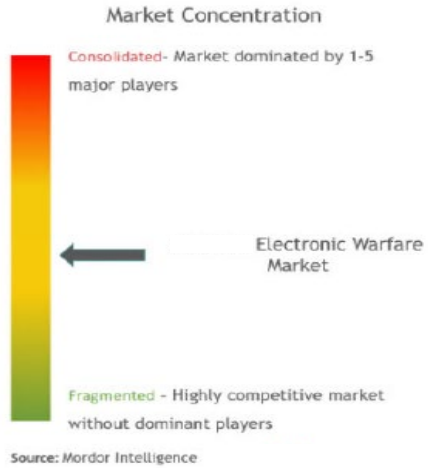
EW MARKET STRUCTURE

CHARACTERISTIC	*PERFECT COMPETITION*	*MONOPOLISTIC COMPETITION*	*OLIGOPOLY*	*MONOPOLY*
Number of firms	*Many*	*Many*	*Few*	*One*
Type of product	*Identical*	*Differentiated*	*Identical or differentiated*	*Unique*
Ease of entry	*High*	*High*	*Low*	*Entry blocked*
Examples of industries	• *Wheat* • *Apples*	• *Selling DVDs* • *Restaurants*	• *Manufacturing computers* • *Manufacturing automobiles*	• *First-class mail delivery* • *Tap water*

Source: Hubbard & O'Brien

Major Players

1. Lockheed Martin Corporation
2. Raytheon Copany
3. BAE Systems plc
4. Northrop Grumman Corporation
5. Saab AB



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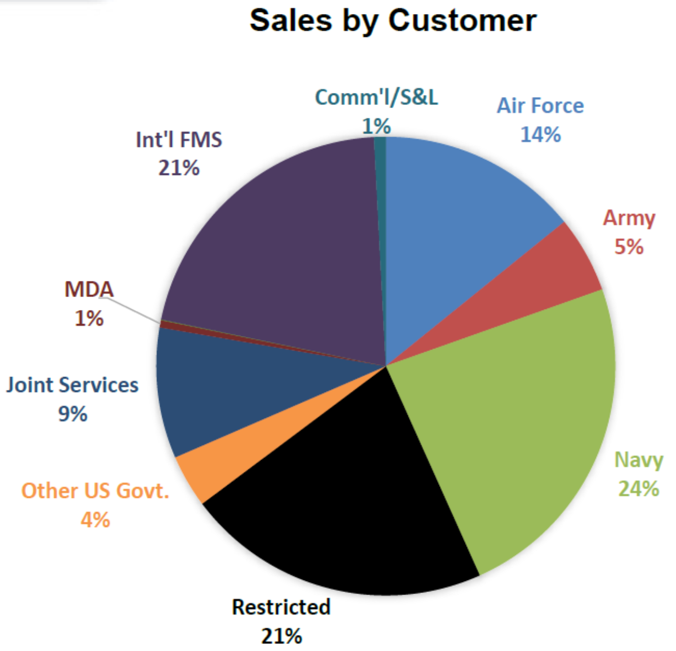
EW Market– Threat of New Entrants



Threat of New Entrants

- 31 main EW vendors
  - Over 260 vendors … just in Counter UAS
- Greater expected global demand
  - $17B USD, 2020; $20.9B USD, 2028
- Ease of Market Entry
  - Various technologies makeup EW
    - Hardware and software
  - Inexpensive Move to Software Defined EW
    - Low investment costs
    - Low Operations & Maintenance costs
  - Low barriers of entry (policy/regulations)
  - Abondance of distribution channels
- Multiple uses = multiple vendors
  - Not restricted to war/contingency zones
  - Civilian sector usage growing

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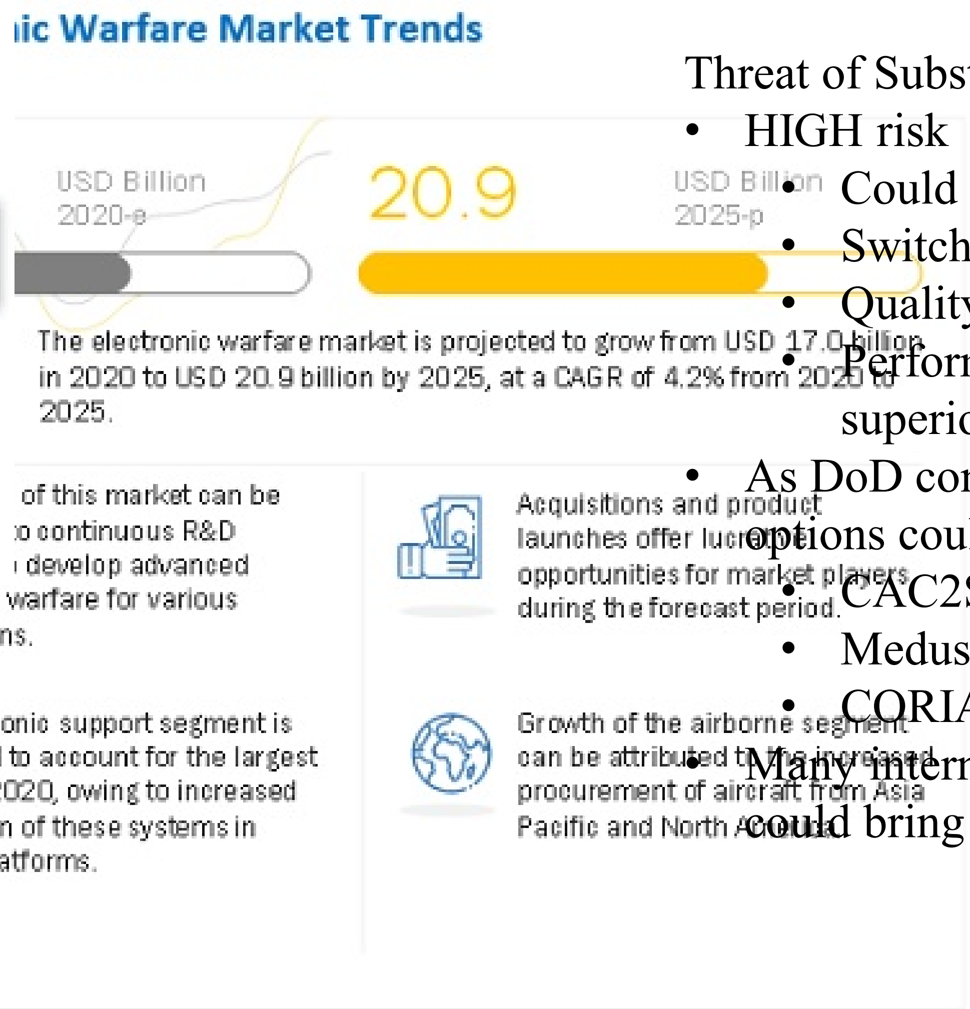
EW Market– Threat of Substitutes



Threat of Substitutes

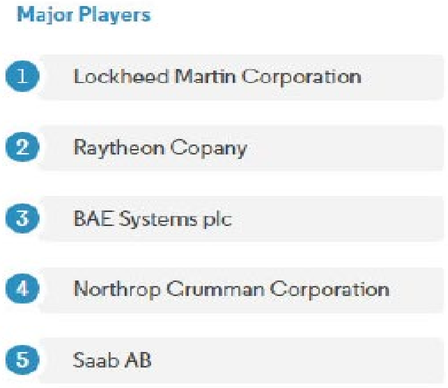
- HIGH risk
  - Could be cheaper
  - Switching costs are low – experimental
  - Quality assumed to be equal or superior
  - Performance assumed to be equal or superior
- As DoD continues to assess capabilities other options could evolve
  - CAC2S – USMC
  - Medusa – AF
  - CORIAN - Navy
- Many international and commercial entrants could bring additional substitutes

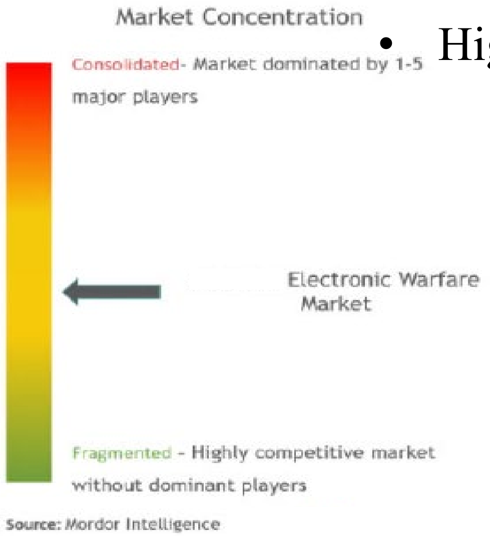
Iggy

EW Market– Rivalry Among Competitors

Rivalry among Competitors - HIGH risk

- Competitors are many, __NOT__ equal size
- Long operating cycles
- High number of competitors bidding on program
- Buyer behavior increases rivalry
  - Low switching cost
  - Buyer has single gate keeper
- High rivalry limits the profitability of an industry





NG Preparing for Strategic Change

NG Published Mission Systems Strategy
- Enable the national defense strategies of the US and its allies
- Focus on mission systems that deliver superiority in highly contested environments
- Combine hardware, software, cyber, and artificial intelligence with systems thinking to create speed, connectivity, and value for our customers
- Digitally transform the way we do business

<u>Preparing for Change</u>
- Flat DoD Budgets
  - multi-function solutions
  - multi-domain warfare capability
- Mission integration- JADC2
- Adapt to change in Administration and NDS priorities- enhanced role for mission systems in INDO-PACOM
- Naval increase

Iggy

Performance

How does this relate to "shareholder value"?

$$\frac{\text{Revenue - Cost}}{\text{Investment}} > \text{Cost of Capital}$$

ROIC
- Cost of capital
Value

Cash Flow

Firm Value → Shareholder Value

Firm Operating Environment

- Largest customer is the U.S. government. Sales to the U.S. government accounted for 84 percent, 83 percent and 82 percent of sales during the years ended December 31, 2020, 2019 and 2018, respectively.
- Competition with many companies in the defense, intelligence and federal civil markets. Boeing Company, General Dynamics, L3Harris Technologies, Lockheed Martin, and Raytheon Technologies are some of the primary competitors.
- December 31, 2020, total backlog, which is equivalent to the company's remaining performance obligations, was $81.0 billion as compared with $64.8 billion at December 31, 2019.
- Have not experienced significant delays in the supply or availability of raw materials, nor experienced a significant price increase for raw materials.
- Culture is an important factor in ability to continue attracting and retaining qualified employees, particularly those with security clearances and requisite skills in multiple areas, including science, technology, engineering and math.

NOC 2020 10K

Business Risks

- We depend heavily on a single customer, the U.S. government. Changes in this customer's priorities and spending could effect on our financial position, results of operations and/or cash flows.
- Significant delays or reductions in appropriations for our programs may negatively impact our business and programs.
- We face various risks related to health epidemics, pandemics and similar outbreaks, which may have effects on our business.
- Our business could be negatively impacted by cyber and other security threats or disruptions.
- Our earnings and profitability depend, in part, on subcontractor and supplier performance and financial viability as well as raw material and component availability and pricing.
- Our ability to win new competitions and meet the needs of our customers depends, in part, on our ability to maintain a qualified workforce.
- Our future success depends, in part, on our ability to develop new products and new technologies and maintain technologies, facilities and equipment to win new competitions and meet the needs of our customers.

NOC 2020 10K

Data – Financial Performance

$ millions

	Latest Year	One Year Ago	Two Years Ago
Firm Sales	36,799	33,841	30,095
Firm Operating Profits (income)	4,065	3,969	3,780
Firm Effective Tax Rate	14.50	11.77	13.71
Firm Net Profit (earnings)	3,189	2,248	3,229
Firm Cash Flow from Operations	4,305	4,297	3,827
Firm Total Assets	44.469	41,089	37,653
Shareholders' Equity	10,579	8,819	8,187
Price per Share (US$, historical, year-end)	167	168	171
Earnings per Share (US$, fully diluted)	19.03	13.22	18.49
Firm ROIC	12.70	11.00	10.19
Firm WACC	5.92	6.50	8.05

- All Firm level trends are positive year over year.
- ROIC > WACC and improving year over year.

Data – Business Segments Value Creation

	Latest Year	One Year Ago	Two Years Ago
Aeronautics Systems Sales	12,169	11,116	10.293
Aeronautics Systems Operating Profit (income)	1,206	1,188	1,128
Aeronautics Systems Assets	8,997	9,104	9,750
Aeronautics Systems ROIC	7.01	7.77	7.56
Defense Systems Sales	7,543	7,495	6,612
Defense Systems Operating Profit (income)	846	793	697
Defense Systems Assets	7,352	7,120	10,368
Defense Systems ROIC	7.94	7.69	7.27
Mission Systems Sales	10,080	9,410	8,949
Mission Systems Operating Profit (income)	1,459	1,408	1,245
Mission Systems Assets	10,029	9,934	11,047
Mission Systems ROIC	10.24	10.87	9.59
Space Systems Sales	8,744	7,425	5,845
Space Systems Operating Profit (income)	893	794	644
Space Systems Assets	10,028	10,595	2,957
Space Systems ROIC	7.22	7.77	8.19
Firm WACC	5.92	6.50	8.05

- Major reorganization in 2019
- Segment ROIC is a calculated value. [Segment Operating Profits x (1 - effective corporate tax rate)]/ Segment Invested Capital
- All segments are creating value except in the transition year
- The IS capabilities are managed under the Mission Systems Business Units.

Dayle

Financial Risk Ratios

	Latest Year	On Year Ago	Two Years Ago
Northrop Debt-to-Equity Ratio (total)	3.20	3.66	3.60
Raytheon Debt-to-Equity Ratio (total)	1.22	2.43	2.43
Lockheed Martin Debt-to-Equity Ratio (total)	7.43	14.19	31.15
Boeing Debt-to-Equity Ratio (total)	-9.29	-16.47	344.98
Aerospace and Defense Average	-	-	-
Northrop Current Ratio	1.60	1.13	1.17
Raytheon Current Ratio	1.21	1.08	1.13
Lockheed Martin Current Ratio	1.39	1.22	1.12
Boeing Current Ratio	1.39	1.05	1.08
Aerospace and Defense Average	1.36	1.08	1.10
Northrop Long-Term-Debt-to-Equity Ratio	1.42	1.57	1.76
Raytheon Long-Term-Debt-to-Equity Ratio	0.44	1.04	1.18
Lockheed Long-Term-Debt-to-Equity Ratio	2.02	4.05	10.12
Boeing Long-Term-Debt-to-Equity Ratio	-	-	40.85
Aerospace and Defense Average	1.74	2.16	1.82

Liquidity & Solvency Risk – L/SHE

- Industry comparison
- Y-Y trend is decreasing
- Financing growth with debt

Liquidity Risk – CA/CL

- CR > 1 = good
- Y-Y trend is > 1
- Capital can cover ST debt
- Default unlikely

Solvency Risk – LTD/E

- Industry comparison
- Y-Y trend is decreasing
- Below industry average
- Default unlikely

What has been the impact of the Covid crisis on Northrop's financial metrics?

- Our customers have generally continued to make timely payments, and we are working with them to consider the possibility of additional cost recoveries.
- The company's overall 2020 revenue and operating income were not significantly impacted by COVID-19.

	Year Ended December 31			% Change in	
$ in millions, except per share amounts	**2020**	2019	2018	**2020**	2019
Sales	**$ 36,799**	$ 33,841	$ 30,095	**9 %**	12 %
Operating costs and expenses	**32,734**	29,872	26,315	**10 %**	14 %
Operating costs and expenses as a % of sales	***89.0 %***	*88.3 %*	*87.4 %*		
Operating income	**4,065**	3,969	3,780	**2 %**	5 %
Operating margin rate	***11.0 %***	*11.7 %*	*12.6 %*		
Mark-to-market pension and OPB expense	**(1,034)**	(1,800)	(655)	**(43)%**	175 %
Federal and foreign income tax expense	**539**	300	513	**80 %**	(42)%
Effective income tax rate	***14.5 %***	*11.8 %*	*13.7 %*		
Net earnings	**3,189**	2,248	3,229	**42 %**	(30)%
Diluted earnings per share	**19.03**	13.22	18.49	**44 %**	(29)%

NOC 2020 10K

Conduct

Jeff

Northrup Grumman's Strategic Game Board

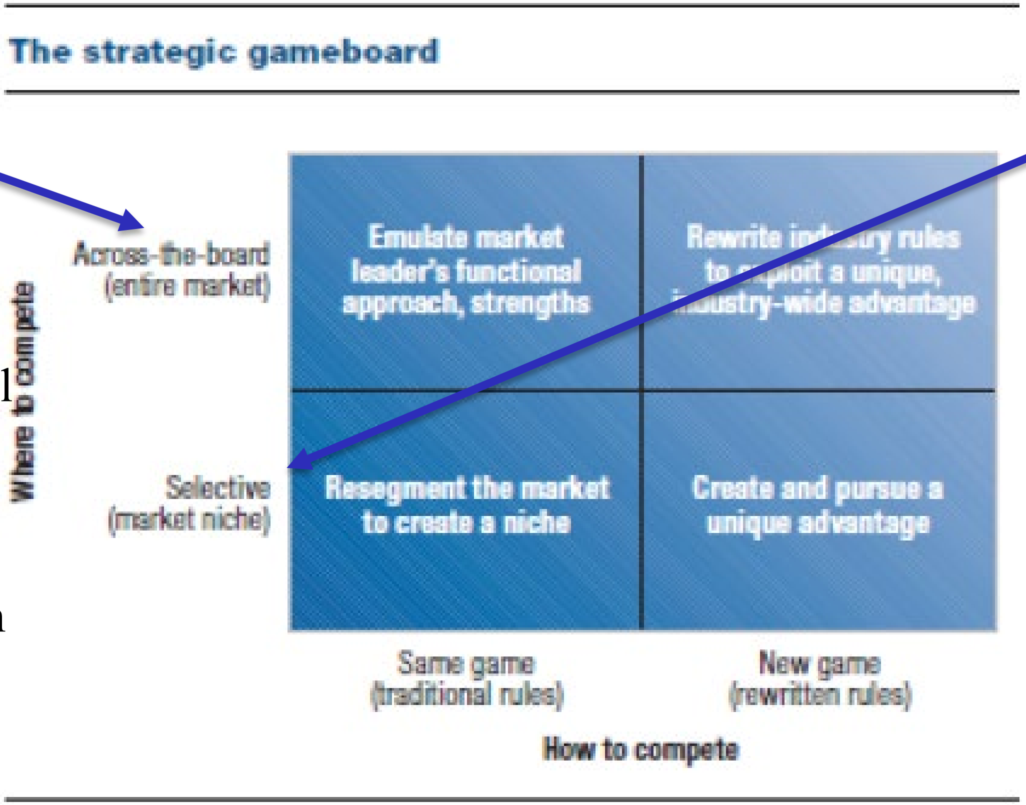
Firm

- Where to compete
  - Across-the-board Manned/Unmanned Aircraft, C2, Sensors, Cyber, Space, Nuclear Triad
  - 85% DoD, some International
  - USAF and USN centric

