JULY 2022

North America Is a Region, Too

An Integrated, Phased, and Affordable Approach to Air and Missile Defense for the Homeland

AUTHORS
Tom Karako
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A Report of the CSIS Missile Defense Project

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Center for Strategic & International Studies
1616 Rhode Island Avenue, NW
Washington, DC 20036
202-887-0200 | www.csis.org

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Methodology

The architecture described herein is derived only from open-source information. Notional defended areas are derived using the methodology of the Congressional Budget Office's report, *National Cruise Missile Defense: Issues and Alternatives* (2021), identifying "government facilities, military bases, [and] power infrastructure" as likely targets by a peer-state in a non-nuclear conflict.[1] Many of the architecture images depicted here were built with SMARTset, a software program for conducting air and missile defense simulations. The views and analysis expressed herein are solely those of the authors and do not represent the position of the United States Department of Defense.

Contents

List of Figures VII

List of Tables IX

Executive Summary X

1 | Weapons of Choice 1

Cruise Missile Characteristics 2

No Longer a Sanctuary 3

Non-nuclear Strategic Attack: Deterrence by Denial 8

2 | Today's Limited Defensive Capability 9

The North Warning System 9

The National Capital Region 12

Capabilities Lying Fallow 13

No Sanctuary Is Inviolate 13

3 | The CBO Defense Design 14

Defend It All 15

Sensor Choice 16

Overreliance on Fighters 17

An Instructive Contribution 20

4 | Principles Informing Defense Design 21

Preferential Defense 21

Multi-mission Applications 23

Attend to the Full Attack Life Cycle 24

Defense in Depth 25

Balancing Persistence with Flexibility and Mobility 25

Throw Nothing Away 26

Affordability 28

5 | A New Defense Design 29

Global Threat Awareness 30

A Twenty-First Century DEW Line 31

Wide-Area Surveillance 34

Prioritized Area Defenses 40

Flexible and Adaptive Elements 45

Federated Command and Control 46

6 | Phased Implementation **48**

Phase 1 49

Phase 2 50

Phase 3 52

Future Evolution 55

7 | Coming Soon to a Theater Near You **57**

Appendix: Cost Data and Methodology **58**

About the Authors **64**

Endnotes **66**

List of Figures

Figure 1 | Complete CSIS Architecture Laydown XII

Figure 2 | Missile Trajectories 3

Figure 3 | Kh-101 Launch 5

Figure 4 | Cruise Missile Threat to North America from the Arctic 5

Figure 5 | Range of Sea-Launched Kalibr Cruise Missile 6

Figure 6 | Cruise Missile Launches from the Caspian Sea, 2015 6

Figure 7 | Russian Missile Attacks on Ukraine, 2022 7

Figure 8 | Cold War Air and Missile Detection Elements 10

Figure 9 | Radar Locations in the North Warning System 11

Figure 10 | Oliktok Long Range Radar Site 11

Figure 11 | National Advanced Surface-to-Air Missile System 12

Figure 12 | CBO Report 16

Figure 13 | CBO's Perimeter-Based Defense Design 17

Figure 14 | Mixed, Elevated Sensors Mitigate Horizon and Power Propagation Problems 18

Figure 15 | Relation of Warning Time and Range to Intercept Possibilities 19

Figure 16 | U.S. Navy's Relocatable OTHR 27

Figure 17 | Circa-1980s Plan for OTH-B Coverage 28

Figure 18 | Five Layers of Defense 30

Figure 19 | Over-the-Horizon Radar Operation 31

Figure 20 | Jindalee Operational Radar Network Coverage 32

Figure 21 | Jindalee Over-the-Horizon Radar 33

Figure 22 | FAA and Military Radar Locations 34

Figure 23 | FAA and Military Radar Coverage 35

Figure 24 | Customs and Border Protection Tethered Aerostat Radar System 36

Figure 25 | Estimated Coverage of Tethered Aerostat Radar System from 10,000 feet 37

Figure 26 | NOAA Doppler Weather Radar Locations 38

Figure 27 | NOAA Doppler Weather Radar Coverage 38

Figure 28 | Doppler Detection of Bird Dispersal 39
Figure 29 | LTE Cell Coverage in CONUS 40
Figure 30 | Passive Acoustic Sensors from World War I 41
Figure 31 | Time to Decide 42
Figure 32 | PAD Elements and Configurations 44
Figure 33 | PAD+ Elements and Configurations 45
Figure 34 | Ground Alert Fighter Range—20-Minute Warning 46
Figure 35 | Phase 1 Overview 50
Figure 36 | Abandoned Cold War OTH-B Arrays near Moscow, Maine 51
Figure 37 | Phase 2 Overview 52
Figure 38 | Phase 3 Overview 54
Figure 39 | PAD Radar Coverage 54
Figure 40 | Complete CSIS Architecture Laydown 55
Figure 41 | CSIS Defense Design 20-Year Budget 59
Figure 42 | Alternative Low-Cost OTHR Configuration 60

List of Tables

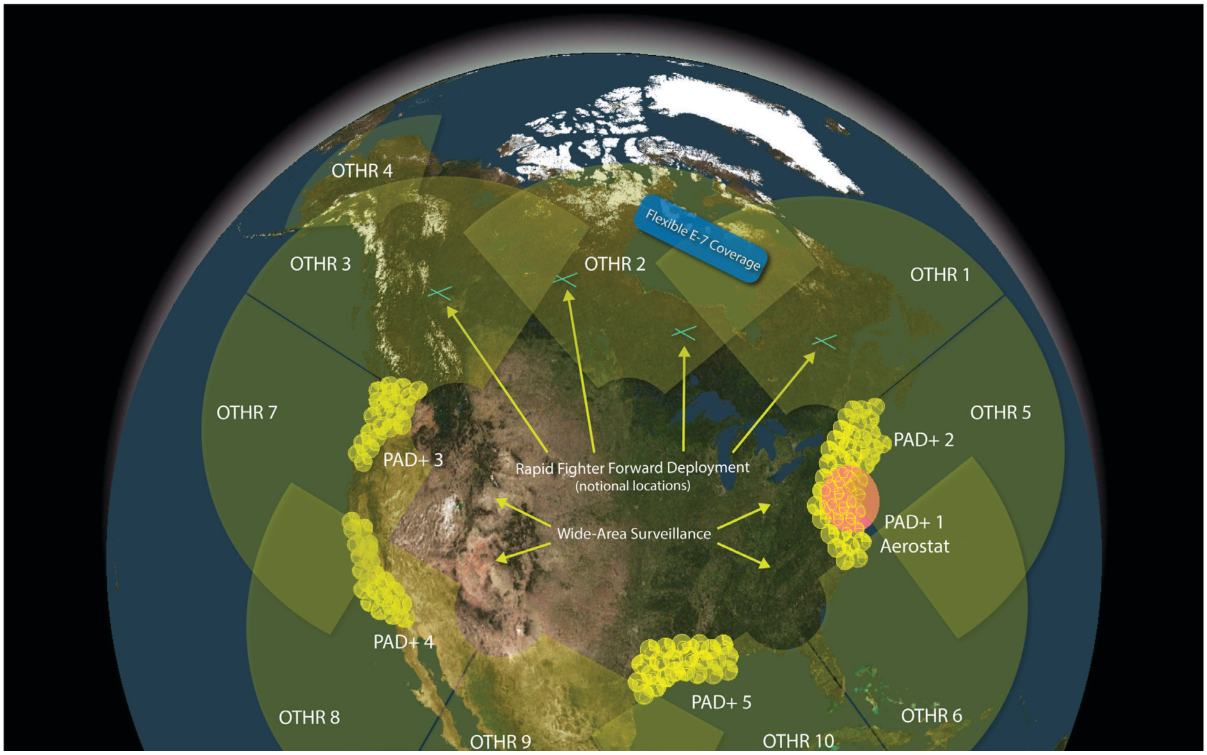
Table 1 | Complete CSIS Architecture Costs XII
Table 2 | Cost Data for CBO Defense Designs 15
Table 3 | Temporal Elements of the Cruise Missile Defense Kill Chain 29
Table 4 | A Phased Approach 49
Table 5 | Architecture Implementation by Phase 53
Table 6 | Complete CSIS Architecture Costs 58

Executive Summary

- U.S. air and missile defense efforts have long been characterized by a striking dichotomy. Defenses for the homeland have largely focused on long-range ballistic threats, while cruise missile defense and other air defense efforts have focused on regional and force protection applications to the exclusion of the homeland. The lingering homeland-regional dichotomy creates a vulnerability that near-peer adversaries are seeking to exploit.
- A changed strategic environment and the proliferation of sophisticated air and missile threats have made the homeland-regional dichotomy increasingly obsolete. In a sense, it ignores the fact that North America is a region, too. As seen in Ukraine and other recent conflicts, precision-guided cruise missiles have become a weapon of choice, capable of inflicting strategic effects.
- Given threat developments, homeland cruise missile defense may be getting traction, reflected by 2022 appropriations, the 2023 defense budget submission, and statements by senior military and government officials.
- The perception that homeland cruise missile defense is pointless stems from the outdated assumption that the cruise missile threat to the homeland is a lesser included case of strategic nuclear attack, which is primarily deterred by the threat of retaliation. Deterring non-nuclear air and missile attack, however, requires deterrence by denial.
- The perception that homeland cruise missile defense is unaffordable or impractical stems from assumptions about element types and the scope of the defended asset list. A 2021 Congressional Budget Office study developed four architectures with 20-year acquisition and sustainment costs ranging from $77 billion to $466 billion, in 2021 dollars. These architectures were unfortunately hampered by methodological constraints and by element selection, resulting in brittle and expensive solutions.

- Ongoing efforts to design and realize air and missile defenses for the U.S. territory of Guam will be an especially important guide for element selection, systems integration, and command and control challenges.
- Because of the significant potential utility for integrating both defense and non-defense sensors within the homeland, development of wide-area surveillance represents an important test case for the Biden administration’s strategy of integrated deterrence.
- Homeland cruise missile defense designs might also be usefully informed by the principles of preferential defense, multi-mission applications, attending the full threat life cycle, defense in depth, balancing persistence with flexibility, throwing nothing away, and affordability.
- The homeland cruise missile defense architecture depicted here consists of five layers and is implemented over three phases. Its primary elements include over-the-horizon radars, towered sensors, an aerostat, three types of interceptors, command and control operation centers, and a mobile airborne asset.
- The defense design depicted here has a projected acquisition cost of $14.9 billion and a phased operations and sustainment cost of $17.8 billion, for a total of $32.7 billion over the first 20 years, in 2023 dollars. Annual sustainment for the fully developed architecture is forecasted to cost about $1.2 billion per year.
- No weapon system is perfect, and perfection is the enemy of the good. Even if limited and imperfect, a sufficient and affordable defense can complicate adversary planning and strengthen deterrence.
- Should the Department of Defense soon designate a military service or agency as the executive agent with authority to design and procure homeland cruise missile defense capability, acquisition efforts could begin in earnest in FY 2024.

Figure 1: Complete CSIS Architecture Laydown



Source: CSIS Missile Defense Project.

Table 1: Complete CSIS Architecture Costs

	20-Year Total Cost (billions, 2023 dollars)		
System	**Acquisition**	**Sustainment**	**Total**
Over-the-Horizon Radars	$5.70	$5.57	$11.27
PAD Radars	$3.55	$3.77	$7.32
Aerostats	$1.12	$0.60	$1.72
Wedgetail	$0.79	$0.56	$1.35
Layered Shooters, Command and Control, and System Integration	$3.71	$7.30	$11.01
Totals	**$14.87**	**$17.79**	**$32.66**

Source: CSIS Missile Defense Project.

1

Weapons of Choice

U.S. air and missile defense efforts have long been characterized by a striking dichotomy. Defenses for the homeland have largely focused on long-range ballistic threats, while cruise missile defense and other air defense efforts have focused on regional and force protection applications to the exclusion of the homeland. This compartmentalization assumes that battles in one place will only consist of certain parts of the threat spectrum, and battles elsewhere will consist only of others. That lingering dichotomy creates a vulnerability that near-peer adversaries now seek to exploit.

A changed strategic environment and the proliferation of sophisticated air and missile threats are making the homeland-regional distinction increasingly obsolete. In a sense, it ignores the fact that North America is a region, too. As with any other region, attacks on assets in North America could be designed to shape the political and military calculus of U.S. policymakers. Addressing this new reality requires new approaches, concepts, and capabilities. In the words of Deputy Secretary of Defense Kathleen Hicks, "The way in which we have to think about missile defense, both regionally and here in the United States, really has to evolve substantially."[2]

Within an increasingly broad and diverse air and missile threat spectrum, the ubiquitous land-attack cruise missile lies at its center.[3] Emerging hypersonic missile threats garner significant attention, but garden-variety cruise missiles represent one of the most underappreciated, high-capacity, and near-term threats to the U.S. homeland. As seen in Ukraine and several other recent conflicts, the employment of precision-guided cruise missiles has become commonplace.[4] In the words of Assistant Secretary of Defense John Plumb, "Offensive missiles are increasingly weapons of choice for Russia, China, North Korea, and Iran, for use in conflict and to coerce and intimidate their neighbors both in peacetime and crisis."[5]

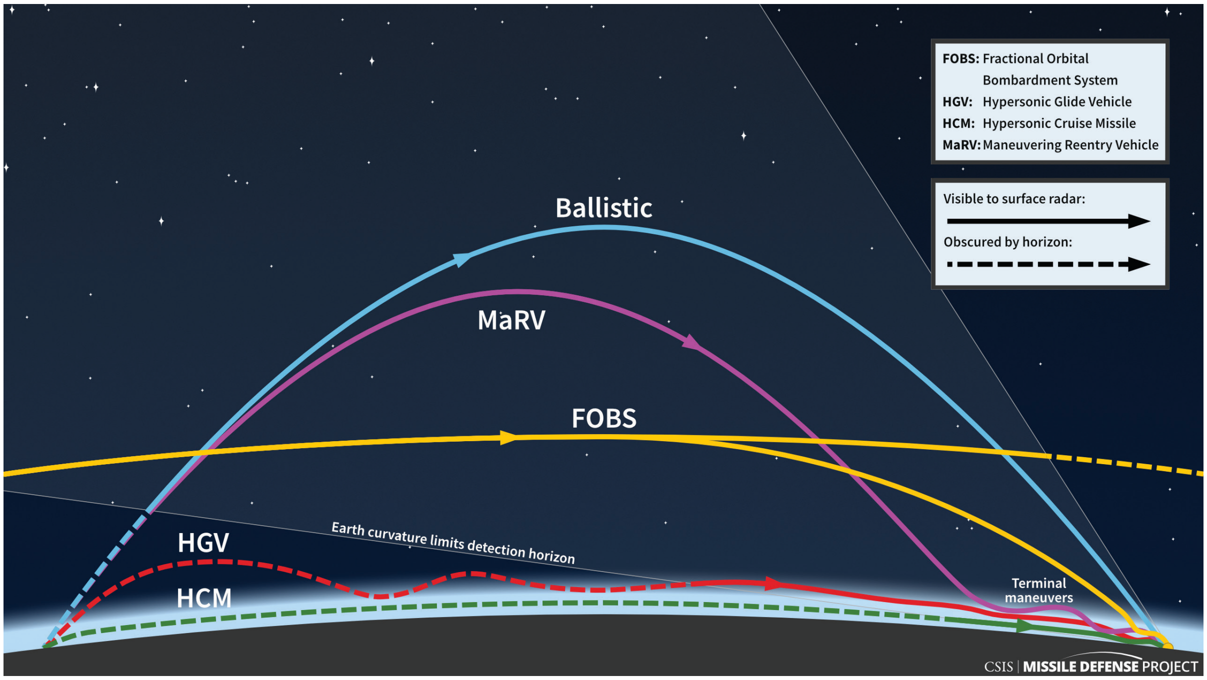
The near-complete lack of homeland cruise missile defense and related forms of air defense more broadly has created a deterrence problem. The perception that such defenses are pointless stems from the outdated assumption that a cruise missile attack on the homeland is a lesser included case of strategic nuclear attack, which is primarily deterred by the threat of retaliation. Cruise missiles or another form of non-nuclear strategic attack pose a different problem. An adversary seeking to change America's strategic calculus may be tempted to employ long-range, conventionally armed strikes to achieve strategic effect while remaining below the nuclear threshold. Deterring non-nuclear air and missile attack with strategic effects will require an element of deterrence by denial not present today.

Efforts to realize homeland cruise missile defense have already begun with the development of air and missile defense for Guam, a U.S. territory. While protection of the continental United States poses a different problem, the efforts for the defense of Guam will be especially instructive for element selection, system integration, and command and control development. In this sense, the road to homeland cruise missile defense for North America will go through Guam.

Cruise Missile Characteristics

The launch profile, midflight characteristics, and target area capabilities of cruise missiles differ considerably from ballistic missiles. Ballistic missiles produce highly detectable thermal launch signatures and fly on high, parabolic flight paths with largely predictable trajectories (Figure 2). Land-attack cruise missiles are more difficult to detect; can be launched from air-, ground-, sea-, and undersea-based platforms; and their flight is challenging to track with infrared sensors. Cruise missiles travel at low altitude under powered flight for hundreds or thousands of kilometers. This flight path creates massive detection and tracking challenges due to the curvature of the earth and background clutter. A typical surface-based radar has a search horizon of around 40 km for a target at typical cruise missile altitudes—making surface-based ballistic missile detection radars insufficient. Whereas ballistic missile sensors and decisionmakers usually have tens of minutes to observe an incoming munition and pair it with interceptors, a subsonic cruise missile first detected at the horizon may close the remaining distance in just over two minutes. A salvo of cruise missiles can use onboard navigation and autonomous target recognition to maneuver, loiter, and attack from several directions simultaneously.

Figure 2: Missile Trajectories



Source: CSIS Missile Defense Project.

No Longer a Sanctuary

At one time, the United States had a virtual monopoly on reliable, precision-guided, long-range cruise missiles, but that is no longer the case.[6] Dennis Gormley, a scholar who long flagged the emerging cruise missile threat, predicted that they would join ballistic missiles as a "complementary" means to threaten adversaries with high reliability and effectiveness.[7] With the proliferation of highly reliable and effective cruise missiles, that prophecy has now come true. Adversaries' decades-long investments to gain a significant and credible non-nuclear attack capability against the United States are now manifest.

In 2015, Admiral James Winnefeld, then-vice chairman of the Joint Chiefs of Staff, described the deterrence problem conventionally armed cruise missiles posed to the homeland and expressed his view that the threat had become greater than that of regional ballistic missiles.[8] In 2016, the Joint Staff released *Joint Operating Environment 2035*, which warned that "Adversaries will threaten the homeland not to physically destroy the United States, or even in anticipation of materially hindering its economic or military potential, but rather to change the decision calculus of leaders or the public's appetite for foreign military operations."[9]

In 2019, General Terrence J. O'Shaughnessy, then-commander of U.S. Northern Command (USNORTHCOM) and North American Aerospace Defense Command (NORAD), testified that Russia "has only recently developed and deployed capabilities to threaten us below the nuclear threshold . . . and its new generation of air- and sea-launched cruise missiles feature significantly greater standoff ranges and accuracy than their predecessors, allowing them to strike North America from well outside NORAD radar coverage."[10]

O'Shaughnessy's concerns have been echoed and extended by his successor. This year, General Glen VanHerck highlighted the threat posed by Russia's air-launched AS-23A cruise missile, noting its "extended range that enables Russian bombers flying well outside NORAD radar coverage—and in some cases from inside Russian airspace—to threaten targets throughout North America."[11]

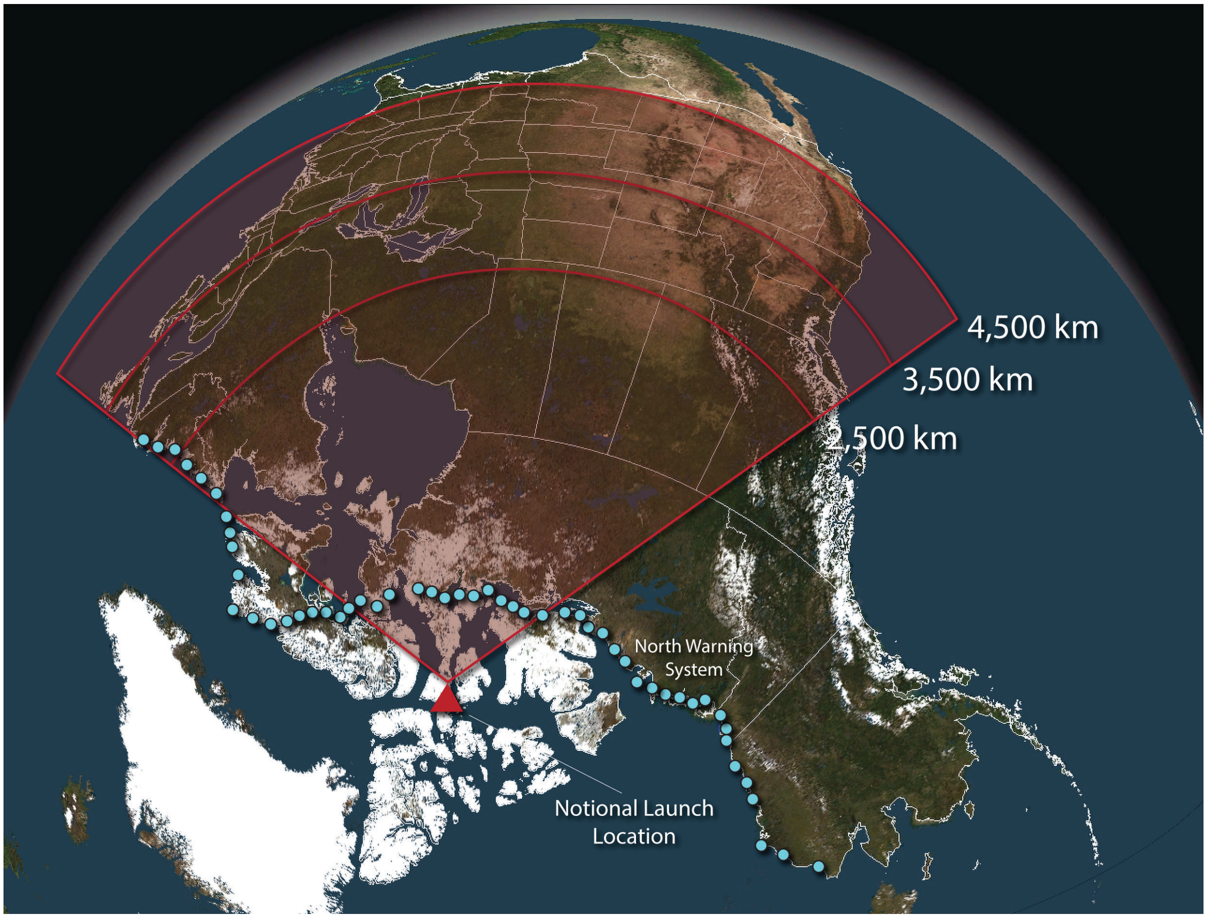
Earlier land-attack cruise missiles such as Russia's Kh-55 and Kh-555, developed for use in the European theater, gave way to other long-range missiles apparently designed to hold targets at risk outside that theater. This new generation of cruise missiles includes Russia's Kh-101/AS-23A that began full-scale development in the 1990s and was fielded in 2012 (Figure 3). These missiles boast GLONASS-based inflight navigation, low-altitude flight profiles, and a range of over 2,500 km—by some accounts, 4,500 km—sufficient to reach many North American targets even if launched from well outside the early warning zone for the United States and Canada (Figure 4).

> *"You might ask, if we choose to not invest the enormous resources that would be required to defend against a massive Russian ICBM attack coming over the North Pole, then why on earth would we care about cruise missile defense in the homeland?*
>
> *Well, the element of surprise is nearly impossible with an ICBM attack, and we will always have time to react. We can't necessarily say the same thing for a cruise missile attack, which could be intended to take away our ability to decide in response to an ICBM attack.*
>
> *This is a key point, and is why homeland cruise missile defense is shifting above regional ballistic missile defense, in my mind, as far as importance goes, since defending our national leadership and our ability to decide through our command and control capability, is part of the 'impose costs' leg of deterrence.*
>
> *This has implications for budgets and for stationing of our missile defense assets. We're devoting a good deal of attention to ensuring we're properly configured against such an attack on the homeland, and we need to continue to do so. This includes the [Joint Land Attack Cruise Missile Defense Elevated Sensor] test we're currently conducting at the Aberdeen proving ground, in case you've happened to have seen that dirigible hovering over Northern Maryland, as well as other systems we are putting in place to greatly enhance our early warning around the National Capital Region.*
>
> *We're also looking at changing out some of the systems we will use to knock down any cruise missiles headed towards our nation's capital. But we're going to have to eventually extend this to the areas around our nation we believe are the most important to protect."*
>
> — Admiral James Winnefeld, Vice Chairman of the Joint Chiefs of Staff, 2015[12]

Figure 3: Kh-101 Launch

Source: Russian Ministry of Defense.[13]

Figure 4: Cruise Missile Threat to North America from the Arctic



Source: CSIS Missile Defense Project.

Sea-launched cruise missiles, such as the 3M-14 Kalibr (NATO designation SS-N-30A), pose a similar threat. With a range of 1,500 to 2,500 km, a salvo of these subsonic cruise missiles could launch from a submarine off the coast of North America with little to no warning, striking targets deep in the homeland (Figure 5).[14] If deployed on the quiet Russian Yasen-class submarines, such as the *Severodvinsk* or the recently fielded *Kazan*, these missiles could pose a significant threat to North America (Figure 6).[15]

Figure 5: Range of Sea-Launched Kalibr Cruise Missile

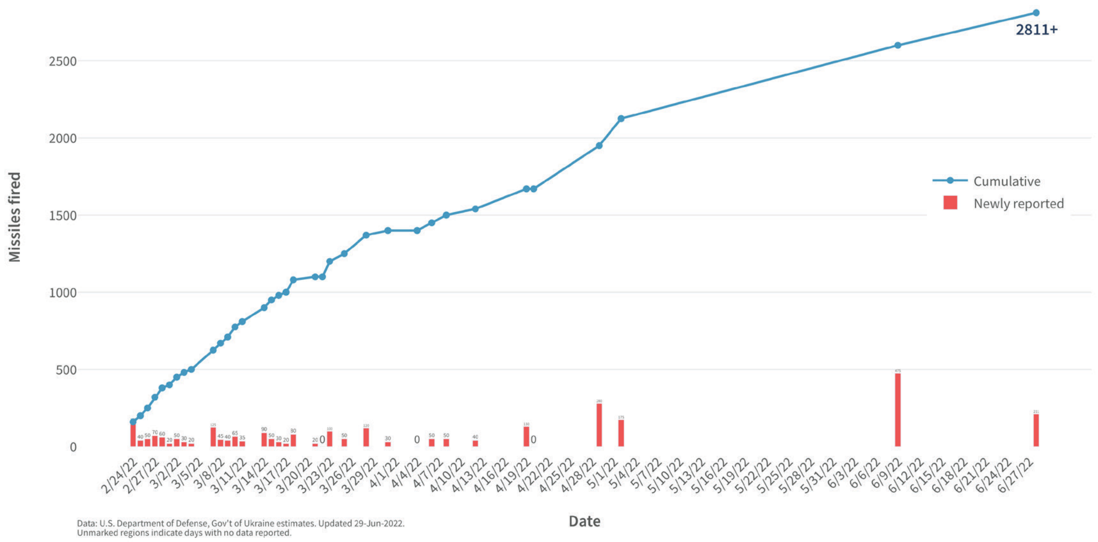
Source: CSIS Missile Defense Project.

