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Missile Defense: The End of the Interim Solution

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> **I propose "a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles."**
>
> **President Ronald Reagan**
> **Washington, DC, March 23, 1983**

Abstract: Given well-established criteria to assess the ability of missile defense systems to deter missile attacks, current missile defense systems are rapidly becoming ineffective against emerging threats. Yet the US Department of Defense (DoD) continues to make significant investments in the marginal improvement of today's systems. An assessment and strategy to reallocate funding to accelerate the development of directed energy systems is urgently needed for the United States and its allies and partners to deploy effective missile defenses by the end of this decade.

Introduction

Since the 1940s, the United States has struggled, with poor results, to develop a counter to missile threats. Despite investing more than $250 billion in missile defense since President Reagan announced an intense pursuit of strategic missile defenses in 1983, US defense against missile attacks is very limited and still principally relies on retaliatory attacks against regional threats and nuclear deterrence against strategic threats.[1] Until practical directed energy defenses (e.g., pulsed lasers, high-power microwaves) are available, an

1 John Isaacs and Samuel M. Hickey, "Missile Defense Costs Soar Out of This World," Center for Arms Control and Non-Proliferation, January 26, 2021, updated October 26, 2021, https://armscontrolcenter.org/missile-defense-costs-soar-out-of-this-world/.

"interim solution" has been to rely on kinetic interceptor missile systems. Unfortunately, missile interceptor systems can be overwhelmed by large salvos of unsophisticated missiles and missile launches from unexpected locations, or outmaneuvered by a warhead after an interceptor has been launched. (In the interest of disclosure, L3Harris Technologies, Inc. where I serve as a vice president focused on venture capital fund investments, is a defense contractor and has conducted directed energy research in the past. The thoughts represented in this paper are my own and do not represent the views of L3Harris Technologies, Inc.)

The interim solution, which has been pursued for years, has been adequately effective in the past, albeit at a great expense, against limited missile attacks; however, emerging threats will soon render interceptor-based active missile defense systems less effective.

A recent US Department of Defense intelligence report concluded:

> Overall, the threats posed by ballistic missile delivery systems are likely to continue to increase and grow more complex. Adversary ballistic missile systems are becoming more mobile, survivable, reliable, and accurate while also achieving longer ranges. Hypersonic glide vehicles (HGVs) delivered by ballistic missile boosters are an emerging threat that will pose new challenges to missile defense systems. Prelaunch survivability is likely to increase as potential adversaries strengthen their denial and deception measures and increasingly base missiles on mobile platforms. Increasing technical and operational countermeasures continue to challenge defensive systems in ballistic missiles.[2]

Despite this eventuality, DoD continues to invest significantly more in marginal improvements in the performance and reliability of missile interceptors rather than in the development of directed energy (DE) solutions necessary to counter emerging threats by the end of this decade. Given the rapidly changing pace of threat technologies, a review of the logic behind these investment decisions is warranted.

Missile defense investment logic

Determining a practical logic for calculating the effective return on investment (ROI) for pursuing advanced missile defense technologies is problematic. Conflicting ROI calculation results arise due to inconsistent methods of determining the cost to develop and deploy a missile defense system versus one or more of the following factors (1) the cost of adversaries' offensive missile attacks, (2) the value of the lives and assets being protected, (3) the economic value of freedom of access to key regions, and (4) the geopolitical value of countering regional coercion by potential adversaries. Complicating the issue, the development timelines for missile defense systems typically span multiple decades, thus defensive technologies are often obsolete when the systems are ultimately deployed. Regardless of the economic calculation of the value versus cost of missile defenses, their limited or ineffective ability to counter emerging threats renders value vs. cost calculations irrelevant. Cooperative international deployment of missile defense capabilities does not alleviate these issues.

President Reagan's arms control advisor, Paul Nitze, proposed simple, yet compelling, criteria for evaluating investments in missile defenses to deter missile attacks that are as insightful today as when he presented them in a speech to the Philadelphia World Affairs Council in 1985.[3] His criteria for deterrence was practical: (1) the proposed missile defense system has to actually work, (2) it has to be able to survive attacks against it, and (3) the system must be "cost effective at the margin" (i.e., missile defense engagements should be less expensive than the missiles they are designed to shoot down). Additionally, if the up-front costs for the basic system bankrupted a nation, then the marginal cost would no longer be relevant. This paper uses the Nitze criteria to assess the current investment trends in the development and application of missile defense technologies compared to missile threat trends.

