USC SHIELD Executive Program Cohort '23

Capstone Problem Statement

Abstract:

Cruise missiles are relatively small, fast, and difficult-to-detect threats that can target key critical infrastructure with the potential for devastating effects. Recent advances in cruise missiles increase the standoff range from which they can be launched, enable hypersonic speeds, and decrease their detectability by radars, creating a multi-axis threat that stresses even the most advanced defensive systems. To combat these threats, there is a need for a network of systems capable of early detection and engagement of threats. Past efforts have proven too costly for defense beyond the national capital. However, the emergence of the People's Republic of China as the U.S. pacing challenge, the shift from strategic deterrence to deterrence by denial, and the acquisition of over-the-horizon radar systems create an opportunity for a fresh look at North American cruise missile defense. This paper asks, given these developments, "How should the Department of Defense establish a credible, innovative, and technology-centric defense architecture for cruise missile defense of the homeland?"

Introduction

The problem of cruise missile attacks on North America has long bedeviled those tasked with cruise missile defense. General VanHerck, the Commander of NORAD/USNORTHCOM, recently explained to the Senate Armed Services Committee that his ability to defend the homeland from cruise missiles "has eroded and continues to erode" (VanHerck, 2022, p. 3). This

is chiefly due to advances in cruise missile design. Advances in cruise missiles over the last decade have enabled greater missile ranges while decreasing radar cross-sections. Greater ranges enable bombers to launch missiles without ever approaching North America. This capability deprives North American cruise missile defenses of some of the most telling indications and warnings of impending cruise missile attacks that were used in the past to focus defensive efforts.

Without the indications and warnings from approaching bombers, cruise missile defense relies on North American air surveillance radars to provide initial indications of inbound cruise missiles. However, the reduced radar cross-section and low-flight profiles of cruise missiles significantly reduce radar detection ranges. With sufficient detection range, there is enough time to scramble and position aircraft to intercept the difficult-to-detect and fast-moving missiles.

When considered at scale, the tactical problem of cruise missile defense quickly becomes an overwhelming operational and strategic problem: cruise missiles can appear at almost any point on a 360-degree angle of attack to North America, and cruise missile defense response timelines are insufficient to intercept missiles anywhere outside of the U.S. national capital region. The National Capitol Region has an integrated air and missile defense system incorporating additional sensors, communication capabilities, and ground-based air defenses to produce a credible cruise missile defense capability (JADOC, 2023). Expanding such a system to the rest of North America is a ‘bridge too far’ for current political and budgetary realities. The result has been the erosion of credible cruise missile defense that General VanHerck described.

However, the confluence of three changing factors creates the opportunity to take a fresh look at the challenge of North American cruise missile defense. First, the PRC is emerging as the pacing challenge for the United States, eclipsing Russia. Second, with the rise of China, the U.S.

is shifting from a CENTCOM VEO focus to preparing for the possibility of great power conflict in the Indo-Pacific region. Finally, acquiring over-the-horizon radars in North America enables various solutions to some of the cruise missile defense's most challenging technical and force management challenges. These three factors suggest that fresh thinking about homeland cruise missile defense may lead to breakthroughs in this longstanding policy and national security challenge.

This paper will first discuss the background of the challenge inherent to cruise missile defense, including Russian and PRC cruise missile developments. Second, this paper will explore the emergence of the PRC as the U.S. pacing challenge. Third, the need for a shift from strategic deterrence to deterrence by denial, and fourth, the consequences of the recent acquisitions of additional over-the-horizon radars in North America. Finally, the paper will recommend an agile cruise missile defense architecture as both affordable and effective for the cruise missile defense of North America.

The Cruise Missile Threat

Cruise Missile Developments

First, some background on cruise missiles helps establish the problem of cruise missile defense. Most cruise missiles comprise a booster, an onboard propulsion system, fuel, a warhead, and various navigation and guidance systems. These systems are integrated into an aerodynamic frame, most equipped with fins for stabilization and maneuverability. The booster provides the initial thrust needed to get the missile airborne. Typically, this section detaches after the initial seconds of flight, and the onboard propulsion system takes over to propel the missile along its flight path to its target. Typical propulsion systems include ramjet, turbofan, and turbojet, each with advantages and disadvantages. It is important to note that these systems are also used in aviation manufacturing, which makes restricting their sale or transfer problematic.

The type and amount of onboard fuel available largely determine the base range of the cruise missile. Liquid-fueled cruise missiles require highly corrosive chemicals to be loaded before the flight. Once fueled, these missiles must be fired or refueled to prevent damage to the missile's fuel tank. Solid-fueled missiles are more stable, allowing them to remain dormant for much longer before use.

The warhead contains the destructive force of the cruise missile. Conventional cruise missiles have high explosive shape charges, allowing precision strikes that limit collateral damage. However, cruise missiles are increasingly capable of delivering weapons of mass destruction payloads, including nuclear, chemical, and biological agents. The size and type of warhead a cruise missile carries largely determines its use. Because the warhead is so versatile, cruise missiles can be used for various missions, including the first strike at the onset of conventional hostilities, precision strikes for policing actions, or possibly even as a terror weapon for deterrence.

The final segment of the cruise missile contains the guidance and navigation systems. Like the onboard propulsion systems, the components and software associated with this segment are also dual-use technology.

Cruise Missile Flight Path

Cruise missiles can be launched from land, air, or sea from ranges that are hundreds to thousands of kilometers from a target. Though cruise missiles employ a variety of flight profiles, there are distinct phases of flight that are common. The booster is initiated in the boost phase until it exhausts its fuel supply and separates from the cruise missile. During this phase, the cruise missile accelerates, beginning an almost ballistic trajectory to gain speed and altitude. Once the booster separates, the cruise missile begins the midcourse phase of flight. It is here where cruise missile flight is unique compared to other missile threats. The cruise missile follows a preprogrammed flight path using sophisticated guidance and navigational systems. Many cruise missiles fly at very low altitudes, sometimes just meters off the ground, at speeds ranging from subsonic to hypersonic. Often flight paths take advantage of terrain features that mask the cruise missile from detection by ground-based sensors.

