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AIR DOMAIN

Final Report

MODERNIZING THE 2030 FUTURE FORCE FOR GREAT POWER COMBAT

The Dwight D. Eisenhower School
for National Security and Resource Strategy
National Defense University
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ABSTRACT.

The air domain is a critical National Security industry driving a broad spectrum of technology development. Air domain is a technology integrator of capabilities from other industry studies such as munitions, information technology, and electronic warfare. Therefore, the air domain drives economic growth across multiple business sectors. Great Power Competition and the emergence of Russian and Chinese advanced tactical aircraft, air defense, and subsystems threaten America's technical superiority in the air domain. Policymakers must focus on accelerating generation 4.5 fighter acquisitions, bolstering research and development in universal communications systems and low-cost attritable and expendable manned and unmanned teaming technologies, and, finally, reinforcing critical rare earth elements supply chain challenges by funding mining and manufacturing domestically and encouraging allied production. The 2021 Air Domain Industry Study for the Eisenhower School of National Security and Resources Strategy consists of the following authors:

Air Domain Industry Students	
Lieutenant Colonel John E. Burrell	United States Air Force
Lieutenant Colonel Jesse P. Caldwell	United States Air Force
Lieutenant Colonel John G. Dayton	United States Air Force
Commander Tessa M. Denaro	United States Navy
Lieutenant Colonel Sidi Sadio Diallo	Mali Air Force
Commander William P. Frank	United States Navy
Lieutenant Colonel Brian R. Grant	United States Marine Corps
Lieutenant Colonel Gergely Grof	Hungarian Air Force
Commodore Syed Faisal Hameed	Pakistani Navy
Colonel Gilad Kenan	Israeli Air Force
Mr. Joshua M. Lenzini	Department of the Army
Lieutenant Colonel Thomas F. Meagher	United States Air Force
Lieutenant Colonel Stephan L. Nowakowski	United States Army
Lieutenant Colonel Ryan C. Nesrsta	United States Army
Lieutenant Colonel Julie Anne Rudy	United States Air Force
Mr. Travis C. Stalcup	Office of Management and Budget
Air Domain Industry Faculty	
Dr. Tim Russo	Air Domain Faculty Lead
Captain Mark J. Morin	Air Domain Deputy Faculty Lead

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INTRODUCTION

The dawn of the 21st century presented America with a unipolar world free from large-scale competition with great powers. September 11, 2001, forever changed the world and shifted America's focus, significantly impacting the United States' National Defense Strategy. This dramatic shift in focus embroiled America into a decades-long counter-insurgency regional conflict in the Middle East and Central Asia. The post 9/11 emphasis on non-state actors and unconventional warfare drove new requirements centered on small-scale regional conflict, reducing resourcing and acquisitions programs needed to compete in Great Power Combat.

Twenty years later, the United States is experiencing a global shift in strategic competition as Russia and China grapple with expanding their spheres of influence. It is now clear the world is entering an era of multipolar Great Power Competition. America is facing a different world, containing multiple peer competitors striving to gain a worldwide strategic advantage. Moreover, Russia and China's advanced military modernization programs are rapidly reducing the technical and military superiority the U.S. has enjoyed over the past several decades. As a result, America must refocus on Great Power Competition to ensure the military is ready and resourced to fight tonight while developing a future force for 2030. The 2030 force drives new resourcing requirements to meet the challenges of this complex global security environment.[1] The return to Great Power Competition presents the United States with an increasingly lethal and disruptive battlefield, across multiple domains with ever-increasing speed and reach of forces that render long-standing forward "sanctuary" bases vulnerable.[2] This new paradigm obliges America to preserve its "fight tonight" force while modernizing and resourcing a future 2030 force capable of high-end, near-peer conflict and long-range strike in a contested and degraded operational battlespace.

THESIS:

The long-term effects of defense industrial base consolidation, near-term impacts of the Coronavirus Disease 2019 (COVID-19) on the aircraft industry, continued budget uncertainty, and the resurgence of global power competition requires the Department of Defense (DoD) to modify fighter fleet modernization strategies, accelerate the fighter modernization plan, and reevaluate U.S. government research funding, acquisition efforts, and material supply strategies.

RESEARCH METHODOLOGY:

Research gathered from a review of recent literature, interviews, industry site visits, and guest speakers form the basis of this report. Representatives from the DoD key acquisition leaders, the aerospace industry, second and third-tier suppliers, and operational military units were interviewed and featured as guest speakers to provide holistic perspectives. In addition, members of the seminar conducted independent research on the wide-ranging air domain topics included within this report. However, the preponderance of research incorporated into this paper focuses upon fighter aircraft.

DISCLAIMER:

The views expressed within this report reflect those of the Air Domain seminar. They do not reflect the official policy or position of the United States government, DoD, or the National Defense University's Eisenhower School for National Security and Resource Strategy.

DOMESTIC AIRCRAFT INDUSTRY

The aircraft industry's strategic environment includes commercial and defense aircraft manufacturers, the aircraft industry's health, gap analysis, and strategic outlook. First, a detailed examination of the various aircraft sectors determines how each industry sector operates. Next, a thorough review of select firms within America's prime aircraft industry will provide a holistic picture of the industry's financial health and growth potential. An analysis of American air defense capabilities will demonstrate current gaps. Finally, a look at the strategic outlook for the American firms concludes a review of the domestic aircraft industry. This analysis provides a current snapshot of the aircraft industry's strategic environment and offers critical insights into future trends, enabling an understanding of the current landscape and forecasted developments.

AIRCRAFT SECTOR DESCRIPTION:

The aircraft industry sectors comprise commercial and defense aviation aircraft, products, and support services. These aircraft industry sectors support the defense aircraft industrial base, including fixed-wing, rotary-wing, and unmanned aircraft systems/vehicles (UAS/UAV) required for air-to-air and air-to-ground military operations and transport. Fixed-wing aircraft includes fighters, bombers, cargo, transportation, and any manned aircraft utilizing a set of fixed wings to generate lift for forward flight. Both fixed and rotary-wing, large airframes and subsystems rely heavily on commercial technologies, processes, manufacturing, and military and commercial aerospace sustainment programs. However, defense-unique design and manufacturing skills are required to meet military weapon systems' requirements, produce next-generation stealth aircraft, and maintain a technological advantage over any near-peer adversary.

Rotary-wing aircraft includes helicopters used for various military applications in three primary mission areas: combat, combat support, and combat services. Unlike their commercial counterparts, military helicopters operate in harsh battlefield environments, which require robust, advanced capabilities and integrated systems such as fire control, armor, weaponry, night vision, advanced avionics, stealth, speed, survivability, and additional power. In addition, the specific attributes of combat helicopters drive unique engineering capabilities to design, manufacture, integrate, and test military helicopter systems that commercial aircraft do not require.

UAV/UAS comprises both fixed-wing and rotary-wing aircraft and the necessary components, equipment, network, and personnel to remotely operate unmanned aircraft systems. The unmanned aircraft systems industry ranges from small bird-sized aircraft to larger aircraft with wingspans exceeding 100 feet categorized into five distinct categories. Initially, six broad functional categories comprised various UAV/UAS aircraft, including target and decoy, reconnaissance, combat, logistics, research and development (R&D), and civil and commercial. However, the growing demand for increasingly sophisticated and versatile unmanned systems reflects the military's insatiable appetite for intelligence, surveillance, and reconnaissance (ISR). Moreover, the desire for autonomous and loyal wingman aircraft capable of integrated strike operations will reduce the risk to deployed forces and increase combat power.

The aviation industrial base is small, with just six companies manufacturing most U.S. military aircraft platforms (Boeing, Lockheed Martin, Northrop Grumman, Textron, Airbus, and General Atomics). These six companies possess the skills and experience to transition new weapon systems from the R&D phase through development, production, and sustainment.

Table 1: Aircraft Industry Manufacturers and U.S. Weapon System

Company	Aircraft Type
Boeing	F/A-18 Hornet/Super Hornet, P-8 Poseidon, EA-18G Growler, E-6 Mercury, A-10 Thunderbolt II, B-52 Stratofortress, B-1 Lancer, C-17 Globmaster III, E-3 Sentry, F-15 Eagle, KC-46 Pegasus, VC-25, T-7A Red Hawk, AH-64 Apache, CH-47 Chinook, RQ-21 Blackjack, MQ-25 Stingray
Lockheed Martin	F-35 Lightning II, P-3 Orion/ARIES, C-130 Hercules, F-16 Fighting Falcon, F-22 Raptor, U-2 Dragon Lady, C-5 Galaxy, UH-60 Black Hawk, RQ-170 Sentinel
Northrop Grumman	E-2D Advanced Hawkeye, B-2 Spirit, B-21 Raider, E-8 Joint STARS, MQ-4C Triton, MQ-8 Fire Scout
Textron	RQ-7B Shadow
Airbus	UH-72A Lakota
General Atomics	MQ-1 Gray Eagle, MQ-9 Reaper

Porter's Diamond provides an analytical framework to understand the U.S. air domain industry as it exists today. Porter identifies four attributes of national competitive advantage in each industry: factor conditions; demand conditions; related and supporting industries; and firm strategy, structure, and rivalry.[3] Chance and government action operate across the diamond to shape national advantage. Applied to the defense aerospace industry, Porter's Diamond reveals elements of U.S. historical advantage to provide considerations for shifting trends in an era of Great Power Competition.

The first quadrant contains the factor conditions and describes the highly technical elements of production required to compete in an industry.[4] The U.S. air domain benefits from human capital, university aerospace programs, infrastructure, commercial capital, and defense budgets. As a result, the U.S. retains an advantage, but other nations are creating factor conditions to support an indigenous industry that competes in the air domain. Therefore, as the accuracy of computational and digital design methods improves and these tools proliferate, the relevance of certain factor conditions may shift and diminish U.S. advantage.

The next quadrant, demand conditions, evaluates "home-market demand" for an industry's product.[5] U.S. security commitments and global military strategy provide strong home-market demand for military aircraft. Historically, strong demand and interservice rivalry created competition and innovation.[6] Porter's Diamond analysis reveals a heavy reliance upon the U.S. government and a deep interdependence within the industry (see Appendix A). The prime defense contractors rely upon the U.S. government for large contracts, including aircraft acquisition and maintenance and repair operations. The U.S. government is also the approval authority for lucrative Foreign Military Sales (FMS) and direct commercial exports, giving the it an even more prominent role in the industry. The commercial aerospace industry benefits from a sizeable domestic aviation market driven by an expansive U.S. geography. The quality and quantity of U.S. aircraft created demand momentum for military and commercial exports. Historically, this demand provided a competitive advantage for the U.S. industry.

However, increasing aircraft costs and less frequent competition lowers domestic military demand. In addition, the high price for exquisite U.S. aircraft and foreign preference for indigenous aerospace industries may reduce future export demand.[7] Similarly, the commercial market continues to see demand conditions and market share shift toward Europe and, in the future, possibly China.[8] In China, both civilian and military aerospace growth suggests improving Chinese demand conditions, potentially reducing the U.S. long-term competitive advantage in the air domain.

The presence or absence of internationally competitive, related, and supporting industries constitutes the third quadrant of Porter's Diamond.[9] Historically, U.S. aerospace firms benefited from the civilian aviation industry and a network of high-end, advanced suppliers. However, two trends may erode that advantage. First, the air domain industry continues to shift toward a more global supply network as companies seek greater efficiency and leverage a more technological competitive advantage. Second, there are fewer dual-use standard components between civilian and military suppliers and related industries, especially Tier One and Tier Two suppliers. As a result, the industry still benefits from the related and supporting civilian industries but with diminished advantage. However, as military technology advanced, the defense aerospace industry shifted focus to integrating military-unique subsystems. As a result, the defense aerospace industry now derives a competitive advantage from the broader defense industry across all domains and subsystem technologies—delivered through software.[10] Software, networking, and other digital technologies are essential related industries required for addressing 21st-century conflict. Linkages between the military, aerospace industry, and leading technology companies are relatively weak, inhibiting U.S. competitive advantage.

The final quadrant of Porter's Diamond depicts the air domain's firm strategy, structure, and rivalry. Shareholder structures, free-market culture, access to capital, and public support for aviation certainly backstop U.S. competitive advantage; however, the political economy of defense acquisitions creates a unique corner of Porter's Diamond compared to other industries. In addition, the government acts as both a monopsonist buyer and a potent regulator over the defense air domain industry. Finally, the Military Industrial Congressional Complex and the Iron Triangle characterized by symbiotic relationships between industry, the military, and Congress significantly shape the strategy, structure, and rivalry within the air domain industry.