- How to compete
  - Both price and differentiation
  - Both as Prime and Tier 1-3 Sub
  - 50/50 split CP/FF Contracts

- When to compete
  - Risk-DoD budget
  - Customer focus; space, missile defense, hypersonics, AI

Jeff



"We continue, however, to be very disciplined about the opportunities we select to bid," Kathy Warden, Northrop Grumman president and chief operating officer told investors. "For example, we recently elected to not pursue two bids, GPS satellites and the next generation of F-35 DAS, as we determined that they were not attractive for us. We believe that applying strict assessment criteria in selecting our business pursuits is critical to long-term sustained performance."- 2018 Investor Call

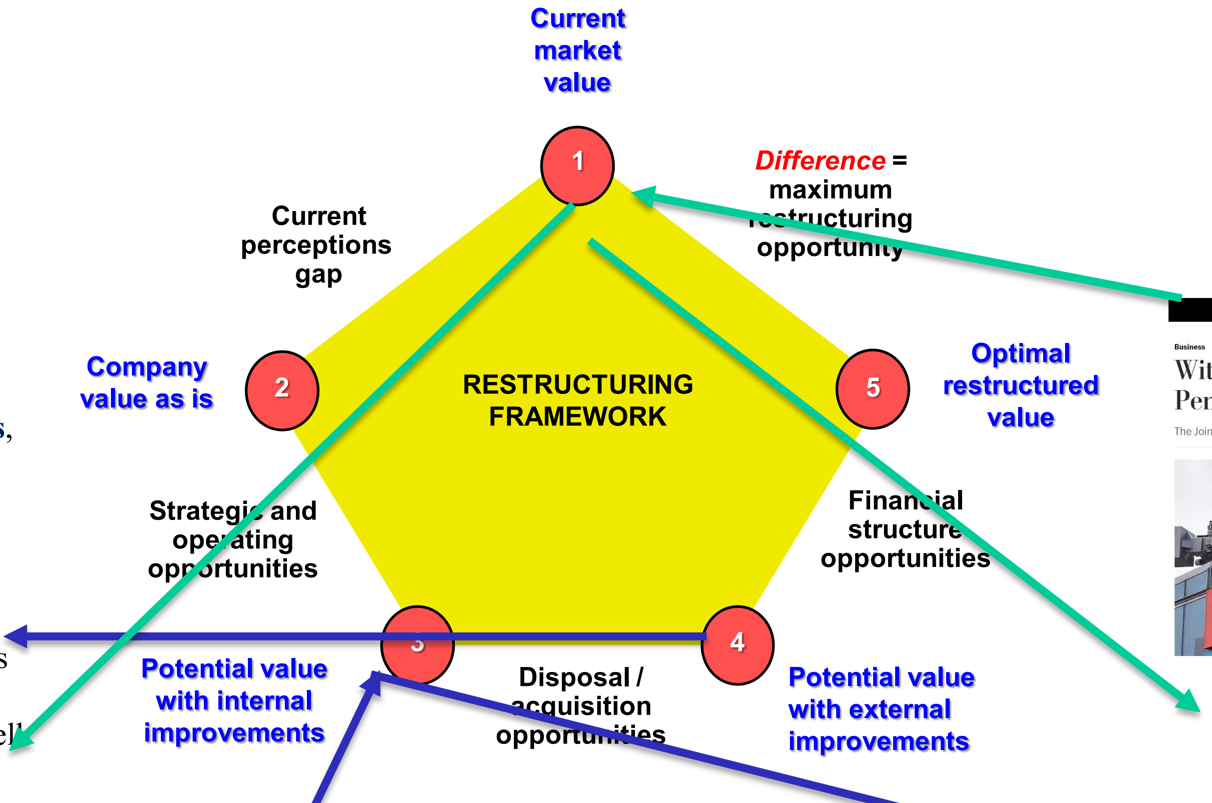
Mission Systems

- Where to compete
  - Airborne Sensors & Networks; Cyber & Intelligence Mission Solutions; Maritime/Land Systems & Sensors; and Navigation, Targeting & Survivability.
  - Across ACAT's
- How to compete
  - System of System leader and Component provider
  - Lead in radar and IR Countermeasures

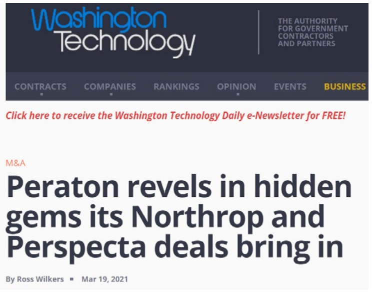
When to compete
- Follow the $$

NG Evolves: M&A / Restructuring

- 1996-acquired the defense and electronics businesses of Westinghouse Electric Corporation
- 2001-acquired Litton Industries, Inc., a global electronics and information technology company, and one of the nation's leading full-service shipbuilders
- **2001- acquired Newport News Shipbuilding Inc**
- **2011- spin-off Huntington Ingalls Industries**, Inc. (HII) operates former Shipbuilding business, comprised largely of a part of Litton Industries and Newport News Shipbuilding.
- 2018- acquired Orbital ATK, Inc., a global leader in the development and production of launch vehicles, missile products and satellites and other space systems.
- 2020- entered into a definitive agreement to sell our IT and mission support services business for $3.4 billion in cash



The McKinsey Restructuring Pentagon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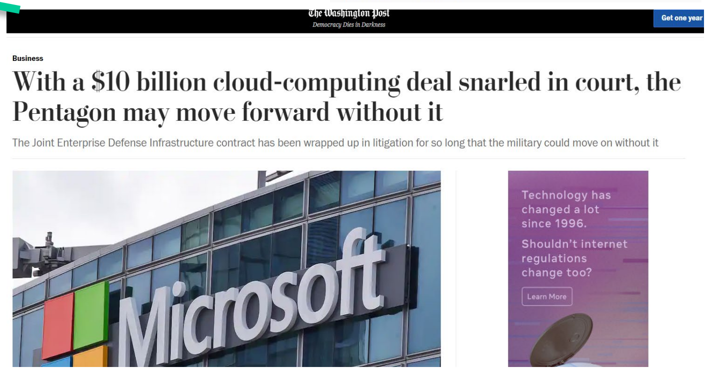
M&A
Peraton revels in hidden gems its Northrop and Perspecta deals bring in
By Ross Wilkers • Mar 19, 2021


The Washington Post
Democracy Dies in Darkness
Get one year
Business
With a $10 billion cloud-computing deal snarled in court, the Pentagon may move forward without it
The Joint Enterprise Defense Infrastructure contract has been wrapped up in litigation for so long that the military could move on without it

2019- four operating sectors: Aerospace Systems, Innovation Systems, Mission Systems and Technology Services.

2020-reorganized sectors to "better align the company's broad portfolio to serve its customers' needs. The four new sectors are: Aeronautics Systems, Defense Systems, Mission Systems and Space Systems.

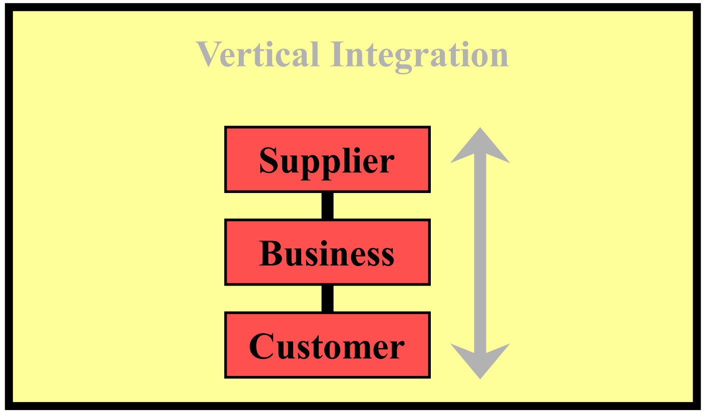
Trump Officially Establishes US Space Force with 2020 Defense Bill Signing

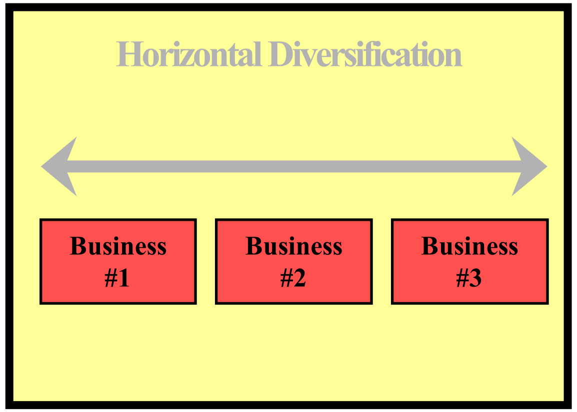
By Leonard David December 21, 2019

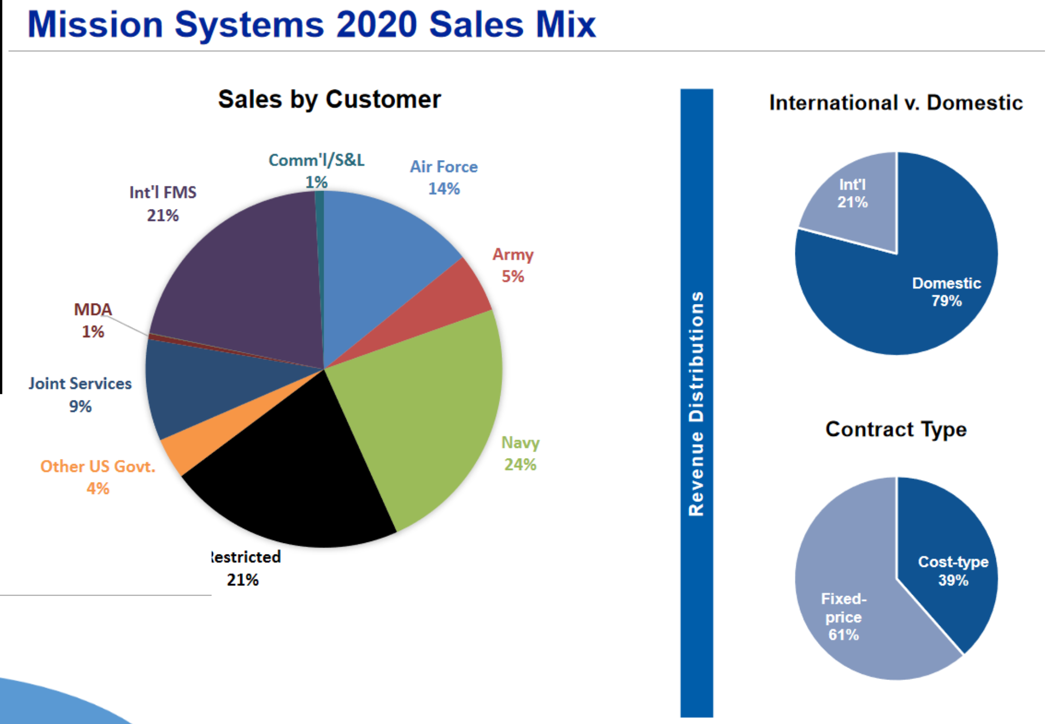
The new branch will be stood up over the next 18 months.

Jeff

NG MS Boundaries



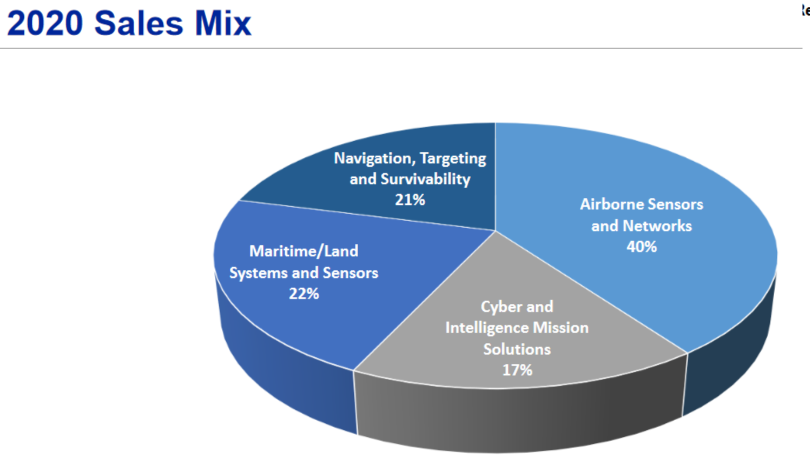




- Prime- Naval Surface space, CREW

- Sub- to competitors
  Airborne Systems
  Counter Measures
- Depot Services and Supply Chai
  legacy/ fielded systems AN/ALQ
  155/161/184/

- Trusted Foundry- sell to self



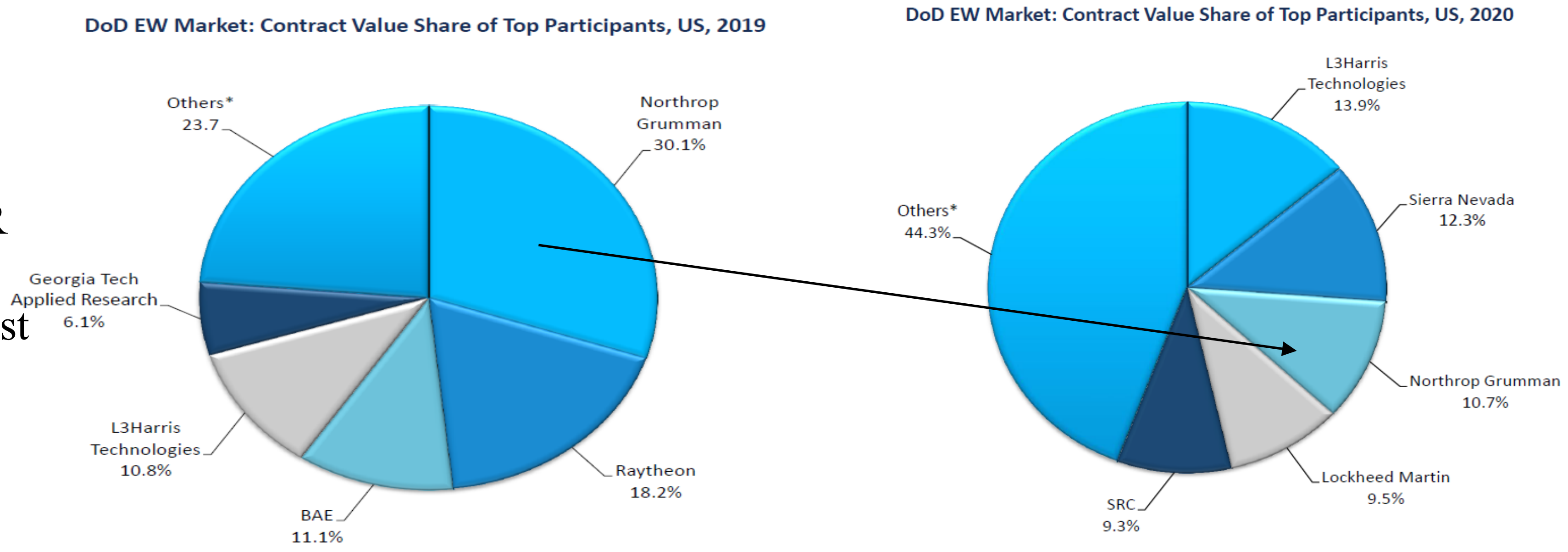
By Domain: Ground- Air- Space- Sea-Cyber
By Service: Navy (Air and Surface), USAF, USA &USMC

Jeff

NG Strategy and Alignment To Future Trends

Projections

- The US DoD EW budget spending for 2019–2025 is estimated to grow at a CAGR of 3.0%.
- RFCMs will remain the largest segment



Source: **US DoD Electronic Warfare, 2020–2025 Global Aerospace & Defense Research Team at Frost & Sullivan**

Must Adapt to this near-term change

- Large systems integrators continue to dominate contract awards
- Non-competed contracts continue to gain ground- $3,690.9 million (63%)
- Counter UAV made up 14.3% of the EW contract value in 2020, $839.7 million.
- **IR** countermeasures made up 5.1% of the EW contract value in 2020, $300.2 million
- **RFCMs** made up 61.7% of the EW contract value in 2020, $3,606.7 million
- RWR made up 16.1% of the EW contract value in 2020, $941.8 million.

Jeff

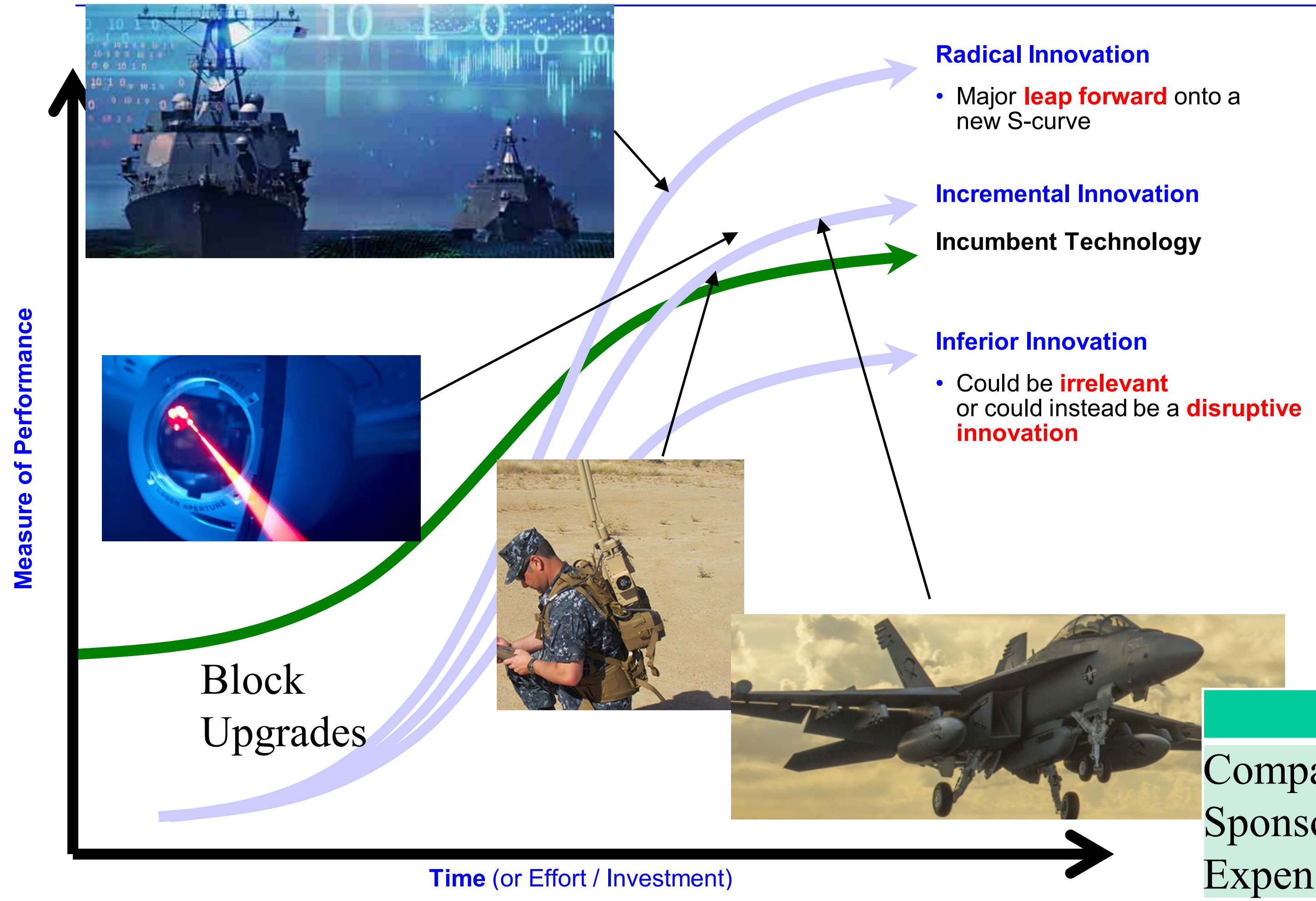
NG Strategic Opportunities

DoD EW Market: SWOT Analysis, US, 2020 Source: Frost & Sullivan

Company	Strengths	Weaknesses	Opportunities	Threats
Northrop Grumman	• Product innovation for unmanned vehicles • Airborne networks • Market lead for IR countermeasures	• Focus on Navy and Air Force EW systems; few Army EW contracts in 2020 • Lack of counter UAV contracts in 2020	• Foreign military EW system sales • Develop a counter UAV system and participate in this important nascent market	• Advanced EW systems produced by foreign firms • Merging of EW/IO operations may may impact current programs
	• Maximize CIRCM production contract, seek contract options for new platforms, FMS, and DS • Sole-source award strategy based on proven performance metrics against threats	• Loosing RFCM to L3Harris and SNC • Partnership with SNC (non-compete?) • “Other” in C-UAS, rejection by JCO	• Acquisition of Innovative “Other” in C-UAS • Lobby for easing of restrictions on FMS/DS of EW tech	• Pace of threat • DoD push to common architectures and multi-role systems limits competitive advantage