The final phase of flight is the terminal phase, where the cruise missile detonates on, above, or near its target. Based on the flight path, this could be from any direction making cruise missiles an actual 360-degree threat. The accuracy of a missile is expressed in terms of the likelihood that the missile will impact within a circular area called the circular error probable (CEP). The CEP number defines the radius of a circle around the point of aim where 50 percent of the missiles fired will land. Generally, the lower the CEP, the more accurate the missile.

Cruise Missile Acquisition

Countries can acquire cruise missiles in a variety of ways. For those with the requisite knowledge and access to component technology, indigenous production is the preferred method to build a cruise missile arsenal (Gormley, 2010). Russia and China are examples of countries with this capability. Failing to have the expertise to manufacture a cruise missile, a government may seek to purchase a complete system from a known manufacturer. The difficulty in monitoring and tracking the manufacture and distribution of cruise missile components and systems remains challenging. One must only look at the global proliferation of these systems to see the limited effects achieved through current non-proliferation agreements.

Alternatively, a country may convert an existing Air-to-Surface Cruise Missile (ASCM) into and Land Attack Cruise Missile (LACM). Despite the widespread and large quantities of ASCMs worldwide, only a few have the potential for this conversion (Gormley, 2010). Nevertheless, it remains an option for countries that need to possess the means to develop or manufacture their cruise missile arsenal indigenously.

Converting an unarmed drone into a cruise missile provides another opportunity for a country to acquire a cruise missile arsenal (Gormley, 2010). This scenario is more troubling, with over 40 countries indigenously producing UAS for various military and non-military applications (Gormley, 2010). The prevalence of drones and other unmanned aerial systems has increased significantly in the last two decades. The threat these systems pose continues to grow, as they become increasingly prevalent on the modern battlefield. The current conflict in Ukraine underscores the use of drones as an ordinance-delivery method.

Similarly, converting small aircraft kits into missile systems is another potential source for building a cruise missile inventory (Gormley, 2010). This situation, coupled with the UAS conversions, presents a desirable option for asymmetric or terrorist organizations due to their relative ease of attainability and cost-effectiveness. To compound the issue, these converted systems are challenging to detect or classify due to their ability to blend in with already congested airspace in today's operational environment.

As discussed above, modern cruise missiles can be launched from air-, ground-, sea-, and undersea-based platforms (Karako et al., 2022). They have ranges of thousands of kilometers, are stealthy, fly shallow-altitude profiles that are difficult to detect by radar, and "can use onboard navigation and autonomous target recognition to maneuver, loiter, and attack from several directions simultaneously" (Karako et al., 2022, p. 2).

Russia

In 2012, Russia fielded a new generation of cruise missiles with a range of 2,500 km– 2,800 km, possibly as much as 6,000 km (Karako et al., 2022). The Kh 101-102 can be either conventional or nuclear warheads and is covered in radar-absorbing material, making radar detection of the low-flying, small cruise missile even more difficult. The standoff ranges of the missiles enable bombers to launch the missiles far beyond existing radar detection ranges in North America, creating a difficult timing challenge when initial detection of inbound cruise missiles may take place a matter of minutes before impact, which is well inside response timelines of air defenses.

China

The People's Republic of China (PRC) possesses conventional and nuclear land-attack cruise missiles with ranges estimated to be greater than 1,200 miles. Since 2014, the PRC has been developing hypersonic glide vehicles and hypersonic cruise missiles. PRC hypersonic glide vehicles can reach nearly Mach 10, maneuver to avoid missile defenses, and carry conventional or nuclear payloads (Hypersonic Weapons Basics, 2018). The PRC has several operational cruise missiles that can be launched by air, ship, or submarine (Missiles of China, 2021). The PRC submarine fleet is expected to grow to between 65 and 70 submarines in the 2020s (China Submarine Capabilities, 2023). These capabilities indicate that the PRC already possesses a limited cruise missile threat to North America and is currently working on expanding its capabilities to target North America.

The Challenge of Cruise Missile Defense: F2T2EA

The Air Force divides dynamic targeting into six steps: find, fix, track, target, engage, and assess (F2T2EA) (AFDP 3-06, 27). The F2T2EA process provides a helpful way of presenting

the difficulties of cruise missile defense for each of the six steps of the process. The following section explains the challenges of cruise missile defense through the F2T2EA process.

Find and Fix

The find and fix phases begin with the initial detection and characterization of targets. The find phase is the initial detection of an emerging target by sensors. Sensors routinely find many emerging targets, only some of which warrant further investigation. In the fixed phase, targets that need engagement are distinguished from those threats that do not require engagement, spurious sensor returns, and friendly targets.

In the case of homeland cruise missile defense, find and fix begins with radar detection of a missile or the launch platform, such as a long-range bomber carrying cruise missiles . Before the advent of modern long-range cruise missiles, cruise missile-carrying bombers had to approach within a specific range of targets in North America. This situation allowed air defenses to track and target the bomber before the missile launch. Indications and warnings of cruise missile-carrying bombers approaching the North American landmass enabled the scrambling of alert fighters to intercept bombers at their required approach points to North America. The find phase of cruise missile defense was enabled by indications and warning of bomber approach and tracking of bombers in their launch areas by NORAD fighters. Fighters could observe any launch of cruise missiles by the bombers and engage either bombers or missiles at their point of origin.