Industry responds to military requirements, government policy, and politics to evolve strategies and structures that create value. The government influences firms through various means, such as the Federal Acquisition Regulation (FAR), acquisition preferences, political oversight, defense industrial policy, and budgetary constraints. This government influence creates high barriers for entry, thus influencing rivalry. Over time, the American airline industry has consolidated and merged into a complex relationship of customers, buyers, and suppliers. Bureaucratic-strategic theory explains past market exits and failures as punishment for being unresponsive to military demands.[11] Often procurement decisions select winners to sustain a broad industrial base with multiple rivals rather than on the merits of competition. In 1993 during the famous "last supper," Deputy Secretary of Defense William Perry warned defense industry executives of future budget cuts and encouraged consolidation.[12] Over time, this consolidation provided diversification for firms, mitigating the adverse effects of losing any single competition.

The current business and incentive models adapted to these trends. Fewer, less frequent aircraft competitions often meant firms had to win to stay in business. Since winning implies long-term sustainment and modernization, firms tended to lower development prices and profits and instead rely on the "prize" of future earnings in the monopolistic phases of the program.[13] The prize system of "buying in" to a weapon system created benefits for the government, but government priorities may need to shift. Today, Lockheed Martin dominates the fighter aircraft market, the interval between competitions is two decades, and operations and sustainment drive

70 percent of aircraft lifecycle costs. [14] The evolved firm strategy, structure, and state of rivalry may now undermine U.S. competitive advantage.

PRIME AIRCRAFT INDUSTRY EVALUATION:

Examining three firms within the American aircraft industry provides a comprehensive analysis of the U.S. aircraft defense market. The Boeing Company, Lockheed Martin, and Raytheon design, manufacture, and produce aircraft systems and subsystems for commercial and military applications. Furthermore, the three firms compete in multiple aircraft market segments, including commercial, defense, and space. A complex technological and industrial base with numerous original equipment manufacturers (OEM) and non-original equipment manufacturers (non-OEM) supports the three primary aircraft industry manufacturers. In many cases, the same OEM and non-OEM suppliers support multiple prime aircraft industry manufacturers.

The Boeing Company is one of the world's largest aerospace firms, competing and partnering globally with many other companies.[15] In addition, Boeing is a supplier of both military and commercial aviation products and services. Boeing's organizational structure includes three primary operations divisions: Boeing Commercial Airplanes; Boeing Defense, Space, Security; and Boeing Global Services.[16] Like many firms heavily involved in the commercial airline business, the COVID-19 pandemic caused significant financial strain on Boeing, specifically its Commercial Airplanes division.[17] In recent years, Boeing's largest income source, the Boeing Commercial Airplanes division, has become increasingly dependent on 737 MAX sales. Prior to the two catastrophic crashes that led to its grounding, the 737 MAX accounted for 70 percent of commercial airline deliveries. These events drastically decreased Boeing's revenue.[18] The impact of COVID-19 and the 737 MAX grounding resulted in a net loss of almost $12 billion due to a loss of revenue generated by the firm's Commercial Airplanes division.[19] However, Boeing partially offset the sharp decline in earnings with revenues generated by the other divisions of the company.[20]

Boeing competes in multiple global aircraft sectors as their strategic gameboard strategy. The Commercial Airplanes division serves as the foundational division of Boeing. In addition, Boeing runs a diverse defense business, including fixed-wing and rotor-wing aircraft, UAVs, and space. The Boeing Global Services division has grown significantly since its inception in 2017 and supports both the Boeing commercial and defense divisions. In recent years, specifically after losing the Joint Strike Fighter (JSF) competition to Lockheed Martin and the release of and increased sales from Airbus' A321neo launch, Boeing's total sales have diminished. However, the COVID-19 pandemics' impact on commercial aviation delayed Airbus from gaining an increased market share. Additionally, the increasing demand for Boeing's legacy fighters provides Boeing a chance to recover.

Boeing relies on revenues from Defense, Space, and Security division sales, which remained above $26 billion for 2018 and 2019 and increased by $162 million in 2020. [21] The steady revenue generated by the Defense, Space, and Security division during the 737 MAX and COVID-19-related issues is an example of the benefits of the company’s diversification among its segments. Furthermore, the company's Global Services division did see a decline in revenue as commercial sales slowed, but also experienced growth from increased defense-related sales. Overall, the firm's diversity has supported continued production of the 737 MAX and 787 commercial airplanes by increasing its liabilities through debt and unsold inventory during 2020.[22]

Despite the overall decline in revenue and a net loss, Boeing continued to pay dividends to shareholders. However, the dividends did not increase as the company assumed debt to support the production of commercial airplanes without associated sales.[23] As a result, Boeing is considered a blue chip company based on its increased share prices and continued dividend payouts, but this may change in 2021 if revenues do not improve.[24]

Lockheed Martin primarily competes in the defense aircraft sector. Additionally, as a defense firm, Lockheed's relationship with the U.S. government is essential. The U.S. government is not only its primary customer, but it is also the regulatory gatekeeper for exporting products to other international customers. As a result, Lockheed faces domestic and international competition, which forces it to regularly improve its products, creating a perpetual market for nations to modernize their capabilities.

Lockheed Martin’s strong financial performance in 2020 resulted in $6.8 billion in net income from $65.4 billion in total revenue.[25] Lockheed Martin's Rotary and Mission Systems (RMS) business unit, comprising the Aeronautics business unit and Sikorsky helicopters, accounts for its aircraft industry sales. The Aeronautics business unit accounted for $26 billion (40 percent) of Lockheed Martin's revenue in 2020, whereas RMS accounted for $16 billion (25 percent) of revenue. This revenue was approximately 71 percent U.S. government sales and 29 percent international sales. Further analysis shows products provided 83 percent of the revenues, with 17 percent generated from services.[26] Lockheed Martin's sales backlog increased during 2020, with the majority from the aircraft industry, including the F-35, F-16, C-130J, multiple helicopters, and other classified systems.[27] This financial performance extended trends of consistent revenue and income growth over the past five years. In addition, in 2020, Lockheed's shareholders benefited from $2.8 billion in dividends and $1.1 billion in share repurchases.[28]

Lockheed Martin’s Strategic Game Board encompasses global competition across existing domains for military solutions, leveraging complementary expertise throughout their portfolio. They are the leading stealth fighter producer within the air domain with their F-22 and F-35 product lines, maintaining market leadership and industry advantage. The F-16 is the leading globally-exported, 4th-generation fighter aircraft. In addition, they have a continued hold on support and production market share among allied nations. Additional air domain areas include cargo aircraft, such as the long-running C-130 line, manned reconnaissance (U-2), and rotary-wing markets with their Sikorsky acquisition. They compete directly against Bell and Boeing. Lockheed Martin has a lower presence in the permissive-environment UAV market within open-source portfolios, leading to future growth opportunities.

Lockheed’s long-term strategy relies on continued product support demand, including the vast C-130 fleet, F-16 support, and F-35 operation and maintenance requirements. They compete primarily for large government platform contracts, serving as the platform integrator, and often compete directly with Boeing for cargo and fighter solutions. Lockheed targets acquisitions when appropriate, including their acquisition of General Dynamics jet aircraft in 1992, leading to the F-16 portfolio and additional F-22 shares. Additionally, their primary mechanism for competing in the rotary-wing program was through their Sikorsky acquisition strategy. Finally, their continued focus on innovation drives their strategic vision to maintain technical advantages for their product offerings.

Raytheon Technologies participates in a diverse set of markets related to defense and civil aerospace, cyber, intelligence, missiles, and missile defense. The development and sales of aircraft and engines provide the bulk of Raytheon’s revenue. As a result, Raytheon’s environment has a small number of sellers and a single government buyer. The market is also populated by similar products and competitors, particularly in high-bypass turbofans and avionics. In 2019, when Raytheon merged with United Technologies, 80 percent of its sales were to sovereign governments—with 60 percent of sales to the United States. At the time, United Technologies was less reliant on military aerospace sales, with 86 percent of sales coming from commercial services, industrial services, and commercial aerospace customers.[29] As a result, the merger of these two firms resulted in a diversified customer base. The firm's most important customers remain sovereign governments, but U.S. military sales accounted for just under half of total annual sales.[30] Another 30 percent of sales were to other U.S. defense contractors and aircraft manufacturers, largely Airbus and Boeing.[31]

Raytheon's Strategic Game Board emphasizes R&D, particularly in networks, cybersecurity, and directed energy (DE). Independent R&D has declined by as much as two-thirds within the industry. These horizontal business activities continue to serve as a staple of the industry as firms seek to consolidate, diversify within the firm, and capitalize on a small domestic engineering talent pool that accomplishes the brunt of the technical work. Lastly, vertical integration to de-risk supply chains and maximizing upstream and downstream profit centers is becoming a defining industry feature. Similarly, Raytheon engages in more collaborative efforts with foreign partners to diversify its customer base.

Raytheon and United Technologies' April 2020 merger provides Raytheon access to selective markets in DE, space, cyber, and intelligence. Raytheon now has market-leading expertise within a broad portfolio and will aggressively compete in niche markets while continuing its general frontal assault on other areas of the defense market. Raytheon does not see a viable path for competition in the fixed and rotary-wing platform end-item markets since Raytheon's divesting of Hawker and Beech in 2007 (sold to Textron).

A Value Net analysis reveals the signigicant interdependence of the the American aircraft industry. Industry customers are principally the U.S. government and defense prime contractors (primes), although Boeing has a sizeable commercial segment. In addition, American aircraft firms sell to one another while simultaneously competing. Consequently, a look at American industry suppliers shows a commonality exposing a weakness in the supply chain. The complementing sectors for Boeing, Lockheed Martin, Raytheon vary slightly depending upon their focus and place within the production line. Raytheon does not produce end-items, limiting its complementors to supporting other firms. However, Boeing and Lockheed Martin have a more significant complementing segment. Appendix A provides an examination of Boeing, Lockheed Martin, and Raytheon’s Value Nets.

AIRCRAFT INDUSTRY GAP ANALYSIS:

Congressional annual reports from fiscal year (FY) 2015 to FY 2020 identify three critical gaps in the aircraft industry (see Appendix D). First, reports indicate there is an increase in aircraft design capability deficiencies affecting specific innovative manufacturing techniques. Second, there is a reduction in the required human capital to maintain a robust technological, industrial base. This deficiency requires an increase in domestic STEM-based education programs. Finally, outsourcing created significant deficiencies and introduced lag into the supply chain affecting domestic manufacturing programs. Reducing new defense programs led to aircraft design capability gaps, including the lose of the perishable skills required to design complex military aircraft like 5th- and 6th-generation fighters.

The manufacturing of large, complex, single-pour aluminum and magnesium sand castings is problematic because of the aircraft industry's consolidation, which has reduced available facilities and human capital. The reduction in qualified engineers available to replace the retirement-aged workforce highlights unique human capital deficiencies. Opportunities for hands-on, real-time transfer of knowledge to the next-generation workforce are minimal because of the dwindling number of new design programs and industry consolidation. Additionally, software skills are a critical issue for the aircraft sector. For example, 4th-generation fighters' software comprises approximately 15 percent of the total engineering of the aircraft. Conversely, 5th-generation fighters software accounts for over 40 percent of the engineering of the aircraft. In 6th-generation fighters, the trend will grow significantly.

With intense competition from other industries (e.g., cybersecurity, healthcare, R&D), it is increasingly difficult to hire skilled, security-cleared, and capable software engineers. Finally, the consolidation of prime and lower-tiered suppliers in the aircraft industry is concerning. Consolidation or integration of prime suppliers in the industry has expanded into the supply chain's sub-tiers, creating additional risks for single or sole-source vendors for many aircraft components. In addition, due to the COVID-19-driven downturn of the commercial aviation industry, suppliers may choose to downsize their production capacity by closing facilities or not operating equipment and manufacturing machines. This down-sizing can potentially create supply chain bottlenecks, particularly when airline passenger traffic numbers improve and the aircraft OEMs start increasing order quantities to meet renewed demand.

