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LETTER FROM THE EDITORS

Welcome to the June 2025 issue of AFPC's *Defense Dossier*. As missile threats grow more numerous and complex, air and missile defense has become a foundational element of American security. Hypersonic glide vehicles, saturation attacks, and maneuvering warheads are no longer future concerns—they are today's battlefield realities. The challenge is no longer whether the United States can build a comprehensive missile defense system, but whether it will choose to do so before deterrence fails.

This issue explores the strategic, technical, operational, and fiscal dimensions of that choice. We begin with a broad assessment of how the space domain has become central to modern deterrence, and why dominance in orbit is now essential to protecting American interests on Earth. From there, we examine the specific challenges posed by hypersonic weapons, the architectural innovations required to counter them, and the urgent need for responsive detection and interception capabilities.

We revisit a once-abandoned concept—space-based interceptors—that may now be viable thanks to commercial launch advances and satellite miniaturization. We then draw lessons from the evolving missile threat environment in Ukraine and the Middle East, where layered defenses and coalition cooperation have proven critical but far from sufficient. Finally, we turn to the fiscal and bureaucratic realities that will determine whether today's Golden Dome initiative can move from vision to implementation.

Missile defense is no longer a niche mission. It has become a test of national will. The strategic challenge is clear, and the technologies are within reach. What remains is for policymakers to make the hard choices necessary to realize a credible, integrated, and future-ready defense architecture.

We hope this edition provides insight, clarity, and direction at a time when getting missile defense right is both important and urgent.

All the best,

Ilan Berman
Chief Editor

Richard M. Harrison
Managing Editor

Missile Defense and Space: The Next Frontier for Strategic Advantage

William Schneider, Jr.

A quarter century ago, optimism prevailed. The Cold War had ended, the Soviet Union dissolved into 15 independent states, the seven captive nations of the Warsaw Pact had regained their independence, and China's admittance to the World Trade Organization seemed to affirm its commitment to a peaceful rise.

The contrast with the strategic environment in 2025 could scarcely be starker. Today, a four-nation adversary coalition of China, Russia, Iran, and North Korea has emerged as a comprehensive treaty-based diplomatic, economic, intelligence, military, defense-industrial and a nuclear (or near-nuclear) armed bloc. Their aims are a single-minded sequence of initiatives aimed at limiting U.S. influence, access, weakening its alliances, and diminishing its ability to shape events. Forming a classic Mackinder alliance on a continental scale, they do not require sea-lines of communication and can conduct and sustain military operations in multiple global theaters. In parallel, the diplomatic structure of bilateral and multilateral arms control arrangements has vanished in waves of treaty non-compliance and nuclear rearmament.[1]

The collapse of the promising post-Cold War diplomatic environment, particularly with China and Russia, has given way to a new dimension of warfare: conflict in space. Throughout the Cold War, the space domain enjoyed a diplomatic status that insulated it from becoming a zone of conflict. Initially, that confidence stemmed from the successful negotiation, in 1967, of a Treaty-based regime to prevent its militarization.[2] But recent years have seen a pronounced shift away from this status quo. China's 2015 declaration that space was a domain of warfare aligned with an overt shift in its security policy to one increasingly confrontational toward the U.S. and its allies.[3] More recently, in 2024, Russia deployed space-based infrastructure enabling the use of nuclear weapons in space.[4] For its part, NATO declared space to be an "operational domain" of warfare as far back as 2019.[5]

SHIFTING TERRAIN

The emergence of this coalition and its ability to operate as a pseudo-alliance has reinforced one of the most challenging elements of contemporary international security affairs: that all wars are world wars. Their collaboration, both overt and covert, is extensive, continuing, and largely immune to U.S. and allied countermeasures.

The examples are legion. Militarily, Iran's naval combatant vessels operate in Latin America; North Korean and Chinese troops operate under Russian command in Ukraine; North Korea builds tunnels for Iran's proxy, Hezbollah, and; China assists attacks by Yemen's Iranian-supported Houthis on U.S. Navy ships in the Red Sea.[6] The defense-industrial collaboration among these nations is widely known and broadly publicized, as are the extensive economic, trade, and financial links between them.

These characteristics reinforce the significance of military operations in space, because space is the unifying theater of operations upon which all others now depend. In the U.S., the transformation of the technologies of space operations from being primarily military to the civil sector has marked the most significant technical shift since World War II. Civil sector technologies now contribute to the creation of military space capabilities.[7]

This development has enabled the U.S. to sustain its role as the dominant player in space. Meanwhile, the 2020 creation of the United States Space Force has helped mitigate the prior limitations stemming from not having dedicated national security space R&D or an operational entity in that domain amid explosive growth in satellites and counterspace weapons by adversary nations (see accompanying charts).

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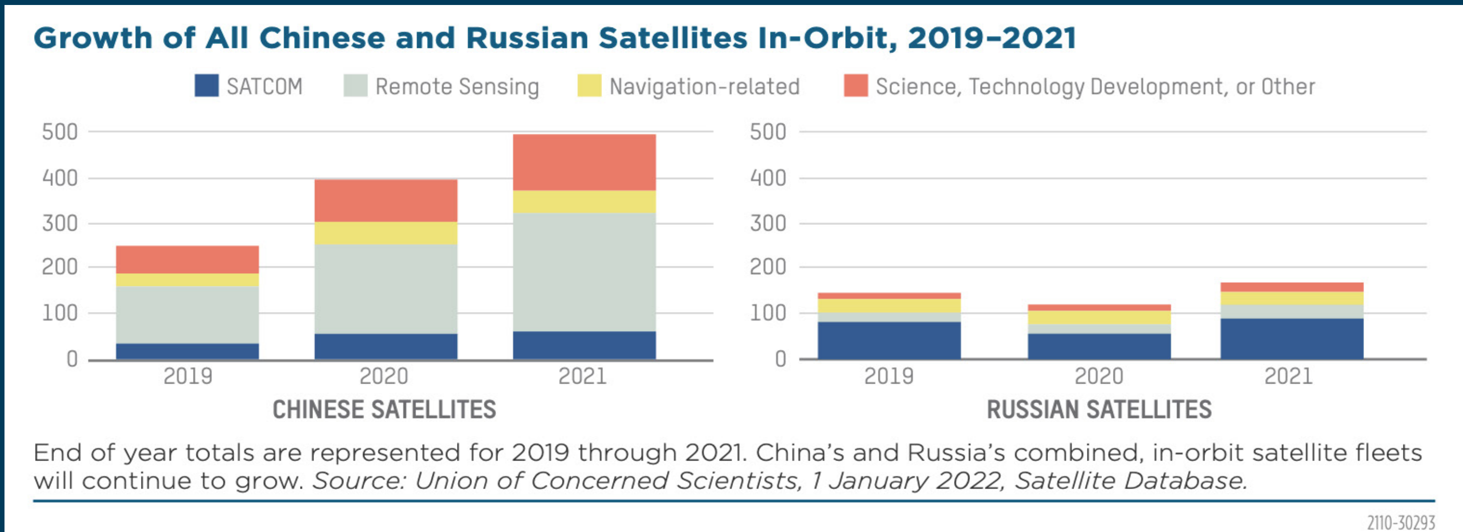
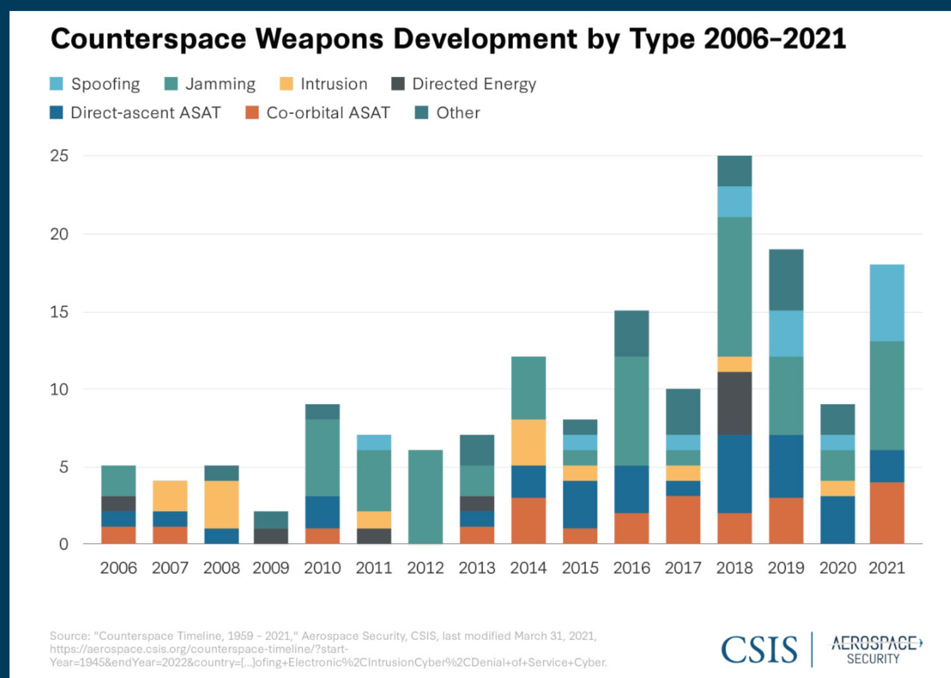