The development of long-range cruise missiles has dramatically complicated the find and fix phases. Bombers no longer have to approach the North American landmass to launch their missiles. Instead of relying on indications and warning of approach bombers, the first indications of inbound modern cruise missiles will likely be radar detection of the cruise missiles themselves. However, cruise missile size and flight profiles make radar detection by ground-based surveillance radars difficult; “a typical surface-based radar has a search horizon of around

40 km for a target at typical cruise missile altitudes" (Karako et al., 2022, p. 2). Such a short detection range means that "a subsonic cruise missile first detected at the horizon may close the remaining distance in just over two minutes" (Karako et al., 2022, p. 2). Though airborne warning systems such as the E-3 Sentry can provide much longer detection ranges, they must be cued and launched hours ahead to the correct location to detect incoming cruise missiles. The approach of bombers provided this cueing with sufficient time in the past. Still, now that bombers can launch their missiles from further away, cueing is no longer a reliable means of positioning an E-3 for intercept.

Track and Target

Two minutes leaves far too little time for legacy homeland air defense capabilities to accomplish the remaining steps of the F2T2EA process. The Track phase maintains positional awareness of targets for engagement and enables the prediction of future locations to position friendly forces. Tracking a target over time also provides additional information about flight characteristics to identify the target type better. The Target phase involves pairing weapons or other non-kinetic means of defense with targets. Both kinetic and non-kinetic engagement means effectors are selected based on their ability to engage the target before it reaches defended assets. Additionally, the target phase includes the approval process for engagement orders against the target.

The legacy homeland defense construct outside the National Capitol Region depends primarily on fighter aircraft intercepting airborne targets. Armed alert fighters sit at the ready at numerous bases in North America. However, even though they are prepared to scramble immediately, getting fighters airborne and intercepting a target still takes time. Two minutes of time is completely inadequate to get fighters airborne and in position to intercept incoming cruise missiles. The only possibility would be if fighters were already airborne in combat air patrols

over the intended targets of cruise missiles attack. Even in this case, two minutes of detection will likely provide insufficient time to get fighters to engage and obtain engagement authorization for a first volley of cruise missiles. The conclusion is that the legacy homeland air defense construct would not effectively engage a first wave of cruise missiles even if satisfactory advanced warning resulted in fighters already in combat air patrols over a cruise missile target.

Engage and Assess

The Engage and Assess phases involve using effectors on cruise missiles and confirmation that the effectors successfully defeated the cruise missile. The legacy homeland air defense construct relies primarily on air-to-air missiles for engagement and pilot confirmation of successful destruction of the target. Though current air-to-air missiles are effective for engaging cruise missiles, alert fighters can only carry a certain number of missiles, limiting the number of cruise missiles that can be engaged by fighter aircraft.

Modern Cruise Missiles Challenge Legacy F2T2EA

The legacy homeland air defense construct has several significant challenges with modern cruise missiles. The first one is the short detection range for current effector timelines. As discussed above, modern cruise missiles may be launched from ranges outside of sensor coverage. Small, low-flying, low-observable cruise missiles can evade current sensor coverages until within as little as 40 km of ground-based sensors in North America. Standoff launch ranges make early cueing of airborne sensor platforms unlikely to supplement ground-based detection. The result is that limitations of the current cruise missile defense system in the Find phase of the F2T2EA process render all subsequent phases far behind the timelines necessary for effective engagement.

The second significant challenge is the target phase. Outside the National Capitol Region (NCR), the reliance on alert fighters dictates the minimum timelines for successful engagement.

Though alert timelines are classified, it took 15 minutes for alert fighters to get airborne on 9/11, which provides a useful unclassified baseline (W. W. Norton, 2004). On 9/11, the military had nine minutes between notification of threat aircraft and the impact of those aircraft into the World Trade Center. The scrambled fighters were airborne six minutes after the impacts had already occurred.

Though many changes were made to homeland air defense architecture after 9/11, these changes were limited to other alert bases, increased access to civilian ground-based radar sites, and additional capabilities in the National Capital Region. There needs to be more room for improvement given what it takes alert aircraft to scramble, get airborne, communicate with command and control, travel to intercept points, and engage targets. Thus, the example of 9/11 demonstrates that detection ranges and targeting timelines render existing infrastructure a "limited defensive capability, but not much more" (Karako et al., 2022, 9).

Changes to Post-9/11 Environment Enabling a New Look at Cruise Missile

Defense Change 1: The NDS and the Pacing Challenge of the PRC

The first significant change is the shift from the post-Cold War focus. Since the early 1990s, the U.S. military has sized and shaped for two significant conflicts plus an asymmetric conflict. The last three decades have been focused on violent extremist organizations, primarily in CENTCOM and AFRICOM, while maintaining a stable deterrence of Russian strategic attack. This status quo definitively changed with the 2018 National Defense Strategy, the shift to a single conflict posture, and the identification of the PRC as the nation's primary pacing challenge. The Russian invasion of Ukraine has only further solidified the focus on China as the appropriate pacing challenge for the foreseeable future. At the same time, Russia remains a primary concern for strategic deterrence.

The 2022 NDS continues the focus on China, which has far-reaching implications for considering cruise missile defense. Though the Cold War included periods of intense tensions between the U.S. and the USSR over Cuba, Berlin, and South East Asia, more recent post-Cold War relations between the U.S. and Russia have not included such tension. About the PRC, on the other hand, the status of Taiwan is a significant potential flash point. Sometimes called “the most dangerous place on Earth” (Metz, 2021, para. 1), the PRC has repeatedly suggested a willingness to use force to “reunite” Taiwan and mainland China, while the U.S. has maintained an ambiguous security commitment to assist Taiwan in the event of an attack by the PRC. The August 2022 visit to Taiwan of the Speaker of the U.S. House of Representatives resulted in large-scale PRC military exercises in the vicinity of the Taiwan Straits and fears of a fourth Taiwan Straits Crisis (Lin, Hart, Funaiole, Lu, Price, & Kaufman, 2022).

