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Industry Study

Final Report
Missile Defense

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Executive Summary

The 2021 National Defense University Eisenhower School Missile Defense Industry Study examined the missile defense industry to gain strategic perspective on the U.S. and global industrial base that supports the resource requirements of national security[1]. The data we gathered through academic research and site visits[2] with missile defense customers and capability providers shed light on the need for the U.S. government to integrate missile defense and nuclear deterrence strategies, focus investments on innovative capabilities that provide a high return on investment, and provide resources to enable new worker and small business entry into the Defense Industrial Base. This report documents the research, analytic processes, and gathered insights of the study team regarding the missile defense segment of the Defense Industrial Base. It provides our policy recommendations for national and defense leaders to improve the layered missile defense system and assist missile defense capability providers by:

- Strengthening and unifying U.S. policy on missile defense
- Leveraging alliances and reengaging competitors
- Investing in disruptive, high return weapons
- Using modeling and simulation to drive investment
- Addressing industrial base and supply chain vulnerabilities

[1] This study was completed through a period of Presidential Administration transition and relies on interim national security guidance to guide recommendation priorities found in this report.
[2] Travel and in-person meeting restrictions established in response to the 2019 Severe Acute Respiratory Syndrome Coronavirus pandemic limited physical site visits and secure facility access by the study team.

Academic Year 2021 – Missile Defense Industry Study Acknowledgements

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While the United States relies on deterrence to protect against large and technically sophisticated Russian and Chinese intercontinental ballistic missile threats to the U.S. homeland, U.S. active missile defense can and must outpace existing and potential rogue state offensive missile capabilities. To do so, the United States will pursue advanced missile defense concepts and technologies for homeland defense.[3]

Introduction

The U.S. Missile Defense System (MDS) bolsters deterrence for the nation and provides credible security assurance to our allies and partners. Missile defense "protects against missile attacks to limit damage, supports U.S. military operations if deterrence fails, and hedges against future uncertainties and risks."[4] While we rely on deterrence to protect against an attack by large numbers of technically sophisticated intercontinental ballistic missiles (ICBM) on the homeland, U.S. active missile defenses can and must outpace the existing and potential missile capabilities of rogue states and non-state actors. To do so, the Department of Defense (DOD) and Department of Homeland Defense (DHS) pursue advanced missile defense concepts and technologies for homeland defense.[5] By "staying ahead" of the technological capability of the missile threats from rogue actors, the U.S. seeks to dissuade adversaries from investing in advanced and ballistic missile technology.[6] Admittedly, as our adversaries field increasingly dangerous, diverse, and expansive offensive threats, we are compelled to provide an equally advanced response. Considering the speed with which adversaries could develop capabilities to threaten homeland security, successive administrations have sought to develop a responsive, adaptable, and lethal missile defense system with Congressional support.

Strategic Guidance

The Interim National Security Strategic Guidance (INSSG) approved by President Biden in March 2021, and the 2019 Missile Defense Review (MDR) are the two most informative strategic policy statements that will set the course for the nation's missile defense strategy under the current administration. The President's guidance charges the U.S. to renew, revisit, and modernize our military capabilities, and ensure our network of alliances and partnerships collectively maintain a strategic advantage to guarantee peace and prosperity. In this fashion the President has spoken to the changing distribution of powers that could yield new threats resulting from a "revolution in technology that poses both peril and promise."[7] His message highlights a need for the nation to invest in its people as well as the technological and industrial base to sustain our competitive advantage. The INSSG also highlights a need to work with our allies and partners to encourage them to accomplish the same.

The 2019 MDR, produced by the Office of the Secretary of Defense (OSD), describes a growing threat to the U.S. homeland posed by advanced ICBM. The review asserts that Russia and China each demonstrated and deployed extensive nuclear and strategic weapon capabilities

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[3] "Missile Defense Review 2019", Department of Defense, 2019, p. III, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.pdf.
[4] "Missile Defense Review 2019", p. I.
[5] "Missile Defense Review 2019", p. III.
[6] "Missile Defense Review 2019", p. VIII.
[7] "Interim National Security Strategic Guidance", The White House, March 2021, p. 9, retrieved on May 11, 2021, from https://www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf.

as part of national strategies to enhance political influence or establish themselves as a global hegemon.[8] Both countries continue developing and testing maneuverable reentry vehicles (MaRV) and hypersonic glide vehicles (HGV) designed to overcome existing missile defense systems. The MDR also acknowledges that the North Korea (DPRK) has demonstrated nuclear weapons capability in support of "explicit nuclear missile threats against the U.S. and allies"[9] while Iran seeks to develop the same. In addition to the threat of ICBM delivered attacks to the homeland are that of new short and intermediate-range missiles to U.S. territories, allies, and interests.

The INSSG and 2019 MDR depict the missile defense industry as a critical national asset to the security of the U.S. and its allies and partners. MDS capabilities employ supporting components like diplomacy, sensors, communication nodes, missiles, and passive and cyber defenses to create integrated, overlapping coverage. The missile defense industry produces sensors, integrated networks, and kinetic kill interceptors for homeland and regional missile defense capabilities. The MDS serves as a powerful deterrent to rogue nations looking to develop ICBM capabilities or attack U.S. interests.

Adversaries are currently fielding increasingly dangerous or diverse offensive threats that require a credible response, and successful missile defeat by existing missile defense systems is becoming increasingly difficult. Moreover, at the speed that foreign threats could challenge homeland security, an advanced, highly adaptable, and lethal deterrent is increasing in importance. Historically, Congress has met this challenge by generously supporting missile defense programs; however, the 2019 Severe Acute Respiratory Syndrome Coronavirus (COVID-19) pandemic and a new U.S. Presidential Administration have raised questions about the priority of missile defense investments that enable the missile defense industrial base (DIB).

Purpose

Our 2021 National Defense University (NDU) Eisenhower School (ES) Industry Study ("the Seminar") examined the missile defense industry to gain a strategic perspective on the U.S. and global industrial base that supports the resource requirements of national security. This examination included industry analysis regarding the general welfare of the missile defense industry, current systems within the layered missile defense architecture, potential innovation paths to improve upon legacy systems, and policy options to address the challenges within missile defense. NDU academic curriculum consisting of Strategic Acquisition and Resourcing and Industry Analysis courses informed our research process. To accomplish our objectives, we conducted site visits and virtual meetings with multiple customer organizations and capability providers that participate in missile defenses. Government organizations providing direct input to this study include the Missile Defense Agency (MDA), North American Aerospace Defense Command, U.S. Northern Command, the Program Executive Office (PEO) for Missiles and Space, and Army Rapid Capabilities and Critical Technologies Office. We also met with industry representatives of Lockheed Martin Corp., Raytheon Technologies, Aerojet Rocketdyne, and Micro Craft Inc.

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[8] "Missile Defense Review 2019", Department of Defense, 2019, pp. II-III, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.pdf.
[9] "Missile Defense Review 2019", p. II.

Missile Defense has served as an effective and discrete joint enterprise protecting the homeland and supporting the war fighter. As DOD adjusts to changing fiscal realities, preserving the industrial base supply chains, leveraging existing partnerships and economies of scale, and delivering disruptive technologies will be critically necessary to increase our competitive advantage in GPC and prepare for any future challenges/threats. This report captures our conclusions from a five-month assessment of the missile defense industry, its various components, and the markets and DOD key missions it serves. It provides the Seminar's assessment of the missile defense industry through a description of the purpose and status of the MDS; the role and goals of the U.S. government in missile defense; the missile defense industry condition, challenges, and outlook; and our policy and resource recommendations for consideration by national and defense leaders.

The Missile Defense Industry

The U.S. missile defense industry is a critical national asset to the security of the nation and our allies and partners. The sensors, integrated networks, and kinetic kill vehicles (KKV) produced for the MDA and the Services provide a layered defense capability that is a powerful deterrent to rogue nations looking to develop ICBM capabilities or attack our allies or partners. This deterrent can actively neutralize incoming missile threats, encouraging parties like the DPRK and Iran to the negotiating table. Missile defense is unique within the DIB as it includes components from almost all other defense industrial sectors. Ships, aircraft, prime movers, space-based assets, sensors, communications architectures, and integrated networks are required to enable the strategic and regional missile defense systems. Responding to 21st-century missile threats will require the U.S. to retain a robust missile defense capability while advancing the MDS; even as we likely face a period of flat or reduced defense budgets.[10]

The Deputy Assistant Secretary of Defense (Industrial Policy) (DASD(IP)) provides an annual report to Congress assessing the DIB as required by Section 2504 of Title 10 USC.[11] The Fiscal Year (FY) 2020 Industrial Capabilities Report to Congress includes an assessment of missile defense radars as part of the radar and electronic warfare sector and missile defense interceptors in the missiles and munitions sector.[12] Both sector assessments include industrial base challenges applicable to missile defense interceptors and radars, but they are not missile defense specific. The MDA, the Services, and the DASD(IP) need to take active steps to improve industrial base efficiency to maintain legacy systems while developing new capabilities.

The top six U.S. defense contractors – Lockheed Martin Corp., Raytheon Technologies, the Boeing Company, General Dynamics Corp., Northrop Grumman Corp., and Huntington Ingalls Industries – dominate the missile defense industrial base.[13] These six Tier-1 or prime contractors produce components of the MDS including the aircraft, ground vehicles, and ships

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[10] Aaron Mehta Gould Joe, "Biden Requests $715B for Pentagon, Hinting at Administration's Future Priorities", Defense News, April 9, 2021, Retrieved on May 11, 2021, from https://www.defensenews.com/breaking-news/2021/04/09/biden-requests-715b-for-pentagon-hinting-at-administrations-future-priorities/.

[11] "10 U.S. Code § 2504 - Annual Report to Congress", LII / Legal Information Institute, retrieved on May 1, 2021, from https://www.law.cornell.edu/uscode/text/10/2504.

[12] "Fiscal Year 2020 Industrial Capabilities Report to Congress", Office of the Secretary of Defense, January 2020, retrieved on April 18, 2021, from https://media.defense.gov/2021/Jan/14/2002565311/-1/-1/0/FY20-INDUSTRIAL-CAPABILITIES-REPORT.PDF.

[13] "Top-100 U.S. Defense Contractors 2020", Forecast International, retrieved on May 2, 2021, from http://www.fi-aeroweb.com/Top-100-Defense-Contractors.html.

that transport sensors and shooters. Company mergers and acquisitions occurring across the DIB since the famous last supper with Deputy Secretary of Defense William Perry in 1993, have reduced the number of prime contractors from fifty to six.[14] This consolidation affects the missile defense industry, most recently with the Raytheon merger with United Technologies,[15] Northrop acquisition of Orbital ATK,[16] and ongoing Lockheed acquisition of Aerojet Rocketdyne – still under review by the Federal Trade Commission (FTC). The future role of Boeing in missile defense also becomes questionable given that it was not selected to participate in a 2021 Next Generation Interceptor (NGI) development competition. The NGI will add a new kinetic response capability to the MDS to supplement and potentially replace the Ground-Based Interceptors (GBI) that currently address long-range and ICBM threats.