Jeff

NG Innovation



- Naval Focus
  - Digital Transformation
  - Multi-domain Information Warfare through Ships Signal Exploitation Equipment (SSEE) program
- Teaming-Prowler to Growler
- Boeing P-8A Poseidon
- Combat Electromagnetic Environment Simulator (CEESIM)
  - The AN/AAQ-24(V) Directional Infrared Countermeasure (DIRCM)

	2019	2018	2017
Company-Sponsored R&D Expenses	$953M	$764M	$639M

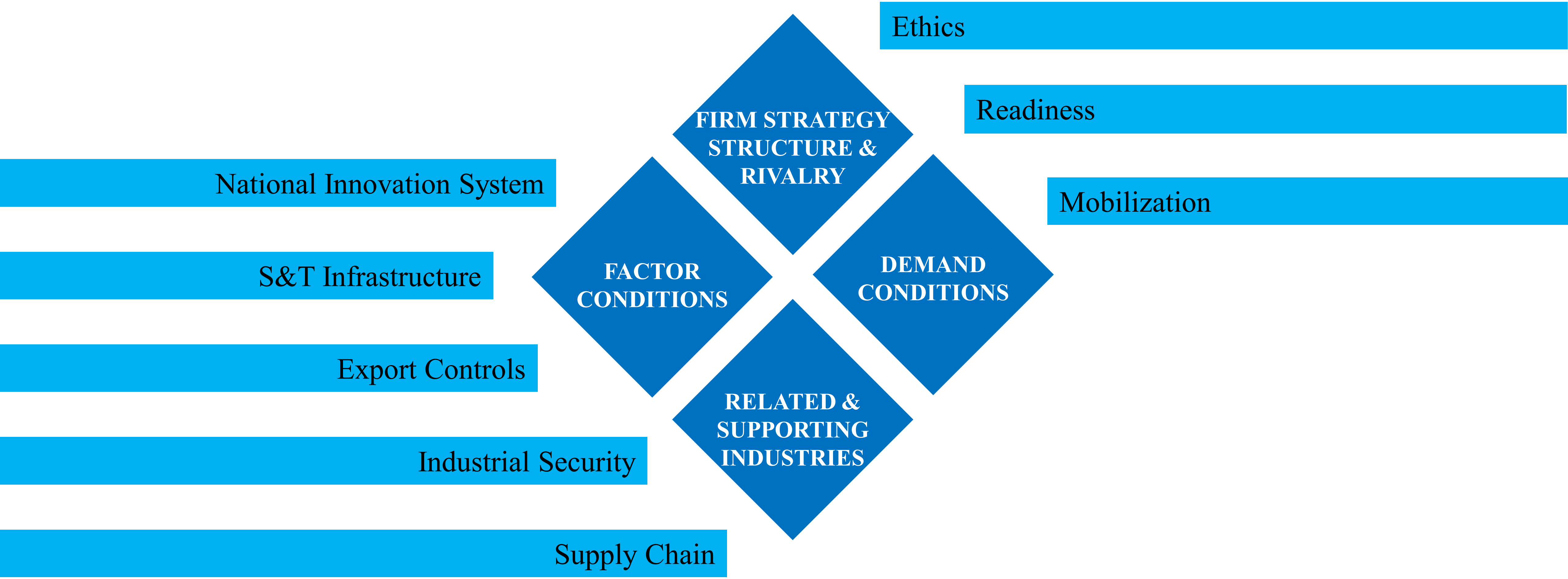
Note: See "A Call for Vision in Managing Technology" by Richard Foster for more on the innovation S-curve

Sustaining Innovation vs. Disruptive Innovation

Jeff

Policy

NGC's Competitive Advantage



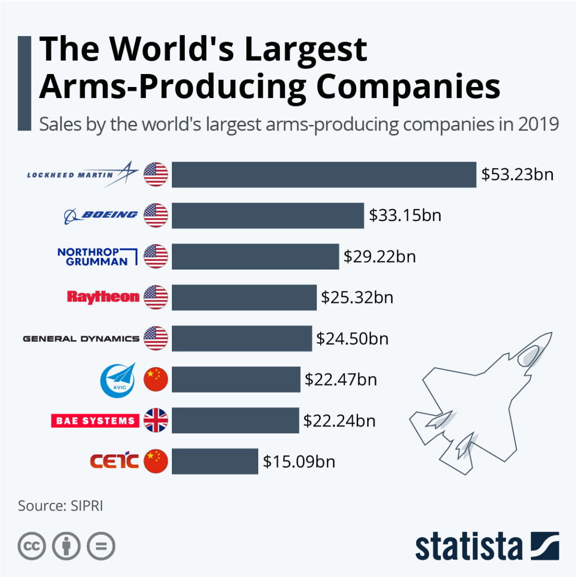
Firm Strategy, Structure, & Rivalry

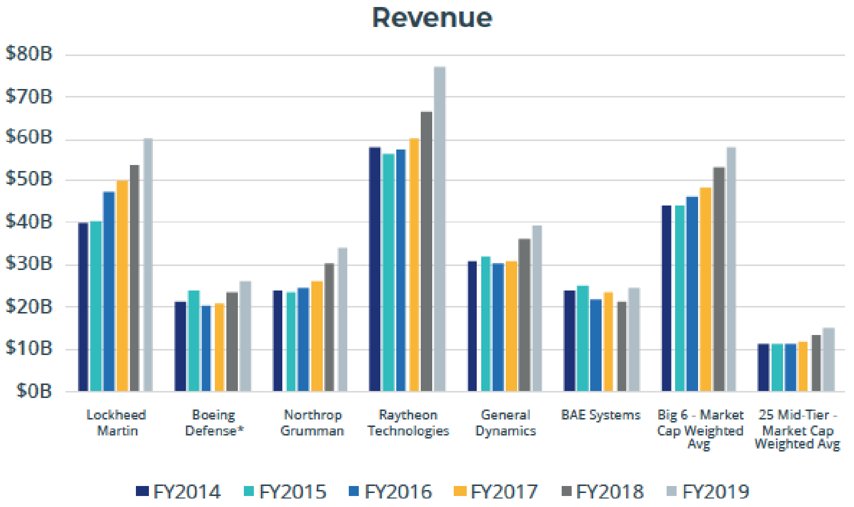
RIVALRY
- 31 companies in the market
- New emphasis on non-traditional

STRUCTURE
- Responsibility to shareholders
- Balanced scorecard

STRATEGY
- Product differentiation
- Balanced portfolio
- NDS-focused

ETHICS & CULTURE





Jennifer

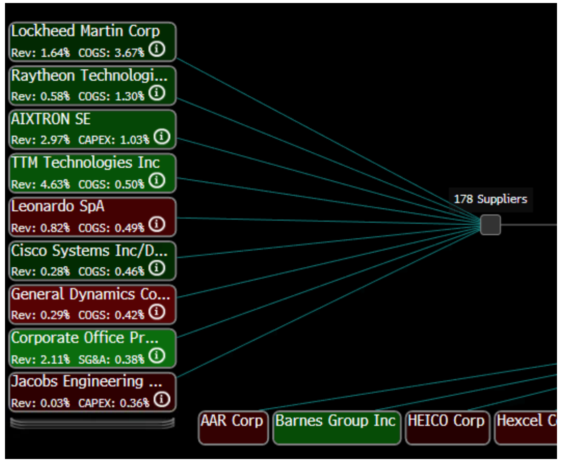
Related & Supporting Industries

SUPPLIERS
- 178 suppliers
- Inherited demands and limitations

SCM
- Strategy driven
- one-Northrop Grumman

SEMICONDUCTORS
- National concerns
- In-house foundry

RELATED INDUSTRIES
- Telecommunications
- Satellite Operations

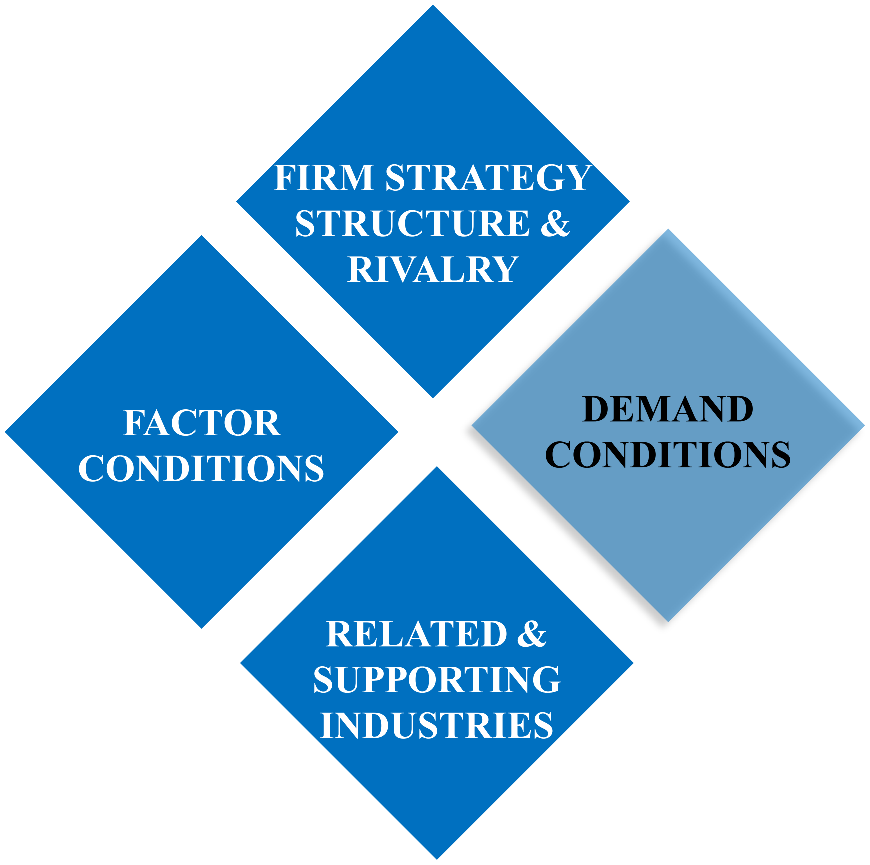


Bloomberg Suppliers

Foundry

Jennifer

Demand Conditions



SOPHISTICATED CUSTOMER

- Emerging EMSO emphasis
- Expected CAGR of 3%
- Demand for innovation
- Quality and safety standards
- Focus on affordability

SURGE & MOBILIZATION

- Recent surge assessment


F-16

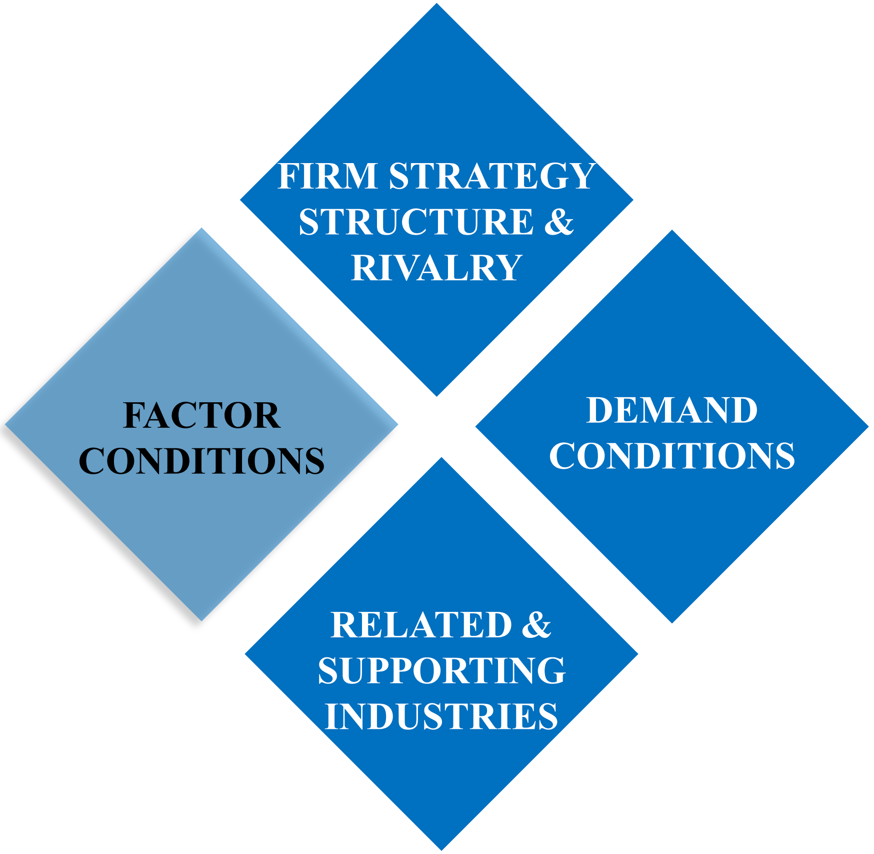

Automation


JTE

Jennifer

CAGR = compound annual growth rate

Factor Conditions

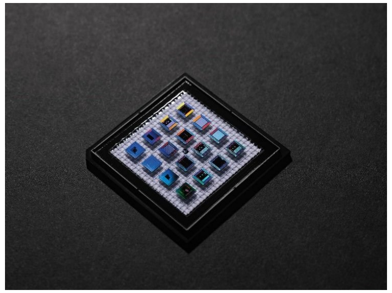


INNOVATION
- 3% of annual revenue -> R&D
- Collaborations with universities
- Investments in STEM

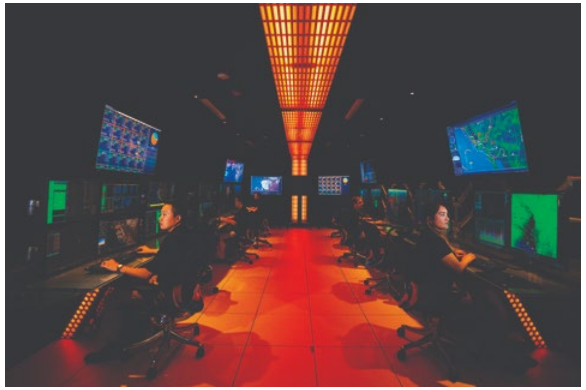
SKILLED LABOR
- 60 years of experience
- Personal investment in mission
- Strong talent management

INFRASTRUCTURE
- High-tech labs and facilities
- Global reach

REGULATIONS
- Export Controls
- Industrial Security



Aether Spy



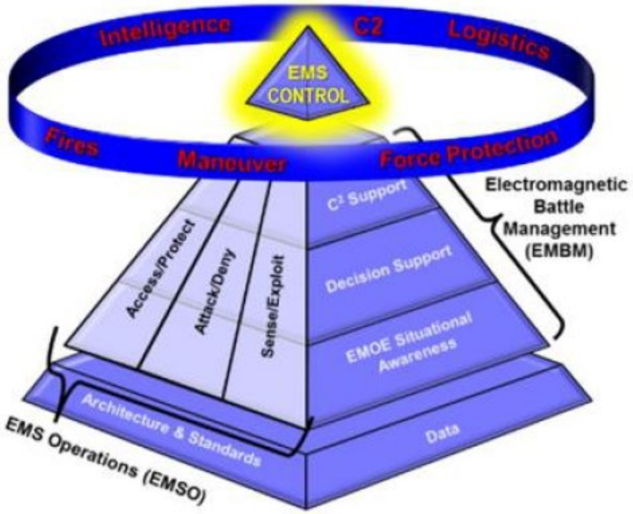
DA/RC

Jennifer

Great Power Competition

CHINA & RUSSIA
- Heavy investment
- Traditional platforms
- In volume
- Targeting U.S. capabilities

US NEEDS
- Leap-Ahead Technologies & Tactics
- Mosaic Warfare
- Attritable Platforms



Government Policy Recommendations

- Continue stressing **skilled labor**, with an emphasis on EW
  - Functional Training
  - STEM Education
  - Increased Pay
- Invest in **competition** within the EW industry
  - Continued Solicitations
  - Performance and Schedule > Cost
- Hold industry to **standards**
- Create **tax incentives** for long-term investments in relevant innovation
- Consider **export control reforms**
  - Intentional Technology Exchange
  - Industry Growth

NG Policy Recommendations

- Invest in **skilled workforce**
  - Functional Training
  - Incentives
- Increase **investment in EMSO**
  - First to Market
  - Multifunction, Multidomain Solutions
- Consider new ways to **address misconduct**
- Continue to emphasize **supply chain management**
  - Second Suppliers
  - Trusted Foundry