Senior military leaders leave no doubt about where they see the most pressing threats to the United States; Gen. Mike Minihan, head of Air Mobility Command, has publicly stated that he expects a conflict between the U.S. and the PRC in 2025 (Cohen, 2023). Though NORAD-NORTHCOM continues to focus on Russia as the primary cruise missile threat, the 2022 designation of the Air Force as the lead service for homeland cruise missile defense (Sherman, 2022) and Secretary of the Air Force Frank Kendall’s top three priorities of “China, China, China” (Tirpak, 2021) suggest that the threat to U.S. national security policy may be shifting. Though Russia possesses more extensive cruise missile capabilities, the PRC poses a more likely and dangerous adversary for the U.S. In particular, a confrontation with China over Taiwan presents the most challenging and likely scenario in which North American cruise missile defense may be a significant factor.

The United States cannot expect to deter cruise missile attacks once conflict begins. "As seen in Ukraine and several other recent conflicts, the employment of precision-guided cruise missiles has become commonplace"(Karako et al., 2022, p. 1). A shift in thinking on cruise missile defense is critical to the success of future U.S. national security policy.

One of the primary ends of military strategy is to provide the Commander in Chief (CINC) with time and options to deal with any crisis. Policymakers may want to use military force in a conflict with the PRC over Taiwan. Part of any calculation for using military force will likely be responses by adversaries. If those responses potentially include cruise missile attacks on the North American landmass, the CINC must confront the lack of credible cruise missile defense. The resultant vulnerability will add costs to some policy options. Therefore, the lack of credible cruise missile defense will limit the policy options available to the CINC in any conflict with the PRC or Russia. This scenario is a departure from past thinking on cruise missile defense as intended to defeat an unprovoked attack from Russia. In the past, an unprovoked attack from Russia was primarily an issue of strategic deterrence; therefore, cruise missile defense functioned as a secondary layer of defense. For this reason, the erosion of credible cruise missile defense has been tolerated by policymakers rather than undertaking the vast investments required for building a credible defense against modern cruise missiles. However, a crisis response mindset oriented toward the PRC presents a far more compelling case for developing credible cruise missile defense to enable increased policy flexibility for policymakers.

Change 2: From Strategic Deterrence to Deterrence by Denial

Offense/Defense Balance

The offense/defense balance is an international relations theory that seeks to determine the probability and likely result of the conflict in the international arena (Anderton, 1992). A vital concept of the theory is that it seeks to describe or predict the nature of war before it is prosecuted. From a realist perspective, the theory assumes a chaotic international environment where states must affect their destiny (Lynn-Jones, 1995). To maintain a strategic advantage, a state may employ an offensive or defensive strategy to maintain national security.

A typical application of the theory suggests that when the defense is perceived to be dominant, wars are less decisive, longer in duration, and more costly in destruction and lives lost (Anderton, 1992). Conversely, when the offense is dominant, wars are quick, decisive, and minor in terms of states involved and overall cost (Anderton, 1992). The theory also applies to weapon systems in addition to states with a focus on the nature of the weapons being developed. For example, if the weapons being produced and their intended use is offensive, this offense is the predominant characteristic of the international environment. Similarly, defense is king when defensive weapons are used (Anderton, 1992).

The argument can be framed another way. In either environment, the focus is to allocate resources to offset the enemy's allocation in the opposite strategy (Lynn-Jones, 1995). For example, in an offensive environment, one state will increase defense spending on offensive weapon systems. Its adversary will then allocate resources to defensive systems to counter the former's military developments, often at a much higher cost. With cruise missiles being a cost-efficient offensive weapon system compared to the measures needed for defense, increased development and proliferation may indicate an offensive environment.

The environment may explain the development of increasingly capable cruise missiles and the perceived need to increase proliferation to shared adversaries. The primary proliferators for cruise missiles and cruise missile technology are former Soviet bloc countries, including Russia and Ukraine (Baker, 2001). Increased tensions between these countries and the United States in an offensive international environment indicate the likelihood of continued and possibly increased proliferation of these weapons and technology. As each side mounts an arsenal of these capable weapons, emphasis on defense from the threat should also increase. However, to conserve national resources to develop offensive capabilities, states may opt for incremental increases in defense system capabilities rather than expending the tremendous amount of national resources required to create a new defense system.

In the case of the United States, this phenomenon is evident with the continued upgrade of Patriot software, interceptors, and radar sets. Despite its lackluster performance in Operation Iraqi Freedom against Iraq's rudimentary cruise missiles, defense efforts focused on incremental updates rather than developing a new cruise missile defense system.

Applicability

An offense/defense theoretical lens lays the foundation for describing the current security environment. Currently, the offense is the dominant principle of war regarding cruise missiles. First, much defense spending in the past two decades focused on generating offensive capabilities. This practice could suggest that the international environment is tending toward the offense. Second, international conflicts after the Cold War were prosecuted with the intent of a decisive, short-duration conflict. The first Gulf War was initiated and closed within 100 hours and included the heavy use of cruise missiles and other new offensive weapon systems. Similarly, despite the conduct, Operations Enduring Freedom and Iraqi Freedom were planned for decisive victory by utilizing sophisticated technology to defeat the opposing force quickly. The following insurgency is more brutal to classify, as there must be a capable government, or state, to prosecute a conventional war.

Key Criticisms

The international environment is no more absolute than the last digit of pi. The constant ebb and flow of international agreements can alter defense spending, which makes determining the exact nature of the international environment difficult. However, the theory has some explanatory power in describing the nature of the international environment at a snapshot in time. This perspective may explain why cruise missiles continue developing and their proliferation continues to be challenging. If states and non-state actors seek to prosecute a short and decisive war, the cruise missile may serve as David's crude rock and sling to bring a giant to its knees. The precise nature of cruise missiles allows an inferior conventional force, or perhaps in a more asymmetric context, an inferior non-state actor that despises the Western culture, a means for inflicting a mortal wound on a superior adversary.

Defense Design

Crisis response shifts the focus of a cruise missile defense system from strategic deterrence to deterrence by denial. Creating a defense design for cruise missile defense is a monumental task that begins with a well-defined list of critical assets and requires the right balance of sensors, shooters, and integrated battle command systems.