On the surface, these mergers and acquisitions seem to reduce competition and increase costs for the missile defense market. However, the missile defense industry continues to be a relatively low-density market dominated by large primes. One of the main reasons for this is the high technology nature of these programs, resulting in a high cost of entry and almost no new companies entering the market. The lack of new entrants means that missile defense work, especially in radars and interceptors, is generally performed by the six prime contractors. The fact that three prime contractors bid on the NGI program – Lockheed, a Northrop Grumman-Raytheon Technologies Team, and Boeing – demonstrates a viable competitive base remains within the missile defense industrial base. Competition ensures companies remain cost-competitive with program bids or face losing production quantities.

The proposed acquisition of Aerojet Rocketdyne by Lockheed raises new concerns about mergers and acquisitions in the missile defense sector. Aerojet is the last Tier-2 domestic supplier of solid rocket motors since the Northrop acquisition of Orbital ATK in 2018. Raytheon opposed the move,[17] and the FTC is still reviewing the proposed merger. Aerojet Rocketdyne representatives stated in an April 8, 2021, virtual engagement that they had approached several companies about a potential acquisition. This acquisition provides an opportunity for Lockheed to vertically integrate solid rocket motor production into missile programs, like Northrop Grumman did upon acquiring Orbital ATK. The acquisition does not provide Lockheed a monopoly in this market since other corporations maintain capability to produce solid rocket motors. If the FTC approves the acquisition, it could impose the same measures to ensure competition as it did with the Northrop acquisition of Orbital ATK.

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[14] Jon Harper, "Defense Industry Could See Another Wave of Mergers, Acquisitions", National Defense: NDIA's Business and Technology Magazine, February 2, 2021, retrieved on May 2, 2021, from https://www.nationaldefensemagazine.org/articles/2021/2/2/defense-industry-could-see-another-wave-of-mergers-acquisitions.

[15] Carten Cordell, "Raytheon Completes Merger with United Technologies", Washington Business Journal, April 3, 2020, retrieved on May 3, 2021, from https://www.bizjournals.com/washington/news/2020/04/03/raytheon-completes-merger-with-united-technologies.html.

[16] "Northrop Grumman Completes Orbital ATK Acquisition, Blake Larson Elected to Lead New Innovation Systems Sector", Northrop Grumman Newsroom, June 6, 2018, retrieved on May 2, 2021, from https://news.northropgrumman.com/news/releases/northrop-grumman-completes-orbital-atk-acquisition-blake-larson-elected-to-lead-new-innovation-systems-sector.

[17] Joe Gould, "Raytheon to Challenge Lockheed's Takeover of Aerojet, CEO Says", Defense News, February 17, 2021, retrieved on May 10, 2021, from https://www.defensenews.com/congress/2021/02/17/raytheon-to-challenge-lockheed-aerojet-merger-ceo-says/.

U.S. Government Role and Goals

Strategic Policy Setting

The Congress and President, through legislation, have exercised their Constitutional authority to define national missile defense policy:

> *It is the policy of the United States to maintain and improve an effective, robust layered missile defense system capable of defending the territory of the United States, allies, deployed forces, and capabilities against the developing and increasingly complex ballistic missile threat with funding subject to the annual authorization of appropriations and the annual appropriation of funds for National Missile Defense.*[18]

This statute goes on to task the Secretary of Defense (SECDEF) and the Chairman of the Joint Chiefs of Staff to jointly review the missile defeat capability, policy, and strategy of the U.S.; a review that includes 18 components, the most important of which are:

- Left- and right-of-launch ballistic missile defense (regional and homeland)
- Full spectrum active, passive, kinetic and non-kinetic defense measures across all platforms and domains
- Hypersonic glide vehicles
- Cruise missile defense for the homeland

For the U.S., nuclear posture and missile defense are essential components of national security and defense strategies. They contribute to the deterrence of adversary aggression and the assurance of allies and partners. Our missile defenses can contribute to defeating and deterring conventional and nuclear-armed missile attacks, whether targeted at American cities or nuclear and military forces. In an era of renewed great power competition, the threats against the U.S. have transformed from terrorist attacks to foreign militaries with increasingly capable ballistic missiles. As the range of ballistic missiles produced by the DPRK and Iran increases, they threaten the U.S. homeland, its population, and infrastructure. One of the key roles of the MDS is to ensure that our adversaries understand a limited nuclear or conventional attack will fail to achieve strategic objectives while triggering responses that will provide extraordinary cost for any adversary – U.S. government strategies clearly communicate that any use of nuclear or conventional weapons will be met with overwhelming retaliatory response. These threats have led to support from the Congress in appropriating more than $8 billion per year for MDA MDS investments.[19]

Notwithstanding the primary missions of deterring and countering DPRK and Iranian missile threats to the homeland, U.S. military planners also consider the potential role of MDS capabilities in interdicting attacks in Europe and East Asia. Strategic deterrence requires the government to maintain a nuclear arsenal capable of surviving and responding to a Russian or

[18] "National Defense Authorization Act for Fiscal Year 2017", Public Law 114-328, Subtitle E—Missile Defense Programs, Section 1681, National Missile Defense Policy, December 23, 2016, retrieved on May 9, 2021, from https://www.congress.gov/114/plaws/publ328/PLAW-114publ328.pdf#page=625.

[19] "Budget Estimates Overview Fiscal Year (FY) 2021", Missile Defense Agency, p.1, retrieved on May 10, 2021, from https://www.mda.mil/global/documents/pdf/budgetfy21.pdf.

Chinese attack. Maintaining strategic deterrence also entails sustaining a robust diplomatic presence overseas, implementing multiple communication strategies, and adopting a consistent and credible military posture.

Strategic Resourcing

Beginning in 1983, President Reagan sought to develop a ballistic missile defense architecture with sufficient capability to nullify the threat of a Russian nuclear attack. Once Congress recognized the cost-prohibitive nature of this approach, they opted to resource a layered missile defense strategy. In total, Congress has appropriated more than $200 billion to missile defense since 1985[20] to develop a far-reaching system of radars, satellites, sensors, naval vessels, with air-, sea-, and ground-based interceptors. Encouraging these appropriations is an expansive network of defense contractors, lobbyists, and strategic think tanks.

More formally, Congress tasked the SECDEF to establish a missile defeat posture and force structure for the nation, including the responsibility to determine the requirements for the missile defeat strategy and inventory, and to acquire the relevant capabilities. When implementing this mandate, the DOD must assess the cost-effectiveness of missile defense programs and employment of the weapons systems. MDA serves at the core of the U.S. defense against enemy missiles that threaten the safety and security of our homeland.[21] The DOD established the MDA to acquire capabilities to defend the homeland against enemy missile threats in 2002. The MDA develops, tests, and integrates weapons systems into the MDS to defend the homeland, deployed U.S. forces and interests, and allies against all types of missiles.[22]

While Congress has designated the DOD to have the lead role, missile defense has a global dimension and requires collaboration with the Department of State (DOS) and other departments and agencies, and cooperation with our allies and partners. The INSSG states, "we will make smart and disciplined choices regarding our national defense and the responsible use of our military while elevating diplomacy as our tool of first resort."[23] The DOS leads the effort in trying to persuade foreign leaders in Moscow and Beijing that U.S. missile defenses are "neither designed nor directed against Russia's or China's strategic nuclear forces."[24] When this has failed, DOS diplomats defend U.S. positions on missile defense in capitals worldwide and multilateral fora. The DOS also negotiates military basing agreements that allow the Services to deploy close-in and regional missile defense capabilities beyond our borders in Romania, Poland, Turkey, the Republic of Korea (ROK), and Japan.[25]

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[20] "Historical Funding for MDA FY85-17* Fiscal Year (FY in Billions)", Missile Defense Agency, retrieved on May 10, 2021, from https://www.mda.mil/global/documents/pdf/FY17_histfunds.pdf.
[21] Stephen M. McCall, "Defense Primer: Ballistic Missile Defense", Congressional Research Service, IF10541, December 29, 2020.
[22] Stephen M. McCall, "Defense Primer: Ballistic Missile Defense", Congressional Research Service, IF10541, December 29, 2020.
[23] "Interim National Security Strategic Guidance", The White House, March 2021, p. 14, retrieved on May 11, 2021, from https://www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf.
[24] Frank Rose, Former Assistant Secretary, Bureau of Arms Control, Verification, and Compliance, remarks, Transatlantic Missile Defense: Defining the Right Threat Set" remarks The Atlantic Council, Washington, DC, July 25, 2015, retrieved on May 10, 2021, from https://2009-2017.state.gov/t/avc/rls/2015/244392.htm.
[25] Frank Rose, Former Assistant Secretary, Bureau of Arms Control, Verification, and Compliance, remarks, Multinational Ballistic Missile Defense Conference" remarks, Seville, Spain, October 6, 2015, retrieved on May 10, 2021, from https://2009-2017.state.gov/t/avc/rls/2015/248035.htm.

The DOD has a unique relationship with the companies and workforce that comprise the DIB. Charged with effectively managing taxpayer-provided resources, the DOD is a monopsony when procuring advanced weapons and intelligence systems from U.S. contractors. However, the shrinking number of sufficiently large defense firms has yielded some power back to industry over the years to promote foreign sales of advanced systems. It is in the interest of the U.S. government to maintain a healthy DIB and incentivize firms to execute investments that achieve productivity gains. The DOD must foster contractor competition to encourage an innovative and robust industrial base to then take advantage of capacity increases. One of the roles of the government is to provide sufficient stability in demand-to-signal to major defense vendors and their Tier-2 and Tier-3 suppliers to ensure capacity and competitiveness for DOD production needs remains a priority.

MDA, the Services, and the DASD(IP) each have roles pushing the missile defense industry efficiency in maintaining legacy systems and new capability development. As global trends move to pull some manufacturing capabilities back to the U.S., the need for qualified human resources will significantly impact surge requirements. To pace the increasing threats from foreign ballistic and cruise missile threats, the DOD must resource efforts that ensure the industrial base acquires or sustains capabilities to defend the homeland. The DOS persuades additional partner nations to cooperate on missile defense but also to consider investing in U.S.-produced missile defense systems that provide superior capability and interoperability.[26] Foreign buyers of missiles and defense systems span many nations such as Israel, the United Kingdom, France, Canada, Japan, Brazil, India, and Turkey. Competition across multiple missile defense system production lines is excellent for the DIB and cost-friendly to the Service budgets.