Source: Defense Intelligence Agency, Challenges to Security in Space–2022, https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf



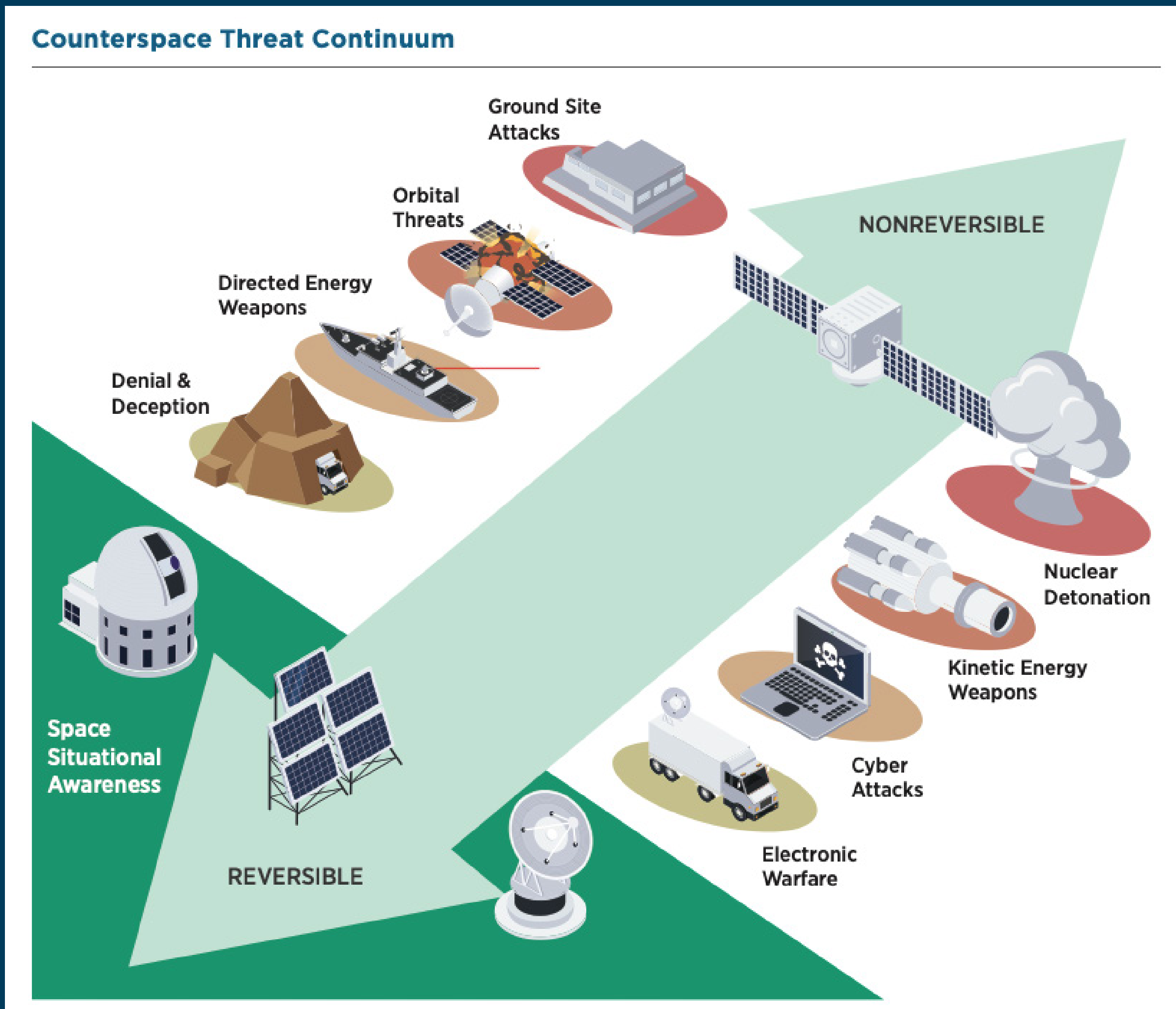
Source: CSIS, Russia Threatens to Target Commercial Satellites, https://www.csis.org/analysis/russia-threatens-target-commercial-satellites

Nevertheless, the scale of the Chinese and Russian systems now available for military and counterspace operations is a reminder of how fundamentally space has become a contested region. Moreover, these capabilities are integrated with other land-sea-air dimensions of adversary forces. And, as is the case with conventional military operations, counterspace operations cover a similar range of capabilities and can be implemented over time with either reversible or non-reversible effects.

RETHINKING DEFENSE

The Trump administration, recognizing that our position is space is contested and implicates all dimensions of U.S. military power, has initiated a profound change in national security policy. This shift has reversed the prior opposition of successive administrations to any defense of the U.S. territory against adversary intercontinental missile systems. Instead, the administration's new policy seeks to create an effective missile defense system for U.S. territory by integrating space capabilities with other U.S. capabilities and leveraging them for national defense.[8]

The core objectives reinforce the traditional goal of missile defense: to deter against a foreign attack on the homeland and guarantee a secure second strike. However, a new dimension has been added. The Trump administration's January 2025 Executive Order directs the DoD to the "development and deployment of proliferated space-based interceptors capable of boost-phase inter-



Source: Defense Intelligence Agency, Challenges to Security in Space–2022, https://www.dia.mil/Portals/110/Documents/News/Military_Power_Publications/Challenges_Security_Space_2022.pdf

cept" and to "defeat missile attacks prior to launch and in the boost phase."[9] These capabilities will require the U.S. to have the ability both to defend its assets in space and to deter or defeat adversary capabilities that could threaten U.S. territory.

These requirements will be developed by the responsible Combatant Command (NORTHCOM) and by Space Command. The proposed system was described in Congressional testimony on April 9th by NORTHCOM Commander General Gregory Guillot as a three-layered ("3-dome") system. The first layer is a "domain awareness" dome. The second will deal with the ICBM threat, and the third "air dome" will address cruise missiles and the air threat. Hypersonic missiles will be addressed in either the ICBM or air dome layers.[10] An innovative "acquisition as a service" approach is being taken toward the financing of the Golden Dome, similar to the financing and operation of Star Shield, the satellite network for military communication.[11]

Fielding the Golden Dome system will contribute to the ability of the Administration to recover the credibility of the core elements of deterrence that have been compromised in recent years:

Deterring the coercive threat of the use of nuclear weapons

Perhaps the most damaging consequence of Russia's second invasion of Ukraine in 2022 has been its successful coercive threat of nuclear weapons usage to partially deter American support for Ukraine. At critical junctures over the past three years, Russia has threatened escalation by manipulating the coercive threat of nuclear use to deter the United States and allies in Europe from providing critical capabilities to Kyiv. The Center for Strategic & International Studies has documented no fewer than 234 instances where Russia leveraged nuclear threats to affect U.S. and allied decision-making.[12]

Russia's manipulation has been further reinforced by its profligate use of systems (cruise and ballistic missiles) that can deliver a conventional or nuclear warhead. Thousands of *Iskander* 9K720 and 9K723 ballistic missiles, as well as the 9K728 and 9K729 cruise missile variant, have been employed in Ukraine. Additionally, more than 800 submarine-launched *Kalibr* ballistic missiles have been fired at targets in Ukraine from Russia's Black Sea submarine fleet. Russia's nuclear-capable *Kinzhal* 47M2 hypersonic missiles are launched from Russian MiG-31 aircraft based at Machulishchy Air Base, near Minsk. More recently, Russia has employed a new, longer-range hypersonic missile, the *Oreshnik*.[13] All of these systems have the capacity to carry nuclear payloads—a fact that is not lost on U.S. military planners.