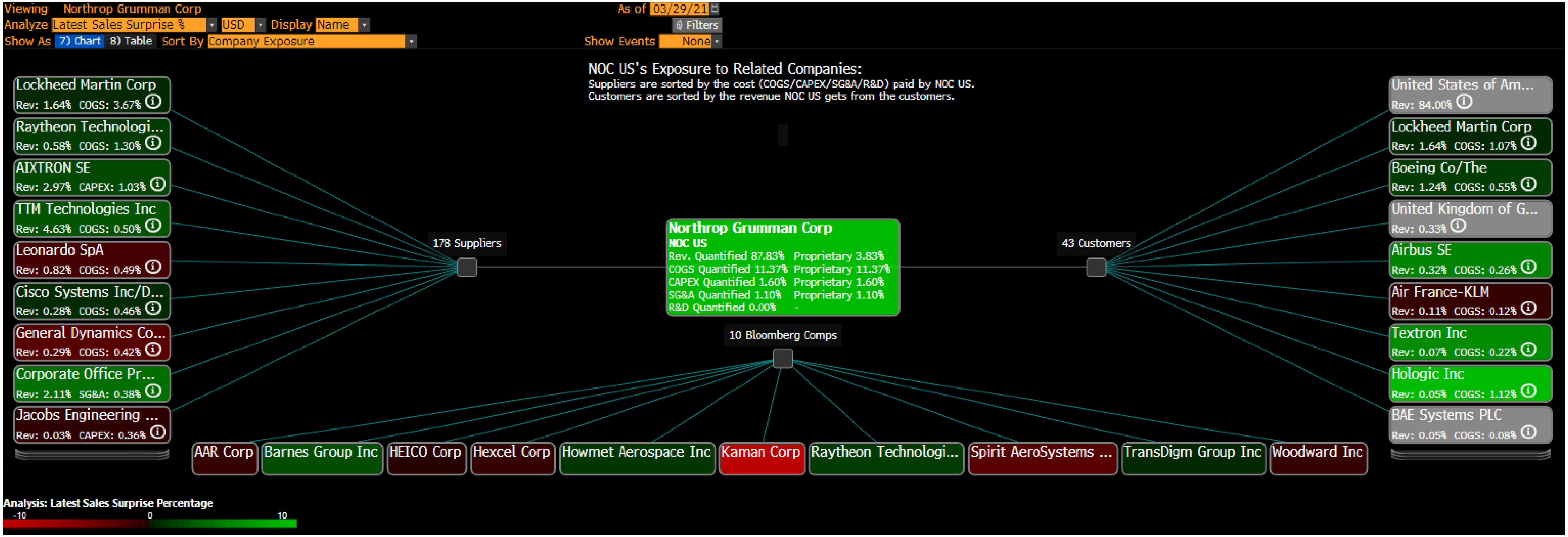
Conclusion

- The Firm and Segments are creating value at an appropriate level of risk
- The Firm is proactive in aligning segments in anticipation of Government need
- Competes in niche markets by traditional rules vertically (prime and sub) and horizontally (domain and service)

Questions

Backup Slides

NG Supply Chain per Bloomberg

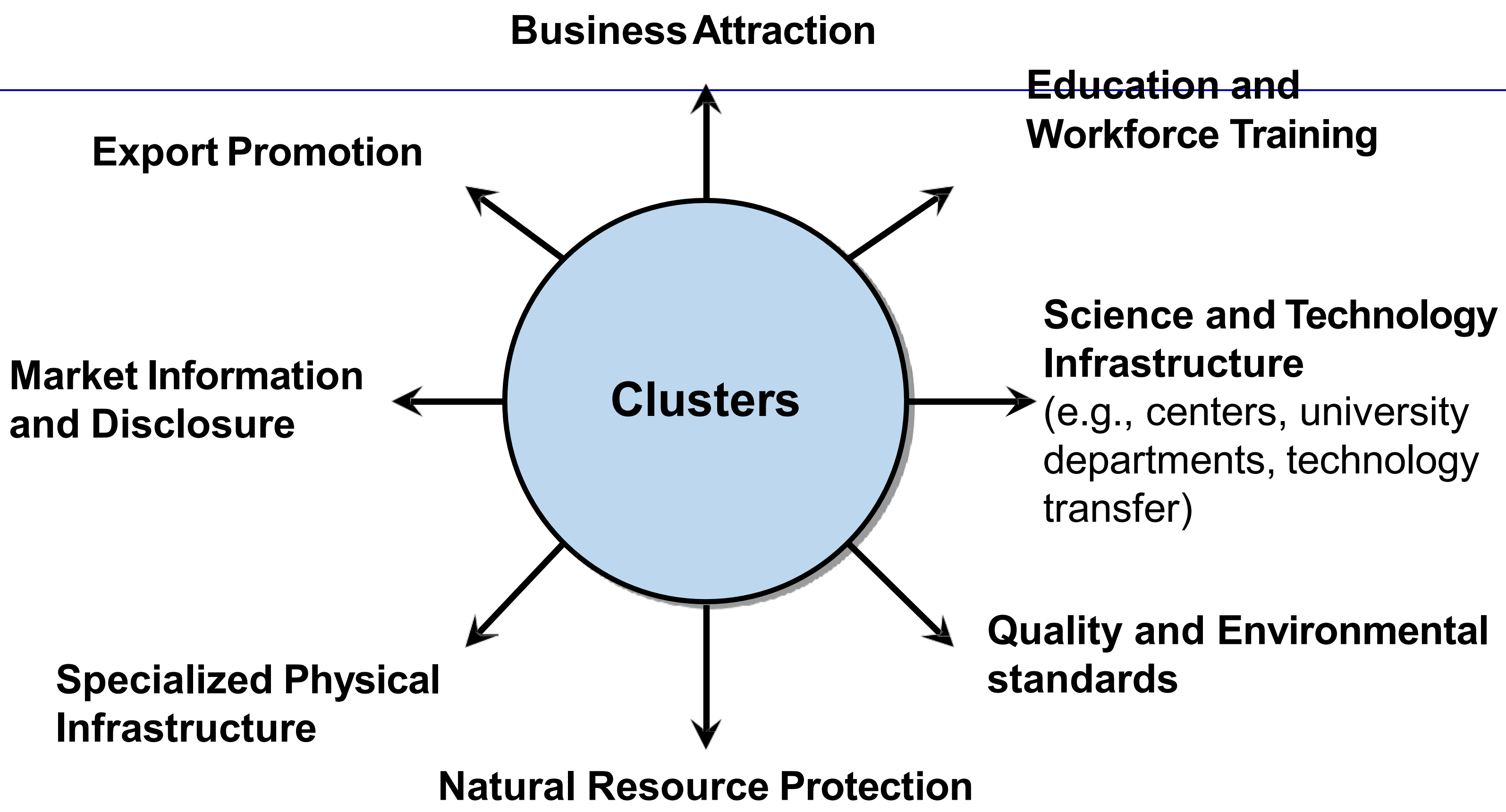


A Word on the EW Market

- Not a monopsony.
  - DoD depends on threats and Congress to set demand.
  - Producers require incentives to produce in quantity.

… DoD does not retain full price setting power.

Public Policy around Clusters



- Clusters provide a framework for **organizing the implementation** of many public policies and public investments directed at economic development to make them more effective

Top 10 Take Away's

- NGC Overall Profile

1.

- Structure

2.
3.

- Performance

4. The Firm and Segments are creating value at an appropriate level of risk
5. The Firm is proactive in aligning segments in anticipation of Government need

- Conduct

6. Competes in niche markets by traditional rules vertically (prime and sub) and horizontally (domain and service)
7. Incremental innovator favoring Naval systems

- Policy

8.
9.
10.

Drivers of National Competitiveness

[redacted]

Quality of the Business Environment

State of Cluster Development

Sophistication of Company Operations and Strategy

[redacted]

Sound Monetary and Fiscal Policies

Human Development and Effective Public Institutions

Endowments

- Productivity ultimately depends on improving the **microeconomic capability** of the economy
- **Many things matter**; there is no silver bullet

Jennifer

Couse vs. Rubric Crosswalk

Introduction
Briefer: Iggy
Time Goal: 3m

Structure
Briefer: Iggy
Time Goal: 10m

Performance
Briefer: Dayle
Time Goal: 8

Conduct
Briefer: Jeff
Time Goal: 8

Policy
Briefer: Jennifer
Time Goal: 8

Take Away's
Briefer: Jennifer
Time Goal: 5

Lesson	Module and Title
	MODULE I (Lessons 1-5) – Business Mission, Markets, and Industry Structure
1	Course Overview and the Mission of Business: To Maximize Shareholder Value
2	Markets I: Concepts
3	Markets II: Policy
4	Industry Structure and Porter's Five Forces
5	Application of Porter's Five Forces to Firm-Briefs Firms
	MODULE II (Lessons 6-10) – Financial Analysis of Corporate Performance
6	Financial Statement Analysis I: Concepts
7	Financial Statement Analysis II: Applications Couplet
8	Financial Statement Analysis III: Applications Couplet
9	Net Present Value Creation / Decision-Making Rule
10	Market Analysis Paper and Brief Out
	MODULE III (Lessons 11-15) – Corporate & Business Strategy
11	Strategic Game Board
12	Innovation and Strategic Change
13	Firm Boundaries and Corporate Strategy
14	Strategy Applications to Smartphone Industry
15	Global Strategy
	MODULE IV (Lessons 16-20) – Industrial Policy, Great Power Competition, and National Security
16	National Competitiveness and Porter's Diamond Model
17	Defense Markets and Monopsony/Bilateral Monopoly
18	National Security Technology Innovations and DARPA
19	Defense Readiness, Surge, and Mobilization at the Industry Level
20	Great Power Competition in the Global Semiconductor Industry
	Module V (Lessons 21-25) – Firm Briefs and Final Processing
21	Firm Briefs 1
22	Firm Briefs 2
23	Firm Briefs 3
24	Firm Briefs 4
25	IS INTEGRATION

Total Time Goal: 42m

Your firm briefs ***story must*** include

A. Firm profile (location, size, history, etc.).
B. Overall firm strategy – the markets it competes in and why.
C. Analytical boundaries of the *relevant* market or markets the firm competes in (the four defining characteristics and position on the competitive spectrum).
D. Structure of the relevant industry or industries that the firm competes in (Five Forces, etc.) ***and how this is changing.***
E. Identification of which of the forces are most important to the firm's success in each industry identified.
F. Identification of peer competitors in the market.
G. The firm's strategy in each market to maximize profitability, given the structure of the industry (Strategic Game Board, Rumelt, etc.)
H. Key means by which the firm pursues its strategy/strategies (R&D, M&A, lobbying, integration vs. diversification, international, etc.).
I. Distinct activities of the firm that are relevant to its strategy.
J. Whether there is alignment among those activities and the overall strategy.
K. The type of innovation the firm engages in and why.
L. The firm's approach to industry change. Potential supply-chain vulnerabilities (e.g., runs through China? Weak suppliers/subs?).
M. Human capital challenges?????????????????.
N. The (best available) metrics to answer the question: Is the firm creating value at an acceptable level of financial risk?
O. Your firm briefs ***story must*** conclude with the key findings relevant to the IS:
   A. An evaluation of the firm's ability to meet U.S. national security needs in the industries covered by the industry study.
   B. Policies (firm and governmental) required to improve the ability of the firm to do so.
P. be sure to address in a substantive manner the following topics of special emphasis in the IS program as they relate to your specific firm-brief firm
- National innovation system dynamics and priorities, including emerging/disruptive technologies and implications for corporate sector strategies.
- Industrial security, supply chain management, trade, industry.
- Market-specific focus on great power competition with Russia and China.
- Readiness, surge, and mobilization.
- Ethics.

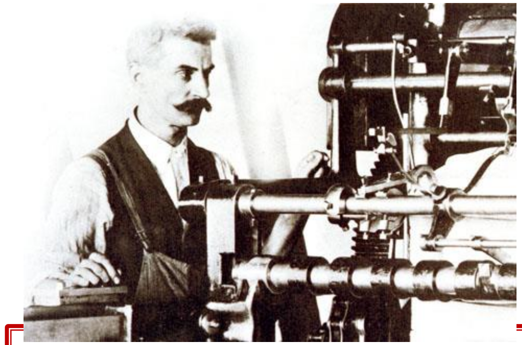
L3HARRIS

Assessment Team Members: Brian Caplin, Dave Danner, Ray Feltham, Shawn Herron

Agenda

- Firm History and Profile
- Ethics and Culture
- Business Segments
- Defense Readiness and Mobilization
- Porters Five Forces
- Market Analysis
- Firm Value
- Supply Chain
- Human Capital
- Strategy Analysis
- National Security Policy Considerations
- Key Findings and Policy Recommendations

Company History: Growing—Together



HARRIS

L3 Technologies

Growth and Transformation…

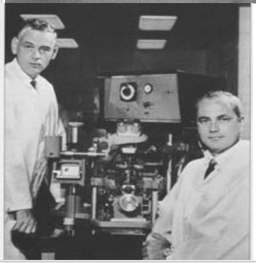
- Founded 1890
  - Printing Industry
- Transition to electronic communications 1950s – 1960s
- 1967 – Acquisition of Radiation, Inc.
  - Space and military technology manufacturer
- 1974 – Moved to Space Coast (Melbourne, FL)
- 1983 – Sale of printing business – 100% electronics focus
- 2015 – Acquisition of ITT Exelis – Broad Defense focus

Growth Through Acquisition…

- Founded 1997 (Lanza, LaPenta & Lehman Bros.)
  - Acquired Paramax Systems Corporation from Lockheed Martin (Unisys Defense/Loral)
- 2000-2018 – 25+ acquisitions
  - Primarily Defense systems related
  - Spanning all warfighting domains
  - Several from major Defense contractors
    - (Raytheon, Boeing, General Dynamics)

"Merger of Equals"
Finalized June 29, 2019

L3HARRIS™
FAST. FORWARD.



Company Profile

Locations and Workforce
- Headquartered in Melbourne, FL
- Over 100 Facilities Worldwide
  - 51 metropolitan areas in the US
  - 36 International metropolitan areas
- 48,000 employees worldwide
  - 88% in the US

L3HARRIS

Merging of Business Cultures
- Harris
  - “Management” Company
- L3 Communications
  - Holding Company
- Impending Leadership Transition
  - From Harris CEO to L3 CEO

William M. “Bill” Brown

Businesses and Revenues
- Four Business Units
  - Integrated Mission Systems
  - Space and Airborne Systems
  - Communication Systems
  - Aviation Systems
- Annual Revenue of $18B+

Christopher E. “Chris” Kubasik

Ethics & Culture

Corporate Values

- Integrity, Respect, Excellence
- Code of Conduct – Customer, supplier and employee relationships and ethical standards
- Employee Helpline (reporting harassment, fraud, etc.)

Inaugural Sustainability Report (2021)

- Environmental impact reduction goals (2026)
  - Greenhouse Gas Reduction
  - Solid Waste Landfill Diversion
- Social
  - Diversity Goals
  - COVID Response
  - Community Volunteerism, STEM Education Grants
- Governance
  - Established BoD strategic oversight processes
  - Implemented enterprise risk management process
  - Expanded ethical and compliance review boards

COVID Response – Utilitarianism

- Internal
  - PPE and other safety precautions for employees
  - Remote work for ~20,000 employees
- External
  - $2M commitment to non-profits for COVID relief
  - $450M in accelerated payments to SB suppliers
  - Community volunteerism by employees

Corporate Strategy – Ethical Egoism

- Advance payments to suppliers preserves potentially fragile supply chains
- Stock repurchases following divestments of non-core businesses
- Maximize value for shareholders

AWARDS AND RECOGNITION

FORTUNE WORLD'S MOST ADMIRED COMPANIES 2021

HUMAN RIGHTS CAMPAIGN

Bloomberg Gender-Equality Index

Forbes | 2020 WORLD'S BEST EMPLOYERS

Great Place To Work. Certified

Business Segments

Integrated Mission Systems (Palm Bay, FL)
- Multi-mission C4ISR systems
- Integrated electrical and electronic systems for maritime platforms
- Advanced electro-optical and infrared solutions

Space and Airborne Systems (Palm Bay, FL)
- Space payloads, sensors and full-mission solutions
- Classified intelligence and cyber defense
- Avionics
- Electronic warfare

"Space Coast" Cluster
- *Surge in Defense and commercial space-oriented businesses*
  - *Prior Harris & L3 presence*
  - *Major Defense primes (Lockheed, Boeing, Northrop Grumman)*
  - *Blue Origin (Bezos – "New Glenn" heavy lift rocket)*
  - *One Web (UK, Bharti (India) – 5G constellation)*
- *Skilled Labor Force (Satellite launch and assembly)*
- *Prox. to Cape Canaveral SFS, Patrick SFB (Space launch ops, AFTAC)*

Communication Systems (Rochester, NY)
- Tactical communications
- Broadband communications
- Integrated vision solutions
- Public safety

Legacy Facility (Possible emerging cluster?)
- *Fmr Harris Communications – Longstanding Rochester NY presence*
  - *3900+ Employees (5000+ statewide) – as of 2020*
  - *Includes Smaller Space & Airborne Systems contingent*

Aviation Systems (Arlington, TX)
- Defense aviation products
- Security, detection and other commercial aviation products
- Mission networks for air traffic management

N. Texas Aerospace Cluster
- *Fmr L3 Technologies Facility – Significant N. Texas presence*
  - *7800 employees in greater Dallas-Ft. Worth area – as of 2018*
  - *Second largest N. Texas manufacturer (after Lockheed-Martin)*
  - *Raytheon, Bell Helicopter,*

Global Business and Opportunities

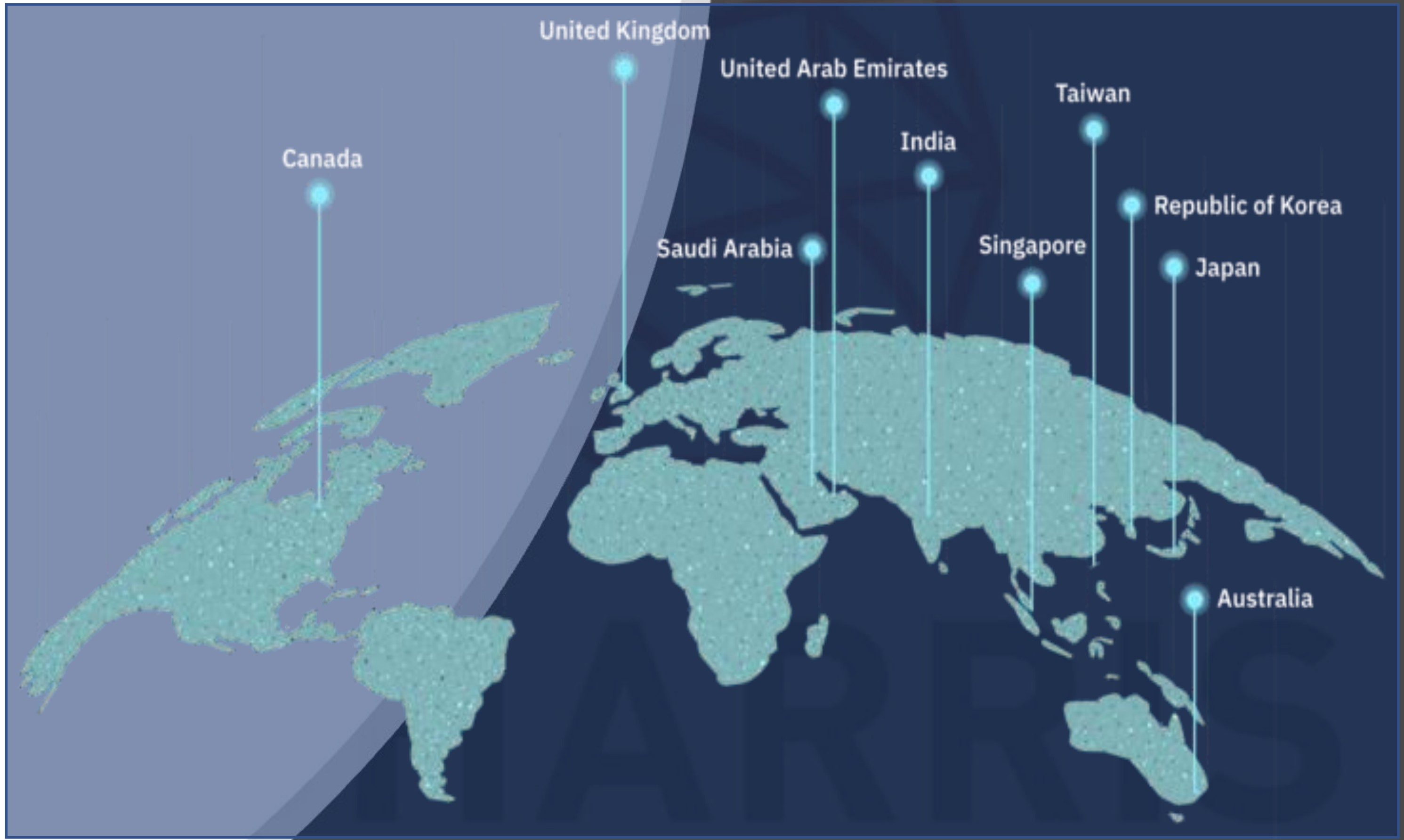
Australia
- ***500+ Employees***
- Tactical Comms, EW