Missile Defense Industry Condition

Like nearly every sector of the defense industry, integrated air and missile defense (IAMD) is a monopsony and oligopoly. Ships, aircraft, prime movers, space-based assets, sensors, communications architectures, integrated networks, and missile interceptors are required to enable the U.S. and regional missile defense systems. The prime contractors dominate the missile defense industrial base while smaller contractors, such as Aerojet, provide solid rocket motors or other niche components. Further down the supply chain is a dearth of companies like Micro Craft that provide "one-of-a-kind and short-run production of advanced, complex aerospace test, flight hardware and systems" that the prime contractors depend upon.[27] Up and down the supply chain, very few companies provide the type of systems engineering expertise or manufacturing required for exacting specifications of the systems associated with IAMD or the MDS.

When considering the counterforces of buyers and suppliers, the competitive dominance (and speculated collusion) of Lockheed and Raytheon essentially balance and offset each other. One such example, the Aegis Combat System, is an amalgamation of Lockheed software and hardware featuring Raytheon sensors and missile interceptors. The interwoven aspects within this element of the missile defense environment point to consolidation at its most effective and have ensured longevity and product dominance. While this "marriage" has effectively produced the most effective weapon system in the world, certain aspects of the program bids and costs are

[26] Working-level U.S. foreign policy professional, interview by Stephanie Holmes, March 16, 2021.
[27] Micro Craft Incorporated Staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Micro Craft Incorporated, Tullahoma, Tennessee, April 22, 2021.

considered suspect. Despite the recent success of the Standard Missile-3 Block IIA, some fear programmatic features surrounding fire control integration and coordination could become prohibitively costly. While this concern merits further investigation and stabilization by the Service programmatic leads, the reality remains that proven Aegis Combat System technology will most likely get it right.

Porter's Diamond Model

Dominance of the U.S. missile defense industry requires a high domestic demand, then high international demand. Economist Michael Porter identifies a high need for a product to encourage multiple vendors to improve their designs and compete in a market. Our discussions with senior representatives from multiple companies during this study demonstrated collective concern generated by the limited demand and desire for competition to provide missile defense system components. The U.S. government customers are hindering interest in product improvement through award of contracts that require a small number of exquisite capabilities that are developed as a one-weapon-fits-all solution. Following award for an initial concept design to one vendor, other companies have little motivation to compete with the incumbent in future competition to develop or produce system. The DIB will benefit from DOD award of smaller missile defense contracts to deliver or integrate system components into the system of systems. The higher upfront cost for government acquisition resources to compete and award multiple small contracts would lead to future cost savings if smaller companies were encouraged and enabled to compete with the prime vendors.

The U.S. missile defense industry suffers from challenges created by vanishing vendors and offshoring. The slow pace of DOD missile development investments challenges component providers when ten-year purchase orders include designs that require electronics – mother boards, memory chips, graphics cards – that are often considered the previous generation and no longer in production by the time of contract award to the prime vendor. Another complication stems from the offshoring of development or production of component parts as U.S. companies with U.S. rent and wages cannot remain competitive with foreign vendors for commercial contracts and cannot sustain production lines on limited purchases or profits from U.S. government contracts. Sustainment of natural resource/material gathering/mining and processing and the Tier-2 and Tier-3 component providers for prime contractors requires federal government infrastructure investments to encourage industry growth. DIB investments will provide infrastructure improvements that are not supported by state or local governments yet are required by critical mines, processing plants, forges, or machine shops.

The DIB requires ready access to materials or system component suppliers with supply lines that avoid foreign government interference or tampering. This access is dependent on the ready availability of skilled and unskilled labor to obtain and process raw resources/materials for missile defense components and expert engineers and scientists for advanced component design and production. The offshoring of each component of a missile defense system, be it synthetic cork for a motor case or transistors for a targeting system, creates risk for U.S. companies that rely on these components to build defense systems. This risk is further transitioned to the DOD when highly specialized parts and components available internationally may not meet U.S. government customer specifications or may be modified to support foreign government espionage techniques. The U.S. government must invest in domestic efforts to sustain a workforce and production lines for materials and components that are critical to development of future missile defense systems.

Porter's Five Forces Model

Unlike the Diamond Model that focuses on broader nationalistic approaches, we use Porter's Five Forces (see Appendix A) to assess industry-specific market conditions that help understand why some products have had greater market competitiveness. Like Porter's Diamond, "Rivalry" has played a central role in the Five Forces model. In this instance, "Rivalry" has been represented as the competition among existing MDA participants and has been the culmination of the other four forces. In this instance, a small number of large prime contractors dominate the missile defense market and compete for missile defense contracts. The four remaining forces have represented equal yet counter forces that acted upon the overall competitive environment. The "Bargaining Power of Suppliers" and the "Bargaining Power of Buyers" have acted as two counter-balanced forces, while the "Threat of New Entrants" and the "Threat of Substitute Products or Services" have served as the other two.

Linking Porter's Models

Porter's Diamond and the Five Forces analytical frameworks are helpful visual aids in understanding specific elements of the market and competitive forces. The models are most often applied within specific markets, regions, or governments for analysis. By superimposing the Five Forces upon the Diamond structure, the reviewer may witness how "Rivalry" acts as the central joining theme between these analytical tools to navigate the two assessments seamlessly and witness the interplay of competition and innovation (see Appendix A).

Industry Challenges

Following the end of the Cold War, industry consolidation, off shoring of critical manufacturing capability, and an aging workforce, combined with continual friction in the federal budget approval process has resulted in a U.S. DIB that is a shadow of its former self. Porter's Models suggest the major challenges facing the industry are critical component shortages and hardware no longer made in the U.S. and scarcity of skilled workers that can maintain security clearances. The ongoing consolidation of traditional defense industry companies as well as an anticipated reduction in defense-related funding by the current administration further exacerbates these problems. It is important to note that these are well-established trends in the DIB that are now reaching the point of creating critical vulnerabilities. With many critical microelectronic parts such as semiconductors and chip sets produced only offshore, total dependence on foreign sources for many raw materials, and only a very small number of domestic manufacturers printing circuit boards, the DOD can no longer delay fiscal and policy action to ensure viability of a capable domestic DIB.

The FY 2020 Industrial Capabilities Report to Congress, does include an assessment of missile defense radars as part of the radar and electronic warfare sector and missile defense interceptors in the missiles and munitions sector, as well as a section dedicated to Directed Energy (DE).[28] The report notes that the U.S. is critically lacking in key areas of the supply

[28] Ibid.

chain. It emphasizes that the DIB has very limited, and in some cases no, suppliers for critical elements of missile defense systems and faces a looming shortage of trained workers. The report states "domestic manufacturing insufficiencies have increased the U.S. dependency on foreign goods, such as raw substrate materials for optics and laser components, and tooling and equipment required for manufacturing of directed energy components."

One of the DIB issues mentioned consistently by industry and government representatives was the challenge of maintaining skilled and unskilled human capital to develop and produce missile defense associated components. Missile defense radars and interceptors require a highly skilled engineering and production workforce within both the prime contractor and Tier-2 suppliers. Competition from commercial firms and security clearance requirements for defense contractors pose significant hiring challenges. The Seminar visited several missile defense production facilities close to commercial automobile assembly plants, automobile parts manufacturers, and commercial distribution centers during this study. Each production center highlighted the attractive options that commercial companies provide for workers that do not want to submit to regular drug testing or await security clearance adjudication. Almost all the companies visited reported increased challenges in finding individuals that could pass security clearance screening requirements; this challenge increases each time another state legalizes marijuana while it remains a Federal crime. The industry study visits to the Lockheed Pike County Operations Facility in Troy, Alabama[29], and Micro Craft in Tullahoma, Tennessee[30], provided excellent perspectives on the human capital challenges in rural areas.

Fiscal challenges are a current and future threat to the DIB. A significant risk for the DIB is the false sense of security that senior military and civilian leaders have in the agility and capacity of current U.S. industry. For example, senior Navy leadership has a perspective of an assumed ability to rapidly upgrade ships if required for great power competition. Naval Sea Systems Command's Vice Admiral William Hilarides described the 2015 decision to forgo MDS upgrades for five Flight IIA destroyers as "dialing the fleet's capability for the near term" relative to the budget. "The fact [is] that when money comes – if tomorrow a war starts and we say 'hey, better go get those five ships modernized' and CNO [asks] 'can you do it three months?' …if we had all the money in the world, we could do it really fast..."[31] Given subsequent reports on the state of the industrial base, that comment may be vastly overstated as the slow pace of DOD missile development investments challenges component providers when ten-year purchase orders include designs that require electronics – mother boards, memory chips, graphics cards – that are often considered previous generation and no longer in production by the time of contract award to the prime vendor. This is one of many examples of a significant potential disconnect between DIB expectation and the reality of scarce availability in private shipyards.[32]

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[29] Lockheed Martin Staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Lockheed Martin Pike County Operations, Troy, Alabama, April 19, 2021.

[30] Micro Craft Incorporated Staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Micro Craft Incorporated, Tullahoma, Tennessee, April 22, 2021.

[31] Megan Eckstein and Sam LaGrone, "Stackley: Fleet Needs More BMD Ships to Meet Demand", USNI News, March 4, 2015, retrieved on May 10, 2021, from https://news.usni.org/2015/03/04/stackley-fleet-needs-more-bmd-ships-to-meet-demand.

[32] Sam LaGrone, "Navy Altered Destroyer Upgrades Due to Budget Pressure, Demand for Ships", USNI News, June 3, 2014, retrieved on May 10, 2021 from https://news.usni.org/2014/06/03/navy-altered-destroyer-upgrade-plan-due-budget-pressure-demand-ships.

The following paragraphs provide specific industrial base insights revealed during this study. These insights corroborate the data found in our scholarly research and analysis of challenges facing the DIB.

Access to Skilled and Unskilled Labor

MDA government representatives highlighted human capital concerns that industry was not building the bench of talent needed to continue supporting missile defense programs.[33] The example cited was that government representatives have seen the same industry employees running tests and launching missiles for 30+ years. MDA has also seen a recent reduction in the ability of industry to provide test range operators and safety personnel for flight tests. The aging workforce is a significant challenge going forward for MDA who maintains a robust flight test schedule critical to current and new missile defense programs.

The Lockheed Martin Pike County Operations Facility includes several missile production lines, including the Terminal High Altitude Area Defense (THAAD) program. Lockheed entered a partnership with the State of Alabama to help recruit and train workers with necessary skills to produce THAAD and other missiles. This partnership resulted in the Alabama Industrial Development Training organization funding the construction of a $2 million facility on the Lockheed Pike County Operations site. This on-site facility runs training classes to certify individuals to work on missile production lines and guarantees an offer of employment at the Pike County site upon graduation. The Lockheed representatives stated that the program provides significant benefit, especially in addressing the competition for workers from the nearby Hyundai assemble plant in Montgomery, AL.