First, the Combatant Commander is responsible for developing a theater Critical Asset List (CAL) to determine what must be defended. The CAL is a prioritized list that identifies everything within a designated area that should be protected from a threat, such as a cruise missile attack (JP 3-01, III-15 – III-16). For North America, the Commander of NORAD-NORTHCOM is the Combatant Commander responsible for developing this list. The CAL is the foundation for all the work conducted in developing a defense design for cruise missile defense that aligns with national priorities and national defense policy.

Joint doctrine describes the process for nominating and prioritizing assets for the CAL based on the "CVT" methodology (JP 3-01, III-16 – III-18). Each asset is evaluated based on the criticality, vulnerability, and threat of an attack on the asset. The result is a prioritized list with the most critical assets for the successful execution of the mission that is in line with the priorities of the Commander.

With the CAL as the baseline, NORTHCOM must develop a Defended Asset List (DAL) based on the apportionment of forces. Beginning with the most critical assets, IAMD resources are assigned to protect the Commander's top priorities at the directed level of protection (JP 3-01, III-18). To develop the defense design with such a finite number of IAMD resources, the lack of a developed CAL handicaps the ability to prioritize the most critical assets. As such, a Theater Level CAL is imperative to the development and execution of any Theater Level DAL to achieve mission success.

While the current analysis and prioritization of the NORTHCOM CAL are classified, one can assume that in terms of cruise missile defense, the CAL will be focused on the critical infrastructure required for continuity of government, strategic military capabilities, and power projection nodes. Given the historical use of cruise missiles as precision strike weapons coupled with the limited WMD payload capacity compared to ballistic missiles, the likelihood of an initial cruise missile strike is most likely aimed at hampering a response rather than a quick bid at a decisive victory.

Change 3: Other-the-Horizon Radar and Emerging Technical Solutions

The sensors within a credible cruise missile defense architecture must be capable of early detection of the threat. Ideally, hundreds of miles from the North American border allow the maximum battlespace for the weapons release authority and tactical system operators. To achieve this level of early warning, the sensor should be capable of detecting and tracking objects over the horizon, and at the proper aspect angle, to effectively identify and discriminate a cruise missile from a crop duster.

The Canadian government and the U.S. Air Force actively seek such a capability. The Defense Research and Development Canada (DRDC) within the Canadian Department of National Defense (DND) is seeking to develop an Over-The-Horizon Radar (OTHR) capability to support a defensive architecture around their capital in Ottawa. Raytheon's Canadian element was awarded the initial contract to build and deliver the Ottawa-based sensor and an additional Polar Over-The-Horizon Radar (POTHR) system consisting of two OTHRs in northern Canada to detect threats well before they enter into North American airspace. Initial operational capability is expected within the FY 2025-27 timeframe. Given that a likely threat to the U.S. homeland will transit the polar regions, this capability will significantly extend the ability of a cruise missile defense architecture to execute the Find and Fix elements of the F2T2EA targeting strategy.

Analysis

When examining the characteristics of practical system components, several vital requirements become clear: a sensor network capable of detecting, tracking, and providing fire control quality data; an engagement system that includes both kinetic or non-kinetic effectors; and a battle command-and-control suite to synthesize and distribute warning and engagement data. Moreover, the system should be relocatable to ease the cost burden, as creating a defensive shield covering North America is not feasible.

Before describing these prospective solutions in detail, it is essential to note that intelligence is critical to the system's success. Early detection requires as much advance notice of an imminent threat as possible. It is unlikely that the American public will tolerate persistent and visible missile launchers spread across their cities. Current systems, such as the NASAMS system employed within the national capital region, are challenging to obscure from public view

while still being in the optimal position to defend a critical asset. However, to protect the critical infrastructure likely to be targeted at the onset of a crisis, the defense must be in place ahead of the first attack. The conundrum can be solved using a multi-tiered, intelligence-informed posture similar to the current Health Protection Condition (HPCON) or Defense Condition (DEFCON) levels. The concept is that the chosen systems are secured at nearby military installations during periods of the low threat of cruise missile attack and are emplaced and staffed as the readiness level increases.

Sensors

The OTHRs planned for Canada and the polar regions are expected to operate in the High-Frequency band (3-30 MHz), which provides sufficient data quality for early warning but is insufficient for generating a fire solution for ground-based effectors. A second sensor layer is required to provide fire control quality data.

To provide this second layer, the U.S. Army's land-based approach to cruise missile defense contains a system of systems on an integrated network. In a cruise missile defense network test performed by Raytheon, they successfully integrated the Joint Land Attack Cruise Missile Elevated Netted Sensor (JLENS), a Patriot missile defense system, and the Navy's Standard Missile-6. The JLENS aerostats could detect the inbound threat with VHS band radar, translate the data to a fire control X-band radar, and transmit the data to an engagement system's computers. The ability of JLENS to integrate into both the Patriot System and SM-6 fire control networks represents a milestone achievement by proving the network-centric concept for cruise missile defense and providing for coalition support of missile defense efforts. This test demonstrated the ability of an elevated dirigible to receive and distribute fire control quality data

to ground-based effectors. Moreover, these tests highlight today's technology to field a foundational system for cruise missile defense of the U.S. homeland.

The successes of the test indicate that the system is ready for deployment as a system of record. The JLENS-Patriot system provides the sensor and shooter system to defeat low-flying, fast-moving threats. While other capabilities are on the horizon, the tested capabilities are already in force today. The question is, should the Patriot system be used for cruise missile defense? Despite success in the test environment, the early failure of the Patriot system against cruise missiles in the second Gulf War casts doubt on the system's effectiveness. Even if it is successful, the cost of using the Patriot's PAC-2 missiles is substantial. Since the early failures, the Patriot system has undergone significant upgrades in hardware and software that dramatically increase the system's performance against cruise missile threats. When evaluating the threat and the availability of systems, the Patriot/JLENS combo is one of the few available today, is interoperable, and can accomplish the mission, albeit with a hefty price tag. The good news is that this initial architecture buys decision space and development time while future systems are developed.