Canada
- ***2300+ Employees***
- Multi-spectral Imaging
- Tactical Comms
- Air Traffic Mgmt

India
- EO/IR/ESM Systems
- Tactical Comms

Japan
- Space-based systems and sensors
- Battlefield Networking

Saudi Arabia
- Tactical Comms
- Battlefield Networking



Singapore
- ***SE Asia Regional Hub***
- Tactical Comms
- USVs
- Avionics

South Korea
- Air & Maritime Comms
- EW and EO/IR Systems

Taiwan
- Battlefield Networking
- Avionics and EW

UAE
- Digital C4I
- Geospatial Sensors

United Kingdom
- ***2000 Employees***
- Airborne Warfare
- Tactical Comms
- USV
- ISR Sensors

Defense Readiness, Surge, and Mobilization

Surge/Mobilization Enabling Factors

- Deliberate integrated planning processes
- Large cash reserves
- Diverse product lines
  - Leverage engineering capabilities across multiple business sectors: Antennas, arrays, precision direction finding, platform integration, advanced capabilities
  - Potential for flexible response depending on DoD Requirement
- Multiple locations worldwide (incl. manufacturing)
  - Familiarity with partners/local factors that could facilitate increased demand
  - Potential for offshore production if required
- Technology-heavy/savvy workforce
  - Over 67% are “Gen X” or younger
  - Ability to move to multiple shifts
  - Cross-training to eliminate single point of failure SMEs

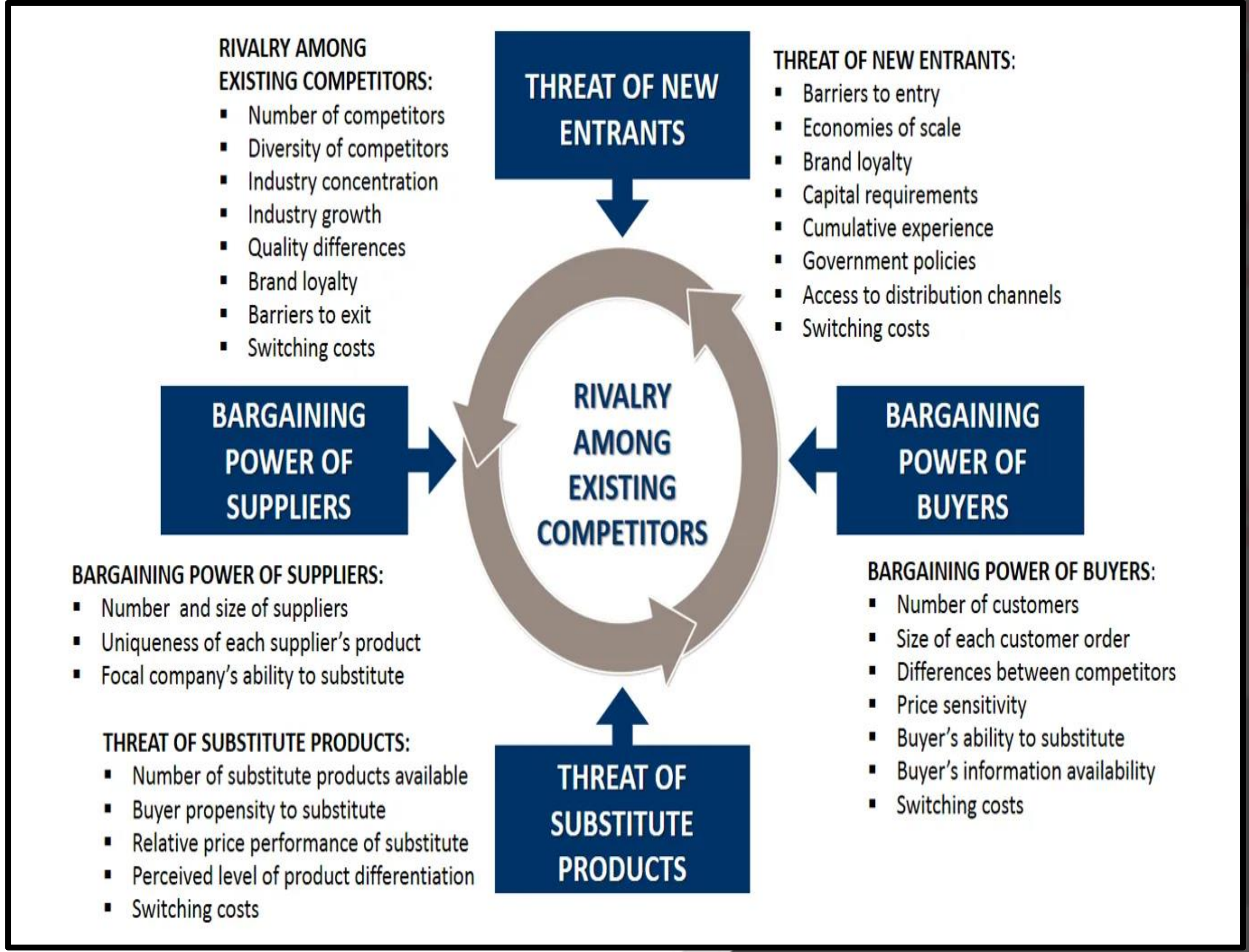
Surge/Mobilization Limiting Factors

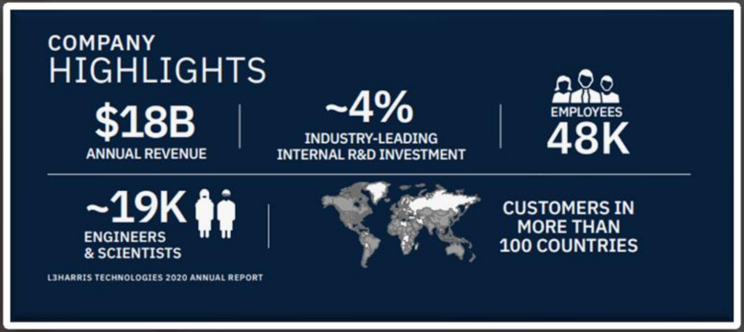
- Workforce
  - Competition with suppliers/other defense contractors for skilled production workers
  - Some non-interchangeable skillsets
- Supply chain – Semi-fragile
  - Some products require rare earth minerals
  - Some products rely on sole-source suppliers
- Platform availability/integration
  - Field installation and training

Policy Recommendations

- STEM workforce development and expansion
  - Academic outreach and financial support
- Improving supply chain resilience

L3 Harris' Four Business Segments and Porters 5 Forces



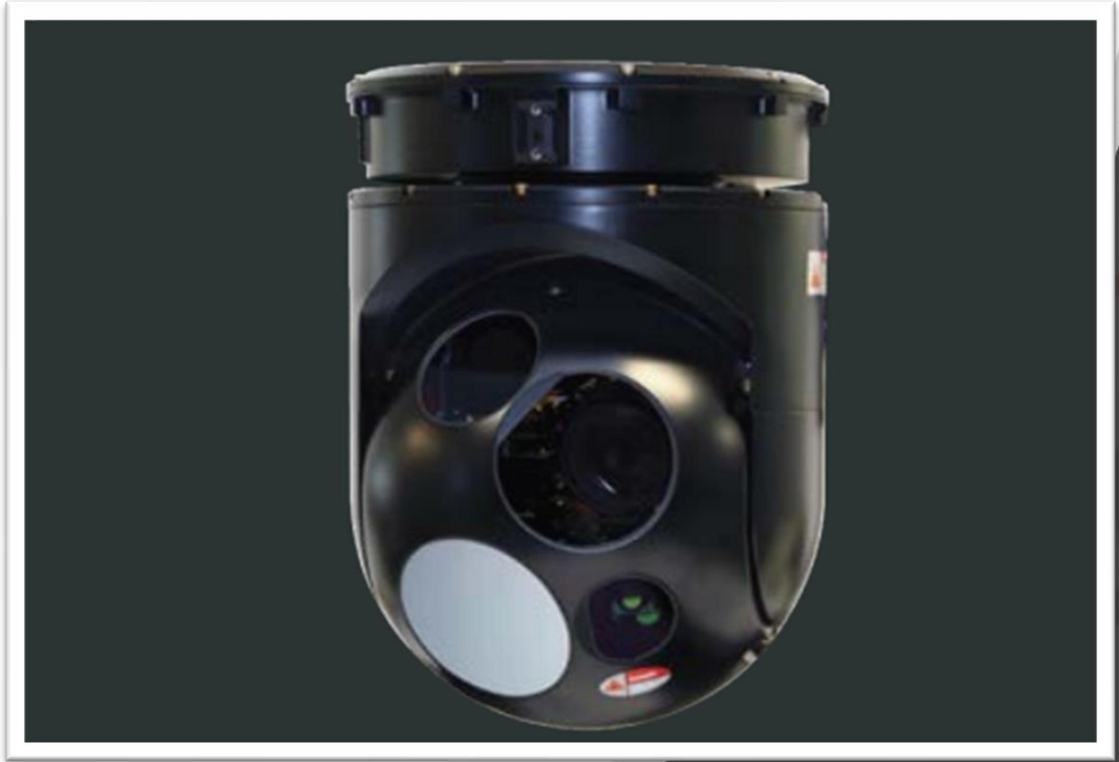


Business Segments and focused Markets

- Integrated Mission Systems:
  - ISR
  - EO
- Space and Airborne Systems:
  - Space
  - EW
- Communication Systems :
  - Tactical Communications
  - Broadband Communications
- Aviation Systems:
  - Defense Aviation
  - Mission Networks

Integrated Mission Systems

A Small, Multi-Sensor, Multi-Spectral Imaging System in a Single Line Replaceable Unit (LRU) - The WESCAM MX-10 is ideal for low-altitude, tactical surveillance & search and rescue (SAR) missions requiring low-weight installation flexibility.



Electro-Optical/IR

Design and manufacture advanced EO/IR sensors and surveillance and targeting systems and provide modernization and life extension maintenance upgrade and support services for military aircraft.

Information, Surveillance and Reconnaissance (ISR)

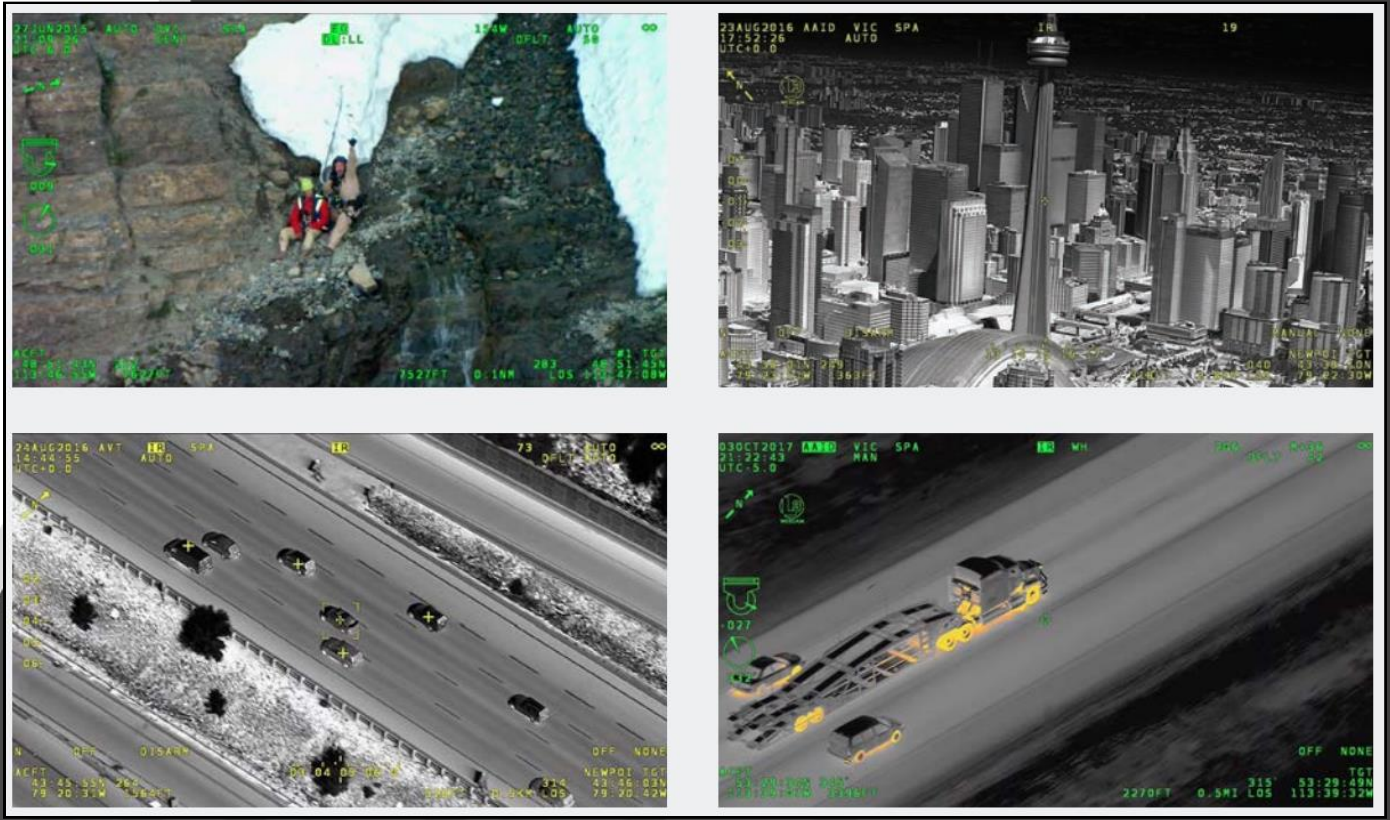
Develop, integrate and maintain multi-mission ISR and communication systems, including fleet management support services, sensor development, modifications and periodic depot maintenance for ISR and airborne missions.

EO/ISR and Actionable Intelligence

Threat of New Entrants:

- It is difficult to join the marketplace –
  - the level of technology
  - Consent innovation
  - Capital requirements

- Threat of Substitutes:
  - An established competitor currently operating effectively may consume a potential revelry – aiding in market share and profitability.
  - Customer Switching cost



Action: Continue to canvas EO/ISR marketplace for potential new technology and ideas from competitors, academia and government innovation factories such as DARPA or WERXs.

Bargaining Power of Customers - Common Across all Four Business Segments

- Buyer concentration to firm concentration ratio
  - Highly competitive EO/ISR defense market
- Degree of dependency upon existing channels of integration
- Bargaining leverage from current platform reliance with high fixed costs

Action: L3Harris' ability to own and control IP in the EO/ISR markets will reduce the bargaining power of customers and the ability of customers to put the firm under pressure and the customer's sensitivity to price changes. Alternative are available, however, limited due to L3H data rights.

- Significant customers include:
  - (EO) National Aeronautics Space Administration, DoD, USN, the U.S. Air Force ("USAF"), select foreign militaries and commercial space companies.
- (ISR) DoD and classified customers within the U.S. Government, U.K. Ministry of Defense, Royal Australian Air Force and other select foreign military services.

✓ 77 percent was derived from sales to U.S. Government, including foreign military whether directly or through prime contractors

✓ 67 percent was derived from contracts under which L3H is the prime contractor

✓ 21 percent was derived from products and services for which the end consumer is located outside the U.S.

Bargaining Power of Customers - Common Across all Four Business Segments

Potential factors:

- Continue long term cost and supply agreements
- Further of differentiation of inputs with international purchasing where practical
- Impact of inputs on cost and differentiation
- Presence of substitute inputs
- Strength of distribution channel
- Supplier concentration to firm in US and business location
- Where able avoid China supply chain dependance

Action: L3Harris' ability source suppliers to maintain a timely provisioning of raw materials, labor and services necessary for end to end support will be key. Seek to further strategic supply relationships

Competitive Rivalry – Common Across all Four Business Segments

LESS IS MORE – DIVESTING TO STREAMLINE

Potential Factors

- Sustainable competitive advantage through innovation (4% or $684M)
    - A technology-focused operating Key investments in advertising
    - Open systems architecture
    - Multi-function system capabilities
    - Software-defined solutions
- Company and becoming a full end-to-end mission solutions prime contractor to drive shareholder value

L3Harris competes domestically and internationally against several large aerospace and defense companies:
BAE Systems, Boeing, Northrop Grumman
General Dynamics, Raytheon Technologies
Lockheed Martin, Thales - *NOT A PRIME - PRIME

Competition is increasing from non-traditional defense contractors

Space and Airborne Systems and Aviation

- **Revenue for SAS is predominantly derived as a prime, supporting U.S. Government contracts-**
  - Departments
  - Agencies
  - Prime contractors

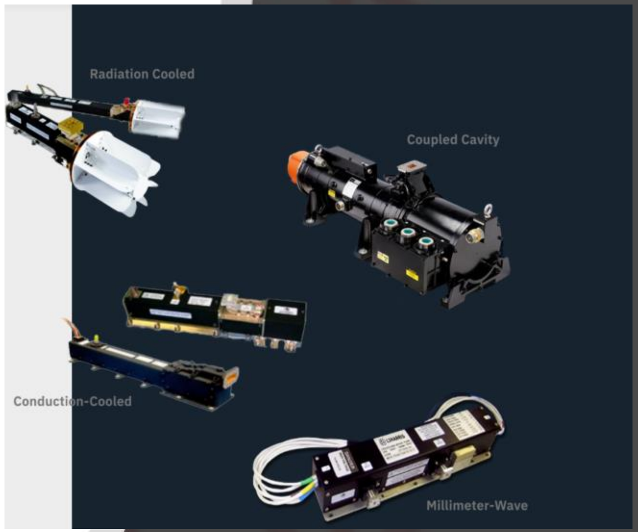
- **Space -**
  - L3H provides space vehicles, payloads and mission software integration
  - Supports next-generation development of satellite system to protect against advanced missiles
  - Demonstrates newly merged L3Harris mission solutions in missile warning and tracking

- **EW –**
  - In the SAS Business sectors provides support across the company Sea Air Land and Space
  - Offensive – Defensive and Support

- **Defense Aviation** - Precision engagement sensors and systems, small UAVs, antennas and arrays, radiofrequency amplifiers and microwave electronic devices
- **Mission Networks** – Critical Information Structure for the FAA

Threat of New Entrants – Space and EW

- The monetary makes it enticing to join the marketplace – may balance the force for entry
  - the level of technology
  - Consent innovation
  - Capital requirements
  - Established performance
  - Demand to ensure access (physical and EMSO)
- Threat of Substitutes:
  - An established competitor currently operating effectively may consume a potential revelry – aiding in market share and profitability.
  - Customer Switching cost



Traveling wave tube (TWT)

Used for radio frequency (RF) amplification at microwave frequencies the primary means of signal amplification utilized in SAT-Comm.