Micro Craft Inc. is a Tier-2 supplier that provides precision machined components for aerospace applications, including missile defense. They reported significant challenges in hiring qualified engineers and machinists to work in their facilities. The Micro Craft representatives attributed part of this challenge to the overall shortage of machinists in the U.S.[34] However, they also experience competition from the Nissan assembly plant an hour away in Smyrna, TN, and Arnold Engineering Development Complex on nearby Arnold Air Force Base. The company recently instituted a formal apprentice program and $1,500 signing bonuses to grow their workforce.

Obsolescence

Obsolescence continues to be a significant issue for the missile defense industry in sustaining legacy programs. The challenge is maintaining sufficient production or foreign military sales (FMS) to keep the Tier-2 and Tier-3 suppliers engaged or risk suppliers exiting the market. The loss of suppliers for unique components can result in a long and expensive process to requalify new vendors for production. The requalification process also assumes that the prime contractor has build-to-print stamped drawings or owns the technical data necessary to manufacture the component. The Seminar learned from several industry representatives that

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[33] Missile Defense Agency staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Missile Defense Agency, April 20, 2021.

[34] Ivan Rosenberg and Mike Bastine, "A Unique Solution to Tackle the Shortage of CNC Machinists | Tooling U-SME" Tooling University, Accelerate blog, February 19, 2019, retrieved on May 2, 2021, from https://www.toolingu.com/resources/blog/february-2019/a-unique-solution-to-tackle-the-shortage-of-cnc.

technical data packages for defense components are often incomplete, especially those developed by small or niche businesses. Buying the intellectual property will not always enable production as specific engineering knowledge often resides solely with the workforce that developed the tools to produce components.

The Lockheed Martin Moorestown, New Jersey, facility provided a prime example of obsolescence challenges associated with the SPY-1 phased array radar system.[35] The SPY-1 production line is going cold as the last production units enter testing for delivery to the Spanish Navy. By the summer of 2021, there will be no ability to build additional SPY-1 phased arrays without establishment and qualification of a new production line or viable supplier chain. This loss of production capability creates risk to U.S. Navy options to address battle losses involving the Aegis Destroyers or Cruisers equipped with the SPY-1 radar in a future conflict.

Visits to the Lockheed Martin THAAD production line in Troy, Alabama, and the Raytheon offices in Huntsville, Alabama, provided examples of obsolescence challenges for missile defense interceptors.[36] The THAAD production line is experiencing significant obsolescence issues with the components of the KKV. Lockheed was able to leverage THAAD FMS production for the Kingdom of Saudi Arabia[37] to mitigate the KKV vehicle obsolescence issues. Raytheon also reported obsolescence issues for their exoatmospheric kill vehicle (EKV). Raytheon produces the EKV as a subcontractor to Boeing, the prime integrator for the GBI program. The current EKV is experiencing issues with some parts in production for over 20 years as they continue to sustain and produce these weapons.

Raw Materials

Most study hosts informed the Seminar that raw materials are a significant industrial base issue across the missile defense sector. Ammonium Perchlorate (AP), the primary oxidizer in solid rocket motors, and semiconductors for electronic components were the most often mentioned issues in study engagements. The sole domestic supplier for AP, American Pacific, limits the competitive base by supplying solid rocket motors for all U.S. government missile defense and space launch programs. The French company Safran is the only other qualified AP source in the world and supplies all European Union solid rocket motor needs.[38] The DASD(IP) annual report to Congress on defense industrial base issues highlights the single domestic AP source as a critical issue almost every year. The FY 2020 Industrial Capabilities Report to Congress cited a recent study that determined a government-owned/contractor-operated facility to produce AP would not be cost-effective.[39] The same report indicated that another U.S. company is developing a capability to produce AP from domestic materials. The report did not

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[35] Lockheed Martin Staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Lockheed Martin, Moorestown, New Jersey, April 14, 2021.

[36] Raytheon Technologies Staff, 2021 National Defense University Eisenhower School Missile Defense Industry Study site visit to Raytheon Technologies, Huntsville, Alabama, April 14, 2021.

[37] "Lockheed Wins $933M to Build THAADs for US, Saudi Arabia", Defense World.net, March 25, 2020, retrieved on May 2, 2021, from https://www.defenseworld.net/news/26578/Lockheed_Wins__933M_to_Build_THAADs_for_US__Saudi_Arabia#.YI9kzrVKjcs.

[38] Jen Judson, "US Industrial Base at Risk for Key Rocket Motor Ingredient", Defense News, August 8, 2017, retrieved on May 10, 2021, from https://www.defensenews.com/space/2017/06/21/us-industrial-base-at-risk-for-key-rocket-motor-ingredient/.

[39] "10 U.S. Code § 2504 - Annual Report to Congress", LII / Legal Information Institute, retrieved on May 1, 2021, from https://www.law.cornell.edu/uscode/text/10/2504.

provide additional information on the specific vendor or the production process, but this could be a viable solution to eliminate AP as a single point of failure in the missile defense production process.

Semiconductors are a critical issue for the missile defense industry as the low industry demand for semiconductors, compounded with challenges to global production by the COVID-19 pandemic, created a worldwide semiconductor shortage.[40] The missile defense industry has the unique challenge of ensuring the security of supply for semiconductors to reduce cyber vulnerabilities for U.S. missile defense systems, and there are no current solutions proposed to address reliance on foreign suppliers for this critical industry commodity.

Industry Outlook

DOD Role in Missile Defense Industry Outlook

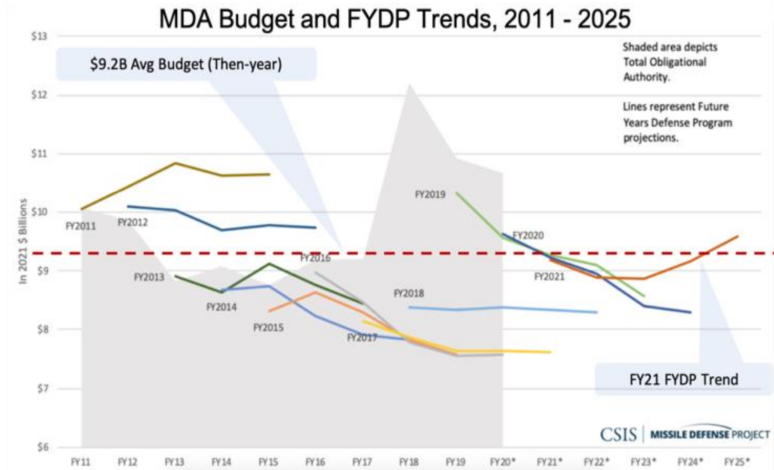
The U.S. continues to lead global missile defense spending as the largest missile defense market, excluding China. With accelerating ICBM capability growth in China, DPRK, and Iran, this trend is expected to continue influencing demand in the regional and ballistic missile defense industrial base, as well as research and development spending for the foreseeable future. President Biden's topline for DOD represents a slight resource decrease from FY 2021 when adjusted for inflation and will challenge industry to consider the strategic impact of DOD program re-prioritization on primary and supporting industries.

Currently, the ballistic missile defense segment dominates the Defense market. Missile defense spending is split between homeland and regional systems, with ground-based and sea-based kinetic systems receiving the most attention and resources. Cruise missile defense receives less Presidential and Congressional attention as government efforts to determine defense requirements and feasibility are uncertain regarding the future of this mission within missile defense industrial base. Changing resource needs are driving the industry to de-prioritize technology development activities for cruise missile defense systems. The MDA focus on improved sensor technology, model-based engineering, and reduced risk acquisition practices such as "fly-to-buy" strategies positively influences industry rivalry among prime contractors.

Demand Outlook

Congress and DOD leaders endorse missile defense programs based on perceived threats and the technology available to address them. In the U.S., the Congressional Budget Office projects missile defense costs to increase as shown in the Figure 1. Stimulus debt and a re-focus on domestic programs will place additional downward pressure on missile defense budgets in FY 2022 and beyond. Lack of insight into President Biden's position on missile defense and budget uncertainty will make industry investment planning difficult. In the near-term, DOD research and development spending for incremental modernization of legacy systems and follow-on procurement of defense systems will sustain industry growth projections with mostly duopolistic contract competition. INSSG changes to missile defense priorities will drive long-term product

[40] Lesley Stahl, "Chip Shortage Highlights U.S. Dependence on Fragile Supply Chain"60 Minutes, CBSNews.com, May 2, 2021, retrieved on May 10, 2021, from https://www.cbsnews.com/news/semiconductor-chip-shortage-60-minutes-2021-05-02/.



Based on 2021 Budget request Source: https://www.csis.org/analysis/inflection-point-missile-defense-and-defeat-2021-budget

Figure 1

differentiation, primarily in discrimination, KKV with multiple interceptors, and network integration for layered defense. Differentiation across defense systems will make future course changes difficult and limit the ability of industry to adapt.

Growing geopolitical conflicts motivate countries to sustain or increase missile defense spending to strengthen their capabilities, despite the COVID-19 pandemic. The global defense market is expected to grow about 2.8% annually through 2026, supported by growth in defense spending. Technological advancements in missile interceptors and sensors will encourage near-term growth in defense capability production and sales. The Asia Pacific region is projected to have the highest annual defense investment growth rate through 2026, presenting an opportunity for U.S. suppliers to increase revenue and offset the impact of flat or declining U.S. defense spending. For instance, India is bolstering its capabilities[41] and Japan announced a ninth straight defense budget increase for FY 2021.[42] However, some FMS may be affected by tightening of U.S. foreign investment rules that are put in place to restrict opportunistic acquisitions by foreign entities.[43]

Russian and Chinese development of MaRV and HGV enable the deployment of nuclear-capable weapons that circumvent existing U.S. missile defenses. New technology in space-based sensors, NGI, high power munitions, and F-35 modernization will play key roles in countering Russian and Chinese threats that drive long-term missile defense industry growth.[44] The prime contractors are anticipating long-term DOD investment in MDS capabilities. A key question for MDA is whether funding will be sufficient to support simultaneous investment in novel capability development while completing reliability upgrades, GBI service life extension, Hawaii-based Aegis ashore radar deployment, and cruise missile defense development.[45] MDA

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[41] Elizabeth Roche, "India is world's 3rd largest military spender, expense rose by 6.8% in 2019," Mint, livemint.com, April 28, 2020, retrieved on May 11, 2021, from https://www.livemint.com/news/india/indian-among-top-three-military-spenders-in-2019-sipri-11587957496033.html.

[42] Junnosuke Kobara and Rieko Miki, "Japan's Defense Ministry eyes record $51.6bn in spending under Suga", Nikkei Asia, September 21, 2020, retrieved on May 11, 2021, from https://asia.nikkei.com/Politics/Japan-after-Abe/Japan-s-Defense-Ministry-eyes-record-51.6bn-in-spending-under-Suga.

