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<u>Enhancing the Industrial and Innovation Base of the Weapons Industry to Retain U.S. Military-Technological Overmatch</u>

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ABSTRACT: United States (U.S.) military-technological overmatch against its adversaries is eroding. Several key challenges related to the industrial and innovation base of the weapons industry are undermining the U.S. ability to maintain dominance. This research study examines the industrial and innovation base of the weapons industry in an effort to identify recommendations for improvement that will allow the U.S. to maintain military-technological overmatch. These recommendations include efforts to: incentivize, enable, and leverage the commercial industrial and innovation base; enhance ally and partner capabilities and create opportunities for the weapons industry; improve talent and workforce in the weapons industry; and strengthen cyber defense and security.

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Introduction

The U.S. weapons industry and its associated industrial and innovation base are critical to protecting and advancing U.S. national security and defense goals. The U.S. must maintain military-technological overmatch against its adversaries as directed in the December 2017 National Security Strategy (NSS):

> The United States must retain overmatch—the combination of capabilities in sufficient scale to prevent enemy success and to ensure that America's sons and daughters will never be in a fair fight. Overmatch strengthens our diplomacy and permits us to shape the international environment to protect our interests.…Ensuring that the U.S. military can defeat our adversaries requires weapon systems that clearly overmatch theirs in lethality…Support for a vibrant domestic manufacturing sector, a solid defense industrial base, and resilient supply chains is a national priority.[1]

Similarly, the January 2018 National Defense Strategy (NDS) emphasizes:

> A more lethal force, strong alliances and partnerships, American technological innovation, and a culture of performance will generate decisive and sustained U.S. military advantages...We cannot expect success fighting tomorrow's conflicts with yesterday's weapons or equipment. To address the scope and pace of our competitors' and adversaries' ambitions and capabilities, we must invest in modernization of key capabilities through sustained, predictable budgets.[2]

Weapons and their enabling technologies are critical capabilities that underpin the need for U.S. military overmatch and lethality, as highlighted in the NSS and NDS. The industrial and innovation base and supply chains that enable weapons research, development, and production are important to the larger U.S. defense industry. First, weapons are critical to enabling overmatch in U.S. and allied warfighting capabilities versus near-peer competitors Russia and China, as well as against adversaries threatening U.S. interests such as North Korea, Iran, and violent extremist organizations. Second, weapons are critical items that require production and prepositioning to prepare for crises and conflicts and can be quickly consumed once fighting breaks out.[3] Next, just as they were a critical component of the precision strike "second offset" of U.S. defense technology, weapons and their enabling technologies will almost certainly be an important element—the lethality element—of any future "third offset" in U.S. defense technology. Weapons in combination with technologies such as autonomous systems, artificial intelligence, robotics, space, sensors, communications, and cyber could very well lead the "third offset."[4] Fourth, weapons and their enabling technologies play a vital role in driving the U.S. defense industry to constantly develop and produce more advanced technologies in areas such as explosives, warheads, guidance and control, propulsion, and other key technologies.[5] Finally, weapons play a key part of U.S. foreign cooperation with allies and partners to provide strategic advantage by enhancing capabilities. This includes the export of weapons through Foreign Military Sales (FMS) and Direct Commercial Sales (DCS) programs as well as cooperating on joint development and production efforts.

The critical *means*—U.S. military capabilities, the defense industrial and innovation base and supply chains that support them—that undergird the *ends* and *ways* of the NSS and NDS are being challenged. To date, the U.S. weapons industry has developed and produced cutting-edge weapons and technologies enabling the U.S. military to achieve military-technological overmatch. However, this position of strategic advantage over U.S. adversaries across domains is eroding.[6] According to Eliot Cohen, "in some areas the United States' military edge is eroding or endangered and needs to be restored or refashioned," and as Chairman of the Joint Chiefs of Staff General Joseph Dunford stated in June 2017, "In just a few years, if we don't change the trajectory, we'll lose our qualitative and quantitative competitive advantage."[7]

Thesis. The United States must focus efforts on the weapons industrial and innovation base to maintain military-technological overmatch against U.S. adversaries. Although the industrial base appears sufficiently positioned to support future qualitative overmatch, some sectors are challenged to support future quantitative overmatch. Furthermore, the innovation base is now at risk in providing sufficient support to future qualitative overmatch in part due to a lack of research and development (R&D) capital. Unless effective actions are taken to address these challenges, the U.S. weapons industry risks falling behind U.S. near-peer threats in both weapon advancement (qualitative) and the sheer ability to mass-produce (quantitative) needed weapons.

Purpose and Scope. The purpose of this paper is to evaluate the U.S. weapons industry in an effort to determine if it meets, and will continue to meet, U.S. national security interests. The study addresses two over-arching questions:

- How well postured is the weapons industry's industrial and innovation base to enable the U.S. to retain and sustain military-technological overmatch?

- What are recommendations to improve the weapons industry's industrial and innovation base to enable the U.S. to retain and sustain military-technological overmatch?

To answer these questions, this paper will first define the weapons industry to scope the study. The study next provides key assumptions to further bound the study. An examination of the industrial and innovation base of the weapons industry follows in an effort to survey a few important cross-cutting issues that affect the weapons industry. Next the study provides an outlook for the future of the weapons industry. Finally, the study offers a conclusion and recommendations intended to enhance the weapons industry's ability to maintain U.S. overmatch.

Weapons Industry Defined

This section explains the working definitions of weapons, enabling technologies, and the weapons industry used to scope and focus this paper.

Weapons and Enabling Technologies. The individual studies that provided the foundation for this paper focused on selected types of weapons and munitions that are important to retaining and sustaining U.S. conventional military-technological overmatch. These include small arms and light weapons, ammunition, precision guided munitions (PGMs), missiles, missile defense, and directed energy weapons. In addition to complete weapons and munitions, the individual studies also examined selected enabling technologies critical to the R&D and production of weapons. This includes explosives, propellants, warheads, fuzes, optics, and propulsion systems such as missile engines and rocket motors. In general, the weapons and enabling technologies addressed in this paper are captured by Categories I to V of the United States Munitions List (USML) with the addition of directed energy weapons.[8] The studies did not address nuclear weapons, cyber weapons, or systems and platforms used to deliver weapons and munitions. While not in the scope of this study, the team recognizes that cyber and other emerging, non-kinetic weapons are important to future U.S. national security, and recommends these topics be addressed in future weapons industry studies.

Weapons Industry. Simply put, this paper defines the U.S. weapons industry as the industrial base involved in the production of weapons and the innovation base involved in the R&D of weapons. The combined "industrial and innovation base" of the weapons industry intertwine and share many of the same organizations and facilities. For example, many of the private industry companies—such as prime contractors and major subcontractors—that are part of the weapons industry are involved in both the production of weapons (the industrial base) and the R&D of weapons (the innovation base). Despite their close linkages, for the purpose of this paper, the team addresses the industrial base and innovation base separately. Of note, this study focuses on the development and production phases of the acquisition cycle and does not address sustainment activities such as maintenance, repair, and the supply of parts.

Key Assumptions

Several key assumptions drive the analysis in this study—changes to these assumptions could have positive or negative effects on the ability of the U.S. weapons industry to support national security and defense goals, especially retaining overmatch. The key assumptions underlying this paper include:

- Near-peer U.S. potential adversaries such as Russia and China will continue their aggressive efforts to undermine and erode U.S. military-technological overmatch.

- North Korea, Iran, and non-state actor adversaries will continue to attempt to exploit perceived U.S. vulnerabilities.

- The U.S. military will continue to face difficult tradeoffs over priorities and funding, specifically between force readiness and force modernization.

- The U.S. government will continue its longstanding policy of relying on free market forces to guide the weapons industry, encouraging competition, and only intervening in the industry when required.

- The U.S. weapons industry will continue facing unpredictable defense budgets as well as "boom and bust" cycles of demand for weapons.

- The U.S. will continue striving to be a world leader in the innovation of weapons technology.

- The U.S. defense industrial base and associated supply chains will continue to be highly consolidated, fragile, and vulnerable to disruption.

- Some sectors of the U.S. weapons industry will continue to be specialized, based on defense-unique components and technology, and largely separate from larger U.S. industry and economy.

- Key high-technology weapons and their critical components will continue to require significant lead-times in production.

- The politics of the Iron Triangle—comprising the Department of Defense (DoD), Congress, and the defense industry—will continue to exert significant influence on U.S. government decisions regarding weapons industry priorities, funding, and programs.

- The U.S. will continue—and possibly increase—its reliance on allies and partners to share the burden on security and defense in key regions. As such, security cooperation and, when authorized, direct commercial sales, must continue to support allied and partner capabilities and capacity to enable strategic multinational operations.

- Globalization and expanding market economics will continue to push supply chains overseas. The weapons industry will continue to rely on foreign technologies unless the U.S. government intervenes with effective laws and regulations.

Industrial Base: Production in the Weapons Industry

Weapons Industry's Industrial Base Defined. This paper defines the U.S. weapons industry's industrial base as comprising three key elements: DoD programs, an organic industrial base, and a commercial industrial base that have created the wide variety of weapons used by the U.S. and its allies and partners.[9] First, the industrial base includes DoD weapons production programs that are managed by the Program Executive Officers (PEOs) and program offices of the U.S. Air Force, Navy, Marine Corps, and Army. Next, the industrial base includes an organic industrial base made up of DoD-controlled organizations including government-owned, government-operated (GOGO) and government-owned, contractor-operated (GOCO) facilities that conduct weapons-related production.[10] Third, the industrial base has a commercial industrial base comprised of private industry companies—including prime contractors and major subcontractors—that produce weapons and related technologies.[11] Finally, both the organic and commercial industrial bases rely on supply chains made up of multiple tiers of DoD organizations and private industry companies for the supply of materials, parts, and equipment. The organic and commercial industrial bases and their supply chains thus collectively provide the capabilities—that is, the technologies, parts, components, and products—necessary to successfully produce weapons.[12]

Status of the Industrial Base: Porter's Five Forces. Using Michael Porter's "Five Forces" framework, this paper assesses the current status of the underlying structure of the weapons industry, by addressing the strength of the industry's five forces of competitors, buyers, suppliers, the potential for new entrants, and the potential for substitutes.[13]

<u>Competitors</u>. A high degree of rivalry exists among the relatively small number of prime contractors who compete in the weapons industry. Factors such as a highly concentrated

industry, policy of mandated competitions in defense programs, limited number of customers, and the complexity of products play into this rivalry. After significant consolidation of the defense industry since the 1990s, the “Big Five” competitors in the weapons industry today are Raytheon, Lockheed Martin, Boeing, Northrup Grumman, and General Dynamics.[14] Additional U.S. competitors in the industry producing weapons include Orbital/Alliant Techsystems (Orbital ATK), BAE Systems, and Textron Systems. Companies comprising the small arms industry are numerous but the larger manufacturers supporting the DoD and the consumer base are Fabrique Nationale-America (FN), Heckler and Koch (HK), SIG Sauer, Ruger, Colt, Benelli, and Remington. Numerous companies from Europe, Israel, South Africa, Brazil, and India produce weapons in niche areas. In many cases, these U.S. and foreign companies are “competimates,” acting as suppliers of components to each other and collaborating on joint programs while also competing for weapons contracts and markets. Obviously, the U.S. competes with adversaries such as Russia, China, Iran, and North Korea in producing weapons for their use and export.

<u>Buyers</u>. There is a high degree of bargaining power of the buyers—primarily the DoD, and to a lesser extent, foreign customers. The existence of the DoD as the single main (monopsony) buyer drives this in the U.S., and the limits on selling to other countries via Foreign Military Sales (FMS) and Direct Commercial Sales (DCS) accentuates the bargaining power of the buyers. In addition to the DoD, U.S. companies sell weapons to dozens of allies and partners around the world through FMS and DCS programs.[15] The small arms sector also supplies commercial and law enforcement markets in addition to the DoD.