- XM satellite radio
- Use a credit card,
- Watched satellite television
- Long-distance telephone calls

- Viper Shield AN / ALQ-254(V)1 All-digital Electronic Warfare Suite – Leveraged EW technology across cutting
- L3Harris Technologies $104 Million Contract for F/A-18 Electronic Warfare System Sept 2020
- B-1B BOMBER ELECTRONIC WARFARE SYSTEM (June 2020)

Communication Systems

Comms Systems: 24% of total L3Harris revenue
Tactical & Broadband Communications: provided to U.S. Army, USAF, U.S. Marine Corps, USN, SOCOM and international defense customers

- 69 percent was derived from sales to U.S. Government customers, including foreign military sales funded through the U.S. Government, whether directly or through prime contractors;
- 70 percent Prime contracts; and
- 28 percent from products and services for which the end consumer is located outside the U.S

Cornerstone of Harris prior to the L3 – Harris merger -- 24 percent of our total revenue

Tactical Communication

Software - defined Handheld, Manpack and Small Form-Fit ("HMS") radios to the U.S. Army.

BB Comms –

Develop, design, manufacture and integrate broadband secured mobile networked Comms for airborne, space and surface data link terminals, ground stations and transportable tactical satellite communication ("SATCOM") systems used on manned aircraft, unmanned aerial vehicles ("UAVs") and naval ships. Significant customers include U.S. defense and intelligence agencies.

- Dual-use options make the market more assessable to traditional telecom companies – may increase competition for entry
  - the level of technology
  - Consent innovation
  - Capital requirements
  - Established performance
  - Software Defined enhances capability and support
- Threat of Substitutes:
  - An established competitor currently operating effectively may consume a potential revelry – aiding in market share and profitability.
  - Customer Switching cost
  - Decreased with strategic partnerships and customers (Raytheon and FAA)

Market Assessments Summary

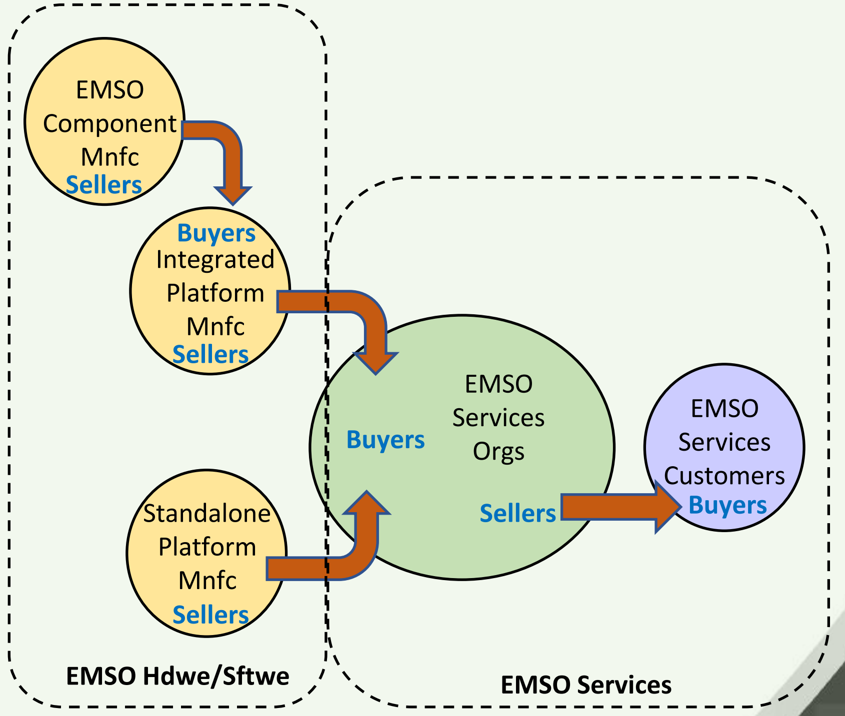
- Market Assessment(s)
  - Strongest Force
  - Concerns
  - Breaking Rivalry (Co-Frenemies)
  - Data "Gongulator"
  - Type of Markets

- International Business
  - Opportunities
  - Concerns
  - Firewalls

- Great Power Competition


Market Analysis – Firm EMSO Products

Electromagnetic Spectrum Operations(EMSO) Product Market



Modified from: Clark Groves, "Perspectives on Offensive and Defensive Space Operations: Space as a Warfighting Domain" (unclassified briefing presented November 2020, Fort McNair, DC),

Buyer: Near monopsony. Seller: Oligopoly

EMSO Market Characteristics

- EMSO Product Sellers
  - Subcomponent makers – hardware/software
  - Prime vendors – integrated and standalone platforms
- EMSO Product Buyers - EMSO Services Organizations and Services Customers
  - Governments
    - USG – Defense and Civil
    - International
    - State and local
    - Private commercial (e.g., airlines)
  - Prime vendors – integrated platform

L3Harris in prime and sub-k roles

- 60% of revenue as a prime
- 80% of revenue from USG (includes FMS)
- 20% of revenue from international end user

Market Analysis Financials (1 of 2)

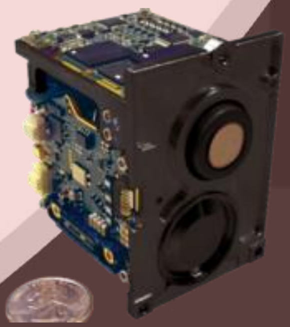
Integrated Mission Systems

- Revenue: $5.54B
- Revenue Growth: 0%
- Operating Income: $847M
- Income Growth: 0%
- Operating Margin: 15.3%
- ROIC: 7.82%
- Assets: $8.91B
- **Value (ROIC above WACC): -0.23%**

- Revenue generated from USG (includes FMS): $4.26B (77%)
- Revenue generated as Prime: $3.72B (67%)
- Revenue generated from international sales: $1.15B (21%)

ISR: WESCAM MX

EO/IR: Onyx Infrared Sensor



Space and Airborne Systems

- Revenue: $4.95B
- Revenue Growth: 14%
- Operating Income: $932M
- Income Growth: $14%
- Operating Margin: 18.8%
- ROIC: 11.07%
- Assets: $6.93B
- **Value (ROIC above WACC): 3.02%**

- Revenue generated from USG (includes FMS): $4.46B (90%)
- Revenue generated as Prime: $2.67B (54%)
- Revenue generated from international sales: $0.743 (15%)

Space: HYPERCUBE Infrared Sounding and 3D Wind Measurement

EW: AN/ALQ-214 (IDECM) F/A 18 Countermeasure System

Market Analysis Financials (2 of 2)

Communication Systems

- Revenue: $4.43B
- Revenue Growth: 33%
- Operating Income: $1.08M
- Income Growth: 30%
- Operating Margin: 24.4%
- ROIC: 8.75%
- Assets: $5.75B
- **Value (ROIC above WACC): 15.5%**

- Revenue generated from USG (includes FMS): $3.06B (69%)
- Revenue generated as Prime: $2.60B (70%)
- Revenue generated from international sales: $0.32B (28%)

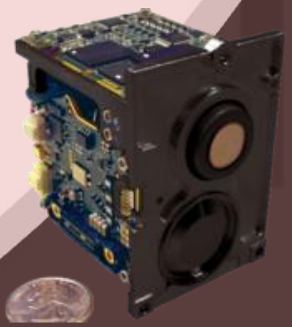
Aviation Systems

- Revenue: $3.45B
- Revenue Growth: 0%
- Operating Income: -$177M
- Income Growth – 0%
- Operating Margin: -5.10%
- ROIC: -0.29%
- Assets: $5.03B
- **Value (ROIC above WACC): -8.08%**

- Revenue generated from USG (includes FMS): $2.45B (71%)
- Revenue generated as Prime: $2.25B (65%)
- Revenue generated from international sales: $0.62B (18%)

ISR: WESCAM MX

EO/IR: Onyx Infrared Sensor



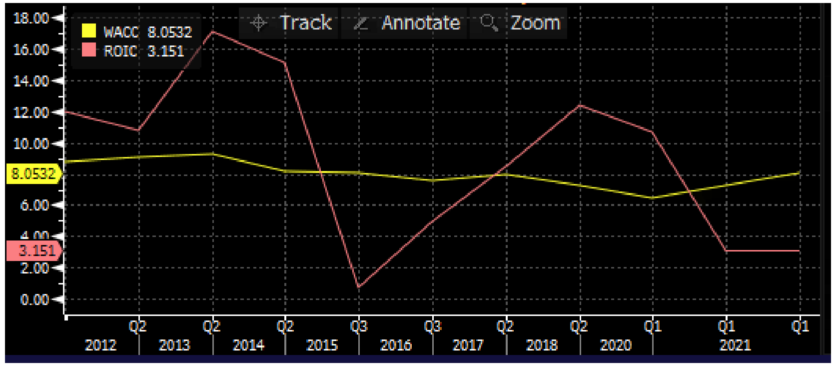
Defense Aviation: Military Airborne Surveillance System (MASS)

Mission Systems: Rotodome – Airborne Early Warning Antennas and Rotary Couplers

Firm Value Creation

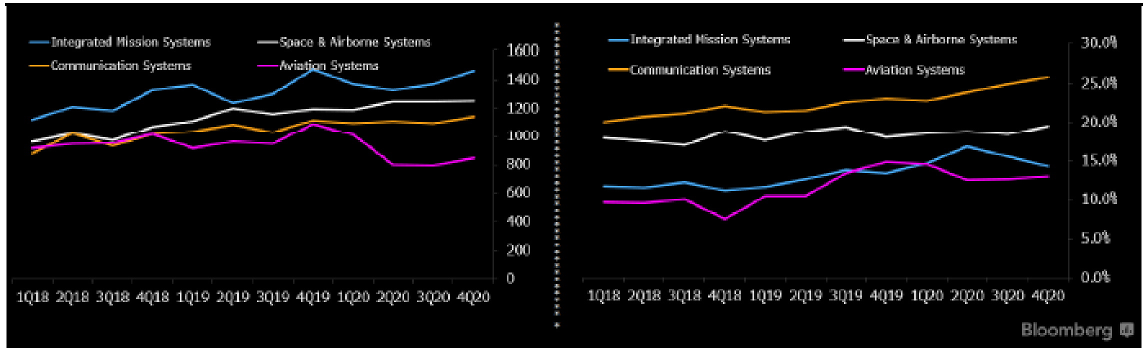
Key Value Indicators

- - 4.9% Value Creation in FY20 (WACC > ROIC)



Source: Bloomberg

Revenue and Operating Margin by Segment

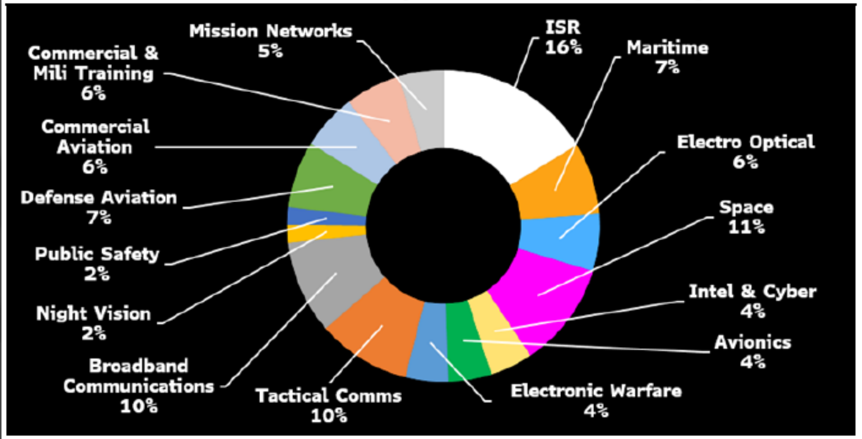


Source: Bloomberg Intelligence

Key Value Indicators

- Revenue increase 1% to $18.2B
- Organic revenue growth: up 2.9%
- Earnings per share: up 13%
- Backlog: Funded up 3.4%, Un-funded up 7.6%
- Free cash flow (FCF): $2.9B
- New $6B share repurchase program and 20% dividend increase
- R&D Spend: ~4% of revenue (~$684M)
- Positive Debt-to-Equity (0.78) and Current Ratio (1.57)

L3Harris Revenue by Product (Post-Merger)

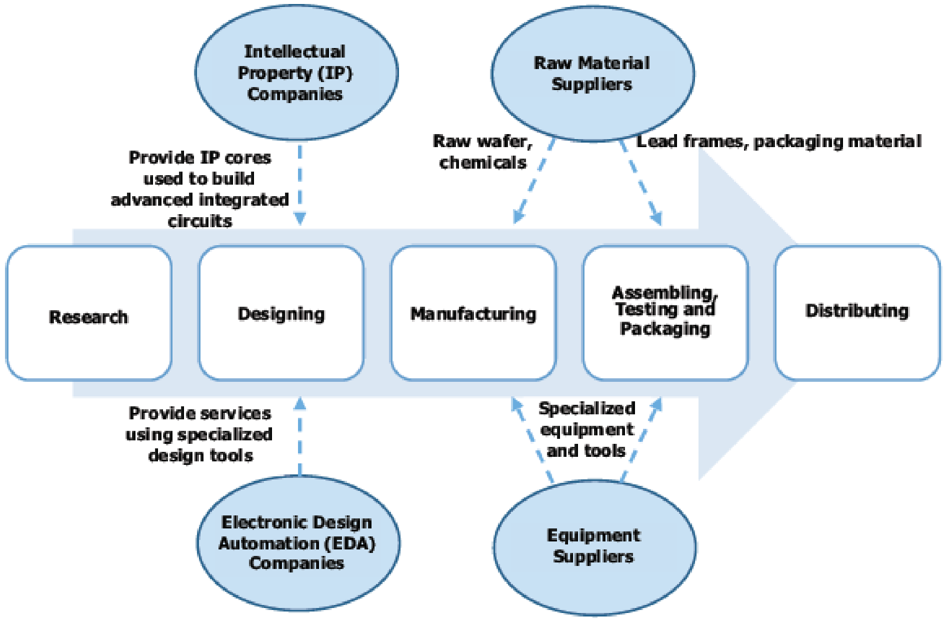


Source: Bloomberg Intelligence

Supply Chain

EMSO Product Supply Chain

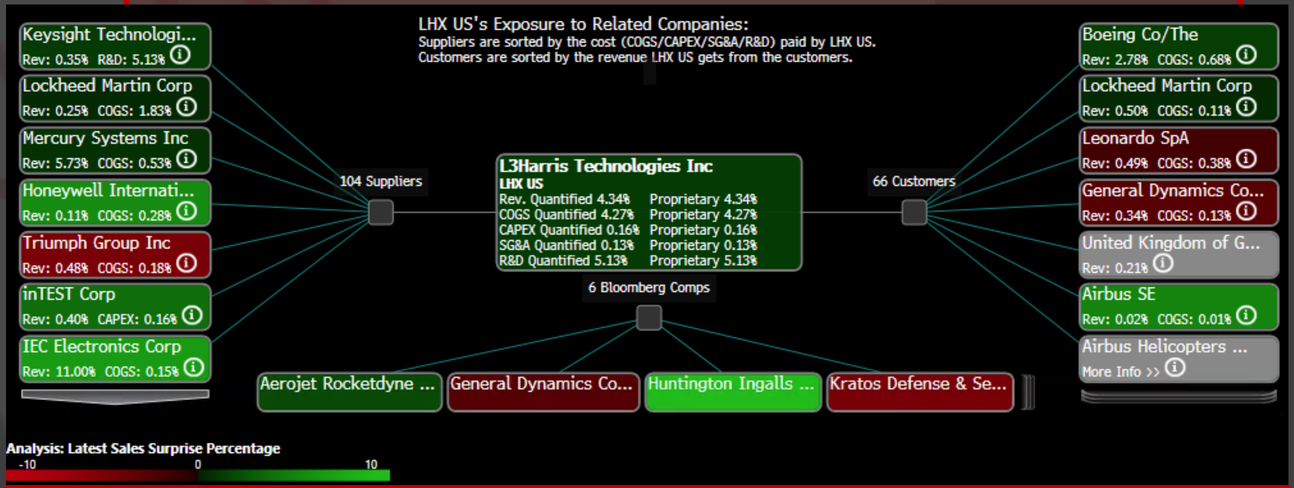
- **L3Harris position in the value chain**



Source: "Beyond Borders: The Global Semiconductor Value Chain," Semiconductor Industry Association, May 2016

Potential Supply Chain Vulnerabilities

- 104 suppliers, each with additional layers of suppliers
- L3Harris has 66 customers
- **No real visibility on supply chain sourcing below 2nd or 3rd level of sub-k**



Entire defense industry suffers from lack of visibility into full supply chain – raw materials to components to end products.