AIRCRAFT INDUSTRY STRATEGIC OUTLOOK:

In 2020, the defense and aerospace sector declined in performance compared to the previous few years. This sharp decline in performance is due, in large part, to a downturn in the commercial aircraft sector and acute impacts from the global COVID-19 pandemic. In May 2020, air travel declined by 91.3 percent from the previous year, thus reducing demand for commercial aircraft. However, Airbus reported a backlog of 7,184 jets for commercial aircraft manufacturing, and Boeing's backlog was 4,223 aircraft at the end of 2020. [32] As a result, market projections indicate growth to increase from roughly $170 billion in 2020 to $303 billion by 2026.[33] The coronavirus pandemic further aggravated supply chain issues in the defense and aircraft sector. As a result, these supply chain issues created significant challenges in maintaining and sustaining the health of the aircraft industrial base. Therefore, the health of the defense and aircraft industrial base is inextricably linked to the recovery of the commercial aircraft industry. This could take three to five years to return to pre-COVID global passenger traffic, and thus, commercial aircraft sales. Commercial sector passenger traffic plummeted drastically in 2020. The commercial airlines' subsequent losses resulted in the cancellation or deferral of aircraft orders, thereby reducing the demand for commercial aircraft. Air travel will return to pre-pandemic levels in the 2023-2024 timeframe and continue increasing thereafter.[34]

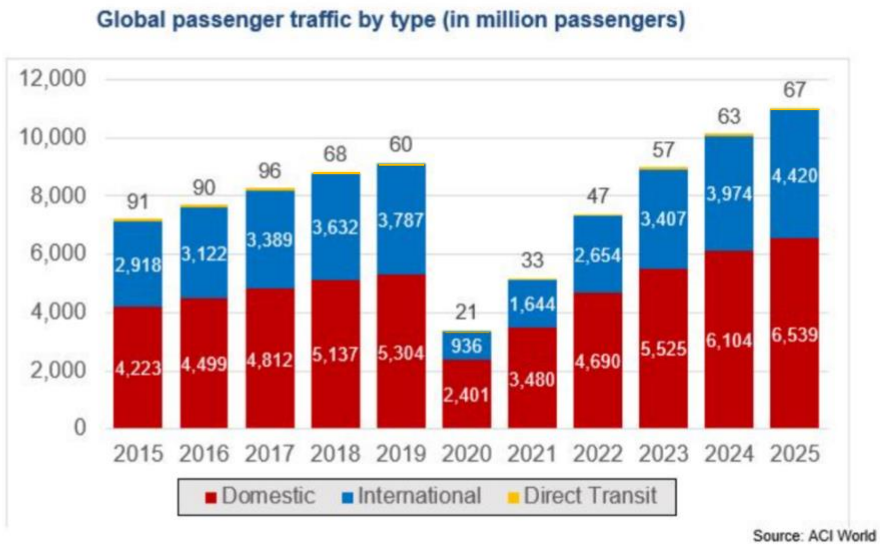

Figure 1: Global Passenger Traffic Forecast[35]

Despite the COVID-19-driven decrease in market demand, growth has occured in other portions of the aircraft industry. For example, there is increasing demand for helicopters and business jets to transport medical supplies, conduct VIP transport, and satisfy expanded cargo and freight operations. Recently, FedEx Express announced an order for 12 Boeing 767 freighters and 12 Boeing 777 freighters, and Atlas Air Worldwide Holdings, Inc. ordered four new Boeing 747-8 freighter aircraft.[36] Additionally, the global helicopter market size predicts growth from $21.3 billion in 2020 to $36.9 billion by 2025, with an average growth rate of 11.7 percent from 2020 to 2025.[37] This pending cargo aircraft purchase and projected growth in the transport helicopter market may mitigate the overall decline of the commercial aircraft market.

Boeing is well poised to recover from the 737 MAX and COVID-related challenges it experienced in 2019 and 2020. The company's diversity among its business divisions allows it to absorb downward trends in a specific market, such as commercial or military aviation. Its strong product lines, relationship with the U.S. and foreign militaries, and established ties with airlines worldwide will contribute to future success. The recertification and deliveries of the 737 MAX and increased F-15EX purchases are both indicators of the company's health.[38]

As a focused defense contractor, Lockheed Martin Corporation experienced only minor financial impacts from COVID-19. Lockheed Martin's government work continued, and Lockheed will likely receive consideration for excess costs incurred due to COVID-19 mitigations. However, long-term costs and schedule impacts may not have yet materialized. In addition, Lockheed Martin continues to reduce its overall company inventory to improve its financial performance. However, this might increase the risk of disruptions to government sales contracts.

Lockheed Martin is likely to continue its strong performance, led by the aircraft industry and F-35 sales, projecting 4 percent sales growth for 2021. Lockheed Martin is seeking opportunities to compete in the advanced UAS markets. Furthermore, Lockheed Martin will continue efforts to increase international sales, particularly for the F-35. However, the F-35 poses a significant risk for Lockheed Martin since it accounts for 28 percent of annual net sales.[39] In addition, the current political climate and budget environment could create pressure to decrease F-35 procurement quantities. If that occurs, Lockheed Martin will struggle to maintain its revenue growth projections. Despite any short-term F-35 risks, Lockheed Martin's diversification across the defense market and breadth in the aircraft industry mitigates most long-term risks.

The United Technologies and Raytheon merger created a large aircraft industry-focused defense contractor.[40] Raytheon reported net sales of $56.6 billion in 2020. However, organic sales decreased by $10 billion, so the increase from 2019 is due to divestitures and sales from the merger.[41] Defense companies with a heavy reliance on commercial sales performed far worse in 2020 than defense primes that relied on only military sales. Raytheon endured a negative $3.5 billion in net income and negative $2.6 billion in earnings per share (EPS) in 2020, likely attributed to impacts on the commercial sector from the COVID-19 pandemic.[42] However, Raytheon enjoys a robust market capitalization compared to many of its competitors, and if required to adjust its balance sheets quickly, it could raise the required capital. In addition, Raytheon's experience will support the Joint All Domain Command and Control (JADC2) concept currently touted by the DoD with its aerospace systems-based portfolio. This may provide Raytheon with a particular advantage over peers should it push the value of its integrated systems, working together to deliver unique multi-domain operational capabilities.

Combat Aircraft Industry Economic Trends:

Currently, Lockheed Martin's F-22 and F-35 are the only operational 5th-generation fighters. Therefore, Lockheed Martin dominates fighter aircraft production and should control at least a 47 percent of global marketshare (by value) over the next decade.[43] Global military spending exhibited notable inconsistencies in recent years. Some developed countries' defense budgets have gradually declined during recent years due to budget sequestration in the defense sector. For example, Germany, UK, Spain, Italy, Ireland, Belgium, and France undertook stringent measures to reduce military spending, resulting in an overall reduction in defense spending from 2011 through 2018. However, U.S. defense spending fluctuated over the last decade, resulting in a 19.9 percent decrease from 2011 through 2017 and then rising 8.5 percent in 2019 to $718.7 billion. The DoD aircraft procurement budget for FY 2020 through FY 2024 is relatively stable. This stability is primarily due to the B-21 Raider and the Future Vertical Lift (FVL) programs entering low-rate initial production (LRIP) as the F-35 and the T-7A programs reach peak production and procurement. After 2029, procurement funding will likely transition to the development of 6th-generation aircraft, cargo aircraft, and unmanned systems.

Additionally, the UAS sector is another rapidly expanding sector in the aircraft industry. UAS for ISR, attack, electronic warfare (EW), and other mission sets are becoming more ubiquitous on the battlefield. The global UAS market is expected to grow from 5.4 percent from from $440.4 billion in 2019 to $543.9 billion in 2025.[44]

Finally, the COVID-19 pandemic negatively impacted companies with sizeable commercial aviation sales and self-funded R&D much harder than defense-focused sales. For example, in 2020, Boeing spent approximately $2.5 billion on R&D, of which $713 million went toward its Defense, Space, and Security division.[45] These R&D investments represent decreases from 2019 when the Boeing spent $3.219 billion company-wide and $758 million on defense applications.[46] Moreover, Boeing's defense-focused R&D decreased annually since 2013, when investment peaked at $1.215 billion.[47] In contrast, Lockheed, a primarily defense-focused company, increased R&D each year since 2011, rising from $585 million to a steady amount of $1.3 billion annually from 2018-2020.[48]

U.S. FIGHTER MODERNIZATION AND ACQUISITION EFFORTS

The 2018 National Defense Strategy focused the United States on the return to Great Power Competition.[49] The emerging global environment and the pace of technological change threaten to erode or even overturn U.S. military advantage. Historically, the U.S. military maintained air superiority through the constant pursuit of new technologies, increasing system complexity, and multidisciplinary integration across an ever-growing list of mission systems. However, complexity increased costs and extended schedules, higher unit costs reduced production quantities, and growing sustainment costs diverted funds from modernization.[50] The F-35 exemplifies the trend in technology, complexity, integration, and ultimately frustration over high prices and a long development timeline.[51] The F-22 experienced similar trends leading to substantial cuts in production quantities. Absent a peer threat, the United States accepted the development cost and schedule growth while also shifting funds to sustainment. For the United States Air Force (USAF), the result is nearly the smallest, oldest fleet in its history, just as its technological advantage erodes.[52]

The U.S. can no longer guarantee its dominance against innovative and technologically advanced adversaries such as China. As a result, the legacy approach to acquisitions in the air domain is inadequate. For example, the USAF's Air Superiority 2030 Flight Plan states:

> The speed of capability development and fielding will be critical to retain the U.S. advantage in the air. As the pace of technological advancements continues to increase, the Air Force must leverage experimentation and prototyping to infuse advanced technologies into the force. Additionally, the Air Force must reject thinking focused on "next generation" platforms.[53]

The future air domain may look very different as the USAF upgrades existing systems and develops new technologies, such as autonomy, artificial intelligence (AI), hypersonic, and DE weapon systems. However, the traditional approach is likely to deliver an exquisite, next-generation aircraft with more complexity, at higher costs, over a long development timeline, and in low quantities. The challenge is how to deal with the increasing complexity and uncertainty from technological change to produce advanced designs with decreased production costs.

THE DRIVE FOR A 5TH-GENERATION FIGHTER:

The F-22 Raptor entered service in 2005 as America's first 5th-generation fighter aircraft. The stealthy and highly maneuverable aircraft's design aimed to reinforce U.S. air dominance after Russia's development and deployment of advanced 4th-generation fighters.[54] The F-22 Raptor's capabilities far exceed 4th-generation aircraft in four design areas. First, the aircraft's inherent stealth-designed capability drove a competitive advantage over all 4th-generation aircraft. The stealth technology included a new airframe design and radar absorbing materials to significantly decrease radar cross-section and lower the probability of detection. Second, the F-22 possesses a supercruise capability that utilizes powerful and effective engines to allow the jet to cruise at supersonic speed without fuel-guzzling afterburners. Third, the addition of thrust vectoring technology, an aerodynamically improved design, and an advanced flight control system to give the F-22 super-maneuverability. Finally, the most significant and revolutionary attribute of 5th-generation aircraft is the various advanced sensors that enable an integrated and distributable combat picture. This improved situational awareness allows the F-22 to operate independently in a very efficient fashion. The F-22's 4th-generation counterparts usually require support from external data sources and heavily rely on the pilot's ability to integrate and interpret data from multiple sources in the cockpit.[55] These superior traits embody the defining characteristics of the 5th-generation fighters. While the F-22 established the 5th-generation fighter, the United States ultimately purchased only 186 aircraft, approximately half of the original USAF requirement. Defense budget pressure amidst conflicts in Iraq and Afghanistan with little F-22 involvement forced decisions prioritizing low-end conflict requirements against long-term near-peer air dominance capabilities.