Russia's ability to deter the U.S. and its allies from measures that support Ukraine's territorial defense has also been strengthened by its promulgation of a change in its operational doctrine—one which significantly lowers the threshold for nuclear use.[14] In turn, this doctrinal change has been supported by Russian military exercises using simulated theater ("sub-strategic") nuclear surrogates.[15]

Russia's manipulation of nuclear threats has now affected the policy choices of three U.S. Presidents. President Obama chose not to respond to Russia's annexation of Crimea in 2014 and Russia's subsequent invasion of Donetsk and Luhansk provinces in 2015, or its refusal to comply with the Minsk Peace Agreements. Both Presidents Biden and Trump have adapted their policy choices in Ukraine as well, citing the risk of "World War III" as the basis for their decisions.

Rebuilding the credibility of the extended deterrent

Closely aligned with the need to deter the coercive threat or use of nuclear weapons is the need to restore the confidence of American allies. The cumulative effect of the failure of successive administrations to deter the diplomatic manipulation of nuclear threats has eroded the credibility of the U.S. nuclear deterrent. Serious consideration is now being given in Europe to the creation of a European nuclear deterrent separate from that possessed by the U.S.—and perhaps that of the UK as well.[16]

The consequences have accumulated. The build-up of adversary nuclear capabilities, including Russia's introduction of six new intercontinental nuclear delivery systems, China's very large increase in its nuclear force structure, and North Korea's development of ICBMs, has magnified the fact that the U.S. can be deterred by the coercive threat of nuclear weapons.

These circumstances not only complicate the ability of future Presidents to deter coercive diplomacy by America's adversaries. They also diminish the effectiveness of the U.S. government's 80-year-long campaign to prevent nuclear proliferation.

> **Russia has leveraged nuclear threats 234 times to affect U.S. and allied decision-making during the Ukraine conflict.**

Limiting the consequences of deterrence failure

An effective capability to defend U.S. assets in space is a crucial dimension in the chain of capabilities needed to sustain deterrence. The Golden Dome program, if successfully fielded, will enable the U.S. to limit the consequences of a deterrence failure arising from adversary air and missile attack. The Golden Dome is critically dependent on its space-based component, and injecting doubt into the mind of a potential attacker is critical to sustaining deterrence and discouraging adversary manipulation of nuclear threats, especially in an extreme crisis.

> **Eliminating the space component of Golden Dome will become essential for any prospective attacker.**

Both China and Russia have deployed formidable capabilities in space that are designed to functionally eliminate the U.S. national security presence in space. Eliminating the space component of Golden Dome will become essential for any prospective attacker. And the proliferation of space systems on orbit for years in support of a variety of military missions, including intelligence surveillance and reconnaissance, Earth observation, communications, navigation and counter-space, will invariably make these capabilities targets in the event of a conflict. In turn, a major conflict may begin in an ambiguous manner, as critical space capabilities face attacks that could appear as malfunctions and other problems that degrade their performance, but which are instead adversary attempts to degrade U.S. capabilities.

These circumstances underscore the importance of space as the critical enabler for damage limitation through missile defense. In turn, the ability to credibly limit damage to U.S. territory or other areas of importance will be critical to sustaining the credibility of the American nuclear deterrent.[17]

NEW CHALLENGES

The fundamental changes to the strategic environment facing the United States poses a grave threat to American interests and security. These changes have been shaped by the cumulative effects of technology, a diplomatic convergence of interests among U.S. adversaries, and our own policy choices over the past decade or more, which have enabled adversary nations to pose a profound threat to us and our allies. The threat today also incorporates traditional domains of conflict with the extraordinary scope and scale of the adversary threat in space. Dominance in space-based sensors, communication, and counter-space capabilities is crucial to deter or prevail in future conflicts. The U.S. needs dominant capabilities in space to deter the coercive threat or use of nuclear weapons in a future conflict.

By its nature, such a capability also requires being able to defend U.S. assets in space. Deploying a credible system of missile defenses enables the U.S. to safeguard the crucial instruments that sustain global stability—among them the extended U.S. nuclear deterrent to U.S. allies, a compelling capacity to limit the consequences of deterrence failure, and the global nuclear non-proliferation regime.

APPENDIX: TYPES OF COUNTERSPACE WEAPONS[18]

(Kinetic, Non-Kinetic Physical, Electronic, and Cyber)

	Kinetic Physical			Non-kinetic Physical			
Types of Attack	Ground Station Attack	Direct-Ascent ASAT	Co-orbital ASAT	High Altitude Nuclear Detonation	High-Powered Laser	Laser Dazzling or Blinding	High-Powered Microwave
Attribution	Variable attribution, depending on mode of attack	Launch site can be attributed	Can be attributed by tracking previous-ly known oribt	Launch site can be attributed	Limited attribution	Clear attribution of the laser's location at the time of attack	Limited attribution
Reversibility	Irreversible	Irreversible	Irreversible or re-versible depend-ing on capabilities	Irreversible	Irreversible	Reversible or irreversible; attacker may or may not be able to control	Reversible or irreversible; attacker may or may not be able to control
Awareness	May or may not be publicly known	Publicly known depending on trajectory	May or may not be publicly known	Publicly known	Only satellite operator will be aware	Only satellite operator will be aware	Only satellite operator will be aware
Attacker Damage Assessment	Near real-time confirmation of success	Near real-time confirmation of success	Near real-time confirmation of success	Near real-time confirmation of success	Limited confirmation of success if satellite begins to drift uncontrolled	No confirmation of success	Limited confirmation of success if satellite begins to drift uncontrolled
Collateral Damage	Station may control multi-ple satellites; potential for loss of life	Orbital debris could affect other satellites in similar orbits	May or may not produce orbital debris	Higher radiation levels in orbit would persist for months or years	Could leave target satellite disabled and uncontrollable	None	Could leave target satellite disabled and uncontrol-lable

	Electronic			Cyber		
Types of Attack	Uplink Jamming	Downlink Jamming	Spoofing	Data Interccept or Monitoring	Data Corruption	Seizure of Control
Attribution	Modest attribution depending on mode of attack	Modest attribution depending on mode of attack	Modest attribution depending on mode of attack	Limited or uncertain attribution	Limited or uncertain attribution	Limited or uncertain attribution
Reversibility	Reversible	Reversible	Reversible	Reversible	Reversible	Irreversible or reversible, depending on mode of attack
Awareness	Satellite operator will be aware; may or may not be known to the public	Satellite operator will be aware; may or may not be known to the public	May or may not be known to the public	May or may not be known to the public	Satellite operator will be aware; may or may not be known to the public	Satellite operator will be aware; may or may not be known to the public
Attacker Damage Assessment	No confirmation of success	Limited confirmation of success if monitoring of the local RF environment is possible	Limited confirmation of success if effects are visible	Near real-time confirmation of success	Near real-time confirmation of success	Near real-time confirmation of success
Collateral Damage	Only dirupts the signals targeted and possible adjacent frequencies	Only disrupts the signals targeted and possible adjacent frequencies	Only corrupts the specific RF signals targeted	None	None	Could leave target satellite disabled and uncontrollable

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Slaying the Hypersonic Beast

Brent D. Ziarnick

In early 2025, the United States marked a milestone in its hypersonic missile defense efforts with the successful "Stellar Banshee" FTX-40 test.[1] The Missile Defense Agency's experimental Glide Phase Interceptor (GPI) engaged a surrogate hypersonic target, providing a high-profile demonstration of progress against one of the most technically daunting threats in modern warfare. For U.S. policymakers, defense planners, and international observers, the event offered a useful opportunity to assess where the United States stands in addressing the accelerating challenge of hypersonic weapons.

