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Perceived Gap within the United States Marine Corps' Integrated Air Defense System (IADS) Capability

March 2024

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Naval Postgraduate School

Prepared for the Naval Postgraduate School, Monterey, CA 93943

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ABSTRACT

This thesis identifies a significant capability gap in the United States Marine Corps' (USMC's) Integrated Air Defense System (IADS), particularly in medium-altitude and medium-range air defense systems. The research points to the USMC's reliance on a singular, short-range, and low-altitude organic air defense system with the FIM-92 Stinger missile. It discusses the challenges posed by peer adversaries such as the People's Republic of China (PRC) and Russia with advanced air power capabilities that threaten U.S. control of the air in contested spaces. Despite updates to doctrine such as the Expeditionary Advanced Base Operations (EABO) concept and new systems like the Marine Air Defense Integrated System (MADIS), which counters small UAS and low flying threats, the USMC lacks organic capabilities against medium-altitude and medium-range air threats. This thesis uses multi-criteria decision analysis (MCDA) to aid in the analysis of alternatives (AoA) and highlights how acquiring an air defense system that can use either the Tamir interceptor or the AIM-9X missile can bolster the USMC IADS.

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LIST OF ACRONYMS AND ABBREVIATIONS

AADC	Area Air Defense Commander
AAF	Adaptive Acquisition Framework
ACE	Air/Aviation Combat Element
AGL	Above Ground Level
AMD	Air and Missile Defense
AMDC	Air and Missile Defense Commander
AoA	Analysis of Alternatives
AOR	Area of Responsibility
C2	Command and Control
CAMM	Common Anti-Air Modular Missile
CBA	Capabilities Based Assessment
CCDR	Combatant Commanders
CDD	Capabilities Development Document
CD&I	Combat Development and Integration
CJCS	Chairman of the Joint Chiefs of Staff
CONOPS	Concept of Operations
C-RAM	Counter-Rockets, Artillery, and Mortars
CWC	Composite Warfare Commander
DAS	Defense Acquisition System
DCA	Defensive Counterair
DOTmLPF-P	Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities-Policy
EABO	Expeditionary Advance Base Operations
EW	Electronic Warfare

FMF	Fleet Marine Force
FoS	Family of Systems
GBAD	Ground Based Air Defense
GCC	Geographic Combatant Commander
HE	High Explosive
HIMARS	High Mobility Artillery Rocket System
HVU	High Value Units
IADS	Integrated Air Defense System
ICBM	Intercontinental Ballistic Missile
ICD	Initial Capabilities Document
IFPC	Indirect Fire Protection Capability
INDOPACOM	Indo-Pacific Command
ISR	Intelligence, Surveillance, and Reconnaissance
JCIDS	Joint Capabilities Integration and Development System
JFC	Joint Force Commander
JFACC	Joint Force Air Component Commander
JLTV	Joint Light Tactical Vehicle
LAAB	Littoral Antiair Battalion
LAAD	Low Altitude Air Defense
LOCE	Littoral Operations in a Contested Environment
MADIS	Marine Air Defense Integrated System
MAGTF	Marine Air Ground Task Force
MANPADS	Man-Portable Air-Defense System
MCDA	Multi-Criteria Decision Analysis
METL	Mission Essential Task List

MTA	Middle Tier Acquisition
NASAMS	National Advanced Surface-To-Air Missile System
NDS	National Defense Strategy
NMESIS	Navy/Marine Corps Expeditionary Ship Interdiction System
NMS	National Military Strategy
NSS	National Security Strategy
OCA	Offensive Counterair
PLAAF	People's Liberation Army Air Force
PPBE	Planning, Programming, Budgeting, and Execution
PRC	People's Republic of China
RADC	Regional Air Defense Commander
SADC	Sector Air Defense Commander
SAM	Surface-to-Air Missile
SCS	South China Sea
SecDef	Secretary of Defense
SIF	Stand In Forces
TM EABO	Tentative Manual for Expeditionary Advance Base Operations
UAS	Unmanned Aerial System
UAVs	Unmanned Aerial Vehicles
UNCTAD	United Nations Conference on Trade and Development
U.S.	United States
USG	United States Government
USMC	United States Marine Corps
WEZ	Weapons Engagement Zone

I. INTRODUCTION

The thesis explores the current capabilities and systems within the Marine Corps' air defense assets, highlighting gaps in coverage crucial for effectively deterring pacing threats. It also explores the air and missile threats posed by peer and near-pear adversaries with a focus on manned and unmanned aircraft. Additionally, it offers recommendations on weapon systems and munitions that can be integrated into the Marine Corps’ current arsenal to bridge these gaps in air defense capability. This comprehensive analysis aims to equip senior leaders with a robust framework for informed decision-making. It is designed to aid in the acquisition of essential air defense weapon systems that bolster deterrence measures and extend organic surface to air engagement ranges and altitudes, ensuring the Marine Corps’ adept execution of sea control and sea denial operations, aligning with the principles of EABO.

The endorsement of the tentative manual for Expeditionary Advanced Base Operations (EABO) signifies a paradigm shift from prolonged land warfare, marking the Marine Corps' transition back into its naval roots. This shift was underscored when the Chief of Naval Operations and the Commandant of the Marine Corps approved the concept for EABO. This concept “seeks to address challenges created by potential adversary advantages in geographic location, weapons system range, precision and capacity while creating opportunities by improving our own ability to maneuver and exploit control over key maritime terrain” (United States Marine Corps [USMC], 2021, p. 15). In this context, the discussion of maritime terrains inherently encompasses sea control and sea denial operations. As defined by the Joint Chiefs of Staff, “Sea control operations are those operations designed to secure use of the maritime domain by one’s own forces and to prevent its use by the enemy. Sea control is the essence of sea power and is a necessary ingredient in the successful accomplishment of all naval missions” (Joint Chiefs of Staff [JCS], 2021, p. I-3).

In addition to being able facilitate the use of the maritime domain by one’s own forces or being able to deny the use of that domain by one’s adversary, naval operations also rely on air superiority. The Joint Chiefs of Staff define air superiority as a level of dominance in the air that allows a group to carry out its activities at any time or place without disruption from enemy threats (JCS, 2018b). With the overarching objective to reincorporate the Marine Corps into naval forces and refine its maritime capabilities, it is essential that the Marine Corps be able to support the broader naval force in executing sea control and sea denial operations and in establishing air superiority. The effectiveness of these operations hinges on the Marine Corps' ability to deter enemy forces. According to the Joint Chiefs of Staff, "Deterrence influences potential adversaries not to take threatening actions. It is a state of mind brought about by the existence of a credible threat of unacceptable counteraction. Deterrence requires convincing those adversaries that a contemplated action will not achieve the desire result by fear of the consequences" (JCS, 2021, pg. 1-3). The relevance of these definitions to this research is of the utmost importance, as they align with the consensus at all command levels that the Marine Corps is instrumental in sea control and sea denial operations. However, to fulfill this role effectively, the Marine Corps must possess the capability to deter adversaries' ability to maneuver through the maritime domain. Within the scope of this research, the terms pacing threats, peer, and near-peer adversaries are used interchangeably with the People's Republic of China (PRC) and Russia.

A. ASSUMPTIONS

Due to the timing and nature of this project, we make multiple assumptions about the political situation, advancement of technology and manufacturing, acquisitions of planned capabilities and systems, and the overall role the USMC plays in National Security. There is a need to assume that the United States continues to seek diplomatic and economic means to negotiate and influence other nations and state actors to ensure the security of American citizens and the interests of the United States. We also assume military capabilities continue to serve as a deterrence within the competition continuum in hopes to remain below the level of armed conflict with peer and near-peer adversaries. We assume, that due to the rapid nature of technology advancements and the manufacturing and proliferation of systems such as UAS drones and long-range precision strike munitions, that obtaining and retaining sea control and air superiority is no longer guaranteed for U.S. military forces.

B. PROBLEM

Based on joint operational doctrine and the current USMC planning guidance, Marine Corps leaders acknowledge a capabilities gap within the Marine Corps' integrated air defense system (IADS) (Berger, 2020). From the outset of General Berger's Force Design 2030 efforts, he states that the Marines have a current shortfall in capabilities within the IADS specifically referencing medium to long-ranges air defense systems (Berger, 2020). Currently, the USMC possesses only one organic surface to air weapons system which is limited to short range and low altitude engagements. While the key advantage to the EABO concept is the distributed nature of our forces, the Joint Chiefs of Staff highlight that peer adversaries often possess robust capabilities allowing them to project air power throughout the contested battlespace and challenge our ability to gain and maintain control of the air (JCS, 2018b). In "Missing: Expeditionary Air Defense," author Ben DiDonato emphasized that through updated doctrine, such as the EABO concept and using emerging systems, such as Marine Air Defense Integrated System (MADIS), provides the Marine Corps with the ability to counter threats such as small, unmanned ariel systems (UAS) and modern missiles. The USMC, however, still lacks an organic capability to defend against traditional aircraft and larger UASs (DiDonato, 2022). The critique highlights a major concern because portions of the Fleet Marine Force (FMF) are expected to operate within contested areas and possibly inside of the adversaries' weapon engagement zone (WEZ). This means the capability to defend forces from aerial threats is necessary for survivability. Considering the situation currently faced in the Indo-Pacific Command (INDOPACOM) theater, the PRC possesses the ability to use manned and unmanned aircraft not only for offensive operations, but also intelligence, surveillance, reconnaissance, and targeting activities. Without the ability to provide organic defensive capabilities at adequate altitudes and ranges, those Stand-in Forces remain vulnerable (USMC, 2021a).

By applying principles from the Defense Acquisition System and the Joint Capabilities Integration and Development System, this thesis analyzes capabilities gap within the USMC's current air defense systems. We conduct a capabilities-based assessment to verify that the capability gap in the USMC's IADS does exists and establish a link between the strategic and service level guidance and doctrine, recent service manuals, USMC Concept of Operations for air defense, threats from possible adversaries, and the need to identify potential non-materiel or materiel solutions.

This thesis seeks to answer the following questions: Primary research question: Is there a capabilities gap within the USMC's IADS? Secondary research question: How can the gap be filled? What are the effectiveness ratio values of various materiel options to close the gap? Through our research, we verify the existence of a capabilities gap within the USMC's IADS, specifically the ability to deter medium range and medium altitude threats. Additionally, we analyzed several air defense systems that are already fielded that can satisfy the gap in air defense coverage. Lastly, we propose criteria to evaluate the air defense weapon systems against each other and find that missiles such as the Tamir and AIM-9X increase capability, but at different costs, allowing decision makers to determine if increases in cost are worth the increases in specific capabilities.

C. METHODOLOGY

In the upcoming chapters, we use a combination of qualitative and quantitative analyses by exploring the threats emanating from the PRC and Russia, evaluate the capabilities of current and past air defense systems employed by the U.S., and conduct a capabilities-based assessment (CBA) to verify the existence of a capability gap. The CBA's operational context is derived from national strategy, as well as Joint and Service level doctrine, aiming to assess the necessity for augmenting the capabilities of air defense systems currently in use by the USMC, particularly in the context of countering adversarial threats. We assess possible non-materiel solutions through a Doctrine, Organization, Training, materiel, Leadership and Education, Personnel, Facilities-Policy (DOTmLPF-P) analysis to see whether a change to any of these can fill the gap. If a materiel solution is needed, then an analysis of alternative (AoA) of potential materiel options is explored using the multi-criteria decision analysis (MCDA) and cost effectiveness analysis (CEA) framework. These tools allow us to analyze criteria and characteristics of various air defense systems, weighting them against specified criteria and mission requirements necessary to deter adversarial forces in an EABO environment.

The development of a detailed MCDA and CEA equips us with the insights needed to conduct an AoA that offers informed recommendations for establishing new requirements to satisfy a capability gap within the Marine Corps' air defense arsenal. We identify and analyze several air defense systems along with the medium-range missiles those systems can employ. While all the systems presented as alternatives could be used to enhance the Marine Corp's organic air defense capability, not all of them fit into modern operational doctrine or guidance. Two of the most cost-effective missiles this research identifies are the Tamir and AIM-9X which can increase the USMC's ability to deter aerial threats at greater ranges and altitudes in comparison to the currently used FIM-92 Stinger missile.

D. FRAMEWORK

Chapter I, Introduction, began by presenting how senior leaders throughout the chain of command recognize that a capability gap exists within the Marine Corps' IADS. Next, the chapter highlighted why the capability gap is a problem for the United States to remain in competition with peer and near-peer adversaries. The chapter ends by highlighting the motivation for the thesis project and the research methodology used to address the research questions.

Chapter II, Literature Review, introduces and expounds upon studies, articles, and publications that focus on current and future operating environments for the Marine Corps and U.S. Joint Forces. This section offers an in-depth threat analysis of both the PRC and Russia, with a particular focus on their economic and political influence on the global and regional levels as well as their recent efforts into modernizing their military tactics and air and missile capabilities. Chapter II examines foundational military documents, ranging from the Executive to the Service level and further examines Joint Publication on Joint Operations and Countering Air and Missile Threats and Marine Corps-specific documents and doctrines, such as Force Design 2030, the EABO manual, and the Concept for Stand-In Forces.

Chapter III, Capabilities Based Assessment, follows the process steps outlined in the Manual for the Operation of the Joint Capabilities Integration and Development System. Steps three through seven provide an analytical basis for identifying current capabilities and the associated capability gap this thesis aims to highlight. We cover the operational context to include applicable threats and relevant Service concepts and the Ground Based Air Defense (GBAD) Concepts of Operations (CONOPS). We identify current capabilities based on systems currently possessed by the Marine Corps and illustrate the gap between those capabilities and the threat. We then associate this gap to risk to mission and risk to force regarding current and future operating concepts. We then address both non-materiel and materiel solution approaches to close this capabilities gap.

Chapter IV, Analysis of Alternatives through Multi-Criteria Decision Analysis, focuses on potential materiel solutions and conducts an AoA using a MCDA process. Through our MCDA model, we seek to identify viable expeditionary air defense capabilities for the Marine Corps. The specific materiel solutions that we analyze are either produced and utilized by the U.S. military or by allied countries. This allows us to compare system attributes and identify feasible options to mitigate the capabilities gap. The process contains an analysis of current and emerging weapon systems that would meet the Marine Corps criteria of being expeditionary and survivable. By adding cost effectiveness analysis component of the different weapons systems allows for follow on sensitivity analysis and builds the framework for the acquisitions strategy.

Chapter V Conclusion summarizes the thesis, highlights the findings, and presents recommendations that satisfy the problem. This chapter restates the assumptions and limitations, while providing opportunities for future research.

E. SUMMARY

This concludes Chapter I, Introduction. The chapter included an overview of the thesis' purpose, academic research problem, and the scope of the project by highlighting a capability need that must be fielded to bridge the gap in the Marine Corps' current IADS to successfully deter peer adversaries air and missile capabilities. Chapter I also identifies the necessary assumptions that were made to complete the research. The final topics of discussion in the chapter were the research methodology used to complete the report and the framework used to provide an overview of this thesis project's structure. Chapter II, Literature Review, discusses recent changes to guiding doctrine and policies, peer threats and capabilities, along with documents and government reports associated with force structure realignment, stand-in forces.

II. LITERATURE REVIEW

This chapter provides a literature review covering topics ranging from strategic and operations guidance and doctrine, potential threats and their capabilities, air defense from a U.S. Joint Forces and USMC perspective, and the use of MCDA in supporting an AoA within the Defense Acquisitions System. Attention is given to the growing threat of the PRC and Russia as peer and near-peer adversaries, the need to bolster air and missile defenses at the joint force level, and the need to bolster air and missile defenses at the service level for the Marine Corps. The literature review covers the escalating threat from China and Russia concentrates on their respective military modernization activities. China's focus is primarily on enhancing its air force and Intercontinental Ballistic Missile (ICBM) capabilities (Chase et al., 2009). In contrast, Russia, while already boasting a robust air force and missile program, has significantly increased its investment in UAS platforms (Myre, 2023). The reviewed literature highlights the economic motivations driving these two nations and explores the strategic importance of their geographic locations. A section of the review focuses on statements, and documents from the Joint Chiefs of Staff and senior Marine leaders emphasizing the need to revamp and bolster U.S. air and missile defenses. Specific capability details for each country's aircraft, missiles, and weapon systems are kept at the UNCLASSIFIED level.