After the USAF's reduced its F-22 procurement, all three U.S. military services sought to renew their aging 4th-generation fleet and advance 5th-generation capabilities. However, shrinking defense budgets drove the DoD to develop a standard joint fighter design with customized models to meet each of the services' needs. Thus, the JSF program was launched and resulted in today's F-35 program.[56] The new 5th-generation multi-role fighter program sought to replace various legacy platforms, including the existing F-16s, A-10s, F/A-18s, and AV-8B Harriers across the USAF, U.S. Navy (USN), U.S. Marine Corps (USMC), and export models for allies and partners.[57] Due to specific service requirements, the F-35 program comprised three distinct designs: USAF’s F-35A for conventional take-off and landing, USMC’s F-35B for short take-off and vertical landing (STOVL), and USN and USMC’s F-35C with an extended wingspan, robust landing gear, and arresting hook for carrier operation.[58] The program’s broad commonality initially planned for 70 percent to achieve economies of scale to reduce unit cost. However, technical complexities, a dispersed global supply chain, and engineering challenges disrupted the F-35 program, causing it to lag years behind and exceed its budget by billions of dollars over the last decade. Moreover, unit costs have ballooned from $60 million to over $100 million.[59]

Unfortunately, the integration challenges and technological barriers turned out to be much more complex. As of May 2020, the F-35 program is six and a half years behind schedule and $13.5 billion over budget.[60] Furthermore, as the actual commonality between the models decreased to approximately 25 percent, operation and sustainment costs are significantly higher than 4th-generation aircraft, positioning the F-35 program to become the most expensive DoD acquisition ever undertaken. The program is estimated to cost $1 trillion over its lifetime, a 38 percent increase from the initial 2001 estimate.[61]

The current USAF F-15C/D Eagle fleet is aging with the average jet purchased over 30 years ago. [62] Initial program requirements designed the F-15 for a 4,000 flight-hour lifespan, but the current fleet underwent a life extension program extending the airframes to 8,000 total flight hours. [63] However, a portion of the fleet has already exceeded this limit. [64] Additionally, the F-15C/D is a single-role air superiority fighter with no ability to attack ground targets. Approximately 200 of the F-15C/Ds are still in service today. Upgraded versions of the F-15, like the new F-15EX Eagle II, have already been manufactured for export in varying configurations.[65] The countries operating newly manufactured F-15 variants include Saudi Arabia, Singapore, Qatar, and South Korea designated as the F-15SA, S.G., QA,[66] and K variants.[67]

The new Eagle II systematization will likely proceed faster and easier than any previous programs due to similarities with the legacy F-15C.[68] For example, 90 percent of the ground handling equipment and 80 percent of the spare parts are the same, integrating easily into existing training, infrastructure, and logistics. [69] In addition, the avionics suite accounts for many of the F-15EX changes.[70] The electronics upgrades include a digital fly-by-wire flight control system and an active, electronically-scanned array radar.[71] Additionally, the F-15EX will possess a newly designed Eagle Passive Active Warning Survivability System (EPAWSS), replacing the old electronic self-defense system in addition to electro-optical sensors for detecting approaching missiles.[72] More importantly, the F-15EX is designed to last longer with a 20,000 flight-hours lifecycle. The cockpit instruments are completely redesigned, incorporating a single, sizeable liquid crystal display. The airframe structure is complete, and digital computer-aided design reduced the number of components while increasing load-bearing capacity.

The U.S. F-15s were all made with different versions of the Pratt & Whitney (P&W) F100, and export versions contained an engine from rival General Electric (GE). The F-15EX's GE F110-129 version does not differ significantly in the maximum 13-ton dynamometer thrust, but its performance increases to 16 tons at low altitudes near the speed of sound.[73] Simultaneously, its fuel consumption is more favorable. With the same amount of fuel, the F-15EX can fly 250 nautical miles longer than the current F-15E.

The number of conventional armaments increases by activating an external attach point under the wings. Two additional missile launcher rails are available so the plane can carry four additional missiles compared to the original variant. In addition to eight self-defense air combat missiles, the aircraft can carry spare tanks, either seven one-ton bombs or 28 small diameter bombs.[74] Additionally, the aircraft is compatible with the Sniper targeting pod for close air support missions in addition to the Legion container for long-range detection and identification of air and ground targets.[75]

Based on international demand, the F-15EX will leverage export demand to lower costs. In those countries already using U.S. aircraft (F-16 or F-15C/D/E), the transition to advanced U.S. technology is more accessible and arguably more cost-efficient. Eight countries (five in Europe) have a standardized F-16 fleet, and they have committed to purchasing 5th-generation F-35 aircraft. In addition, Israel, Japan, South Korea, Singapore, and Saudi Arabia are flying outdated versions of the F-15 and will seek to replace them with the new F-15EX.[76]

RESEARCH AND DEVELOPMENT TARGET AREAS:

Industry and government R&D are critical to enabling America's national innovation system and enables required technological advances. Targeting several areas for expedited and focused R&D allows vital technologies and capabilities that enhance the existing force structure and help create future U.S. technological advantage.

Information security, sovereignty, and intelligence protection remain a challenge. The future fight will require near-instantaneous sharing of information to define the battlespace, identify critical enemy information nodes, and strike taskings. Although connected to the Link-16 network, 5th-generation F-35s (and other stealthy U.S. aircraft like the B-2, F-22, and some unmanned aircraft) use a private network for tactical cooperation called Multifunction Advanced Data Link (MADL). This data link is directional and narrow with fast switching, making it highly secure.[77] However, 4.5-generation fighters use Link-16 for their tactical information sharing, far more modest than their stealthy successors' data sharing. This technology gap is a barrier to efficient cooperation between 5th-generation and 4.5-generation aircraft.[78]

The F-15EX will serve to bridge the gap between 5th-generation and 4.5-generation aircraft and help to augment and enhance the strike capabilities of 5th-generation fleet. However, a critical deficiency affecting near real-time coordination is the inherent incompatibility of disparate data link architectures. Therefore, the United States and its allies must develop a standard for classified information sharing to augment the Link-16 network and allow rapid data transfer between 5th-generation and 4.5-generation aircraft.

Additionally, the integration of AI and UAVs into the air domain will create new challenges and new opportunities. Norine MacDonald and George Howell address these advancements and the potential changes to the character of modern warfare: "The competition in AI and unmanned aerial vehicles (UAVs) marks the onset of the '7th Military Revolution' the states that integrate these advances first will have a prodigious military advantage."[79] The U.S. has the capital and technological resources to develop AI and UAV technology ahead of its competition.[80] Focusing on low-cost and mid-range expendable and attritable manned-unmanned teaming (MUM-T) technologies, the United States can efficiently and rapidly field autonomous wingman UAVs. These autonomous aircraft will enhance manned aviation capabilities and achieve an advantage on the modern battlefield.[81]

MUM-T mission sets will range across the spectrum of strike, reconnaissance, surveillance, target acquisition (RSTA); command, control, communications, intelligence (C3I); assault transport, and combat cargo.[82] Future MUM-T systems must perform the same broad mission sets that manned and unmanned aircraft perform today. On future battlefields with a near-peer competitor, MUM-T and loitering munition systems must possess the capability to successfully execute their tasking in an anti-access/area denial (A2/AD) environment using functional platform-based AI core and AI network "nervous system" technologies. [83][84]

The design characteristics of MUM-Ts comprise three distinct categories. First, expendables are low-cost systems priced at less than $2 million, include systems launched from fighters, bombers, or ships, and can provide sub-munition and jammer delivery or act as aerial defenders.[85] Second, attritables are larger, range from $10 million to $20 million, and operate alongside manned platforms to expand their operational reach, lethality, and performance.[86] Third, large survivable UAVs include optionally-manned aircraft and cost over $50 million. Survivable UAVs provide the same set of capabilities as manned aircraft, except the planned design includes a safe recovery to the home base on land or at sea when the mission complete.[87]

Expendables include the Loitering Munitions such as Northrop Grumman's Hero Air-Launched Effects (ALE) and Raytheon's Block 3 Coyote.[88] Attriables include DoD Medium Altitude Long Endurance (MALE) non-autonomous attritable UAV, and future concepts such as General Atomics' original MQ-9 Reaper, the RQ-170 Sentinel, Boeing's Loyal Wingman, Boeing's MQ-25 Stingray, Krato's XQ-58A Valkyrie, and Bell's V-247 Vigilant.[89] High-end, survivable systems include General Atomics' upgraded MQ-9B Sky Guardian ($100 million) and top-end Next Gen Multi-Role UAS concepts.[90]

All three categories are considered MUM-T systems.[91] Not all are entirely autonomous, but the conceptual programs across all types are trending toward teaming to address the limitations that an A2/AD environment would create for current man-in-the-loop command and control technologies.[92] For example, proximity-based wingman networking is more difficult for an enemy to deny in a distributed battlefield compared to conventional MALE and HALE terminal-based, remotely-piloted unmanned systems.[93]

It may be tempting to invest primarily in a highly sophisticated top-end survivable unmanned wingman concept to accomplish the same range of mission sets as a current 4.5- or 5th-generation fighter.[94] However, the concurrency risk for AI development is high, the cost is likely unaffordable, and the networking system to support the unmanned system in an A2/AD environment may not exist.[95] A better strategy is to exploit advancements in each of the three categories of MUM-T wingman, concentrating on more technologically mature and less costly expendable and attritable systems.[96]

Expendable loitering munitions can economically provide increased stand-off, improved lethality, and greater air-to-ground volume of fire.[97] Single mission or limited mission set attritable systems can provide more range (tanking), increased volume (by carrying additional munitions), networking (C3I and off-board processing), or high-value airborne asset protection (HVAAP) capabilities.[98]

A survivable platform that has high technological concurrency issues will incur high risk during production. Therefore, it is critical to prioritize low and mid-tier MUM-T systems to offer a more attractive acquisition strategy. In addition, cost-effective and selective mission enhancements from attritable MUM-Ts could augment existing manned systems now and bypass the high costs and delays associated with "exquisite, unmanned platform development." [99] There have been successful efforts to improve the value proposition of unmanned UAVs further by turning legacy platforms, such as mothballed F-16s, into MUM-T platforms for the B-21 and F-35.[100] The same challenges associated with AI integration, respective position keeping, and collaborative targeting will require resolution.[101] However, with a sizable, ready-to-fly preservation fleet with an existing supply chain, the DoD can significantly reduce costs by foregoing the development of new, bespoke platforms.

In the military UAV market, China is rapidly fielding "capable enough" MALE platforms to foreign militaries, and they have developed an advanced mini-quadcopter manufacturing and distribution sector.[102] However, the more immediate concern for the United States is China's advantage and progress in AI systems integration.[103] China is actively pursuing the integration and widespread military adoption of AI as part of its civilian-military innovation strategy.[104] The United States needs to compete across the board, focusing on the entire market of systems (expendable, attritable, and survivable). The DoD must prioritize both platform-centric AI core capabilities and AI nervous system networks to improve individual system performance and connect all battlefield aviation assets. Platform-centric AI core nervous system network connectivity will drive a strategic advantage against the most capable near-peer competitors.

NEXT-GENERATION AIR DOMINANCE:

Advancing technology in the air domain and related industries provides a potential opportunity for change. Agile development, digital engineering, open systems, autonomy, advanced manufacturing, and advances in UAS are paramount in future designs. However, these design characteristics may combine in ways that disrupt operational concepts, acquisition approaches, and the current industrial model. As a result, disrupting the system may drive high development costs, lengthy development timelines, and costly sustainment. Former Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics, Dr. Will Roper, championed a path to change in the air domain—an approach exemplified in the Digital Century Series concept for Next Generation Air Dominance (NGAD). Roper believes a radical shift in the air domain industry's model is necessary to implement the National Defense Strategy and retain dominance in the air domain. Roper cautions:

> How we build aircraft, that does not make sense. Approaching NGAD the way we did the F-35 would put us at great risk. It would shrink the industrial base even further and incentivize companies to get out of the fighter-building business.[105]

NGAD is a classified USAF program budgeted for $9 billion from 2019 to 2025 focused on air superiority technologies and capabilities with few details publicly available.[106] However, according to the Congressional Budget Office (CBO), "NGAD could take the form of a single aircraft [or] many complementary systems—manned, unmanned, optionally manned, cyber, electronic—forms that would not resemble the traditional 'fighter.'"[107]

Roper is a proponent of the Digital Century Series acquisition approach. This approach will produce small batches of approximately 100 aircraft, with new competitions every five to seven years; aircraft are designed to avoid depot-level maintenance and retire when obsolete. According to Roper, the goal for the Digital Century Series is to drastically shift the business model to confront current acquisition challenges, such as:

> Infrequent, expensive, existential aircraft competitions; industry 'buy-in-to-win' profit loss in design and early production; sustainment dominated business cases [with] vendor lock-in to recoup losses; large procurement lots and sole-source mods to counter threats; [and] older, difficult to retire fleets.[108]

Additionally, Roper highlights six areas required to succeed: managing a closed fighter ecosystem, rewarding design, sharing standard components and subsystems, iterating rapidly through design cycles rather than focusing on manufacturing, avoiding service life extensions or costly depot maintenance, and changing the industry's business model to increase competition and innovation.[109]

Roper expects to disrupt the traditional acquisition model by leveraging advances in the "digital trinity" of digital engineering and management, agile software, and open architecture.[110] USAF analysis suggests digital engineering alone, when applied to the legacy business model, could "drop the cost of a notional future aircraft by 10 percent over a thirty-year lifecycle."[111] One goal for the Digital Century Series is to pay an "up-front price" for a new aircraft that includes the "total price of ownership" and avoids modernization and sustainment costs.[112] According to Roper, internal USAF cost analysis suggests that this up-front pricing would be "slightly cheaper than a traditional acquisition" with potential for more significant savings.[113] The USAF conducted numerous trades and research to validate costs savings for NGAD when digital engineering combines with the Digital Century Series methodology:

> For example, fleet trades like design cycle timeline, number of aircraft per procurement lot, and entire aircraft service life; competition trades like number of competing vendors and sub-vendors, incentive structures, and business cases, especially for companies not selected for production lots; and affordability trades like essential system commonality between vendors, allowed aircraft variability between awarded lots, and workforce, facilities, and tooling sizing.[114]

The analysis suggests NGAD could reap savings of 25 percent. One notional example increases costs for development by 17 percent and production by 28 percent while lowering costs for modernization by 75 percent and sustainment by 48 percent. This new and innovative concept represents a drastic shift from sustainment to production and development.[115]

<u>DOD BUDGET UNCERTAINTY CHALLENGES:</u>

Facing a future of flatlining budgets and the weight of standing up a new service, the DoD must prioritize critical weapon systems needed to support the future 2030 force. The budgetary impacts from the COVID-19 pandemic on DoD funding are not yet known. However, it is safe to presume the DoD budget will encounter flatlined or reductions due to multiple trillion-dollar stimulus packages.[116] In addition, the United States Space Force was established in 2019 and will continue growing until it reaches full operations capability within the next five years.[117] As the newest component of the DoD, the Space Force will require initial funding and future budgetary consideration to meet new and emerging requirements.