UNDERSTANDING THE HYPERSONIC THREAT

Hypersonic weapons, broadly defined as those traveling at speeds greater than Mach 5 and capable of atmospheric maneuver, are often categorized into two primary types: hypersonic glide vehicles (HGVs) and hypersonic cruise missiles (HCMs). These systems differ significantly from traditional ballistic missiles in that they do not follow a fixed trajectory. Instead, they can maneuver throughout their flight path, often at altitudes of between 20 and 60 kilometers, complicating detection and interception efforts from existing ground-based sensors and radars.[2]

Russia and China have prioritized the deployment of such systems. Russia's *Avangard* HGV and *Kinzhal* missile have been publicly claimed as operational, with the former first fielded in 2019. Similarly, China's *DF-17* HGV is believed to have been fielded as early as 2020 and is now integrated into the People's Liberation Army Rocket Force.[3] These developments are viewed by analysts as part of broader anti-access/area denial (A2/AD) strategies that aim to restrict U.S. freedom of maneuver in key theaters such as the Indo-Pacific and Eastern Europe.

What makes hypersonic weapons particularly challenging from a defense standpoint is not just their speed, but their maneuverability and altitude as well. As noted by the Congressional Budget Office (CBO), these features allow hypersonic systems to bypass traditional midcourse missile defense systems, which were designed with traditional—and relatively simple—ballistic missiles in mind.[4]

CURRENT LIMITATIONS

The current architecture of U.S. missile defense is not optimized to detect or intercept hypersonic threats across all phases of flight. Legacy systems like the Army's Patriot and Terminal Hight Altitude Area Defense (THAAD) batteries were built to counter ballistic and cruise missile threats, particularly in their terminal phase. These systems have shown some promise—for example, reports from Ukraine suggest that *Patriot* batteries have successfully engaged Russia's *Kinzhal* missile—but such intercepts remain rare and context-dependent.[5]

One critical U.S. limitation lies in its sensor architecture. Surface-based radars are restricted by the curvature of the Earth, which limits their line-of-sight coverage. This makes it difficult to detect and track low-flying hypersonic weapons until they are already in their terminal phase, leaving very little time for interception.[6] Likewise, existing space-based assets such as the Space-Based Infrared System (SBIRS) can detect launches but are not optimized for fire-control quality tracking of maneuvering threats.

To address these gaps, the Department of Defense is investing in the Space Force's space-based tracking capabilities. The Proliferated Warfighter Space Architecture (PWSA), led by the Space Development Agency (SDA), is intended to provide global coverage using large constellations of wide-field-of-view satellites in low Earth orbit. This system will work in tandem with the Hypersonic and Ballistic Tracking Space Sensor (HBTSS),

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which is designed to provide more precise tracking data to interceptor systems.[7] Additionally, the Space Systems Command is developing a complementary constellation in medium Earth orbit to enhance resilience and fill coverage gaps.[8]

While these developments represent meaningful progress, much of the architecture remains in development. As of early 2025, several of the tracking layers are only in the early deployment or prototype phases, with full operational coverage still years away. Importantly, the transition from missile "warning" to missile "tracking" to fire control–quality data requires the fusing of multiple sensor modalities. That integration is as much a software challenge as a hardware one. Delays in fusing optical, infrared, and radar data across domains due to software integration issues have historically derailed major space programs, and Congress has urged DoD to prioritize the matter.[9]

In a hypersonic engagement, even a few seconds' delay in transmitting sensor data from satellites to ground stations and then to interceptor launch platforms can render fire-control data obsolete.

A further technical obstacle is latency. In a hypersonic engagement, even a few seconds' delay in transmitting sensor data from satellites to ground stations and then to interceptor launch platforms can render fire-control data obsolete. To mitigate this, the SDA's Transport Layer aims to create a space-based mesh network that allows data to be routed between satellites in orbit—dramatically reducing time to action. However, scaling this capability across hundreds of satellites introduces new complexities in software validation, cybersecurity, and cross-service interoperability.

THE ROLE OF GLIDE PHASE INTERCEPTION

The Glide Phase Interceptor (GPI), featured in the Stellar Banshee test, is designed to engage hypersonic threats during their midcourse or "glide" phase—before they begin unpredictable terminal maneuvers. Unlike terminal systems, a glide-phase interceptor has a broader engagement envelope and, if successful, could provide a crucial layer of defense against hypersonics.

The GPI is intended to be integrated into the Aegis weapon system, which is deployed aboard U.S. *Arleigh Burke*-class and many allied nations' destroyers. This offers a mobility advantage, enabling regional coverage and the potential to place interceptors closer to anticipated threat vectors. However, achieving a successful intercept during the glide phase is highly complex. It requires accurate, low latency tracking data to guide the interceptor to a fast-moving, maneuvering target amid background clutter at the upper edge of the atmosphere. This places extraordinary demands on onboard sensors and communications bandwidth.

Although originally envisioned to achieve operational capability by the mid-2030s, recent congressional direction has accelerated timelines to deploy an Aegis-based GPI hypersonic missile defense capability, calling for initial operational capability by 2029 and full fielding by 2032.[10] In addition to the GPI, DARPA's Glide Breaker program aims to develop a lightweight, highly maneuverable interceptor designed to counter HGVs at extended range. Glide Breaker is still in its early technology maturation stage, though, and is unlikely to be operational before the early 2030s.

Another concept under discussion is the reintroduction of space-based interceptors. These would be stationed in orbit and could theoretically engage hypersonic or ballistic targets during early flight. However, such systems face serious arms control, budgetary, and technical hurdles—particularly regarding rules of engagement and target discrimination. Still, recent congressional language, including the 2025 *National Defense Authorization Act*, has directed DoD to study options for orbital interceptors under President Trump's "Iron Dome for America" initiative.[11]

STRATEGIC CONSIDERATIONS

Beyond the technical challenges, hypersonic weapons present broader strategic questions. Because of their high speed and maneuverability, they compress decision-making timelines for national leaders, potentially complicating crisis stability. The opaque flight paths of HGVs can create ambiguity about their targets, raising concerns about inadvertent escalation, especially since the world's hypersonic powers are also nuclear powers.[12]

Additionally, many U.S. allies face regional vulnerabilities to hypersonic systems. Forward bases in Japan, South Korea, and Europe may be at increased risk from hypersonics, given the shorter time-to-target associated with these weapons. Cooperative missile defense initiatives—like Japan's involvement in the GPI and the ongoing integration of NATO's missile defense networks—are viewed as important components of a broader regional strategy.

As stated earlier, President Trump and some defense analysts have advocated for a "Iron Dome for America"—a layered domestic missile defense system that includes capability against hypersonic, ballistic, and cruise missile threats. Trump's January 2025 executive order directed the Department of Defense to explore such options, including the potential role of space-based interceptors and non-kinetic defenses.[13] While ambitious, such efforts underscore growing bipartisan interest in expanding the scope of homeland missile defense beyond traditional ballistic threats.

The challenge of defending against hypersonics has also led to renewed discussions about the balance between deterrence by denial (through active defenses) and deterrence by punishment (through retaliatory capabilities).[14] The emerging consensus appears to favor a hybrid approach, recognizing that no missile defense system will be foolproof but that raising the cost, risk and complexity of an adversary's strike plan can help deter the violent use of hypersonic systems in the first place.

> **The challenge of countering hypersonic weapons is not insurmountable, but it does require a multi-faceted and sustained effort over time.**

LOOKING AHEAD

The "Stellar Banshee" test, while encouraging, represents one data point in a much larger and ongoing effort to adapt missile defense to a rapidly changing threat environment. The U.S. and its allies are actively investing in space-based sensors, glide-phase interceptors, and advanced command and control systems to close existing gaps. However, the pace of adversary developments continues to be a driving factor.

While the defense community has made clear progress in understanding the requirements for hypersonic defense—ranging from detection to fire-control quality tracking to interceptor performance—many of these capabilities remain in transition. Key programs will require sustained investment, technical maturation, and integration across multiple agencies and international partners.