Once such a system was jointly developed, and unfortunately named, Integrated Sensor is Structure (ISIS) airship. The program began in 2004 and was awarded a $400 million contract to develop an initial smaller-scale demonstration system scheduled for 2014, followed by a full-scale operational system planned for 2020. The system promised a substantial 10-year flight time, providing the persistence and the sensor suite required for an effective homeland cruise missile defense sensor.

Unfortunately, cost overruns and technological challenges caused the ISIS airship program to be defunded in 2015. This setback to the overhead aerostat development effort was made worse by the poor timing of a JLENS aerostat that broke loose from its docking station, dragging its tether cable over 160 miles from Maryland to Pennsylvania, causing over $1.5 million in damage. Despite these stumbling blocks, the need for elevated netted sensors remains valid. Maintaining a persistent, relocatable overhead sensor is still the primary goal for the homeland's cruise missile defense.

So, there is a conundrum. Does the defense department continue to advocate for funding for ISIS, the technologically challenged aspirational program, or for JLENS, the technically proven public relations challenge? There may be another solution. In March of 2022, the Israeli Directorate of Defense Research and Development (DDR&D) announced the deployment of their homeland defense aerostat, Sky Dew, which provides the overhead netted sensor capabilities required for a cruise missile defense architecture. The system was developed through a partnership between the U.S.-based company TCOM and the Missile Defense Agency (MDA), indicating that the technology is available within the U.S. today. This option may be the interim solution between the aspirational ISIS program and the complex history of the JLENS system.

Effectors

Each service within the U.S. military enables the missile defense force. The U.S. Navy utilizes guided-missile destroyers as part of a comprehensive fleet defense system that employs an array of weapons and sensors. The Aegis combat weapons system integrates air, surface, and anti-submarine warfare sensors and engagement systems. These warships purchased by the Navy enhance the class and provide a capable defense against anti-ship cruise and ballistic missiles. They are multi-mission platforms well suited to provide early warning and kinetic defeat opportunities in a layered defense architecture.

The U.S. Air Force defeats hostile cruise missiles through defensive layers. Specifically, it uses the E-3 surveillance platform and the advanced AMRAAM interceptor to maximize detection and engagement opportunities. F/A-22 fighters penetrate deep into enemy airspace and receive cueing data from the E-3's radar. If a cruise missile threat penetrates the initial layer, a series of F-15Cs and F/A-18 E/Fs are postured to engage the threat. Unfortunately, in some cases, the defense-in-depth strategy is insufficient as events unfold too quickly to exercise the kill chain adequately.

Moreover, the episodic nature of the defense begs the question: Is this solution the ideal defense strategy in terms of effectiveness and cost? Maintaining multiple defensive layers of airborne sensors and shooters is a costly endeavor. The mere existence of multiple layers of defense suggests a significant chance a cruise missile would get through, or the impact of a single successful attack warrants the extreme cost of the defense.

Patriot Missile Defense System

The Patriot missile defense system is designed to defend against various airborne threats, including ballistic missiles, cruise missiles, and aircraft. To defend against cruise missiles, the Patriot system uses organic MPQ-65 Patriot radar and either PAC-2 or PAC-3 interceptors. The Patriot radar detects and tracks incoming threats, generates a fire solution, and launches and guides interceptors to engage threats before they reach their intended targets. The Patriot's two types of interceptors, the PAC-2 and PAC-3, destroy the threat differently. The PAC-2 family of missiles is a blast-fragmentation missile designed to destroy targets by releasing a cloud of small, high-velocity fragments. The PAC-3 missile is a hit-to-kill missile designed to impact and eliminate the incoming threat with the kinetic force of a high-speed collision.

For cruise missiles, a threat missile is detected either organically with the Patriot radar or remotely with data passed from other sensors through a tactical datalink network. When deemed a threat, the Patriot system determines the optimal intercept point and launches the appropriate interceptor. The interceptor missile then flies to intercept the incoming missile, using its onboard guidance system to adjust its course as necessary. Once the interceptor missile is near the incoming missile, it detonates, destroying the threat. Overall, the Patriot system's ability to detect and track incoming cruise missiles and its interceptor missiles' speed and accuracy make it an effective defense against these threats.

There are limitations, however. The Patriot radar provides continuous guidance and control of the interceptors once launched. The interceptor and threat must remain within the Patriot radar's field of view to prosecute a successful engagement. Given a cruise missile's ability to maneuver and use masking terrain, the geography surrounding a critical asset may make using Patriot as a cruise missile defense solution less effective. As mentioned, using a multi-million-dollar interceptor against a much less costly cruise missile also begs for a more cost-effective solution.

Patriot does have some points in its favor, however. It is a combat-proven system capable of engaging various cruise missile threats. It is also a rapidly deployable and relocatable system that can be integrated into multiple tactical datalink networks to aid in acquiring and tracking threats. Finally, the Patriot system was successfully integrated with the JLENS sensor suite, which satisfies the requirement to link the sensor and shooters within the cruise missile defense architecture.

NASAMS

The Norwegian Advanced Surface-to-Air Missile System (NASAMS) Defense System is a highly advanced air defense system designed to defend against various airborne threats, including cruise missiles. To defend against cruise missiles, the NASAMS system employs a multi-layered approach, which includes an early warning, threat ID, target tracking, a kinetic intercept effector, and a command and control suite for the system.

To achieve early warning, the system employs a variety of sensors, including radar and optical sensors, to detect incoming threats out to 180 km. Once a threat is detected, the system uses advanced algorithms to analyze the data and identify the threat. The system tracks an incoming cruise missile utilizing a combination of radar and optical sensors that provide high accuracy to support generating a fire solution for the engagement system. The system is equipped with a range of interceptors, including the AIM-120 Advanced Medium-Range Air-to-Air Missile (AMRAAM), which is used to shoot down incoming threats. The entire system is controlled by a centralized command and control center, which coordinates the activities of all the sensors and interceptors and ensures that the system can respond quickly and effectively to any threat.