The DoD is divided operationally into individual service components. It is customary for each service to prioritize its requirements and missions above other services to ensure they can support all facets of its doctrinal core mission areas. Therefore, each service must develop funding priorities to address core required mission areas followed by capabilities in desired mission areas. Moreover, it is critical for services to recognize that if funding is not available to meet desired mission area requirements, joint capabilities may provide interim support. First, the DoD must ensure no critical capability gaps exist in the 2030 future force. The DoD can mitigate capability gaps by providing the services with clear and concise guidance of the required and desired mission areas to prioritize them.

Additionally, if capability gaps exist, the DoD can identify interservice capabilities available to augment force across the joint spectrum of warfare via the Joint Staff. Diligent reviews and interservice coordination can help offset the possibility of capability gaps. Secondly, the reality of planning and resourcing for future combat operations is unknown. Therefore, there is potentially a plan that will not account for all future threats to national security. As a result, the DoD proactively works to counter unknown future threats. Lastly, the U.S. political landscape is potentially one of the most considerable risks facing the future force. The new administration has not yet made it clear how the DoD budget will address revised aims. In addition to a new president, lack of congressional support for budgetary funding requests could reduce the DoD budget. There is no doubt resource scarcity, challenges, and risks will force the Department to make trade-offs.

SUPPLY CHAIN CHALLENGES:

Today's defense aircraft industry relies heavily on technologies and materials, many of which were produced solely through America's domestic industrial base. Unfortunately, the current industrial manufacturing base has shifted away from domestic supply chains to one with increased reliance on foreign nations, mainly China, to supply materials critical to America's national security infrastructure. The shift away from domestic production of rare earth elements (REE) necessary to produce our most advanced technologies, specifically commercial and military aircraft platforms, has become particularly troubling in recent years.

Current debates among DoD aviation planners center around the design of future aviation platforms, ranging from reliance on unmanned systems to investing in 4.5-generation systems. However, regardless of what platforms satisfy our military aircraft 2030 future force, the dependence on REE to produce these systems will likely not subside. Additionally, the over-reliance on foreign supply chains for rare earth materials will negatively impact the U.S.'s ability to meet national security objectives, specifically in the production of 4th-, 4.5-, 5th-, and 6th-generation aircraft and related subsystems.

REE includes 15 lanthanides as well as scandium and yttrium.[118] The REE is a lynchpin in the defense aerospace industry supply chain, with application in aircraft materials such as those used in the F-35, aircraft radars, fiber-optic cables, and lasers used for precision targeting.[119] For example, according to a 2013 report from the U.S. Congressional Research Service, “Each F-35 Lightning II aircraft — considered one of the world's most sophisticated, maneuverable, and stealthy fighter jets — requires approximately 920 pounds of rare-earth materials."[120]

From the mid-1950s until almost 2000, the Mountain Pass facility located in California was the largest rare earth production and export mine globally.[121] Since there was no other domestic and very little international competition in the REE market, the Mountain Pass mine remained profitable. This single facility provided the domestic-based supply chain to support America's technological and industrial base. The Mountain Pass facility was successful because it contained a large concentration of REE, on-site production facilities, and excess capital to support manufacturing and distribution. These factors presented the market with exceptionally high barriers to entry, further solidifying the monopoly held by the U.S.-based firm. Although the United States remained the largest global supplier and producer of REE during this time, China began small-scale production in the 1950s and later developed large domestic operations in Baotou, Shandong, and Sichuan.[122]

Domestic demand of REE to support U.S. manufacturing bolstered control of the industry throughout much of the Cold War. However, after the Cold War ended, the global shift in trade policies, combined with advanced shipping and communication technologies, resulted in many firms moving their manufacturing to countries that could produce goods at a lower price.[123] Unfortunately, REE market supporting technologies also moved overseas. Additionally, the production of REE in countries with cheaper labor began to negatively impact the U.S. firms, mainly the Mountain Pass operation. With REE production moving overseas, the domestic market faltered. China now enjoys a heavy demand from domestic customers as well as locations throughout Asia. In 1986, the Chinese output of REE surpassed the United States for the first time in history.[124] According to rare earth consultant Jeffery Greene:

> Chinese rare earth-producing firms were largely unprofitable but could survive through direct and indirect support by the Chinese government. This backing enabled China's rare earth industry to continue to mine and export these materials at prices far below the actual costs of production.[125]

In 2002 the Mountain Pass mine shut down due to several environmental infractions and increased competition from China.[126] By 2008, newly developed technologies to reduce environmental impacts drove Molycorp to reopen the mine and compete with Chinese suppliers.[127] With little to no support from the Pentagon or U.S. government to revitalize the once-dominant U.S. firm, Molycorp's ownership of the Mountain Pass mine was short-lived, and in 2015 Molycorp filed for bankruptcy and sold its shares of the firm.[128] Today Mountain Pass still mines REE but maintains none of the production facilities it once did and is partially owned by a Chinese firm. Nearly all the minerals Mountain Pass now mines are shipped to China for processing, leaving the United States with no domestic supply of REE.

Unfortunately, the United States has lacked the clear long-term strategy or government support needed to compete globally in the REE market. China and the United States enjoy abundant resources for REE in the form of deposits located throughout both countries.[129] In the recent past, China focused heavily on creating a skilled labor force, a scientific base, and an expansive infrastructure to support their REE industry.[130] The market's oversaturation with Chinese REE led to foreign firms struggling to compete with China's low overhead. Chinese REE industries are also primarily supported by the Chinese government, allowing firms to focus more on long-term control of the market vice short-term profits. The United States can match

China's created conditions. However, the inability to prioritize and nurture these factors to compete with China remains a significant roadblock to regaining a standing in the international and domestic market. These factors solidified China's success in the REE industry, allowing it to become a globally dominant owner in the market.

GREAT POWER COMPETITION and GLOBAL ENVIRONMENT

For nearly 50 years, the United States has enjoyed air superiority and supremacy in conflicts and wars worldwide. Although competitors have fielded some capable and competitive platforms, the combined training, capability, size, and lethality of the United States and allies in the air domain rendered our competitors' air forces ineffective. While embroiled in the twenty-year Global War on Terror, the monopoly the United States enjoyed in the air has quickly eroded. America's adversary's capabilities started to pace the United States, but U.S. Armed Forces improved tactics, techniques, and procedures to maintain a competitive edge. However, that gap is quickly shrinking. The United States can no longer rest on more flight time or better training to ensure superiority or supremacy. Adversary military training now parallels that of U.S. forces own, and with their focus on advanced platform development, U.S. success in the current and 2030 battlespace is in jeopardy. The United States must focus on 5th-generation and 6th-generation aircraft development to maintain its advantage.

RUSSIAN MODERNIZATION AND COMPETITION:

Russia's encroachment on Eastern Europe signals a desire to gain a strategic advantage in Europe. Russia's annexation of Crimea, wide-ranging aggressive measures across Europe, and its rapid nuclear and conventional modernization highlight President Putin's regime's desire to aggressively extend geostrategic influence and increase leverage regionally and internationally.[131] Russia has initiated a significant military modernization following its suboptimal performance in the invasion of Georgia in 2008.[132] While Russia considers the military campaign successful, it highlighted several significant deficiencies across Russian military training, organization, and equipment.[133] Since the Georgia conflict ended, President Vladimir Putin has directed a substantial refresh of the Russian military to streamline command structures, increase the frequency and realism of combat training, upgrade legacy systems and introduce new-generation equipment.[134] Russia's conventional modernization efforts manifest lessons learned from deployments in Crimea and combat operations in Syria. Russia is currently developing the Su-57 5th-generation stealth ground-attack fighter aircraft designed to counter Western 5th-generation aircraft. In 2018, Russia deployed a small number of prototype Su-57 aircraft for real-world combat operational testing in Syria.[135] The success of this test led Russia to place an order for the first 12 production standard Su-57s to build the foundation for the first operational Russian 5th-generation fighter squadron.

The Russian 5th-generation fighter is the Su-57, also known as the PAK-FA or T-50. The aircraft is in its final development stages and is supposed to enter operational service soon. Although not as stealthy as the F-35, the Su-57 has an impressive internal bay payload and powerful engines with thrust vectoring, providing this jet superior maneuverability. Russia is also focusing on replacing the MiG-31 with the MiG-41 5th-generation fighter aircraft as part of ongoing Russian military modernization projects.[136] However, aerospace experts question whether the Russian government and the Russian aircraft industry have the resources to produce another 5th-generation aircraft. According to Russian news reports, the MiG-41 will employ stealth technology, reach a speed of Mach 4-4.3, carry anti-satellite missiles, and perform tasks in Arctic and near-space environments.[137] If it enters service, the MiG-41 will serve as the country's second 5th-generation fighter after the Su-57.[138]

In addition to developing 5th-generation fighter aircraft, Russia remains committed to the modernization of its strategic forces. As a result, Russia is improving its legacy systems and introducing new and "exotic" delivery systems.[139] Russia's nuclear modernization encompasses all facets of its nuclear arsenal. Strategic modernization includes new land-based intercontinental ballistic missiles (ICBM), submarine-launched ballistic missiles (SLBM), novel hypersonic weapons, and a modernized bomber force including a dual-capable (conventional and nuclear) stealth variant, nuclear-capable cruise missiles, and.[140] Russia's nuclear modernization program is evident across their triad with the development of a new version of the Tu-160 Blackjack, currently serving as a bridge to a next-generation bomber, the Tupolev PAK-DA.[141] Additionally, Russia recently deployed a new SSBN, the Borei class, employing the new SS-N-23 SLBM, with at least three operational boats and another five in various stages of construction.[142] Moreover, Russia's ICBM force is rapidly replacing older systems with two new versions of the SS-27 Mod-1 and -2, which employ a single warhead missile with road-mobile and silo-based variants and the Mod-2 utilizing multiple independent reentry vehicles.[143]

A Porter's Diamond analysis of Russia's aerospace industry illuminates a state-sponsored conglomeration of smaller entities within the air domain (see Appendix B). The Russian strategy is to consolidate small domestic enterprises into a large organization, focusing upon military sales to allies and parts and supply chain sources. Their long-term goal is to develop their commercial airline industry for more significant domestic and international sales. The demand for their helicopters is worldwide, and non-Western governments buy their military aircraft. Russia hopes to provide small parts internationally as a substitute for traditional Western supply chains. They also look to partner with China in the rare earths market. Russia generally has the resources available to manufacture aerospace equipment, although microchips can be harder to acquire. Russia has limited means to support the production of 5th-generation fighters, but they are a long way from competing with the American aerospace industry.