As the defense landscape continues to evolve, assessments of missile defense architectures will likely need to remain flexible, layered, and focused on resilience. The challenge of countering hypersonic weapons is not insurmountable, but it does require a multi-faceted and sustained effort over time. Tests like that of the FTX-40 offer a glimpse of what is possible—and underscore the importance of sustained and intelligent effort in overcoming one of the most important threats of the 21st century.

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Missile Defense Must Go Back to the Future

Arno G. Ledebuhr

On March 23, 1983, President Ronald Reagan stood before the American public in a televised address from the Oval Office, delivering a speech that would reverberate through history. In it, he introduced the Strategic Defense Initiative (SDI), a radical departure from the Cold War's prevailing doctrine of mutually assured destruction (MAD).[1]

"What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack?" Reagan asked, painting a vision of a world where defense, not offense, defined security. He proposed a system to intercept and destroy ballistic missiles before they could strike, aiming to make nuclear weapons "impotent and obsolete."

This ambitious program quickly nicknamed "Star Wars" by a skeptical press, sought to harness the most advanced technologies of the era to create an impenetrable shield in space. Within this grand initiative emerged Brilliant Pebbles (BP), a concept so ingenious it promised to redefine missile defense then—and can still do so now.

Brilliant Pebbles was a space-based interceptor (SBI) system designed to strike missiles during their boost phase, the fleeting window when they are most vulnerable—slow, bright, and free of decoys. Conceived in the late 1980s, BP represented the pinnacle of SDI's evolution, yet it was canceled in 1993 amid shifting political winds. However, the challenges it aimed to address—proliferating missile threats and the limitations of ground-based defenses—have only intensified. With modern advancements in space technology, the abandonment of the Anti-Ballistic Missile (ABM) Treaty, and the rise of hypersonic threats, BP's revival offers a compelling path forward, especially in the context of President Trump's "Golden Dome for America" initiative.

THE BIRTH OF BRILLIANT PEBBLES

The Strategic Defense Initiative began with lofty aspirations but cumbersome concepts. Among the early ideas for SBIs, was "Smart Rocks," a system of massive 900+ kg interceptors housed in centralized "space garages." These behemoths were designed to collide with incoming missiles using sheer kinetic force, a "hit-to-kill" approach that eliminated the need for explosive warheads. However, their size and concentration made them glaring targets. Red/Blue team exercises quickly revealed a fatal flaw: adversaries could deploy anti-satellite (ASAT) weapons to obliterate these garages, rendering the system ineffective. The cost-exchange ratio tilted heavily toward offense—building more missiles was cheaper than defending against them. Survivability became the critical challenge, and SDI needed a rethink.

In 1987, a trio of brilliant minds—Dr. Lowell Wood and Dr. Edward Teller at Lawrence Livermore National Laboratory (LLNL), along with Dr. Greg Canavan at Los Alamos—proposed a transformative solution. They drew inspiration from the evolving consumer electronics revolution, where Moore's Law was driving exponential improvements in computing power and miniaturization. The result was Brilliant Pebbles: a fleet of small, autonomous interceptors, each weighing just 50 kg, deployed individually across low Earth orbit (LEO). Unlike the clustered Smart Rocks, BP's distributed architecture scattered thousands of these "singlets" across space, making them resilient to attack. Each SBI consists of a miniaturized Kill Vehicle (KV), (a self-guided projectile) with a small microsat "lifejacket" shell, containing sensors, propulsion, and communication—creating a distributed sat-

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ellite network that was both robust and cost-effective. The BPs, as proposed, were to be able to operate in a fully directed manner, or in fully autonomous fashion, to survive any adversarial attack on command-and-control links. This early AI approach offered greater survivability and enabled the system to gracefully respond in any contested environment. Survivability was considered a key feature, and one that would discourage any attempts at decapitation attacks against the command authority.

Brilliant Pebbles was a concept ahead of its time, halted not by technical failure but by political expediency.

This design was a radical departure from prevailing technology— one that anticipated today's mega-constellations, like SpaceX's Starlink, which plans to eventually have 42,000 satellites in orbit. Since starting in 2019, SpaceX has launched over 8,600 Starlink satellites, totaling over 4,300 metric tons put in orbit. In the 1980s, deploying even a modest 100 metric tons for a 2,000-interceptor BP constellation seemed a Herculean task, constrained by the era's expensive, single-use rockets. Today, reusable launch vehicles like the Falcon 9 and soon-to-be-operational Starship have slashed costs, making such a system not only feasible but economically viable. Starship's V3 is expected to place up to 200 metric tons in LEO for <$0.1B and it has a payload volume of 600-1000-cubic-meters, allowing up to 4000 BPs to be put into orbit on a single launch.

At its core, BP targeted missiles in their boost phase, the initial minutes after launch when they burn brightly and move slowly, with exhaust plumes visible from thousands of kilometers away. This phase offered a strategic advantage: missiles lack decoys or countermeasures at this stage, simplifying targeting. BP's interceptors could engage early, then adapt to ascent, midcourse, or terminal phases as needed, providing layered defense with global reach.

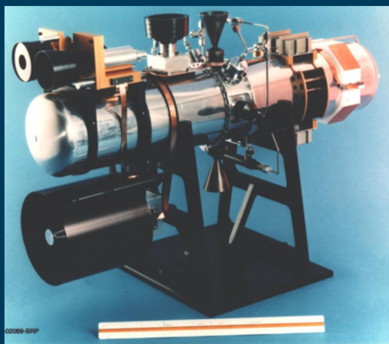
The system's two-stage design featured a Kick Stage for initial propulsion and a KV for precision strikes. The Kick Stage provided an initial 2.5 km/s, and started the interceptor towards the Predicted Intercept Point (PIP) ensuring the KV could reach distant targets swiftly. The KV, a mere 8.5 kg, was equipped with an innovative pump-fed Divert and Attitude Control System (DACS) using hydrazine. The KV was designed to deliver over 2.5 km/s of velocity and 10g acceleration near burnout, enabling agile, hit-to-kill intercepts. Together, they formed a lightweight, high-performance weapon tailored to neutralize even the most advanced threats.

An outer Lifejacket provided all the satellite functions and carried the solar arrays and was envisioned as a lightweight protective overwrap, which encapsulated the small KV and its Kick Stage, offering both thermal management, and debris, EMI and X-ray shielding. It was designed to provide all the orbital functions, like attitude control, power generation, communications, orbital drag makeup, and autonomous station keeping, minimizing the need for continuous ground control of these normal functions.

Each BP also carried its own organic "surveillance" capability for the detection and tracking of boosting missiles. And it hosted a low bandwidth open-loop laser communications system offering a limited ship-to-ship launch warning notification as a backup to the RF communications links. RF links from strategic ground control points would enable the relay of alerts and any tasking, which would be relayed within the constellation by both RF and laser comm.

VALIDATION THROUGH TESTING, CANCELLATION THROUGH POLITICS

Brilliant Pebbles wasn't just a theoretical exercise. The system went through a myriad of component ground tests, and a series of flight tests as well. Early in 1990, the team at Livermore were well into the design and prototyping of hardware for the third generation KV (see Figure), which would have carried the operational design's 6 kg of hydrazine but with a dry mass ~2X higher, just under 5kg. However, before this design could be fully built, the program was transitioned into a supporting role and the Livermore team was asked to help transition the design



1990 Mock-up of the 3rd Gen Brilliant Pebble KV:
Each of its two lightweight piston tanks were only 252 grams empty and held 3 kg of propellant. Each was 12.7 cm in diameter and 30 cm long. They carried the Sensors and Avionics Payloads on either side of the Pump-Fed Cruciform DACS Propulsion System. If completed it would have had >1.8 km/s velocity change and >5g burnout acceleration.