Criteria 1. The proposed system has to work.

Current missile defense systems can counter missile threats in limited scenarios; however, the following practical considerations lend insight into the enduring effectiveness of these systems compared to evolving trends in missile threats. The

2 *Ballistic and Cruise Missile Threat*, US Department of Defense, National Air and Space Intelligence Center (NASIC), in collaboration with the Defense Intelligence Ballistic Missile Analysis Committee (DIBMAC), July 2020, 38.

3 John K. Vaughn, *The Nitze Criteria and the Bush Missile Defense Architecture*, US Army War College, Strategic Research Project, 2002, 3.

The dual-sided ballistic missile early warning radar Thule AFB, Greenland. The range of early warning radars is limited by the curvature of the Earth. Courtesy photo US Air Force.

basic operational concept of all US missile defense systems currently deployed consist of (1) tracking of a ballistic missile warhead as it glides unpowered after deployment and predicting where it will be when it is within the range of an interceptor, (2) flying the interceptor to that precise location and time, and (3) deploying a "kill vehicle" to perform final maneuvers to intercept the incoming warhead.

There are three factors in contemporary missile threat developments—missile raid size, warhead maneuverability, and missile launcher mobility—that threaten the existing missile defense paradigm.

Effectiveness against large raids of missiles: The simultaneous launch of a large salvo of unsophisticated missiles from different launch locations and ranges constitutes the most serious threat to the effectiveness of existing missile defense. As described in a 2020 analysis by the Defense Intelligence Ballistic Missile Analysis Committee titled *Ballistic and Cruise Missile Threat*, significant missile proliferation will continue as an attractive alternative for countries that cannot afford air forces.[4] Additionally, missiles are becoming more accessible and operational by non-state actors, as illustrated by the multiple cruise missile (or long-range drone)[5] attacks of Saudi Arabian oil refiner-

4 *Ballistic and Cruise Missile Threat*, 4.

5 The UN report referred to the attack platform used as "long range drones"; however, these "drones" had all the characteristics of cruise missiles: self-guided, fly in a straight line at low altitudes for over 900 km, and strike predetermined targets.

The first of two Terminal High Altitude Area Defense (THAAD) interceptors is launched during a successful intercept test. US Army photo. September 10, 2013.

ies by Houthis in Yemen.[6] A January 2019 United Nations Security Council report described the smuggling and assembly of long-range, accurate, Quds-1 cruise missiles (or long-range drones) into Yemen.[7] The report presciently warned of the imminent use of those cruise missiles. On September 14, 2019, the Houthis claimed they launched over a dozen drones (effectively cruise missiles) that simultaneously struck Saudi Arabian oil fields from different locations, temporarily disrupting 5.7 million barrels per day of Aramco oil production (50 percent of Saudi oil production) and causing a spike in global oil prices.[8] The Houthis, with Iranian support, continue to launch more capable Quds-2 cruise missiles at targets 900 kilometers (560 miles) away from multiple locations.[9]

Enabling this proliferation is the availability of mobile missile launchers, larger solid rocket motors (SRMs), highly accurate inertial guidance and control (G&C) systems, easily transshipped and assembled long-range cruise missiles operable by inexperienced personnel, and the employment of salvo launch tactics. The increasing availability of SRMs on the international arms market enables the mobility of launchers (making knowledge of their locations challenging), dramatically reduces the training required to launch missiles, increases missile range, makes them easier to transport, and makes it more difficult to track missile shipments. Equally concerning, SRMs and accurate inertial G&C systems enable the disguised deployments on mobile platforms including merchant ships and commercial trucks, as well as the development of submarine-launched missiles.

6 Ben Hubbard, Palko Karasz, and Stanley Reed, "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran," *New York Times*, September 15, 2019.

7 United Nations Security Council, *Final Report of the Panel of Experts on Yemen*, S/2019/83 (also S/2019/348), January 25, 2019.