CHINESE MODERNIZATION AND COMPETITION:

Similarly, China is expending vast amounts of resources in an ambitious effort to modernize and transform its entire military force by 2050 to gain a strategic advantage on the world stage.[144] China is conducting a strategic island-building campaign coupled with a comprehensive restructuring and modernization of the military. As a result, by 2050, the People's Liberation Army (PLA), which consists of ground, air, naval, and nuclear forces, will possess the ability to conduct complex, joint operations. In addition, China's A2/AD strategy will provide the PLA the freedom of maneuver in the areas identified as key to their security strategy – namely the South and East China Seas.[145] These developments signal the PRC's willingness to expend considerable resources to "undertake assertive military initiatives" supporting territorial claims in the Pacific.[146] No less alarming are China's efforts to develop an overseas basing capability to support enhanced power projection capabilities. These bases will provide the future force with significant power projection capabilities for China's rapidly modernized force to include the J-20 stealth aircraft currently in development. Finally, China's rapid nuclear modernization consists of newly fielded road-mobile and silo-based ICBMs, and a highly advanced ballistic missile submarine in addition to developing the H-20, a new dual-capable (conventional and nuclear) strategic bomber.[147] For the first time, China's nuclear force modernization programs will actualize a credible nuclear triad, joining only Russia and the United States as nations that possess this capability.

Likewise, China is very interested in developing an actual 5th-generation fighter aircraft. The Chinese models include Chengdu's J-20 and Shenyang's J-31. China considers the former to be the direct competitor for Lockheed Martin's F-22 Raptor. The J-20 first flew in January 2011, and the J-20 entered limited service in February 2018. The J-20 is a reasonably sophisticated aircraft, but the aircraft's stealth and sensor fusion are still inferior to the F-22.[148] Shenyang's J-31 is under development by Chengdu corporation with approval to export specific aircraft models for sale to other nations.[149] The J-31 resembles the F-35 and strengthens the assumption the F-35 program heavily influenced the J-31 designs. [150] The J-31 airframes are full-sized airframe designs with internal weapons bays and capable of further design and development into a true 5th-generation fighter. The J-31 first flew in October 2012, but the program has slowed significantly due to technical difficulties and funding issues.[151] However, the PLA was less committed to the success of the aircraft development program and underfunded the project, so the development of the J-31 aircraft came to a halt after the initial test flights. Continued aircraft development will require significant design work on the aircraft's avionics and weapons suite, the development of maintenance and infrastructure facilities, and substantially more flight and systems testing. [152]

A close look at the Chinese aerospace industry through Porter's Diamond shows a situation like Russia, with a few notable exceptions (see Appendix B). The sector is state-sponsored, and its strategy features sales to foreign governments, parts, and a desire to break into the commercial market. However, China has more foreign military sales, a larger parts supply chain, and is farther along in commercial ventures than Russia. China is taking advantage of the U.S. hesitancy to sell military equipment to foreign governments, offering their products and parts supply unimpeded by laws or public opinion. Many governments would instead take a risk on quality for the opportunity to own platforms and equipment sooner or even at all. In addition, China is a major international supplier of parts and REE. The Chinese market has beneficial factor conditions like plentiful labor and resources. Through civil-military fusion, China may be better positioned to leverage relationships between its aerospace and technology industry to innovate across the air domain to build a competitive advantage. Thanks to its favorable market conditions and availability of resources, it has a strong foothold in the international supply market. Overall, China will produce a 5th-generation fighter given time and make inroads into the commercial segment.

POLICY RECOMMENDATIONS

FIGHTER MODERNIZATION AND INVESTMENT:

The DoD must resource the services to accelerate acquisition and expand the planned fleet size to provide a capable 4.5-generation fleet to augment and integrate with the 5th-generation fleet.

1. The DoD must accelerate 4.5-generation aircraft investments by 33 percent per year, and increasing lot buys by four aircraft per year, committing to purchasing a total of 192 F-15EX aircraft.[153]

Although the F-35 will become the dominant fighter of the USAF and U.S. allies in Europe, the Middle East, and the Pacific throughout the next decade, this process is incremental.

The force will employ an integration of 4.5- and 5th-generation aircraft. Each generation will bring its strengths to the fight and augment the limitation of the other aircraft. For example, USN F/A-18 E/Fs Super Hornets and USAF F-15EX Eagle IIs will operate alongside the F-35s until 2040. The F/A-18 E/F and the F-15EX will deliver "lethality and flexibility" and serve as a "bomb truck" to augment the limited payload of the stealth conjured F-35.[154] Although it is more challenging to train, assimilate, and coordinate, the integrated warfighting package will leverage the total force capacity resulting in significantly improved outcomes during a high-end near-peer conflict.

<u>BOLSTER R&D INVESTMENTS:</u>

The DoD must increase R&D investments to ensure rapid development of the future force. Critical R&D priorities and policies include:

1. Provide a tiered corporate tax structure to bolster innovative R&D spending.
2. Increase R&D over FY21 levels by 20 percent through the FYDP.
    a. Invest in universal communication systems
    b. Invest in low-cost attritable and expendable MUM-T systems

First, increasing defense R&D investments and future corporate tax incentives will increase industry and government R&D collaboration. The 2011 Budget Control Act (Public Law 112-25) sequestration cuts resulted in substantial R&D decreases from 2012-2015. The DoD's specific contracted R&D obligations to the industry require proper resourcing (see Appendix C).[155]

The current administration plans to reverse the 2017 corporate tax decreases partially and increase the corporate tax rate from 21 percent to 28 percent while eliminating the Foreign Derived Intangible Income R&D incentives as part of the Made in America Tax Plan for infrastructure and workforce improvements.[156] However, since the updated tax plan seeks to expand more effective R&D investment incentives, the administration should implement a tiered corporate tax structure that incentivizes corporations with a lower tax rate based on an increased percentage of R&D spending.

As a result, the DoD must continue increasing its R&D as a percentage of the overall budget to enable required advancements, looking to increase the overall R&D expenditures by 20 percent over current levels.

UNIVERSAL DATALINK COMMUNICATION SYSTEMS

Next, the DoD must bolster R&D to develop a universal data link system:

1. Appoint a single service component to lead a joint data link task force
    a. Develop a standard common data link and data link translation compatible with NATO and coalition partners
    b. Data link must provide an economical, backward compatible capability for integration into legacy systems.

Lockheed Martin demonstrated a capability to connect the Link-16 network to the MADL. A U-2 surveillance aircraft equipped with the Enterprise Open System Architecture Mission Computer version 2 (EMC2) or the "Einstein Box" established a gateway and enabled

4.5- and 5th-generation aircraft to communicate.[157] Moreover, Link-16 is already part of the NATO Standardization Agreement 5516, providing specifications for data exchange between compatible NATO systems via Link-16.[158] Appendix F details NATO and European future fighter generation. Using a third-party gateway to bridge the two networks will save the need to equip 4.5-generation fighters with new systems requiring costly updates to follow the 5th-generation development program.

LOW-COST ATTRITABLE & EXPENDABLE MANNED-UNMANNED TEAMING

Finally, AI and autonomous integrated operations are critical components to successfully modernizing the force for future near-peer conflict.[159] Therefore, the DoD must invest in AI and autonomous related technologies centered on these recommendations:

1. Prioritize developing a DoD-aligned AI “nervous system” to integrate platform-centric AI cores for a standard operating architecture.[160]
2. Develop an AI “horizontal open innovation coalition” to synchronize intellectual, financial, and engineering resources between the United States and allies[161]
3. The United States must prioritize UAV development and acquisition efforts on more economical expendable and attritable systems over higher cost survivable systems that have increased concurrency risk.[162]

Combat aircraft serve as battlefield sensors individually gathering information.[163] However, providing a holistic view of the battlespace requires the data to seamlessly transfer to other platforms in the network through a functional AI “nervous system.”[164] Big data alone will not win in future wars. It must be synthesized and aggregated promptly to create a usable real-time battlefield picture utilized by combatant commanders.[165] The DoD has concentrated and prioritized platform-centric AI core capabilities for too long; it must now integrate all platforms onto the same AI network.[166]

Combining America’s intellectual, financial, and engineering resources with its allies will rapidly develop this critical capability.[167] The United States, NATO members, Israel, Australia, India, South Korea, and Japan as an AI “horizontal open innovation coalition can counter China’s AI advances.”[168] China is building its coalition of willing partners to further its innovation and market share.[169] The United States must expand and continue its recent efforts to increase FMS and direct commercial sales with Pacific regional partners and European allies to match China’s efforts.

In this effort, the United States must re-prioritize its UAV development strategy and re-balance its funding effort to increase focus on expendable and attritable technologies.[170] The United States has long concentrated on exquisite, costly, and complex UAV systems.[171] Instead, the DoD must invest in applying the functional AI “nervous system” to connect MUM-T assets on the battlefield.[172] Harnessing economical expendable and attritable UAV aircraft will enhance 4.5-generation aircraft serving as combat multipliers. Unfortunately, China has outpaced the U.S. efforts in this area.[173] Leveraging an international coalition for innovation and properly prioritizing nearly mature “attritable” AI technology will allow the United States to close the gap.

REINFORCE RARE EARTH ELEMENTS SUPPLY CHAIN:

REE are critical to the daily operations and manufacturing of materials to support America's defense industrial base. Therefore, the U.S. government must work to restore domestic REE mining, processing, and production facilities. Consequently, it is critical to focus on the following priorities:

1. Leverage the Defense Production Act (DPA) to fund critical mining and manufacturing sites.
2. Department of State (DOS) should continue diplomatic efforts to bolster new mining and production facilities by our allies.

The United States currently maintains no domestic REE processing and production capabilities. The government must re-establish domestic mines' processing capability, purchase back the Chinese held interest in domestic mines, and develop a sustainable and long-term strategy involving commercial and military customers. Therefore, a task force chaired by the Department of the Interior and joined by other key stakeholders within the iron triangle must develop a strategic vision to restore America's REE industry. The task force's initial objective should focus on re-establishing production capabilities at the MP Materials mine in California.

In addition to supporting domestic mining corporations, the DOS should continue diplomatic efforts to bolster new mining and production facilities by our allies. Currently, progress in supporting our allies is slow and laborious. For example, Australia and Canada share the American concern with overreliance on China and are running parallel efforts to find alternative sources of REE. Mutually beneficial agreements between nations will help reduce our dependence on China and lend to improved production processes or forms of alternatives, as discussed earlier. While U.S. efforts should first focus on domestic capabilities, supporting the development of supply chains in Australia and Canada through treaties and tariff-free incentives will help bridge the gap as we transition to a more robust domestic supply chain.

CONCLUSION

As America returns to the Great Power Competition, it must posture the high-end force for combat between great powers. Russia and China both recognize the strategic advantage the United States maintains in air superiority by possessing an aircraft fleet comprised of operational 5th-generation fighter aircraft. Therefore, both Russia and China are in the advanced phases of developing domestic production capability of 5th-generation fighter aircraft and advanced air defense capabilities.[174] The U.S. air domain is relatively healthy; Boeing, Lockheed Martin, and Raytheon are strong and performing well. However, the U.S. aerospace industry has potential vulnerabilities and risks. First, the acquisition of the 2030 future force is too slow, and policymakers need to accelerate the process, enabling the U.S. to dominate in great power combat. Next, while the procurement and development phases are ongoing for the 2030 Force, the U.S. needs to invest in the modernization of their current 4th-generation fighters, making them a threat today.

Additionally, the DoD must increase R&D to develop a modern and agile high-end military force capable of meeting Russian and Chinese threats. New and innovative solutions are critical to bridging the gap between 4th-generation and 5th-generation aircraft and future 6th-generation aircraft. Advanced 4.5-generation aircraft, like the F-15EX, outfitted with universal data link communications systems, will effectively augment our 5th-generation aircraft and pair well with our allies, ensuring America retains a strategic advantage while building the future 2030 force. Moreover, low-cost and expendable MUM-T needs to be introduced into the American inventory, expanding the capabilities of the current inventory as a force-multiplier. Finally, U.S. policymakers should leverage the Defense Production Act to fund the mining of rare earth elements and encourage U.S. allies to bolster their rare earth production. These three recommendations will leave the United States best-postured to win at Great Power Combat.