<u>Suppliers</u>. A medium degree of bargaining power of the suppliers to the prime contractors exists, in particular the major subcontractors who supply the primes with key components. This pressure is driven upward, on the one hand, because suppliers provide specialized inputs, the primes have high switching costs for key technologies, and there are concentrated suppliers in key areas. On the other hand, this pressure is driven downward because the primes can use alternative suppliers for non-specialized inputs.

<u>New Entrants and Substitutes</u>. For the fourth and fifth forces, there is a low degree of both threat of new entrants and threat of substitutes. The low threat of new entrants—for example, major subcontractors that might attempt to forward-integrate to produce complete weapons—is due to the very high startup costs, steep learning curve, necessary technical capabilities and experience, and capital requirements to enter the industry, as well as the extreme regulations imposed on the industry. The low threat of substitutes is due to the dominance of the weapons industry in producing “lethality” for the DoD and foreign customers.

<u>The Iron Triangle: The Sixth Force</u>. In addition to the five forces mentioned above, the Iron Triangle (DoD, Congress, and industry) exerts a significant influence on the weapons industry as a so-called “sixth force.”[16] First, the military services within the DoD exert influence through their requirements, programs, and budget requests for weapons. Next, the U.S. Congress influences the industry through its control of defense budgets, oversight of defense programs, and interests in creating and maintaining jobs in the congressional districts of its members. Related to these first two points of the Iron Triangle, defense acquisition decisions are *de facto* industrial policy decisions for the weapons industry as a whole. These decisions determine which companies will produce weapons for decades and influence the overall health of the industry

through the number of weapons programs that exist.[17] Also related to these two points of the Iron Triangle are the extensive U.S. government policies, laws, regulations, and rules that exert control over the industry and its production, export, and international cooperation activities—that is, the influence exerted by the "triptych" of the U.S. government roles of regulator, customer, and sponsor of the weapons industry.[18]

The third point of the Iron Triangle, U.S. industry—including the prime contractors, subcontractors, and suppliers—influences the weapons industry through its ability to influence the DoD and Congress, both directly and via its powerful lobby, including organizations such as the National Defense Industrial Association (NDIA), the Aerospace Industries Association (AIA), and the National Rifle Association (NRA).

In summary, the three forces that exert the strongest influence on the weapons industrial base are the degree of rivalry among the existing competitors, the bargaining power of buyers, and the Iron Triangle—these forces significantly affect the industry, its sustained health, and its ability to support U.S. national security and defense strategies.

Key Challenges. What are the key challenges, both recent and longstanding, that affect the weapons industrial base and its ability to support U.S. military-technological overmatch? This paper identifies eight key challenges to the weapons industry: (1) Unstable and unpredictable defense budgets; (2) consolidation of prime contractors and subcontractors; (3) fragility of the industrial base and supply chains; (4) cyber and physical threats to the supply chains; (5) lack of visibility into the industrial base and supply chains; (6) specialized weapons industry detached from the larger economy; (7) adverse impact of the "boom and bust" cycle on the industrial base; and (8) the resulting lack of capacity to surge weapons production in the short-term. The extensive literature on the U.S. defense industrial base has identified other challenges, but these challenges are the focus of this study.[19]

<u>Unstable and Unpredictable Defense Budgets</u>. The weapons industry continues to face unstable and unpredictable defense budgets that undermine the ability of its firms to plan and manage their operations and supply chains to produce the weapons required by the U.S. military. This funding instability and unpredictability can also dissuade companies from participating in defense contracts and can even cause them to leave the weapons industry altogether. According to the AIA, "the foundation of a healthy manufacturing and defense industrial base is a consistent demand signal, with robust, stable and balanced budgets that enable the industrial base to align investments in R&D and production facilities, and to secure their sources of supply to meet the DoD's needs."[20] The 2018 NDS affirmed this problem, calling for a "consistent, multiyear investment to restore warfighting readiness and field a lethal force," and CJCS Dunford stated in June 2017 that "we can maintain our competitive advantage with sustained, sufficient, and predictable funding."[21]

<u>Consolidation of Prime Contractors and Subcontractors</u>. Since the end of the Cold War, the overall defense industry—including the weapons industry—experienced a significant consolidation through mergers and acquisitions, with the top fifty defense firms transforming into today's "Big Five" prime contractors.[22] This consolidation affected both the prime contractors and the major subcontractors who supply key components to the primes. This

consolidation has resulted in decreased levels of competition in both prime contractors and major subcontractors, and contributes to the decreased overall capacity and resilience of the weapons industry.

Fragility of Industrial Base and Supply Chains. The weapons industry faces fragility challenges in specific sectors such as PGMs, missiles, explosives, and propellants. For items that are critical to the production of weapons for the U.S. military and its allies and partners, this fragility undermines the industry's ability to surge production in the event of conflict with a major power.[23] The items and their supply chains of highest concern are those that are both fragile and critical—supply chains for items are *fragile* if they are likely to be disrupted, and they are *critical* if the items are difficult to replace if disrupted.[24] This challenge is not new—the DoD has been concerned for decades about the fragility of the defense industrial base and its ability to surge. This description by RAND in 1978 fully applies to 2018, forty years later:

> A major concern of the Department of Defense (DoD) is the ability of industry to respond successfully to the surge demand for its output that might accompany direct or indirect U.S. involvement in an international crisis. The production chain supporting delivery of defense materiel to the DoD can be extremely complex. A surge of demand is likely to put pressure on each sector in the chain not only to secure the necessary additional inputs but also to call on any excess production capacity to meet the added demand for its output by firms higher in the chain.[25]

Many items important to the weapons industry—such as missile engines, solid rocket motors, fuzes, thermal batteries, explosives, and propellants—are both fragile and critical, thus creating a severe overall fragility challenge for the industry as a whole.[26] According to a 2017 Government Accountability Office report, "98 percent of suppliers within the missile and munitions sector are single sources of supply, it is not possible to find replacements for parts if a supplier stops production, and requalification for new parts or materials can be very costly, especially for larger missile systems."[27] Also, the DoD's Annual Industrial Capabilities report of 2016 stated that the U.S. munitions and missile industrial sector "is dominated by single/sole source suppliers" and challenged by bottlenecks with critical sub-tier suppliers.[28] This lack of U.S.-based suppliers has also forced reliance on foreign suppliers for many key items used in the weapons industry to include propellant materials.[29] According to the 2017 NSS, "today, we rely on single domestic sources for some products and foreign supply chains for others, and we face the possibility of not being able to produce specialized components for the military at home."[30]

Cyber and Physical Threats to Supply Chains. The supply chains of the weapons industry face a variety of cyber and physical threats from adversaries. These have the potential to undermine the ability of the industry to support U.S. military overmatch in the future.[31] These supply chain threats can be organized into four categories: (1) adversaries' attempts to steal data, software, or hardware that they can use to develop or improve their own weapons; (2) adversaries' efforts to steal data, software, or hardware that they can use to develop countermeasures to U.S. or allied weapons; (3) adversaries' attempts to disrupt weapons programs by inserting software or hardware; and (4) adversaries' attempts to disrupt the operation of deployed weapons by inserting software or hardware.[32]

Lack of Visibility into the Industrial Base/Supply Chains. The DoD faces a significant challenge in simply understanding the complex picture of the many tiers of suppliers that support the weapons industry.[33] This lack of visibility is driven by "stove piped" perspectives of the supply chains, where PEOs and program offices focus on the supply chains of their portfolio of programs, prime contractors focus on the supply chains of their product lines, and the OSD's Manufacturing and Industrial Base Policy (MIBP) office and Joint Chiefs of Staff (JCS)'s J4/Munitions focus on sectors.[34] Other factors include the lack of resources required to systematically map and monitor these extensive supply chains and the classification and proprietary "firewalls" that limit information sharing by DoD organizations and prime contractors.[35] Without clear visibility into the supply chains, the DoD and prime contractors face challenges in identifying and addressing the potential vulnerabilities that lead to fragility.[36]

Specialized Weapons Industry Detached from Larger Economy. Several sectors of the weapons industry—including ammunition, PGMs, and missiles—are highly specialized and separate from the larger U.S. industry and economy due to their strong reliance on defense-unique technologies and components, many of which require long lead times to produce. This hinders the ability of the larger industry and economy to contribute—especially quickly—to any efforts to surge weapons production in time of crisis or armed conflict.[37]

Impact of "Boom and Bust" Cycle on Industry. The fragility of the weapons industry is exacerbated by the "boom and bust" cycle of the DoD demand for weapons. Both extremes of this cycle can have negative effects on the industry—"boom" times can place severe pressure on the producers and associated supply chains to meet production demands, while "bust" times can result in cold or dismantled production lines and economic hardship for companies. For example, due to a recent surge in U.S. and foreign demands for PGMs and missiles, the industry as of 2016-2018 was experiencing a "boom" period, its first since the early 2000s, which has placed enormous pressure on the industrial base and supply chains for maximum production.[38] In its FY2019 budget request, the DoD requested an increased procurement of several PGMs and missiles—totaling almost 70,000 units, up from 57,000 from the previous year.[39] Several defense firms have ramped up production to meet the demand requiring them to expand production capacity and exert pressure on the suppliers of items used in their production, many of whom have needed to add significant capacity to handle the surge.[40] Such surges, and the inevitable downturns that follow, put severe pressures on the subcontractors and smaller companies of the supply chains to the prime contractors—pressures to ramp up production, maximize capacity, and expand and build new facilities before and during the surge, and then the need to ramp down capacity after the surge.[41] According to the DoD's 2015 Annual Industrial Capabilities report:

> The munitions and missile industrial sector is routinely impacted by significant shifts in DoD demand as a result of various factors, but it is primarily due to the initiation or drawdown of conflicts…This cycle of ramp-ups followed by declines of demand and production adds significant management challenges to munitions, missile companies, and their critical sub-tier suppliers.[42]

Limited Short-Term Surge Capacity. The combination of the challenges above results in the limited capacity of the industry to surge production of weapons in the short-term to support the U.S. military—as well as allies and partners—in a crisis or armed conflict. This limitation applies to specific sectors of the weapons industry, including ammunition, PGMs, and missiles, as well as the key enabling technologies required to produce them such as explosives, propellants, missile engines, solid rocket motors, fuzes, and thermal batteries, many of which have long lead times to produce.

Industrial Base Conclusion. Although the weapons industry's industrial base is sufficiently positioned to enable the U.S. to retain and sustain *qualitative* overmatch, due to the toxic mix of challenges listed above, some sectors—such as PGMs and missiles—will be challenged to support *quantitative* overmatch, especially if a full-scale armed conflict breaks out with a near-peer competitor. In other words, the weapons industry is sufficiently positioned to continue producing technologically advanced weapons to overwhelm adversaries (qualitative overmatch), but some sectors will be challenged produce such weapons in sufficient quantities to overwhelm adversaries during a sustained armed conflict (quantitative overmatch). According to one analyst, "major wars against peer competitors burn up weapons and munitions at a ferocious rate far beyond what the highly consolidated and fragile U.S. defense industry can produce."[43] The weapons industry's limited ability to surge production in the short-term against a near-peer adversary will be challenged by the "ferocious rate" of consumption of critical weapons such as small arms and light weapons, ammunition, PGMs, and missiles unless significant efforts are made to address the underlying challenges.

Innovation Base: Research and Development in the Weapons Industry

Weapons Industry Innovation Base Defined. With every new mode of transportation, humans have quickly adapted weapons to change the battlefield and methods of fighting wars. The 2017 NSS and 2018 NDS frame a renewed focus on innovation in order to provide strategic overmatch capabilities against near-peer adversaries. As the NDS states, "we cannot expect success fighting tomorrow's conflicts with yesterday's weapons or equipment," and calls for the U.S. to invest now to accelerate the modernization of key capabilities to build a more lethal fighting force.[44]

The *Business Dictionary* defines innovation as the process of translating an idea or invention into a good or service that creates value or for which customers will pay. The distinction between innovation and invention is critical as it outlines the process for which ideas generated in academia are used to provide capability to the end user, in this case the warfighter and commercial consumer. Innovation in the weapons industry is the key differentiator that ensures competitive advantage in a rapidly growing global weapons industry. As time has progressed, innovation has driven weapons capability from weapons with little accuracy to highly lethal and precise weapons. Additionally, innovation in weapons often follows a process whereby an idea developed by the government, adopted by the commercial market, is then adapted again by the government.