8 Hubbard, Karasz, and Reed, "Saudi Oil Installations Hit."

9 Sarah Dadouch, "Yemen's Houthis Claim Missile Attack on Saudi Oil Facility," *Washington Post*, March 4, 2021.

Effectiveness against maneuvering threats: On the near-peer end of the threat spectrum, the development and deployment of maneuverable reentry vehicles (RVs), late-deploying multiple independent RVs (MIRVs), and hypersonic flight vehicles by China, Russia, and other countries effectively counters all current missile defense systems that rely on the accurate predictability of a missile's trajectory in order to intercept them later in flight. Hypersonic missiles typically travel at velocities between Mach 7 (2.4 km per second) and Mach 19 (6.5 km/s). Missile interceptors typically fly tens of seconds prior to intercepting a target, thus the hypersonic target can travel at least 24 km to 65 km (or even hundreds of kilometers for long-range threats) after an interceptor is launched. There is significant opportunity for a warhead to maneuver beyond the limited divert capability of an interceptor's kill vehicle. Additionally, hypersonic missiles fly at lower altitudes than ballistic missiles, thus they are more difficult to track using radars whose line of sight is limited by the Earth's horizon.[10] Recent investments in small, highly maneuverable, interceptors will likely improve the ability to counter hypersonic glide vehicles, but the inherent limitations of even those kinetic interceptors limits their effectiveness to essentially the terminal phase of a threat missile's flight where defenses are less attractive.

Effectiveness against launch location uncertainty: Traditionally, US strategic missile defenses have been oriented to attacks from Iran or North Korea. Yet today, geometric realities dictate that future threat trajectories toward the United States from the south may be as likely as trajectories from the northwest or northeast. This increased threat is due to the development of submarine-launched missiles, concealed cargo ship launchers, or the procurement of mobile, intermediate-range, missile systems by potential adversaries south of the United States. These factors create significant uncertainty about the ability to protect the US homeland from geographically unanticipated trajectories.

Criteria 2: It has to survive attacks against it.

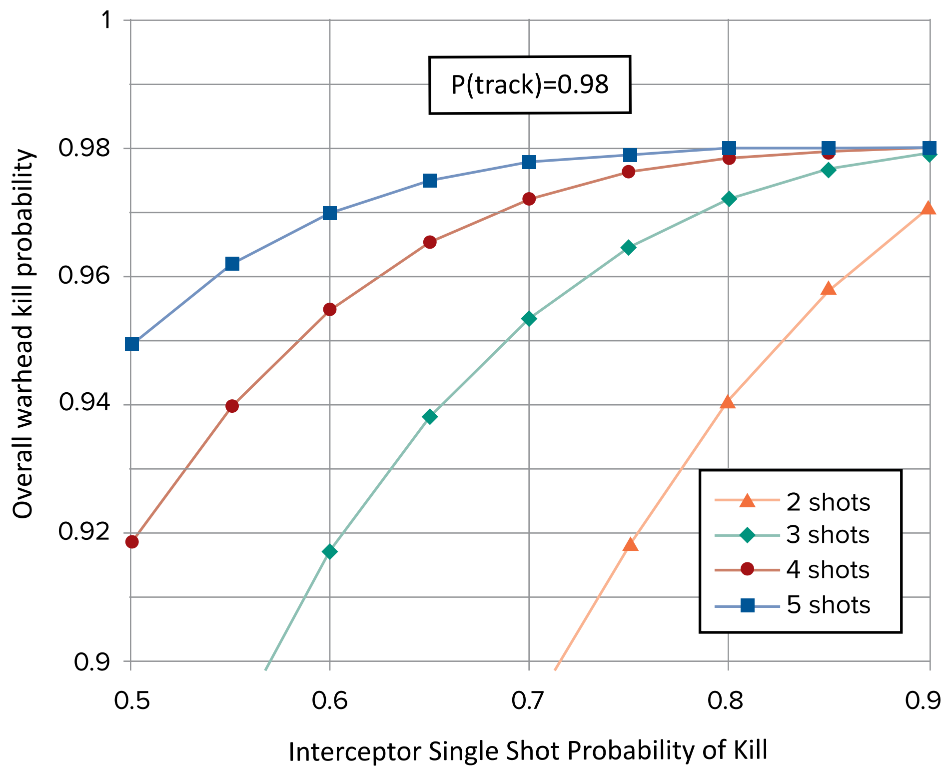
The more vulnerable a missile defense system is to an attack, the more of its own resources must be spent on self-defense. The location of fixed-site missile defense components, such as US national missile defense missile fields in Alaska and all US long-range radars, are well known publicly and require extensive resources to ensure their security while being susceptible to missile, drone, special operations attacks as well as cyberattacks on utilities and command and control infrastructure. Likewise, transportable missile defense systems, like Aegis, Patriot, and Terminal High-Altitude Area Defense (THAAD), rely on powerful, radiofrequency-emitting radars that can acts as beacons for adversary attacks.