A. BACKGROUND

In response to global challenges and adversaries like the PRC and Russia, President Biden and the 2022 National Defense Strategy emphasize the urgency of strengthening U.S. deterrence, especially against threats undermining democracy and international order (Biden, 2022; U.S. Department of Defense, 2022). Military leaders, recognizing the evolving nature of threats, proactively adapted U.S. defense strategies. General Neller and Admiral Richardson signed the Littoral Operations in a Contested Environment (LOCE) document in 2017, highlighting the importance of naval integration and capability enhancement in contested littoral environments (Neller & Richardson, 2017). General Berger's 2019 guidance took this strategic foresight further by aligning the Marine Corps with the 2018 NDS and focusing on transforming the USMC into a more agile naval expeditionary force. His Force Design 2030 initiative highlights the need to improve expeditionary air defense systems and extend their operational range to counter sophisticated threats (Berger, 2020, 2021, 2022, 2023). The subsequent publications, The Tentative Manual for Expeditionary Advance Base Operations and A Concept for Stand-in Forces, in 2021, lay out strategies for operating in contested zones and enhancing air and missile defense capabilities within adversaries' weapons engagement zones (WEZ) (USMC, 2021a, 2021b; USMC, 2023). The Ground Based Air Defense (GBAD) Concept of Operations (CONOPS) also advocates for investing in modern air defense weapon systems to tackle peer and near-peer air threats (Combat Development and Integration [CD&I], 2020). These efforts contribute to a broader evolution in U.S. Naval doctrine, aiming to keep the Marine Corps and the Navy prepared and capable of deterring threats, maintaining a forward, adaptive posture amid global security challenges (USMC, 2023).

B. THREAT ANALYSIS: PEOPLE'S REPUBLIC OF CHINA

The PLA was largely overlooked by the U.S. Military for decades, but this is no longer the case. Chase et al. asserts "Much attention has been devoted to China's massive build-up of SRBMs opposite Taiwan, but Beijing is making equally impressive strides in the modernization of its theater and strategic conventional and nuclear missile forces" (Chase et al., 2009, para. 3). Furthermore, the authors claim China is also advancing in the creation of missiles equipped with conventional weapons, potentially granting the PLA a powerful means to target regional bases and U.S. aircraft carriers near Taiwan. (Chase et al., 2009). China's overhaul of the PLA Air Force (PLAAF) extends beyond the modernization of strategic missiles. Cozad & Beauchamp-Mustafaga (2017) note in a recent study:

> Since its inception, the PLAAF has primarily focused on territorial defense, with little emphasis on issues beyond China's mainland. However, since 2014, under the leadership of Chinese President and Commander-in-Chief Xi Jinping, there has been a marked shift towards expansionism out into the South China Sea. The PLAAF is now aligned with PLA efforts to defend China's maritime interests, reflecting a significant enhancement in its over-water capabilities. This reorientation is part of a broader strategy to prepare for military confrontations, especially in the maritime domain, by shaping the

> security environment to achieve victory without direct combat. Key initiatives in the PLAAF's current modernization drive include the development of long-distance maritime power projection, enhanced strategic conventional deterrence, and fortified maritime strike capabilities (p. 7).

The extensive modernization of China's missile arsenal and the transformation of the PLAAF underscores the evolving threat faced by the United States. China's emphasis on enhancing its over-water and maritime strike capabilities, along with its strategic focus on long-distance power projection, signifies a robust, multifaceted military force capable of operating beyond its borders. These advancements not only amplify China's regional influence but also challenge U.S. military dominance in the Asia-Pacific region. As China continues to close the technological and operational gaps, its ascent as a pacing threat necessitates a comprehensive reevaluation and adaptation of U.S. defense strategies to safeguard its interests and allies in an increasingly contested environment.

Heath (2023) explains the PRC has maintained a quest to modernize and expand their military over the decades. The PRC committed to increasing their defense budget by about 10 percent annually from 2000 to 2016. However, that budgetary growth has steadied between roughly five to seven percent annually (Heath, 2023). These numbers translate to an estimated $230 billion defense budget in 2022 (Heath, 2023). This growth in defense budget and spending has raised concerns among many U.S. military leaders and DOD officials. These modernization efforts translate into the PRC gaining advancements in capabilities including fifth generation aircraft, unmanned aerial vehicles (UAVs) ranging from small to extended endurance, long range precision strike munitions, and large Naval vessels to include aircraft carriers and submarines. Heath goes on to write that:

> Surging defense budgets have yielded an increasingly lethal and capable People's Liberation Army (PLA). U.S. officials have steadily warned of an eroding military advantage in the face of rapid PLA gains. During his service, U.S. Air Force Maj. Gen. Cameron Holt stated that China was acquiring weapons at "five to six times" the rate of the United States. For some, the buildup alone provides reasons to fear conflict. Observers point to the rapid modernization as unambiguous evidence that China is preparing for war with the United States. In March 2021, Admiral Philip Davidson, then-head of U.S. Indo-Pacific Command, warned that the PRC could take military action against Taiwan by 2027. Admiral Michael

> Gilday, the chief of Naval operations, added that he can't rule out a PRC attempt to invade as early as 2023 (Heath, 2023, p. 1).

Policy Analyst, Kimberly Hsu, writes that amid the PRC's pronounced military modernization lies a significant spotlight on their advancements in UAS technology. As China's deep dive into UAS equipment offers a glimpse into its future warfare strategies, emphasizing the utilization of autonomous and remote-controlled systems (Hsu, 2013). Figure 1 shows a list of China's operational UAS platforms by function.

Function	Developer/ Manufacturer	Designator	Est. Date in Service
Target Drones. Used for target training			
Target drone, air sampling for nuclear tests	Nanjing University of Aeronautics and Astronautics (based on Soviet La-17)	Chang Kong-1	Late 1970s
Target drone, cruise missile simulation	Nanjing Research Institute on Simulation Technique/PLA General Staff Department (GSD) 60th Institute[10]	Tian Jian 1	~2005
Target drone, multipurpose	Northwestern Polytechnic University (precursor to Xi'an ASN Technology Group)	Ba-2	Early 1970s
Target drone, naval anti-aircraft artillery	Xi'an ASN Technology Group	Ba-9	?
MINI: Micro, Mini, and Short-Range. Ranges from handheld platforms with a range of less than 10 km to those with a range of approximately 70 km			
Micro and mini models for reconnaissance	Beijing Wisewell Avionics Science and Technology Company	AW series	Mid-2000s
Short-range rotary wing reconnaissance, communication relay[11]	Nanjing Research Institute on Simulation Technique/PLA GSD 60th Institute	Z series, (I-Z, Z-2, Z-3, Z-5)	Early 2000s
Short- and medium-range reconnaissance	Nanjing Research Institute on Simulation Technique/PLA GSD 60th Institute	W/PW series (W-30, W-50, PW-1, PW-2)	?
TACTICAL: Medium-Range. Approximate max range 150 km-200 km			
Medium-range, real-time reconnaissance	Xi'an ASN Technology Group	ASN 104/105	Late 1980s
Medium-range multirole	Xi'an ASN Technology Group	ASN 206	Mid-1990s
Medium-range endurance multirole	Xi'an ASN Technology Group	ASN 207	Early 2000s
Medium-range, naval use	Xi'an ASN Technology Group	ASN 209	~2011
TACTICAL: Medium-Range, antiradiation. Targets ground-based radar, approximate max range 500 km			
Antiradiation destruction of ground-based radar	Israel-exported: Israel Aerospace Industries	Harpy	Early 2000s
STRATEGIC: Low-altitude deep penetration. Max range 2500 km, max endurance 3 hours for reconnaissance missions			
Low-altitude deep-penetration reconnaissance	Beijing University of Aeronautics and Astronautics (based on U.S. Firebee)	WZ-5 (exported as CH-1)	~1981
STRATEGIC: Medium-altitude long-endurance. Reported max range 2400, max endurance 40 hours for reconnaissance and other missions			
Medium-altitude long-endurance multirole	Beijing University of Aeronautics and Astronautics	BZK-005	Mid- to late 2000s

Figure 1. A list of China's operational UAS platforms by function, Source: Hsu (2013)

This analysis gains importance as long-range UASs from mainland China enhance ISR capabilities. These improvements significantly boost the PRC's over-the-horizon targeting capabilities. The PRC’s investments in shorter-range UAS allow for improvements in ISR capability on targets in Taiwan and in the Taiwan Strait. Lastly, China’s UAS industry is “developing medium altitude, long endurance (MALE) [UAS] and high altitude, long endurance (HALE) [UAS]” (Hsu, 2013, p. 5). These advancements in UAS technology greatly improve the PRC’s ISRT capabilities and pose an increased risk to friendly forces.

Chase et. al. (2009) asserts that the modernization of the PLA in China, particularly in missile capabilities, signifies a strategic shift in the Indo-Pacific region. The PLA has been actively developing conventionally armed missiles capable of targeting regional bases and U.S. aircraft carriers, especially near Taiwan. Their deployment of road-mobile ICBMs and advancements in nuclear-powered ballistic missile submarines underscore China's commitment to bolstering its nuclear force's reliability and credibility. Furthermore, Beijing's acceleration of medium- and long-range missile tests, combined with their focus on medium-range ballistic missiles equipped with advanced targeting systems, poses significant challenges for American strategists. This is especially evident in the defense of Taiwan, where the rapid expansion of China's short-range missile arsenal aims to deter and complicate potential U.S. military interventions. These developments not only enhance China's regional defense capabilities but also have the potential to reshape the balance of power in the Indo-Pacific, challenging longstanding U.S. dominance and introducing new geopolitical dynamics (Chase et al., 2009). Figure 2 shows China’s ballistic and cruise missile arsenal with associated ranges and Figure 3 shows the DOD’s estimate of capacity for each threat based on the type of system.

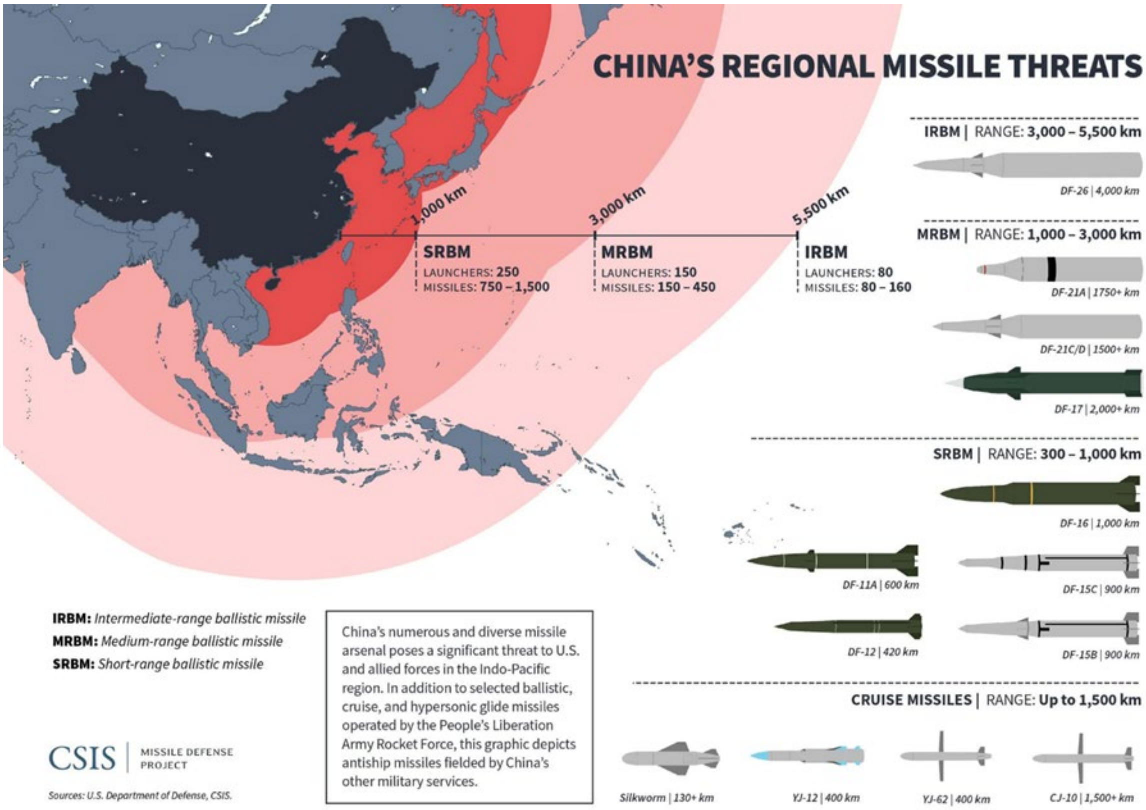

Figure 2. An overview of China's ballistic and cruise missile arsenal, Source: Center for Strategic and International Studies [CSIS] (2021).

DOD Estimates For China's Rocket Forces

China's Rocket Force 2019

System	Launchers	Missiles	Estimated Range
ICBM	90	90	>5,500km
IRBM	80	80-160	3,000-5,500km
MRBM	150	150-450	1,000-3,000km
SRBM	250	750-1500	300-1,000km
GLCM	90	270-540	>1,500km

China's Rocket Force 2018

System	Launchers	Missiles	Estimated Range
ICBM	50-75	75-100	5,400-13,000+ km
IRBM	16-30	16-30	3,000+ km
MRBM	100-125	200-300	1,500+ km
SRBM	250-300	1,000-1,200	300-1,000 km
GLCM	40-55	200-300	1,500+ km

Source: DOD annual report on Chinese military developments, 2018 and 2019 *Annotations: Kristensen/Korda, FAS 2019*

Figure 3. DOD estimates for China's ballistic and cruise missile capacity based on system type, Source: Kristensen & Korda (2019).

The expansion of China's military capabilities highlights the critical need to scrutinize its strategic objectives. China's unique geographical position as a central hub in global trade routes accentuates its pursuit of military superiority, enabling it to exert significant influence over regional and international commerce. Recognizing and understanding these advancements is not only crucial for regional stability but also for maintaining a balance in global military dynamics.

Over the past thirty years the Peoples Republic of China (PRC) has experienced unprecedented economic growth. Their economy now ranks number two in the world, trailing only the U.S. (The World Bank, 2023). In fact, "since China began to open up and reform its economy in 1978, GDP growth has averaged over 9 percent a year" (The World Bank, 2023, para. 1). However, the PRC's economic growth has slowed recently and their "high growth based on investment, low-cost manufacturing and exports has largely reached its limits and has led to economic, social, and environmental imbalances. Reducing these imbalances requires shifts in the structure of the economy from manufacturing to high value services, from investment to consumption, and from high to low carbon intensity" (The World Bank, 2023, para. 3).

The country's strategic geography and its position as the world's number two economy, places the PRC in one of the most influential locations globally. The South China Sea (SCS) is one of the most transited waterways in the world for global trade. The United Nations Conference on Trade and Development (UNCTAD) estimates that one third of global shipping transits the SCS (CSIS, 2017). One third of global shipping translates to roughly $5.3 trillion worth of goods for the global economy transiting the SCS, $1.2 trillion of which relates to trade with the U.S. (CSIC, 2017).

Furthermore, Moulton highlights how the PRC is overt regarding their country's desire to influence and control the SCS and:

> has dredged and reclaimed thousands of square feet in the SCS over the past eight years. These artificial islands house sophisticated infrastructure including runways, support buildings, loading piers, and satellite communication antennas. Beijing's ability to deploy aircraft, missiles, and missile defense systems to any of these islands expands its power projection by 620 miles, enabling China to strike any of the other claimants. The regional countries' reliance on SCS resources to

> feed and provide income to their people is the primary reason why Chinese military expansion is causing angst among the United States and its Indo-Pacific allies. Beijing's SCS actions improved the PRC's ability to influence the world economy. Washington D.C. and U.S. allies are concerned with the PRC's growing capability to affect the strategically important SCS shipping lane. Additionally, roughly one-third of global seaborne oil and more than one-half of global trade in liquefied natural gas traveled on the SCS sea lines of communication. In 2012, the International Energy Agency published the World Energy Outlook, which assessed that 90 percent of Middle Eastern fuel exports would be destined for Asia by 2035 and travel through the SCS (Moulton, 2022, para. 3).

The PRC's expanding military force, strong global economy, and strategic geographic location place it in a position to influence global trade and politics. This places the PRC at odds with the U.S.'s strategic interests in the region creating a delicate competitive environment. Both countries want to satisfy their own national interests, but neither wants to tip the scales into full-scale war.

C. THREAT ANALYSIS: RUSSIA

In Europe, Russia continues to act in an adversarial way threatening the interests of the United States and its allies alike over the past several decades. Russia has pushed forth major modernization efforts in the post-Cold War era. Since the dissolution of the USSR in 1991, Russia's military has undergone a significant transformation, emerging from the shadows of the Cold War. In the initial years following the USSR's dissolution, the Russian armed forces faced challenges marked by a significant reduction in force and an inability to institute modernizing policy. However, from 2007-2008 onwards, a noticeable enhancement in operational capacity and readiness marked a turning point (Palmer, 2015).

The occupation of Crimea and support for ethnic Russians in Ukraine exemplify this increased military capability. In the realm of command and control, Russia initiated substantive reforms to elevate its military efficiency. The previously established military districts and theater commands gave way to four military districts—West, East, Center, and South—each paired with Joint Commands (Palmer, 2015). This restructuring aimed at fostering enhanced coordination and responsiveness in diverse military scenarios.