L3Harris Human Capital

Human Capitol Snapshot

- ~48,000 employees (88% based in the US)
  - 19,000 engineers and scientists
  - Security clearance (TS/SCI) required
- Competition with commercial industry
- Generational snapshot
  - 31% retire next 5-10
  - 35 % retire next 15-20
- Advantages
  - EW/EMSO provides **intellectual challenges** not found in commercial work
  - **Appeal of supporting US national defense mission** offsetting private sector pay differentials

Mitigating Actions

- Partnerships with university / STEM programs
- Production side (assembly) rigorous training program
- 60-year partnership with NASA
- E3 – excellence, everywhere, everyday

Strategy Analysis

<u>Corporate Strategy:</u>
•*Realign R&D Efforts to extend positions (multifunction; open architecture)*
•Revenue Synergies from L3 and Harris Merger (Space and EMS)
•Divestitures and portfolio shaping to drive shareholder value (margin; growth)

<u>Business Strategy:</u>
•*Increase International Sales*
•Modernization and Upgrades
•Multiyear contracts for niche requirement gaps

<u>Manufacturing Strategy</u>
•Current: Lean Manufacturing strategy
•Desired: Flexible manufacturing strategy

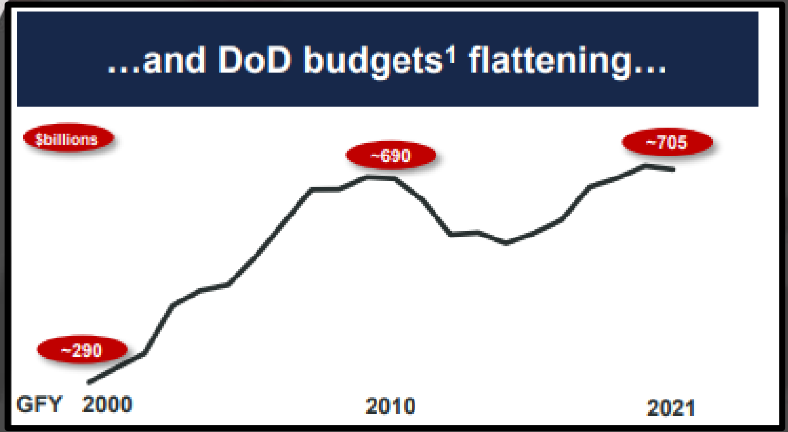
Muscle Movements include a…

- Changing Culture;
- Focus on R&D;
- Increase in Cashflow;
- Flattening Organization (nimble like big tech);
- Sprint to solutions (hypersonic tracking constellation)

Driving Factors

Onshoring:

- Supplier optimization and volume leverage…targeting ~35% reduction in suppliers since merger



"We're moving towards more of an integrated model where we're sharing ideas across the company...We had our technologists together at the end of September [and] started to share different ideas." The company intends to "invest ahead of the curve on innovation ahead of need" to meet the Pentagon's "affordable innovation now" desires, CEO Brown

Decrease Product Costs – Offset – Compete to Collaborate

SWOT Analysis

STRENGTHS

- Niche Exquisite Defense Products
- Strengths of Modernized Legacy Capabilities
- Large portfolio of Patent Products
- Increased Resources
- Talent for Rapid R&D Dev
- Cash Flow

OPPORTUNITY

- Multifunction Capabilities
- Increase Foreign Sales for China Threat
- Cash to invest in differentiated technologies
- Industry trends supporting long-term growth
- Advancing Cultural Turbulence

L3HARRIS™

WEAKNESSES

- Siloed Similar Business Segments
- DoD Flat Budget Expectations and Reliance
- Counter model toward priority R&D
- Policy Challenges with Foreign Opportunity

THREAT

- New Entrants increased Competition
- Chinese IP Theft
- Shortages of raw materials and semiconductors
- Decreased DoD Budget

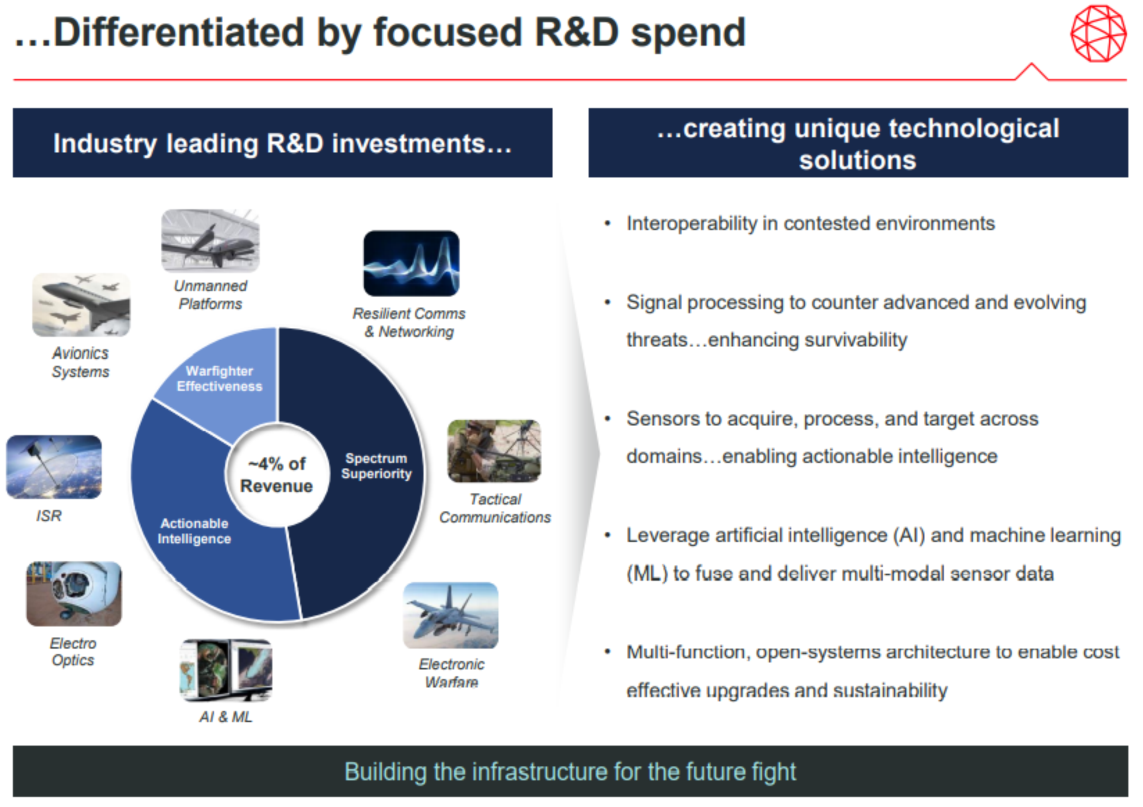
Restructuring

CLAN CULTURE+MERITOCRACY ➔DENISON-ADHOCRACY

Path: Vertical Integration through synergies

From: Four quasi-Diversified Business Segments
Upside similar engineering and business:

- **Opportunity for shared resources/activities**
- **Transfer skills among business units**
- **Increase Resources**



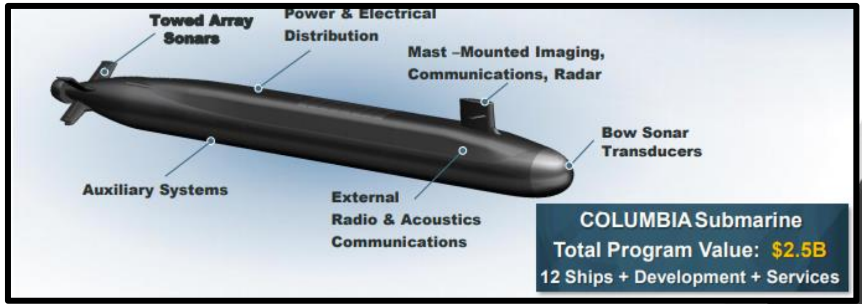
Mechanistic rigid form to a more Organic flexible form requires an integration strategy

Base Portfolio remains traditional...growth in providing relevant capabilities for future defense challenges

Dual Glidepath

Change in anticipation of the future and positioning for the present to meet shareholder expectations….

- Business of next gen Jammer and tac radios with a consistent base to remain a contributing firm to prime contracts. .
- R&D risks aligned with expected growth – increased power in the Columbia class sub and multifunction capabilities



National Defense Strategy

Insatiable Demand for Signals Intelligence

Peer competition driving increased US and International SIGINT demand

Resilient and Survivable Networks

Joint All Domain Command & Control connecting every sensor to every weapon

Global Force Projection

Focus on maritime superiority driving growth in number of ships, submarines, and unmanned vessels

Advanced Technologies and Capabilities

Pacing the threat … modernizing with affordable solutions

Key Findings and Policy Recommendations (1 of 2)

- Tax breaks for innovation that meet National Security Requirements
- Review of partnership export controls to reduce restrictions with measured mitigations with Quad Partners (Japan, India, Australia – L3Harris Int HQs)
- National Security defined taxonomy for open architecture; Closed systems deter innovation and competition (JADC2).
- Promote competition: deter current Defense Industrial Base Company Acquisition model

"Some consolidation is probably inevitable [because] the Defense Department isn't sized ... in many areas to maintain a large base, but extreme consolidation does create challenges for innovation." DepSecDef Kathleen Hicks, 2021

Key Findings and Policy Recommendations (2 of 2)

- Merger has positioned L3Harris to contend as a future large prime system integrator to support current National Security EMSO capability and capacity requirements
- Government Policies incentivizing STEM workforce
- Security of supply chain affects support to National Security Requirements; Surge capacity has LIMFACS
- L3Harris remains a critical defense manufacturer for National Security in an increasingly competitive technological trade space

Questions?

Team Raytheon Firm Briefing

Industry Analysis, Eisenhower School

Afeku, Bowers, Callow

Agenda

- Background (Afeku)
  - Profile
  - Strategy
  - Boundaries of the relevant markets
  - Structure of industries
  - Identification of forces most important and peer competitors
- Covid Impacts (Bowers)
- Strategy (Bowers)
  - Firm's strategy in each market
  - Key means of pursuing strategy
  - Distinct Activities and alignment with overall strategy
- Approach and Valuation (Callow)
  - Types of Innovation
  - Approach to changing industry
  - Potential supply chain vulnerabilities
  - Human capital challenges
  - Financial Risk
- Recommendations/Conclusions (All)

Mission and Vision

- **Mission: Affordable Quality Solutions On-time, Every Time: At Raytheon, everything starts with the customer. We strive to solve their toughest challenges in an environment with little room for error**

- **Our VISION reflects that focus: We are one global team creating trusted, innovative solutions to make the world a safer place.**
  - We are one global team, across our company and with our suppliers and partners because innovation comes from a diversity of thought and ability.
  - We provide trusted, innovative solutions that work the first-time every time because customers are focused on the mission and their lives are depending on our technology.
  - We make the world a safer place by delivering affordable products to customers who face existential threats with limited budgets.

Firm Profile - Raytheon Technologies

Background

- Raytheon Technologies (NYSE: RTX) is an aerospace and defense company that provides advanced systems and services for commercial, military and government customers worldwide.
- The company was formed in 2020 through the combination of Raytheon Company and the United Technologies Corporation aerospace businesses, and is headquartered in Waltham, Massachusetts.

Firm Size

- Employees = 181,000
- Engineers = 61, 000
- Patents = 46,000
- Pro Forma Adjusted Revenue = $64.6 Billion
- Years of Combined Innovation = 190 + years
- Annual company and customer funded Research and Development = ~$7.5 Billion

History

- The Raytheon Company was founded in 1922 in Cambridge, Massachusetts by Laurence K. Marshall, Vannevar Bush, and Charles G. Smith as the American Appliance Company.
- Its focus was originally on new refrigeration technology, soon shifted to electronics.
- The company's first product was a gaseous (helium) rectifier that was based on Charles Smith's earlier astronomical research of the star Zeta Puppis.
- The electron tube was christened with the name Raytheon ("light of/from the gods" and was used in a battery eliminator, a type of radio-receiver power supply that plugged into the power grid in place of large batteries.
- This made it possible to convert household alternating current to direct current for radios and thus eliminate the need for expensive, short-lived batteries.

Business Segments

- Collins Aerospace
- Pratt and Whitney
- Raytheon Intelligence and Space (RIS)
- Raytheon Missiles and Defense (RMD)

Firm Strategy - Raytheon Technologies

Overall Strategy

- Build upon areas of strength within our key mission areas;
- Focus additional resources on emerging opportunities within the DoD market;
- Extend Raytheon's advanced cyber solutions beyond the U.S. government into international and commercial markets; and
- Engage key countries as individual markets with multiple customers.

Core Markets

- Integrated air and missile defense
- Electronic Warfare (EW)
- Command, control, communications, computers, cyber, intelligence, surveillance and reconnaissance
- Space Systems
- Effects
- Cyber

Domestic Considerations

- U.S. government sales, excluding foreign military sales, accounted for 69% of our total net sales in 2019.
- Our principal U.S. government customer is the U.S. Department of Defense (DoD).

International Considerations

- Internationally, the growing threat of additional terrorist activity, cyber threats, emerging nuclear states, long-range missiles and conventional military threats have led to an increase in demand for defense systems and services and other security solutions.
- In 2019, our sales to customers outside of the U.S. accounted for 29% of our total net sales (including foreign military sales through the U.S. government).

Boundaries of Relevant Markets - Raytheon Technologies

Factors driving the direction of the markets

- Resource Mobility: A U.S. subsidiary of Cobham has agreed to supply electronic warfare systems and provide aerospace support services to 12 programs under three Raytheon Technologies units as part of a $500M agreement between the two companies.
- The global electronic warfare market is expected to see the advent of a range of platforms, units, and systems. The adoption of electronic warfare in land, air, maritime, cyberspace, and space is boosting the market.
- 2020 Department of Defense Electromagnetic Spectrum Superiority Strategy

Electronic Warfare Category of product and Services

- Next Generation Jammer (NGJ) program
- HEL Weapon Systems for Counter-UAS and Precision Strike program
- Integrated electronic warfare suites
- Electronic warfare planning and management tools (EW PMT)
- Multi-function Integrated Receiver/Exciter System (MFIRES)
- Towed decoys
- Radar warning receivers
- Radar and communications countermeasures and missile warning sensors

Where on the Spectrum

Perfect Competition | Monopolistic Competition | Monopoly

Monopolistic Competition Characteristics

- Large number buyers and sellers
- Each Firm produces a differentiated products
- Firms compete on products pricing and marketing
- Limited barriers to entry and exit

Structure of Industries - Raytheon Technologies (1 of 2)

Implications of Porters Five Forces

- By analyzing all five competitive forces Raytheon Company strategists can gain a complete picture of what impacts the profitability of the organization in Aerospace/Defense Products & Services industry.
- They can identify game changing trends early on and can swiftly respond to exploit the emerging opportunity.
- By understanding the Porter Five Forces in great detail Raytheon Company's managers can shape those forces in their favor.

Threats of New Entrants

- By innovating new products and services. New products not only brings new customers to the fold but also give old customers a reason to buy Raytheon Company's products.
- By building economies of scale so that it can lower the fixed cost per unit.
- Building capacities and spending money on research and development. New entrants are less likely to enter a dynamic industry where the established players such as Raytheon Company keep defining the standards regularly.
- It significantly reduces the window of extraordinary profits for the new firms thus discourage new players in the industry.

Bargaining Power of Suppliers

- By building efficient supply chain with multiple suppliers.
- By experimenting with product designs using different materials so that if the prices go up of one raw material then company can shift to another.
- Developing dedicated suppliers whose business depends upon the firm. One of the lessons Raytheon Company can learn from Wal-Mart and Nike is how these companies developed third party manufacturers whose business solely depends on them thus creating a scenario where these third party manufacturers have significantly less bargaining power compared to Wal-Mart and Nike.

Bargaining Power of Buyers

- By building a large base of customers. This will be helpful in two ways. It will reduce the bargaining power of the buyers plus it will provide an opportunity to the firm to streamline its sales and production process.
- By rapidly innovating new products. Customers often seek discounts and offerings on established products so if Raytheon Company keep on coming up with new products then it can limit the bargaining power of buyers.
- New products will also reduce the defection of existing customers of Raytheon Company to its competitors.

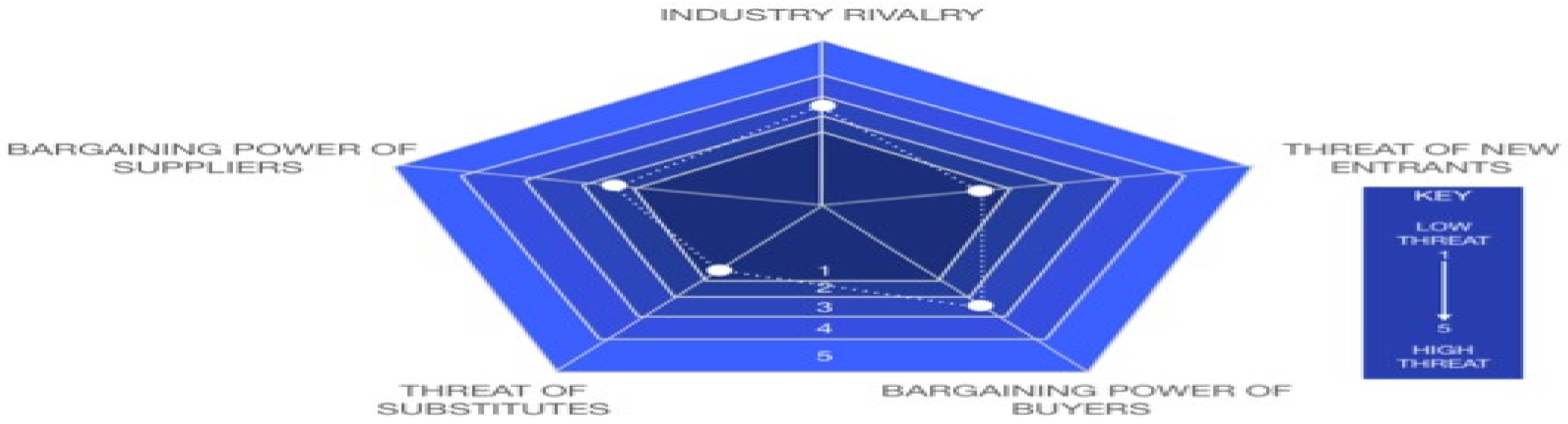
Structure of Industries - Raytheon Technologies (2 of 2)

Threats of Substitute Products

- By being service oriented rather than just product oriented.
- By understanding the core needs of the customer rather than what the customer is buying.
- By increasing the switching cost for the customers

Rivalry among the Existing Competitors

- By building a sustainable differentiation
- By building to scale so that it can compete better
- Collaborating with competitors to increase the market size rather than just competing for small market.



Peer Competitors in the Market - Raytheon Technologies (1 of 2)

Global Top Electronic Warfare Systems Players by Revenue (2018-2020)
(Annual Revenue in Millions of $)

Year	2018	2019	2020
Raytheon	**1344**	**1386**	**1444**
BAE System	1503	1562	1618
Thales Group	1441	1483	1515
Northrup Grumman	1376	1405	1435
Lockheed Martin	1110	1190	1223
Leonardo	953	1072	1069
General Dynamics	889	993	953
L3Harris Technologies	497	523	544
Mercury Systems	128	161	162
Elbit Systems	821	856	847
Saab	124	144	133

Peer Competitors in the Market - Raytheon Technologies (2 of 2)

RTN Sales vs its Competitors

- Comparing the results to its competitors, Raytheon reported Total Revenue increase in the 4 quarter 2019 by 6.55 % year on year, while most of its competitors experienced contraction in revenues by -7.9 %, recorded in the same quarter.

Net Income Comparison

- Raytheon Company Net Income in the 4th quarter 2019 grew year on year by 6.53 %, while most of its competitors have experienced contraction in net income by -61.68 %.

Overall Company Market Share Q4 2019

- With revenue growth of 6.55 % within overall company, Raytheon Company achieved improvement in market share, within overall company to approximate 8.51 %.