Source: Lawrence Livermore National Laboratory - SBI Technology Overview Briefing 2001, by Dr. Arno G. Ledebuhr

and architecture over to five competing industry teams. Concurrently with the project development and testing, the program had been intensively reviewed by multiple government groups, including the Defense Science Board and the JASONS (a group of senior physicists), which reportedly found "no showstoppers" or any fundamental flaws in the concept. BP secured Pentagon approval for Demonstration and Validation (DemVal), with a validated cost of $10 billion in 1988 dollars (approximately $20 billion today) for development, deployment, and 20 years of operations—a bargain compared to modern missile defense systems.[2]

Yet, despite its promise, BP met an untimely end in 1993. The Clinton administration, taking office amid a post-Cold War thaw, prioritized arms control over ambitious defenses. The ABM Treaty, signed in 1972, restricted space-based missile defenses, and adherence to it became a cornerstone of U.S.-Russia relations. Defense Secretary Les Aspin famously declared it was time to "take the stars out of Star Wars," redirecting focus to ground-based systems and MAD. BP's cancellation wasn't a verdict on its technology—its components had proven their worth—but a casualty of political strategy.

The decision redirected the talented team and shelved innovations decades ahead of their time. However, the ABM Treaty's shackles were lifted in 2002 when President George W. Bush withdrew from it, clearing a legal path for space-based defenses like BP.[3]

In 1994, after the program was terminated, two final technology demonstrations were carried out. First the DACS hardware was repurposed into a miniaturized sounding rocket test called ASTRID, which demonstrated all the key lightweight propulsion components and subsystems in a limited flight experiment at Vandenburg AFB. That same year, the Clementine Lunar Mapping mission was flown, utilizing modified BP sensors and electronics. Over its two-month mission in lunar polar orbit, Clementine captured 1.8 million images across 13 spectral bands, mapping the moon in unprecedented detail. Its success earned it a place in the Smithsonian, a testament to the technology's reliability. These missions confirmed that BP's components were not just speculative but far along the path toward deployment.

A MODERN REVIVAL—BP 2.0

Today's strategic environment bears little resemblance to that of the 1990s. The proliferation of intercontinental ballistic missiles (ICBMs), the advent of hypersonic glide vehicles (HGVs), and the development of fractional orbital bombardment systems (FOBS) have outpaced current defenses. HGVs, traveling at speeds exceeding Mach 5 with unpredictable trajectories, can evade midcourse interceptors like the Ground-based Midcourse Defense (GMD). These threats go well beyond what surface-based missile defense systems can address and demand a return to boost-phase interception. Here, a space-based system, moving at orbital velocity, would offer global coverage and response times unattainable from the ground.

Modern technology has aligned perfectly with BP's vision. SpaceX's Starlink constellation, with its current 7,100+ operational satellites, proves that large, distributed networks are practical and affordable. Planet Labs' fleet of over 150 CubeSats—each 5-6 kg, and only 10cm x 10cm x 34cm in size (less than half the width of a typical shoe box)—are equipped with advanced imagers, attitude control, and high data-rate RF downlink, and manage to downlink 11 terabytes of satellite image data per day, demonstrating the power of miniaturization. These commercial systems provide a wealth of off-the-shelf components that a BP 2.0 could adapt, reducing development costs. Meanwhile, the rapid production of small drones (such as by Ukraine) offers a model for scalable manufacturing.[4]

A modern BP 2.0 program could leverage these trends, maintaining its distributed architecture with updated technologies at both lower cost and mass. Incorporating BP's pump-fed DACS propulsion technologies, along with state-of-the-art avionics and sensor technologies, easily supports a 50kg mass per SBI while carrying ~4km/

sec of velocity change in the KV alone. In production, BP 2.0 cost estimates range between $0.1-1M each, allowing for a significant increase in their number, up to a "mega-constellation" size. Building 20,000 BP 2.0s, which is half the size of Starlink's envisioned end state, and assuming a conservative unit cost of $0.9M along with launch costs for 5 Starships, would be less than $20B. These estimates are approximate, but it appears a BP 2.0 constellation of ten times the size will cost approximately what the original BP constellation would have cost for just 2000 SBIs. The ten-fold increase will reduce their spacing, by ~1/3, which in turn would improve their effectiveness and significantly simplify their design.

Closer spacing reduces the needed fly-out speed, effectively eliminating the need for a kick stage. Modern propulsion technologies for the Lifejacket offer drag make-up at much lower altitudes, <300 km orbits, leading to shorter fly-out times and a higher percentage of boost phase kills. Advanced design concepts leverage the KV's propulsive capabilities, enabling deeper endo-atmospheric intercepts against HGVs. The future is rich with possibilities for a BP 2.0 as we update the missile defense architecture and optimize SBI design under the Golden Dome initiative. In other words, the case for going "back to the future" is stronger than ever.

China and Russia are expanding their missile arsenals, deploying hypersonic weapons and countermeasures that outmatch current U.S. defenses. A space-based BP 2.0 could intercept these threats from any launch point to any target, fulfilling Reagan's vision at a fraction of the cost of ground-based alternatives. The affordability of space access has flipped the cost calculus: Starlink's 4,300 metric tons in orbit dwarf the 100 metric tons once envisioned for BP, showing that defense can now outpace offense.

Yet challenges remain. China's dominance in worldwide drone production and its three planned commercial mega-constellations (which will cumulatively field about 40,000 satellites) pose a supply chain and near-peer risk. The need for the U.S. to begin onshoring the capability for producing large volumes of components and subsystems needed for satellites and SBI manufacturing is therefore essential. Investment in this infrastructure could position the U.S. as a leader in space-based defense, countering adversary advances.[5]

A VISION REBORN

Brilliant Pebbles was a concept ahead of its time, halted not by technical failure but by political expediency. Its validation through laboratory testing and the Clementine and ASTRID demonstrations showcased its potential, while its cancellation in 1993 left a void in missile defense innovation. Today, with miniaturized technology, reusable rockets, and escalating threats, BP's blueprint offers a path to strategic superiority. By reviving and modernizing this system, the U.S. can finally make nuclear missiles "impotent and obsolete," securing a future where defense triumphs over destruction. It's time for policymakers to dust off BP's blueprint and build the Golden Dome that America needs.

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Integrating Air and Missile Defense in Regional Conflicts

Harold "Punch" Moulton

As adversaries make advances in both missile technology and tactics, air and missile defense has emerged as a critical aspect of modern regional warfare. Recent conflicts in Ukraine and Israel highlight the growing complexity of missile threats and offer valuable lessons for designing effective defenses against evolving technological innovations and operational challenges.

In regional conflicts, our forces are facing an increasingly complex array of threats. Adversaries are ready to employ an assortment of missile technologies, including ballistic missiles, cruise missiles (which include Unmanned Aerial Vehicles (UAVs) on one-way attack missions), hypersonic cruise and glide missiles, and innovative systems like Fractional Orbital Bombardment Systems (FOBS). The threats are evolving and multiplying faster than ever, demanding advanced defensive capabilities to counter their sophistication and volume.

So, what's driving the critical need for action in the Missile Defense domain? There are several factors:

- Ballistic missiles with maneuvering capabilities and multiple warheads (MIRVs and submunitions) capable of greater evasion and lethality.
- The proliferation of inexpensive attack UAVs (cruise missiles by another name) allowing new actors to pose credible missile threats.
- Complex attacks—combining ballistic and cruise missiles from multiple directions— with the potential to strain and overpower existing defenses, and;
- Attack volumes much larger than the past, overwhelming defense capacity.

CASE STUDY #1: UKRAINE

The war in Ukraine highlights the operational and strategic importance of Integrating Air and Missile Defense (IAMD). Since Russia's full-scale invasion in 2022, neither it nor Ukraine have managed to achieve decisive air superiority. Thus, air and ballistic attacks have become the preferred method for both sides to strike at long range.

Over the last three years, Ukraine has faced a significant conventional regional missile threat stemming from Russia's extensive and modernized arsenal. The *Iskander* systems, air-launched and maritime-launched cruise missiles, and advanced weapons like the *Oreshnik* missile (with dozens of independent warheads) demonstrate a capability to strike at Ukraine from multiple domains—land, sea, and air. Russia has further augmented its large missile arsenal with Iranian cruise missiles (one-way attack drones) and North Korean ballistic missiles. That complex and robust threat has delivered relentless missile attacks targeting Ukrainian cities, energy infrastructure, and military installations broadly across the nation.

Ukraine's efforts to counter Russian missile threats have become a crucial aspect of its overall defense strategy. Ukraine has relied on a mix of indigenous systems and international support to counter Russia's extensive arsenal of ballistic and cruise missiles. High-end Western systems like Patriot, NASAMS, and SAMP/T significantly enhanced Ukraine's interception capabilities.