Figure 6: Cruise Missile Launches from the Caspian Sea, 2015

Source: Russian Ministry of Defense.[16]

These long-range air- and sea-launched cruise missiles have seen use in Syria and Ukraine. Lieutenant General Dan Karbler, commander of Army Space and Missile Defense Command, recently noted that the Ukraine conflict has "witnessed the largest use of offensive missile systems in Europe since World War II."[17] In the first 125 days of the conflict, Russia reportedly employed over 2,800 missiles (Figure 7).

Figure 7: Russian Missile Attacks on Ukraine, 2022



Data: U.S. Department of Defense, Gov't of Ukraine estimates. Updated 29-Jun-2022.
Unmarked regions indicate days with no data reported.

Source: CSIS Missile Defense Project.

Cruise missiles are not boutique capabilities, but rather weapons of choice. As John Plumb further notes, "The sobering reality of the tragic event in Ukraine, in which Russia has used a broad array of missiles to attack, and in my opinion, terrorize civilian populations, highlights the extent to which our adversaries are prepared to use missiles in a conflict."[18]

Despite these warnings and real-world combat employment of hundreds of cruise missiles in recent years, policy and programmatic attention to homeland cruise missile defense has thus far been rather modest.[19]

Unlike its 2010 predecessor that focused on ballistic missile defense, the 2019 Missile Defense Review (MDR) highlighted the rise of near-peer cruise missile and other threats, took note of several NORAD/USNORTHCOM studies of the matter, and directed senior defense officials to recommend an organization to have cruise missile defense acquisition authority within six months of the review's release, pursuant to a 2017 National Defense Authorization Act statutory requirement to do so. No such designation, however, has yet been made.[20] Neither the 2019 MDR nor the Trump administration's associated defense budget requests seemed to do much besides admire the problem.[21]

This neglect of homeland cruise missile defense may be slowly changing. In response to a request from the Missile Defense Agency, $13.9 million was included for cruise missile defense experiments in its FY 2022 budget.[22] The 2022 omnibus appropriations bill also included $67.4 million to research and develop over-the-horizon radar capabilities, as well as $192.4 million for the defense of Guam.[23] FY 2023 budget documents further suggest that the yet-unreleased 2022 National Defense Strategy highlights the long-range cruise missile threat from Russia.[24]

Cruise and other missiles have become “a common and expected facet of modern warfare,” John Plumb further notes, which “makes our missile defeat and missile defense efforts more important than ever.”[25]

Non-nuclear Strategic Attack: Deterrence by Denial

One misperception about homeland cruise missile defense is that it is unnecessary, inasmuch as a cruise missile attack on the homeland is an adjunct to or lesser included case for strategic nuclear war, which is deterred by the threat of U.S. nuclear retaliation. As Admiral Winnefeld put it, “You might ask, if we choose to not invest the enormous resources that would be required to defend against a massive Russian ICBM attack coming over the North Pole, then why on earth would we care about cruise missile defense in the homeland?”[26]

Strategic nuclear attack is not the issue, however, but non-nuclear attack with strategic effect. The foundation for U.S. national security is the nuclear deterrent and the threat of nuclear response. Adversaries are deterred from strategic nuclear attack due to the credible threat of overwhelming punishment in a nuclear counterstrike. The specter of non-nuclear attack with strategic effect is what an adversary thinks it might be able to do below the threshold for U.S. nuclear response.[27] Such a prospect has been raised by General VanHerck:

> In pursuit of their regional objectives, Russia and China intend to hold targets in the homeland at risk below the nuclear threshold in order to limit decision space for our senior leaders by threatening national critical infrastructure and by undermining our will and disrupting and delaying our ability to project power forward in a crisis.[28]

This prospect no doubt informs U.S. Indo-Pacific Command’s prioritization of active air and missile defense of the U.S. territory of Guam, but it applies to the homeland more broadly. Potential objects of non-nuclear strategic attack might include early warning radars, command and control facilities, and military points of debarkation such as ports and airfields. Such attacks—perhaps in conjunction with attacks on space-based sensors and communication—could have significant strategic effects. Non-military targets in the homeland might include ports, power generation, financial nodes, and other critical infrastructure.

In the absence of adopting and credibly communicating a policy of nuclear first use in response to conventional attacks on the homeland—an unlikely step—the deterrence of non-nuclear attacks with strategic effect requires both a credible threat of offensive punishment and a credible capability to deny benefit. An adversary willing to pay the expected cost of a conventional retaliation for a successful attack may not follow through if their confidence in that attack is diminished.

In short, deterrence by threat of non-nuclear punishment may not be enough. Both passive and active defense become necessary to achieve deterrence by denial. Even if limited in capacity and defended area, a demonstrated defensive capability contributes to deterrence by creating uncertainty and raising the threshold for non-nuclear strategic attack.[29]

2

Today's Limited Defensive Capability

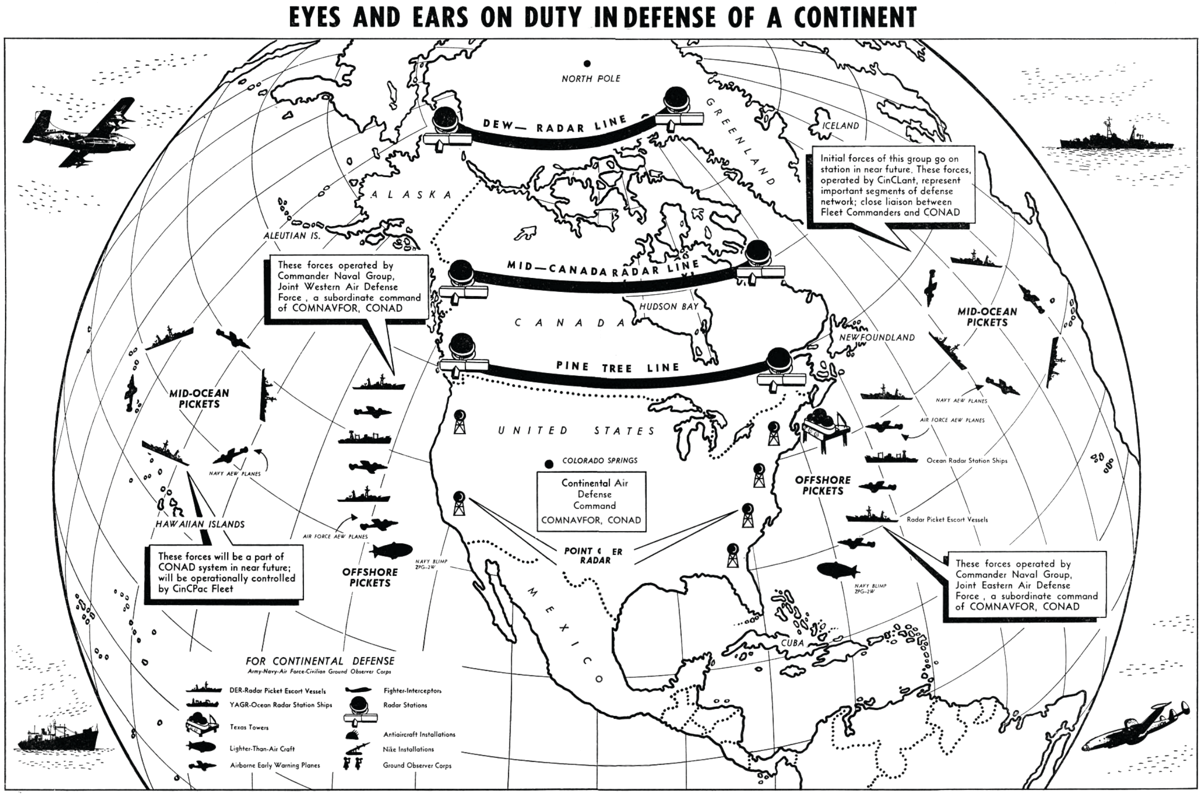
The United States today has precious little to detect, track, identify, or intercept cruise missiles and other aerial forms of attack on the U.S. homeland. Legacy equipment and institutions from both the Cold War and post-2001 counterterrorism efforts provide a limited defensive capability, but not much more. Modernizing these older functions and elements is necessary but insufficient. An effective binational air and missile defense of North America requires new capabilities and a new defense design.

The North Warning System

North American Aerospace Defense Command (NORAD) is a binational U.S. and Canadian organization responsible for both early warning and defense against air breathing and ballistic missile threats to North America, including hypersonic weapons. Born from the need to sense and respond to Russian air and missile threats during the Cold War, NORAD's charter expanded in 2006 to include maritime domain awareness.[30] Closely partnered with NORAD is U.S. Northern Command (USNORTHCOM), the geographic combatant command responsible for leading the Department of Defense's (DOD) response to maritime and ballistic missile threats to the United States.[31]

Together, the United States and Canada operate the North Warning System (NWS), a line of short- and long-range radars across northern Canada and Alaska, and a network of alert fighter bases for response (Figure 9). NORAD integrates the 47 NWS picket radars in Canada with Alaskan and coastal defense radars to detect medium- and high-altitude aerial threats. Its effectiveness, however, is greatly reduced for lower-altitude, low-observable threats. The age, immobility, and known locations of the radars allow coverage gaps to be assessed.[32] Modernizing these systems is necessary but insufficient to the cruise missile challenge.

Figure 8: Cold War Air and Missile Detection Elements

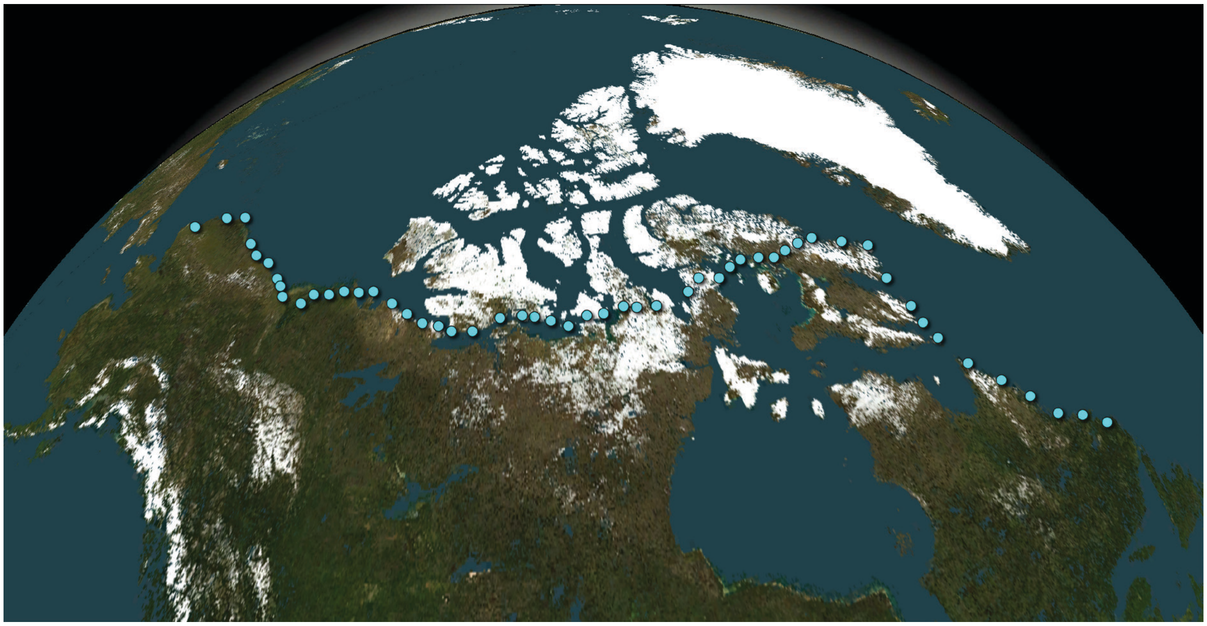


Source: U.S. Navy.[33]

Defeating cruise missile threats requires an ability to both detect the threat and decide how to respond. Today's capabilities fall far short of that goal. The current system of command and control, though staffed by highly dedicated U.S. and Canadian military personnel, employs 1990s-era technology and uses 1960s-era decision processes. Information on threats is communicated verbally by a literal game of telephone between multiple forward sensing locations and decisionmakers across several command echelons. Without a robust cruise missile sensing capability, operators must provide telephone-based recommendations with little more than momentary detections of fast, low unidentified objects that may have since evaded radar coverage.

Sensor data flowing to these command and control systems often does not combine with sensors from other systems or domains. Data feeds from the Ballistic Missile Defense System's Command and Control, Battle Management, and Communications program, for instance, are available but technically cloistered. Operators are left to visually assess 15 screens to comprehend the defended airspace and assess the threat. These human beings are not in the loop generating machine-based options, nor are they on the loop monitoring machine-generated recommendations. Instead, human beings literally are the loop—manually assessing threats, ranges, and options and relying on intuition and years of experience to make recommendations. The closest homeland defense currently comes to multi-mission integration is by swivel chair—operators yelling missile status updates to one another on the operations floor.

Figure 9: Radar Locations in the North Warning System



Source: CSIS Missile Defense Project.

Figure 10: Oliktok Long Range Radar Site

Source: U.S. Air Force photo/Tommie Baker.

Besides a near complete lack of mission integration, there are almost no purpose-built defenses against low-altitude cruise missile threats. Instead, defenders make do with capabilities built for other threats in other theaters. Current homeland defense paradigms use ground-based fighter aircraft—often in high demand by other combatant commands—on rapid alert postures to launch and intercept threats using air-to-air missiles. Fighters work well for slower-moving, higher-altitude threats, such as hijacked aircraft, but struggle to intercept low-altitude cruise missiles that can maneuver and approach a target from any direction. Without minutes of early warning and a predictable cruise missile flight path, fighters struggle to arrive at the right place and time to find a threat that may already have flown outside engagement range.

These limitations do not just affect the United States. Noting that the NWS is "becoming increasingly challenged by modern weapons technology, including advanced cruise missiles," the Canadian government has indicated interest in modernizing the existing binational air defense sensors and associated network of airfields.[34] In June 2022, Canadian prime minister Justin Trudeau visited NORAD headquarters in Colorado, the first such visit by a prime minister since his father Pierre Trudeau visited in 1977.[35] Following this visit, Canada announced it would invest $4.9 billion (U.S. dollars) over the next six years to create a new Northern Approaches Surveillance system of two over-the-horizon radars and a network of classified sensors.[36]

The National Capital Region

While fighter aircraft theoretically provide some air and missile defense across North America, there is one persistent but limited surface-to-air capability in the National Capital Region (NCR). Improvements to NCR defense against cruise missile threats over the past two decades include "several surface-to-air missile sites and fighters on alert at Andrews Air Force Base."[37] The 2019 Missile Defense Review (MDR) noted NORAD was improving defensive coverage of the NCR by "incorporating advanced sensors into the existing architecture" and "expanding surveillance capabilities."[38] For the time being, however, the NCR's air defense capability is thin and geographically limited.[39]

Figure 11: National Advanced Surface-to-Air Missile System

Source: Raytheon Technologies. Reprinted with permission.

Capabilities Lying Fallow

One aspect of today's thin defense stems from a failure to integrate existing capabilities. In 2015, a man piloting a small gyrocopter flew over 100 km at an altitutde of 100 meters from Gettysburg, Pennsylvania, into restricted airspace over Washington, D.C., to land on the Capitol lawn.[40] No one sensor held consistent track of the low-altitude threat; most radars likely ignored the occasional gyrocopter returns as ground clutter or weather. Following the event, USNORTHCOM and NORAD explored ways to analyze the incident's recorded radar returns. Using newer tracking algorithms, USNORTHCOM and NORAD could both detect and accurately track the gyrocopter from the fallow data earlier systems had ignored.[41]

Even without a new, purpose-built architecture, numerous sensors across North America could contribute to such tracks. U.S. Customs and Border Protection, for instance, operates a handful of tethered aerostats along the southern border. The Navy operates a test radar at Wallops Island on the Virginia coastline. The Federal Aviation Administration has numerous air traffic control radars across the country and plans to modernize many of them under a program called Spectrum Efficient National Surveillance Radar.[42] Even sensors as unlikely as the National Oceanic and Atmospheric Administration's network of 160 doppler weather radars may usefully augment surveillance, as might numerous commercial radars.[43]

Few if any of these disparate sensors may be able to independently create tracks with their existing algorithms. But all could supply raw data, which when fused with others nationwide and processed through machine learning, could identify anomalous activity and nominate possible tracks. The same sensors could be directed to default to aerial surveillance mode whenever they are not performing their regular functions. By leveraging these numerous data feeds currently lying fallow—including non-DOD sensors—an integrated, nationwide approach could substantially contribute to wide-area surveillance and serve as a bridge to purpose-built capability. The challenge represents an important test case for the Biden administration's strategy of integrated deterrence.

No Sanctuary Is Inviolate

Air superiority can no longer be taken for granted, even in North America. The homeland can no longer be assumed to be a sanctuary. Decades of believing that conflict and so-called regional missile threats were limited to other regions has created a vulnerability at home that adversaries now seek to exploit. Military planners that look with apprehension at graphics depicting the depth of Russian and Chinese air defense rings are sometimes shocked to see a comparable map of U.S. air defenses, almost nonexistent save for limited coverage over the nation's capital.[44] Today's threats require that those maps of homeland air and missile defenses be redrawn.

3

The CBO Defense Design

In February 2021, the Congressional Budget Office (CBO) published *National Cruise Missile Defense: Issues and Alternatives*.[45] The report examined the likelihood of a land-attack cruise missile strike against the continental United States and the availability of effective sensing and defense systems. CBO's analysis compared five individual sensor types: towered radars elevated at 700 feet; aerostats at 10,000 feet; Airborne Early Warning and Control (AEW&C) aircraft at 30,000 feet; high-altitude long-endurance unmanned aerial vehicles (HALE-UAVs) at 60,000 feet; and sensors in low earth orbit at 600 miles altitude. For intercept mechanisms, CBO employed fighter aircraft launched from ground alert airfields and long-range surface-to-air missiles (LR-SAMs). Each of their four primary defense designs included an increased number of fighters and alert airfields as well as LR-SAMs.

CBO's analysis appears to be based on sound fiscal calculations, a thorough assessment of available sensors and shooters, and a solid analysis of the challenges inherent in detecting, tracking, and engaging low-altitude cruise missiles. Nevertheless, their architectures appear to have been hampered by a handful of assumptions about "the composition . . . of potential nationwide cruise missile defense architectures."[46] Specifically, the exclusion of a more limited defended asset list and a handful of other assumptions about sensors and interceptor mechanisms led to relatively high acquisition and sustainment costs.[47] Examining these assumptions helps point toward the possibility of more effective and more affordable defense designs.[48]

CBO developed cost estimates for a comprehensive defense of the continental United States using a perimeter-based defense design, single-type sensor coverage, and a high reliance on fighter aircraft for both sensing and engagement. These assumptions produced several defense design options ranging in cost from $77 billion to $466 billion (in 2021 dollars) and included acquisition and 20 years of operations and sustainment (Table 2).

Table 2: Cost Data for CBO Defense Designs

	Detection & Tracking Sensors		Shooters		Cost (billions, 2021 dollars)		
	Number of Locations or Orbits	*Number of Systems for Continuous Operation*	*Number of LR-SAM Sites*	*Number of Fighter Locations*	*Initial Acquisition*	*Annual Operation and Support*	*20-Year Total*
Architecture 1: Detection and Tracking with Radar on HALE-UAVs	23	64	20–30	30–40	13–15	2.7–3.5	77–98
Architecture 2: Detection and Tracking with Radar on Modified Commercial Aircraft (AEW&C aircraft)	31	124	40–50	50–90	28–36	7.7–10.2	187–246
Architecture 3: Detection and Tracking with Radar on Aerostats	50	75	60–800	N/A	30–86	2.3–17.7	98–466
Architecture 4: Detection and Tracking with Space-Based Radar	78	78	20	10–15	58–97	0.7–1.1	106–179

Source: Congressional Budget Office.[49]

Three aspects of CBO's analysis merit specific attention: the extent of the defended asset list, the sensor architecture, and the relatively high degree of reliance upon manned fighters. Scrutinizing these design assumptions and applying new principles reveals alternative options, not only for cruise missile defense but for integrated air and missile defense more broadly.

Defend It All

A fundamental assumption informing each of CBO's four architectures is the extent of the defended area, a paradigm walling off all of the contiguous United States (CONUS). They do so with a 9,300-mile perimeter of airborne or ground-based radars (Figure 13). Several alternative single-sensor types of ground- and air-based sensors were considered for the perimeter. CBO optimizes their defense designs for two variables: increased warning time and maximum interceptor coverage. While they considered towered radars, their recommended designs prioritized high-altitude or space-based sensor elevation to maximize detection ranges.

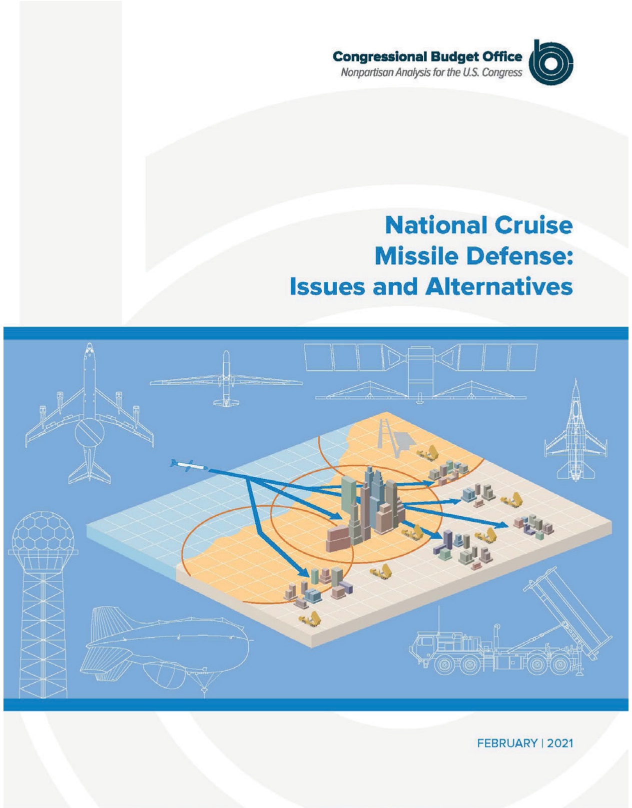
Regardless of type, however, any perimeter defense is brittle. A single sensor failure—whether down for maintenance or created through deliberate attack—would open a hole in the perimeter, and once open the interior would be vulnerable. Relying upon a single sensor also limits track-quality coverage of targets. A swarm could overwhelm a point in the perimeter simply by overwhelming its ability to track and process multiple tracks.

CBO's architectures appear to prioritize a thin defense of a comprehensive defended asset list over a thicker and more robust defense of fewer locations. The resulting 20-year cost to provide even a light defense of a vast area ranged from $77 billion to $466 billion. The considerable cost variation is due to alternative combinations of sensors and interceptors and varying desired warning times of 5 or 15 minutes. While the CBO examined several variations and derivations from this design, the fundamental perimeter defense paradigm remained unchanged. Constrained by a mandate of comprehensive coverage for all of CONUS—by equating the defended asset list with the critical asset list—the defense design becomes brittle.

Sensor Choice

Another feature of CBO's defense design is the assumption that any one architecture relies upon a single sensor type (either HALE-UAV, aerostat, AEW&C, or satellite). While simplifying options eases budgetary analysis, a single sensor type limits capability by eliminating elements that would not independently provide the assumed five minutes of warning time. Combining or layering multiple sensor types, phenomenologies, and locations has many benefits, providing defense in depth and supporting functions other than detection. Longer-range detection, for instance, can be augmented by shorter-range electrooptical or infrared sensors to help with the vexing problems of combat identification and fire control-quality tracks. By only considering standalone sensor types, CBO removed towered radars as a less attractive option because of their shorter, lower range.

Figure 12: CBO Report



Congressional Budget Office
Nonpartisan Analysis for the U.S. Congress

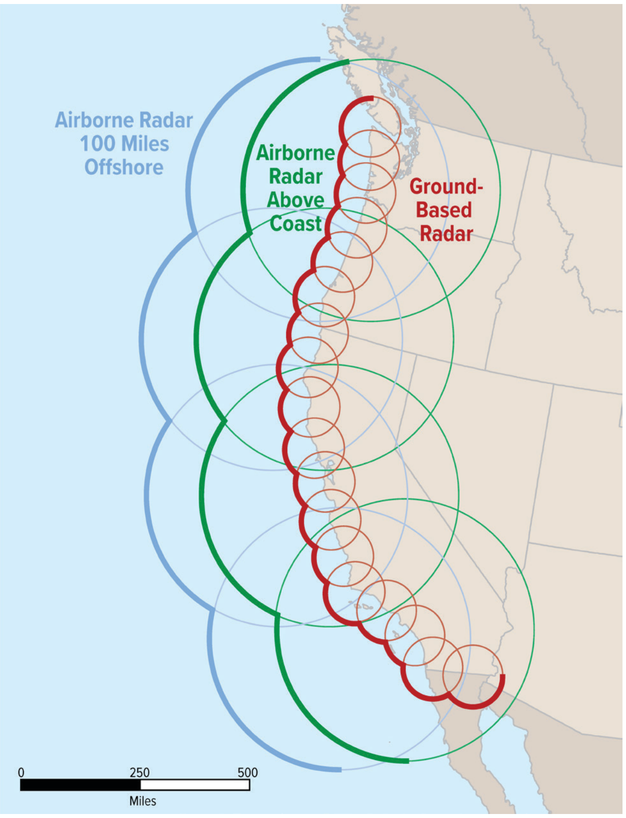
National Cruise
Missile Defense:
Issues and Alternatives

FEBRUARY | 2021

Source: Congressional Budget Office.[50]

While prudently optimizing their architectures to contend with the radar horizon, CBO overlooked another challenge: power propagation. Radar power, and the resulting return measured in change in decibels, falls off exponentially with range. Detecting targets at range beyond that obscured by the curvature of the earth, approximately 40 km, requires significant power generation. While a high-altitude unmanned aerial system (UAS) may have the potential to see hundreds of kilometers by negating the radar horizon problem, it would require prohibitive levels of power to see small radar cross-section targets at those ranges. Radar energy delivered on target—and returned—is arguably a greater challenge than the curvature of the earth—one of the challenges of space-based radar. By discounting towered radars as a viable option, CBO eliminated an element that, when networked together over a large area, and especially when combined with other sensors, can arguably solve both the horizon and energy propagation problems (Figure 14).