[43] "Rep. Banks Introduces Bill to Stop Predatory Acquisitions by China During COVID-19", banks.house.gov press release, May 5, 2020, retrieved on May 11, 2021, from https://banks.house.gov/news/documentsingle.aspx?DocumentID=1676.

[44] Todd Harrison, Seamus P. Daniels, Mark F. Cancian, Tom Karako & Wes Rumbaugh, "What To Look for in The FY 2022 Defense Budget Request", Defense 360, April 2021, retrieved on May 11, 2021 from https://defense360.csis.org/wp-content/uploads/2021/04/FY-2022-Preview_Final.pdf.

[45] Todd Harrison, Seamus P. Daniels, Mark F. Cancian, Tom Karako & Wes Rumbaugh, "What To Look for in The FY 2022 Defense Budget Request", Defense 360, April 2021, retrieved on May 11, 2021 from https://defense360.csis.org/wp-content/uploads/2021/04/FY-2022-Preview_Final.pdf.

focus on reduced risk acquisition strategies such as competitive prototyping and "fly-before-buy" enhances perceived program affordability but threatens industry profit margins through cost of competition increases. Prime contractors experiencing reduced profit potential and more demand to create shareholder value, will be pressured to complete additional corporate acquisitions to build talent pools, reduce supply costs, bring advanced technology in-house, and diversify through focus on dual-use defense/commercial technology development.

Just as threats are evolving – cyber, artificial intelligence/machine learning, HGV, hybrid warfare, anti-satellite weapons, and more – so are conditions that shape diplomacy and the U.S. missile defense industry. DPRK acceleration of development and testing of sophisticated, road-mobile ballistic missiles is driving DHS and the U.S. Strategic Command to grapple with the realities of mission demand change. Our adversaries are pushing us to invest in different technology with a focus on space-based sensors, NGI, and high-power munitions. MaRV and HGV will play a key role in the industrial outlook as continuing development and testing programs enable Russia and China to deploy new or modified nuclear or conventional weapons that can circumvent known U.S. missile defenses. This new investment will boost growth in the national defense space architecture and F-35 modernization layers of the MDS.

The DOD will increasingly use modern open system architecture, Other Transactional Authorities (OTA), cost-plus fixed-fee contracts, and other means to engage in prototyping and leverage commercial technology investments. This helps reduce cost and increase competition across the missile defense budget. Many of the contractors visited by the Seminar mentioned the DOD push to involve non-traditional defense contractors in the missile defense industrial base; OTA are a means to execute this plan in the future. DOD trends toward open systems, more streamlined development processes, and more efficient contracting strategies will tempt commercial firms to compete for military programs. These major drivers of growth in the industry likely will persist through the mid-term, creating new rivalry among the prime competitors. The conditions created by DOD will threaten profit margins by increasing the cost of competition through prototyping and bid and proposal activities.

Industry Rivalry

The U.S. missile defense market is highly protected and closed, leading to sustained market concentration. Mergers, acquisitions, co-operative agreements, and international joint ventures with Israeli, Japanese, and other foreign partners support continued growth of U.S. defense contractors and allows for faster access to advanced technology that may not be available in the U.S. today.

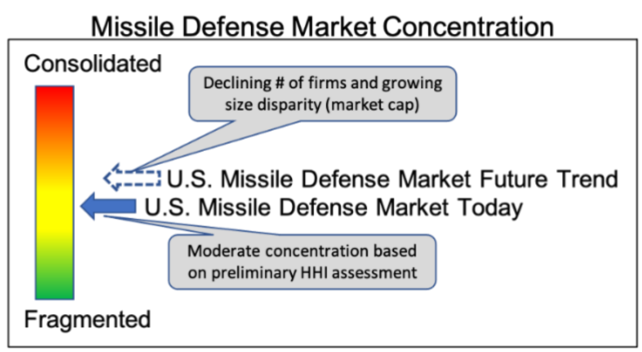

Figure 2

Competition for U.S. government contracts has been declining over the past two decades with the prime defense contractors winning over half of the competed contracts. To gain long-term contracts and expand global presence, the prime defense contractors are investing significantly to develop new command and control, ground and space-based sensors, and interceptor capabilities.

Increased focus on a layered missile defense strategy in parallel with an uncertain near-term budget outlook may increase DIB consolidation and vertical integration as prime contractors seek to protect current market position and profit margins. Vertical integration within their supply chains is likely to add to decreased competition among missile defense suppliers. We learned that missile defense primes are diversifying their portfolios with commercial acquisitions to protect against volatility or declining defense budgets. Boeing and Raytheon have significant commercial activity. Lockheed income streams are primarily from DOD and FMS, but the Aerojet merger will provide new access to commercial space launch markets. These actions are not likely to reduce DOD bargaining power as the stability of government contracts are desirable. The DOD is expected to continue wielding influence over the missile defense market with favorable payment terms that support the liquidity and cash requirements of both prime contractors and the extended supply chain.

Supporting Industry Outlook

The missile defense supply base is not homogeneous, and any DOD budget uncertainty will affect suppliers in different ways, depending on whether they serve both commercial and defense markets. As most missile defense suppliers are highly specialized with unique expertise and equipment, they could struggle to make production line modifications in response to varying demand from DOD. Uncertainty in missile defense budgets will accentuate the challenge many suppliers have overcoming COVID-19 impacts that could last for a year or more. Vendors bankrupted by unstable markets could leave missile defense primes vulnerable to declining supply of critical parts for their programs (e.g., semiconductors). New and advanced detection capabilities depend on faster semiconductors as Russia and China locate missiles closer to the U.S. Semiconductors are critical to most emerging military technology including space, weapons, and Command & Control, Battle Management & Communications capabilities. Global supply shortages could last from six months to two years, impacting missile defense absent revived investment in the U.S. semiconductor industrial base.

The missile defense industrial base will also benefit from the increased participation of commercial suppliers looking to take advantage of a flattening and competitive DOD budget, layered defense strategy, innovation goals, and acquisition efficiency objectives. President Trump's FY 2021 proposal included $3.2 billion for "missile defeat or left-of-launch" capability.[46] Competition will likely remain intense between firms seeking to supply the offensive left-of-launch cyber capability to support the MDS. Notably, existing defense contractors, such as Raytheon, have established cyber divisions that compete for DOD-funded cyber-attack programs. Virtualization may bring novel means to increase engagement capability and capacity of legacy systems and add mobilization methods that "all the money in the world" could not rapidly field, so long as ship capacity remains a hurdle. Virtualization also offers opportunities for competition within industry training platforms. The forces that drive innovation are resident in the technology base and the U.S. government can improve bargaining power with prime vendors through scale increases or contracts appropriate for small businesses.

The market for solid state components that enable high-power munitions is developing rapidly in both the commercial and military areas. On the commercial side, laser use is growing

[46] "Ballistic Missile Defense," The Heritage Foundation, retrieved on January 27, 2021, from https://www.heritage.org/2021-index-us-military-strength/assessment-us-military-power/ballistic-missile-defense.

in automotive, electronics, medical, and telecommunications production globally.[47] Investments in modeling and simulation (M&S) will reduce development cost and shorten delivery timelines. Further investment in M&S for operational testing could reduce U.S. range expenditures. Growth in missile defense M&S will offer non-traditional suppliers an opportunity to compete with prime vendors, and the DOD will benefit from a highly competitive market.

Policy Recommendations

The current U.S. policy rightfully emphasizes that Washington does not intend for missile defense to upset the strategic balance with Russia and China.[48] According to the 2019 MDR, the system bolsters deterrence against aggression, assures U.S. allies and partners, strengthens diplomacy, limits the damage of missile attacks, supports U.S. military operations if deterrence fails, and protects against future risks.[49] In reality, missile defense aims to outpace "rogue state offensive capabilities" with limited homeland defense.[50] Our recommendations seek to build an adaptable and innovative system that delivers these goals in the most cost-efficient and effective manner, while building resilience and strength in the U.S. DIB.

The ideal U.S. missile defense system not only advances military objectives, but also strengthens our economy and the U.S. negotiating position across a range of national security issues. Currently, funding for U.S. missile defenses does not match the ambition outlined in the 2019 MDR; this mismatch between resourcing and objectives disadvantages the entire system and provides fuel for skeptics in the expert community and Congress. The INSSG lacks adequate insight into the Biden administration's strategy for missile defense other than promoting diplomacy to the tool of "first resort" and pledging to ensure "our strategic deterrent remains safe, secure, and effective."[51] As the new administration clarifies its position on missile defense, it should consider secure and aligned funding for the stated objectives.

The following recommendations support a balanced, integrated approach to counter a broader range of missile threats through active and passive missile defenses, investing more in human capital and innovation, leveraging the strength of our alliances and partnerships, and overhauling the whole-of-government strategy to better defend the U.S. in this dynamic threat environment.

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[47] Stone, Mark, "Global Solid-State Laser Market 2020 Report Overview, Consumption by Region, Company Profiles, Value Chain and Sales Analysis to 2026", MarketWatch, retrieved on April 28, 2021 from https://www.marketwatch.com/press-release/global-solid-state-laser-market-2020-report-overview-consumption-by-region-company-profiles-value-chain-and-sales-analysis-to-2026-2021-04-14.

[48] Frank Rose, Former Assistant Secretary, Bureau of Arms Control, Verification, and Compliance, remarks, Multinational Ballistic Missile Defense Conference, Seville, Spain, October 6, 2015, retrieved on May 10, 2021, from https://2009-2017.state.gov/t/avc/rls/2015/248035.htm.

[49] "Missile Defense Review 2019", Department of Defense, 2019, p. I, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.pdf.

[50] "Missile Defense Review 2019", p. 22.

[51] "Interim National Security Strategic Guidance", The White House, March 2021, p. 13, retrieved on May 11, 2021, from https://www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf.

Policy Process

We recommend reexamination of processes that formulate and execute missile defense.

- Centralize the National Policymaking Process: The National Security Council (NSC) should coordinate missile defense policy to ensure that the equities of all departments and agencies factor into a policymaking process that considers missile defense as one tool within a range of options. This includes coordinating the drafting of all missile defense-related strategic documents, including the MDR. NSC leadership could add one director position to the Directorate for Defense Policy to assume this role.
- Streamline Strategic Reviews: The NSC should develop a Strategic Deterrence Review that combines the Nuclear Posture Review (NPR) and MDR to ensure the objectives for offensive and defensive deterrence align. This would allow the NSC to develop and execute policy that strengthens and aligns the three pillars of strategic stability: nuclear deterrence, missile defense, and arms control. This review is key to providing decision makers an analytical basis for investment decisions in missile defense and modernization of the nuclear triad.
- Strengthen the State Department Role: As the Biden administration seeks to elevate the role of diplomacy, the current policy formulation mechanisms for missile defense are insufficient to achieve that desired outcome. The DOS currently plays a minimal and often reactionary role on missile defense, usually inserting its views later in the policy formulation process. State should detail officers to MDA and the theater focused combatant commands to better synchronize DOS and DOD efforts. The NSC should increase the role of DOS diplomats in drafting missile defense-related strategic documents. High-level missile defense negotiations with other countries should proceed in a 2+2 format with diplomatic and military representatives from each side to avoid stove-piping information and presentation of a united diplomacy/military strategy.