Moreover, consolidations within the air force and aerospace defense forces were executed to counter the burgeoning threat posed by conventional precision-strike capabilities globally and fortify support for Russian strategic nuclear forces. The transformation extended to force structure, with a strategic shift from Soviet-era divisions to smaller, more agile brigades. Although these brigades are equipped with post-Soviet equipment, there are concerns about their limited combat potential. The re-establishment of tank and motorized rifle divisions in the Western Military District underscores a revived focus on large combined-arms formations, positioning Russia to deter or repel adversaries effectively.

A significant aspect of Russia's military transformation has been the emphasis on training and exercising (Palmer 2015). Palmer goes on to say "Russian armed forces' manpower is being partly professionalized to reduce dependence on conscripts, create a cadre of well-educated professionals, and form a pool of well-trained and combat-effective formations" (Palmer, 2015, p. 5). Annual theater-level joint exercises like *Zapad, Vostok, Kavkaz*, and *Tsentr* are instrumental in testing and enhancing the capacity for large-scale combined-arms operations (Palmer, 2015). The incorporation of strategic nuclear forces in these exercises reflects a holistic approach to military readiness. The readiness and responsiveness of the Russian military have been amplified through the implementation of large-scale "snap alert" exercises. The rapid deployment of significant troop numbers over extensive distances underscores enhanced mobility and operational readiness. These developments are especially pertinent given the geopolitical tensions and the need for rapid and effective military responses. The economic challenges, including international sanctions and domestic economic constraints, have not markedly deterred Russia's military modernization trajectory.

A new State Armaments Program, covering 2016-2025, is expected to continue the trend of modernization, underscoring the nation's commitment to elevating its military capabilities (Palmer, 2015). The evolution of Russia's military is deeply rooted in identity and ideology, intertwined with domestic politics and foreign policy. The military transformation signifies not just a shift in operational capabilities but also reflects Russia's strategic posture, characterized by a determination to assert its stance in the global arena. This transformation, amid economic and geopolitical challenges, underscores Russia’s resilience and adaptability, elevating its profile as a military power and reflecting its broader strategic, ideological, and economic imperatives in the contemporary global landscape. These comprehensive developments highlight Russia's progression and underscore the nation's resurgence as a potent military force in the international arena (Palmer, 2015).

In February 2022, Russia launched an extensive air campaign into Ukraine, sparking expectations of a conventional warfare scenario characterized by waves of manned fighter jets targeting key locations with bombs and munitions. The assumption, held by most of the world, was that Russia's larger air force would quickly overpower Ukraine's smaller counterpart, securing air superiority in the process (Myre, 2023). Despite the significant disparity in size, Ukraine managed to deliver substantial blows to Russian fighter jets and helicopters in the war's initial months, defying the odds (Myre, 2023).

This unexpected resilience from the Ukrainian forces prompted Russia to alter its approach. They transitioned to employing unmanned aerial systems (UAS) drones and missile strikes as a means of targeting Ukrainian assets, while seemingly reserving their human pilots for a later phase of the conflict (Myre, 2023). This strategic adaptation was predicated on the expectation that Ukraine's air defense missile supplies would eventually dwindle, allowing Russian fighter jets to recommence their attacks with diminished threats (Myre, 2023).

As the conflict intensified, Ukraine began to increasingly rely on UAS and drones for a diverse array of applications, encompassing both combat and non-combat roles (Myre, 2023). One notable example was the deployment of Draganfly drones, designed to transport pharmaceuticals and essential medical supplies to locations that were otherwise inaccessible to conventional ambulances (Myre, 2023).

Both Russia and Ukraine employed a variety of UAS models in this conflict, some of which are shown in Figure 4. Among those used by Russia were the SHAED-136 and the ORLAN-10. Ukraine, on the other hand, utilized drones such as the BAYRAKTAR TB2 and the SWITCHBLADE 300. Notably, both sides have been reported to employ the MAVIC 3 model, with the situation on the battlefield becoming so convoluted that neither Russian nor Ukrainian soldiers could easily differentiate between friendly and hostile drones (Khurshudyan & Ilyushina, 2022).

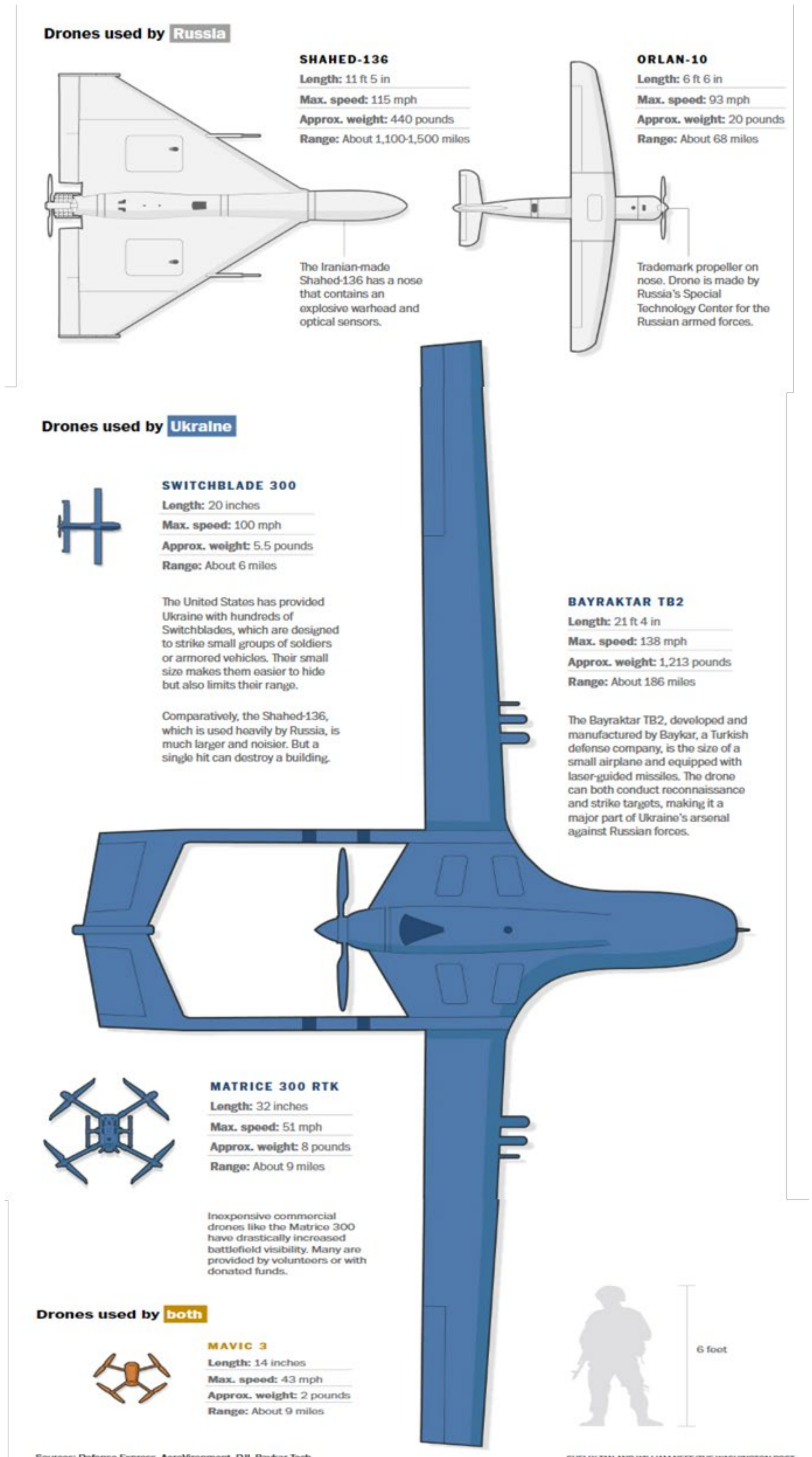

Figure 4. Example of Drones used in 2022 War Between Russia and Ukraine, Source: Khurshudyan & Ilyushina (2022).

The proliferation of UAS at relatively low costs has had a profound impact on the nature of contemporary warfare. UASs offer advantages like versatility and cost-effectiveness, which not only extend their strategic utility but also significantly reduce the risk to human pilots. Yagil Henkin has conducted an extensive analysis of Russia's use of manned aircraft, UASs, and non-lethal air support within the context of the ongoing conflict in Ukraine. This research included an in-depth comparison of recent operations with historical conflicts, shedding light on the unique aspects of the current engagements (Henkin, 2022).

The war in Ukraine, characterized by substantial casualties on both sides, has been particularly intense when juxtaposed against contemporary small wars and counter-insurgency operations. Nevertheless, these numbers, though high in the contemporary context, are not unprecedented in the broader scope of historical conflicts (Henkin, 2022). One noteworthy aspect of this fight is the fact that neither Russia nor Ukraine has managed to establish and maintain air superiority, despite Russia's numerical advantage in combat aircraft (Henkin, 2022). This situation has led to considerable losses for the Russian side, particularly to Surface-to-Air Missile (SAM) systems (Henkin, 2022).

Both sides have had to grapple with modern air defense systems, yet this has not deterred the occurrence of successful strikes. Ukraine's effective use of UASs and drones, in particular, has proven to be a cost-effective strategy for conducting lethal attacks and performing Intelligence, Surveillance, and Reconnaissance (ISR) operations (Henkin, 2022). With time, it has become increasingly evident that UASs are vulnerable, particularly when exposed to ground fire and electronic countermeasures, factors that significantly depend on their operating altitude. Nevertheless, given the estimated cost of roughly $10,000 per unit, UASs continues to provide an economical means of conducting lethal attacks and ISR operations (Henkin, 2022).

Furthermore, the ongoing conflict in Ukraine has underscored the evolving landscape of modern warfare, as Henkin's research references modern "Western" militaries and their historical reliance on precision-guided munitions and air superiority. This raises the possibility that future operations involving the United States and other potential adversaries may encounter scenarios where the establishment and maintenance of air superiority are formidable challenges. In such cases, there may be a notable increase in the utilization of UASs and traditional manned aircraft in unconventional roles. Additionally, there could be an elevated demand for Surface-to-Air Missiles (SAMs), including large-scale systems and man-portable air-defense systems (MANPADS), as a means to counter adversary aviation assets (Henkin, 2022).

Vladimir Putin's deep dissatisfaction with the dissolution of the Soviet Union in 1991, which led to Ukraine's independence and the independence of thirteen other countries, diminishing Russia's status as a global power, motivated his decision to invade Ukraine (Warren, 2022). From the outset, Putin and many Russian elites refused to fully accept Ukraine's newfound independence (Warren, 2022). Over the subsequent three decades, several factors exacerbated Putin's frustration and led to his desire to regain control over Ukraine. These factors included policy differences between Russia and the West, geopolitical events like NATO expansion, Western interventions such as the U.S. invasion of Iraq, and Ukraine's pro-European movements (Warren, 2022). Putin initially attempted a peaceful integration of Ukraine into Russia's sphere of influence, as he had done with Belarus, but when these efforts failed, he turned to military force.

Furthermore, Putin's strategy has included the use of "false flag" operations and misinformation tactics, which have been a part of Russia's standard repertoire (Warren, 2022). These tactics aim to justify Russia's actions and influence not only Western media but also the perceptions of the Russian public (Warren, 2022). Putin has employed similar strategies to justify previous military interventions, such as Russia's invasion of Georgia in 2008 and its invasion of Crimea in 2014 (Warren, 2022).

Moreover, Putin's actions in Ukraine have received mixed reactions from the Russian people. Although seizing Crimea was a politically popular move, polling data proved that there was far less enthusiasm and support for conflict in Ukraine (Warren, 2022). As with most countries, there is the potential for a "rally around the flag" effect when a nation goes to war. However, support for the invasion may wane over time, particularly if it results in prolonged warfare and a rising number of casualties. Additionally, the impact of sanctions on the Russian economy may contribute to a decline in enthusiasm for the war (Warren, 2022).

The Russian invasion of Ukraine represents his determination to restore Russian influence, reject Ukraine's sovereignty, and respond to what Putin views as provocative actions by Western powers (Warren, 2022). This move is part of his broader goal to reestablish Russia as a dominant regional power and counter perceived Western encroachment into the post-Soviet territory. While the Russian people's views on the war remain mixed, with the potential for evolving sentiments, Putin's use of "false flag" tactics and misinformation further complicates the situation and influences perceptions of the conflict (Warren, 2022).

Under the leadership of Vladimir Putin, Russia invaded Ukraine in 2022 with a multifaceted set of motives, including the desire to reestablish Russian influence regionally and globally, and prominently, to seize control of Ukraine's vast natural resources. As Robert Muggah pointed out in his article on "Russia's Resource Grab in Ukraine", Ukraine possesses an array of valuable resources, including energy, minerals, and agriculture, making it an attractive target for resource-driven expansion.

It is worth noting that Russia's capture of Crimea in 2014 was a pivotal moment in this pursuit. Muggah and Dryganov highlight this importance by stating: "Russia's seizure of Crimea in 2014 and much of the rest of Ukraine's Black Sea coat this year means that Moscow now has control over an estimated 80 percent of Ukraine's massive offshore hydrocarbon deposits, including over 37 billion cubic meters of natural gas" (Muggah & Dryganov, 2022, para. 5). This strategic acquisition significantly enhanced Russia's access to critical energy resources, reinforcing its influence in the European energy market. Moreover, Ukraine's eastern regions and its section of the Black Sea, which include areas now threatened with Russia control, hold a significant share of Ukraine's conventional oil, natural gas, coal production, and reserves. Nearly three quarters of Ukraine's natural gas and virtually all of its coal production and reserves are concentrated in these regions, granting Russia substantial leverage in these energy resources (Muggah & Dryganov, 2022).

Additionally, Ukraine's significance extends to the realm of industrial minerals and rare earth metals. "Ukraine has commercially relevant deposits of 117 of the 120 most-used industrial minerals across more than 8,700 surveyed deposits" (Muggah &

Dryganov, 2022, para. 8). The global importance of these resources cannot be overstated, as they are crucial in various industries, including manufacturing, electronics, and green energy technologies. Rare earth metals have become increasingly critical due to their role in various advanced technologies, such as electric vehicle battery production.

Furthermore, Ukraine's agricultural sector plays a pivotal role in feeding the world. Ukraine is a major supplier of essential food to all corners of the world, including corn, wheat, barley, and sunflower seed and safflower oil (Muggah & Dryganov, 2022). “In 2021, Ukraine supplied 12 percent of global wheat, 16 percent of all corn, 18 percent of all barley, and nearly half of the world's supply of sunflower seed and safflower oil, with agricultural exports totaling almost $28 billion” (Muggah & Dryganov, 2022, para. 11). These exports are crucial for ensuring food security and meeting the dietary needs of a vast population, particularly in developing countries across Asia, Africa, and the Middle East.

Russia's invasion of Ukraine is underpinned by its pursuit of control over Ukraine's abundant natural resources. These resources encompass energy, minerals, and agriculture and offer Russia a strategic advantage in global commodity markets. The capture of Crimea in 2014 further solidified Russia's access to critical energy resources, while Ukraine's industrial minerals and rare earth metals are of immense importance to advanced industries. Simultaneously, Ukraine's agricultural sector is a linchpin in global food supply chains, emphasizing the resource-driven motivation behind the conflict (Muggah & Dryganov, 2022).

The ongoing war in Ukraine, sparked by Russia's extensive air campaign in early 2022, defied initial expectations of a conventional warfare scenario. Ukraine's unexpected resilience prompted strategic adaptations from both Russia and Ukraine, primarily using unmanned aerial systems (UAS) and drones in both direct conflict and in support activities. This battlespace highlighted the evolving nature of modern warfare and the increasing importance of UAS in contemporary operations between highly modernized adversaries where control of the battlespace, to include air and maritime areas, is not guaranteed. Additionally, Vladimir Putin's motivations for invading Ukraine were rooted in a desire to restore Russian influence, gain control Ukraine's vast natural resources, and counter perceived Western encroachment in the region. This multifaceted conflict underscored the complex interplay of military, geopolitical, and economic factors in today's global landscape.

D. AIR AND MISSILE DEFENSE: JOINT FORCE

The strategic value of air and missile defense in contemporary warfare is critical and indispensable. The evolution of threats beyond traditional combat zones and the enhancement of enemy capabilities highlights a landscape where the sovereignty of airspace and the ability to counter inbound threats are paramount. The Joint Force Commander (JFC) plays a pivotal role in orchestrating a robust defense mechanism that not only ensures the safety of friendly skies but equally curtails the operational freedom of adversaries. Integrating offensive and defensive counterair operations and the synergy between various components of the Joint Force and Geographic Combatant Commander (GCC) are integral to fostering a defense mechanism that is as impenetrable as it is responsive.