Figure 13: CBO's Perimeter-Based Defense Design



Source: Congressional Budget Office.[51]

Overreliance on Fighters

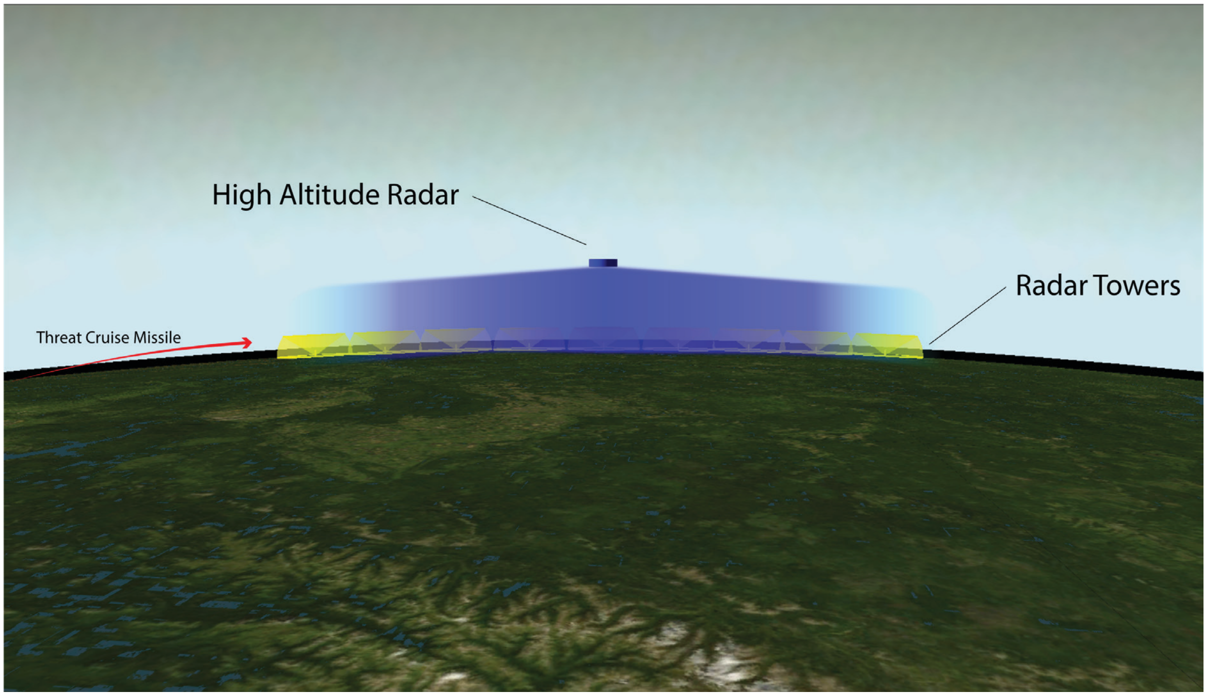
Another aspect of the CBO defense designs is their relative reliance upon manned aircraft as a primary means of engaging, identifying, and intercepting cruise missiles.

Even before Desert Storm, the American way of war prioritized the mobile and flexible quality of manned fighter aircraft for ensuring air superiority. As a means to provide air defense for ground-based targets, however, it has serious limitations. Fighters are required to cut circles in the sky for hours on end in airborne patrols and must be combined with manned high-demand, low-density Airborne Warning and Control Systems (AWACS) flying radars and Air Battle Managers. These highly coordinated and choreographed air defense teams are supported by constant rotations of airborne air refueling aircraft to keep the defenders in the air. To provide continuous coverage of one defended area, a single airborne defensive team of this nature requires several AWACS aircraft, as many tankers, and one and a half fighter squadrons. If fighters defend without airborne early warning support, their detection capabilities are considerably reduced. Keeping the fighters on the ground in an alert status reduces the number of aircraft required for defense but induces minutes of delay to start the aircraft, taxi, take off, and accelerate toward the threat.

CBO's reliance upon fighter interceptors appears to derive from an understandable respect for the significant challenges of operating—and authorizing the firing of missiles—within the congested national airspace system.[52] To address this challenge, CBO highlights the desirability to visually identify and discriminate cruise missile threats from civilian or friendly aircraft: a pilot has to see it.

Combat identification challenges are real but not insurmountable. Operational insight is instructive here. North American airspace is monitored daily by binational North American Aerospace Defense Command air defenders under a graduated engagement decision level. During normal operations, the bar for engaging a potential threat is extremely high to limit the chance of accidental engagement. With indications and warning for a potential attack, coordination with civil air traffic agencies increases and air defenders are given more authority to engage. A cruise missile defense tailored more heavily toward surface-to-air missiles would operate under this type of graduated authorities, through the use of technical and procedural means of combat identification to minimize the possibility of inadvertent engagement. Simply relying upon visual identification by a pilot may not be the best solution.

Figure 14: Mixed, Elevated Sensors Mitigate Horizon and Power Propagation Problems



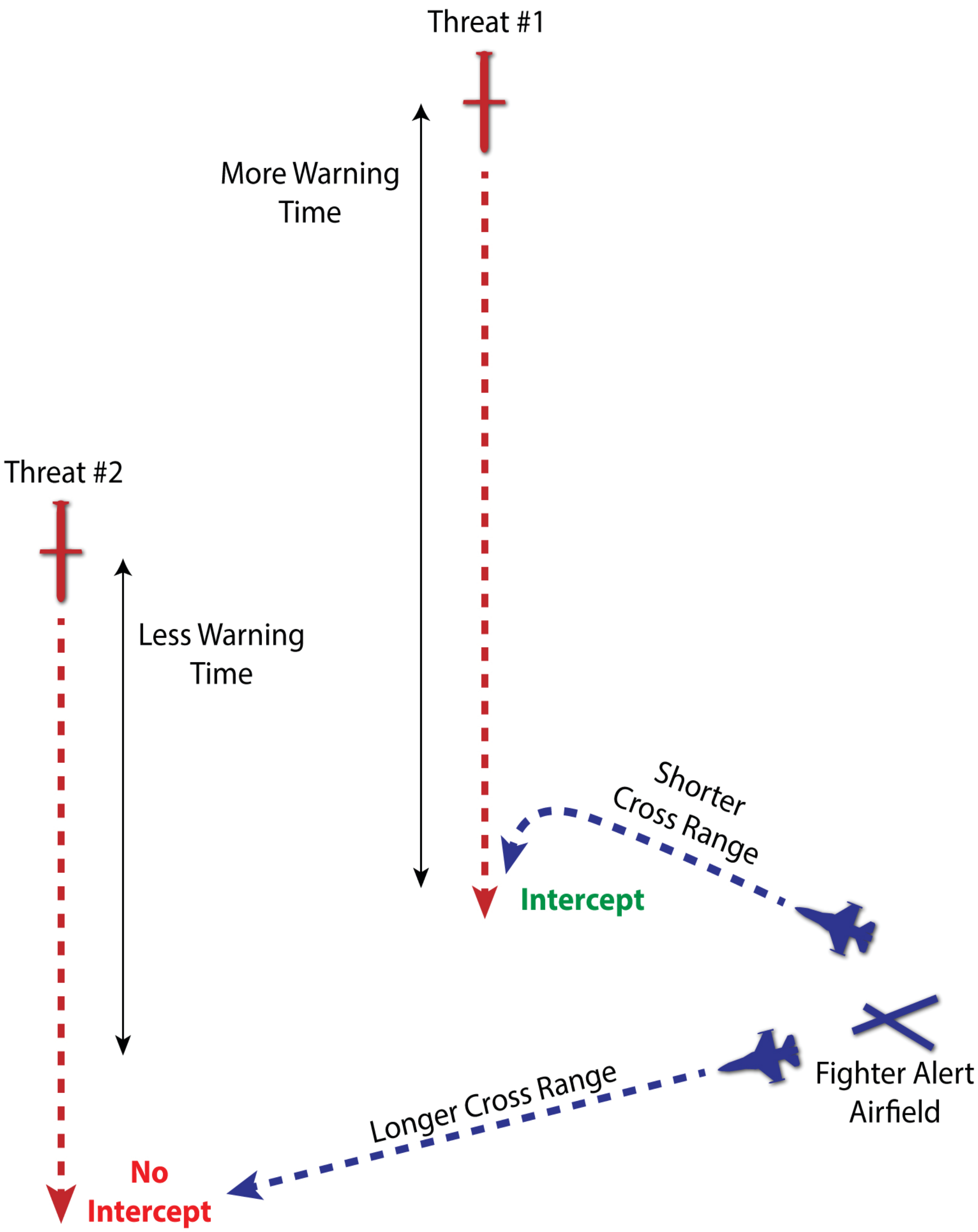
Source: CSIS Missile Defense Project.

A related shortcoming is CBO's relatively high reliance upon fighters to conduct engagements of threat missiles. Besides delays involved in alerting and launching a manned fighter, successful intercept is further complicated by the cruise missile's maneuverability, its low observable profile, and relative speed—a fighter may be only slightly faster than the cruise missile. The time required to launch, climb, and accelerate toward a cruise missile target can be measured in minutes for a fighter but in seconds for a surface-to-air missile.

Successfully conducting such an intercept requires either considerable early warning, low cross range, or an intercepting aircraft considerably faster than the cruise missile (Figure 15). Relying upon ground-based alert fighters requires more airfields distributed across the defended perimeter to reduce the cross-range distance the fighters would be required to travel. Three of CBO's four primary architectures multiply the number of airfields and fighter aircraft based in the United States, adding between 10 and 90 bases at $10 million per location.[53]

While manned aircraft can provide a highly mobile and effective means of air defense, they are not a sustainable solution for more than a few days of continuous coverage and are extremely expensive to operate. Manned aircraft have tremendous potential to supplement homeland cruise missile defense operations, but they should not be the primary means of engagement.

Figure 15: Relation of Warning Time and Range to Intercept Possibilities



Source: CSIS Missile Defense Project.

An Instructive Contribution

The 2021 CBO study is an instructive contribution to the conversation about the feasibility, purposes, element selection, and design of homeland cruise missile defense. The congressional direction of its analysis, however, appears to have adversely constrained their solutions. Identifying those constraints and adopting other guiding principles can inform a more effective and affordable defense design.

4

Principles Informing Defense Design

While comprehensive coverage of the territory of all 50 states was a driver of homeland ballistic missile defense, it is neither possible nor affordable to equally defend every critical asset or even broad areas that cruise missiles might target. Effective, near-term, and affordable air and cruise missile defense of the homeland will require rethinking assumptions and applying alternative principles. Seven such principles include: preferential defense, multi-mission applications, attending to the full attack life cycle, defense in depth, balancing persistence with flexibility, throwing nothing away, and affordability.

Principles

1. Preferential Defense
2. Multi-mission Applications
3. Attend to the Full Attack Life Cycle
4. Defense in Depth
5. Balancing Persistence with Flexibility and Mobility
6. Throw Nothing Away
7. Affordability

Preferential Defense

The beginning of wisdom for homeland cruise missile defense is to recognize the necessity of preferential defense. Perfect or geographically comprehensive defense is impossible. Choosing instead to credibly defend a select number of target areas lucrative to an adversary for their political, economic, or military impact could achieve a marked effect on deterrence. As Admiral James Winnefeld, vice chairman of the Joint Chiefs of Staff, said in 2015, “We probably can’t protect the entire country from cruise missiles, without breaking the bank, but there are important areas in this country that we need to make sure are defended from that kind of an attack.”[54]

The measure of nationwide cruise missile defense is not simply binary—defended or undefended—but rather graduated, based on the vulnerability of individual targets most valuable to an adversary. Covering every cow pasture with the same defenses as a major containerized munition port achieves little deterrence or defense benefit. Population centers, moreover, may not at all be primary targets of non-nuclear cruise missile attack.

Choosing to credibly defend a limited number of areas can therefore substantially contribute to deterrence by denial. Defending higher value targets at the expense of others can drive an adversary to attack a lower-tier target, accept the increased likelihood of an unsuccessful attack, or search for other means of influence.

Efficiencies gained by preferential defense could be taken to an extreme of protecting only specific points. While perhaps tempting for cost reasons, a point defense or self-defense approach would be a mistake for homeland cruise missile defense.

It may be possible to detect and engage some cruise missile threats in the terminal phase, but relying on this last-ditch approach is highly brittle and too predictable. A cruise missile traveling at a nominal 0.75 Mach covers over 11 km per minute. A point defense with a 40 km radius of detection and engagement around a critical asset translates to only four minutes from first detection to impact. A layered area defense with a 160 km buffer of threat detection buys significantly more time.

Area-wide defense strikes a balance between the extremes of point defense and an effort to defend everything. Area defense allows for layering of sensors and shooters and justifies its employment in longer-range elements. Point defense, with large numbers of highly localized and distributed elements, may in fact be more complicated and expensive, due to the number of critical assets grouped together in certain clumps around the country. Because the maneuverability of cruise missiles precludes advanced knowledge of the target, point defenses would have to be highly proliferated across some areas.

Determining which areas contain the most critical assets and which should be resourced with defenses is the process of creating a critical asset list (CAL) and deriving from it a defended asset list (DAL). This is a familiar process for DOD but is by no means easy, given the complexity of what different agencies or stakeholders view as critical.[55] If debates from the 1990s about national ballistic missile defense coverage are any indication, the political hurdles of developing a homeland cruise missile defense DAL should not be underestimated.[56] Identifying the critical military, economic, financial, and commercial assets is a daunting, whole-of-government task.

Critical Asset List (CAL): What should be defended.

Defended Asset List (DAL): What will be defended, given available resources, the threat, and the phase of conflict.

Combining preferential defense with selected area-wide coverage helps alleviate the need to solidify the DAL before defense construction may begin. It simplifies the need to develop and exhaustively rank a "one-to-N" whole-of-government list of every critical asset in the country. Choosing instead to prioritize the defense of concentrations of critical infrastructure abstracts the challenge to broad areas. Comprehensive early warning, paired with additional mobile and flexible assets to protect and deter attack on other elements of the country outside the prioritized areas, can further alleviate the DAL challenge.

Multi-mission Applications

Another guiding principle is that homeland cruise missile defenses should be developed with an eye to more than just cruise missile threats. When recently asked about the homeland cruise missile challenge, Deputy Secretary of Defense Kathleen Hicks urged that it be framed more comprehensively:

> I'm going to broaden [the issue of homeland cruise missile defense] a little to integrated air and missile defense, whether it's unmanned systems, low-slow flyers as we used to just call them, up through the cruise missile challenge, which we have long had that challenge from Russia to think through, all the way up through the more advanced threats we're seeing today.[57]

Besides the challenge and expense of bespoke and stovepiped systems, long lead times and rapidly changing and blurring threats demand an integrated approach with, at minimum, an ability to adapt and evolve over time to at least similar or adjacent missions. Within the air and missile threat spectrum, other threats near today's cruise missile threats include fixed- and rotary-wing aircraft, unmanned aerial systems (UASs), and airbreathing hypersonic cruise missiles.

Several effectors within the Army's Patriot family are multi-mission capable, as are today's ground-launched AIM-120s for the National Advanced Surface-to-Air Missile System (NASAMS). The U.S. Navy's Standard Missile-6 has several applications, including cruise missile defense, air defense, and Sea-Based Terminal hypersonic defense.

Launchers, too, should be flexible to mix and match effectors. The Army's M-903 launcher can support mixed loads, and the IFPC launcher for C-RAM will also be interceptor agnostic. The Navy's Mk 41 launcher has the flexibility to carry numerous different missiles, including the forthcoming Glide Phase Interceptor for hypersonic defense. Emerging high-power microwaves, ultra-short pulse lasers, and other directed energy systems will likely be useful to engage multiple threats.

The multi-threat expectation also applies to sensors. Both Aegis- and several Army-centric radars have multi-mission capabilities. Over-the-horizon radars (OTHRs) can also do so at significant range, in both air and maritime domains.[58] Undersecretary of Defense for Research and Engineering Heidi Shyu recently highlighted the value of multifunctional sensors: "I'm interested in pushing the technology toward a single sensor that has the ability to listen, the ability to do jamming, the ability to communicate, the ability to inject, all in one."

Integrate: ˈin-tə-ˌgrāt. Transitive verb. To form or bring together into a unified whole.

While no sensor is omniscient or omnipotent, the next best thing is an all-knowing (or at least well-integrated) sensor network. Just as an operations center for the defense of Guam will probably need to integrate both Army and Navy elements—Integrated Air and Missile Defense Battle Command System and Aegis command and control systems—an operations center for homeland cruise missile defense for North America will need to integrate multiple data feeds, workstations, and fire control systems.

Attend to the Full Attack Life Cycle

Cruise missile defense of North America should not begin with detecting an incoming threat. Such a posture cedes time to the adversary and favors the attacker, with a cost imposition measured in time and tactical surprise. A third principle to inform defense design is to relentlessly influence an enemy's entire attack life cycle, beginning far left of launch. Such an approach includes influencing adversary decision calculus days in advance by sowing uncertainty and surprise, refuting any sense that an attack would escape attribution, and deploying threats to potential launch platforms.

The life cycle of a missile threat may end over North America, but it begins much earlier. In the event of indications of a potential decision to attack the homeland, combatant commands, in partnership with the interagency, could collaborate on a whole-of-government response, which may include diplomatic, informational, and economic means as well as a military response. From demonstrating the resolve of a growing network of U.S. allies and partners to exposing the cracks in tenuous Chinese partnerships or Russian economic networks, global deterrence actions should present rapid dilemmas and complicate adversary homeland attack decisions.[59] Using common cloud-based data sets and decision tools, combatant commanders could collaborate in minutes, not days, on how to create global deterrent effects and multiple dilemmas for adversaries. Such actions taken to deter attacks on the homeland have been demonstrated by U.S. Northern Command (USNORTHCOM) in recent Global Information Dominance Experiments.[60] Such measures seem to be at the heart of the vision for integrated deterrence.

> *"My focus is not on endgame kinetic defeat of all those potential threats. It's really about deterring in the first place and campaigning to ensure that anybody that would have nefarious activity on their mind would never believe that they can be successful with a strike on our homeland with a cruise missile or any other missile or threat."*
>
> — General Glen VanHerck, April 25, 2022[61]

If an attack decision is not deterred, the preceding hours and days provide opportunities to observe preparations and to take de-escalation measures. Observations of such preparations—long the purview of exquisite sensors in geosynchronous orbit controlled by the intelligence community—may now be augmented by additional detections from low earth orbit more directly accessible by operational units.[62]

Employing such observations can improve pattern-of-life understanding of tactical staging locations and across the operational battlespace. Performant computer vision algorithms can identify not just increased numbers of aircraft at an airfield but also analyze data from thousands of aircraft and support vehicles over multiple locations and weeks of collection to understand when an adversary is preparing an attack. Detecting a 30 percent change in the number of logistics vehicles around strategic bombers or heightened alert of enemy air defenses does not confirm adversarial intent, but it can provide warning sufficient to take other deterrence measures. Such awareness can afford commanders the opportunity to deploy fighters and early warning aircraft as well as heighten the alert of active defenses.

Once an adversary bomber or submarine launch platform sorties out, it should be tracked to constrain its options by holding it at risk from the air or below the surface. The best way to defeat an air-launched cruise missile is before launch—targeting the delivery platforms with forward-based fighters or other means in Northern Canada and Alaska to canalize adversary approach options. A Mk 48 torpedo is likewise an especially effective way to defeat sea-launched cruise missiles—while still aboard the threat vessel.[63] If the missile is launched at any distance, OTHRs can provide warning of subsonic missiles hours in advance of their arrival.

Attending to the missile threat's entire life cycle, from the attack deliberation and decision (the archer) to the launch platform (the bow) and the delivery system (the arrow), increases the potential to deter an attack and provides more opportunities to engage the threat.

Defense in Depth

Defense in depth has long been an effective method for achieving resilience when protecting an area. As seen with picket lines in the U.S. Civil War, the Dowding System of the Battle of Britain, and the DEW Line in the Cold War, layering and integrating detection capabilities provides more warning opportunities than can any single perimeter.

For homeland cruise missile defense, a deep defense allows for broad early warning, tracking of threats during their approach, and increasingly robust sensing and engagement around the defended area. Such depth should extend beyond traditional combatant command geographic boundaries. Various long-range sensors in different domains and at staggered intervals to a defended asset better support attribution, detection, track capacity, composite tracks, combat identification, and potentially fire control quality data.[64]

By contrast, relying on even a single line of high-altitude sensors spread across hundreds of kilometers of coastline, even if affording the ability to detect and track threats at range, produces single points of failure. Any one sensor failure or maintenance issue could open a major gap in the line of coverage. In the event of a large raid, a single sensor may struggle to track the entire swarm.

Layered sensors and defense in depth augment area-wide defense by graduating the level of defensive coverage and buying time for the defender.

Balancing Persistence with Flexibility and Mobility

A fifth principle to shape element selection is that of balance. The benefits of fixed elements should be balanced against the benefits of mobility, and the desire for dedicated and persistent capabilities should be balanced with the desire for global flexibility.

Today, the sensors and effectors used to defend North America are of types typically used for overseas deployments or other missions. Air defense is a high demand, low-density resource, meaning periodic demands to protect or assure allies and partners with air defense during crisis or unexpected conflict can effectively degrade the primacy of homeland defense. A constant or perennial struggle between North American Aerospace Defense Command (NORAD), USNORTHCOM, and other geographic combatant commands for high-demand, low-density air defense assets is not a good solution. Anticipating this tension counsels that at least some homeland defense capabilities be purpose built in a fixed or semi-fixed character.

Integrated air and missile defense for North America affects other combatant commands in part because an adversary may threaten the U.S. homeland to influence American involvement in a conflict half a world away. As such, there is wisdom in retaining homeland air defense assets relatively more dedicated and persistent in tactical availability to USNORTHCOM, rather than as fungible assets in the global force management competition. To preserve the primacy of homeland defense, the general desire to maximize mobility and flexibility can be tempered. Not everything needs to be mobile; fixed or semi-fixed assets may be good enough. In the homeland environment, ground-based sensors and effectors are more efficient and cost effective than airborne platforms that are sustainable only for short periods and provide limited defense capability.

At the same time, flexibility and mobility remain important metrics within any defense design. Calculating the possibility of overwhelming the defensive assets in a single defended area with a swarm of munitions is relatively straightforward with known defender locations and assets. That same calculation can be complicated with the introduction of mobile airborne early warning assets and fighters. If an adversary appears to threaten an undefended area, mobile early warning or fighter aircraft could potentially be surged there. Semi-fixed or mobile ground-based launchers might also need to be repositioned within an area.

A mix of mobile, semi-fixed, and fixed elements can help achieve the necessary flexibility and mobility within the defense design while retaining the relative primacy of homeland defense. Fixed assets cannot be flown away, preserving the primacy of homeland defense, while mobile and flexible assets allow commanders to adjust levels of area defense based on perceived risk.

Throw Nothing Away

Another guiding principle to inform homeland air defense is to throw nothing away. A lesson from the war in Ukraine is that weapons and sensors of the past can have effective uses even in the face of a high-end adversary. Rather than scrapping or mothballing older systems, integrating data feeds and shooters into a new homeland defense architecture can strengthen the overall defense.

Apparently antiquated radars, and those made for other purposes, for instance, can nevertheless be useful, especially with software updates to redirect raw data feeds. NORAD recently demonstrated that Federal Aviation Administration and military air traffic surveillance radars hold air surveillance potential.[65] Those systems operate with 1980s algorithms to declutter low radar cross-section returns to make air traffic control and awareness more efficient. That same efficiency, however, throws data away. Their feeds currently filter out 98 percent of raw radar returns using legacy algorithms that may mask objects such as cruise missiles or UASs operating below normal airliner altitudes and flight profiles.[66] Other sensors, some experimental and some aligned to other missions, hold further promise, including naval test radars at Wallops Island, aerostats on the southern border and maritime approaches, the Relocatable Over-the-Horizon Radar (R-OTHR) used for counterdrug operations in the Caribbean, and numerous others across the continental United States and Canada (Figure 16).[67]

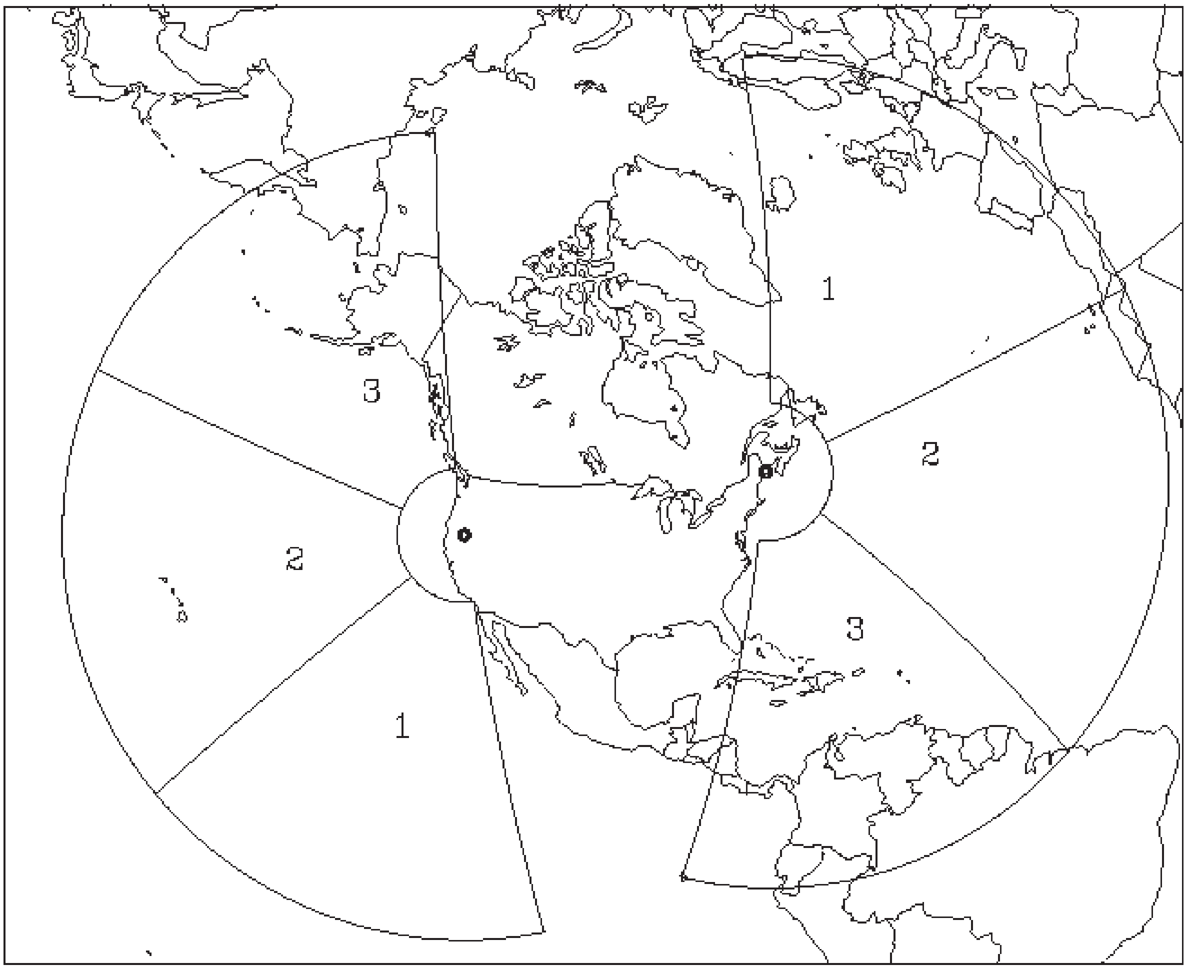
Figure 16: U.S. Navy's Relocatable OTHR

Source: U.S. Navy.[68]

Though these sensors are not optimal for cruise missile detection, unlocking and integrating their unfiltered returns into a new architecture could contribute to threat tracking and engagement in the interior of North America.[69]

The mere effort to catalogue existing candidates reveals a cautionary tale. Some past investments that would have proved useful have already been thrown away. The Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS), or components thereof, might have proven useful today had it and its spare not been disassembled in the late 2010s. During the 1980s, the United States made a major investment in Over-the-Horizon-Backscatter (OTH-B) radars to provide greatly increased early warning of nuclear bomber attack from the Soviet Union. Construction began on several coastal transmit-and-receive sites, but they were terminated at the end of the Cold War (Figure 17). After being held by DOD in caretaker status for several decades, the land and infrastructure was recently sold to private owners. If DOD still owned those OTH-B sites, the required time for site surveys, environmental impact studies, and procurement of OTHR systems in the defense design below might be considerably reduced.