International Engagement

We recommend focus on increasing missile defense cooperation with allies and partners, promoting more productive conversations with near-peer competitors, and better advocating for U.S. missile defense firms overseas.

- Intensify Diplomatic Engagement with Allies and Partners: DOS, in consultation with the NSC and the DOD, should pursue a diplomatic full-court press with our allies and partners involved in our top missile defense priorities. Similar to State consultations with partners before the 2019 MDR, the U.S. should engage the North Atlantic Treaty Organization (NATO), Japan, ROK, the Gulf Cooperation Council, Israel, and others to demonstrate commitment to continued cooperation and shore up our partners' willingness to deter aggression.[52] In particular, the U.S. should establish annual missile defense talks with Japan, South Korea, and Australia considering the missile threats emanating from the Indo-Pacific region and U.S. forces deployed there.
- Increase Interoperability: The U.S. should boost investment in missile defense integration with NATO allies and Gulf Cooperation Council partners to counter current and future adversary offensive capabilities, strengthen our deterrence, and project U.S.

[52] Working-level U.S. foreign policy professional, interview by Stephanie Holmes, March 16, 2021.

power worldwide. Integration with allied and partner capabilities through information sharing, burden sharing, and coordinated command and control will increase the overall effectiveness of layered missile defense. Moreover, such investment will create new long-term customers for U.S. firms involved in missile defense. The United State should also organize more joint trainings and exercises, intensify intelligence sharing to relevant allies and partners, and reinvigorate efforts to advocate for missile defense FMS.

- Renew Talks with Russia and China: The Biden administration should reassess the missile defense engagement strategy with Russia and China. The lack of dialogue on missile defense has motivated both to pursue advanced weapons and defenses. The U.S. should pursue a "crawl, walk, run" strategy to establish trust with China given its lack of experience with inspections or transparency measures.[53] Agreeing on confidence-building measures with Russia and China will be extremely difficult given in this period of heightened great power competition. The objective would be to increase transparency, and ultimately, to reduce offensive missile capabilities to mitigate the need for expensive missile defense systems.

Technology Investment

DOD must prioritize investments in advanced and disruptive missile defense capabilities, potentially at the expense of the NGI.

- Reconsider NGI: The OSD and MDA justify use of disruptive missile defense technologies that are not yet technically mature;[54] however, given the GBI project track record and cost, the current kinetic system is not mature either. If the country is going to spend $18 billion on a new missile defense technology, it should be one with a return-on-investment orders of magnitude higher than the NGI[55] – which suggests the underlying technology must change. Consider extending the development schedule to ensure NGI incorporates new technologies, vice a version of those used in the GBI KKV.
- Launch an Integrated High-Energy Laser Weapon Program: DOD should prioritize launch of an integrated high-energy laser weapon program for missile defense. The requisite laser power is on the order of high hundreds to low thousands of kilowatts, but with both the Army and Navy actively pursuing 300kW class lasers, ballistic missile defense requirements are now greater by a factor of only three to four. This is within the scope of a concerted development effort. There have been requests for information issued and subsequently cancelled, by MDA as recently as 2019 for a megawatt-class

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[53] Ibid.
[54] Eric Tegler, "Airplanes With Lasers Won't Be Shooting Down Ballistic Missiles Anytime Soon", Forbes, August 5, 2020, https://www.forbes.com/sites/erictegler/2020/08/05/airplanes-with-lasers-wont-be-shooting-down-ballistic-missiles-anytime-soon/.
[55] Jen Judson, "Next-gen intercontinental ballistic missile interceptor estimated cost? Nearly $18B", Defense News, April 27, 2021, https://www.defensenews.com/pentagon/2021/04/27/next-gen-intercontinental-ballistic-missile-interceptor-estimated-to-cost-nearly-18-billion/.

laser,[56] and laser scaling work brought under the OSD.[57] Similarly, laser weapons for short-range air defense (SHORAD) demonstrate proof of concept in capabilities both from a cost and capacity perspective.

- Fund Disruptive Projects: The SECDEF should align the Chairman of the Joint Chiefs of Staff Program Operating Memorandum and National Intelligence Programming Guidance to ensure sufficient resourcing to a variety of disruptive projects such as high-power munitions and cyberweapons that enable left-of-launch or in-flight threat system denial and defeat. Kinetic or cyber solutions to disrupt launch capabilities are a potential lower cost substitute to interceptors, but require enabling technology investments for effectiveness (i.e., generators, sensors).
- Protect and Grow the Laser Industrial Base: As laser weapons improve in performance and drop in cost, they will begin to transition from an augmentation to a replacement of existing systems (e.g., PAC-3). DOD should act now to protect and grow the laser industrial base to provide the technology development and production capacity to meet missile defense goals.

Use Modeling and Simulation to Drive Investment

The current U.S. posture could counter rogue state ballistic missiles directed against the homeland. However, to stay ahead of the growing offensive regional and ballistic missile threats, the U.S. should examine, test, and exploit innovative missile defense concepts and technologies, including for cruise and hypersonic missiles.

- Integrate High-Fidelity M&S: DOD should create an independent organization within the Office of the Director, Operational Test and Evaluation and aligned with the relevant DOD Research and Engineering organizations to accredit and integrate high-fidelity M&S that supports experimentation with the robustness of operational test. An independent organization could manage M&S accreditation policy, coordinate test funding, and establish integration requirements for M&S, bridging the gaps between missile defense acquisition agencies and operational test authorities. The unified organization would address disparate or misaligned M&S funding streams that prevent the development of mature models for operational test flights and the integration of commercial technology.

Defense Industrial Base / Supply Chain Vulnerabilities

MDA, as the DOD lead for missile defense, should conduct an annual review of the missile defense sector, including an assessment of obsolescence issues for legacy programs, the effects of mergers and acquisitions, the strength of human capital, and second and third-tier supply chain vulnerabilities, including critical sole-source components. This report would go a

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[56] John Keller, "Military eyes prototype megawatt-class laser weapon for ballistic missile defense in next seven years", Military & Aerospace Electronics, April 2, 2019, https://www.militaryaerospace.com/sensors/article/16722085/military-eyes-prototype-megawattclass-laser-weapon-for-ballistic-missile-defense-in-next-seven-years.

[57] Justin Doubleday, "Pentagon punts MDA's laser ambitions, shifts funding toward OSD-led 'laser scaling'", Inside Defense, February 19, 2020, https://insidedefense.com/daily-news/pentagon-punts-mdas-laser-ambitions-shifts-funding-toward-osd-led-laser-scaling.

step lower than the current DASP(IP) report that assesses the overall DIB. The following recommendations target these potential weaknesses in the defense industrial base.

- Support Vertical Integration: The MDA and other relevant agencies should support mergers and acquisitions that increase vertical integration of the supply chain so long as they do not create or expend a monopoly. As an additional safeguard, the MDA should back FTC restrictions on new entities to ensure competitive access. Specifically, MDA should not oppose the proposed Lockheed acquisition of Aerojet since Lockheed did not previously produce solid rocket motors. The MDA should support FTC restrictions on the new Lockheed-Aerojet entity to ensure Raytheon and other vendors maintain competitive access to Aerojet solid rocket motors.
- Address Human Capital Challenges: The NSC, in partnership with MDA, the Services, and the missile defense industry, should evaluate human capital challenges across the missile defense enterprise, including the competitiveness of salaries. For example, hiring bonuses for skilled machinists may indicate defense contract salaries fail to compete within local or regional labor markets. The MDA could encourage contractors to pay such incentives by making them cost-reimbursable in contracts for specific critical programs and should partner with industry and state governments on training programs. Veteran hiring incentives and federal training grants also may help recruit skilled workers to the industry. To expand the applicant pool for critical jobs, the U.S. Government should reconsider security clearance obstacles, such as federal laws against marijuana possession or use.
- Better Track Obsolescence Issues: The MDA should establish an obsolescence working group to recommend steps policymakers should take to mitigate specific issues. It and the Services should participate in capability requirements development processes to address of component or material obsolescence in missile defense contracts, including government purpose data rights for intellectual property and technical data packages of sufficient detail to reproduce components if vendors exit the supply chain. Future contracts associated with the MDS should require prime contractors to submit regular reports on the supply chain and the viability of surge or mobilization capability to inform MDA and the Services assessments of program surge risks for contingency operations, legacy system sustainment, or production program termination.
- Identify and Support Critical Suppliers – The MDA and Services should work with the prime contractors and industry groups to gain greater visibility of the Tier-2 and Tier-3 supplier base to allow MDA to identify critical suppliers, assess and address the challenges they face, and encourage non-traditional defense contractors to participate in missile defense programs. This effort would identify burdensome requirements that dissuade small businesses from entering the missile defense market (i.e., over-classification of components).

Resourcing Considerations – Pursue a Commonsense Approach

Our recommendations do not require significant amounts of new funding; however, they would require realignment of resources and experts. Ensuring the right approach for U.S. missile defenses requires balancing both the offensive and defensive elements of deterrence against budgetary reality. As outlined in the 2018 U.S. NPR, effective deterrence depends upon China, Russia, DPRK, and Iran not miscalculating the consequences of limited nuclear or conventional first use, either regionally or against the U.S.[58] These adversaries must understand that any use of nuclear or conventional weapons (a) is unacceptable, (b) will not achieve their objectives, and (c) will trigger U.S. retaliation. In parallel, the U.S. must confront the limitations of both missile defense technology and resourcing.

The concept of an impenetrable shield capable of defending the U.S. against a massive strategic attack is unrealistic; however, when paired with the counter-offensive deterrent of mutual assured destruction, the right mix of missile defense options can complicate missile attacks being contemplated by adversaries. Both traditional and emerging disruptive missile defeat options (see below) constitute a portion of the mix, but the technological investment involved must be carefully calibrated so as not to waste limited funding by crowding out other more productive uses. As a result, the mix also must include passive defense options such as hardening, dispersal, deception, redundancy, and enhanced resilience of bases, logistics, and other key facilities and functions, including both military assets at home and abroad and key national infrastructure within the U.S. Such passive defenses ensure a measure of flexibility against emerging threats (such as hypersonic and cruise missiles) without forcing the DOD to constantly chase the next technical challenge.