In Joint Publication 3-0: The JFC is tasked with neutralizing threats in the airspace to safeguard forces. This allows friendly forces increased mobility, maneuverability, and protection, while restricting the enemy's operational freedom. This is achieved through counterair operations that blend offensive and defensive strategies to gain control over the airspace and offer protection by incapacitating or eliminating threats in the airspace at all stages. The execution of the counterair mission is a collective effort, requiring the contribution of each component of the joint force to ensure operational success. Service capability and force structure are intentionally designed to rely on all components, aiming to augment complementary effects and reduce vulnerabilities. Given its joint and interdependent nature, every component of the joint force is typically assigned roles in support of counterair operations. To streamline command and ensure efficient planning and execution, the JFC usually appoints an Area Air Defense Commander (AADC) and a Joint Force Air Component Commander (JFACC) to centralize planning and direction while allowing decentralized execution in countering air and missile threats (JCS, 2018b). Additionally, joint combat typically concentrates on operations within designated operational areas (OAs), threats can emerge from beyond these areas, and even outside a GCC's Area of Responsibility (AOR). Specifically, the enemy's missiles and long-range aircraft can be challenging, necessitating a defense integration both within and beyond the GCC's AOR. The GCC is responsible for integrating air and missile defense within the theatre. The Secretary of Defense (SecDef) supports this by establishing command relationships for global missile defense and other operations that span across AORs. The Commander of U.S. Strategic Command (CDRUSSTRATCOM) plays a coordinating role in the planning of global missile defense, involving other Combatant Commanders (CCDRs), service component commanders, and U.S. Government (USG) departments and agencies as needed. This coordinated effort aims to integrate offensive counterair (OCA) and defensive counterair (DCA) operations, along with other required capabilities, to achieve the JFC's intended outcomes (JCS 2018b).

Joint Publication 3-01: Countering Air and Missile threats contains a Counterair Framework developed and published by the Joint Chiefs of Staff. The structure for the Counterair Framework is built on combining OCA and DCA operations, executed by all qualified components of the joint force, to address both air and missile threats. Typically, OCA operations aim to control the adversary's airspace and inhibit the initiation of threats. In contrast, DCA operations focus on neutralizing or minimizing the impact of threats in the airspace that try to infiltrate or assault through allied territory (JCS, 2018a).

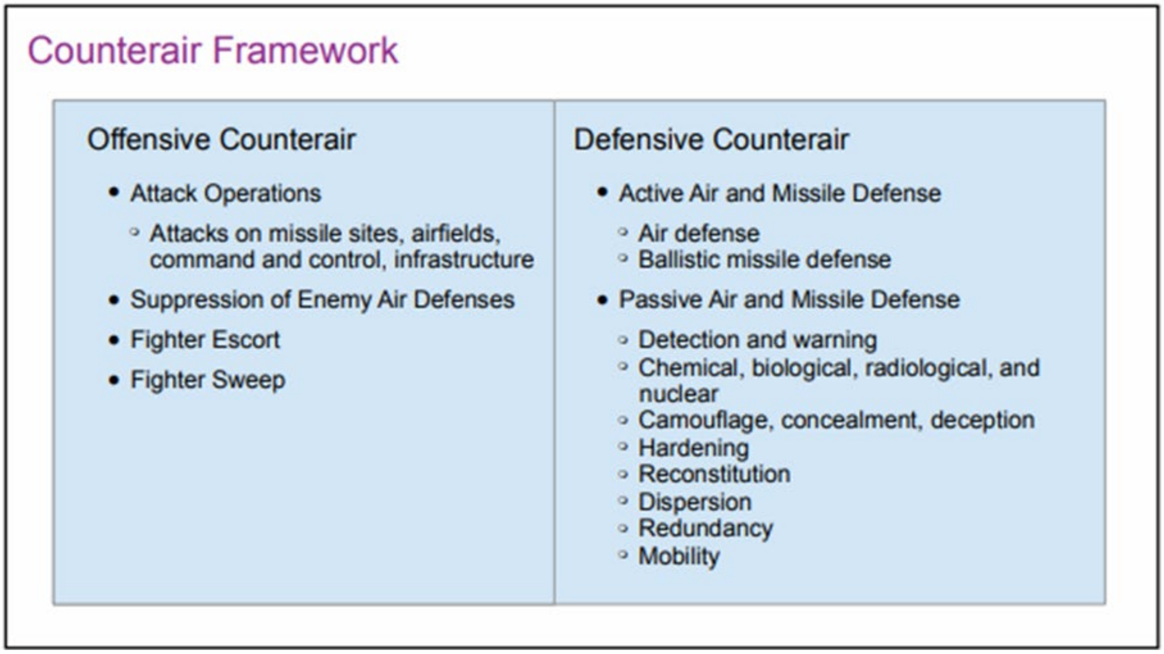

Figure 5. Counterair Framework from Joint Publication 3-01: Countering Air and Missile Threats, Source: JCS (2018a).

The complexities of air and missile defense, as highlighted in the Joint Publications, is indicative of a military doctrine that is evolving, responsive, and comprehensive. The role of the JFC, supported by an array of specialized forces and strategic frameworks, underscores a reality in which the defense responds to threats by preempting, managing, and turning them into strategic advantages. Each piece of the puzzle, from the counterair operations to the roles of the AADC and JFACC, and the overarching guidance of the SecDef and CDRUSSTRATCOM, culminates in a defense mechanism that is not just about protecting friendly skies but is equally about asserting dominance and control. In this dynamic landscape, the joint and interdependent nature of air and missile defense is not just a strategic imperative but a testament to the multifaceted, multi-dimensional nature of modern warfare where threats are as varied as the mechanisms to counter them. The adaptive and integrative approach of the joint force ensures that the United States remains steps ahead, turning potential vulnerabilities into fortified strengths. Each iteration of defense, each strategic move is about ensuring that the nation's air and missile defense is not just a response mechanism but a strategic tool in the broader theatre of national security.

E. AIR AND MISSILE DEFENSE: USMC

As global military landscapes evolve, the U.S. Marine Corps faces the challenge of redefining and enhancing its air and missile defense protocols. In 2021, while serving at Combat Development and Integration (CD&I), General Smith, now Commandant of the Marine Corps, endorsed the TM EABO. The signing of this manual underscored a strategic shift the Marine Corps would take towards intensifying the role of the littoral force in multi-domain conflicts, particularly forward deployed within the WEZ, see Figure 6. This evolution is marked by the integration of complex defense mechanisms, efficient communication networks, and the strategic maneuvering of Air and Missile Defense (AMD) resources. Concurrently, the revelations by General Neller and Admiral Richardson in "Littoral Operations in a Contested Environment" (2017), and General Berger's emphasis in the 38th Commandant's Planning Guidance and Force Design 2030 update, accentuate the urgent need to address capacity challenges, reinvigorate sea control strategies, and bolster defenses against increasingly sophisticated threats in the era of missile warfare.

In 2017, General Neller and Admiral Richardson published Littoral Operations in a Contested Environment. Both asserted that the Navy and Marine Corps face capacity challenges in key regions, potentially requiring additional assets for effective air and missile defense in the presence of land-based precision weapons. The underutilization of Marine Air-Ground Task Forces (MAGTFs), the post-Cold War composition of the surface force, and the risk to high value units (HVUs) in complex geographies illustrate these challenges. MAGTFs, designed primarily for power projection ashore, have untapped potential in sea control. Post-Cold War, sea control capabilities were de-emphasized, but the rise of sophisticated sea denial strategies necessitates a shift to an offensive approach. HVUs are crucial, and their loss could severely impact operations, making it unwise to deploy them in complex inshore operations where the adversary can maximize weapon systems. A tactically defensive orientation is expected in littoral operations, and to shift to a more offensive stance, strong screening, and scouting capabilities are essential, complemented by lower-end units to accept calculated risks (Neller & Richardson, 2017).

In the 38th Commandant's Planning Guidance released to the Marine Corps; General Berger stated:

> We must continue to prioritize investments in modern, sophisticated air defense capabilities to include those capabilities which are required by our forward-deployed stand-in forces for persistence inside the adversary WEZ. Regardless of capability enhancements to our overall lethality, if our forward deployed forces are unable to persist inside the WEZ, then they will likely be irrelevant – if not potential liabilities. We are witnessing the emergence of an era of missile warfare and must ensure our forces possess the capabilities required to mitigate those threats for themselves, the fleet, and joint force. We must expand our research on this issue, and investigate the merits of directed energy capabilities, as well as counter-precision guided munitions (C-PGM) systems for our forward deployed forces (Berger, 2019, p. 14).

The Commandant's quote highlights the critical role that a modernized integrated air and missile defense system plays in contemporary conflicts. His words encapsulate the essence of this thesis, conveying the urgency of modernization in a succinct manner. This same sense of urgency characterizes his discussions with Congress, ensuring that the significance of updating U.S. defenses is universally acknowledged. The time has come to implement a strategy for procuring the systems essential for empowering stand-in forces to thrive in a distributed operational landscape.

The TM EABO highlights the critical roles and responsibilities entrusted to the littoral force, emphasizing its imperative task to maintain a presence within the WEZ amidst a multi-domain fight. A specific focus is laid on air and missile defense, where the manual emphasizes the need for synergized efforts with the Air and Missile Defense Commander (AMDC), who often serve as the Sector Air Defense Commander (SADC) or the Regional Air Defense Commander (RADC), and the Area Air Defense Commander (AADC). Within this collaborative framework, the littoral force emerges as a pivotal entity, spearheading initiatives to safeguard key areas and assets as depicted in Figure 6. A comprehensive strategy underlines these defense operations, summarizing the formulation of a kill chain, identification, and protection of critical assets, and delegation of authority to specialized air-control entities. An efficient communication network facilitating real-time information exchange among various defense components is integral to this strategy. Defense mechanisms are characterized by a blend of joint and organic surface-to-air weapons, spanning short to long ranges. These are complemented by a network of local and external sensors, ensuring timely alerts and warnings. Strategic allocation and maneuvering of AMD resources are essential. There is a need for a detailed approach that matches the imperatives of operational efficacy and asset protection. It necessitates the frequent relocation of AMD assets to mitigate vulnerabilities while ensuring an unwavering defense of key zones. Moreover, the littoral force's adeptness at integrating with external networks and its competence in overseeing Naval and joint operations are underscored as critical attributes (USMC, 2021b).

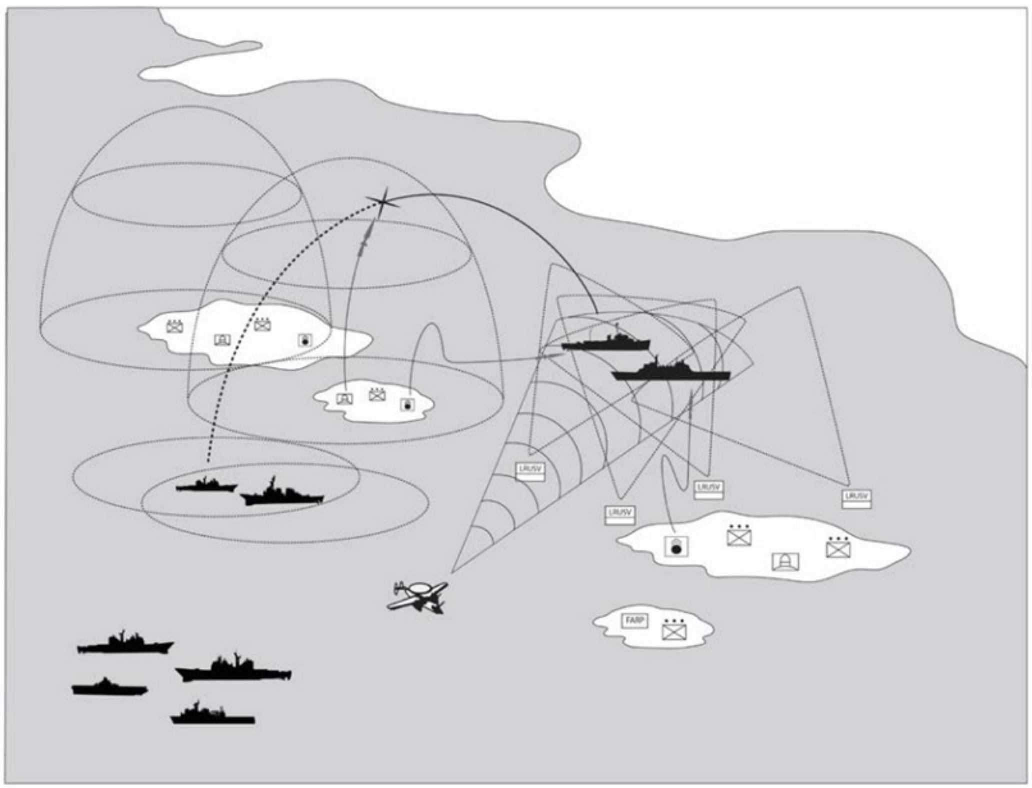

Figure 8-1. Notional concepts of employment for maritime fires

Figure 6. TM EABO Notional Antiair Warfare unit of action intercept, Source: USMC (2021b).

In December 2021, General Berger signed A Concept for Stand-In Forces which he used to help outline the Marine Corps' role within the modern operational environment where potential and actual adversaries possess modern and comparable capabilities to those of the United States. The Stand-In Force (SIF) is strategically positioned forward in contested areas within the battlespace, often inside the adversaries

WEZ, see Figure 7. These SIFs disrupt the adversary's ability to plan and act against U.S. interests throughout the competition continuum. The SIF does this by forcing the adversary to commit its limited resources to a variety of geographically dispersed locations in the battlespace. Critical characteristics of the SIF is their low signature, high mobility, and dispersion throughout the battlespace making them increasingly difficult to locate and target (USMC, 2021a). General Berger also acknowledges in A Concept for Stand-In Forces that "[w]e must be prepared to do this with our available organic means, but equally as important we need to complete naval and joint kill webs, helping to bring all-domain effects to bear when needed" (USMC, 2021a, para. 4). Additionally, tasks pertaining to air defense for SIFs, the Marine Littoral Regiment in particular, range from coordinating air and missile defense to conducting short-range GBAD in support of maneuver units and expeditionary based and medium-range GBAD in support of expeditionary bases. Medium range is defined by Combat Development and Integration, Headquarters Marine Corps, as a range between 20 kilometers and 100 kilometers for surface to air weapons systems (CD&I, 2020). Currently, the Marine Corps possesses no capabilities to conduct this task with surface to air weapon systems.

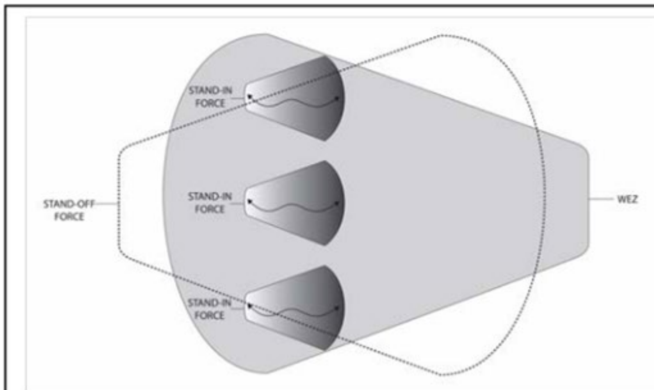

Figure 1-1. Idealized conceptual depiction of stand-off and stand-in engagement

Figure 7. TM EABO Stand-off and Stand-in forces' engagement zones, Source: USMC (2021b).

The overarching narrative emerging from the USMC documents is the urgent imperatives to bolster air and missile defenses and adapt to the intricate dynamics of contemporary battlefields. The integration of advanced defense strategies, the rejuvenation of sea control capacities, and the need for a robust framework to protect

HVUs in complex terrains are central themes. The synthesis of insights from TM EABO, the reflections on littoral operations, and the directions from the Commandant's Planning Guidance illuminate the pathway for the Marine Corps' evolution. It underscores the essence of innovation, adaptability, and the strategic integration of technology and intelligence to navigate the multifaceted challenges of modern warfare, ensuring that the Marine Corps is not just abreast of contemporary threats, but also anticipates future combat landscapes.

F. MULTI CRITERIA DECISION ANALYSIS

General guidance provided by the DOD for the conduct of an AoA focuses the study to develop meaningful measures of effectiveness based on ground rules, constraints, assumption, and required performance tasks of the capability. When evaluating alternatives, many of these pieces of information are pulled from documents such as the Initial Capabilities Document, Concept of Operations, or Urgent Needs Statements. However, example frameworks and methodologies provided in the *Analysis of Alternatives (AoA) Handbook* only depict grading criteria that can result in a yes or no distinction. For example, if the performance task was to detect and identify threats and the metric was measured in percentages, the evaluation criteria would be listed as greater than or equal to 95%. This leads to an evaluation of the alternative being either acceptable of unacceptable (Office of Aerospace Studies, 2017). With evaluation results calling into a category of either acceptable or unacceptable, the decision makers are left without a firm understanding of how different systems compare or how much more or less effective one alternative is compared to another.