Figure 17: Circa-1980s Plan for OTH-B Coverage



Source: National Oceanic and Atmospheric Administration.[70]

Affordability

A final, practical principle is affordability. Despite being the top defense priority, robust homeland cruise missile defense cannot cost a half-trillion dollars. As each of the above six principles is taken into account, their application must ultimately meet the test of a seventh: if homeland integrated air and missile defense is to be achieved, a cost-effective approach is required. The practical application of all seven principles will take imagination and innovation.

Together, these principles provide the basis for a new defense design paradigm—one that is achievable and scoped to address the evolving air and missile threat spectrum. Such an approach is necessary to evolve air and missile defenses not just for the North American region but other regions as well.

5

A New Defense Design

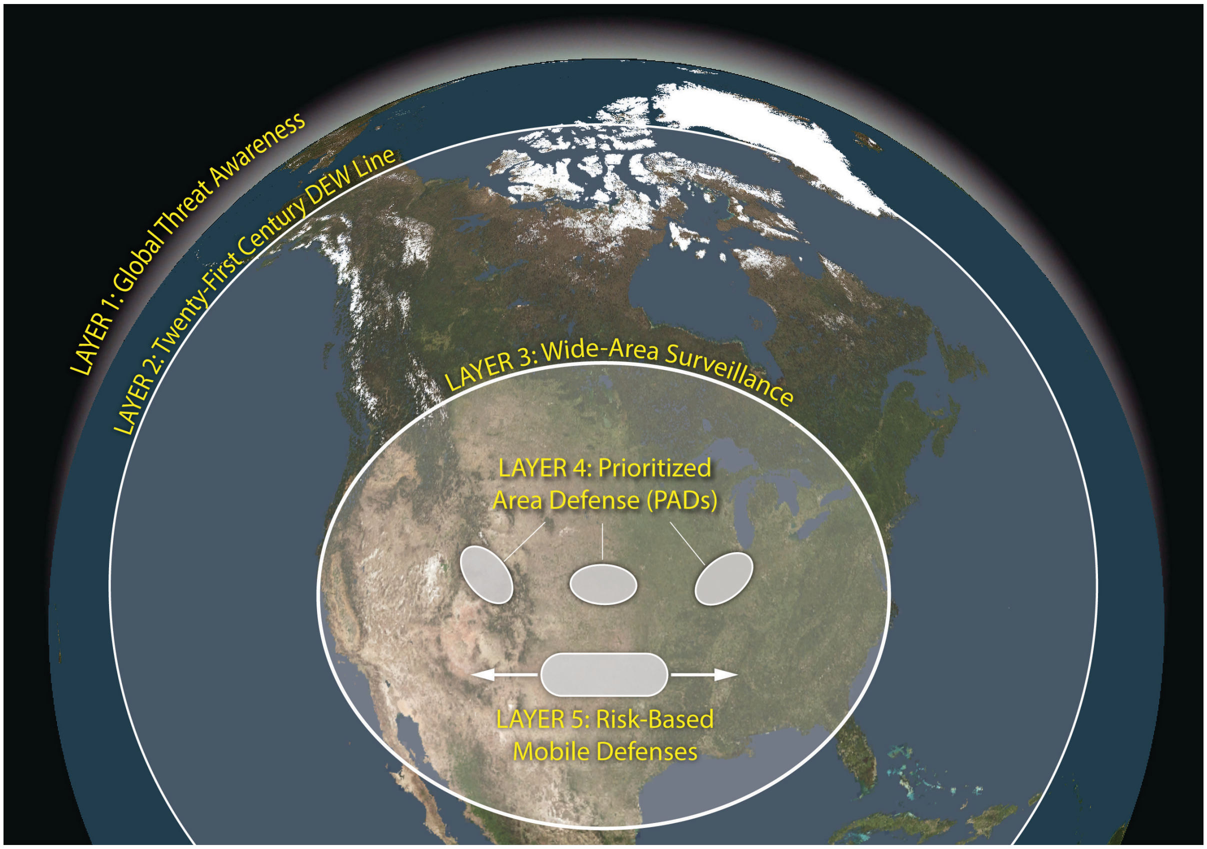
Applying the principles discussed above, this report develops a notional architecture for homeland cruise missile defense, consisting of five layers. The first layer consists of intelligence-informed global threat awareness, which provides an understanding of adversary pattern of life and alerting when an attack may be imminent. The second layer is devoted to distant early warning, a kind of twenty-first century DEW Line, with significant, 360-degree over-the-horizon detection of air and maritime threats approaching North America. The third layer focuses on wide-area surveillance internal to North America, integrating existing sensor capability to help maintain custody of potential threats. Each of these three layers both provides early warning and helps cue the next layer's protection of a limited defended asset list. The fourth layer, Prioritized Area Defense, provides weighted defensive coverage around a handful of areas within which many critical assets are clustered. A fifth and final layer introduces mobility and flexibility for either forward deployment or coverage elsewhere on the continent (Figure 18).

Table 3: Temporal Elements of the Cruise Missile Defense Kill Chain

1: Warning	2: Custody	3: Track/Identify/Pair	4: Decision Time
– Time provided by detections of unidentified air objects.	– Time and defense options provided by wide-area surveillance for maintaining custody of threats as they transit.	– Time to produce track and positive identification of threats and pair them with engagement options.	– Time available for human authorities to confirm a hostile threat, communicate to leaders, decide whether to engage, and select an intercept option.
5: Interceptor Launch	**6: Intercept**	**7: Assess and Reengage**	
– Time required to communicate the engagement decision and launch the surface-to-air interceptor.	– Time required for the interceptor to transit to and intercept the threat.	– Time required to assess target engagement and launch another interceptor, if necessary and possible.	

Source: CSIS Missile Defense Project.

Figure 18: Five Layers of Defense



Source: CSIS Missile Defense Project.

Five Layers

1. Global Threat Awareness
2. Twenty-First Century DEW Line
3. Wide-Area Surveillance
4. Prioritized Area Defense
5. Risk-Based Mobile Defenses

Global Threat Awareness

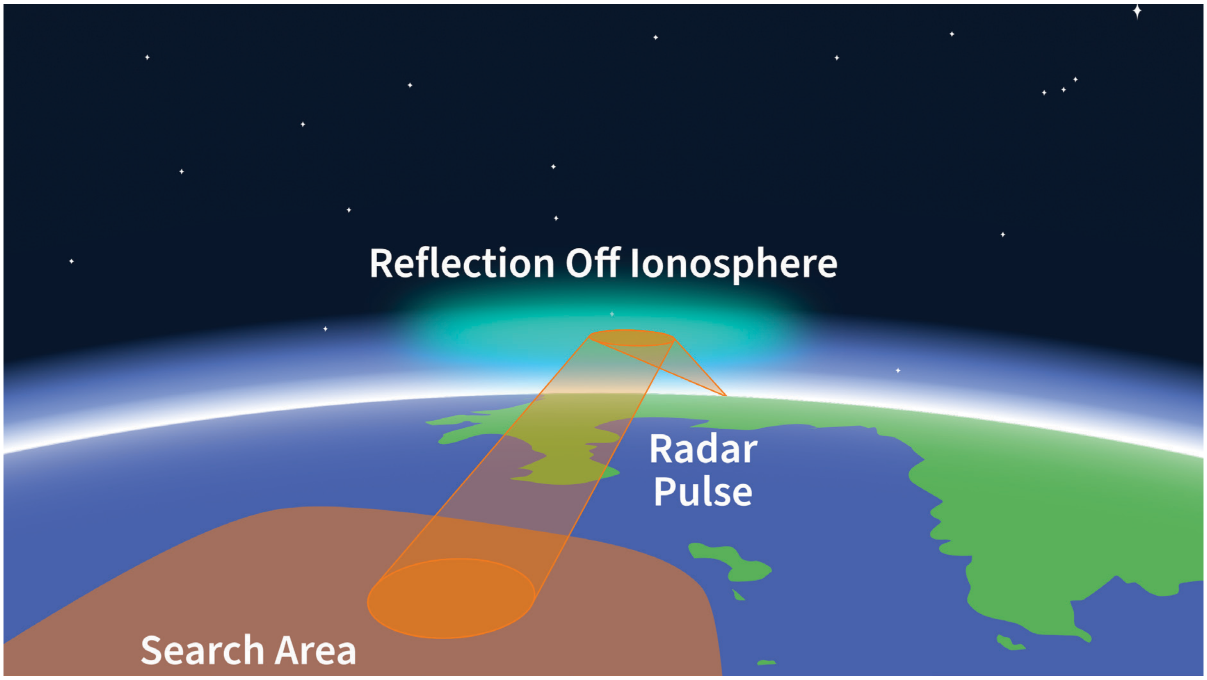
The first layer of protection combines indications and warning derived from a variety of intelligence, surveillance, and reconnaissance sources. Threats to North America from strategic competitors do not emerge out of a strategic vacuum but are the result of days or weeks of deliberation and logistical preparation. Adversary decisions and the readying of forces for a potential attack are often not confined to one threat operating location or even a single region. As adversaries seek opportunities to hold North American assets at risk, they increasingly act across traditional combatant command boundaries, confounding the way that Western planners have divided the world for decades. In order to detect and analyze a potential strike against North America, awareness cannot be stovepiped by region. Data should instead be integrated to create a global perspective.

For instance, if an adversary forward deploys refueling aircraft while simultaneously increasing planning activities at strategic and tactical command centers or reinforcing their own defenses, these events may be observable through subtle cues in intelligence collection. Increased electro-optical and radar-based sensing, including through commercial satellite constellations, may provide a more granular understanding of adversary patterns of life.[71] A single human might note more vehicles than normal at the command center of a bomber base, but machines can correlate that information with numerous other small changes in activity over an entire region to provide more comprehensive insight into potential attack preparations. Machine-enabled indications and warning globally accessible to multiple combatant commanders can better equip them to anticipate and actively deter an attack.

A Twenty-First Century DEW Line

The second layer represents a new manifestation of the multitiered distant early warning line (DEW Line) of radars which evolved into the North Warning System. If deterrence fails and an adversary decides to launch a non-nuclear cruise missile attack, early warning, decision time, and defensive options become the most critical factors. In the past, it was sufficient to detect the platform, but longer-range cruise missiles today require improved capability.

Figure 19: Over-the-Horizon Radar Operation

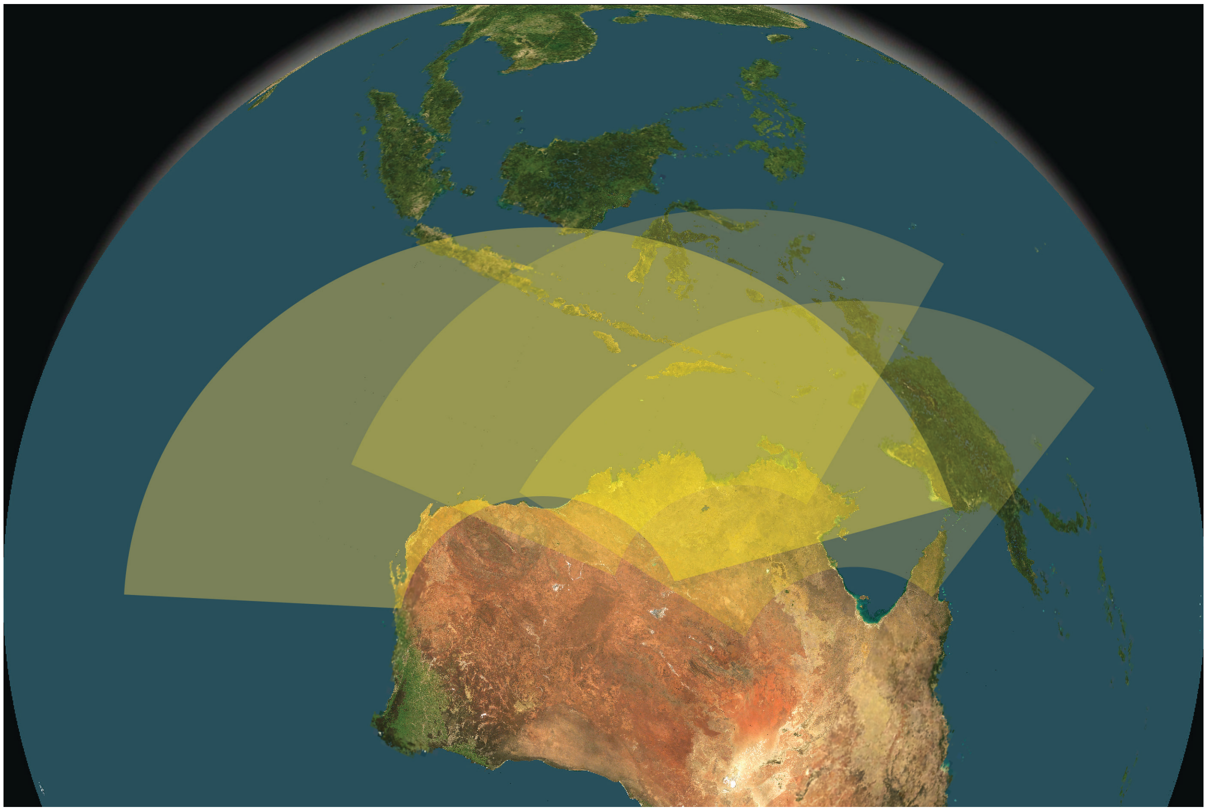


Source: CSIS Missile Defense Project.

This twenty-first century DEW Line is likely to consist of over-the-horizon radars (OTHRs). OTHR is a decades-old technology in use today by the U.S. government to detect air and maritime targets in the Gulf of Mexico and Caribbean for counternarcotics and other missions (Figure 19). Its modernization and potential against peer-level air and maritime threats was realized in the 2010s by Australia in their multiphase Jindalee Operational Radar Network (Figures 20–21).[72]

OTHRs operate by making use of the reflective properties of the ionosphere, bouncing long-range radar beams off the atmosphere and over the curvature of the earth. While OTHR achieves incredibly long-range detection, it may not be able to discriminate tightly packed formations or conduct combat identification. While OTHR capability is reduced in the High North above around 70 degrees of latitude due to ionospheric disturbances, mitigations still allow for early warning of Arctic threats.

Figure 20: Jindalee Operational Radar Network Coverage



Source: CSIS Missile Defense Project.

While OTHR can surveil millions of square kilometers, its beam must be directly aimed at small sequential footprints for a few seconds each—requiring time to cover a large area. Overlapping OTHR fields can minimize surveillance time and mutually reinforce radar returns. The radar can detect both high- and low-altitude air targets of various speeds as well as maritime objects. These and other factors make OTHRs an excellent candidate for integrated homeland defense early warning.

The utility of OTHRs for homeland cruise missile defense appears to be confirmed by the FY 2023 defense budget request, which reportedly includes "$278 million for new over-the-horizon radars to improve our ability to detect and decrease the risks from cruise missile strikes against U.S. critical assets."[73]

While OTHRs may not currently support combat identification or fire control-quality data, detecting uncooperative aerial objects at a distance of 3,000 km can potentially provide hours of early warning, thereby supporting engagement or positive identification by other means. Even if OTHR-based early warning does not provide fire control-quality tracks, it can supply generic attack direction, range, expected time of arrival, and possibly raid size.

The OTHR layer may thus represent the most critical element of the defense design: by removing the element of surprise from an adversary's attack, detection complicates adversary decisionmaking, enhances attribution, and provides early warning—qualities the original warning line provided against Cold War bombers. Even if it were not supplemented by active defense intercept means, robust OTHR early warning—a twenty-first century DEW Line—would substantially contribute to deterrence.

> *"When you talk about over the horizon radars, that is that really first robust investment that's being made in PB23 that recognizes the fact that you need broad area surveillance. Those that study over-the-horizon radars know that they can see far and they can give you a pretty good picture. Then where you'll go from there is you'll take that broad surveillance, and you'll neck it down and go to tracking radars."*
>
> — Vice Admiral Jon Hill, May 23, 2022[74]

Figure 21: Jindalee Over-the-Horizon Radar

Source: Royal Australian Air Force.[75]

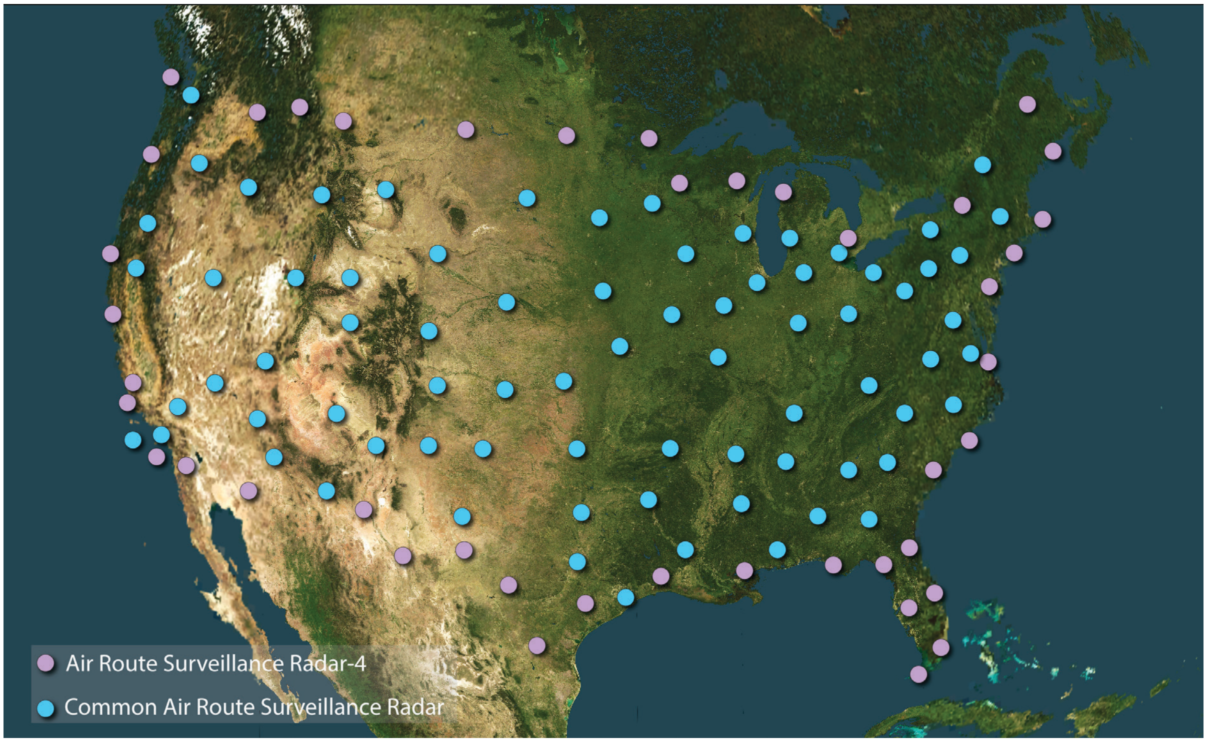
Wide-Area Surveillance

Although OTHRs can provide deep coverage, they are far-sighted—constrained by a minimum detection range of approximately 1,000 km. The distance required to bounce off the ionosphere and come back down creates a short-range coverage gap. To maintain custody of maneuverable threats closer to home, a layer of persistent, wide-area surveillance (WAS) becomes necessary. Like OTHRs, WAS may not provide high-quality tracking, combat identification, or discrimination but would help maintain threat custody.

Of all the layers, implementing WAS will require the most imagination, innovation, and whole-of-government coordination. Without investing in a purpose-built network of sensors, a WAS layer could be created using existing military, civil, and dual-use sensors. Although developed for other missions, these sensors can provide excellent "signals of opportunity" when integrated with other data through machine learning to create fused tracks of interest. Building these tracks requires access, however, to the raw sensor feeds.

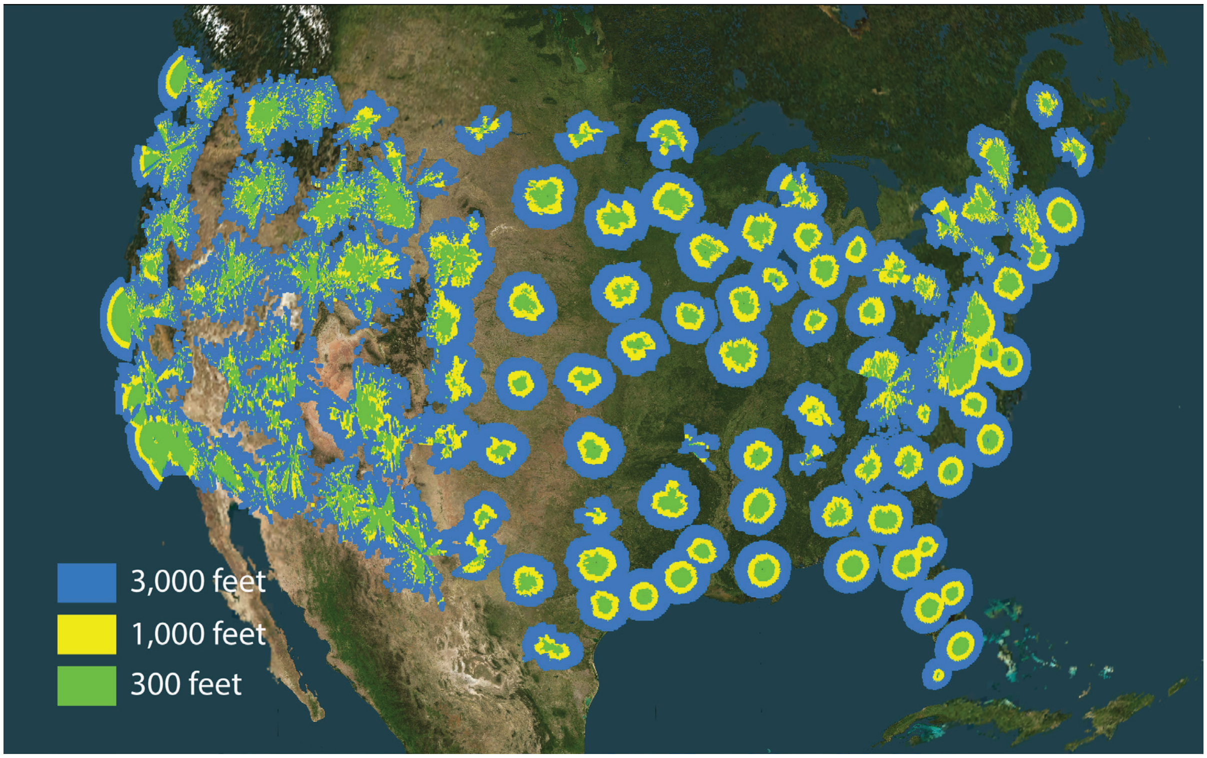
The North Warning System provides an instructive example of how gaining access to raw sensor feeds can yield new capability. Because they were built to optimize detection of medium- or high-altitude bombers, the algorithms on these radars filter out the majority of raw radar returns in favor of that expected threat. The subtle detections from low-altitude, low-cross-section objects, such as that from a cruise missile threat of today, is rejected by legacy algorithms as clutter.[76] The raw data from these and other sensors across North America could be used to augment WAS. Even if a cruise missile or unmanned aerial system (UAS) threat travels below the radar horizon of national airspace system radars, the incorporation of these sensors—albeit far from perfect—can help create an integrated air picture and maintain threat custody.

Figure 22: FAA and Military Radar Locations



Source: CSIS Missile Defense Project.

Figure 23: FAA and Military Radar Coverage



Source: CSIS Missile Defense Project.

Several categories of sensors are possible candidates for inclusion in the WAS layer. First and foremost is raw Federal Aviation Administration (FAA) civil air traffic radar, including both older Common Air Route Surveillance Radars run by the FAA and the newer Air Route Surveillance Radar-4 acquired in partnership with the Air Force (Figures 22–23). These sensors already contribute to air domain awareness with legacy algorithms tuned to track large airliners at medium altitude. While reportedly scheduled for an upgrade, accessing the raw feeds of the current radars even in the near term can contribute to maintaining custody of low-altitude, non-cooperative threats such as cruise missiles. Airport surveillance radars, typically detecting aerial objects within about 100 km around individual airports, could provide an additional layer of national-level custody of threats.