The NASAMS Defense System's multi-layered approach and advanced technology make it highly effective at defending against cruise missiles and other airborne threats. Unsurprisingly, this system is in place at our nation's capital providing defense for the NCR. It is another example of a system integrated into an existing defense architecture. Moreover, 13 countries are actively procuring or planning to acquire the system. The system has a steep price tag of roughly $200 million per unit. Like the Patriot system, it satisfies the mobility and performance requirements for a credible cruise missile defense architecture with a smaller footprint.

Command and Control

A system of sensors and shooters is a good start when establishing a foundational cruise missile defense system. However, a battle command suite to control is essential to demonstrate a credible capability. Given the vast array of capabilities available to support cruise missile defense spanning all services, there is a need for a centralized C2 system to enable a Joint All Domain

Command and Control (JADC2) concept. The joint community has historically struggled to achieve this concept, as previous efforts have alluded mainly to the joint force.

In today's joint force, two systems are prominent in discussing the command and control of missile defense platforms. These systems serve as the connective tissue between detection and engagement capabilities and provide the battle management functions required to ensure the primary mission of all defensive systems: the protection of friendly forces. The descriptions below outline the essential functions and components of these systems.

C2BMC

The Missile Defense Agency describes the C2BMC Suite as "The Command and Control, Battle Management, and Communications (C2BMC) program is the integrating element of the Missile Defense System. It is a vital operational system that enables the U.S. president, secretary of defense and combatant commanders at strategic, regional and operational levels to systematically plan ballistic missile defense operations, to collectively see the battle develop, and to dynamically manage designated networked sensors and weapons systems to achieve global and regional mission objectives" (MDA, 2022, para. 1).." The system links a variety of sensors and shooters through a series of data paths to distribute early warning data and provide battle management capabilities to remote nodes. The system can link global detection and engagement systems into a coherent common operating picture to provide decision space for a weapons release authority.

The system can be installed in three ways: a complete suite installation, remote workstations, or web browser client. The full suite consists of enterprise work stations (EWS), mission servers, network management equipment, security and external connection equipment, and internal and external communications connectivity, as required. EWS provides the user

interface to the software and databases needed to process messages and perform BMDS planning, control, and execution functions. The network management equipment includes the software required to perform BMDS communications planning, monitoring, and control and the hardware and software needed to support system administration and manage the various communications interfaces. The security and external connections equipment provides the physical interface to the host center and connectivity to the BMDS communication network(s).

Remote installations consist of an EWS connected to a server at a separate location. Remote workstations depend on the host suite for communications and network management but otherwise provide the user with the capability to interact fully with the planning and situational awareness C2BMC software applications. Web browser installations offer the most limited capability, allowing users to view the BMDS summary screen. Operators may interact with the display screen but have no further access to the data.

IBCS

An alternative solution to enable C2 of a cruise missile defense system is the Army's Integrated Air and Missile Defense Battle Command System (IBCS) to allow the "'any sensor, best shooter' concept. IBCS provides an opportunity to conveniently emplace a C2 structure to manage the ground-based sensor and shooter layer for a cruise missile defense system, free of geographical constraints of previous battle command systems.

The system comprises a central Engagement Operations Center (EOC) and Integrated Fire Control Network (IFCN) relay stations. The EOC consists of a truck-mounted tactical shelter that provides a controlled environment for EOC hardware, software, and communications equipment. It allows for the hasty emplacement of a Minimum Engagement Capability (MEC), creating a rapidly mobile command and control center that enhances the system's survivability.

The IFCN relay provides the interface to the component Plug and Fight A-Kit (Sensor or Weapon) to enable IFC network access or serve as an IFC network communications relay between nodes.

Alternatively, the system can be operated in an IBCS Collaborative Environment. In this configuration, the system provides the hardware necessary for long durations to conduct Engagement Operations (EO) and Force Operations (FO). It provides multifunctional workstations for the fire control element consisting of the Fire Control Officer, Weapons Control Officer, Surveillance Officer, and Identification Officer. The ICE offers Workstations to support Force Operations of support elements and create a functional operations center. The tactical version of the system employs a large tent structure, though the components can be emplaced into a rigid stand structure if desired.

An Agile Approach to Cruise Missile Defense

Establishing a cruise missile defense system for the homeland is warranted based on the changing operational environment and rapid advancement of threat weapon systems. The cost has historically been the primary consideration when deciding if a system will be funded. In previous instances, adversary capabilities and the perceived level of risk were not sufficient justification for the cost required to counter a multi-axis attack from an adversary. A Center for Strategic and International Studies (CSIS) study found that previous attempts to design a cruise missile defense architecture could cost anywhere from $77 billion to $466 billion (Karako, et al., 2022, p. 14). The CSIS team was able to design an architecture that cut the low-end estimate in half at $32 billion (Karako et al., 2022, p. 58). However, these architectures assumed the defense of a much larger defended area necessary to achieve a minimally credible defense capability.

For sensors, the already funded OTHR programs will significantly assist in identifying and tracking threats at long ranges. A second layer of sensors will substantially aid in target tracking and cueing of terminal defense systems. To this end, elevated sensors, such as JLENS are uniquely equipped to provide the aspect angle and discrimination capabilities to provide fire solutions for the appropriate shooters within the network. This alternative also establishes the initial mid-range sensing layer within the system that can be modified or upgraded over time as new technologies and capabilities are produced and fielded.

The shooters identified earlier are the most realistic options for a credible capability today. Patriot is expensive, heavy, and not easily obscured. However, it has the right capabilities for the terminal engagement of a cruise missile fired toward the U.S. homeland. It is moveable and can begin operations quickly, within 1-2 hours, once it arrives at a tactical site. This is not to say that Patriot is the long-term solution to the nation's cruise missile problem. The high cost of sustained operations and limited magazine depth are correctly cited for not creating an enduring design with the Patriot system. Instead, it is a first step in ensuring the nation is prepared to defend against an attack should a crisis occur before other systems can be procured or developed. An expensive, clunky design is preferable to no design at all.