A 2009 study conducted by the U.S. Government Accountability Office (GAO) found that many of the DOD programs of record at that time either did not conduct a thorough AoA or that the AoA was too limited in scope to provide leadership and decision makers with the necessary performance and cost data. Of the thirty-two programs that were reviewed, ten of them did not conduct AoAs, and thirteen programs conducted limited AoAs where they compared the current system to only one alternative. One example of a program that conducted a limited scope AoA was the Army's Armed Reconnaissance Helicopter program which did not consider any unmanned aerial systems, increasing the procurement of additional attack helicopters, purchasing other reconnaissance assets, or any combination of the three. The program suffered an increase in development cost of $580 million dollars within three years of development. On the other hand, the Navy's P-8A Multi-mission Maritime Aircraft, set to replace the aging P-3C, analyzed numerous concepts and possible solutions during its AoA. GAO reported, at the time, that the P-8A program had not experienced unexpected cost growths throughout its first four years and had remained on schedule. One of the factors behind these inconsistencies with the AoAs was that guidance was not given and when it was it was often either late or ambiguous. Ultimately, the recommendations made by GAO were to increase their effectiveness by establishing specific criteria and guidelines on the conduct of the AoA, to include technical and other program risks, and by requiring the AoAs to be completed prior to the program's key performance parameters were finalized (Sullivan, 2009).

Without further guidance on establishing a methodology that seeks to normalize performance across the numerous alternatives being assessed, decision makers will likely be placed in situations where they must make difficult decisions without adequate information about the details that separate the alternative options. Multi-Criteria Decision Analysis (MCDA) models can be used to analyze the effectiveness of numerous alternative solutions and provide additional clarity for decision makers. Deterministic MCDA models use specific criteria weights and performance ranges, removing uncertainties that may exist, and provide a multi-attribute value often as an effectiveness ratio (Mahalak, 2018). In his studies, David Mahalak, focused on how decision support tools based on MCDA models could be used to facilitate the AoA process. He used an example scenario where he considered the selection of an optical receiver for an airborne light detection and ranging system. After collecting performance data on six alternative solutions, his study produced a set of models comparing those alternatives based on overall performance, established by the performance requirements, and cost of each solution.

The information covered here in Chapter 2 provides background understanding to the reader about two potential adversaries the U.S. could come into conflict within the future. We also provided background on guidance provided for the conduct of air defense with regards to the U.S. Joint Force and the USMC. Lastly, we covered how MCDA can be used as a tool to aid in the conduct of an AoA. The information we have covered here in Chapter 2 paves the wave for the analysis in Chapter 3.

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III. CAPABILITIES-BASED ASSESSMENT

This chapter conducts a capabilities-based assessment (CBA) to verify a gap within the current capability set of the Marine Corps. Conducting a CBA is an integral part of the Joint Capabilities Integration and Development System (JCIDS) process. Its purpose is to conduct a comprehensive analysis of a mission area or set of activities and evaluate a Service's or the joint force's capability and capacity to successfully accomplish those assigned tasks. The CBA aims to define the operational context, identify capabilities and gaps, assess operational risks if those gaps are not addressed, and provide recommendations for addressing them through material or non-material solutions (Hyten, 2021).

Overall, the CBA serves as a vital tool in the defense acquisition system by providing a thorough assessment of capability gaps that leads to evaluating potential solutions and supporting the development of operational capability requirements. It opens the door to use tools like an AoA or DOTmLPF-P analysis which enable decision-makers to make informed choices regarding materiel and non-materiel solutions and ensures that the military's capabilities align with strategic goals and priorities.

A. OPERATIONAL CONTEXT

The operational environment for the USMC air defense community is marked by evolving threats from potential peer adversaries such as PLA and Russia. The PLA has undergone a significant modernization of its missile arsenal and the PLA Air Force, focusing on over-water and maritime strike capabilities, challenging U.S. military dominance in the Asia-Pacific region. Russia, on the other hand, has transformed its military since 2007, emphasizing command and control reforms, force structure changes, and extensive training, showcasing adaptability and resilience.

In response to these evolving threats, the USMC is refocusing its air and missile defense priorities. General Berger's emphasis on the TM EABO manual and the Concept for Stand-In Forces reflects a strategic shift towards enhancing the role of littoral forces in multi-domain conflicts. This includes addressing capacity challenges, reinvigorating sea control strategies, the importance of expeditionary mobility, and bolstering defenses against sophisticated threats to include manned and unmanned aircraft.

The USMC's approach involves integrating complex defense mechanisms, efficient communication networks, and strategic maneuvering of assets to include air and missile defense resources. The TM EABO emphasizes the need for synergized efforts with the Air and Missile Defense Commander within a collaborative framework, highlighting the importance of the littoral force. Additionally, General Berger's Concept for Stand-In Forces further highlights the importance of low-signature, high-mobility forces disrupting adversary plans and committing resources to geographically dispersed locations.

Overall, the USMC recognizes the urgent need for modernizing its integrated air and missile defense system, adapting to contemporary battlefields, and anticipating future combat landscapes. The synthesis of insights from various documents underscores the essence of innovation, adaptability, and strategic integration of technology and intelligence to navigate the multifaceted challenges of modern warfare.

B. CAPABILITIES AND CAPABILITY GAP

1. GBAD History

The U.S. military's GBAD systems evolved significantly to counter changing aerial threats, as outlined by Kenneth P. Werrell in Archie to SAM: A Short Operational History of Ground-Based Air Defense. Initially, during World War II, manual anti-aircraft guns like the M1 and M2 played crucial roles against enemy aircraft. The Cold War saw technological advances in response to Soviet air threats, with the Marine Corps adopting the radar-guided Hawk missile system (Werrell, 2005). The Gulf War demanded further adaptation, emphasizing mobile and rapid-deployment GBAD strategies. Systems such as the Marine Corps' Avenger and the Army's Patriot missile system demonstrated effectiveness against conventional and ballistic missile threats in Iraq, showcasing an integrated defense approach (Werrell, 2005).

During the Global War on Terror, the U.S. faced unconventional threats like drones and IEDs, prompting a shift towards systems capable of countering a wider range of challenges, including counter-rocket, artillery, mortar (C-RAM) systems like the Phalanx to protect bases. This era emphasized versatility and adaptability in GBAD strategies to remain effective against evolving threats (Werrell, 2005). Overall, the continuous adaptation and innovation of GBAD weapon systems reflect the U.S. military's commitment to defending against diverse aerial threats, ensuring the protection of troops and critical assets.

2. GBAD CONOP

To accurately identify the Marine Corps' Capability Requirements (CRs) and isolate the current capability gap within the Corps' air defense systems, we rely on the Ground-Based Air Defense Concept of Operations (GBAD CONOPS) published in 2020 and mission essential task lists (METLs) for units responsible for countering air threats in defense of Marine, Naval, and Joint Forces. We also address the capabilities and characteristics of current and emerging air defense systems owned by the Marine Corps and the risk presented by the gap in capability.

In June of 2020, the Deputy Commandant for CD&I signed and published the GBAD CONOPS to describe concepts and capabilities the Marine Corps planned to utilize to counter air threats in the current and future battlespaces. Within the CONOPS, the need for a Family of Systems (FoS) was identified to execute the various tasks within air defense. This GBAD FoS would center around the introduction, development, and acquisition of the Marine Air Defense Integrated System (MADIS) to replace the aging fleet of Fire Unit Vehicles (FUVs) currently employed by Marine Corps air defense units. This new GBAD FoS would be developed and delivered in incremental stages with Increments 1 and 2 focused on addressing threats from fixed and rotary wing assets as well as Group 1 through 3 UAS while Increment 3 would seek to address threats from cruise missiles, Rockets, Artillery, and Mortars (RAM), and Group 3 and 4 UAS (CD&I, 2020).

While the GBAD CONOPS solidified the operational concepts and constructs for Marine air defense units, this CONOPS confirmed that within the Joint Services, there is a shared fundamental requirement for ground-based systems designed to provide protection against aerial threats. To establish continuity throughout service areas focused on GBAD capabilities, such as the U.S. Army's Maneuver Short Range Air Defense (M-SHORAD) and Indirect Fire Protection Capability (IFPC), the GBAD CONOPS sought to define surface-to-air weapons capabilities by range and altitude. These defined ranges and altitudes had not previously been defined within U.S. Joint Service doctrine.

Surface-to-Air Weapons Capability by Range	
Short Range	< 20 km
Medium Range	20 – 100 km
Long Range	> 100 km

Figure 8. Defined Surface-to-Air Weapons Capability by Range, Source: CD&I (2020).

Surface-to-Air Weapons Capability by Altitude	
Low Altitude	< 20,000 ft
Medium Altitude	20,000 – 40,000 ft
High Altitude	> 40,000 ft

Figure 9. Defined Surface-to-Air Weapons Capability by Altitude, Source: CD&I (2020).

3. GBAD Units and Weapon Systems

The Marine Corps currently has two types of units that conduct active air defense tasks. Those two units are the Low Altitude Air Defense (LAAD) Battalion and the Littoral Anti-Air Defense Battalion (LAAB). These units are given missions and responsibilities that fall within their assigned METL. These include, but are not limited to, providing task organized forces, supporting amphibious operations, and conducting ground-based air defense. Both units provide forces to support the overall mission of the Marine Expeditionary Force (MEF). Each LAAD Battalion support the numerous Marine Expeditionary Units (MEUs) that support the MEFs while the LAAB and the Marine Littoral Regiment are specifically referenced in the second edition of the TM EABO as supporting III MEF within INDOPACOM. While the SIF does not specifically identify III MEF or the MLR as the primary executors of this concept, the idea of a force, trained and equipped to execute missions across a wide spectrum of operations, designed to be survivable through its employment of mobility and maneuver, and impose credible threat to adversary goals is why the Marine Corps established the first MLR (United States Marine Corps Flagship, n.d.). By supporting the MEUs and the MLR, the LAAD and LAAB Battalions provide vital air defense capabilities in forward deployed areas to include maritime and littoral environments.

The FIM-92 Stinger missile is the main kinetic air defense weapon employed by the USMC. It is a shoulder fired, man-portable, surface-to-air missile with an effective range of roughly 4.8km or 3 miles and an effective altitude of 12,500ft (Missile Defense Advocacy Alliance, n.d.). The Stinger missile has been adapted to be fired from other platforms such as the M197 Avenger and the AH-64 Apache helicopter, but neither of these platforms are employed by the Marine Corps. Additionally, there have been aids designed for the operator such by binoculars, night vision targeting sights, and electro-optical/infrared sensors to assist in locating and identifying targets but these aids to not add any additional range to the missile itself.

Currently, the prime mover available and utilized by the Marine Corps GBAD units is the M1114 High Mobility Multi-Wheeled Vehicle. These vehicles allow for the employment of M2A1 heavy machine guns or the M240 medium machine gun mounted in the turret located at the top of the vehicle. The max effective ranges for both systems are listed at 1,830 meters (6,003 feet) and 1,800 meters (5,905 feet) for area targets respectively. Utilizing these crew served weapons to counter aircraft or UAS is very difficult due to ballistic trajectory and size of the impact damage of the rounds they fire can create.

The emerging GBAD capability described in the GBAD CONOPS is the FoS that include the MADIS and the Light Marine Air Defense Integrated System (L-MADIS). Increment 1 of MADIS is described as a modernized GBAD system the incorporates a mix of current and emerging technologies into a Joint Light Tactical Vehicle (JLTV) as the prime mover. Within the MADIS system, there would be a pair of vehicles that would incorporate C2 systems, surveillance systems, kinetic and non-kinetic defeat systems. The ability to counter aerial threats relies on the system’s ability to identify, target, and defeat the threat. The MADIS' kinetic defeat options rely on the FIM-92 Stinger missile and the XM914 30mm cannon system, which is an updated version of the M230LF 30mm Bushmaster produced by Northrop Grumman. While firing the Stinger missile from the MADIS platform does not extend the range or altitude of the missile, the modern 30mm cannon is capable of firing air-burst proximity fused rounds which would greatly increase the lethality of the crew served weapons currently used by the LAAD and LAAB Marines. Non-kinetic capabilities include electronic warfare (EW) capabilities such as radio frequency jammers to defeat UAS. The current EW equipment used on the MADIS FoS does not have an effective range listed in unclassified sources. The L-MADIS operate similarly as a pair of vehicles based on the Ultra-Light Tactical Vehicle. While the L-MADIS has no organic kinetic defeat capabilities, the L-MADIS has similar C2, passive and active sensing, and EW capabilities. The size of the L-MADIS also allows it to be transported via organic rotary wing and tilt-rotor platforms. Tables 1 and 2 show the max effective ranges and altitude for air defense weapon systems organic to the Marine Corps and the maximum service ceilings of active aircraft and UAVs used by Russia and the PRC:

Table 1. Max Effective Ranges/Altitudes of USMC's organic Air Defense Weapon Systems

Weapon System	Max Effective Range (Meters / Feet)	Max Effective Altitude (ft)
FIM-92	4,800 / 15,748	12,500
M2A1	1,830 / 6,003	N/A
M240B	1,800 / 5,905	N/A
XM914	1,500 / 4,921	N/A

Table 2. Service Ceilings for Russian and Chinese Aircraft and UAVs

	Platform	Max Service Flight Ceiling (ft)	Platform Type
PLAAF Aviation Assets	Sukhoi SU-30	56,800	Fixed Wing
	Chengdu J-10	59,000	Fixed Wing
	Shenyang J-16	56,800	Fixed Wing
	Chengdu J-20	66,000	Fixed Wing
	Mil Mi-8	16,000	Rotary Wing
	Harbin Z-9	14,800	Rotary Wing
	Changhe Z-8	10,330	Rotary Wing
	Eurocopter AS332	16,990	Rotary Wing
PLA UAV Assets	ASN 206	19,600	UAV
	ASN 207	19,600	UAV
	BZK-005	26,000	UAV
Russian Aviation Assets	Mikoyan MiG-35	59,000	Fixed Wing
	Sukhoi SU-30	56,800	Fixed Wing
	Sukhoi SU-34	56,000	Fixed Wing
	Sukhoi SU-35	59,000	Fixed Wing
	Sukhoi SU-57	66,000	Fixed Wing
	Sukhoi SU-24	36,000	Fixed Wing
	Sukhoi SU-25	23,000	Fixed Wing
	Kamov Ka-27	16,000	Rotary Wing
	Kamov Ka-52	18,000	Rotary Wing
	Mil Mi-24	16,100	Rotary Wing
	Mil Mi-28	18,700	Rotary Wing
Russian UAVs	Orlan-10	16,000	UAV
	Mavic 3	3,280	UAV

With our current legacy and emerging capabilities sets, ground-based air defense units within the Marine Corps do not yet fully fill the gap as defined as short range and low altitude. While the current capabilities fill portions of these spectrums, it is imperative that Marines be able to counter aviation threats at greater ranges and altitudes. While there is currently only one LAAB established, a new LAAD Battalion was recently activated on Hawaii in 2022, demonstrating growth in the Corps' air defense and aviation command and control communities. On the other hand, the FIM-92 Stinger missile has not seen major updates or upgrades in range since the 1995 delivery of the Stinger Reprogrammable Microprocessor (RMP) Block I. This thesis is not calling into question the effectiveness of the FIM-92; however we are establishing the requirement for extended range and altitude due to the flight ceilings of threat aircraft and UAVs of a complimentary system to the FIM-92 Stinger missile and MADIS FoS.

Based on the USMC's current and emerging air defense system's max effective ranges and the max service ceiling for peer adversary aviation threats, the gap in air defense capability can be described as one of a lack of fielded capability solution. This research has established the capability limits of current systems and the need to develop and field complimentary systems with extended ranges and altitudes that can be employed in expeditionary environments while establishing the USMC IADS in support of Naval and Marine Corps littoral operations. Developing and delivering extended range and altitude capabilities for air defense units that reach into the medium range and medium altitude blocks as referenced in Figures 8 and 9 provide the Marine Corps' SIF with ability to deter adversary strike and ISR platforms. Table 2 depicts the listed max service flight ceiling of various aircraft according to open-source material. Figure 10 depicts the engagement capability of the FIM-92 Stinger Missile along with various other U.S. and allied nations' missiles used in air defense along with the reported flight ceiling for multiple UAS, rotary wing, and fixed wing aircraft used by the PRC and Russia. Based on these specifications, aircraft that shar similar flight ceilings with the Orlan-10 and the Mi-24 are outside of the reported effective engagement range of the USMC's current kinetic surface to air missile. Of note for Figure 10, the service ceiling listed for the Orlan-10 and Mi-24 are only 100ft apart.