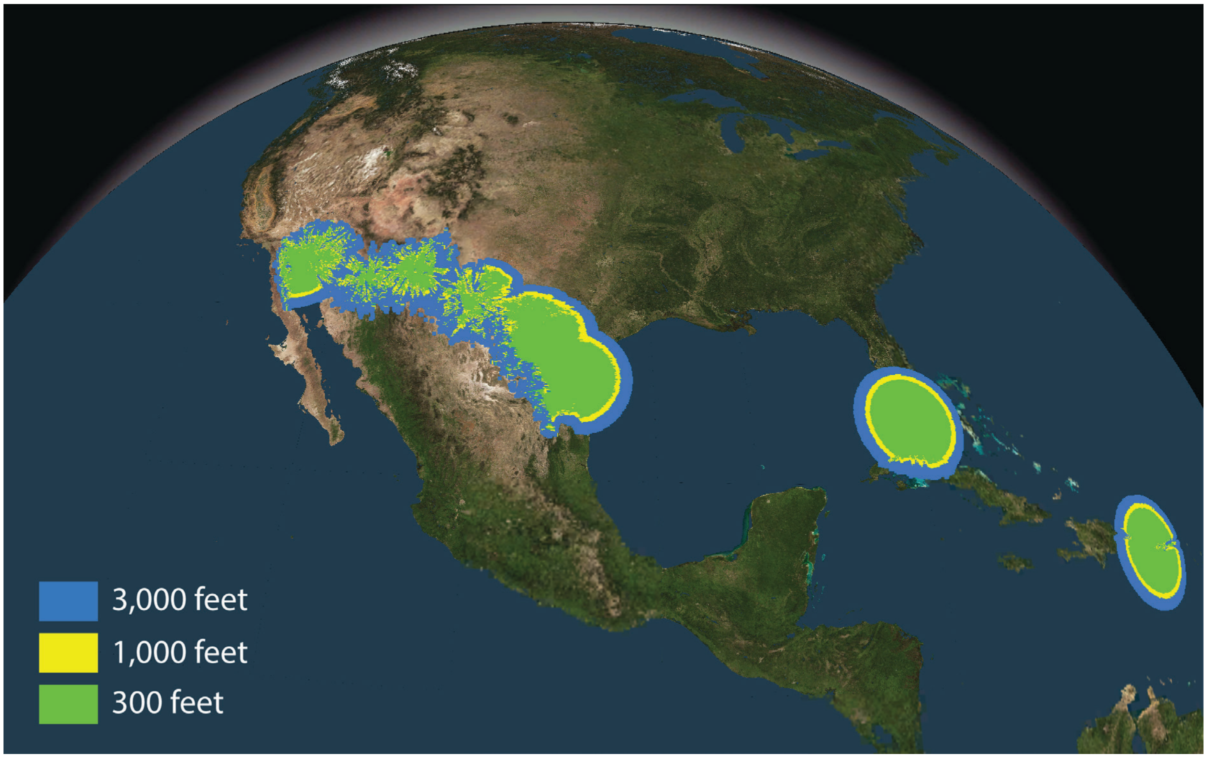
Another source on the southern approaches is the existing fleet of Tethered Aerostat Radar Systems operated by U.S. Customs and Border Protection. Operating between 10,000 and 15,000 feet in altitude, these elevated sensors provide radar-based air domain awareness that could augment surveillance and detection (Figures 24–25).

Figure 24: Customs and Border Protection Tethered Aerostat Radar System

Source: U.S. Customs and Border Protection.[77]

A third potential source is the 160 doppler weather radars (Figures 26–27). While using an S-band frequency (less accurate for threat detection), and typically aimed above the horizon and therefore less focused on the low-altitude flight environment, the integration of these sensors could aid in threat custody in the interior of North America. Dopplers have, for instance, tracked the dispersal of a flock of birds—a very low-radar-cross-section target (Figure 28).[78] Unfiltered radar data from these sensors could provide another source on which to apply machine learning and in time could be used to maintain custody of non-cooperative threats.

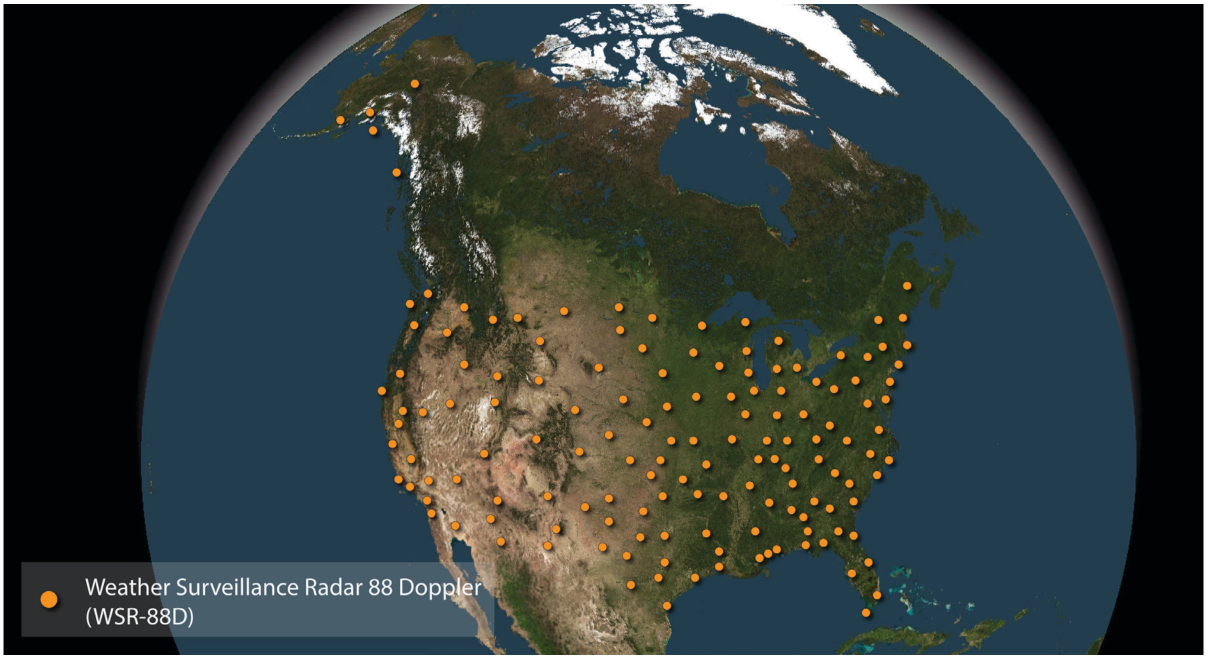
Figure 25: Estimated Coverage of Tethered Aerostat Radar System from 10,000 Feet



Source: CSIS Missile Defense Project.

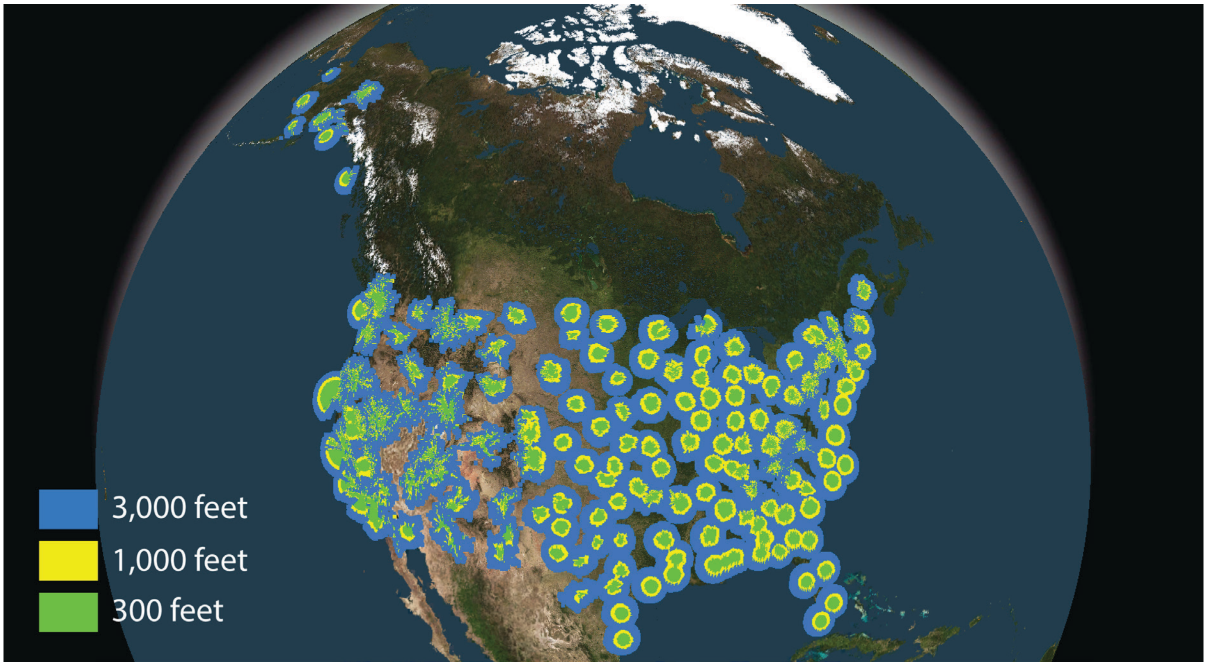
Passive sensing represents a fourth category of potential means to support WAS. One category of passive sensing takes advantage of the considerable electromagnetic signatures and emissions across North America. These signatures include television, radio, and various communications signals, including cellular towers, which are rich within the continental United States (Figure 29).[79] Anything that radiates on or over North America with a known frequency, position, and power could potentially provide a decibel change detection to passive receivers, if shared spectrum challenges can be overcome. Normal air activity can be quickly mapped and correlated with known air objects.[80] Acoustic sensors, once standard in days before radar, trained to listen to the distinctive engine sounds of cruise missiles or other aircraft may be yet another source (Figure 30). To be sure, these are different sorts of capabilities and approaches compared to legacy missile defense efforts. General Glen VanHerck has highlighted the need to move in innovative ways like this, saying, “What I want to let the industry, the Missile Defense Agency, and the services do is let their minds run wild on capabilities to accomplish this mission.”[81]

Figure 26: NOAA Doppler Weather Radar Locations



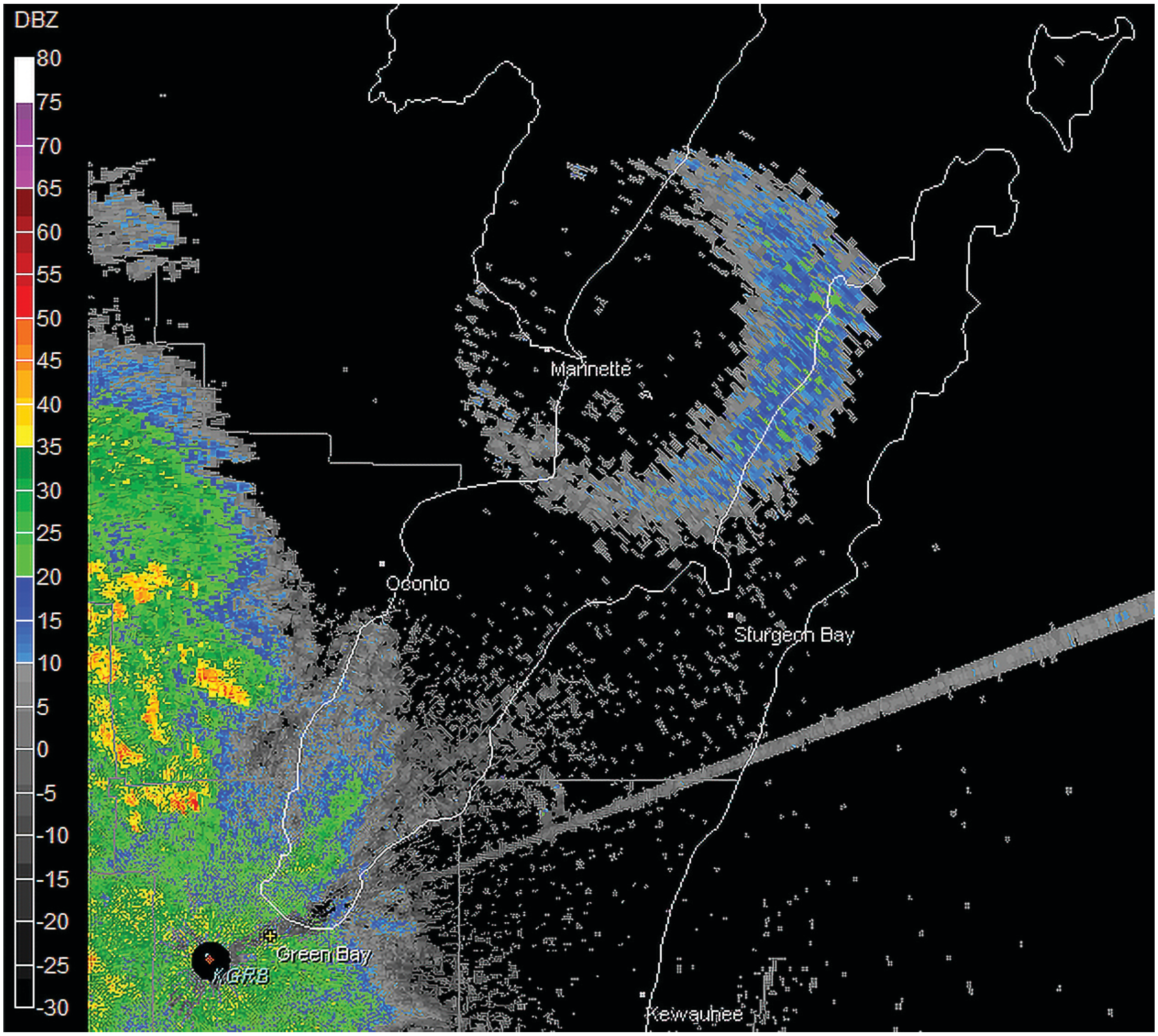
Source: CSIS Missile Defense Project.

Figure 27: NOAA Doppler Weather Radar Coverage



Source: CSIS Missile Defense Project.

Figure 28: Doppler Detection of Bird Dispersal

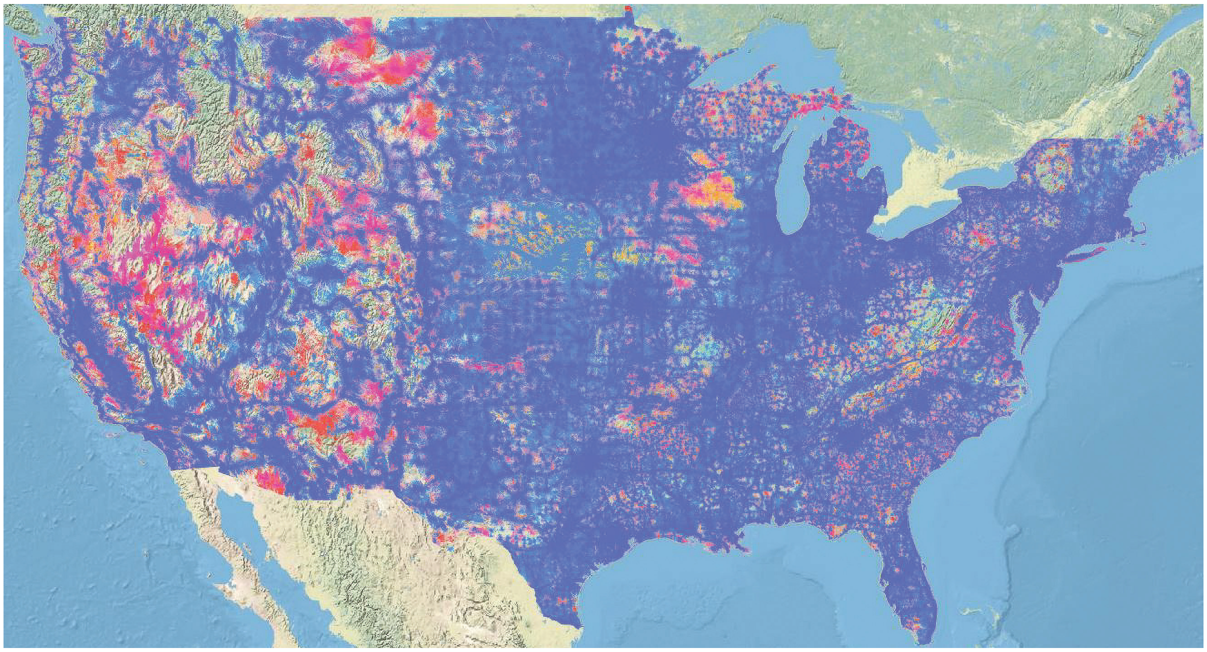


Source: National Weather Service.[82]

Passive sensing of any type is likely to be supplemental or a "bell-ringer" capability rather than one providing fire control-quality track or combat identification. It nevertheless may be useful for anomalous or non-cooperative air objects to be identified and marked by machines as worthy of further investigation. Past budget documents describe the Army Long-Range Persistent Surveillance as "a passive sensor that provides long range surveillance" against cruise missile, fixed-wing, rotary-wing, and UASs.[83]

Inasmuch as WAS will draw upon assets from entities other than DOD, its implementation will be an important test case for the Pentagon's concept of integrated deterrence.

Figure 29: LTE Cell Coverage in CONUS



Source: Federal Communications Commission.[84]

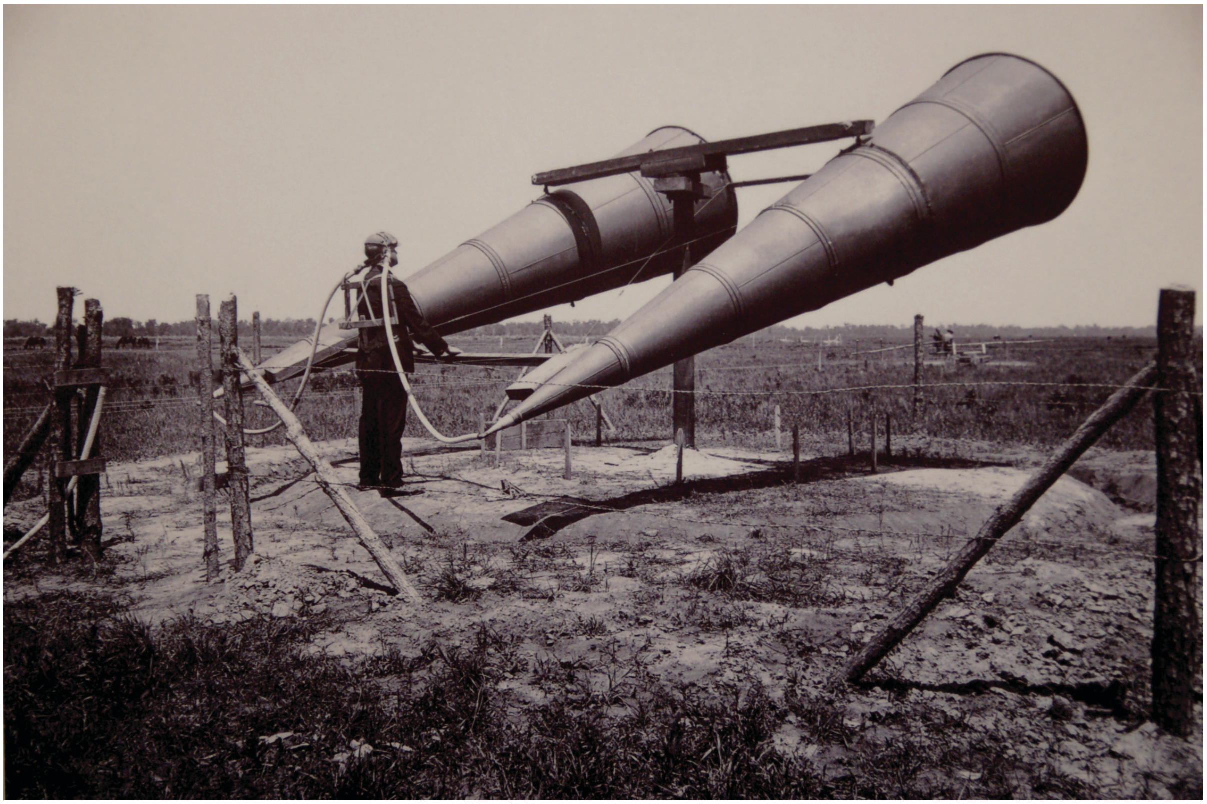
Prioritized Area Defenses

Supported by these three layers of detection and tracking, Prioritized Area Defenses (PADs) are the heart of active defense in this design. The 2021 CBO report identifies "government facilities, military bases, [and] power infrastructure" as likely targets of a cruise missile attack by a near-peer state.[85] The defense design depicted here leveraged this open-source analysis to notionally pick five broad areas with a large concentration of these types of high-value assets. These areas were abstracted to a national level to reduce any potential sensitivities about particular assets.

COVERAGE AND TIME

The PAD design outlined here leverages tactical defense in depth and proliferated tower-based sensors to provide overlapping sensor coverage for low-altitude targets well outside the radar horizon of single-point ground sensors. The use of sensor towers distributed across the PAD negates the challenges of radar horizon, effectively creating a large, organic sensor network able to track threats from medium to low altitude. This distance creates time for defenders to confirm threats, pair interceptors, and communicate decisions. Because the PADs are cued by OTHRs and other WAS systems, internal tracking could be supplemented with up to a few hours of early warning.

Figure 30: Passive Acoustic Sensors from World War I



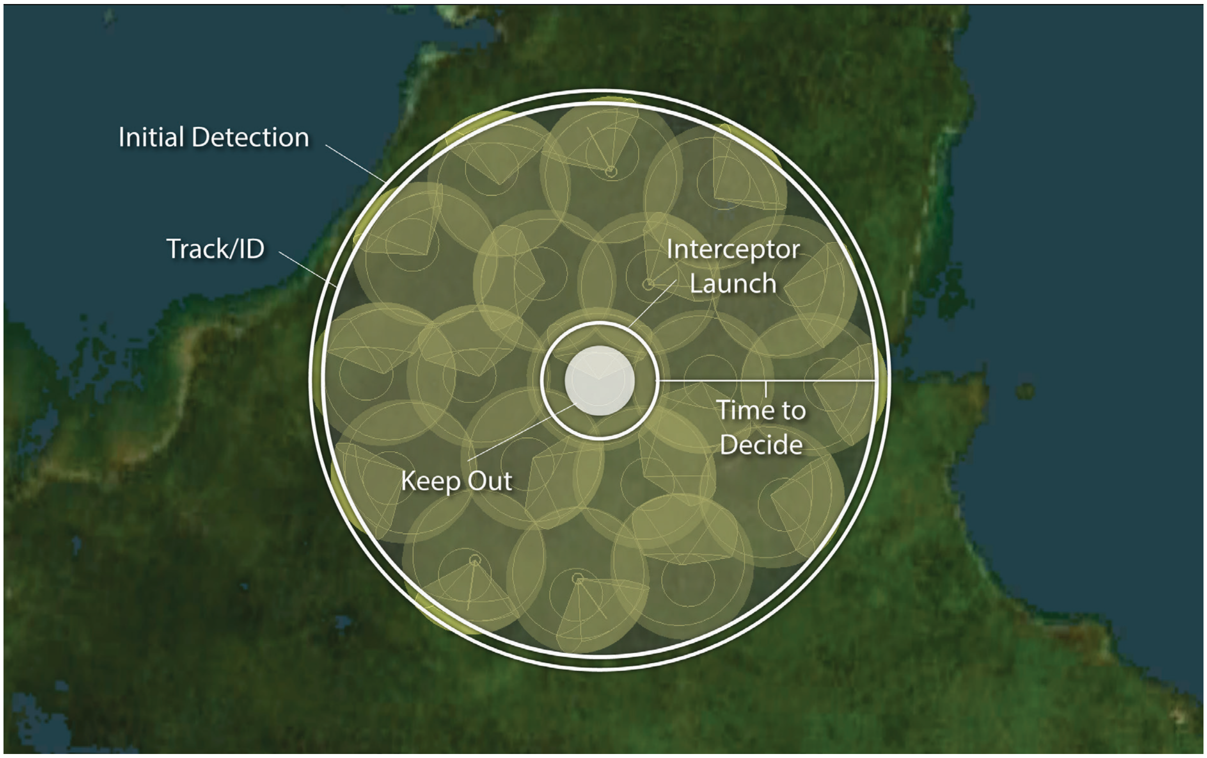
Source: Curious Expeditions.[86]

As threats approach a PAD target area, the clock begins ticking for defenders to decide if and how to engage them. The defender's time to decide lies between the initial detection, track, and identification as a threat enters the PAD and the minimum engagement range to keep threats outside the specific defended area. This amount of time, derived from the speed of the threat, distance of sensor coverage, and capabilities of the interceptor, provides national leaders and local defenders with the time available to confirm threats, pair interceptors, and communicate decisions. With a notional "keep out" area over a defended area around PAD center, a PAD could provide defenders with up to 14 minutes and 44 seconds to decide (Figure 31). This time will vary based on the location of defended areas inside the PAD and the location of sensor and interceptor emplacements.

MULTI-SENSOR TOWERS

Each PAD consists of a honeycomb of 19 networked sensor towers, 300 feet in height. At that elevation, such sensors can maximize detection range while minimizing horizon challenges. Significantly lower than CBO's considered 700-foot towers, 300 feet provides a compromise between increased capability and ease of emplacement, operation, and maintenance. The lower height also opens the possibility of using existing radio, television, or cellular towers. Overlapping coverage between the towers provides resilience if one sensor fails, is attacked, or is impaired by background environmental clutter or electromagnetic noise. The multi-sensor phenomenology enhances the ability to conduct combat identification as well as track more threat objects. Specific tower heights and locations would be highly contingent on natural and artificial terrain, surface clutter, and existing assets.

Figure 31: Time to Decide



	Detect	Track/ID (10 sec)	Decision Time (14 min: 44 sec)	Interceptor Launch (5 sec)	Threat Intercept (21 sec)
Time to Target (min:sec)	16:40	16:32	1:26	1:21	1:00
Range to Target	250 km	248 km	27 km	25 km	15 km

Assumptions:

- Required Keep Out: 15 km from PAD center
- Threat: speed 250 m/sec, altitude 100 m
- Sensors: Autonomous detection, track, and identification
- Command and Control: tactical C2 from single operator, machine-generated engagement options, human confirmation and decision
- Interceptor: speed 0.7 km/sec, launch reaction time 5 sec, launch location at PAD center

Source: CSIS Missile Defense Project.

The selection of towered-based radars itself represents a kind of middle ground compared to other capability alternatives. The cruise missile detection and tracking challenge is one of both horizon and range. Ground-based radar sensing from a single point, regardless of energy output, is throttled by a short horizon. Conversely, an elevated tethered sensor at 10,000 feet can see considerably farther, but there are limitations in size, weight, and power, in the number of tracked objects, and in the risk of a single point of failure. Effectively detecting and tracking low-altitude targets at a range of some 250 km requires a great deal of radar power to propagate energy, increasing cost.

The PAD towers are placed in an overlapping pattern with approximately 60 km between sensors, for a total coverage radius of approximately 250 km or 196,000 km^2. The depicted circular arrangement of towers is purely notional: actual locations and configurations would depend upon defended asset location, platform and siting availability, assessment of likely attack avenues of approach, and environmental factors.

Eighteen of the nineteen towers would host single, rotating, electronically scanned phased-array radars with a detection and tracking range of approximately 75 km. The nineteenth tower at PAD center would have an Aegis fire control radar which would support the medium- to long-range Aegis interceptors at PAD center. Together, this PAD network supports 360-degree detection, identification, track, and fire control.

The overlapping spacing of the towers provides resilience in the event of element failure. Given both the number of radars and the presence of numerous other electromagnetic emissions across North America, measures will need to be taken to mitigate electromagnetic interference. Such efforts might include physical or algorithmic filtering, passive shielding, angle and frequency diversity, and other means.