COVID Impacts

- Air Travel disruption the greatest impact on customer side with commercial aviation deferring MR&O, retiring aircraft
- Organic Sales decreased $4.1B
- Backlogs
  - Remaining Performance Obligations (RPO) $149.409M (P&W majority with 52%)
  - Projected 70% complete by 31 December 2021

- Mitigation
  - Actively mitigate costs and adjust production schedules
  - Preserve capital and cutting dictionary spending
    - $2B in cost reduction and $4B in cash conservation
  - Cut 15K jobs (P&W)
  - Debt leasing to commercial aerospace customers

- Options
  - Press for increased shift in P&W to more government contracts
  - Cut production, manpower and streamline the business
  - Sale of P&W

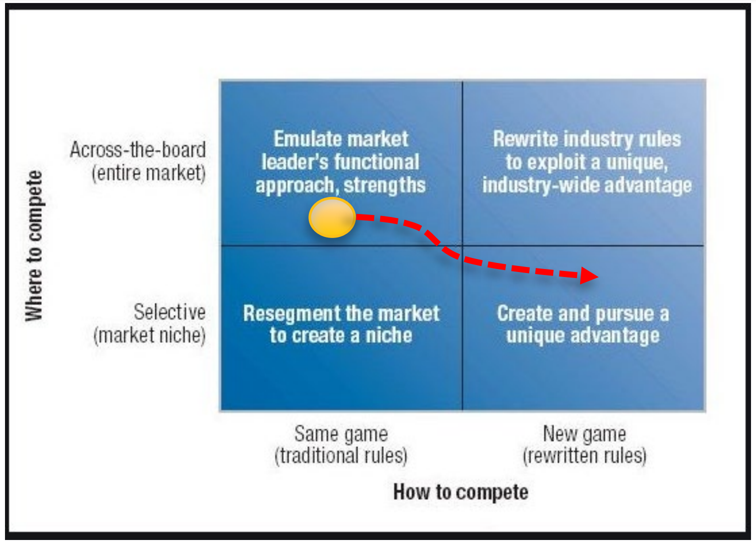
Raytheon's Expanded Strategy, Goals and Values

- *Expanded* Strategy
  - Sensing
  - Effects
  - C3I
  - Mission Support
- Goals
  - Customer
  - Growth
  - People
  - Productivity
- Values
  - People
  - Integrity
  - Commitment
  - Excellence

What is Raytheon's Strategy? – *Electronic Warfare*

Market Strategy

- Focus on 1) Airborne 2) Naval and 3) land based on global EW projected growth trends
- Steadily maintains market share (9%) and revenue $1344M - $1444M
- Currently emulating market leaders with a focus on airborne sensors
- Goal to create a unique advantage through the Next Generation Jammer Mid-Band (NGJ-MB) moving them on the Strategic Gameboard to a "New Game"
- NG and L3 focusing on NGJ-Low Band for USN



Means for Strategy

- Diversification of procurement to strategic sourcing, leverage $23B company to every sourcing decision
- Long Term partnerships and contracts
- NGJ-Mid Band USN contract awarded for $279.4 million in development phase (2013) and $1.2B in 2016
- NGJ-Mid Band - $403M Systems Demonstration Test Articles contract with the USN (IOC 2022) awarded in 2020
- Legal protests for NGJ-LB, continue to aggressive seek out contracts

Distinct Activities for Strategy

- NGJ -MB is at least 10x more powerful than legacy systems (sheer power, range and tasking ability)
- NGJ open systems architecture allows quick upgrades which is critical in the ever-changing EMSO
- Multi functional pods (Sensing, Jamming, Comms, IO) gives *Strength Across the Spectrum*
- NGJ is best in class and RTC plans to expand from mid-band to low-band to beat out competitors (LB IOC 2025)
- Long term they want to modify their pod-based system to support maritime and land-based EW systems
- Aligns with RTC corporate strategy expanding Sensing and Effects

What is Raytheon’s Strategy? – *Electronic Warfare*

Recommendations

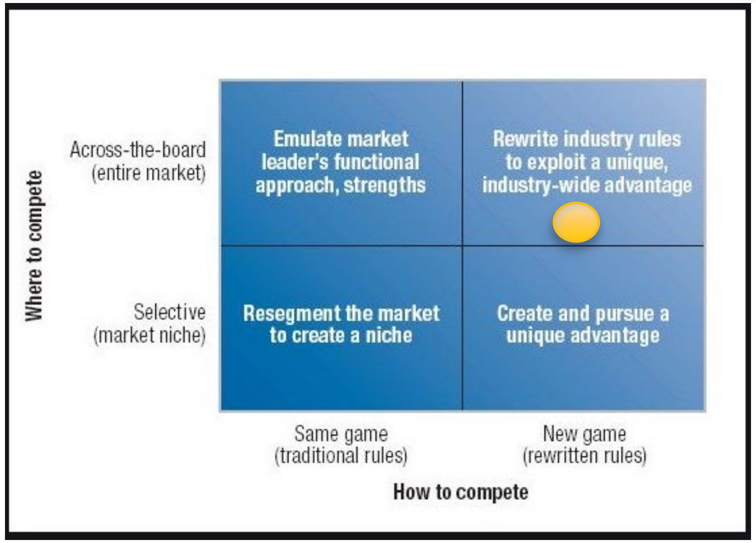
- **Develop GEN5 and GEN 6 airworthiness testing to increase marketability of NGJ-MB**
- **Utilize development and testing advantages from the NGJ-MB to win the NGJ-LB and NGJ-HB contracts**
- **Expand capabilities to ground and maritime based employment**
- **Continue measured investment in other ground based and software-based EW packages**
- **Initiate export control review to enable exporting the technology to Tier 1 allies (South Korea, Australia, UK, Canada, NZ) to coincide with IOC n 3 QTR 2022**

Raytheon’s NGJ-MB on an EA18G

What is Raytheon's Strategy? – CUAS

Market Strategy

- CUAS market direct correlation with UAS market growth to $6 billion by late 2024 (largest growth Asia, North America, EU)
- Currently CUAS market leaders with a full spectrum suite
- Dual markets---sensors and effectors; effectors broken into kinetic and non-kinetic
- Compete NOW as market will grow significantly more than EW systems market



Means for Strategy

- Product Lines: Sentinel CUAS System, Coyote UAS/CUAS
- Produce at scale tailorable to the customer (not just military use)
- RTC one of very few that provide sensor and effector suites with multiple kinetic and non-kinetic options
- Lobby for decreased regulation similar to UAS export control

Distinct Activities for Strategy

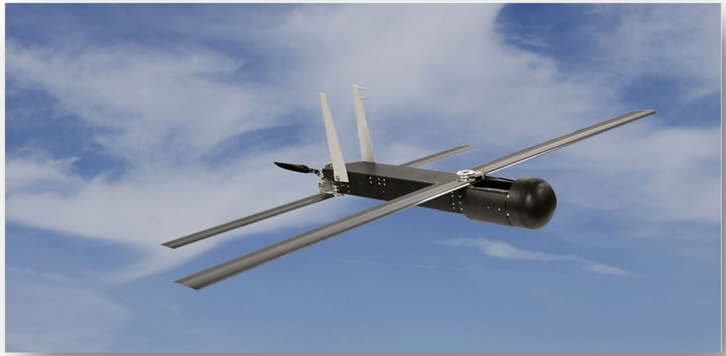
- RTC trusted partner for sensor/shooter systems
- Sentinel (high end use) and coyote (lower end affordable use)
- Huge opportunities to expand market dominance in commercial and security sectors through production at scale
- Aligns with RTC corporate strategy expanding Sensing and Effects

What is Raytheon's Strategy? – *CUAS*

Recommendations

- Continue to *dominate* market with high end and low end CUAS capabilities
- Continue exploring dual use technology in prep for growth of buyers in the private sectors (sensor and non-kinetic effector)
- Focus resources on lobbying and forecasting regulation changes in US, EU, Japan, India and South Korea
- Partner with AI firms to improve ability to identify and track multiple sUAS
- Balance R&D for entire system (Sensor and Effector)
- Focus sales on entire system to tailor system based on regulations and laws of the targeted countries of the market leaders (menu of options)

Raytheon's Sentinel CUAS System



Raytheon's Coyote CUAS System

Innovation

- Combination of mature and advanced technologies
  - Collins and Pratt & Whitney more mature technology focus
    - Commercial and government customers want operational technologies in this space
    - Pratt & Whitney advances in commercial engines, F-35 engine supplier
  - Raytheon Intelligence & Space (RIS) and Missiles & Defense (RMD) more advanced technologies
    - RIS products include laser technologies, EO/IR products, Next Gen Jammer, small satellites and spacecraft components
    - RMD mature tech as well as StormBreaker smart weapon and SM-3 Block IIa ballistic missile defense interceptor
- Participates in SBIR program

Key takeaway – Type of innovation that the firm engages in spans the spectrum.

Industry Change

- Merger with UTC diversifies portfolio
  - 69% of sales to U.S. Government prior to merger, and 29% foreign government (including FMS)
  - After the merger, 46% of sales were to U.S. Government, 15% foreign government (including FMS)
  - Percentage of commercial sales will likely make up even larger percentage after COVID
  - Merger/consolidation activities demonstrate focus on core businesses
    - Raytheon divested Forcepoint in 2020, UTC divested Otis and Carrier
- COVID mitigation
  - Providing financing terms to commercial aerospace customers
  - Lines of credit to weather the downturn
  - Supply chain finance program

Key takeaway – Making strategic moves to diversify portfolio and mitigate COVID downturn in commercial business segments.

Supply Chain

Risks

- Some suppliers have ceased operations due to COVID
- Reliant upon foreign suppliers for certain raw materials
  - Cobalt, tantalum, chromium, rhenium, nickel
  - Scrap reclamation programs and new manufacturing processes to mitigate
- Turkish suppliers, some sole-source, impacted by sanctions
- Microelectronics/semiconductors
  - Defense capabilities require small-batch, niche products
  - Availability of skilled labor in competitive market
- DoD has accelerated contract awards to help firms with larger commercial exposure

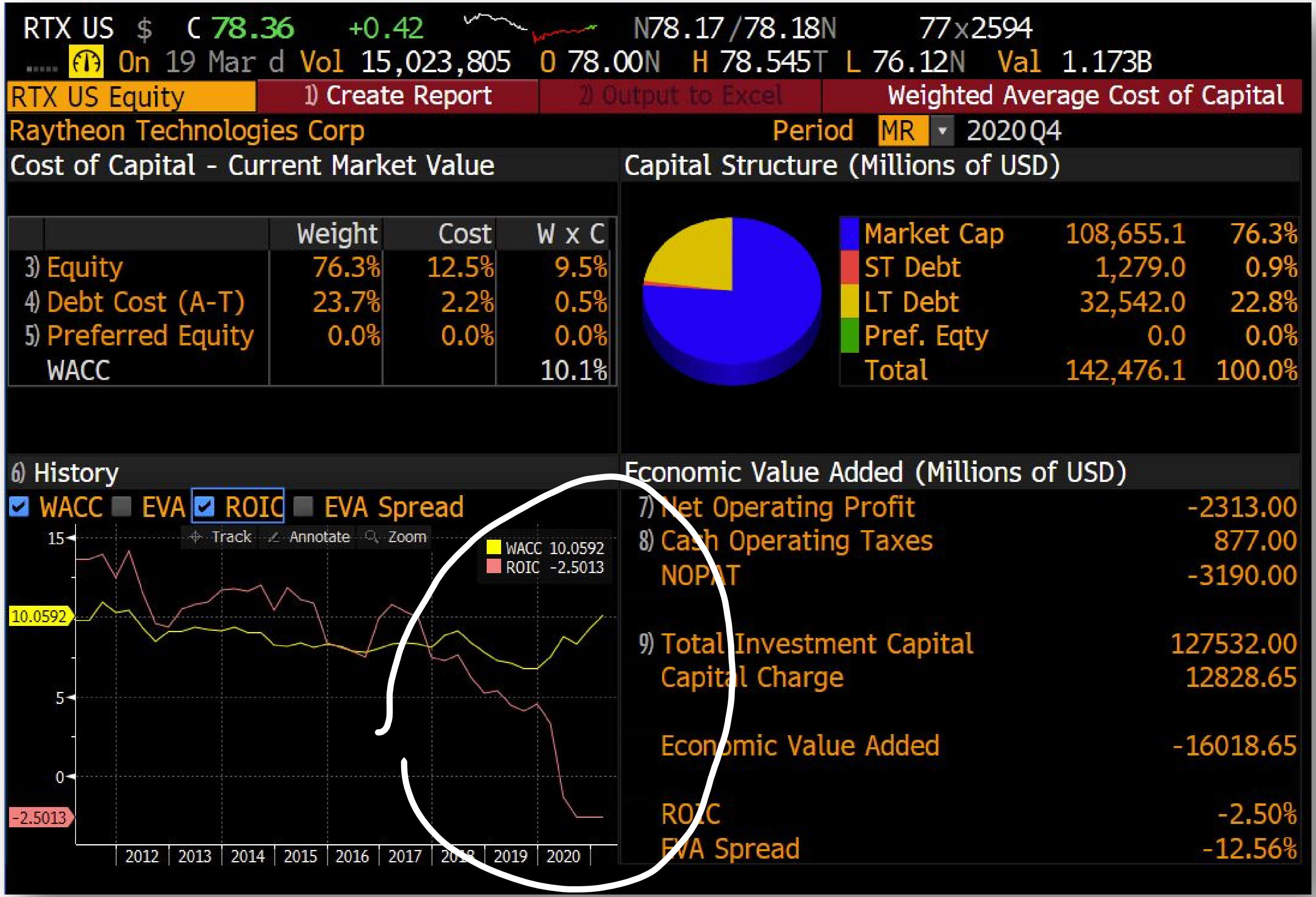
Key takeaway – Mitigate risks through supplier programs and strategic sourcing.

Human Capital

- Recognizes criticality of retaining engineering talent
- Redirecting engineering talent to Defense during Covid slowdown
- Intense competition for STEM talent

Key takeaway – Consolidating operations post-merger. Retaining engineering talent the top priority.

Is the Firm Creating Value?



Key takeaway – ROIC downward trajectory. Crossed the WACC line at the end of 2017.

Stock performance - 2020

Key takeaway – Covid dip with gradual recovery, primarily attributable to under-performing commercial business segments.

Stock performance – 5 years

Key takeaway – Longer view shows COVID impact. 2021 approaching pre-COVID levels.

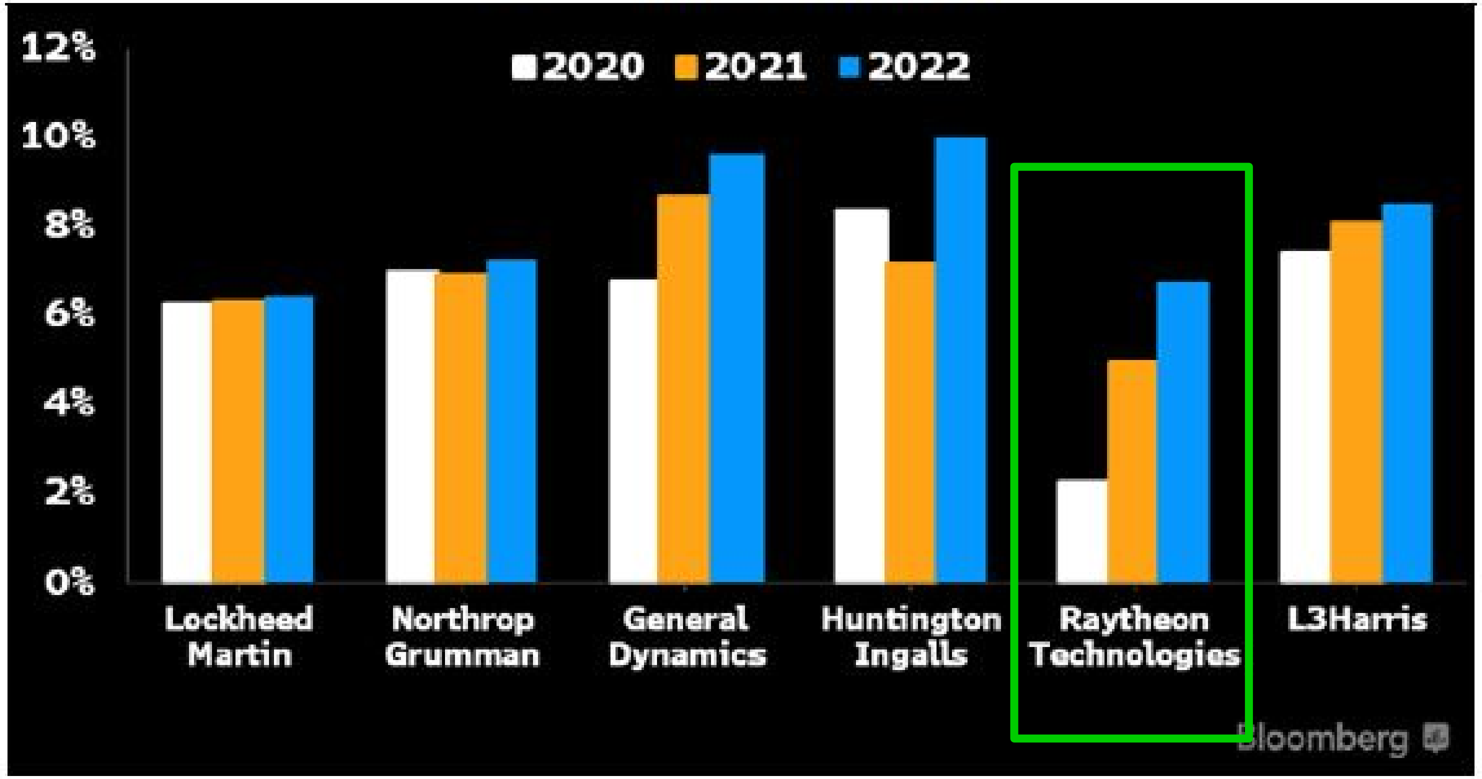
Liquidity

	RTX		RTN		
	2020		Peer	2019	2018
Debt-to-Equity	0.71		3.14	1.83	1.85
Current Ratio	1.21		1.09	1.34	1.43
LTD-to-Equity	0.42		1.18	1.03	1.11

Key takeaway – Liquidity/debt position has improved.

Free Cash Flow Yield

Free-Cash-Flow Yield



Source: Bloomberg Intelligence

Key takeaway – Cash position hurt by commercial side when compared to competitors with less commercial exposure. Long term outlook good.

Is EW business segment creating value?

	RIS	SAS	
	2020	2019	2018
Sales	$ 10,841	$ 7,427	$ 6,748
Operating Profit	$ 1,014	$ 991	$ 884
Assets	$ 20,911	$ 6,979	$ 6,740
ROIC	6.3%	11.9%	12.0%

Key takeaway – EW is destroying value when compared to 10.1 WACC.

Summary

Recommendations/Observations

- Focus on building new unity corporate culture following merger and COVID challenges
- Overall, the firm is not currently creating value, but well positioned as demand for commercial travel normalizes
- Re-evaluate P&W future focus areas, profitability
- Must clear its RPO by end of 2021
- RIS business segment not creating value, but there are promising growth opportunities, particularly CUAS and Next Gen Jammer
- Invest NOW in CUAS capabilities to set the rules
- Firm is well positioned to weather the COVID downturn from a liquidity perspective, but government sales may be concern if spending tightens, particularly foreign sales