In the recent NSS, the executive branch states "a healthy defense industrial base is a critical element of U.S. power and the National Security Innovation Base."[45] This National Security Innovation Base, although somewhat underdeveloped thus far, is understood to include the "American network of knowledge, capabilities, and people—including academia, National Laboratories, and the private sector—that turns ideas into innovations, transforms discoveries into successful commercial products and companies, and protects and enhance the American way of life."[46] Innovation, the process to develop these ideas, and the innovation base are fundamental to the continued supremacy of the DoD and American economic prosperity.

Innovation in the weapons industry is accomplished through three primary methods. First, new ideas generated by academia, oftentimes to solve a problem unrelated to the existing military capability gap but then taken by the private sector or government lab to develop an innovative way to translate it into a useful product. Alternatively, the U.S. government may undertake innovation efforts alone, such as in the development of nuclear weapons, where there is no foreseeable commercial market. Linda Weiss, in her book *America Inc.?: Innovation and Enterprise in the National Security State,* gives great credit to the National Security State, dominated by government actors, for many of the "high-risk, breakthrough technologies and emerging industries" in modern America.[47]

A final method is driven through new uses of commercial items developed in industry or through the government and adopted by industry. An example of this is Global Positioning System (GPS) technology which originally stemmed from science and technology developed to overcome a way to track Soviet satellites. Immediately it became apparent by the DoD they could use GPS to aid in navigation. Ultimately, civilian uses for GPS migrated into innovative products like vehicle navigation and use in automated teller machines (ATMs). The military innovated the use of navigation, opting to implement GPS into precision guided munitions to provide precision strikes on military targets during Operation Desert Storm. This one example highlights the original use for an idea developed by the government, adopted by the commercial market, and then adapted again in the defense market to fill a capability gap.

Status of Innovation in the Weapons Industry. The U.S. weapons industry has for some time lacked sufficient innovation which has caused America's technological edge to be reduced significantly. The current state includes few true innovators largely working to evolve rather than revolutionize capability, and a continued trend of failing to field transformative weapons to warfighters. These key themes are common across the industry spanning from small arms to high-energy lasers.

Lack of Innovation. The U.S. is experiencing the longest continuous stretch of armed conflict in its history. This conflict, however, focuses against a low-level threat placing priority on readiness, troop levels, and capacity over innovation. In support, the weapons industry focused on efforts to improve efficiency thereby increasing production rates to meet demand as well as decrease costs to improve profits. According to the Army Chief of Staff, General Mark Milley, readiness, not new capability, is the number one priority of the U.S. Army.[48] The current focus places a premium on additional bullets for soldiers by squeezing out funds for costly R&D.

Not adequately funding innovation has created a significant risk in defending against the high-end threats such as Russia and China as called for in the NSS. As a striking example from the U.S. Air Force, the "Air Superiority 2030 Flight Plan" released in 2016 postulated the U.S. military will lose air superiority by 2030 unless new capabilities, modernization, and changes to the current acquisition process are adopted and implemented.[49] Similarly, recent advances in North Korea's ballistic missile program and breaking revelations of new Russian missile technology highlight a shortfall in U.S. missile defenses. Adversaries are focusing on increasing range, speed and countermeasures, to include hypersonic glide vehicles flying non-ballistic trajectories. According to the Center for Strategic and International Studies "improvements in sensors may, at the margin, be one of the best ways to improve lethality, raise effective magazine capacity and contribute to a more robust defense."[50] This study asserts that efforts toward such innovative capabilities are insufficient to date.

Few Innovators. Within the weapons industry the number of inventors is relatively few. As discussed above, the weapons industry is significantly smaller after decades of consolidation. The subset of the industry actively engaged in innovative R&D is even smaller. Within the energetics area, for example, there exist only a few manufactures. Built in the 1940s, Radford Army Ammunition Plant in southwestern Virginia is the U.S. military's primary propellant manufacturer.[51] The Naval Surface Warfare Center Indian Head in Maryland and the Holston Army Ammunition Plant in Tennessee complement Radford, each with highly unique development and production capabilities. The huge decrease in demand for explosives has led to massive consolidation, and in turn a focus on production vice innovative development by the remaining performers.

Compounding the industry consolidation is the corresponding atrophy of science and engineering skills required for new development efforts due to lack of demand. Recognizing this shortfall, the DoD has invested in a $14M four-year program with Orbital ATK and Aerojet Rocketdyne to provide training for engineers in the rocket motor field to incorporate new ideas and technology.[52] While a positive step, much more is needed to fill the ranks of innovators as the weapons industry at large suffers from the same condition seen in the missile sector. The NSS stresses that the U.S. must improve efforts and regulations to attract and retain inventors and innovators, as well as collaborate with and utilize private sector technical expertise and R&D capabilities more effectively to help the DoD constantly innovate, to include rapidly fielding innovations.[53]

Evolutionary Innovation. Innovation can either be evolutionary or revolutionary. It is overwhelmingly evolutionary within the weapons industry. As a case in point, firearms innovation is only at the margins, specifically polymer weapons, plastic or lighter-weight ammunition casings, and integration of accessories. Such incremental modifications to existing product lines hardly provide transformative capability and in many cases are attempts to slightly increase market share rather than respond to user demands.

As a uniquely military example, since the inception of long-range aerial missiles in the late 1970s, innovation has stagnated. Only incremental changes have occurred in the decades that followed, due largely to a lack of government investment and interest. As a result, the air-to-air missiles of today look and operate strikingly similar to their ancestors 40 years prior. Specifically, the first Air Intercept Missile (AIM)-9 Sidewinder prototype was built in 1953 and fully entered service with the U.S. Navy and U.S. Air Force in 1956.[54] The AIM has subsequently evolved over the decades into its current form the AIM-9X. However, the missile's primary use is still close range visual engagements. PGMs have suffered a similar fate. As a result of reduced government R&D funding, PGM innovation has recently occurred during the Production and Deployment, rather than Research, Development, Test, and Evaluation phase of acquisition. This, of course, has allowed only minor updates to existing capabilities.

Failure to Field. True innovation takes time, sometimes a very long time. The weapons industry is filled with examples of innovative concepts that never reach the battlefield. In some cases, a lack of genuine user requirement is to blame, while in other cases technology or transition issues prevent full fielding of operational capability. Beginning with the foundational energetics sector, not only does it take time to develop new product, it also takes time to develop the producers. Developing energetics requires special equipment, facilities, and practices.[55] The process requires scientists with at least five to ten years' experience and mentorship in an empirical, trial-and-error process, much the same as occurs in pharmaceutical development. Following, the propellant development takes a lot of time to produce the intended repeatable and reliable desired results. Somewhere along the line, funding, requirements, or interest can change, resulting in mothballing an innovation effort.

Regarding some of the higher-end military systems, innovation has been pursued for decades. Persistent space-based sensor array for missile defense, for example, has been part of the system architecture for five administrations, but has yet to be fielded after successful demonstrations. Similarly, with next-generation weapons, "for more than 50 years, the Department of Defense has pursued the goal of using directed-energy for military purposes."[56] Here again, successful technology demonstrations have largely failed to become formal acquisition programs of record resulting in reduced user awareness and demand, and in turn, reduced corporate investment in high energy laser maturation. As part of the weapons industry field investigations, one senior industry manager quipped that such weapons are "next generation weapons that will always be next generation."[57]

<u>Organic vs. Commercial</u>. Innovation in the weapons industry cannot be viewed through a myopic lens in the hopes of understanding innovation across the broad spectrum of systems. Innovation within the weapons industry varies based upon the end user. Organic innovation, defined as innovation driven by the government, is highly prevalent when the system is complex, or the weapon is not available for sale due to government regulations or no commercial market. Attesting to the need for government direction and funding, both Raytheon and Boeing admitted that their business model consists of resupplying the current weapons with current capabilities, with very little emphasis on modernization to combat the evolving threat environment given the limited corporate R&D budgets.[58]

Commercial innovation is defined as innovation driven by commercial manufacturers. Private industry innovates when they are trying to differentiate amongst competitors for defense contracts or when they are trying to differentiate in the commercial sector and create a diverse and separate revenue stream. The firearms, optics, and ammunition markets are sectors of the weapons industry having a high degree of commercial innovation, although sometimes leveraging military designs for commercial profits. In these cases, there is low potential payoff of new research because of high cost and low return on investment (ROI). Additionally, the required capital in terms of equipment, technology, and highly trained personnel represent a considerable barrier to much of the cutting-edge innovation currently performed organically by the government.

Key Challenge: Motivation. Our national security depends on America having a stable weapons industry, but the most important item to remember is that companies are in business to make profit. Weapons manufacturers innovate and create new products to increase their potential competitive positioning for future business. This is true for those primarily in the commercial market, military suppliers, and firms equally delivering for both.

Some weapons have a limited commercial market and therefore innovation is largely driven by anticipated future U.S. government needs. Weapons firms carefully invest Independent Research and Development (IR&D), but more often await government funds and direction before conducting significant R&D efforts. The most significant challenge to innovation today is the small number of DoD development contracts. Firms are very reluctant to invest without a good chance of return in the form of a military production contract. This challenge is particularly profound within the dual-use munitions sector as well as the military unique weapons like PGMs.

Weapons firms are also reluctant to propose too much innovation for DoD systems. As will be discussed in more detail below, cost as a primary source selection factor drives contractors to propose solutions just meeting the minimum specifications in the request. Firms are seeking to minimize the risk of not be selected for reason of high cost or technical risk. Finally, highly innovative DoD developments risk program cancellation due to cost/schedule overruns during development as the contractors work to overcome technical challenges posed by new technology or manufacturing methods. All these factors create a somewhat risk adverse environment, discouraging innovation.

The commercial weapons market, dominated by small arms, is clearly driven by volume of sales. Firms are undertaking evolutionary innovation as discussed above with resulting profit. Also noteworthy is the strategy of taking products designed for military use and tailoring for commercial sales. Handguns are often used to compete for defense contracts, but then sold commercially to create revenue streams resulting from low margins in the defense industry or failed contract bids. As an example, Glock competed for the U.S. Army Modular Handgun System contract. Despite losing the bid for this large contract, they successfully marketed their Glock 19X to the commercial and law enforcement markets to recoup company investments in the system.

Innovation Base Conclusion. If the U.S. is to continue its place as an international leader it must invest in the industrial base to ensure successful innovation and ensure government policies are right sized to facilitate innovation. Failure to do so will result in a weakening of our ability to defend the country's national interests against near-peer adversaries, transnational terrorist organizations, and nefarious actors seeking to knock America off its pedestal of preeminence. Addressing the challenges facing weapons innovation, particularly burdensome government regulations and policy, will surely set the U.S. on target to achieving strategic overmatch capabilities required to deter and defeat near-peer adversaries.

Key Government Policies and Regulations Affecting the Weapons Industry

In addition to the challenges highlighted above to the weapons industry's industrial and innovation bases, the industry is also challenged by the current state of U.S. policies, laws, and regulations. U.S. defense export and export control policies and regulations, the Defense Acquisition System, intellectual property (IP) regulations, and government contracting type are key headwinds to the weapons industrial and innovation base's ability to generate overmatch capabilities.