In addition to the radars, each of the 19 towers would host electro-optical and infrared (EO/IR) sensors to disambiguate threats in congested areas and aid positive combat identification. These sensors, along with the associated radars, would be machine controlled, allowing for near-autonomous operation. Sensor towers would continuously hand off tracking and identification to others as a potential threat traversed the PAD, allowing a human operator on the loop to validate the threat and select from machine-generated engagement options. This autonomy will be important for both radar resource allocation and frequency deconfliction. This human-machine teaming sensing and engagement of cruise missile-type threats was demonstrated by North American Aerospace Defense Command (NORAD) and U.S. Northern Command (USNORTHCOM) during a live-fire exercise in September 2020, reducing the time from detection to identification and interceptor pairing to mere seconds.[87]

PAD INTERCEPTORS

For its primary engagement layer, each PAD contains 48 medium-range surface-to-air interceptors in four relocatable launchers. These U.S. Army-type interceptors would leverage the tracking and fire control feeds from the sensor towers in addition to their own active seeking capability. Launchers could be emplaced wherever desired in the PAD and for particular defended assets. This interceptor configuration, combined with the overlapping radar and EO/IR sensor tower coverage, provides 360-degree threat engagement capability across the entire PAD, including a simultaneous attack from multiple axes.

A second interceptor layer consists of a single eight-pack Mk 41 Vertical Launching System (VLS) at PAD center with six long-range Aegis-type interceptors with a range of approximately 160 km.

Figure 32: PAD Elements and Configurations

Towered Radars

Medium-Range Interceptor Kinematic Volume

Long-Range Interceptor Kinematic Volume

PAD Configuration

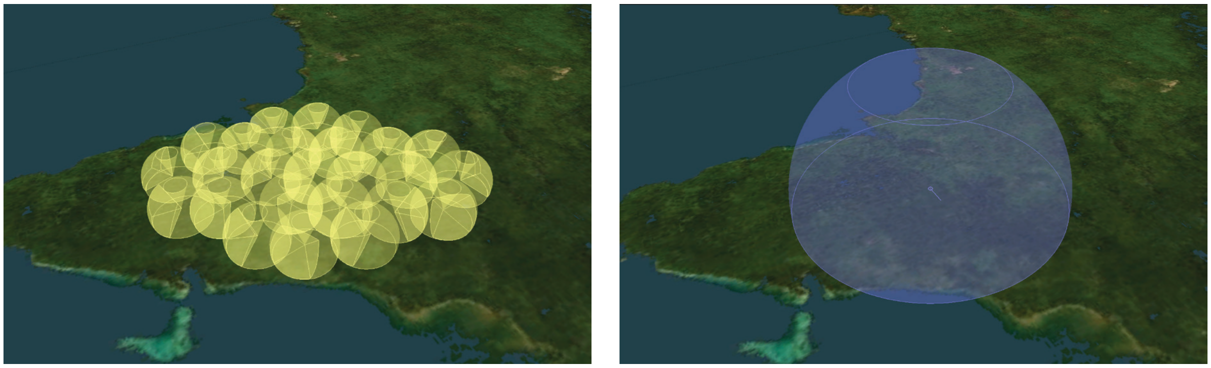
Source: CSIS Missile Defense Project.

PAD+ EVOLUTION

Over time, these baseline PADs evolve to support a thicker defense, called a PAD+. The PAD+ increases the number of sensor towers to 25, providing earlier detections and more time to decide (Figure 33). An additional eight pack of Mk 41 VLS canisters is added with multi-mission extended-range interceptors to engage more advanced threats. As costed here, one of the five PAD+ locations, that for the National Capital Region, receives a single 10,000-foot altitude aerostat for more robust surveillance, discrimination, and combat identification. Finally, each PAD+ is equipped with at least one high-powered microwave (HPM) system for endgame engagement as well as counter-UAS applications.

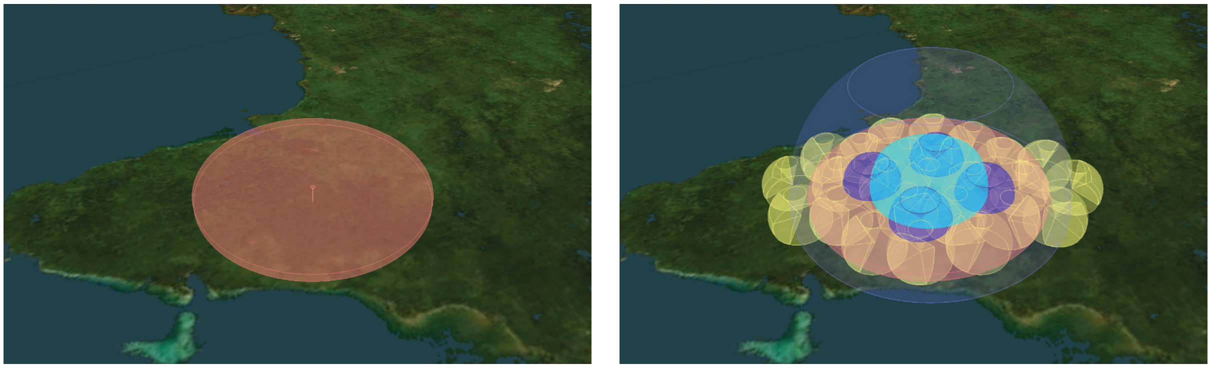
> *“There are multiple ways beyond the kinetic endgame defeat of this that we could potentially be successful in cruise missile defense. And that could be through the use of the electromagnetic spectrum and other non-kinetic means to be able to do something beyond point defense in more of a wide-area defense or a limited-area defense.”*
>
> — General Glen VanHerck, April 25, 2022[88]

Figure 33: PAD+ Elements and Configurations



Towered Radars

Multi-mission Long-Range Interceptor Kinematic Volume



Aerostat at 10,000 Feet

PAD+ Configuration for NCR

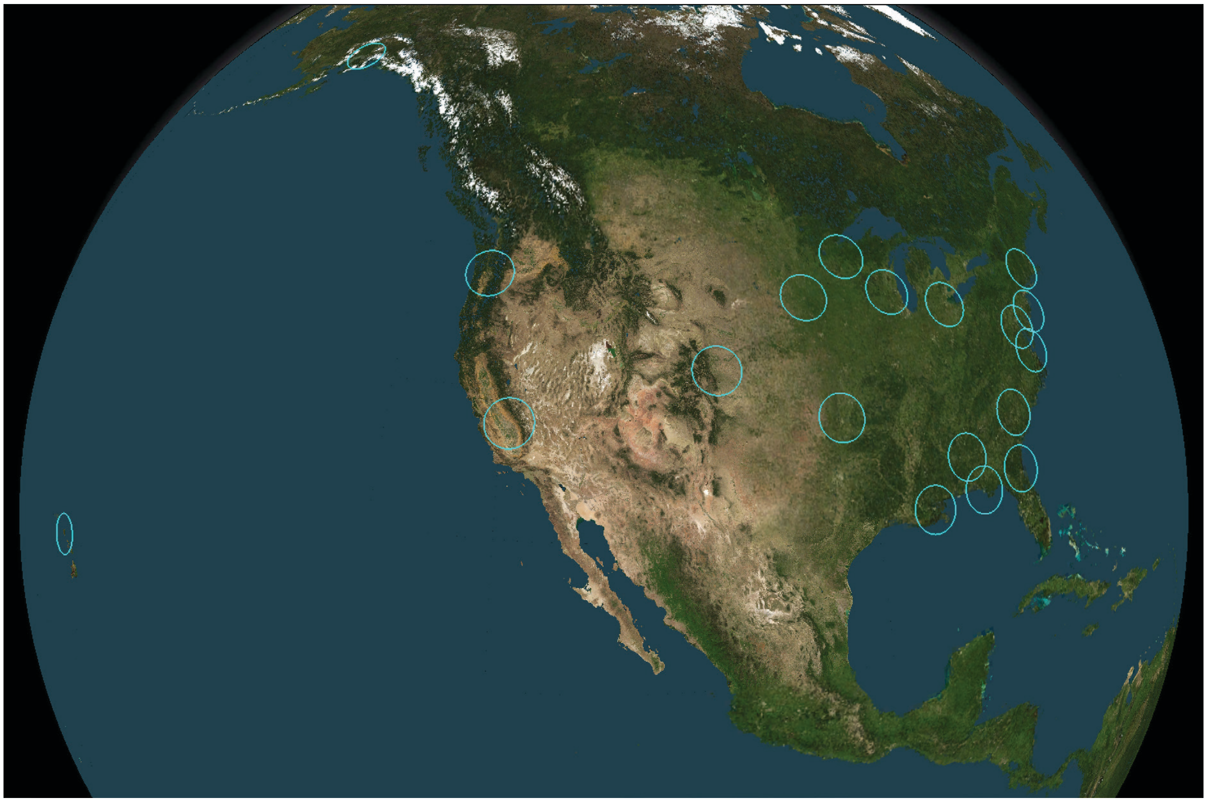
Source: CSIS Missile Defense Project.

Flexible and Adaptive Elements

The fifth and final layer of the defense design applies the principle of balance, supplementing the PAD's various fixed and semi-fixed assets with flexible and mobile platforms. If an attack was anticipated from a particular direction, such as the Greenland-Iceland-UK gap, a commander could surge airborne assets to that avenue of approach. The detection and early warning platform considered here is the E-7 Wedgetail, which the U.S. Air Force has begun to acquire for other purposes. While not able to cover all approaches to North America, E-7s could provide critical, episodic forward airborne early warning and command and control—especially for less-defended areas over the Arctic.

A second type of mobile asset considered here is manned fighter aircraft—the baseline for much of today's quite limited defensive capability (Figure 34). Unlike CBO, the defense design considered here does not include any additional investments in fighter aircraft or alert bases. Instead of making them foundational to both detection and engagement, as the CBO study did, these aircraft remain flexible and supplemental. The prospect of forward deploying these elements could hold threat bombers at risk, canalize attack options, or shore up potential holes in the defense. For example, should F-35s be flying, their sensors would be useful for tracking missile threats even if they were outside weapon engagement range, sharing that information via their Multifunction Advanced Data Link.

Figure 34: Ground Alert Fighter Range—20-Minute Warning



Source: CSIS Missile Defense Project. Image depicts current or near-term AESA-equipped homeland air defense fighter locations and Mach 1.0 flight range with 20-minute warning and 10-minute ground alert posture (160 km). Actual intercept capability dependent on threat flight path relative to alert airfield. Not indicative of actual NORAD alert posture.

Federated Command and Control

A final, critical aspect of homeland air and missile defense is the command and control structure that brings these elements and layers together. Under today's command and control process within NORAD and USNORTHCOM, engaging a suspected air threat involves a methodical and hierarchical process of communicating and verifying a threat via multiple phone calls and several echelons of command. The resulting notification and decision process consumes precious minutes—too long to respond to fast, low-flying cruise missiles. Even with an improved sensor architecture, operators would have to play a game of telephone to call higher command and would be at a severe disadvantage.

Instead, defenders should operate on mission-command-type authorities delegated to subordinate echelons to increase responsiveness. Increasing levels of geopolitical crisis or conflict should correspond to increasing risk-informed authorities delegated to defensive decisionmakers. In normal, day-to-day operations where there is little to no threat from strategic attack, the authority to engage a possible cruise missile threat should be retained at higher levels to minimize inadvertent engagement.

As envisioned here, the respective interceptor systems would be able to rely upon their organic and locally cued command and control systems. Waiting for the nirvana of a perfect Joint All-Domain Command and Control (JADC2) system to control everything may in practice be yet another excuse to kick the can down the road. Detection, tracking, and engagement options for an unknown or suspect track could be retained at higher echelons during steady-state operations with an absence of an expected threat. During more heightened threat conditions or when under attack, these authorities could be delegated to location decision.[89] To the extent possible, however, local defenders would receive a common operating picture and integrated air picture, informed by the Command and Control, Battle Management, and Communications program and other sources. How this will function is currently the object of study, but work currently being done to integrate Army and Aegis air and missile defenses for the defense of Guam will almost certainly inform the effort for homeland cruise missile defense. As Vice Admiral Jon Hill has noted, "what we learn on Guam is also something that can be applied here. Because you've got to remember, Guam is really about the size of Chicago, right? We're defending the size of a very large city. So, I think it's very applicable to what we'll do in the United States."[90]

Realizing even this more modest goal of a single integrated air picture will require improved data integration and processing. Data feeds from numerous sources—across WAS, OTHRs, and others—will need to be fused, analyzed, and curated by artificial intelligence. Instead of requiring humans to monitor thousands of air tracks and identify abnormal flight patterns, algorithms should rapidly identify, correlate, and display them for human scrutiny.

This undertaking is both critical and its need underappreciated. The CBO study budgeted $24 million per LR-SAM site for command and control investments. Based on the experience and initial studies relating to the defense of Guam, the inherent challenges of integrating disparate systems, and the importance of prioritizing command and control, the defense design considered here adopts CBO's cost estimate per interceptor site and adds $500 million for non-recurring system integration cost.

6

Phased Implementation

The layered defense architecture contemplated above can be implemented in a phased and adaptive manner that prioritizes near-term needs, builds upon efforts underway, and spreads the cost over time. The notional acquisition strategy described here occurs in three phases, beginning in FY 2024. Almost all technologies and capabilities described in the defense design below are already operationally fielded, available today without significant research and development, or currently expected to be available in the next several years.

The first phase prioritizes the northern attack vectors and the more robust active defense of the National Capital Region. Subsequent phases scale up both sensor coverage and the number of defended areas. The architecture would remain adaptive, remaining open to additional capabilities, such as counter-unmanned aerial systems (C-UAS) effects, directed energy, and space-based and other forms of advanced sensors, and could be introduced over time after having been validated in the Multi-mission Expandable Test Bed.

Table 4: A Phased Approach

Phase 1

- Four OTHRs: Three northern and one Alaskan
- One PAD
- Integrate existing sensors for WAS

Phase 2

- Four additional, coastal OTHRs
- Four additional PADs

Phase 3

- Two southern approach OTHRs, completing 360-degree coverage
- Evolve PADs to PAD+
- One aerostat for the National Capital Region
- Risk-based mobile defenses (E-7s, fighters)

Future Evolution

- Integrate various space-sensing capabilities
- Broaden to multi-threat capabilities (C-UAS, hypersonic defense)

Source: CSIS Missile Defense Project.

Phase 1

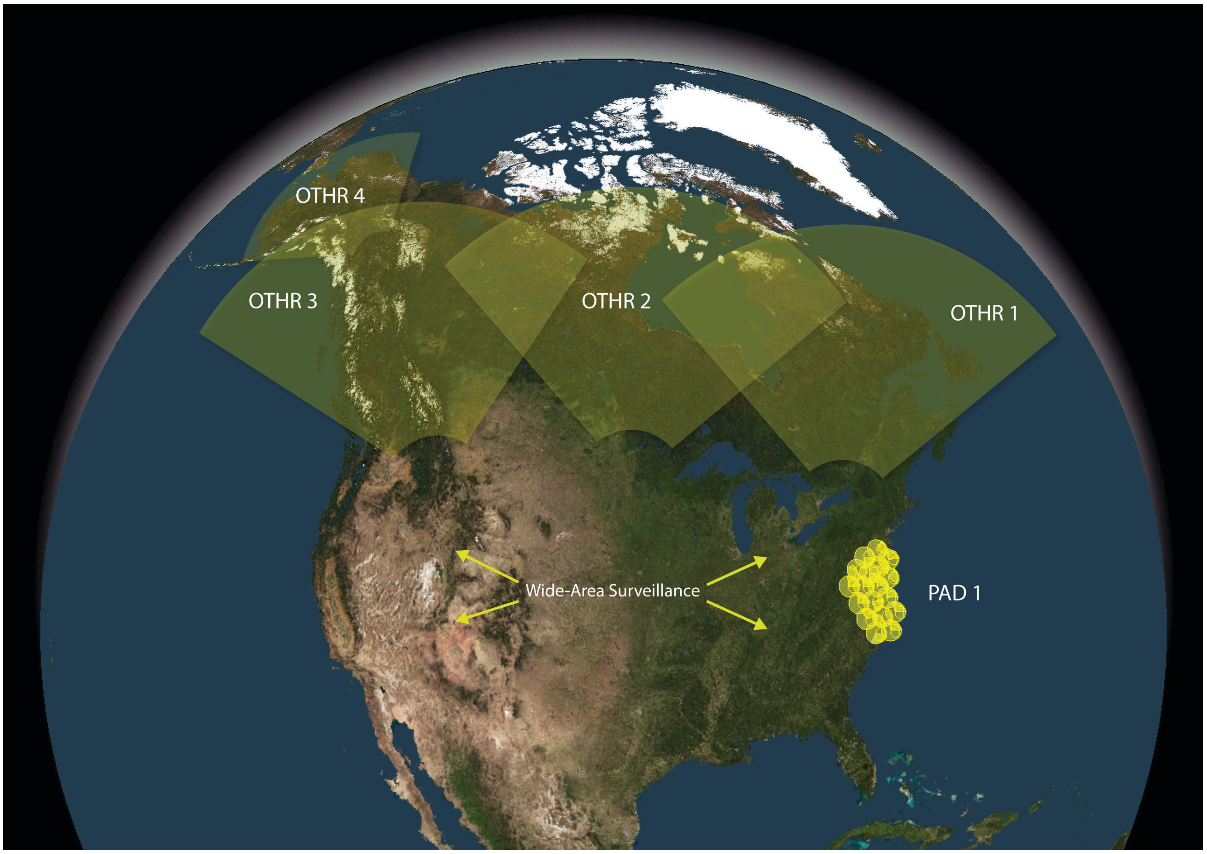
The first phase begins with acquiring four over-the-horizon radar (OTHR) arrays oriented toward the northern and Arctic approaches to North America. The Arctic presents one of the most likely avenues of cruise missile attack by air assets due to the lack of persistent sensing, highly austere environment for defensive assets, and the increasing air activity in that region by near-peer competitors. The standoff launch capability afforded by long-range cruise missiles allows bombers approaching from the north to remain outside of the detection capability of the North Warning System. The immense distance spanned by the northern border of Canada and Alaska—over 6,000 km—makes even short-term defense of this approach with airborne warning assets entirely impractical (Figure 35).

The United States and Canada need persistent sensing for bomber, maritime, and low-altitude missile threats from the northern approach. The lack of available alternatives and growing possibility of an attack from this direction during a crisis or conflict makes northern OTHR fielding the top near-term priority. Although fewer and co-located OTHRs would be possible at the expense of reach, the inclusion of four separate OTHR sites provides both overlapping coverage and resilience and mitigates the loss of northern sensing with an attack or sabotage at a single site.[91]

Phase 1 also includes the first, prototype PAD, which could be located anywhere but is here notionally depicted around the National Capital Region. The first PAD will provide opportunities to discover unexpected integration challenges and adapt before the extensive deployment of sensors in later phases. The locations of the PAD sensors are derived from targeting assumptions of the 2021 CBO report, which identifies “government facilities, military bases, [and] power infrastructure” as likely targets of a cruise missile attack by a near-peer state.[92] The defense design depicted here leveraged this open-source analysis to notionally pick five broad areas with a large concentration of these types of high-value assets. These areas were abstracted to a national level to reduce any potential sensitivities about particular assets. Neither interceptor locations nor actual defended areas are depicted.

Phase 1 also includes the integration of global domain awareness capabilities in development and partially fielded by the new Chief Digital and Artificial Intelligence Office under the deputy secretary of defense.[93] These capabilities include common, global domain awareness data solutions to allow U.S. combatant commands to hold shared real-time awareness of possible threats and to actively collaborate on deterrence responses.[94]

Figure 35: Phase 1 Overview



Source: CSIS Missile Defense Project.

Phase 2

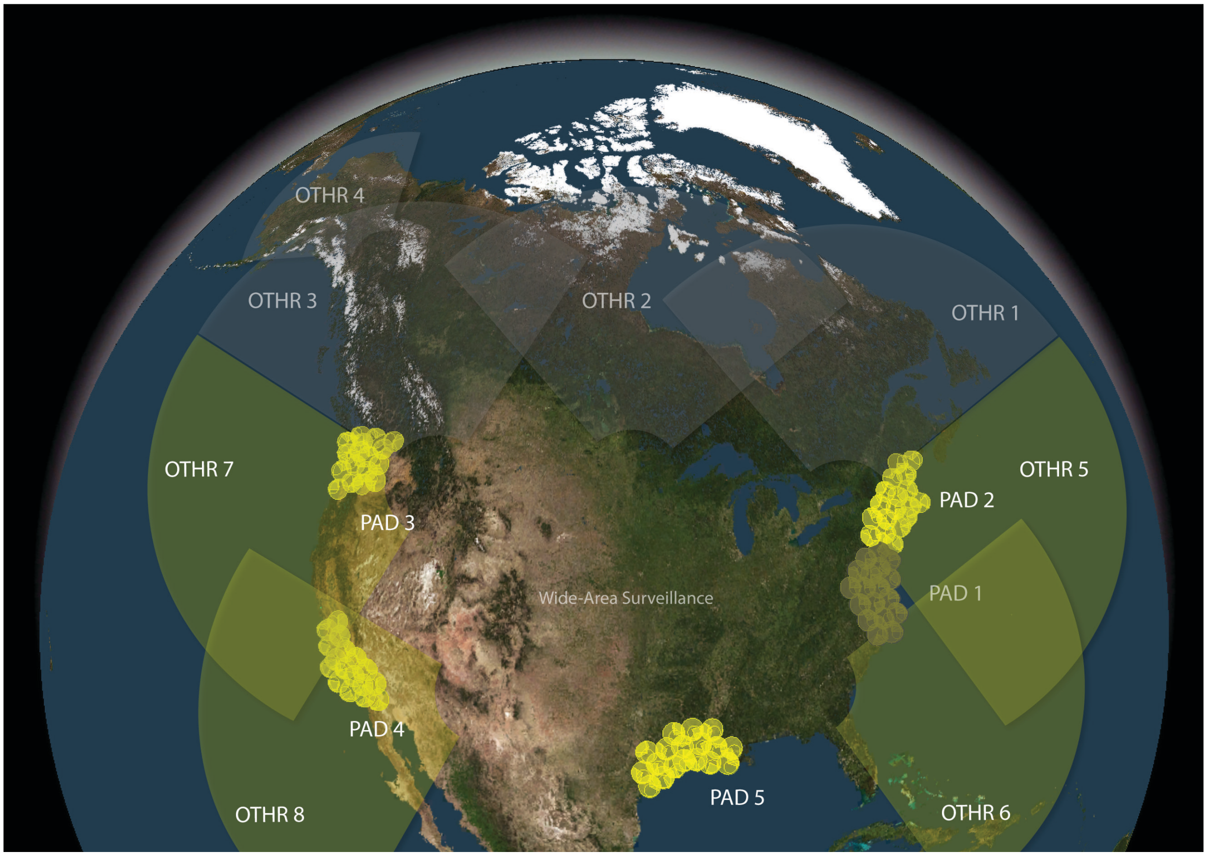
Phase 2 scales up the OTHRs and PADs. Four additional OTHR arrays are focused on the coastal approach. Two of these four new arrays, one on each coast (OTHR 5 in the east and OTHR 7 in the west), are co-located with arrays built in Phase 1. Co-locating arrays creates efficiencies in updating existing site surveys and environmental impact studies. The Over-the-Horizon-Backscatter (OTH-B) radars of the 1980s were likewise located on a similar shared plot of land. Although each 90-degree OTHR array requires considerable acreage, images of the OTH-B arrays in Maine demonstrate how multiple arrays can share land, power, and data-processing infrastructure, useful to both accelerate regulatory approvals and save construction and operating costs (Figure 36).

Figure 36: Abandoned Cold War OTH-B Arrays near Moscow, Maine

Source: Copyright © 2022 by Planet.

Phase 2 adds four additional PADs, for a total of five. By the end of Phase 2, integrated air and missile defense for the homeland would have fielded five PADs, holding a total of 280 interceptors cued by 95 total sensor towers and alerted by eight OTHRs (Figure 37).

Figure 37: Phase 2 Overview



Source: CSIS Missile Defense Project.

Phase 3

The third phase completes the terrestrial layers and adds considerable new capability (Figures 38–39). The southern OTHR arrays round out 360-degree coverage for broad early warning. These arrays (OTHR 9 and 10) are co-located with OTHRs 6 and 8, respectively, to realize operational efficiencies. These arrays cover the southern approaches to North America.[95]

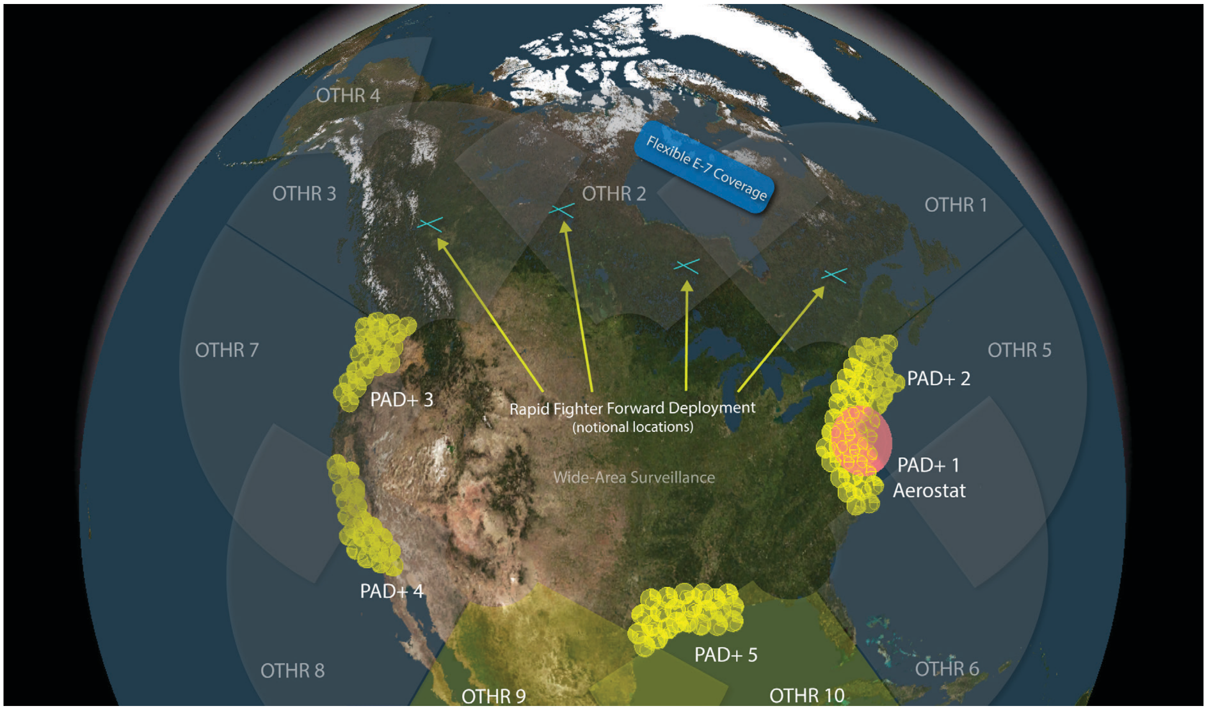
During Phase 3, some or all of the five standard PADs could be enhanced to the PAD+ configuration, which includes additional sensor towers, interceptors, and a high-powered microwave (HPM) system. Phase 3 also introduces an aerostat over the National Capital Region and the E-7 Wedgetail.