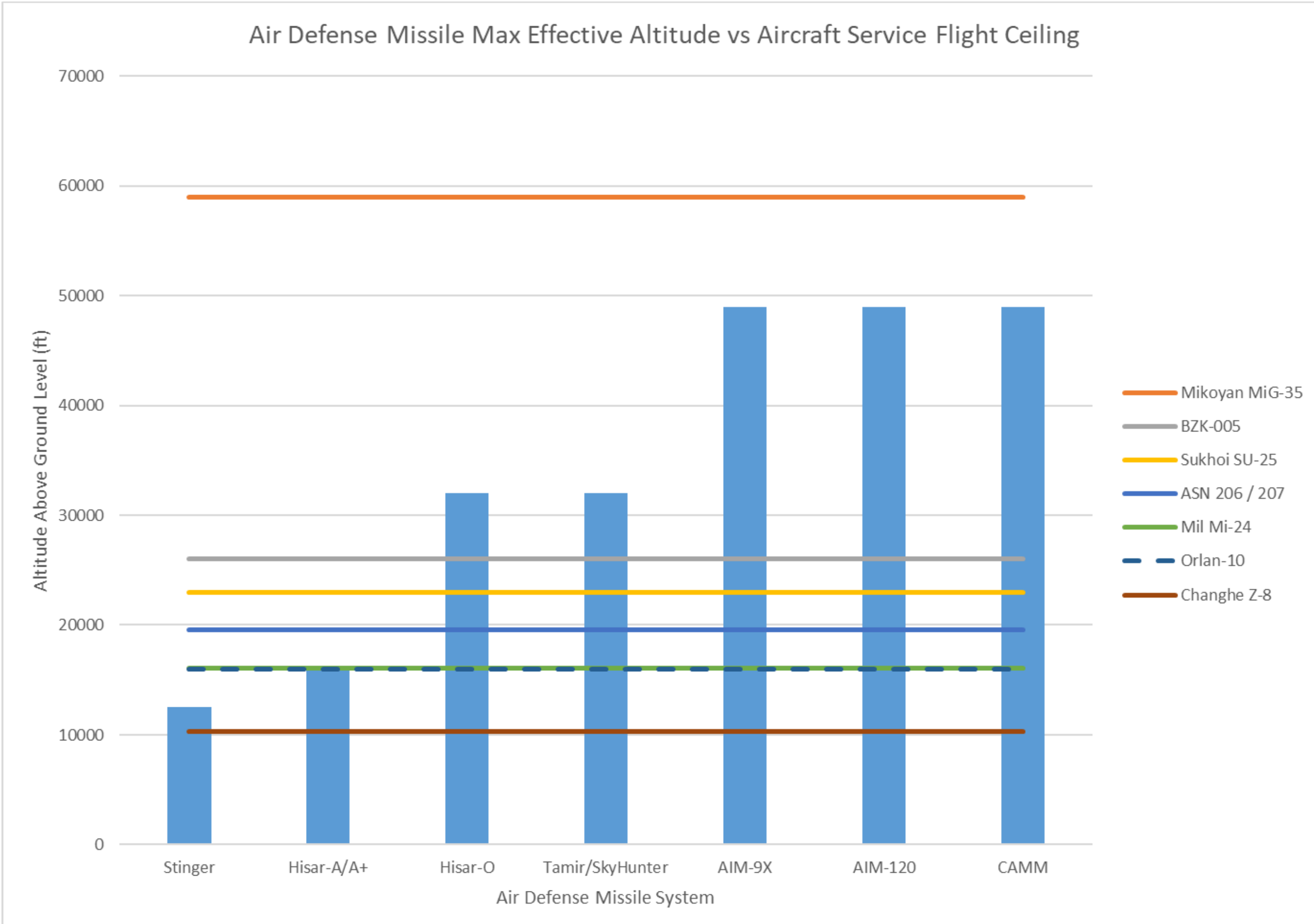

Figure 10. Air Defense Missile Max Effective Altitude vs Aircraft Service Flight Ceiling

C. RISK ASSESSMENT

In accordance with the JCIDS Manual, a comprehensive risk assessment of the capability gap in organic Marine Corps air defense weapon systems against the aerial threats from Russian and Chinese aircraft and UAVs reveals several critical areas of concern. First and foremost, the current capability gap poses a significant operational risk, as existing air defense systems may not effectively detect, track, and neutralize the full spectrum of threats. This gap diminishes the operational effectiveness of the Marine Corps while simultaneously increasing the risk of attrition in high-intensity conflict scenarios. In addition, there is an institutional risk, as a medium range/medium altitude air defense capability is fielded the current training and doctrinal approaches lag the proper employment of such weapon systems as the Marine Corps prepared for the unique challenges posed by peer adversaries. The risk assessment, therefore, highlights the urgent need for accelerated development and procurement of medium range and medium altitude air defense systems, investment in research and development for emerging technologies, and updated training and doctrine to align with the realities of modern aerial warfare. Addressing these risks is paramount to ensuring that the Marine Corps maintains its operational superiority and readiness in the face of peer threats.

Below is an adjusted risk assessment used to highlight the risk associated with the air defense capability gap identified in this thesis. The risk assessment and analysis is based on the risk assessment template from the JCIDS manual and scoped through the lens of a Littoral Force Commander (LFC) conducting EABO (Hyten, 2021). During EABO operations, the LFC is responsible for the protection of the vital area (VA). In the TM EABO volume 2, a VA is a any designated area defended by air defense units under the LFC's command (USMC, 2023). While the size and location of the VA is dependent upon friendly troop location and the anticipated threat's expected ordinance release distance, the intent is that air defense units, organic or in support to the MLR be able to engage threats prior to their ability to launch weapons or conduct ISR.

Table 3. Risk Assessment Related to Air Defense Capability Gap, Adapted from Hyten (2021).

Risk	Criteria	Risk Rating	Rationale
CCMD "Risk to Mission" Ability to execute assigned missions at acceptable human, materiel, financial, and strategic cost	Achieve Objective (CCMD Current Operations)	Moderate	With current range and altitude capabilities, air defense units cannot engage all likely threat system prior to their ordinance-release lines or ISR limits.
	Achieve Plan Objectives (Contingencies)	Low	TMEABO Volume 2 was written and signed with current and emerging capabilities such as MADIS FoS.
	Authorities	Moderate	While LFC has the authorities needed to utilize organic air defense systems, they lack the ability to counter threats beyond the FIM-92's range/altitude; requires requesting additional

			capabilities to intercept aerial threats beyond organic capability.
	Resources Needed to Meet Required Timelines	Low	Emerging capabilities being fielded as planned.
Service/JFP "Risk to Force" Ability to generate trained and ready forces, and to plan for, and enable, and improve national defense.	Meet CCDR Requirements (CCMD Current Operations)	Significant	Based on historical manpower and readiness levels from air defense units, considering the stand up of new units, and the recent recruiting levels for the services, the ability to support GFM requirements may not be above 80%.
	Meet CCDR Requirements (Contingencies)	Moderate	Shortfalls in USMC IADS may lead to minor adjustments to planning activities.
	DOTmLPF-P Capability vs. Threat	Significant	Considering service ceilings for threat aviation assets and effective ranges for air defense systems, adversaries possess the ability to operate outside of our current WEZ.
	Readiness	Significant	Capacity of legacy air defense systems did not increase with personnel increases and the stand-up of new units. Emerging systems to include MADIS FoS have not yet been fielded to units to meet IOC capacity.
	Stress on the Force (Active Component)	Moderate	Historically, air defense units reported roughly 1:1.5 DT; Maintaining a 1:2 DT is optimistic.
	Stress on the Force (Reserve Component)	N/A	Currently, no reserve component LAAD or LAAB units exist organic to the USMC.
	Programmatic	N/A	This thesis is not focused on a current program of re ord.

	Force Development & Industrial Base	Moderate	Current USMC air defense capabilities allow for the accomplishment of short-ranged GBAD as LAAB Core MET. Current capabilities does not allow for the accomplishment for medium-range GBAD in support of maneuver units and a LAAB Core Plus MET.

D. POSSIBLE NON-MATERIEL APPROACH

With the gap verified and risk analyzed for the capability gap within the Corps' current IADS, the next step needed for the CBA process is to evaluate the possibility of non-materiel solution. We conducted an analysis of current USMC's doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTmLPF-P) in order to identify potential solutions that do not require an acquisition or developmental effort.

Doctrine. This thesis explored updated and relevant Joint and Service guidance and doctrinal changes ranging from Joint Operations, Joint Maritime Operations, and Countering Air and Missile Threats to the TM EABO and SIF service publications. While these documents provide guidance and new ways of thinking about how the USMC conducts maneuver warfare in the modern multi-domain battlefield, these documents do not provide the service with the capabilities needed to defend their forces from adversaries with advancing stand-off capabilities.

Organization. The USMC air defense community, specifically the LAAD and LAAB units, have seen growth and the stand up of new units over the years between 2020 and now. Original efforts aligned with Force Design 2030 recommended the two LAAD Battalions stationed on the East and West coasts of the United States increase their personnel numbers by two additional firing batteries while III MEF would see the stand up of three new firing batteries to support the operations of the three MLRs. To date, the East and West coast LAAD Battalions only received orders to stand up one additional battery a piece and the new Battalion that is now stationed in Hawaii only has control over one firing battery while its second is attached and supports the 3d MLR. The current organization of the Marine Corps does not adequately address the capability gap highlighted in this thesis.

Training. With the fielding of the MADIS and L-MADIS systems, the Marines of the LAAD community see a shift in training and formal education due to adjustments to the periods of instructions at the formal training facilities such as the LAAD Military Occupational Specialty (MOS) schoolhouse and other follow-on MOS training facilities such as Marine Aviation Weapons and Tactics Squadron 1 (MAWTS-1). Additional training in either schoolhouse or field training environments cannot increase the engagement range or capabilities of the USMC's current and emerging systems.

Materiel ("m"). Materiel solutions that are currently available from current U.S. DOD acquisitions or Commercial Off The Shelf (COTS) solutions could be used to fill the capability gap in the current IADS of the USMC. The U.S. Army utilizes the Indirect Fire Protection Capability (IFPC) system to defeat aerial threats such as cruise missiles, UAS, and rocket, artillery, and mortars. Increment 2 of the IFPC system is stated to use the AIM-9X Sidewinder missile as its interceptor while also having variants that employ high energy lasers or high-power microwaves. Other potential solutions could be found in the Iron Dome system from Israel, the Hisar family of surface to air missiles from Turkey, the Common Anti-Air Modular Missile (CAMM) family of surface to air missiles from the United Kingdom, or the National Advanced Surface-to-Air Missile System (NASAMS) produced in Norway. Many of these systems possess extended range capabilities but also require larger vehicle footprints to move the large battery of missiles. Mobile systems do not meet the expeditionary requirements the Marines need to operate in the forward edge of the maritime battlespace.

Leadership. Although leadership from the Marine Air Command and Control System and throughout the Marine Corps can be developed to think critically about how the growing threats of advanced aerial systems can be countered, the geographic constraints placed on units operating within forward littoral environments hinder a leader's ability to position their air defense systems far enough away from their vital areas and high value assets to counter the extended ranges of some of the ISR or strike platforms we have listed from Russia or the PRC. Adjustments and progress in leadership and education cannot provide the additional engagement ranges needed to counter peer threats.

Personnel. Personnel constraints already exist in the Marine Corps, however merely shifting around personnel from one MOS to another likely results in a deficiency in personnel from where the numbers were pulled. As mentioned, the organization of air defense units, and thus their personnel numbers, has been increasing through the efforts of Force Design 2030. It is likely to be the case that the LAAD Battalions would need receive an additional firing battery funded, stood up, staffed, and equipped to maintain the capacity to execute their current mission sets while also being able to employ systems with extended range and altitude capabilities.

Facilities. Adjustments to facilities could result in countering or lowing the threat of enemy ISR or mitigate the range of their ordinance-release lines to include increased camouflage or the hardening of static structures. Counter-reconnaissance is a term used in A Concept for Stand in Forces to describe the actions taken by Marine Corps units to prevent the adversary from locating the U.S. Naval Fleet or its assets (Berger, 2021). Through efforts designed to degrade the adversary's ability to conduct ISR and ultimately locate and target U.S. forces, the TM EABO points towards the ability of Marine Corps units to rapidly maneuver through the battle space (USMC, 2023). While modern strategic guidance prioritizes speed and mobility, the options to fortify become less feasible.

The limitation of non-materiel solutions becomes strikingly evident considering the specific challenge faced by the Marine Corps. The Marine Corps' organic air defense weapon systems are currently inadequate against a large majority of the threats anticipated on a modern battlefield. This reality highlights the insufficiency of non-materiel strategies alone. These elements, while foundational to overall defense readiness, prove insufficient in scenarios where advanced, technologically capable threats outpace the capabilities of existing military inventories. This discernible gap necessitates the urgent need for materiel solutions – a strategic effort towards developing and acquiring weapon systems specifically engineered to counter the sophisticated threats posed by adversaries like Russia and China. In the face of rapidly evolving global military challenges, this approach is a fundamental requirement for maintaining strategic superiority and ensuring national security.

E. POSSIBLE MATERIEL APPROACH

In response to the critical need for enhanced medium-range and medium-altitude air defense capabilities on modern battlefields, several promising materiel solutions have emerged. These include systems like the Army's IFPC, NASAMS, the Hisar Missile, and the CAMM. While a number of these systems address the medium range and altitude gap for the Marine Corps, not all are optimized for the EABO mission set required by the Marine Corps. It is likely that an existing system would need modification to meet the Marine Corps' specific requirements. This is due to the Marine Corps' expeditionary nature, which requires the force to be rapidly deployable while remaining reliant on very limited organic mobility assets. However, augmenting the Marine Corps' current organic air defense weapons with additional capabilities would contribute to the development of a robust IADS. Such a system would effectively counter a wide range of aerial threats, including those posed by fighter jets, rotary-wing aircraft, UAVs, and ICBMs, which are characteristic of the capabilities developed by adversaries like Russia and China. The materiel solutions must focus on modular designs that offer scalability and adaptability to various combat scenarios, ensuring the Marine Corps maintains operational superiority in diverse environments.

The U.S. IFPC is a pivotal component of its layered defense strategy, designed to counter a wide array of airborne threats, including rockets, artillery, mortars, cruise missiles, and UAS. At its core, the IFPC program aims to provide Army units with a versatile, highly mobile, and effective air defense system capable of protecting soldiers, critical assets, and infrastructure from indirect fire attacks. The system typically integrates multiple sensors and interceptors, offering 360-degree protection and a high degree of situational awareness (Judson, 2023). A key feature of the IFPC is its interoperability with existing systems, allowing it to work in concert with other defense components like the AIM-9X sidewinder which has been known to engage targets at ranges of more than 10 miles (Air Force, n.d.). This capability enhances the Army's ability to operate in various environments, whether in densely populated urban settings or remote areas, ensuring robust defense against increasingly sophisticated airborne threats.

The NASAMS is a highly adaptable and effective medium to long-range air defense system, developed by Norway's Kongsberg Defence & Aerospace and Raytheon. NASAMS is designed to safeguard key assets and populations from a variety of aerial threats, including manned and unmanned aircraft, drones, and cruise missiles. This ground-based air defense system stands out for its interoperability with NATO air defense networks, making it an attractive option for many NATO members. It operates using the AIM-120 AMRAAM missile, which has a range of over 40km. This proven air-to-air weapon adapted for ground launch and is known for its ability to engage multiple targets simultaneously with high precision. The system's radar and sensor technology allow for accurate target acquisition and tracking, contributing to its reliable defensive capability. NASAMS' modular design ensures ease of deployment and flexibility, enabling it to be quickly set up and repositioned as needed to respond to changing threats. Its integration into a broader air defense network enhances situational awareness and overall defense strategy. With deployments across various nations, NASAMS has been battle-tested and continues to evolve with advancements in missile and radar technology, maintaining its status as a trusted and critical component of national air defense infrastructures (Feickert, 2022).

The Hisar missile system, developed by Turkey, is a family of short to medium-range surface-to-air missiles designed to provide effective air defense against a range of air threats. The Hisar system comes in two primary variants: Hisar-A+ (short-range) and Hisar-O (medium-range). These missile systems are a result of Turkey's efforts to bolster its indigenous defense capabilities and reduce reliance on foreign systems. Hisar-A+ is designed for low-altitude defense, while Hisar-O extends the range and altitude, providing broader coverage. Both variants utilize an infrared seeker for guidance, ensuring precision targeting. The systems are noted for their all-weather capability and are designed to be highly mobile, allowing for rapid deployment and repositioning in response to emerging threats. Integrated with a sophisticated radar and fire control system, Hisar missiles can engage multiple targets simultaneously and are operable in both standalone mode and as part of an integrated air defense system (Roketsan, n.d.).

The CAMM is an advanced, versatile air defense missile developed by MBDA for the United Kingdom. It is designed to provide modern armed forces with comprehensive protection against a wide array of air threats, including fast jets, helicopters, cruise missiles, and UAVs. One of the key features of the CAMM is its modular design, which allows for easy integration with a variety of platforms, such as ships (Sea Ceptor variant) and land-based air defense systems. This missile system employs active radar homing for guidance, providing high accuracy and an all-weather, day-and-night operational capability. The CAMM also boasts a next-generation solid-state active radar seeker and a two-way data link, which enables it to engage multiple targets simultaneously and effectively, even in complex and cluttered environments. Its compact size allows for a higher number of missiles to be stored in a limited space, enhancing the firepower of the platform it is deployed on (MBDA, n.d.).