U.S. Defense Export and Export Control Policies and Regulations. The current state of U.S. policies, laws, and regulations on defense exports and export controls constrains, by design, the ability of the weapons industry to export conventional weapons to allies and partners via FMS and DCS programs. These constraints influence both the U.S. companies' ability to maintain revenues and production lines, and the capabilities of U.S. allies/partners. Recently announced changes to the Conventional Arms Trade policy might alleviate these constraints, but this remains to be seen. According to the Aerospace Industries Association, "the most critical measure of its success is whether the system helps our partners be ready, resilient, and relevant to deter or defend against common adversaries, consistent with U.S. foreign policy objectives. By that measure, the [U.S. defense export] enterprise is not as effective as it could be."[59]

The Arms Export Control Act (AECA) and International Traffic in Arms Regulations (ITAR) also present challenges to the weapons industry. The AECA provides the legal basis for most DoD international programs. It establishes the use, transfer, and security criteria to be used in consideration of transfers of defense articles or services to any country or international organization. The ITAR administers section 38 of the AECA as it pertains to commercial sales and provides a list of export-controlled data and materials known as the U.S. Munitions List (USML). Export to foreign persons of items on the USML requires the prior approval of the Department of State, in consult with the DoD. These limitations on the export of controlled weapons and munitions to foreign customers and the import of components for the domestic production of weapons further shrinks the available market for U.S. weapons producers. Judiciously easing such regulations could create more opportunities for true innovation to rise.

Defense Acquisition System (DAS). Another major challenge to the weapons industry is the bureaucratic, complicated, tedious and lengthy acquisition process that is required to procure equipment in the DoD. The DAS is the tool used to oversee and manage acquisition programs through a highly regulated milestones process. Given today's rapid pace of change, by the time a weapon system is procured through the DAS, the technology is often rendered obsolete. The Department's failure to streamline the process for more commercially available weapons turns many firms away from innovating as the cost to participate in the lengthy process is already high. The NSS stresses the importance of pursuing new approaches to acquisition to reduce cost and shorten processes, which is especially important as the U.S. must harness innovative technologies that are being developed outside of the traditional defense industrial base.

Intellectual Property (IP). A big issue arms manufacturers face with government sales is the loss of control of its IP rights. Defense acquisition regulations usually demand that the IP is included in the award. Many smaller arms manufacturers make a decision to self-pay for all R&D in order to retain the IP, or have made a business decision not to bid on U.S. government contracts so they can innovate and improve as they see fit. Given 95% of global commercial firearms sales are in the U.S., firms rely on the ability to utilize the results of their innovation and IR&D to sell to American commercial customers.[60] Without access to this portion of the market via commercialization of technologies developed for the U.S. government, the investment in IR&D efforts is not worthwhile.

A recent example of a U.S. government firearms purchase that illustrates the hindrances to industry innovation is the Modular Handgun System (MHS) program administered by the U.S. Army on behalf of the DoD and other services.[61] The approach utilized by the Army discouraged innovation by industry because of the requirement to provide significant IP and data rights to the government and the emphasis on price relative to technical performance. There was no incentive within the MHS acquisition construct to convince industry that innovation in support of their MHS proposal would be worthwhile and put them at an advantage in terms of award. The current universal restrictions on exporting specific technologies or selling products to the commercial public that share commonalities with products purchased by the USG are overly restrictive in their broad-brush approach and discourage IR&D investment and innovation efforts by contractors.

Lowest-Price, Technically-Acceptable (LPTA) Government Contract. The Federal Acquisition Regulation (FAR) requires U.S. government officials to procure goods and services on a best-value basis, meaning that "the expected outcome of an acquisition…provides the greatest overall benefit [to the government] in response to the requirement."[62] When selecting an Offeror from a competitive pool for a contract award, the best value continuum includes two extremes – Trade-off and LPTA.[63] Of late, there has been a significant emphasis on LPTA for non-developmental items or when the U.S. government has convinced itself that enhanced performance is not worth a price premium.

To improve the quality of products delivered under future government contracts and to encourage industry to innovate in support of government requirements, it is recommended that the entire range of options within the Best Value Continuum be assessed to ensure price is not being over-emphasized as one size does not fit all. A tradeoff process can still heavily weigh the bottom-line price to the government, but it affords decision makers greater flexibility in selecting a technologically superior solution. The ability for the government to select a higher-priced product when the benefits outweigh the cheaper options is attractive to industry partners that believe in providing high-quality products or innovating and offering new technologies to the warfighter.

Cross-Cutting Weapons Industry Issues

Weapons Exports: Balance of Enhancing Alliances vs. Protecting U.S. Technology. The 2018 NDS states: "…Combined forces able to act together coherently and effectively to achieve military objectives requires interoperability..."[64] The achievement of such interoperability is usually the domain of U.S. Security Cooperation but can also be fulfilled via DCS programs. As such, the U.S., its military and its economy all may benefit from the lawful and authorized export of defense capabilities to foreign governments. However, the concept of successful interoperability and partner capacity walks a critical and difficult balance between achieving our goals for strong alliances and our need to protect national security information, innovation and our technological edge.

The U.S. defense industrial base faces these challenges even as it pursues market access and endeavors to support our national strategies. To those defense contractors, allied interoperability, as it applies for instance to missile defense, is at times in competition with long-term corporate strategies. Foreign governments have become more demanding on matters involving technology sharing and access, workshare and advantageous domestic offset criteria, tailored systems, integration of domestically produced technology, and autonomy on the employment and use of the systems being sold to them. Such demands prove difficult to reconcile against both corporate profitability margins and U.S. constraints on export control, disclosure of classified information (to include data and technology), technical integrity of U.S. systems, and the need for sustained product and industrial innovation. Compounding this dilemma is the need for partner intent and capability to protect any classified information that may be provided to it by the U.S. These challenges will continue and may act in detriment to both defense industry and the U.S. government, unless the U.S. government can engage partners in early and enhanced security dialogue and consider industrial base abilities to support both theater and bilateral security cooperation strategies.

Workforce: Fight for Talent. The weapons industrial and innovation base faces current workforce staffing challenges that will only continue to be exacerbated over time. The industrial base requires a robust and qualified workforce capable of a wide variety of manufacturing and managerial tasks. The innovation base requires an educated and experienced engineering workforce that is motivated to innovate and develop new ideas, products, and approaches. Companies are faced with an aging workforce and are struggling to attract young talent to both backfill those retiring out of the workforce as well as infuse new ideas and approaches to business operations and innovation. In particular, with regard to engineering expertise, weapons firms are having to compete not only among themselves but also against a growing number of technology and engineering firms that are more attractive to some younger talent as they are unassociated with defense missions and not part of a “kill chain.”

In looking ahead, the fight for talent and workforce will only continue to be a problem, and without adequate staffing, the weapons industrial and innovation base will be challenged to maintain the capability and capacity necessary to adequately support the U.S. government’s efforts in protecting and advancing U.S. national security and defense goals.

Cyber: Need for a Defensive Posture. As outlined in the December 2017 NSS, protection of critical infrastructure against cyber actors is a key tenet to our “first and fundamental responsibility to protect the American people, the homeland, and the American way of life”.[65] Cyber threats can come from both conventional and unconventional adversaries that have weaponized the digital domain. The U.S. Council of Economic Advisors has identified six distinct groups of cyber threat actors: nation-states (Russia, China, Iran, and North Korea), corporate competitors, hacktivists, organized criminal groups, opportunists, and corporate insiders.[66] Motivational factors cover a wide range of topics, including industrial espionage, access to proprietary IP, political agenda, profit seeking, notoriety, and disgruntled employees, respectively.[67] Given the complexity of DoD weapons systems and the reliance on the underlying organic and commercial industrial bases, there are many risks to consider when determining if the weapons industrial and innovation base is postured for cyber defense now and in the future. As the industrial and innovation base integrates current and future capabilities by way of common components, tools, capacity enhancements, and services into networked, system-of-systems engineering environments, common operating environments, and modular systems to achieve efficiencies and affordability, the entire supply chain becomes more vulnerable to cyber-related compromise. Cyber defense security threats include threats or a degradation to the confidentiality, availability, and integrity of data and systems. In the case of the weapons industry, cyber attacks can undermine confidence in the weapon used or worse cause harm to the warfighter and reliability by causing changes to tolerances within many of the computer-aided design (CAD) machines used to create systems and sub-systems within the industry. The spectrum of threats includes counterfeit parts, reliability failure, malicious insertion, and information compromise.

Malicious insertion cyber attacks at various entry points throughout the supply chain are becoming more common and can result in a cascading effect throughout a government's or company's entire supply chain of Original Equipment Manufacturers (OEMs), suppliers, integrators, and customers.[68] A recent example was the malware cryptoworm "WannaCry" developed by North Korea that was used to attack Boeing in March 2018. From a national security perspective, unauthorized access to information and systems at any point in the supply chain could weaken our defense posture and/or competitive advantage for a portfolio of critical weapons capabilities if mission data or microelectronics become compromised.

Outlook: Future of the Weapons Industry

What is the future of the weapons industry in terms of its ability to enable the U.S. to retain qualitative and quantitative military-technological overmatch? We expect the current downward trajectory to continue unless the U.S. can effectively address the serious aforementioned challenges to the weapons industry's industrial and innovation base. Without such measures, this unaltered trajectory will lead to an increasingly higher risk of the deterioration of U.S. military-technological overmatch against its current and potential adversarial competitors, such as Russia and China, and against states such as Iran and North Korea in certain niche areas. With an effective mix of these measures, the U.S.—along with its allies and partners—stands a good chance of sustaining and enhancing its military-technological advantages over its adversaries to effectively protect and advance U.S. national interests into the future.

Conclusion and Recommendations

Conclusion. U.S. military-technological overmatch against its adversaries is eroding. Several key challenges are undermining the ability of the weapons industrial and innovation base to enable the U.S. to maintain this overmatch. Although the industrial base appears sufficiently positioned to support future qualitative overmatch, some sectors are challenged to support future quantitative overmatch. Furthermore, the innovation base is now at risk in providing sufficient support to future qualitative overmatch. Unless effective actions are taken to address these challenges, the U.S. weapons industry risks falling behind U.S. near-peer threats in both weapon advancement (qualitative) and the sheer ability to mass-produce (quantitative) needed weapons.

Recommendations. This paper posed two questions. The previous sections addressed the first question, "How well postured are the industrial and innovation bases of the weapons industry to enable the U.S. to retain military-technological overmatch, especially in terms of innovation and production?" The second question put forth was, "What are the recommendations to improve the industrial and innovation bases of the weapons industry to enable the U.S. to retain military-technological overmatch?" The latter question has many complex answers. This paper concedes that there are enduring headwinds that have been acknowledged in government audits and industry feedback.[69] These headwinds include defense budget issues, including a lack of stable and predictable budgets from year to year, continuing resolutions, sequestration, and lapses in appropriations that disrupt the ability of agencies and industries to plan and execute efficiently; a DoD acquisition process that is cumbersome and requires reform to increase agility and reduce lengthy processes; and competing requirements that make force readiness compete for resources with force modernization. This paper does not dismiss these barriers, but such barriers are longstanding issues that have been analyzed and addressed separately in other publications.

To address some of the key challenges to the weapons industry's industrial and innovation base highlighted above, this section provides a set of recommendations, organized into four cross-cutting categories.

Incentivize, Enable, and Leverage the Commercial Industrial and Innovation Base. The U.S. government must find ways to better incentivize and enable the commercial industrial and innovation base to work with the government and support the fulfillment of all weapons requirements. Such efforts will help the DoD more effectively leverage and utilize commercial industry to shore up the weapons industry's R&D and production capabilities and alleviate areas of fragility, enabling the U.S. military to retain and sustain overmatch into the future. Changes can be implemented over both the short and the long term to affect behavior and mindsets as well as policy, regulation, and appropriations, respectively:

<u>Short Term: Behavior and Mindsets</u>

- Improve government-industry communications throughout the acquisition process, beginning with market research and requirements definition. This will allow companies throughout the supply chain to make informed long-term investment and resource allocation decisions to enable increased innovation and improved support of government weapons requirements.
- Modernize acquisition and contract strategies for all types of weapons systems to provide greater stability for the defense industrial base while incentivizing improved contractor performance. Examples include increased use of long-term, multi-year contracts with a guaranteed funding stream; making multiple contract awards for critical weapons to diversify the industrial base and drive continued innovation and competition; and ensuring that price is not over-weighted in the selection criteria to the detriment of superior technical performance or innovative solutions.
- Limit the amount of IP required to be delivered to the government under every weapons contract and allow companies to retain ownership of as much IP as practicable. This will enable companies to use and market the technological advances of their innovation for other products and customers, encouraging greater corporate IR&D investments upfront in support of government weapons requirements.
- Increase the use of commercially-available technologies and commercial-off-the-shelf products in defining and simplifying government weapons requirements, when appropriate, and decrease emphasis on wholly developmental, government-unique requirements.