Table 5: Architecture Implementation by Phase

	Phase 1	Phase 2	Phase 3
OTHRs	– 4 OTHRs (northern)	– 4 OTHRs (eastern and western)	– 2 OTHRs (southern)
PADs	– 1 PAD	– 4 additional PADs	– Increase to PAD+
Single PAD Dimensions	– 500 km across	– 500 km across	– 500 km across – 700 km long
Single PAD Coverage	– 196,000 km^2	– 196,000 km^2	– 269,500 km^2
Sensors per PAD	– 18 medium-range radars – 18 EO/IR sensors – 1 Aegis fire control radar	– 18 medium-range radars – 18 EO/IR sensors – 1 Aegis fire control radar	– 24 medium-range radars – 24 EO/IR sensors – 1 Aegis fire control radar
Shooters per PAD	– 48 medium-range interceptors – 8 long-range interceptors	– 48 medium-range interceptors – 8 long-range interceptors	– 72 medium-range interceptors – 8 long-range interceptors – 8 multi-mission long-range interceptors – 1 HPM
Additional Elements	– Wide-area surveillance integration	– Wide-area surveillance integration	– Wide-area surveillance integration – Flexible E-7 coverage – Rapid fighter forward deployment
Time to Decide	– 14 min 44 sec – Up to 4 hours early warning	– 14 min 44 sec – Up to 4 hours early warning	– 14 min 44 sec min radius – 21 min 24 sec max radius – Up to 4 hours early warning
Acquisition Cost	– $4.2 billion	– $6.3 billion	– $3.6 billion

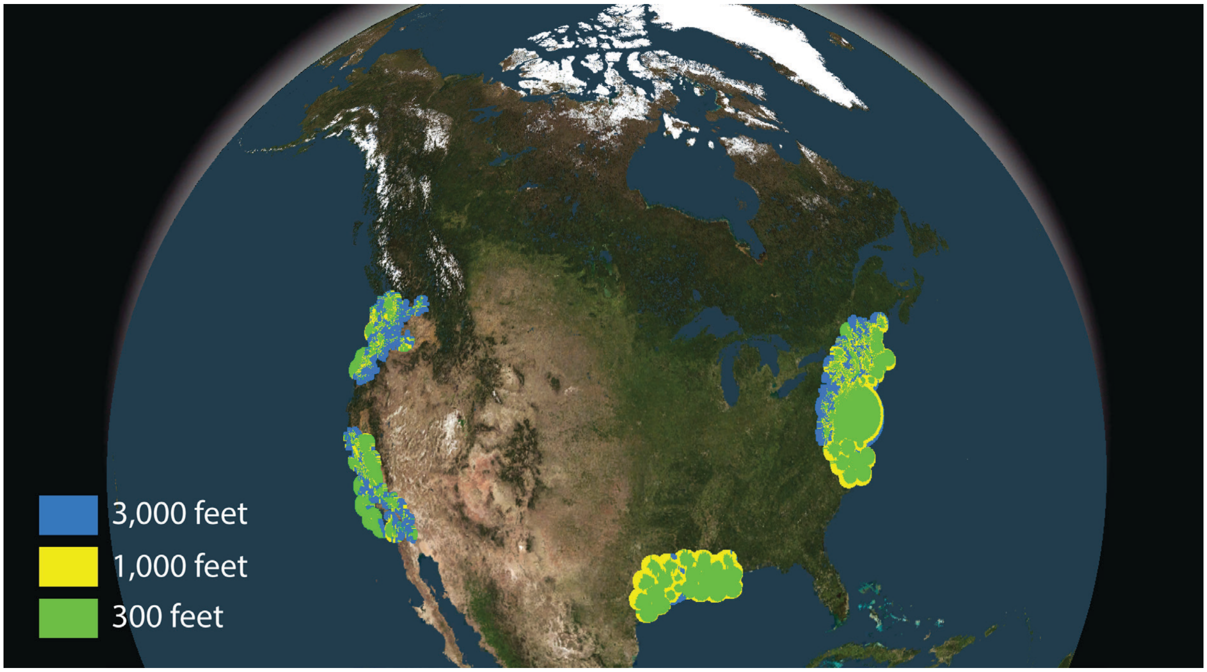
Source: CSIS Missile Defense Project.

Figure 38: Phase 3 Overview



Source: CSIS Missile Defense Project.

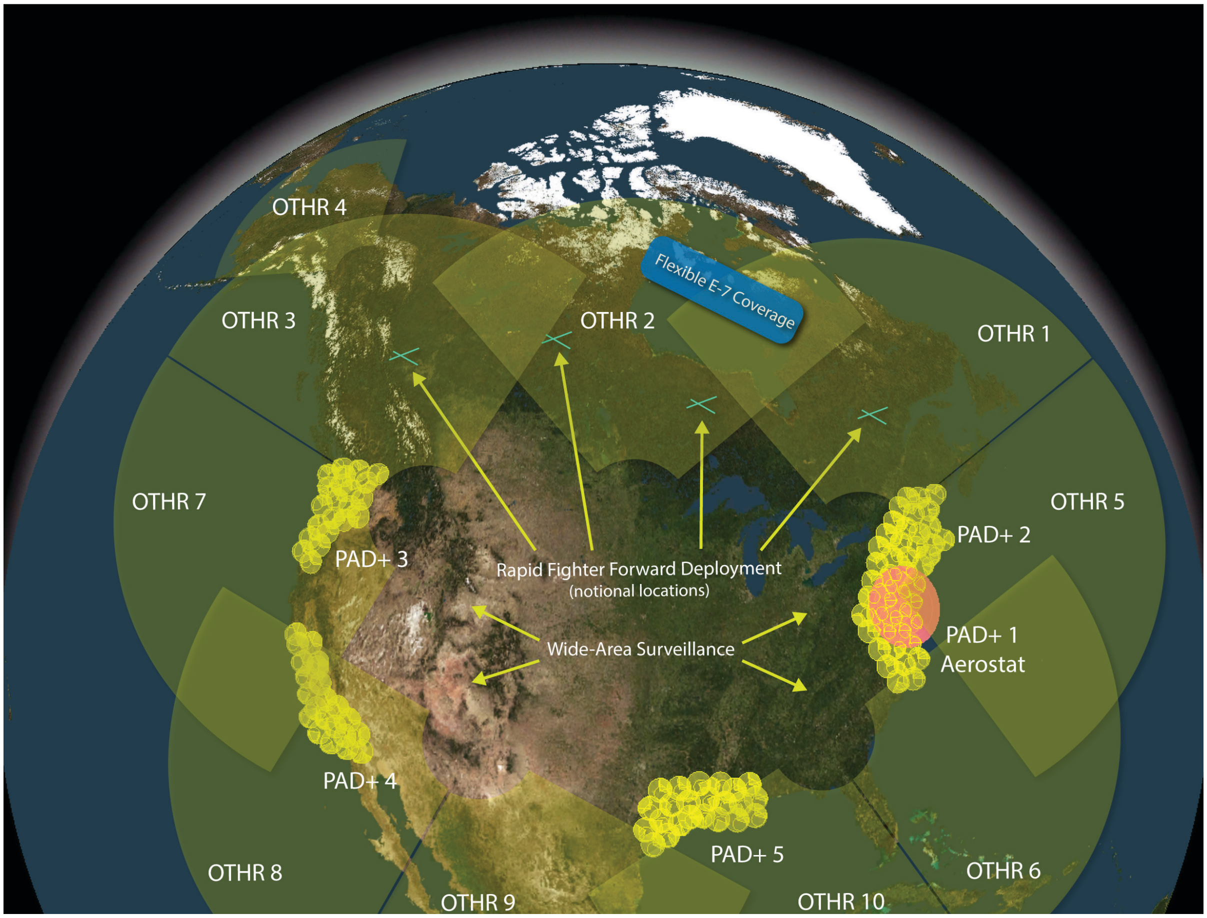
Figure 39: PAD Radar Coverage



Source: CSIS Missile Defense Project.

With the completion of Phase 3, a robust architecture would exist for integrated air and missile defense of the homeland. The architecture would include 360-degree broad early warning, the ability to deter and defeat launch platforms prior to weapon release, a robust engagement capability against multiple waves of missile attacks, and the toothing to expand capability into other missions, including C-UAS and hypersonic defense.

Figure 40: Complete CSIS Architecture Laydown



Source: CSIS Missile Defense Project.

Future Evolution

This baseline defense design would not stand alone or remain static. Existing infrastructure and investments already expected over the next five years can also be leveraged to inform, cue, and support cruise missile defense. Just as wide-area surveillance will be augmented by the integration of existing ground-based air traffic control, weather, and other sensors, other planned capabilities can also be stitched in as they become available.

Although still in development and focused on detecting specific hypersonic threats, the Space Development Agency's Wide Field of View detection satellite constellation, paired with the Missile Defense Agency's Hypersonic and Ballistic Tracking Space Sensor, may provide some capability against lower-altitude and lower-speed threats.[96] To be sure, the thermal signatures of subsonic and supersonic missiles are significantly lower than some of these other threats. Nevertheless, when paired with enhanced signal processing to identify subtle spectrum cues, these sensors may allow these threats to be tracked both before and after the OTHR-based layer. Future space-based radar technology may also contribute. The defense design considered here, however, does not assume that capability will be available or necessary. Work to build a cruise missile defense architecture should not wait until those systems become available.

While PADs are not depicted here for Alaska or Hawaii, both of which host significant military and strategic assets, a similar architecture could be developed for either. The tower-centric architecture was developed in part with an eye to the unique environmental and weather challenges of these locations, where UASs and aerostats may be challenged.

7

Coming Soon to a Theater Near You

Cruise missile and related aerial threats are no longer an emerging threat, they are already here. Threats once dismissed as only a problem for other regions are coming soon to a theater near you.

Accepting homeland air defense risks came with little cost in the 2000s and early 2010s. In today's strategic and threat environment, the dichotomy between regional and homeland air and missile defense has become increasingly obsolete. North America is a region, too, and integrated air and missile defense here is becoming necessary as it is in other regions. Potential adversaries have invested for decades in capabilities to hold the U.S. homeland at risk, and non-nuclear strategic attack is not a lesser included set of deterring large-scale nuclear attack.

That neglect of the mission has now begun to change. Recent policy statements and budget submissions have begun to identify the outlines of a solution. Efforts to provide air and missile defense for the U.S. territory of Guam will drive and inform the efforts for the continental United States and beyond. The way in which the United States thinks about missile defense needs to evolve substantially. Realizing an effective and affordable homeland cruise missile defense will require a set of changed assumptions, including different types of elements, a more limited defended asset list, and multi-mission applications.

The homeland cruise missile defense effort is ultimately about much more than just cruise missiles. It is about addressing the broader air and missile threat spectrum. Passive defenses, attack operations, and active defenses alike will be key to a comprehensive and integrated solution. Indeed, realizing these capabilities for the homeland is both an opportunity and a test case for the Pentagon's strategy of integrated deterrence, requiring cooperation with non-defense departments and agencies.

After it designates an executive agent with acquisition authority, the Pentagon should begin to budget substantially for multiyear implementation, beginning in earnest in FY 2024.

Appendix

Cost Data and Methodology

To assess the cost feasibility of the proposed homeland cruise missile defense architecture, the CSIS study team drew from multiple sources to estimate the costs of each of the components.

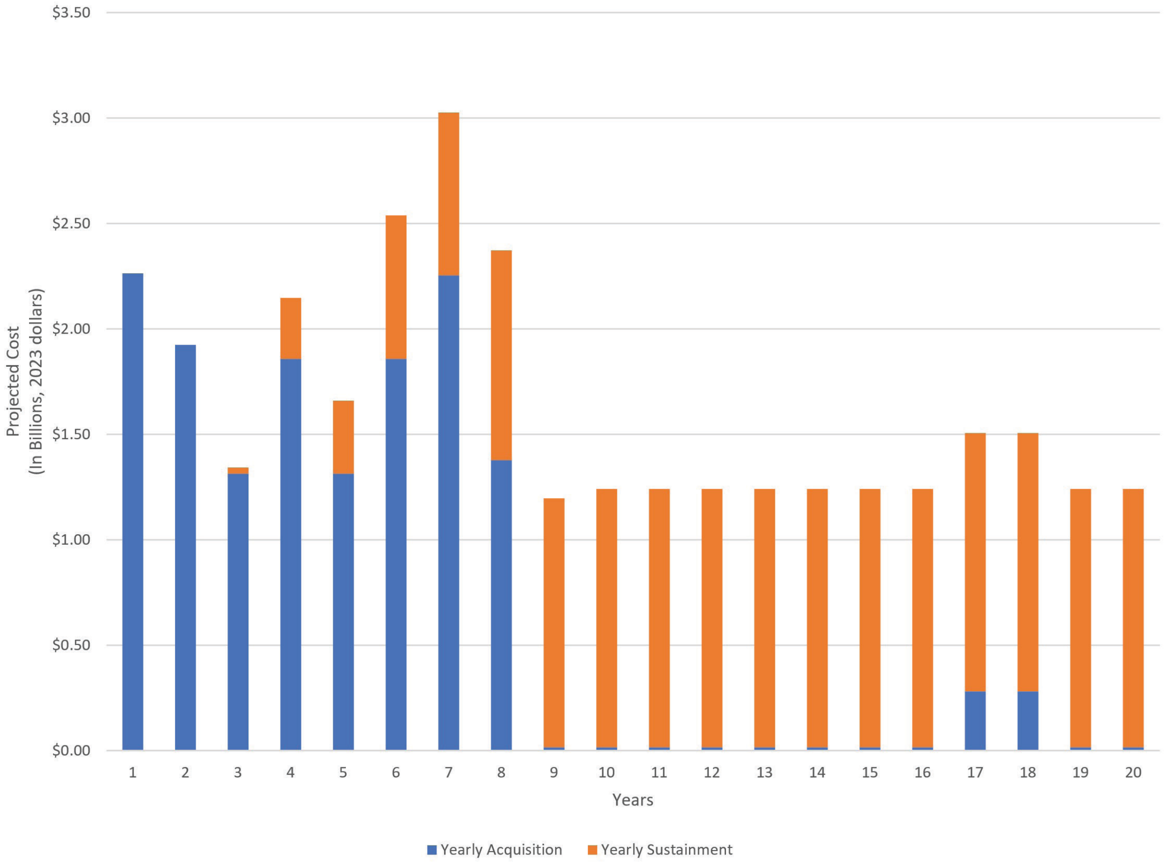
Table 6: Complete CSIS Architecture Costs

	20-Year Total Cost (billions, 2023 dollars)		
System	**Acquisition**	**Sustainment**	**Total**
Over-the-Horizon Radars	$5.70	$5.57	$11.27
PAD Radars	$3.55	$3.77	$7.32
Aerostats	$1.12	$0.60	$1.72
Wedgetail	$0.79	$0.56	$1.35
Layered Shooters, Command and Control, and System Integration	$3.71	$7.30	$11.01
Totals	**$14.87**	**$17.79**	**$32.66**

Source: CSIS Missile Defense Project.

These cost estimates run for 20 years, beginning with the initial investments in year 1 (Table 6). Phase 1 runs the first two years, Phase 2 lasts the next four years, and then Phase 3 lasts the next two years. As a result, Phase 1 assets include more years of annual sustainment costs than assets that are included in Phase 2 or Phase 3. The introduction of the aerostats and Wedgetail aircraft in Phase 3 explains why their acquisition cost is projected as larger than sustainment, as their service life will likely extend beyond the 20-year timeframe, which will produce a more traditional acquisition-to-sustainment cost ratio. Sustainment costs are assessed to begin two years after the initial procurement funding for a system to account for the time required to procure each of the assets (Figure 41).

Figure 41: CSIS Defense Design 20-Year Budget



Source: CSIS Missile Defense Project.

Sensors

OVER-THE-HORIZON RADARS

The study team received estimates of about $600 million for the acquisition cost of a single over-the-horizon radar (OTHR) from subject matter expert interviews. The study team assesses this estimate to include the cost of both the military construction (MILCON) and OTHR component acquisition. Based on Missile Defense Agency (MDA) estimates of the construction cost for the Long-Range Discrimination Radar, the study team divided this $600 million into radar component acquisition costs of about $425 million and construction of supporting facilities cost of $175 million.[97]

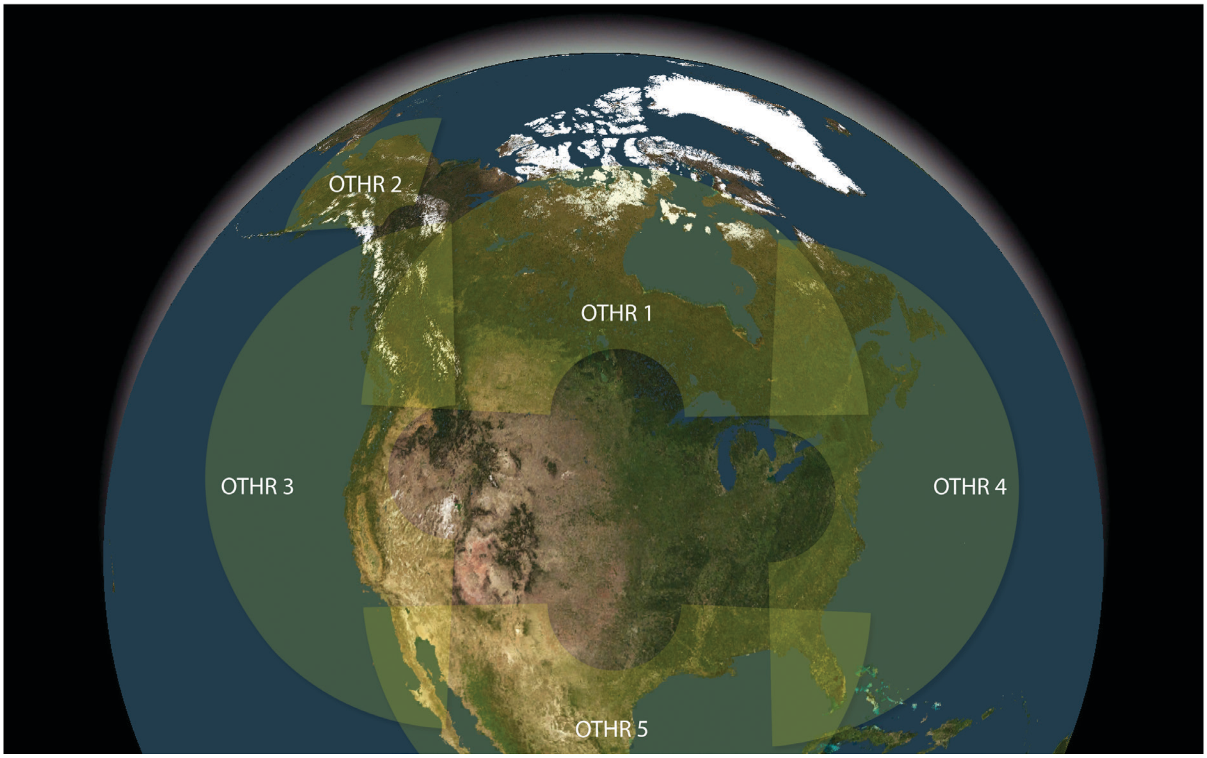
To calculate a yearly sustainment cost, the study team used MDA costs for the TPY-2 radar as a baseline since this is one of the few elements of annual budget data that provides system-level radar sustainment costs. The projected average yearly sustainment cost for MDA's 12 TPY-2 radars is $233 million, which suggests an individual radar sustainment cost of about $19.5 million.[98] MDA recently procured an additional TPY-2 radar for $243 million, which suggests that the yearly sustainment cost for a TPY-2 radar is about 8 percent of its acquisition cost, a figure that lines up with public estimates of the cost of sustaining weather radars.[99] For an OTHR, this produces a yearly sustainment cost of about $34 million.

MDA's sustainment cost does not include the cost to operate the radar sites, which is handled by the Army. A 2012 study included a cost estimate for these Army-specific costs at between $1.4 and $2.7 million in 2010 dollars.[100] Conservatively using the higher of those two figures and adjusting it for inflation produces an estimate of about $3.5 million per year, which produces an overall yearly sustainment cost of about $37.5 million per site.

The co-location of OTHRs would also likely reduce the cost of some of the sites in Phases 2 and 3. The acquisition cost of the radar arrays would be constant, but co-location would likely reduce the need to build extra facilities, reducing MILCON costs to about $100 million and the overall acquisition cost of a co-located OTHR to $525 million. The radar arrays themselves would require similar levels of maintenance, but the co-location could reduce strains on manning, so the study team estimates the yearly sustainment cost of a co-located OTHR radar at about $35.7 million.

An alternative configuration with a smaller number of OTHRs is possible, with five locations instead of six. While reducing resilience and overlap, such a configuration could yield a cost savings of approximately $1.25 billion (Figure 42).

Figure 42: Alternative Low-Cost OTHR Configuration



Source: CSIS Missile Defense Project.

PAD RADARS

Each Prioritized Area Defense (PAD) includes two types of radars: 24 medium-range, Army-derived radars in the final PAD+ configuration, plus a single Aegis fire control radar at PAD center. The medium-range radar cost estimates are based on the most recent Army budget justification documents, providing a unit cost estimate for the newest Sentinel A4 AESA radars of about $16.4 million each.[101] The study team estimates that system integration for the new radar configuration into the towers will also cost around $200 million, based on the cost of previous upgrades to the Sentinel system. Because existing tower infrastructure should reduce necessary MILCON, the study team estimated a $225 million cost per PAD location for any necessary construction or adjustments to towers as well as construction of centralized facilities to operate the towers and to support eventual build out to the PAD+ design. Based on expert interviews, the study team estimated the design and development of the Aegis fire control radar at $65 million and the unit procurement cost at $40 million per PAD.

Using the same procurement-to-sustainment cost ratio as the OTHR produces a yearly sustainment cost estimate for each medium-range radar of about $1.3 million and $3.2 million for the fire control radar. The geographic dispersion of radars in the PADs would also likely require additional manning. Assuming the units required for a single OTHR could sustain and operate five towered radars suggests a yearly sustainment cost of about $13.3 million for the PAD configuration and $17.5 million per year once the PAD+ design is completed.

AEROSTATS

Cost estimates of the aerostat components for the PAD+ concept come the 2021 CBO study, whose estimates were in turn derived from data supporting the cancelled JLENS aerostats.[102] The study team adopted the most conservative CBO estimates for the initial acquisition costs of the 1.5 aerostats required for a continuous orbit of about $590 million for the initial acquisition cost and then $530 million to replace the initial aerostats after 10 years of service. The study team also adopted CBO's more conservative yearly operations and support cost of $50 million for each aerostat location.

E-7 WEDGETAIL

The PAD+ architectures include a flexible deployment of E-7 Wedgetail aircraft. Publicly available data does not include specific procurement unit costs for the E-7, as DOD only recently decided to purchase the aircraft. The acquisition estimates used here are based on data from the United Kingdom purchase of five Wedgetail aircraft for almost $2 billion.[103] Sustainment costs are based on Selected Acquisition Reports for the P-8 Poseidon, which has the same airframe, plus an additional $5 million for the E-7's radar sustainment.[104] Because it is part of a flexible deployment, and not expected to operate at all times, the estimates for the Wedgetail portion assume the homeland cruise missile defense mission will require two new aircraft to fulfill mission requirements.

Engagement Layer

SYSTEM INTEGRATION AND COMMAND AND CONTROL

Estimates for the PAD command and control operations centers are based on the CBO report, which rolls these costs into its estimate for the long-range surface-to-air missile (LR-SAM) system and bases them on Terminal High-Altitude Area Defense battery communications systems. Their estimate is "$24 million would be for vehicles with communications equipment, acquisition of land (if necessary), and construction at the site (for instance, for pads for the launchers, structures for the missile crews, security fencing, and access roads)."[105] Applied to the PAD construct, this would cost about $120 million per PAD, with four medium-range interceptor locations and one Vertical Launching System (VLS) location with communications infrastructure at each. This estimate added an additional $500 million in initial cost for the system integration work needed to design and implement the PAD operations center, a figure not included by CBO. To support the future evolution of the architecture, the estimate also includes $15 million per year for a multi-mission integration environment test bed.

MEDIUM-RANGE INTERCEPTOR

Interceptor costs were estimated by the cost to equip a PAD and then to scale up to the PAD+. Costs for the medium-range interceptor are based on budget data for the PAC-3 Missile Segment Enhancement (MSE) missile Patriot M903 launchers.[106] To equip a single PAD with the four medium-range interceptor sites would cost about $40 million for four launchers and about $197.5 million for interceptors. These figures assume that an individual Patriot launcher is about $10 million, which was derived from interviews with subject matter experts, and that each site requires one launcher carrying 12 missiles each. Moving from the PAD to the PAD+ adds additional interceptor inventory but no additional launchers. The cost of the additional PAD+ interceptors would be about $98.8 million based on a unit cost of $4.1 million per interceptor for an MSE missile.

To improve affordability, an option not represented here is to use the National Advanced Surface to Air Missile System and AIM-120 interceptor currently deployed in the National Capital Region, which has a unit cost of about $1.2 million per interceptor. Replacing the PAC-3 MSE interceptors with AIM-120s would reduce procurement cost by about $976 million.

LONG-RANGE AND MULTI-MISSION LONG-RANGE INTERCEPTORS

The study team used the VLS cost for a DDG-51 destroyer to derive a cost estimate for the VLS used at the center of each PAD, which was estimated to cost about $72.8 million.[107] This cost may be an overestimate, as a DDG-51 includes more VLS cells than are required by the architecture used here. Budget data for other potential sources of land-based VLS variants such as Aegis Ashore and Army Mid-Range Capability did not include componentized costs for launchers in their budget justifications, precluding their use. Because of the larger number of VLS cells in the original PAD procurement, the study team did not add costs for additional cells to the VLS system in Phase 3, when each PAD is upgraded to PAD+.

The eight long-range interceptors for the initial PAD are projected to cost about $19.3 million for each site based on the cost of the SM-2 Block IIIC.[108] The addition of eight multi-mission, long-range interceptors with the PAD+ upgrade is estimated to cost $36.6 million for each site based on cost data for the SM-6.[109]

OPERATIONS AND SUSTAINMENT

Operations and sustainment costs for interceptor sites were estimated using the CBO assumption of $20 million per LR-SAM site. Because each PAD has four medium-range interceptor sites and a VLS site, this comes out to a total of about $100 million per PAD. The CBO's cost estimate was based on the Army National Guard costs to support air defense of the National Capital Region.

HIGH-POWERED MICROWAVE

The study team could not produce a cost estimate for the high-powered microwave component of the PAD+ architecture, so its costs are not included in the totals. Current configurations are only prototypes, and budget justifications do not include sufficiently detailed information to produce a viable cost estimate at this time.