Criteria 3: It must be cost-effective on the margin.

The reliability of missile interceptor systems is key to determining the number of interceptors that must be launched to confidently destroy an incoming missile. In 1998, Stanford University's Center for International Security and Arms Control presented a "Simple Model for Calculating Ballistic Missile Defense Effectiveness," which remains a seminal framework for assessing interceptor-based missile defense systems.[11] In this assessment, system effectiveness as a function of the number of interceptors launched against a single target is calculated as the product of the probability that a threat warhead's trajectory is accurately tracked and predicted, referred to as P_{track}, and the probability of an interceptor's single shot kill probability (SSPK). The P_{track} and SSPK include reliability probabilities. Figure 1 shows the number of interceptors required to attain a probability of destroying one threat warhead as a function of the interceptor SSPK of the systems' interceptors if the P_{track} of the system is 98 percent. For example, if the SSPK of each interceptor is 80 percent, three interceptors would be required to have a required probability of destroying the incoming threat warhead of 97.2 percent. Likewise, increasing the interceptors' SSPK to 85 percent would increase the probability of three interceptors destroying the warhead to 97.6 percent. Of note, unless an individual interceptor's SSPK matches the desired degree of protection (i.e., the desired percentage probability that a threat warhead is intercepted), then two or more interceptors will always be required during an engagement. The cost of a single interceptor (consisting of a sophisticated seeker, command, guidance, and divert systems) and the associated launcher, command and control, sensors, and operators will be significantly greater than the cost of an unsophisticated, or even maneuvering,

10 While hypersonics are not faster than a reentering ballistic missile, the combination of speed, maneuverability, and evasion of existing detection and defense phenomenologies makes hypersonic warheads much more difficult to intercept compared to ballistic (nonmaneuvering) missiles. The line-of-sight distances from a sensor at sea-level is around 20 km due to the Earth's curvature.

11 Dean Wilkening, "A Simple Model for Calculating Ballistic Missile Defense Effectiveness," Center for International Security and Arms Control, Stanford University, August 1998.



The number of inceptors required to achieve probability of kill as a function of SSPK.
(Wilkening, "A Simple Model for Calculating Ballistic Missile Defense Effectiveness.")

missile. In contrast, as reported in a recent Congressional Research Service report, a solid-state laser "can be fired for a marginal cost of less than one dollar per shot (which is the cost of the fuel needed to generate the electricity used in the shot)."[12] Thus, missile interceptor-based systems can never be "cost effective on the margin."

Assessment of current investment logic: Today's missile interceptor defense systems do not meet any of the long-standing criteria for investment in missile defense to deter attacks proposed by Nitze. Given their growing ineffectiveness to meet emerging threats over this decade, considering today's missile interceptor systems as only an interim solution is prudent. Likewise, continued investment in missile interceptor technologies should be balanced with the need to accelerate the development of directed energy capabilities.

Strategy for countering emerging missile threats

The rate of development and deployment of emerging missile threats currently outpaces the pending obsolescence of interceptor missile defense systems. Consistent with the decades-long development times of current hit-to-kill missile defense technologies, such as the Aegis, THAAD, and Ground-based Mid-course Defense (GMD), even with multibillion-dollar annual research budgets, affordable and effective laser and high-powered radiofrequency (RF) systems will take many years to develop. Many of these enabling technologies, such as artificial intelligence-based target acquisition, space-based passive track, discrimination, fire control, beam pointing, and lethality (including microwave, laser, and other radiofrequency effects) have been demonstrated in laboratories after many years of technical setbacks and earlier operationally impractical

12 *Navy Lasers, Railgun, and Gun-Launched Guided Projectile: Background and Issues for Congress*, Congressional Research Service, R44175, updated October 20, 2021, https://crsreports.congress.gov.

The US Navy's Optical Dazzler Interdictor (ODIN) counter-sensor laser is seen here aboard the *Arleigh Burke*-class guided-missile destroyer USS *Stockdale* (DDG 106) underway in the Pacific Ocean. 210712-N-MR124-1064. July 12, 2021. US Navy photo by Mass Communication Specialist Seaman Elisha Smith.

prototypes. However, the advent of highly efficient directed energy systems (with small power and thermal requirements) combined with applied artificial intelligence-fleets of autonomous platforms in sea, air, land, and space domains presents an opportunity to develop effective and affordable directed energy systems by the end of this decade. Two observations are clear. First, while the timeline for the development of effective directed energy missile defense systems is debatable, the need to objectively assess the effectiveness of current missile interceptor systems against emerging threats is not. Second, without a diversion and prioritization of funding in the development of directed energy missile defenses, similar to the development of hit-to-kill technologies during the 1990s and 2000s, the risk remains of funding and operating ineffective missile defense systems at the end of this decade.