Key successes include *Integration*, as Ukraine has effectively linked diverse systems into a cohesive network, leveraging advanced Western radars alongside older

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Soviet-era systems; *Innovation*, including creative tactics like combining acoustic sensors with Artificial Intelligence to improve tracking accuracy for low-altitude threats, and *mobility*, such as decentralized defense units that have increased survivability.

On the other hand, Ukraine continues to face limitations in its ability to defend the entire nation. The first limitation is scarcity, with Kyiv lacking a broad array of advanced IAMD systems—something that means coverage is far from comprehensive across its vast territory. Another is saturation attacks, as Russian simultaneous missile launches and swarms overwhelm defense systems and operators. A third challenge is Russia's advanced threat weapons, since Ukraine does not have the technological ability to defend against Russia's *Oreshnik* (an Intermediate Range Ballistic Missile with multiple warheads/submunitions). Finally, there is the economic burden of operating and maintaining sophisticated missile defense systems, along with the high costs of interceptors strain national resources.

Ukraine's resilience stems in part from NATO support (intelligence sharing, training, and advanced equipment) and dynamic integration of resources. Uniquely, Ukrainian innovation in tactics and "re-tooling" western systems to fit their fight has created a surprisingly durable air and missile defense architecture; however, Russian attacks continue to take a toll on Ukrainian infrastructure and population. Russia's weapons production capacity has increased significantly, while Ukraine remains inadequately armed to match the volume of threat attacks.

Ukraine's experience offers a blueprint for enhancing the effectiveness of missile defense in future regional conflicts: invest in integration, resilience, sustainability, and innovation.

Global missile threats are not standing still, so continuous innovation and adaptation will be key to maintaining a credible and effective missile defense posture.

CASE STUDY #2: ISRAEL

In 2024, Israel faced escalating threats from rockets, cruise missiles, and ballistic missiles. Most notably, two large scale attacks from Iran (in April and again October) marked a major escalation in their long-standing conflict. These attacks represented the largest missile attacks ever attempted in a regional conflict. Israel's defense systems, augmented by partner forces, demonstrated remarkable adaptability and effectiveness in countering these threats.

The first attack occurred in April, when Iran fired 120 ballistic missiles and 200 cruise missiles (including attack UAVs) targeting Israeli military sites. Despite the scale of the assault, Israel and coalition air forces intercepted 99% of the incoming projectiles with a layered defense architecture, resulting in minimal damage and injuries. The second attack took place in October, when Iran launched approximately 180 ballistic missiles at Israeli airbases and the headquarters of the Mossad intelligence service. While this strike was more effective at saturating Israel's defenses, it caused limited damage and few casualties due to successful interceptions by Israeli and allied forces.

Both attacks highlighted Iran's growing missile capabilities, but also the capabilities of robust Israeli and partner defenses. In turn, Israel's remarkable effectiveness countering Iran's missile attacks can be attributed to four key factors.

The first was *warning*. Iran's explicit threats, combined with intelligence from multiple sources, facilitated Israel's defense architecture preparations, as well as those of partner nations arriving/organizing in support of Israel.

The second was *coalition support*. The United States provided fighter aircraft, *Aegis* destroyers, THAAD systems, and intelligence sharing. The UK deployed fighter jets, France "mobilized military resources", Jordan operated defenses over its airspace, and Gulf states contributed radar tracking data.

The third was *layered defenses*. The defense of Israel employed a multi-layered architecture combining forward fighter aircraft to intercept cruise missiles, the Arrow 3 and *Aegis* for mid- course ballistic missile intercepts, and *David's Sling/Arrow 2/THAAD* for terminal defenses.

Fourth, Israel boasted a strong *final layer*. Israel's robust IAMD training, military readiness, and national preparedness ensured that its final intercept opportunities were highly successful.

Nevertheless, the 2024 attacks highlighted several challenges for Israeli defenses. Saturation attacks exposed vulnerabilities, as high volumes of precision-targeted missiles showed the potential of overwhelming even advanced defenses. Low-flying cruise missiles remain difficult to detect without forward radar tracking from partners. And finally, resupply challenges for interceptors highlight the need for sustained inventory management.

The Iran-Israel conflict underscores the offense-defense adaptability imbalance favoring attackers who can modify tactics faster than defenders can respond. Iran's October attack reflected their lessons from the April attack while Israel's defenses had no significant ability to adapt to any potential new strategy. The lesson: IAMD must be ready to counter a broad spectrum of offensive attack strategies…which demands a significant investment well ahead of the next conflict.

Israel's successes highlight the importance of early warning systems, coalition support, layered defenses, and readiness for diverse attack strategies…all lessons for the next IAMD fight.

CHALLENGES, AND THE NEED FOR ADAPTATION

The Ukraine and Israel conflicts reveal critical gaps in current missile defense capabilities. Namely, that:

- We lack the capacity to defend against large volume attacks of ballistic missiles
- We lack the capacity to defend against large volume attacks of cruise missiles
- We lack the capability to defend against next generation maneuvering threats, and;
- Hypersonic missiles and FOBS are on the horizon—and we have no real credible defense against either.

Notably, Russia and Iran are not the only adversaries that have "gone to school" on the Ukraine and Israel conflicts. We can certainly expect China to expand its robust and sophisticated missile arsenal, as well as adjust operational plans to avoid the strengths and exploit recognized weaknesses in U.S./coalition IAMD. North Korea, too, having witnessed the wars in Ukraine and Israel, is already advancing its cruise and ballistic missile capabilities, focusing on survivability, precision, and strategic deterrence.

For America and its allies, meanwhile, the recent conflicts offer valuable insights into improving future missile defense strategies across multiple domains.

Shooters (Effectors)

For the regional fight, a comprehensive missile defense architecture requires: Broad new Area Defenses capable of protecting large regions (i.e., 30 NATO nations in Europe); Advanced layered defenses enabling a "Shoot-Assess-Shoot" operational strategy; New defense capabilities against MIRVs/submunitions from single ballistic missiles; Increased inventories to counter cruise missile swarms and large waves of ballistic missiles; Long-range dynamic interceptors to engage hypersonic threats in the glide/cruise phase; Mobile systems to improve adaptability, and; Expanded technological development, with priority placed on low-cost interceptors for massed attacks, directed energy weapons (lasers and microwaves for rapid-response defenses), and FOBS defenses.

Sensors

Effective IAMD requires advanced sensor systems capable of detecting, tracking, identifying, and discriminating missile threats. Key capabilities needed for the regional fight include:

- Cruise Missile Defense. Successful IAMD requires detecting launches and sustaining track custody of cruise missiles at long ranges. In the short term, using Over-the-Horizon Radars (OTHR) can accomplish this mission, but true persistent global coverage will ultimately demand space-based sensor capability.
- Ballistic/Hypersonic Missile Defense. Engaging ballistic/hypersonic threats necessitates tracking these maneuvering threats with persistent global coverage via space-based sensors and delivering "fire control quality" tracks to the warfighter.

- Discrimination. To enhance intercept success, defenses need the ability to discriminate real warheads from decoys, fuel tanks, balloons and chaff during complex attacks.

Command & Control (C2)

The robust sensor and shooter architecture outlined above requires a transformation of the current C2 architecture. The regional IAMD architecture of the future should be designed to achieve "Right Sensor enabling Best Shooter" operations. Key attributes for C2 include a Common Operational Picture (COP), so the broad network of remote sensors, dispersed shooters, higher headquarters, and adjacent commands are all sharing the same awareness before and during a fight; an automated battle management system to enhance reaction times, optimize architecture performance, and enable efficient command decision-making when facing high-volume attacks; a dedicated cadre of IAMD professionals with an established career path, to ensure commanders have the right support expertise to manage complex IAMD plans and operations, and; regular challenging exercises and planning/preparedness efforts to refine operational procedures and improve coordination among allied forces.