Long Term: Policy, Regulation, and Appropriations

- Finalize export control reform efforts, streamline the ITAR, and relax FMS and DCS rules to enable efficient and increased sales of weapons to partner nations and allies.
- Assess and reform the current government R&D organizational and appropriation structure to enable efficient use of funds, clear organizational responsibilities (without duplicated efforts), and greater ability to collaborate with industry throughout the development process. Examples of potential reforms include increased partnering with industry on cost-sharing R&D efforts for high-priority weapons programs; relaxation of government IP ownership requirements when advancements are made with mixed (government and contractor) funding streams; proactive engagement with industry partners on emerging or developing technologies to build in producibility from the beginning; and increased government R&D appropriations.
- Fund the stockpiling of fragile and critical long lead-time items and production tooling to enable greater contractor production efficiencies and stability.
- Invest in redundant propellant and explosive production capabilities to create a resilient manufacturing and supply chain for this critical and fragile sector.
- Continue monitoring the consolidation and elimination of larger weapons manufacturers and key suppliers.

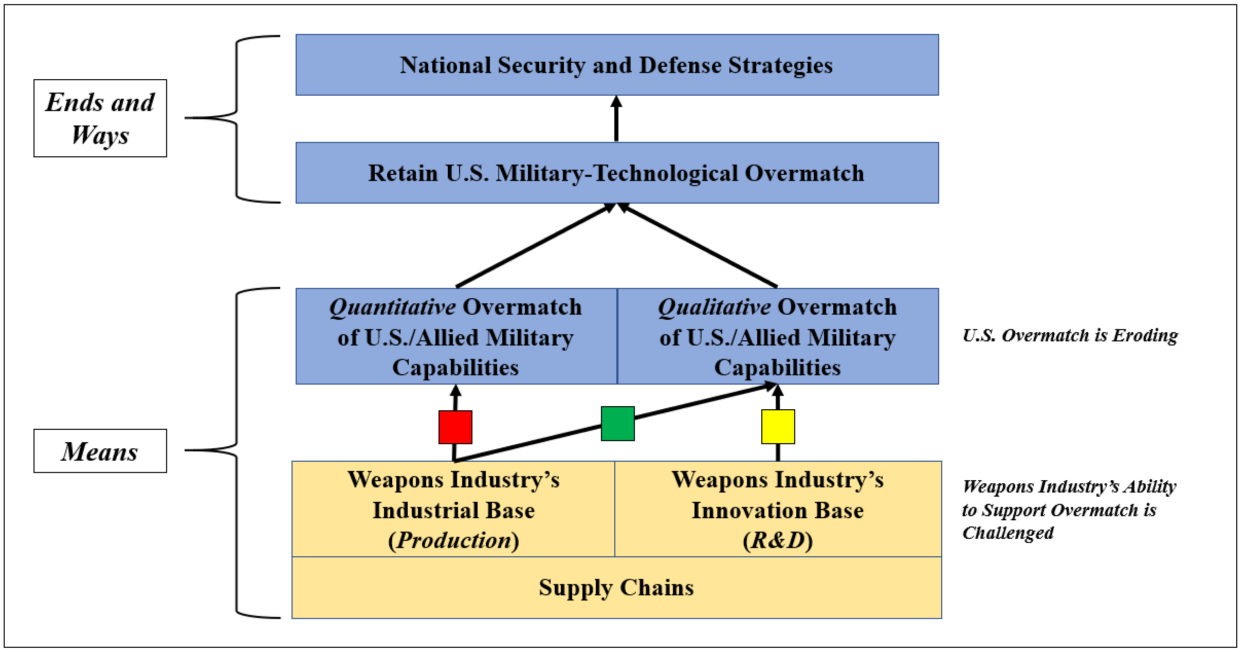
Enhance Ally and Partner Capabilities and Create Opportunities for the Weapons Industry. According to the 2018 NDS, “the Department of Defense will prioritize requests for U.S. military equipment sales, accelerating foreign partner modernization and ability to integrate with U.S. forces.” To achieve this objective and leverage opportunities for the industrial base, we must engage allies and partners in enhanced security dialogue and early consult and integrate the weapons industry on theater and bilateral security cooperation strategies. This can provide insight into current partner capabilities, modernization gaps, and actual customer need. This can also open the door to innovation to meet such needs, and more importantly drive a comprehensive and successful export and security strategy to allow early assessment and mitigation of roadblocks to potential sales—all of which greatly incentivize the industrial base and allows it to better project long term corporate strategies. For example, the U.S. government and DoD should revisit and revise applicable regulations and Title 18, Reg 22 to foster *select and adjudicated* investment by allied foreign weapons manufacturers in the U.S. weapons industry. This will create more opportunities for innovation and competition, thereby driving down prices.

Improve the Weapons Industry’s Talent and Workforce. The U.S. must focus on providing a capable and talented workforce to provide the necessary technological skills required in the ever-changing weapons industry. This process should be two-fold, focusing on both high-end engineering education as well as basic manufacturing skills. The DoD needs to further efforts to invest in programs that increase partnerships to provide specific skills required for defense production. To address the shortage of high-end engineers in complex missile production, the DoD invested $14M in conjunction with missile contractors to ensure a future supply of qualified labor. These programs should be expanded throughout the weapons industry. Also, to address companies’ challenges with aging workforces and attracting young talent, the USG should use creative incentives for weapons firms to actively expand their workforce greening initiatives in order to improve long-term viability.

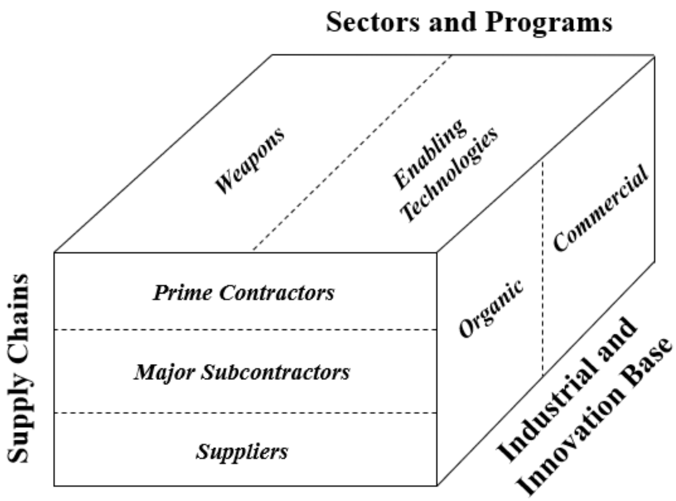
A common theme seen throughout both domestic weapons manufacturing firms as well as Bulgarian firms which we visited was a connection with local technical colleges. These programs help to ensure a competent workforce with the skill set required to operate the newest in Computer Numerically-Controlled (CNC) machines. These programs are vital to increase productivity throughout the weapons industry and should be incentivized amongst firms in the industry. Additionally, the DoD should take steps to foster and grow these programs amongst weapons producers.

Strengthen Cyber Defense and Security. Cyber threats and cyber security gaps create vulnerabilities within U.S. critical infrastructure, the defense industrial base, weapons manufacturing, IP protection, and supply chains. To help the U.S. retain its military-technological competitive advantage against cross-cutting cyber elements affecting the weapons industry, the U.S. must continue to develop and invest in cyber defense and cyber security, including investing in a centralized government cyber defense plan to protect both the manufacturing base of the U.S. weapons industry and sustain confidence and reliability of systems and sub-systems. Furthermore, the U.S. should continue to invest in cyber R&D, leveraging and strengthening governmental and non-governmental partnerships, improving information sharing concerning breaches and vulnerabilities, promoting incentives through fiscal policy, regulation, and acquisition reform, and developing the next generation cyber security workforce and economy.

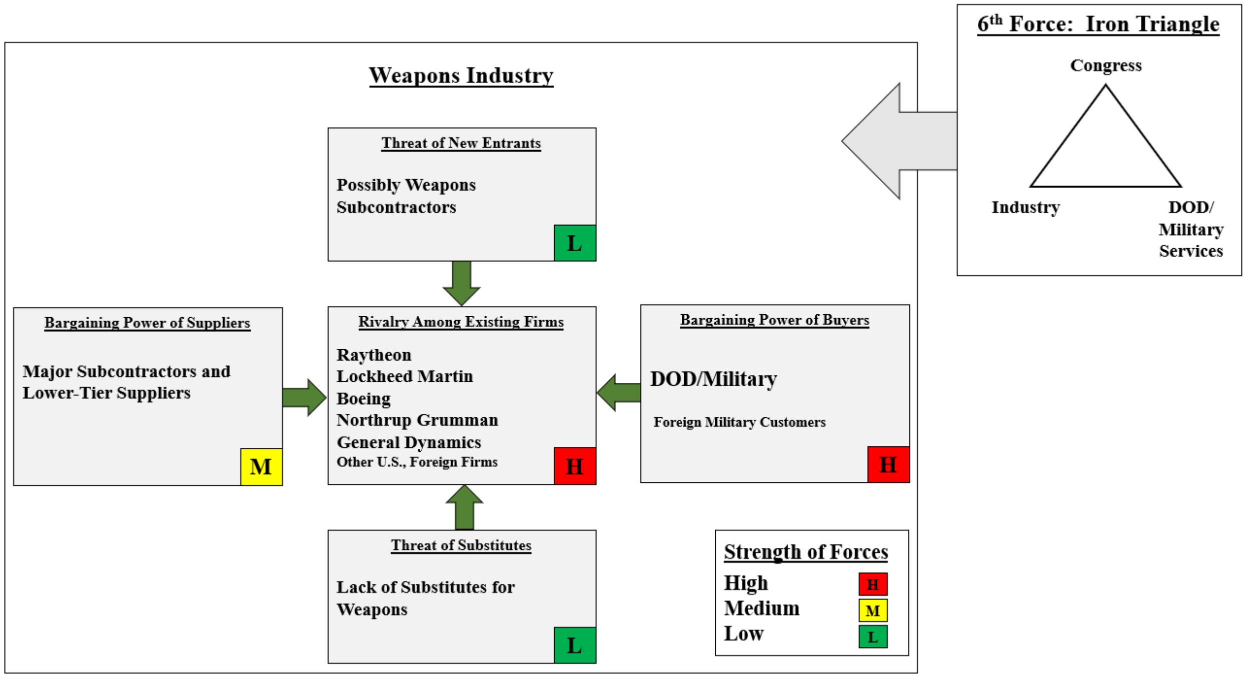
APPENDIX A: Paper Concept[70]



APPENDIX B: Structure of the Weapons Industry[71]



APPENDIX C: Porter's Five Forces and the Weapons Industry



APPENDIX D: Selected U.S. Laws, Regulations, and Policies Affecting the Weapons Industry