Conclusion

The Seminar examined the missile defense industry to gain strategic perspective on the U.S. and global industrial base that supports the resource requirements of national security. The data we gathered through academic research and visits with missile defense customers and capability providers shed light on the need for the U.S. government to integrate missile defense and nuclear deterrence strategies, focus investments on innovative capabilities that provide a high return on investment, and provide resources to enable new worker and small business entry into the DIB. The Seminar recommends that the OSD and MDA continue to closely monitor the DIB for critical component loss like AP or semiconductors and support additional NDU ES research into these topics.

[58] "Nuclear Posture Review 2018," Office of the Secretary of Defense, Page VII.

Appendix A – Porter's Diamond and Five Forces Models

The Seminar analyzed the U.S. missile defense industry between November of 2020 and April of 2021. Analysis began with individual research, NDU ES classes, and Seminar discussions related to DOD missile defense. The analysis culminated with field studies and virtual interactions with representatives of MDA, the PEO for Missiles and Space, and the missile defense industry. We used economist Michael Porter's Five Forces[59] and Porter's Diamond Model[60] to understand better the missile defense industry and the competitive forces driving growth and innovation.

Porter's Diamond

Porter's Diamond model is used to assess three layers of analysis: firm, industry, and nation in describing how nations have succeeded more competitively than others. Imposing its conditions upon the missile defense industry shows how the industry stands compared to other U.S. defense industrial base segments.

Firm Strategy, Structure, and Rivalry – "Rivalry" serves as a central tenant in Porter's Diamond assessment. Firm strategy, structure, and rivalry have represented the attitudes and practices that distinguished and granted a competitive advantage of one firm from another. Porter's Diamond identifies a requirement for domestic competition between vendors to drive innovation. As the DOD is the only domestic customer for missile defense capabilities, prime defense contractors face an ethical dilemma regarding whether to continue to bid for defense contracts that provide low-profit margins as compared to commercial opportunities. For instance, should Boeing dedicate resources to build new or maintain existing F-15 aircraft for cruise missile defense or focus on higher profit per unit civilian aircraft? Suppose Boeing successfully lobbies Congress and the DOD for a new contract for F-15 aircraft for cruise missile defense. Will it experience competition from another U.S. company that may provide a cheaper or better alternative?

Porter's model demonstrates that vendor willingness to improve designs or production processes to expand product performance or reduce costs requires market competition. Allowance of the defense industrial base to consolidate into six prime vendors limits necessary competition and enables these vendors to hinder the entry of new companies with novel ideas into the market. Further, each of these companies is discouraged from participation in future competition as the DOD typically favors continued contract awards to the same vendor from concept development through capability deployment. The DOD must dedicate resources to devise innovative missile defense solutions that encourage innovative proposals from new entrants into the defense market. The alternative is to allow the missile defense industry to stagnate with repackaged ideas.

Demand Conditions – "Demand" conditions serve as the second element in Porter's Diamond. Demand highlights focus areas and reveals the desires of the most prominent market player. This aspect of Porter's Diamond is often manifested in nations having specialized expertise and competitively winning the market (i.e., German automotive market dominance in

[59] Investopedia Staff, "Porter's 5 Forces", Investopedia, retrieved on May 10, 2021, from https://www.investopedia.com/terms/p/porter.asp.
[60] Investopedia Staff, "What Is the Porter Diamond?", Investopedia, retrieved on May 10, 2021, from https://www.investopedia.com/terms/p/porter-diamond.asp.

high-performance luxury vehicles.) In this instance, the MDA desire and commitment through a bumpy acquisition road for an effective long-range interceptor represent "demand" for a critical missile defense capability.

The dominance of the U.S. missile defense industrial base requires a high domestic demand, then high international demand. Porter identifies a high need for a product to encourage multiple vendors to improve their designs and compete in a market. Our discussions with senior representatives from multiple companies demonstrate collective concern generated by the limited U.S. government demand and desire for competition. U.S. government customers are hindering interest in product improvement through the award of contracts that require a one-weapon-fits-all solution. Other companies have little motivation to compete with the incumbent contractor in future competition for a system. The industrial base would benefit from DOD award of missile defense contracts for smaller components and separate integration contracts. The higher upfront cost for multiple contracts would lead to future cost savings as smaller companies were encouraged to compete with the prime vendors at a component level.

Related and Supporting Industries – "Related and Supporting Industries" represents the third component of Porter's Diamond. In the case of missile defense, this analytical facet refers to spillover effects and the benefits of advancing complementary factors of production. In the U.S. Navy Aegis Program, baseline upgrades and other shipboard investments in longevity and sustainment for Arleigh Burke class destroyers directly benefitted the missile defense warfare area, and missile defense investments in maritime forces benefitted the fleet and U.S. shipbuilding industry.

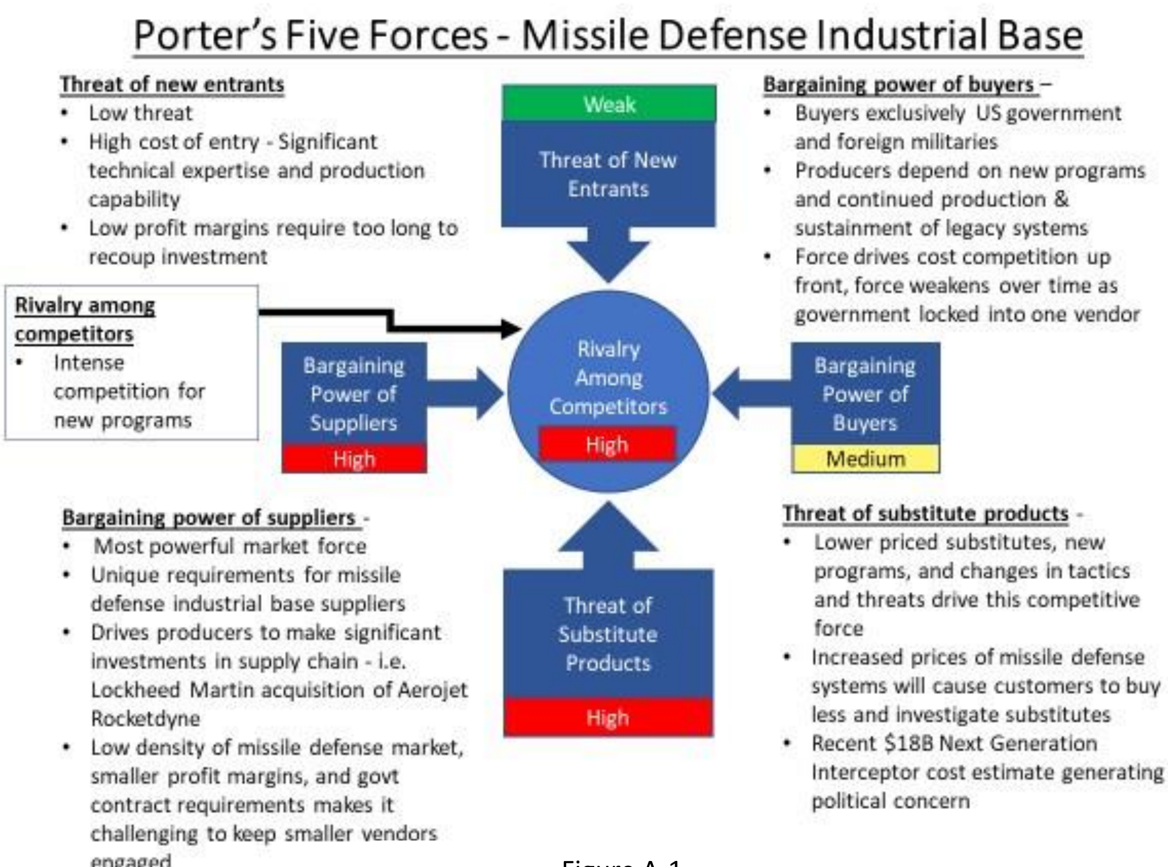

Figure A-1

The U.S. missile defense industry suffers from vanishing vendors and offshoring challenges. The slow pace of missile defense programs provides a challenge to component providers when ten-year purchase orders include designs that require production-certified electronics often considered the previous generation and no longer in production. Sustainment of natural resource/material gathering/mining and processing and the Tier-2 and Tier-3 component providers for prime contractors require federal government infrastructure investments to encourage industry growth. These investments provide infrastructure improvements required by critical mines, processing plants, forges, or machine shops.

Factor Conditions – "Factor Conditions" represent the fourth component in Porter's Diamond and point to those elements of production that have led to specialization and sophistication. In this instance, the market values specialization factors more competitively than general factors. When applied to missile defense requirements, the high-level precision required for target processing, time sensitivity, and mobility all represent critical factor conditions. The DIB requires ready access to materials or system component suppliers with supply lines that avoid foreign government interference or tampering. This access is dependent on the ready availability of skilled and unskilled labor for U.S. companies to obtain and process raw resources/materials for missile defense components and expert engineers and scientists for advanced component design and production. The offshoring of each component of a missile defense system, be it synthetic cork for rocket motor case or transistors for a targeting system, creates risk for US companies that rely on these components to build defense systems. Highly specialized parts and components available internationally may not meet government customer specifications or be modified by bad actors to support foreign government espionage techniques. The US government must invest in domestic efforts to sustain a workforce and production lines for materials and components critical to the missile defense industrial base.

Porter's Five Forces

Unlike the Diamond Model that focuses on broader nationalistic approaches, we use Porter's Five Forces (see Appendix A) to assess industry-specific market conditions that help understand why some products have had greater market competitiveness. Like Porter's Diamond, "Rivalry" has played a central role in the Five Forces model. In this instance, "Rivalry" has been represented as the competition among existing MDA participants and has been the culmination of the other four forces. In this instance, a small number of large prime contractors dominate the missile defense market and compete for missile defense contracts. The four remaining forces have represented equal yet counter forces that acted upon the overall competitive environment. The "Bargaining Power of Suppliers" and the "Bargaining Power of Buyers" have acted as two counter-balanced forces, while the "Threat of New Entrants" and the "Threat of Substitute Products or Services" have served as the other two.