About the Authors

Tom Karako is a senior fellow with the International Security Program and the director of the Missile Defense Project at the Center for Strategic and International Studies, where he arrived in 2014. His research focuses on national security, missile defense, nuclear deterrence, and public law. In 2010–2011, he was an American Political Science Association congressional fellow, working with the professional staff of the House Armed Services Committee and the Subcommittee on Strategic Forces on U.S. strategic forces policy, nonproliferation, and NATO. Dr. Karako is also currently a fellow with the Institute for Politics and Strategy of Carnegie Mellon University. He received his PhD from Claremont Graduate University and his BA from the University of Dallas.

Colonel Matthew Strohmeyer currently serves as an Air Force fellow in the International Security Program at the Center for Strategic and International Studies in Washington, D.C. He served as an F-15E and T-38 instructor pilot with a combined 2,500 flight hours and two combat deployments. He has since held the position of chief of contingency plans and commander's action group director at Pacific Air Forces, where he led efforts to develop Agile Combat Employment and Strategic Shaping concepts. His follow-on command experience includes the 560th FTS and innovation efforts such as Det 24, Squadron Next, and Pilot Training Next. He most recently served at the combatant command-level, where he led ABMS Onramp #1 and #2 and the creation of the Global Information Dominance Experiments (GIDE). Colonel Strohmeyer is a 2001 graduate of the Air Force Academy and holds an MA in history from American Military University and an MA in military science from the School of Advanced Military Studies.

Ian Williams is a fellow in the International Security Program at the Center for Strategic and International Studies and deputy director of the Missile Defense Project, specializing in missile defense and strategic forces, missile proliferation, and deterrence. He is also managing editor of the CSIS website Missile Threat, an online clearinghouse for information and analysis on missile proliferation and missile defense systems. Ian has authored major CSIS studies on U.S. homeland missile defense, nuclear proliferation, and the use of missiles in the Yemeni civil war. He has also written extensively on Iranian and North Korean missile programs, Chinese strategic forces and military strategy, and NATO's missile defense architecture. Ian has made numerous appearances on global news programs, including ABC, NBC, CNN, NPR, and the BBC. His commentary has appeared in newspapers such as the *New York Times*, *Washington Post*, *USA Today*, *Newsweek*, and others. He holds a BA from Southern Illinois University and an MS in defense and strategic studies from Missouri State University, where he is now pursuing his doctorate.

Wes Rumbaugh is an associate fellow in the Missile Defense Project at the Center for Strategic and International Studies. His work focuses on missile defense, conventional long-range strike, budgets and organizations. He has published on the composition of the Missile Defense Agency budget, homeland ballistic missile defense, new operational concepts for missile defense systems, the role of elevated sensors in missile strike and defense, and trends in hypersonic strike. Previously, he was director of advocacy and a Van Cleave fellow at the Missile Defense Advocacy Alliance. He holds a BS in political science from Missouri State University.

Kenneth Harmon is a member of the advisory board for the Missile Defense Project at the Center for Strategic and International Studies. He has been involved in the policy, budget, acquisition, strategy, programs, and technological aspects of space, missile defense, and nuclear deterrence domains for nearly 40 years. Over the course of his career, Harmon has been involved with many programs within these portfolios, with a special focus on programs, budgets, and technologies. He previously worked for McDonnell Douglas, Boeing, and Lockheed Martin and has consulted for a number of other companies. Currently, he is director for strategy for the National Capital Region at IERUS Technologies, Inc. Harmon received his BS in political science with a minor in physics from Utah State University and his MA in international relations from the Defense and Strategic Studies Program at the University of Southern California.

Endnotes

1 David Arthur and Michael Bennett, *National Cruise Missile Defense: Issues and Alternatives* (Washington, DC: Congressional Budget Office, 2021), 4, https://www.cbo.gov/system/files/2021-02/56950-CMD.pdf.

2 Kathleen Hicks and Roger Zakheim, "Linking Resources to Strategy: A Discussion on the National Defense Strategy and FY23 Budget," (presentation, Reagan National Defense Forum, Simi Valley, CA, May 6, 2022), https://www.reaganfoundation.org/media/359078/kathleenhickseventconversationtranscript_0.pdf.

3 Dennis M. Gormley, *Missile Contagion: Cruise Missile Proliferation and the Threat to International Security* (Westport, CT: Praeger Publishers, 2008).

4 John Plumb, *Statement before the Senate Armed Services Committee Strategic Forces Subcommittee*, 117th Cong., 2nd sess., May 18, 2022 (statement of Dr. John Plumb, Assistant Secretary of Defense for Space Policy), https://www.armed-services.senate.gov/imo/media/doc/ASD%20Plumb%20SASC%20SF%20Missile%20Defense%20Written%20Statement%20-%20May,18%202022_FINAL.pdf; Shaan Shaikh, "The Air and Missile War in Nagorno-Karabakh: Lessons for the Future of Strike and Defense," CSIS, *Critical Questions*, December 8, 2020, https://www.csis.org/analysis/air-and-missile-war-nagorno-karabakh-lessons-future-strike-and-defense; and Ian Williams and Shaan Shaikh, *The Missile War in Yemen* (Washington, DC: CSIS, June 2020), https://www.csis.org/analysis/missile-war-yemen-1.

5 John Plumb, *Statement before the House Armed Services Committee Subcommittee on Strategic Force*s, 117th Cong., 2nd sess., May 11, 2022 (statement of Dr. John Plumb, Assistant Secretary of Defense for Space Policy), 1, https://armedservices.house.gov/_cache/files/3/b/3b83d672-da64-4ce7-b1bd-00ed6707e592/28BF09D70A60BA0BAE8E7DC07EE32DC0.2022511-str-witness-statement-plumb.pdf.

6 Thomas Karako and Wes Rumbaugh, *Distributed Defense: New Operational Concepts for Integrated Air and Missile Defense* (Washington, DC: CSIS, 2018), https://www.csis.org/analysis/distributed-defense-0; Thomas Karako and Masao Dahlgren, *Complex Air Defense: Countering the Hypersonic Missile Threat* (Washington, DC: CSIS, 2022), https://www.csis.org/analysis/complex-air-defense-countering-hypersonic-missile-threat; Thomas

Karako, "The Missile Defense Review: Insufficient for Complex and Integrated Attack," *Strategic Studies Quarterly* 13, no. 2 (Summer 2019), 3–15, https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-13_Issue-2/Karako.pdf; and Thomas Karako, *Strategy in the Next Missile Age* (Washington, DC: CSIS, 2020).

7 Gormley, *Missile Contagion*, 6.

8 James A. Winnefeld, Jr., "Missile Defense and U.S. National Security" (speech, May 19, 2015, CSIS, Washington, DC), https://www.csis.org/events/missile-defense-and-us-national-security.

9 Joint Chiefs of Staff, *Joint Operating Environment 2035: The Joint Force in a Contested and Disordered World* (Washington, DC: DOD, July 2016), https://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joe_2035_july16.pdf.

10 Terrence J. O'Shaughnessy, *Statement before the House Armed Services Committee*, 116th Cong., 1st sess., February 26, 2019 (statement of General Terrence J. O'Shaughnessy, Commander, United States Northern Command and North American Aerospace Defense Command), 3, https://www.armed-services.senate.gov/imo/media/doc/OShaughnessy_02-26-19.pdf.

11 Glen D. VanHerck, *Statement before the House Armed Service Committee*, 117th Cong., 2nd sess., March 1, 2022 (statement of General Glen D. VanHerck, Commander, USNORTHCOM), https://www.congress.gov/117/meeting/house/114486/witnesses/HHRG-117-AS00-Wstate-VanHerckG-20220308.pdf.

12 Winnefeld, Jr., "Missile Defense and National Security."

13 Russian Ministry of Defense, "Массированный удар самолетами Дальней авиации по объектам инфраструктуры ИГИЛ в Сирии" [Massive strike by long-range aircraft on ISIS infrastructure facilities in Syria], YouTube video, November 17, 2015, 1:38, https://www.youtube.com/watch?v=igzjX1IKULw/.

14 "3M-14 Kalibr (SS-N-30A)," CSIS, *Missile Threat*, March 2, 2022, https://missilethreat.csis.org/missile/ss-n-30a/; and "Kh-101/Kh-102," CSIS, *Missile Threat*, July 31, 2021, https://missilethreat.csis.org/missile/kh-101-kh-102/.

15 Glen D. Van Herck, *Statement before the House Armed Services Committee Subcommittee on Strategic Forces*, 117th Cong., 2nd sess., March 18, 2022 (statement of General Glen D. VanHerck, Commander, United States Northern Command and North American Aerospace Defense Command), 6, https://www.armed-services.senate.gov/imo/media/doc/USNORTHCOM%20and%20NORAD%202022%20Posture%20Statement%20SASC-SF%20(1).pdf; and Sidharth Kaushal et al., "The Yasen-M and the Future of Russian Submarine Forces," RUSI, May 28, 2021, https://rusi.org/explore-our-research/publications/rusi-defence-systems/yasen-m-and-future-russian-submarine-forces.

16 Russian Ministry of Defense, "Из акватории Каспийского моря по террористам в Сирии нанесен удар 18-ю крылатыми ракетами Калибр-НК" [From the Caspian Sea, terrorists in Syria were hit by 18 Kalibr-NK cruise missiles], YouTube video, November 20, 2015, 0:09, https://www.youtube.com/watch?v=yf2SZ_gjtA0.

17 Daniel Karbler, *Statement before the House Armed Services Committee Subcommittee on Strategic Forces*, 117th Cong., 2nd sess., May 18, 2022 (statement of Lieutenant General Daniel Karbler, Commanding General, U.S. Army Space and Missile Defense Command), 2, https://www.armed-services.senate.gov/download/karbler-statement-05/18/2022.

18 Plumb, *Statement before the Senate Armed Services Committee Strategic Forces Subcommittee*, May 18, 2022.

19 Marcus Weisberger, "JLENS Supporters: Never Mind the Blimp, Save the Radar," Defense One, December 5, 2015, https://www.defenseone.com/technology/2015/12/jlens-supporters-never-mind-blimp-save-radar/124219/; Thomas Karako and Ian Williams, "JLENS Future Bleak, But Need for Capability Remains,"

CSIS, April 5, 2016, https://www.csis.org/analysis/jlens-future-bleak-need-capability-remains; and Jen Judson, “Long Live JLENS? NORTHCOM Scrambles on Cruise Missile Defense,” *Air Force Times*, June 23, 2016, https://www.airforcetimes.com/news/your-air-force/2016/06/23/long-live-jlens-northcom-scrambles-on-cruise-missile-defense/.

20 Jon Hill, *Hearing to Receive Testimony on Missile Defense Strategy, Policies, and Programs in Review of the Defense Authorization Request for Fiscal Year 2022 and the Future Years Defense Program*, 117th Cong., 1st sess., June 9, 2021 (statement of Vice Admiral Jon Hill, Director, Missile Defense Agency), 68–69, https://www.armed-services.senate.gov/imo/media/doc/21-48_06-09-2021.pdf.

21 DOD, *Missile Defense Review* (Washington, DC: 2019), 8, 41, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.PDF.

22 Wes Rumbaugh and Tom Karako, “Seeking Alignment: Missile Defense and Defeat in the 2022 Budget,” CSIS, *CSIS Briefs*, December 10, 2021, https://www.csis.org/analysis/seeking-alignment-missile-defense-and-defeat-2022-budget.

23 *Department of Defense Appropriations Act, 2022*, 117th Cong., 2nd sess., introduced July 15, 2021, 123-D (p. 329 of pdf), https://appropriations.house.gov/sites/democrats.appropriations.house.gov/files/BILLS-117RCP35-JES-DIVISION-C.pdf.

24 Glen D. VanHerck, “USNORTHCOM and NORAD FY23 Unfunded Priority List,” Northern American Aerospace Defense Command and United States Northern Command, April 4, 2022, https://www.taxpayer.net/wp-content/uploads/2022/04/FY2023-UPL_U.S.-Northern-Command.pdf.

25 Plumb, *Statement before the House Armed Services Committee Subcommittee on Strategic Forces*, May 18, 2022, 1.

26 Winnefeld, Jr., “Missile Defense and National Security.”

27 Terrance J. O’Shaughnessy, Matthew J. Strohmeyer, and Christopher D. Forrest, “Strategic Shaping,” *Joint Forces Quarterly* 90 (Third Quarter, 2018), 10–15, https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-90/jfq-90_10-15_OShaughnessy-et-al.pdf?ver=2018-04-11-125441-307.

28 VanHerck, *Statement before the House Armed Service Committee*, March 1, 2022.

29 Brad Roberts, “On the strategic value of ballistic missile defense,” IFRI, *Proliferation Papers* 50, June 2014, https://www.ifri.org/sites/default/files/atoms/files/pp50roberts.pdf.

30 “NORAD History,” North American Aerospace Defense Command, n.d., https://www.norad.mil/About-NORAD/NORAD-History/.

31 “Homeland Defense,” United States Northern Command, n.d., https://www.northcom.mil/HomelandDefense/.

32 “North Warning System,” Wikipedia, last updated June 13, 2022, https://en.wikipedia.org/wiki/North_Warning_System; and Steffan Watkins, “Canadian North Warning System Locations,” Camping Canadian, October 12, 2013, https://campingcdn.blogspot.com/2013/10/canadian-north-warning-system-locations.html.

33 U.S. Navy All Hands magazine, September 1956, via Wikimedia Commons, https://commons.wikimedia.org/wiki/File:North_American_Air_Defence_Command_radar_map_1956.png.

34 “Backgrounder – North Warning System In-Service Support,” Canada Department of National Defense, January 2022, https://www.canada.ca/en/department-national-defence/news/2022/01/backgrounder--north-warning-system-in-service-support.html.

35 Jim Garamone, “Austin Meets Prime Minister Trudeau at Joint U.S.-Canada Command,” DoD News, June 8, 2022, https://www.defense.gov/News/News-Stories/Article/Article/3056554/austin-meets-prime-minister-trudeau-at-joint-us-canada-command/.

36 Anita Anand, “Minister of National Defence Announces Canada’s NORAD Modernization Plan” (speech, Canadian Ministry of Defense, June 20, 2022), https://www.canada.ca/en/department-national-defence/news/2022/06/minister-of-national-defence-announces-canadas-norad-modernization-plan.html.

37 Arthur and Bennett, *National Cruise Missile Defense*, 9.

38 DOD, *Missile Defense Review* (Washington, DC: DOD, 2019), 45, https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-MISSILE-DEFENSE-REVIEW.PDF.

39 Arthur and Bennett, *National Cruise Missile Defense*, 9; and “Glen D. VanHerck, “Rethinking Homeland Defense: Global Integration, Domain Awareness, Information Dominance and Decision Superiority” (interview, CSIS, Washington, DC, August 17, 2021), https://csis-website-prod.s3.amazonaws.com/s3fs-public/event/210817_Karako_Rethinking_Defense2.pdf?EiralxE0MtIERgdXeOtB71tuEemSmcGR.

40 Julie Zauzmer and Mike Debonis, “Gyrocopter Lands on Capitol Lawn; Pilot Is Arrested,” *Washington Post*, April 25, 2015, https://www.washingtonpost.com/news/local/wp/2015/04/15/a-gyrocopter-just-landed-on-the-capitol-lawn/.

41 Nathan Strout, “NORAD Is Using Artificial Intelligence to See the Threats It Used to Miss,” C4ISRNET, March 1, 2021, https://www.c4isrnet.com/artificial-intelligence/2021/03/01/norad-is-using-artificial-intelligence-to-see-the-threats-it-used-to-miss/.

42 Office of Inspector General, “FAA Has Taken Steps To Advance the SENSR Program, but Opportunities and Risks Remain,” Department of Transportation, April 13, 2019, https://www.oig.dot.gov/sites/default/files/FAA%20SENSR%20Program%20Final%20Report%5E04-23-19.pdf.

43 “Next Generation Weather Radar (NEXRAD),” National Centers for Environmental Information, National Oceanic and Atmospheric Administration, n.d., https://www.ncei.noaa.gov/products/radar/next-generation-weather-radar.

44 Ian Williams, “The Russia – NATO A2AD Environment,” CSIS, Missile Threat, January 3, 2017, last modified November 29, 2018, https://missilethreat.csis.org/russia-nato-a2ad-environment/.

45 Arthur and Bennett, *National Cruise Missile Defense*, 3.

46 Ibid., 17.

47 CBO discusses a possible variant for “warning only” without intercept. Arthur and Bennett, *National Cruise Missile Defense*, 46.

48 Arthur and Bennett, *National Cruise Missile Defense*, 1.

49 Ibid., 37.

50 Ibid., cover.

51 Ibid., 35.

52 Ibid., 41.

53 Ibid., 37, 49.

54 Winnefeld, Jr., “Missile Defense and National Security.”

55 An understanding of the national-level critical infrastructure to compile such a list does not fall within the purview of any one government agency. The Department of Energy may feel differently from the Departments of Commerce and Defense about what should be defended first.

56 Bradley Graham, *Hit-to-Kill: The New Battle Over Shielding America From Missile Attack* (New York, NY: Public Affairs, 2003), 125.

57 Hicks and Zakheim, "Linking Resources to Strategy."

58 "Jindalee Operational Radar Network," Royal Australian Air Force, last updated November 3, 2017, https://www.airforce.gov.au/technology/surveillance-command-and-control/jindalee-operational-radar-network.

59 O'Shaughnessy, Strohmeyer, and Forrest, "Strategic Shaping."

60 Glen D. VanHerck, "Rethinking Homeland Defense: Global Integration, Domain Awareness, Information Dominance and Decision Superiority" (interview, CSIS, Washington, DC, August 17, 2021), https://www.csis.org/events/rethinking-homeland-defense-domain-awareness-information-dominance-and-decision-superiority.

61 Glen D. VanHerck (speech, Defense Writers Group, George Washington School of Media and Public Affairs, Washington, DC, April 25, 2022), https://nationalsecuritymedia.gwu.edu/files/2018/02/DWG-VanHerck-220425.pdf.

62 Todd Harrison and Matthew Strohmeyer, "Commercial Space Remote Sensing and its Role in National Security," CSIS, *CSIS Briefs*, February 2, 2022, https://www.csis.org/analysis/commercial-space-remote-sensing-and-its-role-national-security.

63 This insight comes from author conversations with RADM (ret.) Archer Macy.

64 On sensor diversity and elevation, broadly, see, for instance: Karako and Williams, "JLENS Future Bleak"; Tom Karako, "Beyond the Radar Archipelago: A New Roadmap for Missile Defense Sensors," War on the Rocks, November 28, 2018, https://warontherocks.com/2018/11/beyond-the-radar-archipelago-a-new-roadmap-for-missile-defense-sensors/; and Wes Rumbaugh and Tom Karako, "Extending the Horizon: Elevated Sensors for Targeting and Missile Defense," CSIS, *CSIS Briefs*, September 2021, https://www.csis.org/analysis/extending-horizon-elevated-sensors-targeting-and-missile-defense.

65 Nathan Strout, "NORAD is using artificial intelligence to see the threats it used to miss," C4ISR, March 1, 2021, https://www.c4isrnet.com/artificial-intelligence/2021/03/01/norad-is-using-artificial-intelligence-to-see-the-threats-it-used-to-miss/.

66 "NORTHCOM Commander Gen. Glen D. VanHerck Conducts Press Briefing on North American Aerospace Defense Command and U.S. Northern Command Global Information Dominance Experiments," DOD, transcript, July 28, 2021, https://www.defense.gov/News/Transcripts/Transcript/Article/2711594/northcom-commander-gen-glen-d-vanherck-conducts-press-briefing-on-north-america/.

67 Justin Katz, "Raytheon, Navy Finish SPY-6 Testing at Wallops," Breaking Defense, August 2, 2021, https://breakingdefense.com/2021/08/raytheon-navy-finish-spy-6-testing-at-wallops/; and John Keller, "Raytheon to Run ROTHR Over-the-Horizon Surveillance Radar," *Military Aerospace Electronics*, March 1, 2021, https://www.militaryaerospace.com/sensors/article/14198370/radar-overthehorizon-surveillanc.

68 U.S. Navy via Wikimedia Commons, https://commons.wikimedia.org/wiki/File:ROTHR_USNavy_a.png.

69 "North America's Artic Radar Shield Is Due for an Upgrade," *The Economist*, July 29, 2021, https://www.economist.com/the-americas/2021/07/29/north-americas-arctic-radar-shield-is-due-for-an-upgrade.

70 National Oceanic and Atmospheric Administration via Wikimedia Commons, https://commons.wikimedia.org/wiki/File:OTH-B_coverage.gif.

71 Harrison and Strohmeyer, "Commercial Remote Sensing and Its Role in National Security."

72 "Jindalee Operational Radar Network," Royal Australian Air Force.

73 Plumb, *Statement before the Senate Armed Services Committee Strategic Forces Subcommittee*, May 18, 2022.

74 Jon Hill in "MDA and the 2023 Budget," CSIS, transcript, May 23, 2022, https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/220523_MDA_2023_Budget.pdf?Zi1DSNBbXoGoam2P32ES5yiuyI2IWjJQ.

75 "Jindalee Operational Radar Network," Royal Australian Air Force, https://www.airforce.gov.au/technology/surveillance-command-and-control/jindalee-operational-radar-network.

76 "NORTHCOM Commander Gen. Glen D. VanHerck Conducts Press Briefing," DOD.

77 Photo by Donna Burton, U.S. Customs and Border Protection, March 27, 2014, via Flickr, https://www.flickr.com/photos/cbpphotos/13899913784/in/photostream/.

78 "Doppler Radar Detects More Than Rain and Snow," National Weather Service, n.d., https://www.weather.gov/grb/radar_birds.

79 "Mobile LTE Coverage Map," Federal Communications Commission, last updated August 6, 2021, https://www.fcc.gov/BroadbandData/MobileMaps/mobile-map.

80 Sebastian Spenger, "German Air Force Jumping on Passive Radar," Defense News, March 22, 2019, https://www.defensenews.com/global/europe/2019/03/22/german-air-force-jumping-on-passive-radar/.

81 VanHerck (speech, Defense Writers Group).

82 Ibid.

83 U.S. Army Comptroller, *Budget Activity 5A - Justification Book - U.S. Army* (Washington, DC: March 2019), https://www.dacis.com/budget/budget_pdf/FY20/RDTE/A/0604741A_123.pdf.

84 "Mobile LTE Coverage Map," Federal Communications Commission.

85 Arthur and Bennett, *National Cruise Missile Defense*, 18.

86 Photo by Curious Expeditions via Flickr, licensed under CC BY-NC-SA 2.0, https://www.flickr.com/photos/curiousexpeditions/3238871353.

87 Theresa Hitchens, "ABMS Demo Proves AI Chops For C2," Breaking Defense, September 3, 2020, https://breakingdefense.com/2020/09/abms-demo-proves-ai-chops-for-c2/.

88 VanHerck (speech, Defense Writers Group).

89 Martin E. Dempsey, "Mission Command," Joint Chiefs of Staff, April 3, 2012, https://www.jcs.mil/Portals/36/Documents/Publications/missioncommandwhitepaper2012.pdf.

90 Jon Hill in "MDA and the 2023 Budget," CSIS.

91 David Pugliese, "Canada plans new $1-billion radar to protect North American cities," Ottawa Citizen, April 25, 2022, https://ottawacitizen.com/news/local-news/canada-plans-new-1-billion-radar-to-protect-north-american-cities.

92 Arthur and Bennett, *National Cruise Missile Defense*, 4.

93 Terri Moon Cronk, “New DOD Chief Digital Artificial Intelligence Office Launches,” DOD, February 4, 2022, https://www.defense.gov/News/News-Stories/Article/Article/2923986/new-dod-chief-digital-artificial-intelligence-office-launches/.

94 Glen VanHerck, *Hearing to Receive Testimony on Missile Defense Strategy, Policies, and Programs in Review of the Defense Authorization Request for Fiscal Year 2022 and the Future Years Defense Program*, 117th Cong., 1st sess., May 26, 2021 (statement of General Glen VanHerck, Commander, USNORTHCOM), https://www.armed-services.senate.gov/imo/media/doc/21-48_06-09-2021.pdf.

95 Vladimir Isachenkov, “Russia Sends Two Nuclear-Capable Bombers to Venezuela,” Associated Press, December 10, 2018, https://apnews.com/article/europe-russia-venezuela-moscow-8d26f489590041f9b7cac480b0276b10.

96 Karako and Dahlgren, *Complex Air Defense*, 19–22.

97 Missile Defense Agency, *Department of Defense Fiscal Year (FY) 2021 Budget Estimates: Research, Development, Test & Evaluation, Defense-Wide* (Washington, DC: Missile Defense Agency, 2020), liv, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2021/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB21_Justification_Book.pdf.

98 Missile Defense Agency, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates: Research, Development, Test & Evaluation, Defense-Wide* (Washington, DC: 2022), liii, https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2023/budget_justification/pdfs/03_RDT_and_E/RDTE_Vol2_MDA_RDTE_PB23_Justification_Book.pdf.

99 Elena Saltikoff et al., “Maintenance keeps radars running,” *Bulletin of the American Meteorological Society* 98, no. 9 (September 2017), 1833–1840, https://journals.ametsoc.org/view/journals/bams/98/9/bams-d-16-0095.1.xml.

100 National Academies Press, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: National Academies Press, 2012), 272, https://www.nap.edu/catalog/13189/making-sense-of-ballistic-missile-defense-an-assessment-of-concepts.

101 Department of the Army, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates: Other Procurement, Army, Communications and Electronics Equipment, Budget Activity 2* (Washington, DC: U.S. Department of the Army, 2022), 338, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/Procurement/OPA_BA2_Communications_and_Electronics.pdf.

102 Arthur and Bennett, *National Cruise Missile Defense*.

103 UK Ministry of Defence, “Multi-Billion-Pound Deal for Early Warning Aircraft,” press release, March 22, 2019, https://www.gov.uk/government/news/multi-billion-pound-deal-for-early-warning-radar-aircraft.

104 DOD, *P-8A Multi-Mission Maritime Aircraft (P-8A)* (Washington, DC: 2021), https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2019_SARS/20-F-0568_DOC_67_P-8A_SAR_Dec_2019_Full.pdf.

105 Arthur and Bennett, *National Cruise Missile Defense*.

106 Department of the Army, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates: Missile Procurement, Army* (Washington, DC: U.S. Department of the Army, 2022), 21, https://www.asafm.army.mil/Portals/72/Documents/BudgetMaterial/2023/Base%20Budget/Procurement/MSLS_ARMY.pdf.

107 Department of the Navy, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates: Shipbuilding and Conversion, Navy* (Washington, DC: U.S. Department of the Navy, 2022), 220, https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/SCN_Book.pdf.

108 Ibid., 106.

109 Department of the Navy, *Department of Defense Fiscal Year (FY) 2023 Budget Estimates: Weapons Procurement, Navy* (Washington, DC: U.S. Department of the Navy, 2022), 289, https://www.secnav.navy.mil/fmc/fmb/Documents/23pres/WPN_Book.pdf.

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