Laws and Regulations

- National Security Act of 1947
- Defense Production Act (DPA) of 1950, including Title III and Title VII (CFIUS); Defense Production Act (DPA) Title III program, Industrial Base Analysis and Sustainment (IBAS) program
- Title 10, USC, including Chapter 148 - National Defense Technology and Industrial Base, Defense Reinvestment, and Defense Conversion
- The Arms Export Control Act (22 U.S. Code chapter 39 - ARMS EXPORT CONTROL), Export Administration Regulations (15 CFR §§730-774), and International Traffic in Arms Regulations (ITAR) (22 C.F.R. Chapter 1, Subchapter M, parts 120-130), and existing export control reform (ECR) initiatives, and U.S. technology control lists (e.g. U.S. Munitions List (USML) (Part 121.1 of the ITAR), and the Commerce Control list (CCL) (published at 15 CFR §774, Supplement 1.)
- DoD Directives 5000.60 ("Defense Industrial Capabilities Assessments"), dated April 25, 1996, certified current as of December 8, 2003, and 5000.62 ("Review of Mergers or Acquisitions of Major DoD Suppliers on National Security and Public Interest"), February 27, 2017
- Goldwater-Nichols Department of Defense Reorganization Act of 1986
- Various National Defense Authorization Acts (NDAAs)

- Federal Acquisition Regulation (FAR), Defense Federal Acquisition Regulation Supplement (DFARS)
- "Buy American" laws/amendments, including the Buy American Act (41 USC 10a–10d; FAR Part 25.2; DFARS Part 225.2) and the Balance of Payments Program (FAR Part 25.3; DFARS Part 252.3); (each places restrictions on U.S. government purchases of supplies that are not domestic end products)
- Cybersecurity mandates, including the National Institute of Standards and Technology Special Publication 800-171 (NIST SP) – "Protecting Controlled Unclassified Information in Non-federal Information Systems and Organizations" (DFARS 255.204-7012 mandate to comply with the publication)
- Hart-Scott-Rodino Antitrust Improvements Act of 1976 (better known as HSR), which mandates that some mergers and acquisitions be reviewed by the Department of Justice and the Federal Trade Commission
- International cooperation agreements, including security assistance (State - 22 USC) and security cooperation (DoD - 10 USC)
- Treaties/agreements, including those that constrain U.S. and other countries' weapons R&D and production, and those that govern U.S. alliances
- Environmental and safety laws and regulations

<u>Policies</u>

- U.S. government policy since the 1990s toward the defense industry of allowing free market forces to guide the industry and intervening when needed[72]
- National Security Strategy, National Defense Strategy, National Military Strategy, Quadrennial Defense Review
- U.S. defense acquisition system: Joint Capabilities Integration and Development System (JCIDS), DoD Instruction 5000.02 ("Operation of the Defense Acquisition System"), and the Planning, Programming, Budgeting, and Execution (PPBE) system
- Foreign Military Sales (FMS) and Direct Commercial Sales (DCS) programs
- National Security Decision Memorandum (NSDM) 119 ("Disclosure of Classified Military Information to Foreign Governments and International Organizations"), dated July 20, 1971; "National Policy and Procedures for the Disclosure of Classified Military Information to Foreign Governments and International Organizations" (short title: National Disclosure Policy (NDP-1))
- Updated April 2018 Conventional Arms Transfer (CAT) Policy, which superseded and replaced Presidential Policy Directive 27 of January 15, 2014
- Multilateral export control regimes such as the Wassenaar Arrangement and Missile Technology Control Regime

<u>Executive Orders (E.O.)</u>

- E.O. 13806 (2017) ("Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States")
- E.O. 13603 (2012) ("National Defense Resources Preparedness"), which revoked E.O. 12919 (1994)
- E.O. 13788 (2017) ("Buy American and Hire American")
- E.O. 13526 (2009) ("Classified National Security Information")

ENDNOTES:

[1] The White House, *National Security Strategy of the United States of America*, December 2017.

[2] U.S. Department of Defense, "Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge," January 2018, 4, 6.

[3] U.S. Department of Defense, "Program Acquisition Cost By Weapon System: United States Department of Defense Fiscal Year 2019 Budget Request," Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, February 2018, 5-1; Mark Cancian, "Long Wars and Industrial Mobilization: It Won't Be World War II Again," *War on the Rocks* (August 8, 2017), accessed on April 4, 2018, https://warontherocks.com/2017/08/long-wars-and-industrial-mobilization-it-wont-be-world-war-ii-again/.

[4] Deputy Secretary of Defense, Robert Work, "The Third U.S. Offset Strategy and its Implications for Partners and Allies," January 28, 2015, accessed March 25, 2018, http://www.defense.gov/News/Speeches/Speech-View/Article/606641/the-third-us-offset-strategy-and-its-implications-for-partners-and-allies; Robert W. Button, "Thinking Constructively About Overmatch," *The Rand Blog*, March 21, 2017, accessed March 31, 2018, https://www.rand.org/blog/2017/03/thinking-constructively-about-overmatch.html; U.S. Navy, Program Executive Office (Unmanned Aviation and Strike Weapons), "Moving Toward Advanced Weapons: Precision Strike Weapons Pacing the Threat," March 17, 2015.

[5] See for example: U.S. Department of Defense, "Annual Industrial Capabilities," Report to Congress, Fiscal Year 2016, March 2017, 78.

[6] See for example: "Defense Innovation Maintains Military Overmatch Against Adversaries," *DoD News*, May 3, 2017, accessed May 1, 2018, https://www.defense.gov/News/Article/Article/1172099/defense-innovation-maintains-military-overmatch-against-adversaries/. This paper defines overmatch—also referred to as competitive advantage—as having qualitative and quantitative dimensions. Qualitative overmatch refers to the advantage provided by the advanced technological capabilities of the weapons, while quantitative overmatch refers to the advantage provided by the sustained number of weapons—from stockpiles, purchases, or new production—the U.S. military (and its allies and partners) can bring to bear in an armed conflict.

[7] Eliot A. Cohen, *The Big Stick: The Limits of Soft Power and the Necessity of Military Force* (New York, NY: Basic Books, 2016), 63; Jim Garamone, "Dunford Urges Congress to Protect U.S. Competitive Advantage," *DoD News*, June 12, 2017, accessed May 1, 2018, https://www.defense.gov/News/Article/Article/1211668/dunford-urges-congress-to-protect-us-competitive-advantage/.

[8] Relevant USML categories include: Category I (Firearms, Close Assault Weapons and Combat Shotguns), Category II (Guns and Armament), Category III (Ammunition/Ordnance), Category IV (Launch Vehicles, Guided Missiles, Ballistic Missiles, Rockets, Torpedoes, Bombs, and Mines), and Category V (Explosives and Energetic Materials, Propellants, Incendiary Agents, and Their Constituents). Also, the relevant categories of the United Nations Register of Conventional Arms and the Arms Trade Treaty include: Large-caliber artillery systems, missiles, and small arms and light weapons.

[9] This definition borrows from the framework used by the DoD's Manufacturing and Industrial Base Policy (MIBP) website (http://www.businessdefense.gov/Programs/Industrial-Base-Assessments/), as well as the definition of "defense technology and industrial base" in U.S. General Accounting Office, "Defense Industrial Base: Overview of an Emerging Issue," GAO/NSIAD-93-68, March 1993, 1.

[10] NDAA 2017 provides a useful definition of the organic industrial base: "United States military facilities, including arsenals, depots, munition plants and centers, and storage sites, that advance a vital national security interest by producing, maintaining, repairing, and storing materiel, munitions, and hardware." (U.S. House of Representatives, "National Defense Authorization Act for Fiscal Year 2017," November 30, 2016, 81-32.)

[11] See for example: GAO, "Defense Industrial Base: Overview of an Emerging Issue"; U.S. Congressional Research Service, "Defense Primer: U.S. Defense Industrial Base," December 14, 2016.

[12] According to the MIBP, a "capability" in this context is defined as a technology, part, component, or product. See Sally Sleeper, John Starns, and Eugene Warner, "Identifying and Mitigating Industrial Base Risk for the DoD: Results of a Pilot Study," May 14-15, 2014; see also Sally Sleeper, et al, "Trends and Risks in the Global Industrial Base for Defense," presented at the AFCEA Acquisition Research Symposium, August 5, 2014.

[13] Based on Michael E. Porter, "The Five Competitive Forces That Shape Strategy," *Harvard Business Review* (January 2008): 79-93.

[14] For example, a recent report referred to the "Big Five" of the ordnance and missile sector as: Lockheed Martin, Boeing, Raytheon, Northrup Grumman, and General Dynamics. (Rhys McCormick, Andrew P. Hunter, and Gregory Sanders, "Measuring the Impact of Sequestration and the Drawdown on the Defense Industrial Base," Center for Strategic and International Studies, December 2017, vii.)

[15] For example: Raytheon, "2016 Annual Report: Engineering a Safer World"; Jake Gregg, Adam Smith, and Spencer Elkinton, "Raytheon Company," May 2016; Lockheed Martin Corporation, "2016 Annual Report"; COL James Romero, Program Executive Office Missiles and Space, "Overview Huntsville Aerospace Marketing Association," April 8, 2016; U.S. Navy, Program Executive Office (Unmanned Aviation and Strike Weapons), "Moving Toward Advanced Weapons: Precision Strike Weapons Pacing the Threat," March 17, 2015.

[16] Defense industry panel, Eisenhower School Industry Analytics class IA-11, February 6, 2018.

[17] Ibid.

[18] Henrik Heidenkamp, John Louth, and Trevor Taylor, *The Defence Industrial Triptych: Government as a Customer, Sponsor and Regulator of Defence Industry* (Abingdon, UK: Published on behalf of the Royal United Services Institute for Defence and Security Studies by Routledge Journals, 2013).

[19] Other challenges identified include: The cyclical nature of defense procurements, the lack of industrial base structural planning, the lack of industrial responsiveness, the lack of an industrial base to match changing needs, the false perception of autarky, the decline of the capability and capacity of U.S. manufacturing, the growing human capital gaps in the U.S. science, technology, engineering and mathematics (STEM) and trade-related workforce, the unintended consequences of DoD business practices, and the industrial policies of competitor states working to erode the U.S. National Security Innovation Base. (See for example: Jacques S. Gansler, *Democracy's Arsenal: Creating a Twenty-First-Century Defense Industry* (Cambridge, MA: The MIT Press, 2011), 22-33; Aerospace Industries Association, "Fostering the Manufacturing & Defense Industrial Base of the Future," April 2018, 1.)

[20] See for example: Aerospace Industries Association, "Fostering the Manufacturing & Defense Industrial Base of the Future," April 2018, 2.

[21] U.S. Department of Defense, "Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge," January 2018, 5; Jim Garamone, "Dunford Urges Congress to Protect U.S. Competitive Advantage," *DoD News*, June 12, 2017, accessed May 1, 2018, https://www.defense.gov/News/Article/Article/1211668/dunford-urges-congress-to-protect-us-competitive-advantage/.

[22] See for example: Jacques S. Gansler, *Democracy's Arsenal: Creating a Twenty-First-Century Defense Industry* (Cambridge, MA: The MIT Press, 2011), 33; George A. Coggins, "Can American Afford to Modernize the Air Force," *Air Force Journal of Logistics*, Volume XXXIV, Numbers 3 and 4, 33-34; Carlo Kopp, "The Sidewinder Story: The Evolution of the AIM-9 Missile," Air Power Australia, http://www.ausairpower.net/TE-Sidewinder-94.html, accessed April 8, 2018; GAO, "Solid Rocket Motors: DoD and Industry are Addressing Challenges to Minimize Supply Concerns," Report to the Honorable Joe Manchin II, U.S. Senate, October 2017, 8.

[23] Fragility in this context can be viewed as the opposite of resilience or resiliency. According to the Defense Logistics Agency, resiliency is "The ability of a person, program, or organization to perform functions necessary for

mission success," and to do so "in spite of hostile action or adverse conditions." (Defense Logistics Agency, "Glossary of Terms," *Loglines* (January/February 2018): 14.) Another useful definition for resilience comes from the supply chain management discipline: "The ability of a system to both resist disruptions and recover operational capability after disruptions occur." Based on the two factors of Resistance Capacity and Recovery Capacity, supply chains can be generally categorized as: Fragile (low resistance, low recovery), resistant but sluggish (high resistance, low recovery), vulnerable but responsive (low resistance, high recovery), or hardy (high resistance, high recovery). (Steven A. Melnyk, David J. Closs, Stanley E. Griffis, Christopher W. Zobel, and John R. Macdonald, "Understanding Supply Chain Resilience," *Supply Chain 24/7*, November 20, 2015, accessed March 1, 2018, https://www.supplychain247.com/article/understanding_supply_chain_resilience.) One might argue that the weapons industry is currently a mix of "fragile" and "vulnerable but responsive," and we want to find ways to move it to "hardy."