The analysis of medium-range and medium-altitude air defense systems such as the U.S. Army's IFPC, NASAMS, Turkey's Hisar missile system, and the UK's CAMM shows that a number of technologies exist that could satisfy the gap within the USMC's IADS. Each of these systems brings unique capabilities to the table, offering robust protection against a variety of aerial threats. However, while they possess the technological capabilities necessary to address modern air defense challenges, aligning them with the specific mission sets of the U.S. Marine Corps would likely require modifications to the systems mentioned, particularly under the framework of EABO, which demands a unique blend of mobility, versatility, and interoperability. The evolution of a fielded capability solution is necessary for these existing systems to fit the EABO criteria. Although introducing a medium range and altitude air defense system into the Marine Corps' inventory is a transformational change, current DOD and ally capabilities possess the extended range but lack the expeditionary nature required by the Corps. Conducting the CBA allows for the verification that the capability gap exists and opens the door to analyzing the viability of different available options. Chapter 4 further analyses the alternative air defense systems through the MCDA and CEA framework.

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IV. ANALYSIS OF ALTERNATIVES THROUGH MULTI-CRITERIA DECISION ANALYSIS

This chapter focuses on the comparison of multiple alternative solutions based on various characteristics of current systems and those of the alternatives. Within the Joint Capabilities Integration and Development System process, an Analysis of Alternatives (AoA) is initiated to conduct an analytical comparison of materiel solutions based on operational effectiveness, suitability, and costs. The goal of the AoA study is to identify some of the most appropriate options to satisfy the recognized capability need (Office of Aerospace Studies, 2017).

Using a deterministic MCDA model, we define key characteristics and criteria for an air defense system that is capable of engaging threats at medium ranges and medium altitudes while being optimized for employment by the Marine Corps in an EABO environment against peer adversaries. MCDA is a systematic approach to decision-making that considers multiple criteria. Then, analysts can weigh the agreed upon criteria to rank alternatives (Multi-Criteria Decision Analysis (MCDA/MCDM), n.d.). "MCDA, in essence, involves these four key components: **alternatives** (or individuals) to be ranked or chosen from, **criteria** by which the alternatives are evaluated and compared, **weights** representing the relative importance of the criteria, [and] **decision-makers** and potentially other stakeholders, whose preferences are to be considered" (MCDA/MCDM, n.d., para. 8).

Traditional intuitive decision-making, which relies on gut feelings and holistic evaluations, is contrasted with MCDA, which aims to structure and solve decision problems in a formal and transparent manner. By making the decision-making process more explicit and systematic, MCDA reduces biases and group decision-making failures, resulting in better decision outcomes. The MCDA process includes steps such as organizing the decision-making issue, defining the standards, assessing the performance of options, rating the options, assigning importance to the criteria, and utilizing these ratings and importance levels to order the options. The final step involves using the MCDA results to support decision-making and communicate the decision to stakeholders (MCDA/MCDM, n.d.).

A. DEFINE CRITERIA

This thesis uses criteria including effective range and altitude, system mobility, networking capability, crew size, re-arming requirements, seeker guidance, warhead and fuse type, length and weight of munition, and costs. It also could consider other characteristics like accuracy for evaluating alternatives, but it limits its focus to available and unclassified information and data.

The thesis defines effective range and altitude as the maximum distance a surface-to-air munition travels from the system to engage a target effectively, using kilometers for range and feet above ground level (AGL) for altitude. The system and munition's engagement envelope incorporates these criteria, assigning a weight of 0.35 to the engagement envelope in the MCDA comparison to address the USMC's identified capability gap with increased air defense coverage. It weights range more than altitude, noting that many alternative systems and munitions exceed 30,000ft AGL. The analysis sets the upper bounds for range and altitude at 100km and 40,000ft AGL, respectively, aligning with the GBAD CONOPS for medium range and altitude.

The definition of mobility is based on whether a system is wheeled, tracked, or requires trailers and notes the uncertainty in confirming the transportability of the Iron Dome, Hisar, and Sky Saber systems by a C-130 aircraft from open-source materials. It weights mobility at .035, reflecting an analysis of USMC system transportability requirements.

The definition of networking capabilities centers on a system's ability to transmit and receive sensor data and communications through voice and data channels. Since all alternative systems except the Hisar-A+ and Hisar-O support two-way data links, this feature did not enter our MCDA analysis. The focus on re-arming requirements deals with the procedures and equipment necessary for reloading. Open-source materials indicate that the IFPC and AIM-9X are the only system and munition pair not requiring extra heavy equipment for reloading. Owing to these findings and assumptions, we excluded crew size and re-arming requirements from the MCDA analysis.

The thesis identifies seeker guidance based on the munition's seeker technology, including active homing, semi-active homing, or passive homing, and evaluates the capability for mid-course updates and inertial guidance. It groups these criteria and assigns a weight of 0.3. The compared alternative munitions exhibit similar guidance technologies. The evaluation of seeker and guidance technologies assigns higher weight to active and passive homing than to mid-course updates, semi-active homing, and inertial guidance. The rationale for emphasizing active and passive homing over semi-active guidance stems from the reliance of semi-active guidance on external radar to identify the target and bounce radar waves back for the missile's tracking, which escalates the risk to forces, a concern previously highlighted. Moreover, the alternatives predominantly use high explosive warheads with proximity fuses, with the FIM-92 Stinger missile as the sole exception, employing an impact fuse.

This analysis details the munition's length and weight using the English system of measurement, evaluating these characteristics for the munition's physical dimension and assigning them a weight of 0.2. It posits that launching the missile from a vehicle or platform can achieve the desired increase in range and altitude not provided by current USMC air defense weapon systems, such as the FIM-92. Although the missile's physical size impacts its transportability and the logistics footprint required for the system, this aspect is less critical than the engagement envelope or seeker guidance criteria. Attempts to find the physical dimensions of the systems or their components in open-source materials did not succeed.

Open-source materials and websites provide the cost data, using the cost per missile to determine the missile's cost effectiveness in meeting the chapter's requirements. Table 4 presents the overall effectiveness ratio, using the FIM-92 Stinger missile as a baseline, according to the criteria and weighted values this thesis applies to compare the alternative air defense systems outlined in Chapter III.

Table 4. Multi-Criteria Decision Analysis Effectiveness Ratio for the MADIS and FIM-92 Stinger missile

System / Missile	MADIS / FIM-92 Stinger	cost(K$):	$120							
0.35	Engagement Envelope		Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	4.8	0.034	1.5	100	0.020	0.115		0.547
	0.40	Altitude (ft ABG)	12,500	0.236	4,000	40,000	0.094			
0.1	Physical Dimensions							Physical Dimensions		
	0.40	Length (inches)	54	0.955	180	48	0.382	0.968		
	0.15	Diameter (inches)	2.8	0.938	15	2	0.141			
	0.45	Weight (lbs)	33.51	0.991	400	30	0.446			
0.2	Seeker / Guidance							Seeker / Guidance		
	0.30	Active Homing	0	0.000	Yes = 1	No = 0	0.000	0.300		
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	1	1.000	Yes = 1	No = 0	0.300			
	0.20	Mid-Course Update	0	0.000	Yes = 1	No = 0	0.000			
	0.05	Inertial Guidance	0	0.000	Yes = 1	No = 0	0.000			
0.35	Mobility		Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	1	1.000	Yes = 1	Unknown = 0	0.900	1.000		
	0.10	Wheeled or Tracked	1	1.000	Wheeled = 1	Tracked = 0	0.100			

The reasoning for including C-130 transportability within mobility as a highly weighted criteria is because all these alternatives are mobile with either wheeled or tracked vehicles to move throughout the battlespace, but without the ability to be transported via organic USMC air assets, the system lacks the ability to conduct expeditionary operations. Referencing the Marine Corps' MADIS CDD, one of the listed Additional Performance Attributes of the system is they shall be self-contained and not require a trailer. The MADIS Capabilities Development Document also states that the MADIS shall be air-transportable by C-130 and transportable externally by CH-53K as Other System Requirements (CD&I, 2023). Figure 11 provides the objective hierarchy of the criteria in the analysis.

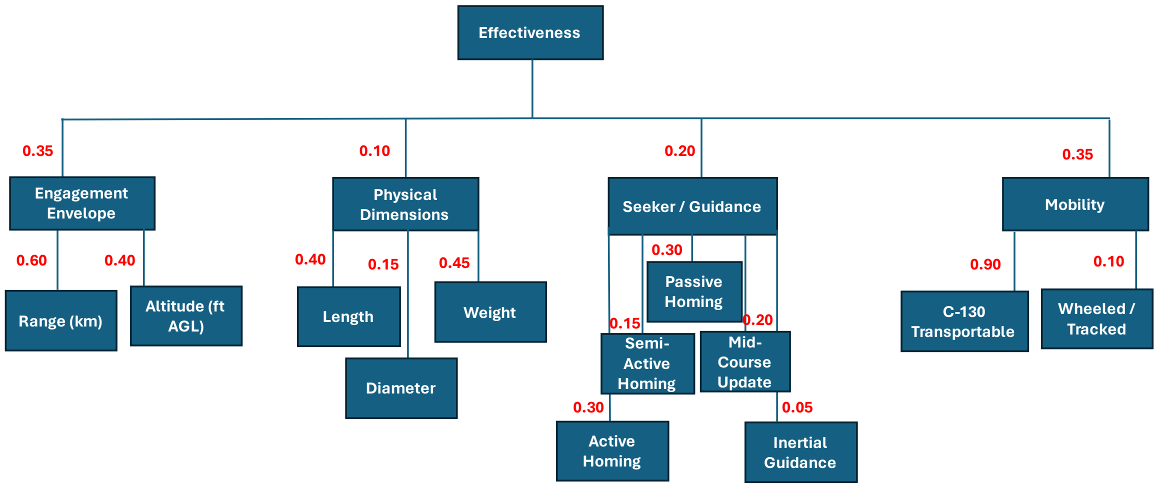

Figure 11. Objective Criteria Hierarchy

It is important to note that systems such as MADIS, L-MADIS, the High Mobility Artillery Rocket System (HIMARS), and unmanned ROGUE Navy/Marine Corps Expeditionary Ship Interdiction System (NMESIS) which fires the Naval Strike Missile have all been designed to accommodate organic air lift capabilities for the Marine Expeditionary Force. Many of these systems are based upon the JLTV as the prime mover apart from the L-MADIS.

B. IDENTIFY ALTERNATIVES

This thesis looks to identify alternative air defense systems and various missiles that can be used to complement the Marine Corps' current inventory of air defense assets. Unclassified objective measures for each system and missile are discussed and are based on the criteria defined in the previous section. The following analysis is then used to build a decision matrix and provide decision makers with quantifiable results.

The Army's IFPC is a wheeled intercept launcher with an estimated effective range and altitude of 35km and over 49,000ft AGL, respectively. Built for the Army, the wheeled system is highly mobile and C-130 transportable for rapid deployment. Real time data transmission is crucial for an Air Defense system and the IFPC is two-way datalink enabled, allowing the system to send and receive data within the Army's

Integrated Battle Command System network. The cost for the AIM-9X missile, which is the primary missile for the IFPC is just roughly $350 thousand per missile (Defense Express, 2023). Re-arming and reloading requirements can be completed manually. IFPC's seeker guidance can be either passive infrared homing or semi-active radar-guided homing. It utilizes a high explosive (HE) warhead with a proximity fuse for detonation (Judson, 2023).

NSAMS is broken into three main components, the fire distribution center, multi-mission launcher, and sentinel radar. Unclassified documentation states that the NASAM has an effective range of 105km and altitude of over 49,000ft AGL. The system is wheeled, while the sentinel radar can be transported in tow by a trailer. Thirteen different countries already use the system, and it has proven to be highly deployable. NASAMS can be transported via C-130, helicopter and sea vessel. Communications and data transfer is essential amongst the various components of NASAMS, as such it is two-way datalink enabled, which allows it to send and receive data. The system requires three operators for mission execution and the missiles can be reloaded manually. The missiles used by the NASAMS use active homing seeker guidance from the sentinel radar and typically use the HE warhead with a proximity fuse (Kongsberg, n.d.). The NASAMS can use either the AIM-9X or AIM-120. The cost per missile estimates for the AIM-120 are just over $1 million per missile (Hollings, 2023).

Like the NASAMS, the Israeli made Iron Dome is comprised of three main components, the ELM 2084 radar, the command-and-control center, and the launcher, which uses the Tamir interceptor missile. Unclassified sources state that the Iron Dome is capable of intercepting targets up to 70km with an effective altitude of more than 32,000ft AGL. The system is wheeled; however, no sources explicitly state that it is C-130 capable. The Iron Dome system is two-way datalink enabled. The Iron Dome requires ground support equipment for the reloading effort. Seeker guidance can be both active and passive and the Tamir interceptor uses the HE warhead with proximity fuse (Army Technology, 2023). Estimated costs for the Tamir missile is between $20 and $100 thousand per missile (Missile Defense Advocacy Alliance, 2022).

Turkey has developed the Hisar system to create their own IADS. The Hisar system can be broken down into the Hisar-A and Hisar-A+, which Turkey has designated as their low altitude system and the Hisar-O, which is the medium altitude system. The Hisar-A+ has an effective range and altitude of 15km and more than 16,000ft AGL, respectively. The Hisar-O extends the effective range and altitude to 25km and just over 32,000ft AGL. Both missiles can be deployed from a tracked ACV-30 and it is unknown if they are C-130 transportable. Additionally, there is currently limited open-source information on the dimensions of the missiles (Army Recognition, 2022). The Hisar is one-way datalink enabled and requires ground support equipment to reload. Seeker guidance for the Hisar system is both passive infrared homing and semi-active homing. The missile uses a HE warhead with proximity fuse (Roketsan, n.d.). There is no unclassified cost data on the Hisar systems, an analogous cost estimate is used to build the decision matrix in the following section based on similarities between the Hisar-A/A+ and the AIM-9X and the Hisar-O and the AIM-120.

The UK's Sky Saber / Sea Ceptor are the land and sea variants of what the British military commonly calls the CAMM. The Common Anti-Air Module Missile has an effective range of 25km and can reach altitudes of greater than 49,000ft AGL. The system is self-contained on a conventional wheeled truck. It is two-way datalink enabled. However, it is currently unknown if the CAMM is C-130 transportable. Unclassified sources state that the CAMM is capable of manual and automated reloading. Seeker guidance for the CAMM uses active homing and typically uses an HE warhead with proximity fusing (MBDA, n.d.). There is no unclassified cost data on the CAMM, an analogous cost estimate is used to build the decision matrix in the following section.

There are several systems that can be considered capable alternatives that satisfy the Marine Corps' capability gap with considerations for increased range and altitude. Table 5 provides a consolidated view of the metrics outlined for the alternative systems.

Table 5. Criteria Metrics for Alternative Air Defense Systems

Criteria	FIM-92	IFPC	NASAMS	Iron Dome	Hisar	Sky Saber / Sea Ceptor
Mobility	Wheeled	Wheeled	Wheeled/ Trailer	Wheeled/ Trailer	Tracked ACV-30	Wheeled
C-130 Transportable	Yes	Yes	Yes	Unknown	Unknown	Unknown
Networking Capability	One-way datalink enabled	Two-way datalink enabled	Two-way datalink enabled	Two-way datalink enabled	One-way datalink enabled	Two-way datalink enabled
Re-arming requirements	Fire and Forget. Can not be reloaded	Manual reloading	Manual reloading	Manual reloading	Requires Ground Support Equipment	Rapid manual or automated reloading
Primary Short/Medium Range Munition	Stinger RMP Block I	AIM-9X	AIM-120	Tamir	Hisar-A/O	CAMM
Range	4.8km	35.4km	105km	70km	A: 15km O:25km	25km
Altitude	12,500ft	49,000ft+	49,000ft+	32,000ft+	A: 16,000ft+ O: 32,000ft+	49,000ft+
Seeker Guidance	Passive IR Homing	Semi-Active Homing, Passive IR Homing	Terminal Active Homing, Mid-Course Update Datalink, Inertial Guidance	Semi-Active Homing, Passive IR Homing	Passive IR Homing, Active Homing, One-Way Datalink, and Inertial Guidance (A/O)	Active Homing, Mid-Course Update, Inertial Guidance
Warhead and Fuse Type	HE warhead with impact fuse	HE warhead with proximity fuses	HE warhead with proximity fuse	HE warhead with proximity fuse	HE warhead with proximity fuse	HE warhead with proximity fuse
Length, Diameter and Weight	4ft 6in / 2.8in / 34lbs	9ft 11in / 5in / 186lbs	12ft / 7in / 356lbs	9ft 10in / 6.3 in / 200lbs	Note 1	10ft 6in / 6.5in / 218lbs
Cost Per System	$120,000 per missile	$337,000 per missile	$1,095,000 per missile	$60,000 per missile	Note 2	Note 2

Note 1: Missile dimensions were not available through open-source materials for reference. Assumption is that the missiles would be similar to AIM-9X and AIM-120 due to similar range.