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APPENDIX A: Value Net Evaluations for Select U.S. Aerospace Firms

U.S. COMPANY	CUSTOMERS	COMPLEMENTORS	SUPPLIERS	COMPETITORS
Boeing	U.S. Government Foreign Governments Airlines Aerospace Industry	Travel Industry Space Industry Tourism Military Conflict Great Power Competition	Raytheon General Electric Dassault Spirit Aerosystems Keysight	Lockheed-Martin Airbus Raytheon SpaceX Embraer
Lockheed-Martin	U.S. Government Foreign Governments	Weapons Avionics Support equipment Occupational health Armor	American Aircraft Flame Enterprises Collins Aerospace Ball Aerospace Adv. Defense Solutions	Boeing Northrup Grumman Bell Sukhoi Shenyang SAAB BAE Dassault Airbus
Raytheon	U.S. Government Airbus Boeing Defense Primes	Defense Spending Prime Contractors Travel Industry Commercial Airlines Aircraft Manufacturers	Keysight MTU Aero Engines Mitsubishi Heavy IBM UPS Aerojet Rocketdyne Howmet Aerospace	Lockheed-Martin Boeing General Dynamics Northrop Grumman BAE Systems L3

Applying the Value Net Model to **The Boeing Company** will aid in developing a holistic understanding of how the firm competes in the global market. Boeing's customers include both commercial entities and government sales. The U.S. government accounted for 31percent of the company's revenue in 2018, the last operating year before the 737 MAX and COVID impacts. Commercial sales of Boeing products include airlines globally, resulting in over 10,000 airplanes currently in service and a backlog of 5,700 airframes. International sales also remain an essential consideration for the firm, with over 150 foreign governments involved in commercial or military sales and 145,000 Boeing employees working in 65 countries worldwide.

Boeing's competitors include the largest aerospace and airplane manufacturers in the world. Boeing directly competes with Airbus regarding the company's most profitable segment, narrow and wide-body airliners. Competing defense and space firms include Lockheed Martin, Northrop Grumman, Raytheon Company, General Dynamics, and SpaceX. While these rival firms offer competition for Boeing, the company also routinely partners and teams with them. This partnering in both the defense and commercial segments allows the company to expand markets, offer a more diverse range of products, and provide or supply areas of expertise needed to win customers.

Complementors for The Boeing Company are varied based on market and segment. Boeing's Defense, Space and Security division benefits from the U.S. and allied defense spending. The global resurgence in Great Power Competition drives a need to resource American and allied forces for conflict with near-peer competitors. Moreover, future conflicts will likely occur in a contested environment that does not guarantee U.S. superiority in the Air Domain. These threats have led to a demand for modern military airframes such as Boeing's F-15EX, which offers a next-generation fighter, minus the stealth and hefty price tag of current 5th generation platforms. Commercially, complimentors include anything that increases the amount of airline travel. Before the COVID pandemic, airline travel increased, generating a demand for new and more efficient airliners such as the 737 MAX and Airbus 320neo families of aircraft.

Boeing has over 12,000 suppliers of various sizes, including 6,000 that are considered small businesses. Boeing suppliers reside in all 50 states and 58 countries. During the 737 MAX and COVID-related revenue declines, many suppliers absorbed a corresponding negative impact on their businesses. For example, one critical supplier to Boeing is Spirit Aerosystems, which supplies airplane fuselages and other aircraft parts to Boeing. With the reduction of Boeing sales, Spirit experienced a decrease in revenue that resulted in employee layoffs. As a result, Spirit has expanded its customer base, resulting in Boeing's loss of negotiating leverage with one of their major suppliers.

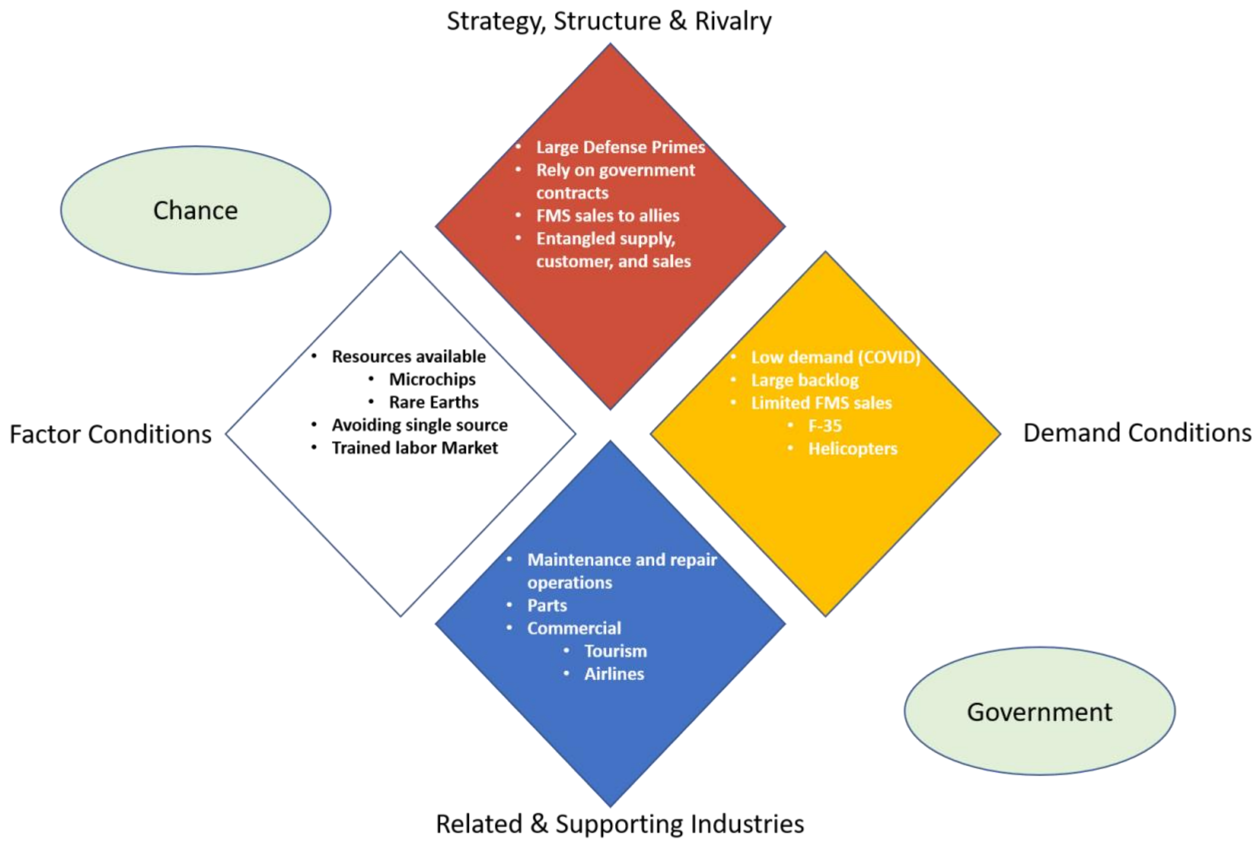
A value net analysis for **Lockheed Martin** in the air domain reveals how the firm interacts with its customers, suppliers, competitors, and complementors to create value. As a defense firm, Lockheed's relationship with the U.S. government is essential to creating value. The U.S. government is not only its primary air domain customer, but it is also the regulatory gatekeeper for exporting its product to other international customers. Lockheed faces domestic and international competition, which forces it to improve its products; in turn, this creates a perpetual market for nations to modernize their capabilities. The air domain competition with other defense industry substitutes also drives Lockheed toward continual innovation; however, Lockheed's diversification across the defense industry mitigates the effects of substitutes. Lockheed's aircraft derive much of their capability and customer value from the defense mission systems and the product evolution derived from Lockheed's vast Tier 1 supplier network. Lockheed further benefits from a competitive dual-use supplier network with overlap to the broader commercial aviation industry, particularly among Tier 2 and Tier 3 suppliers. As a defense aerospace firm, Lockheed's primary complementors are the civilian aerospace market, the broader defense industry, and the demand for national security. Viewed as a whole, Lockheed benefits and creates value from the way it integrates and leverages the interactions across the four elements of the value net: customers, suppliers, competitors, and complementors.

Raytheon is optimally aligned with the commercial market and defense markets in the areas of high by-pass turbofan engines and avionics and system integration. However, COVID pandemic restrictions limit cross-business segment activities and integration. From a U.S. government and DoD perspective, buyer bargaining power, resiliency in the supply chain, and vendors' ability to meet surge and mobilization requirements are all extant challenges. Raytheon can adequately support surge and mobilization requirements for its existing portfolio of fielded products within the civil and defense portfolios. Raytheon Technologies produces components, such as engines and avionics, for major aerospace systems. Its primary competitors include the top defense firms, including Lockheed Martin, Boeing, General Dynamics, Northrop Grumman, and BAE Systems. Merging Raytheon and United resulted in the third-largest defense contractor, trailing just behind Boeing in sales. In addition to its aerospace business, Raytheon competes for a wide variety of government contracts, including information technology, research and development, professional services, and security and protection. In 2019, the firm's largest non-DOD federal customers are the Commerce and Transportation Departments, which awarded contracts totaling nearly $300 million and $200 million, respectively.

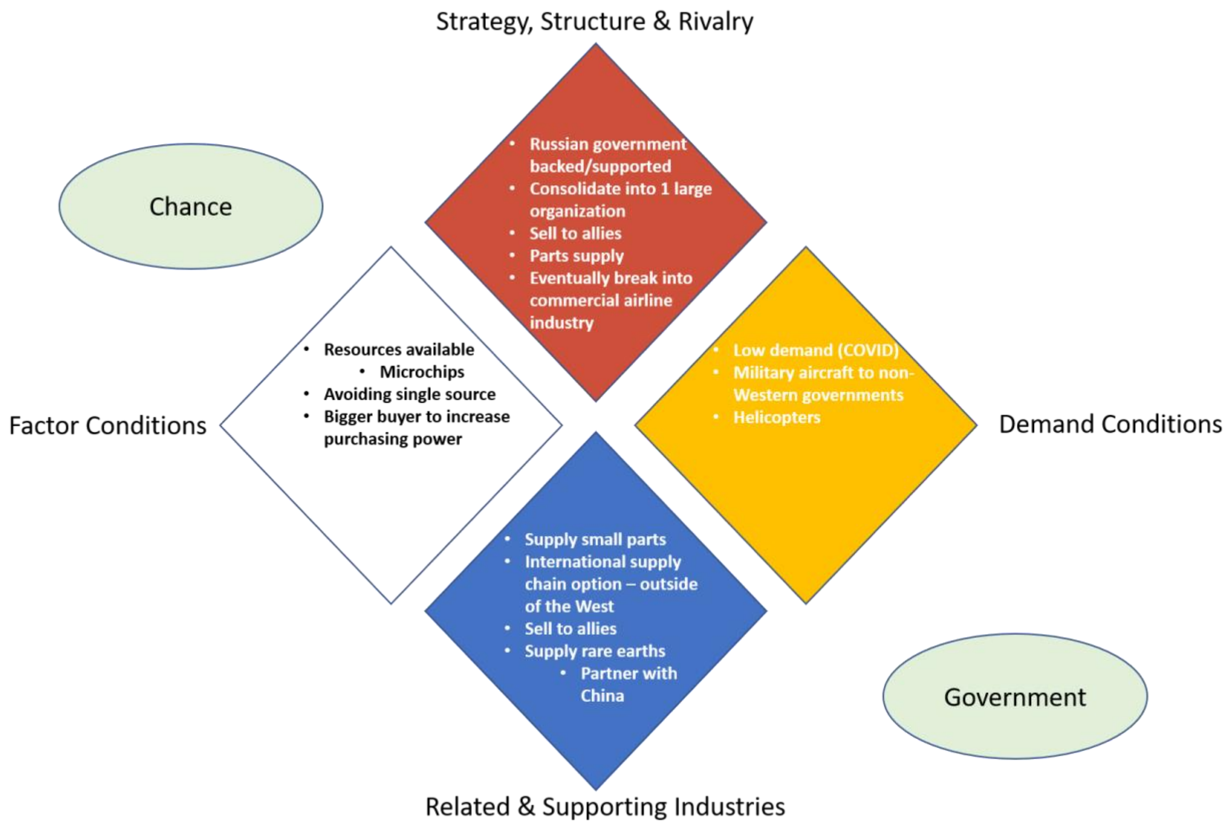
Raytheon's business is affected by three principle complementors. The largest complementor is the U.S. government, specifically the budget of the DoD. Given the enormous volume of sales received for U.S. defense articles, DOD spending authority can significantly affect the firm's business. Likewise, the fortunes of other defense prime contractors like Northrup Grumman and Lockheed Martin also affect Raytheon's business. Development and procurement contracts for these companies' products will require subcomponents furnished by Raytheon. Similarly, given its heavy involvement in aviation, the travel industry, commercial airlines, and aircraft manufacturers complement Raytheon's core business.