[24] *Fragility* is caused by factors such as a low number of suppliers in the sector, allocation of limited critical items to higher priorities, companies exiting the defense sector, bad financial health of suppliers, production that is near the minimum sustaining rate or at the maximum production rate, cyber and physical threats to the supply chains, and reliance on foreign suppliers. *Criticality* is caused by factors such as defense-unique items, reliance on "one deep" single or sole source suppliers, obsolescence of items (no longer produced), long lead times to produce the item, the lack of alternative items, the inability to surge production, the depletion of stockpiles, and the time and resources required to reconstitute a capability to produce the item. (For example: U.S. Department of Defense, Manufacturing and Industrial Base Policy, "Identifying and Mitigating Industrial Base Risk for the DoD: Results of a Pilot Study," May 2014.)

[25] "Why the U.S. Can't Rearm Fast," *Washington Post* (February 10, 1980), accessed April 1, 2018, https://www.washingtonpost.com/archive/opinions/1980/02/10/why-the-us-cant-rearm-fast/420642ea-fb13-48fc-8d36-8c47d535016c/?utm_term=.609326a646a6; Michael D. Miller, "Measuring Industrial Adequacy for a Surge in Military Demand: An Input-Output Approach," RAND Corporation, R-2281-AF, September 1978, v.

[26] For examples of fragile and critical items for weapons industry, see: U.S. Department of Defense, "Fiscal Year 2016 Annual Industrial Capabilities"; U.S. Department of Defense, "Annual Industrial Capabilities Report to Congress for 2015," September 2016, 46-48; U.S. Department of Defense, "Annual Industrial Capabilities Report to Congress," October 2013, B-17; U.S. Department of Defense, Manufacturing and Industrial Base Policy, "Identifying and Mitigating Industrial Base Risk for the DoD: Results of a Pilot Study," May 2014; Dr. Chris Michienzi, Senior Industrial Analyst, Missiles and Munitions, OUSD(A&S), DASD MIBP, "Manufacturing and Industrial Base Policy: Missiles and Munitions Risks, Issues and Mitigations," Eisenhower School presentation, March 12, 2018; U.S. Department of Defense, "Defense Industrial Base Conference: Overview & Objectives," April 11, 2007, accessed March 1, 2018, http://proceedings.ndia.org/7030/Salesses.pdf; U.S. Naval Sea Systems Command, "Energetic Obsolescence Risks," CAD/PAD Industry Summit, October 2015; U.S. Department of Defense, "Critical Energetic Material Initiative," IM/EM Technology Symposium, May 16, 2012; Mark Gunzinger and Bryan Clark, Center for Strategic and Budgetary Assessments, "Sustaining America's Precision Strike Advantage," 2015, 60; U.S. Government Accountability Office, "Solid Rocket Motors: DoD and Industry Are Addressing Challenges to Minimize Supply Concerns," GAO-18-45, October 2017; U.S. Department of Defense, "Manufacturing & Industrial Base Policy Perspectives," Under Secretary of Defense for Acquisition, Technology and Logistics, USD (AT&L), Manufacturing and Industrial Base Policy, July 27, 2016; Jeff Green, "Pentagon must target weak points, improve resiliency in the defense supply chain," *Defense News* (November 1, 2017), accessed January 31, 2018, https://www.defensenews.com/...2017/11/01/pentagon-must-target-weak-points-improve-resiliency-in-the-defense-supply-chain-commentary/; U.S.Securities and Exchange Commission, Form 10-K, Annual Report Pursuant to Section 13 or 15(d) of the Securities Exchange Act of 1934, for the fiscal year ended December 31, 2016, Raytheon Company, 16; U.S. Government Accountability Office, "Defense Supply Chain: DoD Needs Complete Information on Single Sources of Supply to Proactively Manage the Risks," GAO-17-768, September 2017; "PSAR 2016: Acquisition Strategy for 3rd Offset," *The Precision Strike Digest*, 2nd Issue/2016, Volume 29, Number 2 (2016): 5-6; Bradley K. Nelson, "Keeping Track of Horseshoe Nails Industrial Base Analysis and Sustainment," *Defense AT&L* (September-October 2016): 10-12; Albert Defusco, "Historical Overview of HTPB The Military's Preferred Solid Propellant Binder for a Half Century," *Defense Systems Information Analysis Center Journal*, Volume 3, Number 4 (Fall 2016), accessed April 1, 2018, https://www.dsiac.org/resources/journals/dsiac/fall-2016-volume-3-number-4/historical-overview-htpb-military's-preferred.

[27] U.S. General Accountability Office, "Defense Supply Chain: DoD Needs Complete Information on Single Sources of Supply to Proactively Manage the Risks," GAO-17-768, September 2017, 21-22.

[28] U.S. Department of Defense, "Fiscal Year 2016 Annual Industrial Capabilities," 81, 87. Also, according to one analyst, "critical components for munitions are dominated by single- or sole-source second-tier and third-tier suppliers. Interestingly, there is approximately one supplier for every two critical munitions components, reflecting a lack of competition and adequate depth at the subprime level…" (Albert Defusco, "The U.S. Rocket Propulsion Industrial Base: A Status Report," *Defense Systems Information Analysis Center Journal*, Volume 4, Number 1 (Winter 2017), accessed April 1, 2018, https://www.dsiac.org/resources/journals/dsiac/winter-2017-volume-4-number-1/us-rocket-propulsion-industrial-base-status.)

[29] GAO, "Solid Rocket Motors: DoD and Industry are Addressing Challenges to Minimize Supply Concerns," Report to the Honorable Joe Manchin II, U.S. Senate, October 2017, 15.

[30] The White House, "National Security Strategy of the United States of America," December 2017, 29.

[31] Physical methods adversaries might use include the physical theft of items, tampering with parts, inserting counterfeit or cloned parts, or disrupting or denying access to critical components and materials. Cyber methods include the virtual theft of data, the disruption of computer networks, and the malicious insertion of software.

[32] See for example: U.S. Department of Defense, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, "Annual Industrial Capabilities Report to Congress for 2014," September 2016, C-26, 23; National Counterintelligence and Security Center, Supply Chain Directorate, "Supply Chain Risk Management," Intelligence.Gov Background Paper, March 17, 2017, accessed February 2, 2018, https://www.dni.gov/files/NCSC/documents/products/20170317-NCSC--SCRM-Background.pdf; Melinda Reed, Office of the Deputy Assistant Secretary of Defense for Systems Engineering, "System Security Engineering for Program Protection and Cybersecurity 18th Annual NDIA Systems Engineering Conference," Springfield, VA, October 27, 2015; "Supply Chain as an Attack Chain: Key Lessons to Secure Your Business," presentation of panel at RSA Conference 2015, April 20-24, 2015; National Defense Industrial Association, "Cybersecurity for Manufacturing Networks," a White Paper prepared by the NDIA Cybersecurity for Advanced Manufacturing Joint Working Group (CFAM JWG), October 2017, 4.

[33] For example: Dee Reardon, Deputy Assistant Secretary of Defense for Supply Chain Integration, "Life Cycle Sustainment & The DoD Supply Chain," presentation to the Supply Chain Management course, National Defense University, October 4, 2017; Dr. Chris Michienzi, Senior Industrial Analyst, Missiles and Munitions, OUSD(A&S), DASD MIBP, "Manufacturing and Industrial Base Policy: Missiles and Munitions Risks, Issues and Mitigations," Eisenhower School presentation, March 12, 2018; Jeff Green, "Pentagon must target weak points, improve resiliency in the defense supply chain," *Defense News* (November 1, 2017), accessed January 31, 2018, https://www.defensenews.com/...2017/11/01/pentagon-must-target-weak-points-improve-resiliency-in-the-defense-supply-chain-commentary/. Supply chain visibility challenges are not just an issue for the weapons industry, but for industries in general. According to one analyst, "There is a strong likelihood that the focal firm at the center of the network will not even be aware of many of the second- or third-tier suppliers that feed their upstream supply chain." (Martin Christopher, *Logistics and Supply Chain Management*, Fifth Edition (Harlow, UK: Pearson, 2016), 174.)

[34] Other DoD organizations, such as the Defense Contract Management Agency (DCMA), Air Force, Navy, Army, and Missile Defense Agency (MDA), apparently also conduct fragility and criticality assessments of the defense industrial base. (Steve Turdo, Defense Contract Management Agency, "Portfolio Management & Integration (PM&I), Industrial Analysis Center, Mission Briefing," December 2, 2015, slides 7-9, 11; Robert M. Read, Manufacturing and Industrial Base Policy (MIBP), "Need for Industrial Base Rebalance in Pacific Pivot," March 19, 2014, slide 11 U.S. Department of Homeland Security and U.S. Department of Defense, "Defense Industrial Base: Critical Infrastructure and Key Resources Sector-Specific Plan as input to the National Infrastructure Protection Plan," May 2007, 13-15.)

[35] According to one author, "drilling down into defense supply chains to identify unique, fragile, or niche capabilities requires detailed data—almost certainly including propriety and classified information about individual

firms and their defense programs that is not publicly available." (Barry D. Watts, "Sustaining the U.S. Defense Industrial Base as a Strategic Asset," Center for Strategic and Budgetary Assessments, September 2013, 2.) See also: U.S. Government Accountability Office, "Defense Supply Chain: DoD Needs Complete Information on Single Sources of Supply to Proactively Manage the Risks," GAO-17-768, September 2017, 14, 18.

[36] According to a 2013 Defense Science Board (DSB) report, "many tiers in the supply chain (designers, producers, brokers, subsystem suppliers, major system integrators, etc.) limit visibility and make the origins of components difficult to track and certify." (Defense Science Board, "Task Report: Resilient Military Systems and the Advanced Cyber Threat," January 2013, 76.) Also, according to MIBP, the DoD relies in large part on prime contractors to manage their supply chains, and the primes pass this responsibility to sub-tier suppliers—a dynamic which has led to situations where the DoD has not been informed of supply chain problems until years later. (Michienzi, "Manufacturing and Industrial Base Policy: Missiles and Munitions Risks, Issues and Mitigations.")

[37] According to one author, "From a [Defense Technology and Industrial Base (DTIB)] perspective, there are at least three different measures by which production capabilities might be judged. First, there is the question of how efficiently—in terms of cost and quality—the DTIB can produce the weapons and other hardware needed to keep the military fully equipped in peacetime. Second, there is the question of how much production can be surged in a crisis or time of war. Third, there is the question of how quickly and effectively the commercial industrial base can be mobilized to support military production in the event a new peer or near-peer competitor were to emerge." (Steven M. Kosiak, "Buying Tomorrow's Military: Options for Modernizing the U.S. Defense Capital Stock," Center for Strategic and Budgetary Assessments, 2001, 53.) Similarly, a 1992 Office of Technology Assessment report listed three "desirable characteristics for future defense production: 1. it should produce weapons and military equipment efficiently in peacetime, 2. it should be responsive to a regional crisis or war perhaps through increased production ("surge"), and 3. it should be capable of greatly expanding production ('‘mobilization") in a timely fashion if a large global military threat emerges." (Office of Technology Assessment, "Building Future Security: Strategies for Restructuring the Defense Technology and Industrial Base," OTA-ISC-530, June 1992, 13.) Arguably, the weapons industry's industrial base adequately meets the first criterion listed in the two sources, marginally meets the second criterion, but fails to meet the third.