Note 2: Cost per missile for both Hisar-A/O and CAMM were not available from open-source material. Analogous cost estimating methods were used to estimate cost per missile for both systems.

Based on the criteria weighting used in Table 4 to assess the FIM-92 Stinger Missile and the data and specifications listed in Table 5, we built the following tables to depict the analysis and effectiveness for each of our identified alternatives.

Table 6. Multi-Criteria Decision Analysis Effectiveness Ratio for the IFPC system and AIM-9X missile

System / Missile	IFPC / AIM-9X	cost:	$337.0							
0.35		Engagement Envelope	Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	35.4	0.344	1.5	100	0.206	0.706		0.713
	0.40	Altitude (ft ABG)	49,000	1.250	4,000	40,000	0.500			
0.1		Physical Dimensions						Physical Dimensions		
	0.40	Length (inches)	119	0.462	180	48	0.185	0.561		
	0.15	Diameter (inches)	5	0.769	15	2	0.115			
	0.45	Weight (lbs)	186	0.578	400	30	0.260			
0.2		Seeker / Guidance						Seeker / Guidance		
	0.30	Active Homing	0	0.000	Yes = 1	No = 0	0.000	0.300		
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	1	1.000	Yes = 1	No = 0	0.300			
	0.20	Mid-Course Update	0	0.000	Yes = 1	No = 0	0.000			
	0.05	Inertial Guidance	0	0.000	Yes = 1	No = 0	0.000			
0.35		Mobility	Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	1	1.000	Yes = 1	Unknown = 0	0.900	1.000		
	0.10	Wheeled or Tracked	1	1.000	Wheeled = 1	Tracked = 0	0.100			

Table 7. Multi-Criteria Decision Analysis Effectiveness Ratio for the NASAMS and AIM-120 missile

System / Missile	NASAMS / AIM-120	cost:	$1,095							
0.35		Engagement Envelope	Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	105	1.051	1.5	100	0.630	1.130		0.881
	0.40	Altitude (ft ABG)	49,000	1.250	4,000	40,000	0.500			
0.1		Physical Dimensions						Physical Dimensions		
	0.40	Length (inches)	144	0.273	180	48	0.109	0.255		
	0.15	Diameter (inches)	7	0.615	15	2	0.092			
	0.45	Weight (lbs)	356	0.119	400	30	0.054			
0.2		Seeker / Guidance						Seeker / Guidance		
	0.30	Active Homing	1	1.000	Yes = 1	No = 0	0.300	0.550		
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.20	Mid-Course Update	1	1.000	Yes = 1	No = 0	0.200			
	0.05	Inertial Guidance	1	1.000	Yes = 1	No = 0	0.050			
0.35		Mobility	Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	1	1.000	Yes = 1	Unknown = 0	0.900	1.000		
	0.10	Wheeled or Tracked	1	1.000	Wheeled = 1	Tracked = 0	0.100			

Table 8. Multi-Criteria Decision Analysis Effectiveness Ratio for the Iron Dome system and Tamir interceptor

System / Missile	Iron Dome / Tamir	cost:	$60							
0.35	Engagement Envelope		Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	70	0.6954	1.5	100	0.417	0.728		0.453
	0.40	Altitude (ft ABG)	32,000	0.7778	4,000	40,000	0.311			
0.1	Physical Dimensions							Physical Dimensions		
	0.40	Length (inches)	118	0.4697	180	48	0.188	0.532		
	0.15	Diameter (inches)	6.3	0.6692	15	2	0.100			
	0.45	Weight (lbs)	200	0.5405	400	30	0.243			
0.2	Seeker / Guidance							Seeker / Guidance		
	0.30	Active Homing	1	1.0000	Yes = 1	No = 0	0.300	0.550		
	0.15	Semi-Active Homing	0	0.0000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	0	0.0000	Yes = 1	No = 0	0.000			
	0.20	Mid-Course Update	1	1.0000	Yes = 1	No = 0	0.200			
	0.05	Inertial Guidance	1	1.0000	Yes = 1	No = 0	0.050			
0.35	Mobility		Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	0	0.0000	Yes = 1	Unknown = 0	0.000	0.100		
	0.10	Wheeled or Tracked	1	1.0000	Wheeled = 1	Tracked = 0	0.100			

Table 9. Multi-Criteria Decision Analysis Effectiveness Ratio for the Hisar-A/A+ system and missile

System / Missile	Hisar-A+	cost:	$399.5							
0.35	Engagement Envelope		Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	15	0.137	1.5	100	0.082	0.216		0.233
	0.40	Altitude (ft ABG)	16,000	0.333	4,000	40,000	0.133			
0.1	Physical Dimensions							Physical Dimensions		
	0.40	Length (inches)	136	0.333	180	48	0.133	0.480		
	0.15	Diameter (inches)	6	0.692	15	2	0.104			
	0.45	Weight (lbs)	200	0.541	400	30	0.243			
0.2	Seeker / Guidance							Seeker / Guidance		
	0.30	Active Homing	0	0.000	Yes = 1	No = 0	0.000	0.550		
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	1	1.000	Yes = 1	No = 0	0.300			
	0.20	Mid-Course Update	1	1.000	Yes = 1	No = 0	0.200			
	0.05	Inertial Guidance	1	1.000	Yes = 1	No = 0	0.050			
0.35	Mobility		Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	0	0.000	Yes = 1	Unknown = 0	0.000	0.000		
	0.10	Wheeled or Tracked	0	0.000	Wheeled = 1	Tracked = 0	0.000			

Table 10. Multi-Criteria Decision Analysis Effectiveness Ratio for the Hisar-O system and missile

Sytem / Missile	Hisar-O+	cost:	$1,090							
0.35		Engagement Envelope	Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	35	0.340	1.5	100	0.204		0.515	0.306
	0.40	Altitude (ft ABG)	32,000	0.778	4,000	40,000	0.311			
0.1		Physical Dimensions						Physical Dimensions		
	0.40	Length (inches)	165	0.114	180	48	0.045		0.157	
	0.15	Diameter (inches)	8	0.538	15	2	0.081			
	0.45	Weight (lbs)	375	0.068	400	30	0.030			
0.2		Seeker / Guidance						Seeker / Guidance		
	0.30	Active Homing	0	0.000	Yes = 1	No = 0	0.000		0.550	
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	1	1.000	Yes = 1	No = 0	0.300			
	0.20	Mid-Course Update	1	1.000	Yes = 1	No = 0	0.200			
	0.05	Inertial Guidance	1	1.000	Yes = 1	No = 0	0.050			
0.35		Mobility	Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	0	0.000	Yes = 1	Unknown = 0	0.000		0.000	
	0.10	Wheeled or Tracked	0	0.000	Wheeled = 1	Tracked = 0	0.000			

Table 11. Multi-Criteria Decision Analysis Effectiveness Ratio for the Sky Saber and CAMM

Sytem / Missile	Sky Saber / CAMM	cost:	500							
0.35		Engagement Envelope	Measures	Value			Weight*Value	Engagement Envelope		Overall
	0.60	Range (km)	25	0.239	1.5	100	0.143		0.643	0.418
	0.40	Altitude (ft ABG)	49,000	1.250	4,000	40,000	0.500			
0.1		Physical Dimensions						Physical Dimensions		
	0.40	Length (inches)	126	0.409	180	48	0.164		0.483	
	0.15	Diameter (inches)	6.5	0.654	15	2	0.098			
	0.45	Weight (lbs)	218	0.492	400	30	0.221			
0.2		Seeker / Guidance						Seeker / Guidance		
	0.30	Active Homing	1	1.000	Yes = 1	No = 0	0.300		0.550	
	0.15	Semi-Active Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.30	Passive Homing	0	0.000	Yes = 1	No = 0	0.000			
	0.20	Mid-Course Update	1	1.000	Yes = 1	No = 0	0.200			
	0.05	Inertial Guidance	1	1.000	Yes = 1	No = 0	0.050			
0.35		Mobility	Measures	Value			Weight*Value	Mobility		
	0.90	C-130 Transportable	0	0.000	Yes = 1	Unknown = 0	0.000		0.100	
	0.10	Wheeled or Tracked	1	1.000	Wheeled = 1	Tracked = 0	0.100			

C. DECISION MATRIX

While considering the criteria listed in Table 4 along with the characteristics and specifications of the MADIS and the FIM-92 Stinger missile, this thesis developed a comparative model based on the system and munition characteristics, annotated as their effectiveness ratios, and the costs of the munitions. The weighting within this model was based on common trends among the requirements and attributes of Marine Corps systems and Programs of Record as covered earlier in this chapter. Refer to Table 4 for specific weighted values for each criterion.

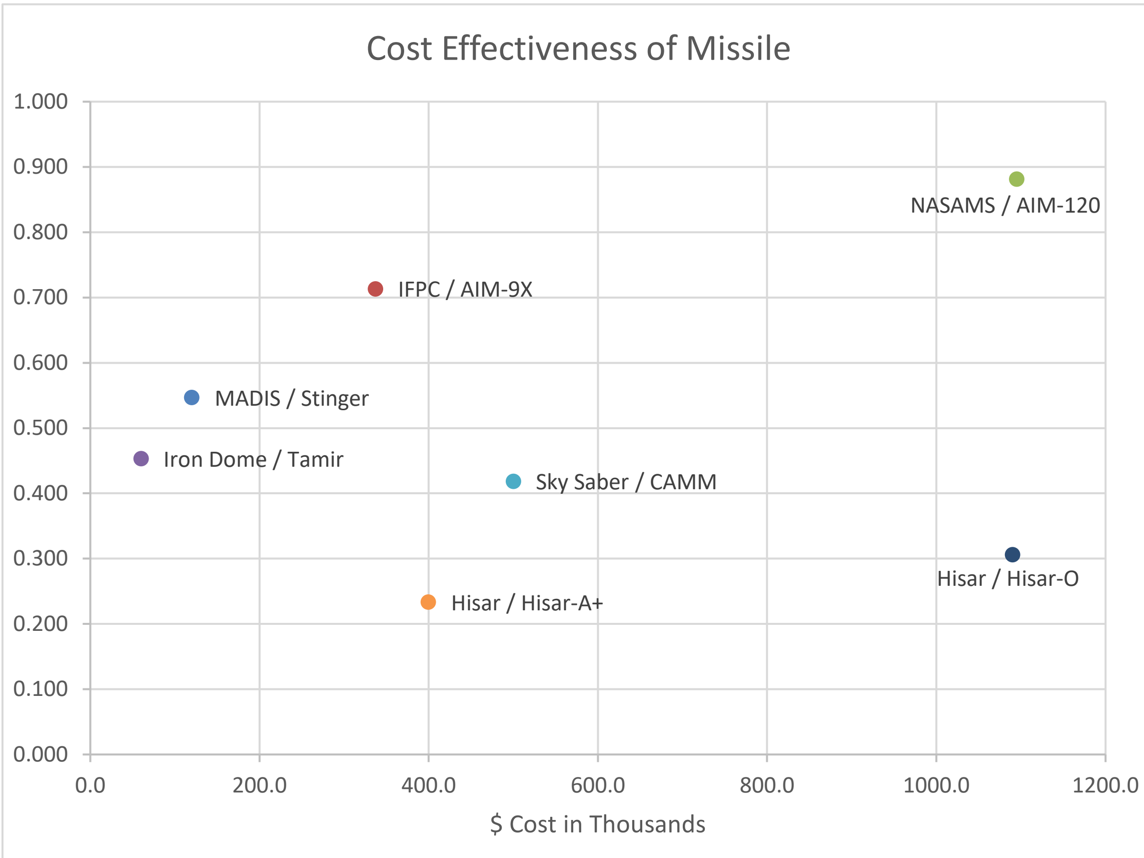

Figure 12. Effectiveness vs. Cost per missile

Based on the MCDA model shown in Figure 11, with cost per missile (in thousands) on the x-axis and weighted effectiveness of system and missile criteria on the y-axis, it can be concluded that multiple systems are not feasible options as they are dominated by others and thus can be eliminated from consideration. This is true for both Hisar systems and the Sky Saber system. This leaves three systems evaluated by this thesis as viable options to complement the MADIS and Stinger missile. While the NASAM system received a 0.88 effectiveness ratio, it costs $1,095,000 per missile. While the NASAM sees a 24% increase in effectiveness over the IFPC, it has a 225%

increase in cost per missile. Comparing the IFPC and Iron Dome system we see a 57% increase in effectiveness at a 462% increase in cost per missile.

Furthermore, our model demonstrates that both the IFPC with the AIM-9X and the Iron Dome with the Tamir interceptor could represent systems that would fill the air defense capability gap by providing increased range and altitude. It is important to note that one of the main factors separating these two is the lack of confirmation by open-source material that the Iron Dome is C-130 transportable. Further sensitivity analysis was conducted and when mobility was removed as a criterion, or assuming that systems such as Iron Dome and Sky Saber are C-130 transportable, then the results changed to indicate that Iron Dome would dominate all alternatives except NASAMS armed with the AIM-120.

These results do not conclude that these systems or munitions are the solutions to the capabilities gap but demonstrate the level of technology and material readiness needed to move forward with developing system requirements. Additional data is needed to confirm and develop a more comprehensive comparison of systems such as vehicle or trailer footprint, the system's ability to be transported via C-130 and the number of C-130s required to deploy the entire system, and the full cost of a single system with all required support equipment. Further consideration will also need to be given with regard to how much additional cost is appropriate to receive increased effectiveness.

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V. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

A. SUMMARY

This thesis analyzed the capability gap within the USMC's IADS, spotlighting the urgent need for the procurement of a complementary air defense system that tackles medium-altitude and medium-range aerial threats. The research questions posed by this thesis were: Is there a capabilities gap within the USMC's IADS? Secondary research question: How can the gap be filled? What are the effectiveness ratio values of various materiel options to close the gap?

This thesis supported the statements and initiatives of General Berger calling for a need to invest in medium range and medium altitude air defense weapons systems. Additionally, the literature that focused on the advancing aerial threats and the current capabilities within the USMC's inventory presented a dilemma in the Marine's ability to deter and defeat threats at adequate distances. To fill this gap, this thesis explored multiple alternative air defense systems in use today by allied countries. Alternatives such as the Iron Dome system from Israel and the Sky Saber system from the United Kingdom in addition to systems currently employed by the U.S. Joint Force such as IFPC and NASAMS were analyzed. Based on these alternative systems and the missiles these systems utilize, our MCDA model calculated effectiveness ratios ranging from 0.23 to 0.88. Analysis of these effectiveness ratios along with the cost of the missiles they use helped to identify which alternatives could provide additional effectiveness with minimal cost increases as compared to the Marine Corp's current Stinger missile.

B. CONCLUSION

In conclusion, closing the identified capability gap is a strategic necessity that requires immediate, focused action. This analysis stressed the importance of a structured MCDA and CEA that incorporates the weights of required capabilities that fit into a layered defense CONOP, which is crucial for the USMC's effectiveness in contested areas, ensuring force protection and strategic deterrence. The fast-paced evolution of aerial threats and the critical roles of air superiority and sea control in modern conflicts underscore the need to promptly address the identified gap. This research addressed the

USMC's critical need to adopt advanced air defense systems, by highlighting alternative systems which provide increased engagement ranges with munitions such as the Tamir and AIM-9X missiles, to effectively deter and mitigate aerial threats. This adoption goes beyond a mere call for procurement but calls for the evolution of the USMC’s IADS and demonstrates the USMC's adaptation to modern warfare, especially within the EABO framework.

C. RECOMMENDATIONS

Based on this thesis, our recommendations for future research include (a) conducting further analysis of the capabilities and characteristics of each of the air defense systems identified in this thesis to include data and specifications at the secret level of classification focusing on effective ranges and physical dimensions of the systems and missiles; (b) conducting a detailed cost-benefit analysis that includes total estimated lifecycle costs for each of the air defense weapon systems used in the analysis: (c) conducting further analysis of the potential to integrate one of the identified missiles with current and emerging vehicles employed by the USMC: (d) and developing an acquisition strategy proposal for the procurement of an air defense weapon system that closes the capability gap while meeting the expeditionary requirements of the Marine Corps’ mission set within the modern EABO environment.

The recommendations aim to steer the USMC toward strengthening its air defense posture, ensuring its operational efficiency in future battlefields. This effort requires a shift in resource allocation as well as a strong commitment to innovation, collaboration, and strategic foresight. Implementing these recommendations equips the USMC to navigate the 21st century's complex security landscape, safeguarding national security interests and fostering global stability.

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