Finally, Raytheon's exquisite system components rely on a stable network of 345 suppliers. The largest supplier is Keysight Technologies, a U.S.-based company that manufactures electronic test and measurement equipment and software. Although its most prominent manufacturer, Keysight accounts for only 0.03 percent of Raytheon's total supply chain. Another Tier Two supplier, Mitsubishi Heavy Industries, is Raytheon's largest foreign supplier and its top Tier three suppliers. However, Raytheon's total exposure to Mitsubishi is minuscule at 0.006 percent. Notwithstanding concerns about Raytheon's access to rare earth minerals and other raw materials like cobalt, Tantalum, chromium, rhenium, and nickel, the firm has no identifiable exposure to Chinese- or Russian-controlled suppliers.

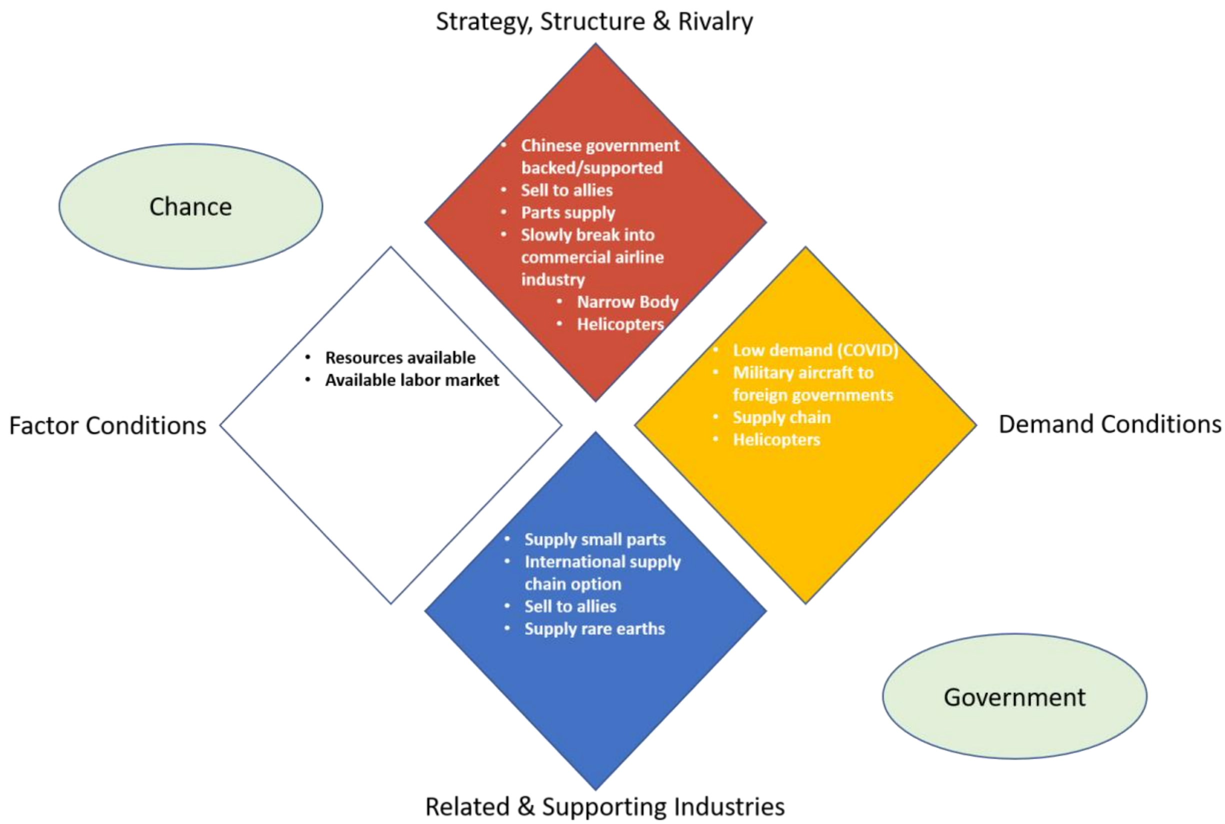
APPENDIX B: Porter's Diamond Analysis on Great Power Competitors



Porter's Diamond 1 - American Aircraft Industry



Porter's Diamond** 2* ***- Russian Aircraft Industry



Porter's Diamond *3* ***- Chinese Aircraft Industry***

APPENDIX C: UAS Categories [iii]

Category	Size	Maximum Gross Takeoff Weight (MGTW) (lbs)	Normal Operating Altitude (ft)	Airspeed (kts)
Group 1	Small	0-20	<1,200 AGL*	<100
Group 2	Medium	21-55	<3,500	<250
Group 3	Large	<1320	<18,000 MSL**	<250
Group 4	Larger	>1320	<18,000 MSL	Any
Group 5	Largest	>1320	>18,000	Any

*Above Ground Level (AGL)

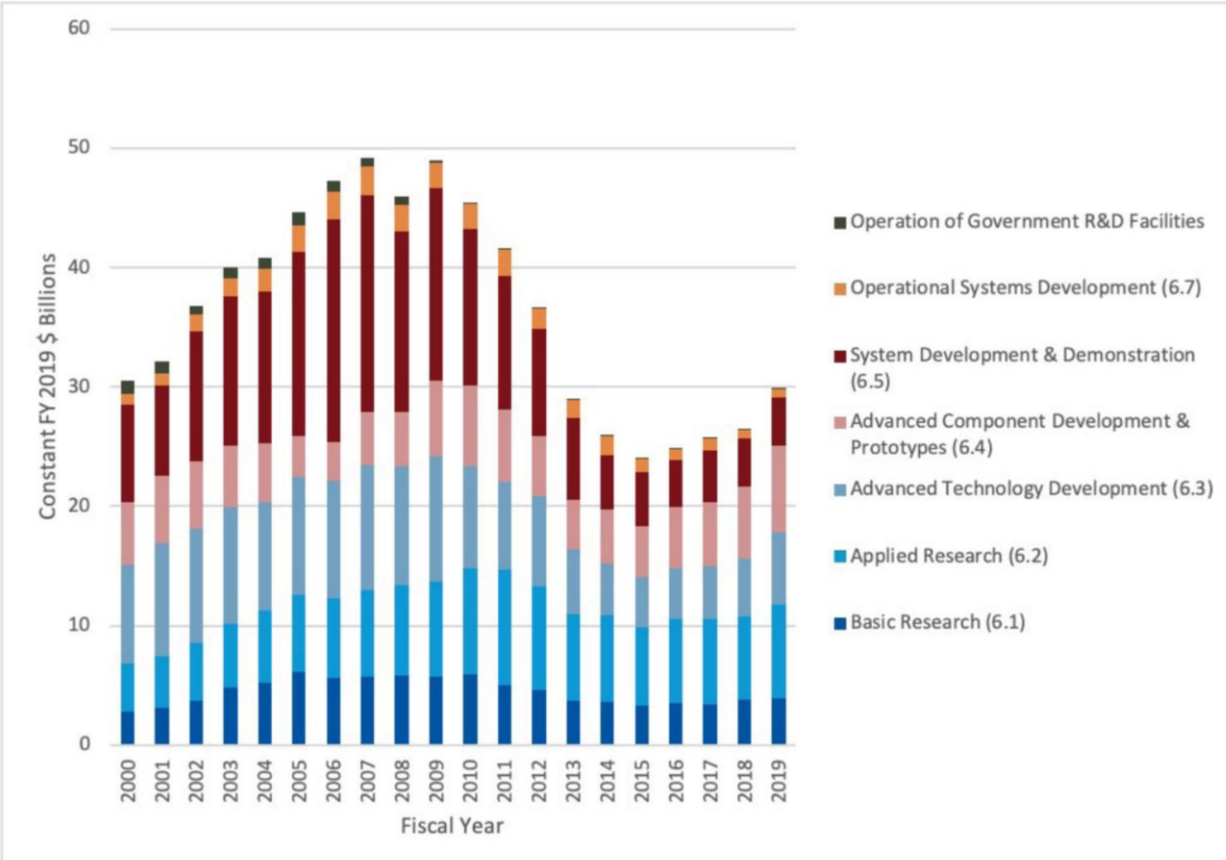
**Mean Sea Level (MSL)

Note: If the UAS / RPA has even one characteristic of the next level, it is classified in that level

Appendix D: Critical Gaps[175] [176] [177] [178] [179] [180]

Fiscal Year / GAP	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020
Design Capabilities/ Manufacturing	Critical aircraft design capabilities are facing shortages.	Steady decline in the number of defense development programs results in lack of opportunities for major design, development and integration work.	Lack of ability to sustain the design and manufacturing skills and capabilities needed for future aircraft design and manufacture.	Only four suppliers with the capability to manufacture large, complex, single-pour aluminum and magnesium sand castings.	Only four suppliers with the capability to manufacture large, complex, single pour aluminum and magnesium sand castings. Only two qualified sources exist for DoD fuel cells, also referred to as fuel "bladders".	Fast growing, game-changing technologies, including artificial intelligence, autonomy, additive manufacturing, and advanced robotics, could become key enablers for the aircraft sector.
Human Capital	Pool of young and cleared engineers available to replace retirement-aged workforce is dwindling.	Opportunities for hands-on, real-time transfer of knowledge to young workforce has been very limited.		Aircraft sector is experiencing a shortage of workers with critical hardware and software design capabilities due to large retirement populations.	Maintaining the capability to innovate becomes increasingly challenging as skilled aerospace, mechanical, electrical, and software engineers leave the workforce.	Prime defense contractors have announced their plans to lay off and/or furlough their workforce (e.g., Boeing 30K, Raytheon 20K, GE 13K) resulting in loss of engineering skills and knowledge.
Supply Chain			Lower tier suppliers, foreign dependency, single or sole sources, and financial viability continue presenting a risk for the aircraft sector.	Consolidation of prime suppliers in the sector has expanded into the sub-tiers of the supply chain, creating additional risks for single or sole source vendors.	Consolidation of prime suppliers in the aircraft sector.	The coronavirus pandemic further aggravated supply chain issues in the aircraft sector as many defense Suppliers experienced facility shutdowns, high absenteeism, furloughs, and financial Instability.

APPENDIX E: DoD R&D Contract Obligations, 2000-2019[181]



APPENDIX F: NATO/European New-Generation Weapons System Program

NATO allies of the United States have initiated a 5th- and 6th-generation aircraft development program labeled the New Generation Weapon System (NGWS). The primary goal is to develop a joint European fighter-bomber that unifies the stand-alone developments currently underway in Europe, drawing on its technological expertise in developing and producing 4th-generation aircraft. This European aircraft development program signals Europe's emerging commitment to secure independence and self-reliance. Moreover, if successful, this program will provide European nations with freedom from American industry and procurement.[182]

The NGWS will serve as a “traditional” manned aircraft capable of operating in collaboration with robotic aircraft and drones for various missions. NGWS will integrate with several systems, including the long-range FCAS (Future Combat Air System) medium-range UAV, which will also work with satellites and winged missiles. Developments currently mark the new weapon system as FCAS. According to experts, the project launched by Germany and France is still in its infancy. There is no noticeable difference between the 4th-generation or 4.5-generation F-15EX or the real 5th-generation F-35.[183] The development of FCAS relies entirely on the European aerospace industry again, drawing on the experience of French Rafale, German-British-Italian-Spanish Typhoon, research from Dassault, Airbus, Thales, and Indra, and later on its multinational manufacturing capacity.[184] FCAS, as a 6th-generation aircraft and weapon system, aims to replace the current 4th-generation European air force types (Rafale, Typhoon, F-16, EF-18, JAS-39) in 2035 and create competition for the 5th-generation F-35 and the U.S. Next Generation Air Dominance (NGAD) aircraft.[185]

The creation of the new generation fighter, the FCAS, which is in the preliminary design stages, is the next logical step in European aircraft development.[186] In addition to the stealth design (or reduced visibility in the official name) and the super-cruising mode, the 6th generation fighters will possess even higher data rates, huge data processing capacity, military I.T. cloud solutions, and artificial intelligence. Thus, they will centrally control a drone swarm or process information from multiple reconnaissance assets into a target. Furthermore, their unique and common feature will be suitable for both pilot and automatic/remote control modes.[187]

Their primary mission is to operate in highly denied environments with continuous collaboration between the platforms, and the master is the fighter. The FCAS will utilize a cross-platform collaboration between the fighter and the remote carriers.[188] In the NGWS/FCAS project, the €1.2 billion commitment is only a fraction of the total cost of developing the prototype and the new technologies needed for it, at an estimated cost of €6 billion.

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