[38] See for example: Jeff Green, "Pentagon must target weak points, improve resiliency in the defense supply chain," *Defense News* (November 1, 2017), accessed January 31, 2018, https://www.defensenews.com/...2017/11/01/pentagon-must-target-weak-points-improve-resiliency-in-the-defense-supply-chain-commentary/; Paul D. Shinkman, "ISIS War Drains U.S. Bomb Supply, *U.S. News* (Feb. 17, 2017); Sandra Erwin, "More Missiles and Munitions: The U.S. Army's Answer to Russia," *Real Clear Defense* (June 7, 2017); Lara Seligman, "Chief of Naval Operations Warns Congress of Munitions Shortfall in 2020," Inside the Pentagon's Inside the Navy, Volume 28, Issue 10 (March 16, 2015); U.S. Department of Defense, "Fiscal Year 2019 Budget Request," Office of the Undersecretary of Defense (Comptroller)/CFO, February 2018; Allyson Versprille, "Industry to Increase Output of Smart Munitions," *National Defense* (May 2016): 22; Sydney J. Freedberg Jr., "Army Needs $45B Of Smart Weapons: Hellfire, GMLRS, ATACMS, Patriot, THAAD," *Breaking Defense*, June 30, 2017, accessed February 1, 2018, https://breakingdefense.com/2017/06/army-needs-45b-of-hellfire-glcms-atacms-patriot-thaad/; U.S. Congress, House Armed Services Committee, "Reform and Rebuild: National Defense Authorization Act for FY18," HASC Communications 52539, undated, 20-21; Rachel Karas, "Industry aims to streamline weapons production as quantities grow," *Inside the Air Force* (March 2, 2018); Aaron Mehta, "Mattis intervened to increase munition buy in FY18 budget request," *Defense News* (May 23, 2017), accessed March 25, 2018, https://www.defensenews.com/congress/budget/2017/05/23/mattis-intervened-to-increase-munition-buy-in-fy18-budget-request/; John A Tirpak, "Munitions Production Surge Planned for At Least Five Years," *Air Force Magazine* (February 22, 2018), accessed March 13, 2018, http://www.airforcemag.com/Features/Pages/2018/February%202018/Munitions-Production-Surge-Planned-for-At-Least-Five-Years.aspx; Paul Sonne, "For Missile Makers, U.S. Demand Surges," *Wall Street Journal* (January 7, 2017): B4; Stephen Snyder, "The U.S. is dropping bombs quicker than it can make them," *Public Radio International* (April 10, 2016), accessed March 25, 2018, https://www.pri.org/stories/2016-04-10/us-dropping-bombs-quicker-it-can-make-them; Marcus Weisgerber, "The U.S. is Raiding its Global Bomb Stockpiles to Fight ISIS," *Defense One* (May 26, 2016), accessed February 1, 2018, http://www.defenseone.com/threats/2016/05/us-raiding-its-global-bomb-stockpiles-fight-isis/128646/; Andrea Shalal, "U.S. arms makers strain to meet demand as Mideast conflicts rage," *Reuters* (December 4, 2015), accessed February 1, 2018, https://www.reuters.com/...ast-crisis-usa-arms-insight/u-s-arms-makers-strain-to-meet-demand-as-mideast-conflicts-rage-

idUSKBN0TN2DA20151204; Aaron Mehta, "Mattis intervened to increase munition buy in FY18 budget request," *Defense News* (May 23, 2017), accessed March 31, 2018, https://www.defensenews.com/congress/budget/2017/05/23/mattis-intervened-to-increase-munition-buy-in-fy18-budget-request/; Dan Lamothe, "Critics say Trump's proposed military buildup isn't happening. Wait until 2019, the Pentagon says," *Washington Post* (May 23, 2017), accessed April 1, 2018, https://www.washingtonpost.com/news/checkpoint/wp/2017/05/23/critics-say-trumps-proposed-military-buildup-isnt-happening-wait-until-2019-the-pentagon-says/?utm_term=.fe7713a223c3.

39 U.S. Air Force, "Fiscal Year 2019 Budget Overview," February 12, 2018; U.S. Department of Defense, "Program Acquisition Cost By Weapon System: United States Department of Defense Fiscal Year 2019 Budget Request," Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, February 2018, 5-1.

40 For example, during 2017 and 2018, Boeing was in the process of ramping up production of the JDAM from 40 to 210 units per day, and quintupling its production of the SDB I; according to the DoD, "the factory will operate at the maximum rate of production" for both the JDAM and SDB I. (Discussions with officials of Boeing Defense, Space and Security (BDS), St. Louis, Missouri, February 2018 and April 2018; Angela Mueller, "Boeing boosts St. Louis production amid increased demand for munitions," *St. Louis Business Journal* (January 5, 2017); John Keller, "Growing demand prompts Air Force to nearly double Boeing JDAM smart munitions contract," *Intelligent Aerospace* (June 6, 2016); Mueller, "Boeing boosts St. Louis production amid increased demand for munitions"; Marcus Weisgerber, "Bombs Away! Lockheed Expanding Missile Factories, Quadruples Bomb Production for ISIS Long Haul," *Defense One*, March 16, 2016, accessed March 25, 2018, http://www.defenseone.com/business/2016/03/lockheed-expands-munitions-factories-isis-future/126725/.) See also: Paul Sonne, "Defense Firms Cash In Amid Soaring Demand for Munitions," *Wall Street Journal* (January 5, 2017); U.S. Department of Defense, "Program Acquisition Cost By Weapon System: United States Department of Defense Fiscal Year 2019 Budget Request," Office of the Undersecretary of Defense (Comptroller)/Chief Financial Officer, February 2018, 5-2.

41 Discussions with officials of Boeing Defense, Space and Security (BDS), St. Louis, Missouri, February 2018, and officials of Raytheon Missile Systems, Tucson, Arizona, April 2018. For example, Raytheon claimed from 2014 to 2018 that the lack of new DoD orders for its Tomahawk cruise missile—with the final new missile to be delivered in mid-2019—will provide irreversible damage to Raytheon's ability to produce the missile in the future and to the industrial base and suppliers that support Tomahawk production, including forcing suppliers out of business or out of the defense sector and driving engineers to other sectors. (Doug Cameron, "Cut Weapons Now, but Then What? -- With Fate of Tomahawk Missiles Unclear, Industry Warns of Future Costs for Restarting, Retooling," *Wall Street Journal* (July 3, 2014): B8; James Drew, "Raytheon Warns Of 10-Year Tomahawk Production Void," *Aerospace Daily & Defense Report* (January 11, 2018): 3; Lara Seligman, "Plan For Tomahawk Production, NGLAW Will Be 'Revisited' In POM-17," *Inside the Pentagon's Inside the Navy*, Volume 28, Issue 11 (March 23, 2015).)

42 U.S. Department of Defense, "Annual Industrial Capabilities Report to Congress for 2015," September 2016, 43, 46.

43 Mark Cancian, "Long Wars and Industrial Mobilization: It Won't Be World War II Again," *War on the Rocks* (August 8, 2017), accessed on April 4, 2018, https://warontherocks.com/2017/08/long-wars-and-industrial-mobilization-it-wont-be-world-war-ii-again/.

44 U.S. Department of Defense, *Summary of the 2018 National Defense Strategy of the Unites States of America: Sharpening the American Military's Competitive Edge*, January 2018, 6.

45 The White House, *National Security Strategy of the United States of America*, December 18, 2017, 29.

46 *National Security Strategy of the United States of America*, 21.

47 Linda Weiss, *America Inc.?: Innovation and Enterprise in the National Security State* (New York: Cornell University, 2014), 2.

[48] Scott S. Haraburda, "Conventional Munitions Industrial Base: The Land Warfare Papers," Volume 113, August 2017.

[49] Enterprise Capability Collaboration Team (ECCT), *Air Superiority 2030 Flight Plan* (Langley Air Force Base, VA: Air Force Publishing, 2016), 2-3.

[50] J. R. Wilson, "Electro-Optical Sensors Key to Missile Defense: Although missile-intercept kill vehicles capture the imagination, electro-optical sensors are the most important component of ballistic missile defense," *Military & Aerospace Electronics* 29, no. 1 (January 2018): 14.

[51] BAE Systems, "Radford Army Ammunition Plant," https://www.baesystems.com/en-us/product/radford-army-ammunition-plant, 2018.

[52] GAO, "Solid Rocket Motors: DoD and Industry are Addressing Challenges to Minimize Supply Concerns," Report to the Honorable Joe Manchin II, U.S. Senate, October 2017, 17.

[53] *National Security Strategy of the United States of America*, 21.

[54] "AIM-9 Sidewinder Legacy Variants (AIM-9B to AIM-9S)," *Jane's* (January 5, 2018): 4.

[55] Darrin Kravitsky and Kevin Gessner, "Navy Center Works to Keep Energetics Industrial Base Moving," *National Defense*, November 1, 2014, http://www.nationaldefensemagazine.org/articles/2014/11/1/2014november-navy-center-works-to-keep-energetics-industrial-base-moving.

[56] George Galdorisi, Captain, U.S. Navy, "U.S. Navy, A Potent One-Two Punch," *U.S. Naval Institute Proceedings*, Volume 142, Issue 3 (March 2016).

[57] Comments from anonymous employee of PGM manufacturer made during a facility tour in Scottsdale, AZ, April 2-3, 2018.

[58] Raytheon and Boeing field studies on April 2-3 and April 6, 2018, respectively.

[59] "Conventional Arms Transfer Policy," Aerospace Industries Association website, accessed May 1, 2018, https://www.aia-aerospace.org/issue/conventional-arms-transfer-policy/.

[60] Comments, Columbia, SC, March 1-2, 2018.

[61] Christopher Woody, "The U.S. military is snapping up the Army's new sidearm," *Business Insider*, March 30, 2018, accessed April 9, 2018, http://www.businessinsider.com/us-military-service-branches-buying-army-modular-handgun-system-2018-3.

[62] Federal Acquisition Regulation (FAR), Subpart 2.1 Definitions, https://www.acquisition.gov/far/html/Subpart%202_1.html#wp1145508.

[63] FAR Subpart 15.1, Source Selection Processes and Techniques, https://www.acquisition.gov/far/html/Subpart%2015_1.html.

[64] U.S. Department of Defense, *Summary of the 2018 National Defense Strategy of the Unites States of America: Sharpening the American Military's Competitive Edge*, January 2018.

[65] Ibid.

[66] Ibid.

[67] Ibid.

[68] John F. Miller, "Addressing Attack Vectors Within the Acquisition Supply Chain and the System-Development Lifecycle," *INCOSE Insight* 16(2), July 2013.

[69] U.S. Government Accountability Office, "Budget Uncertainty and Disruptions Affect Timing of Agency Spending," testimony before the Subcommittee on Federal Spending Oversight and Emergency Management, Committee on Homeland Security and Governmental Affairs, U.S. Senate, September 20, 2017; "Fostering the Manufacturing & Defense Base of the Future." Aerospace Industries Association, April 25, 2018; U.S. Department of Defense, "Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge," January 2018.

[70] Adapted from U.S. Department of Defense, "Defense Industrial Base Capabilities Study: Force Application," October 2004, 9.

[71] Adapted from the graphic "Structure of Defense Firms," in Congressional Research Service, "Defense Primer: U.S. Defense Industrial Base," December 14, 2016, 1.

[72] See for example U.S. Government Accountability Office, "Defense Industrial Base: An Overview of Emerging Issues," GAO/NSIAD-93-68, March 1993. For example, according to the report, "In its November 1991 Report to Congress on the Defense Industrial Base, DoD stated that, generally, free market forces will guide the restructuring of the industrial base. DoD also stated that the ability to meet future national security needs will depend largely on the ability of individual companies to shift from defense to commercial production, and then back again, as required…DoD reiterated its free market strategy but stated its intention to assess and monitor the defense industrial base and take action to preserve a needed critical capability in those "exceptional situations" where it may be lost and cannot be recovered in time to meet an emerging threat."