A much more economical system is NASAMS which is employed by 16 countries around the globe for defense from cruise missiles and other air-breathing threats. Unlike Patriot, NASAMS is tailored to the cruise missile defense mission with much lower operating costs and higher magazine depth to ensure defended sites remain protected following an initial volley of cruise missile shots. One need only look to the current Ukraine conflict for the system's effectiveness. In November 2022, Ukraine received the first two of eight NASAMS systems to defend critical infrastructure from a Russian cruise missile attack. (Hudson, 2022) In the first two days of fielding, the NASAMS system had a perfect record of 25 Russian threats destroyed by 25 interceptors. (Weisgerber, 2022) This performance indicates that the system is well suited to provide the terminal defense capability to address the threat.

In terms of C2, both C2BMC and IBCS are command and control systems used by the U.S. Department of Defense, but ultimately they are designed for different purposes and operate in different ways. C2BMC is a missile defense system that integrates data from various sensors, such as terrestrial and surface radars and Overhead Persistent Infrared (OPIR) satellites, to detect and track incoming ballistic missiles. It can provide a common operating picture to give early warning of a missile launch to bring dormant defensive systems to life or reorient active defenses toward the incoming threat. Currently, the system has limited abilities to control terminal defense systems, but integration efforts could change this.

IBCS (Integrated Battle Command System) is an air and missile defense system that integrates data from various sensors, such as radars and UAVs, to provide a comprehensive picture of the battlefield. It then enables commanders to make informed decisions and direct the engagement of air and missile defense systems.

The main difference between the two systems is that their primary function as C2BMC focuses on missile defense, while IBCS is geared towards air and missile defense. Additionally, C2BMC is based on a legacy software system. It has evolved over decades, while IBCS is a modern, network-centric system designed to adapt quickly to changes in threats and technology. Additionally, C2BMC is already widely fielded across the joint force, whereas IBCS is still developing. Initially, as OTHR and elevated sensors are integrated into C2BMC's existing architecture C2BMC appears to be the right system to integrate and manage a foundational cruise missile defense system for the homeland. As IBCS is fielded and more embedded in our air and missile defense architecture, the two systems can complement each other's capabilities in an integrated C2 network.

Guam Defense System as Proof of Concept

The Department of Defense continuously assesses the operational environment to ensure enduring, generational solutions bridge AMD capability and capacity gaps. They must ensure the United States maintains a competitive advantage in competition and crisis. To this end, the Defense of Guam architecture, as directed by the Pacific Deterrence Initiative, includes the Missile Defense Agency, Army, and Navy systems for 360-degree IAMD defense against various threats, including cruise missiles.

The Guam Defense System (GDS) offers an opportunity to validate the elements of a credible cruise missile defense system that can be more widely implemented if proven successful. The current template leverages existing capabilities, including Patriot, to provide a cruise missile defense underlayer as part of the more extensive missile defense architecture. Specifically, the GDS is designed to include a Patriot battalion controlled by IBCS to provide a cruise missile defense underlayer.

Additionally, the Department of Defense is actively working to integrate multiple C2 capabilities into the overall architecture of the GDS. As this integration occurs, the DOD will gain insight into how IBCS and C2BMC complement each other for their respective roles. The integration of these systems will provide a road map for the integration of cruise missile defense systems controlled by IBCS with the overarching early warning detection and tracking network of C2BMC.

Recommendations

The Department of Defense faces advanced threats to the U.S. homeland. Our adversaries continuously adapt to U.S. technological advancements and force posture to erode U.S. symmetric advantages. Near-peer competition from the PRC and Russia that falls below the threshold of armed conflict allows them to deter the U.S. from rapid intervention during a crisis. To ensure decision space for national leadership, a credible deterrent is needed to change adversary calculus and delay their employment of weapons, including cruise missiles, against the U.S. homeland to delay or deny U.S. intervention.

To meet this minimal level of deterrence, the authors of this paper provide the following recommendations for the Department of Defense:

- Continue to fund and support OTHR programs in U.S. and Canada. Early detection of threats to the U.S. homeland is essential in establishing a credible defensive system and can aid attribution.

- Fund a dirigible program to provide elevated sensing and tracking layers, such as JLENS, ISIS, or Sky Dew. JLENS is a proven capability that faces unfair discrimination. Sky Dew is newly fielded and in use by Israel. Time will tell if it is a worthy replacement for JLENS.

- Identify and prep sites near critical infrastructure for Patriot and Sentinel today to emplace other systems there in the future. This component provides the foundational capability needed for a credible cruise missile defense system. Dedicating the space now ensures the ability to expand the defense in the future.

- Purchase up to five NASAMS to replace the Patriot emplacement sites and continue exploring DE systems. The NASAMS provide a more tailored capability while cutting costs associated with Patriot. Emerging DE systems can further reduce the cost per shot and complement or replace the NASAMS when their programs mature.

- **Leverage existing C2 systems such as C2BMC and IBCS to integrate sensors and shooters. The GDS is accelerating this effort already. The need to integrate forward sensors with a network of terminal defense systems in Guam will provide a template that can be more broadly applied.**

The operational environment continues to evolve with rapidly advancing capabilities. The modest investment in establishing a credible cruise missile defense capability for the homeland better encourages national leaders to act in a crisis. The problem of cruise missile defense of the U.S. homeland will only become more complex and costly if we do not start with a foundational system now. Several methods are available today to stitch together an initial defense capability and help build a bridge to future capabilities, including using directed energy systems, weaponized and untethered dirigibles, and space-based effects. A foundational system creates this bridge and ensures closure of the gap in the U.S. defensive architecture for the homeland.

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