On the surface, these mergers and acquisitions would reduce competition and drive-up costs for the missile defense market. However, Porter's Five Forces for the missile defense industry demonstrates why this is not entirely true. The missile defense business continues to be a relatively low-density market dominated by large primes. One of the main reasons for this is the high technology nature of these programs, resulting in a high cost of entry and almost no new companies entering the market. The lack of new entrants means that missile defense work, especially in radars and interceptors, is generally performed by the same top 6 defense

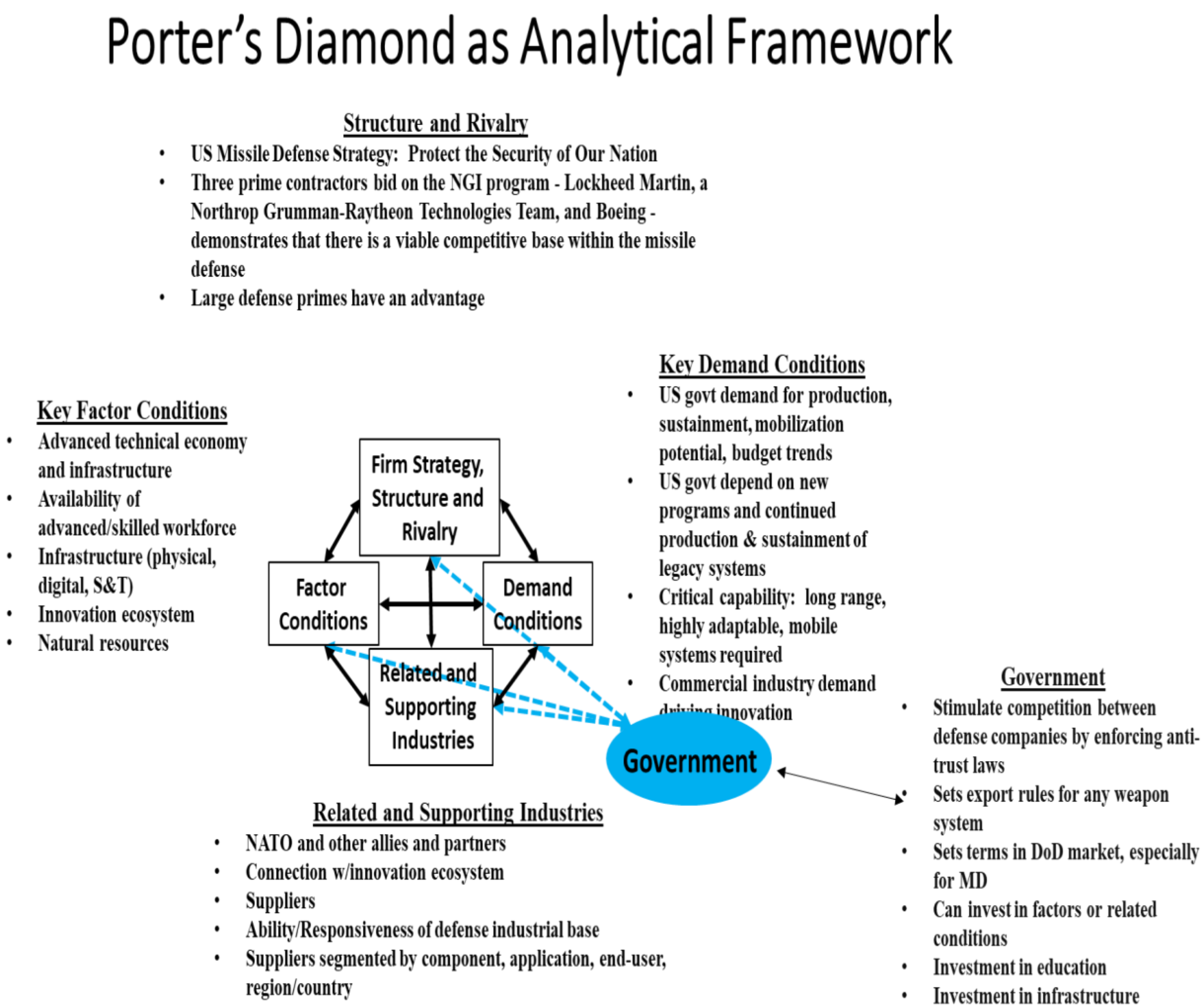

Figure A-2

contractors. The competition between producers also remains a powerful competitive force. This force drives cost competition in industry proposals, especially for new programs like the Next Generation Interceptor (NGI) Program. The fact that three prime contractors bid on the NGI program – Lockheed Martin, a Northrop Grumman-Raytheon Technologies Team, and Boeing[61] – demonstrates that there is a viable competitive base within the missile defense industrial base. The strong competitive force of the threat of substitute products also ensures that the missile defense firms remain cost competitive. New technologies like DE, hypervelocity projectiles, and HGV for left-of-launch are potential substitute products for traditional missile defense interceptors. This competition helps ensure companies remain cost competitive on their programs or face losing production quantities.

Maintaining a viable supplier base continues to be an industrial base challenge across the missile defense sector. As evidenced by Porter's Five Forces for the missile defense industry (see appendix A), the bargaining power of suppliers continues to be a strong competitive force.

[61] Paul McCleary, "DoD Estimates New Missile Defense Program To Cost $17.7B" Breaking Defense (blog), April 27, 2021, retrieved on May 2, 2021, from https://breakingdefense.com/2021/04/dod-estimates-missile-defense-program-to-cost-17-7b/.

The force drives missile defense prime contractors to spend significant time and effort managing their supply chain. The Northrop Grumman acquisition of Orbital ATK and the proposed Lockheed acquisition of Aerojet Rocketdyne are direct examples of this market force driving prime contractors to secure vertical integration of the supply chains. The small profit margins for defense work, limited ability to keep firms engaged with a backlog of work, and burdensome defense contracting, financial reporting, and security requirements also make it difficult for firms to remain in the defense industry. Many of these firms serve as single points of failure for production-certified components. Micro Craft Incorporated representatives used the example of a tornado destroying their production facilities. The representatives stated that it would take two years to reconstitute the facility.

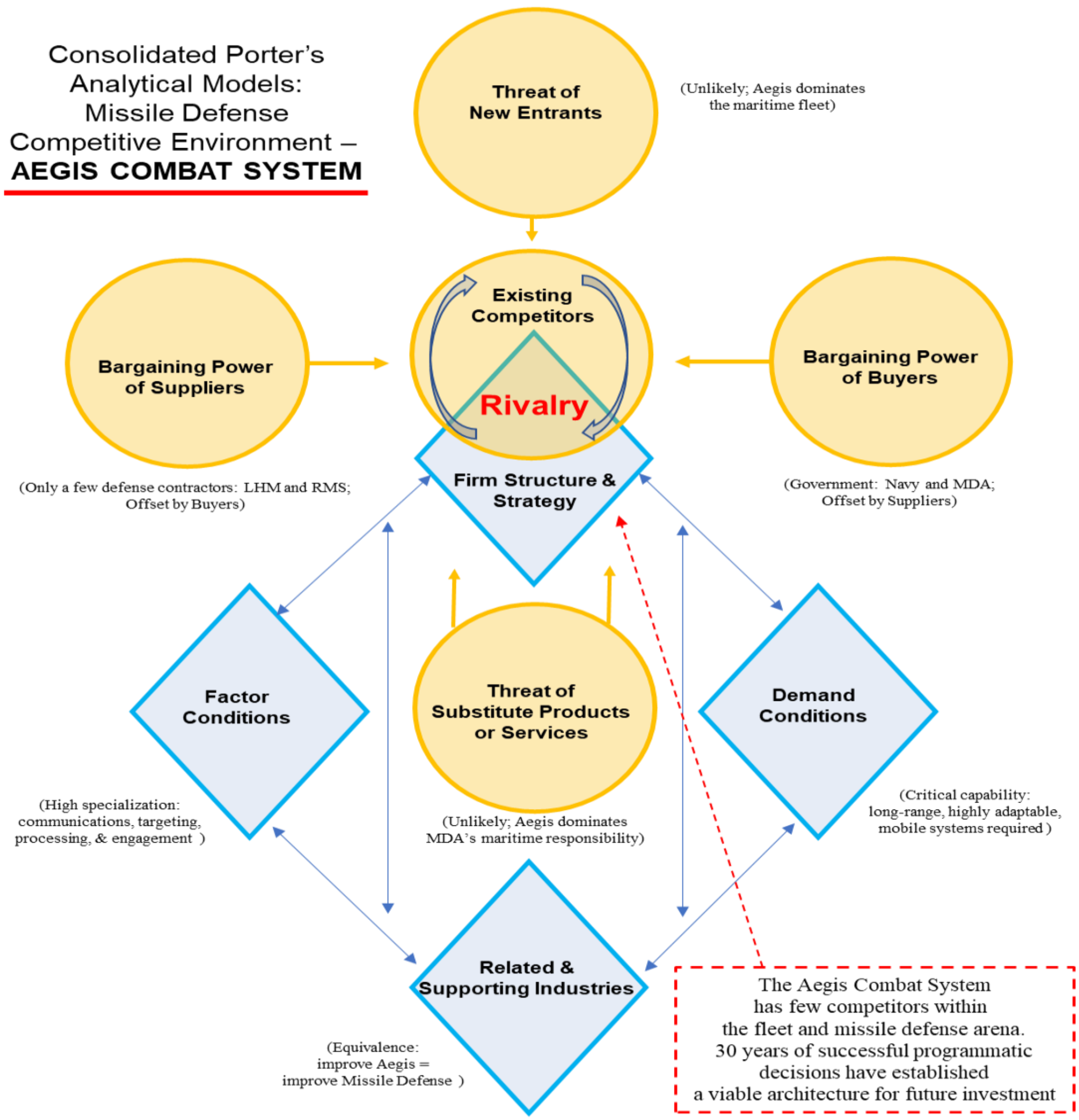

Figure A-3

Appendix B – List of Acronyms

Acronym	Common Term
AP	Ammonium Perchlorate
COVID-19	2019 Severe Acute Respiratory Syndrome Coronavirus
DASP(IP)	Deputy Assistant Secretary of Defense (Industrial Policy)
DE	Directed Energy
DHS	Department of Homeland Security
DIB	Defense Industrial Base
DOD	Department of Defense
DOS	Department of State
DPRK	North Korea
ES	Eisenhower School
EKV	Exoatmospheric Kill Vehicle
FMS	Foreign Military Sales
FTC	Federal Trade Commission
FY	Fiscal Year
GBI	Ground-Based Interceptors
HGV	Hypersonic Glide Vehicles
IAMD	Integrated Air and Missile Defense
ICBM	Intercontinental Ballistic Missiles
INSSG	Interim National Security Strategic Guidance
KKV	Kinetic Kill Vehicles
MaRV	Maneuverable Reentry Vehicles
M&S	Modeling and Simulation
MDA	Missile Defense Agency
MDR	Missile Defense Review
MDS	Missile Defense System
NATO	North Atlantic Treaty Organization
NDU	National Defense University
NGI	Next Generation Interceptor
NPR	Nuclear Posture Review
NSC	National Security Council
OSD	Office of the Secretary of Defense
OTA	Other Transactional Authorities
PEO	Program Executive Office
ROK	Republic of Korea
SECDEF	Secretary of Defense
THAAD	Terminal High Altitude Area Defense