Unfortunately, the US defense industrial base is not well positioned to accelerate the development of directed energy systems to keep pace with emerging missile threats. As stated in a recent DoD report to Congress, shortfalls in manufacturing, supply chain, and workforce competency severely limit the US ability to develop industrial capacity for directed energy systems.[13] DoD has made modest investments in high-energy lasers and high-power microwave programs, such as the Navy's Optical Dazzler Interdictor (ODIN) counter-sensor lasers aboard three *Arleigh Burke*-class guided missile destroyers, the High Energy Laser Weapon System (HELWS), the Phaser high-power microwave system, Air Force Research Laboratory's Tactical High Power Operational Responder (THOR), and the Advanced Test High Energy Asset system (known as ATHENA), which are currently undergoing development

13 *Industrial Capabilities: Report to Congress*, Office of the Secretary of Defense for Acquisition and Sustainment, Industrial Policy, January 2021, 132.

and evaluations.[14] However, due to the slow pace of investment in DE technologies, these systems do not reflect the latest technologies developed in US research institutions, and fall short of the lethality and operationally relevant propagation ranges required to defeat large-scale hypersonic and maneuvering threats by the end of this decade.

The Department of Defense continues to avoid prioritizing the funding necessary to counter emerging threats by end of this decade. For example, in the last president's budget request (PBR) of the Trump administration and the first PBR of the Biden administration, the Missile Defense Agency requested no funding for the development of laser defense systems (the only funding for this research was due to congressionally added appropriation). In contrast, the United Kingdom's recent integrated review of security, defense, development and foreign policy established a strategic investment objective to "keep pace with changing threats posed by adversaries, with greater investment in rapid technology development and adoption."[15] These investments encompass "advanced and next-generation R&D to deliver an enduring military edge in areas including space, directed energy weapons, and advanced high-speed missiles."[16] Furthermore, in acknowledgment of the rapid pace of emerging threat technologies, the UK government announced that it "will prioritise higher-risk research to support the modernisation of our armed forces."[17]

Conclusion and recommendations

Despite the inability of current missile interceptor systems to meet any of the investment criteria proposed by the Reagan administration to deter missile attacks, the United States continues to invest in marginally upgrading interceptor systems' reliability and capability that will be ineffective against the emerging missile threat environment by the end of this decade. Missile interceptors, although economical and resilient against limited threats, present only an interim solution to continually growing missile threats. The development of speed-of-light, directed energy technologies must be accelerated to provide the missile defense necessary to complement the military, economic, and political components of US deterrence strategies.

A comprehensive assessment of the effectiveness of missile interceptor systems compared to a timeline of emerging threat projections is warranted. Likewise, an investment strategy to accelerate the development of directed energy systems to a pace to counter the emerging threats before current US missile defense systems are deemed ineffective by potential US adversaries is suggested. Finally, a budget assessment of the funding of the production, maintenance, and retirement of missile interceptor systems balanced with the need to accelerate the development, testing, and deployment of directed energy missile defense systems is strongly recommended.

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Lieutenant General O'Reilly (Ret.) retired from the Army in 2013 after a thirty-five-year career highlighted by managing unprecedented missile, radar, power, vehicle, construction engineering, watercraft, and logistic research and acquisition programs, cumulating as the director of the US Missile Defense Agency. Pat led the government integration of engineering teams across the aerospace industry and worked with all levels of the executive branch, Congress, industry, and the leadership of forty-two countries. A West Point graduate, Pat was an associate professor of physics at West Point with master's degrees in physics, national security and strategic studies, and management.

Pat has been deployed on multiple hurricane and other natural disasters as a disaster relief associate for the American Red Cross.

14 *Industrial Capabilities*, 130.

15 *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy*, Presented to Parliament by the Prime Minister by Command of Her Majesty, March 2021, 22.

16 *Global Britain in a Competitive Age*, 38.

17 *Global Britain in a Competitive Age*, 38.

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