Missile Defeat

Beyond diplomatic means to deter launches, proactive military measures can prevent missile threats from launching. Offensive operations can target deployed missile systems, garrisons, or supply lines and reduce incoming attacks. In most cases, these "attack operations" will not be initiated until after the conflict begins. Thus, the IAMD architecture must be prepared to absorb initial missile attack waves before friendly offensive operations can eliminate/suppress future attacks. Further, clandestine activities such as cyber operations, special forces missions, and supply chain interdiction can disrupt adversary capabilities preemptively. Both offensive operations and pre-conflict clandestine activities must be enabled by a robust, dedicated intelligence network focused on missile threats globally.

Passive Defenses

IAMD systems are not perfect, and some threat missiles will impact their targets. To mitigate the consequences when intercepts fail, key passive defense measures include hardening critical infrastructure, like command centers, to ensure operational continuity, and deploying effective civilian warning systems modeled after Israel's network to save lives during attacks.

Golden Dome

The United States is currently focused on defending its homeland with the new Golden Dome construct. Initial indications imply space-based sensors and space-based interceptors will be part of the solution. Missile defenses for regional conflicts will likely be able to leverage multiple capabilities/aspects emerging in Golden Dome to include sensors, effectors, and C2.

LESSONS LEARNED

The lessons learned to date from Ukraine and Israel highlight the evolving nature of missile threats and underscore the need for a multi-faceted approach to missile defense. By integrating advanced sensors, layered shooters, efficient next-generation command and control systems, proactive missile defeat capabilities, focused intelligence, and robust passive defenses, the United States and partner nations can enhance resilience against potential attacks from evolving missile threats.

Preparedness derives from a clear-eyed recognition of the threat and the commitment to properly resource measures that defeat and mitigate that threat. Global missile threats are not standing still, so continuous innovation and adaptation will be key to maintaining a credible and effective missile defense posture for future conflicts.

Prioritizing Air and Missile Defense Spending in the Broader Budget Debate

Wes Rumbaugh

President Donald Trump's January "Iron Dome for America" executive order and subsequent planning for the Golden Dome architecture marks a significant expansion of American missile defense policy.[1] Gen. Michael Gutlein, Vice Chief of Space Operations for the U.S. Space Force, compared the scale of Golden Dome to the Manhattan Project, requiring a whole-of-government effort.[2] This is not, however, the first time a Trump administration has set lofty goals for its missile defense policy. Yet previous attempts to invigorate U.S. missile defense fell short in part due to the lack of funding to support them.[3]

Fundamentally, budgets are about prioritization. Because resources are finite, spending must be prioritized and, where priorities conflict, trade-offs are required. Understanding these tradeoffs when planning the Golden Dome architecture will help the Administration better scope its efforts.

Three levels of decision-making or prioritization stand out as having influence over the budget for Golden Dome: within the missile defense portfolio, in the overall Department of Defense capability mix, and across the broader Federal budget. The most expansive concepts for the Golden Dome architecture will require making aligned prioritization decisions across all three levels.

Analyzing the Golden Dome resourcing challenge begins with understanding the size and makeup of the current air and missile defense portfolio. Since 2009, DoD spending on air and missile defense modernization has averaged a little over $20 billion per year (Figure 1). Because air and missile defense programs do not have their own spending title, this figure requires a manual aggregation of program lines into an estimate of overall modernization spending.[4] Since 2018, average spending has been over $25 billion, with most of that growth coming from increased Army and Space Force funding.

The first level of prioritization is within the Golden Dome architecture and the broader missile defense portfolio. Based on both the executive order and reported guidance from Secretary of Defense Pete Hegseth, the Administration is likely to prioritize increasing funding for homeland missile defense. On average, about 12 percent of air and missile defense funding has gone to homeland defense since 2009 (Figure 2). Mixed-use air and missile defense systems, such as space-based missile tracking sensors, make up 32 percent of spending, and theater missile defense systems make up the remaining 56 percent. This spending profile makes sense considering the scope of prior missile defense policy; whereas DoD invested in theater defenses against the full spectrum of air and missile threats, its homeland defense investments were limited to ballistic missile defense against adversaries with limited capabilities, like North Korea.

Decisions about priorities within the various mission sets of the Golden Dome architecture will determine the magnitude of the shift toward spending on homeland defense. Two choices stand out as likely cost drivers: the scale of the space-based interceptor (SBI) layer and that of the homeland cruise missile defense architecture. In each case, maximalist goals would increase the cost of the Golden Dome effort considerably, which would increase the trade-offs required.

With regard to SBIs, although certain assumptions of prior cost estimates have changed, other fundamental challenges remain. Technological developments like reusable space launch vehicles and miniaturization of

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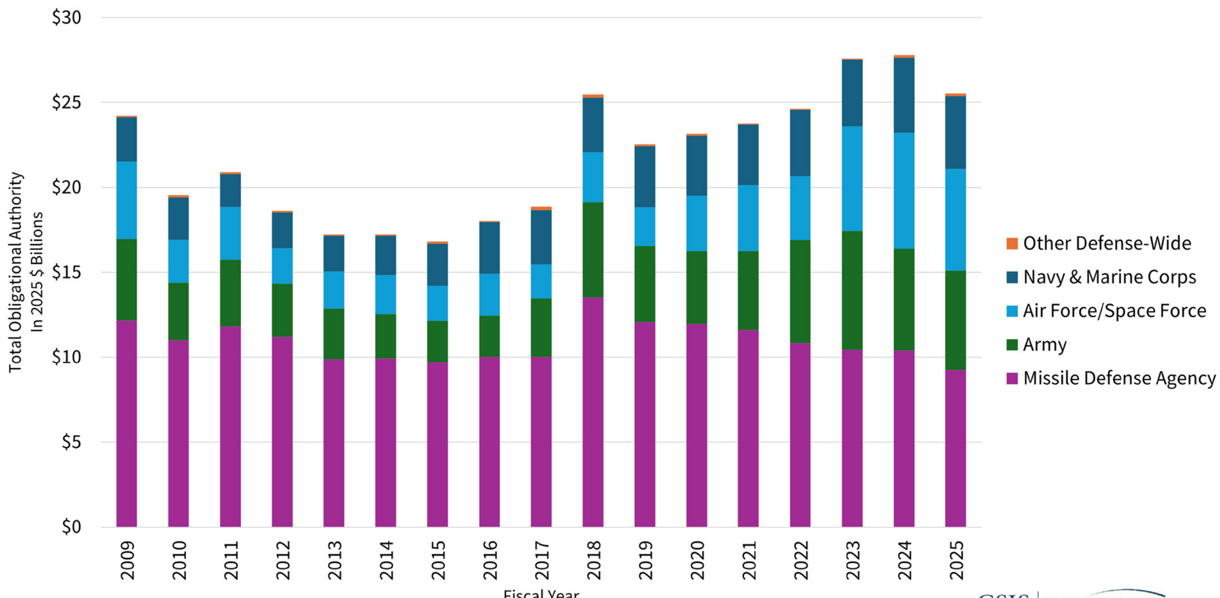
Figure 1: DoD Air and Missile Defense Modernization by Department, 2009–2025



Source: DOD Comptroller and CSIS analysis.

key interceptor components like sensors, avionics, and turbopumps have combined to reduce the cost of space launch and the weight of each interceptor payload.[5] These trends promise considerable savings as compared to prior cost estimates of an SBI constellation. Nevertheless, due to the physics of low Earth orbit, providing coverage against larger salvos of missiles requires procuring significant numbers of interceptors that might need to be refreshed every five years or so.[6] As a result, a maximalist SBI architecture could balloon in cost, requiring even greater resource allocation.

The homeland cruise missile defense component of Golden Dome faces a similar problem. Compared to SBIs, cruise missile defense involves a relatively mature set of technologies, but maximalist goals would again cause significant cost growth. Two studies examining the costs of the homeland cruise missile defense mission illustrate this problem. In 2021, the Congressional Budget Office assessed that a maximal homeland cruise missile defense architecture with coverage of the entire continental United States could cost between $77 and $466 billion (in 2021 dollars) over a 20-year period.[7] By contrast, the Center for Strategic and International Studies analyzed a more focused cruise missile defense architecture that provided preferential defense to certain key areas, with a resulting cost estimate of around $32 billion (in 2023 dollars).[8] Marginal differences in the capabilities examined for each architecture explain some of this variance, but the scale of defended area envisioned was by far the biggest driver of cost savings.

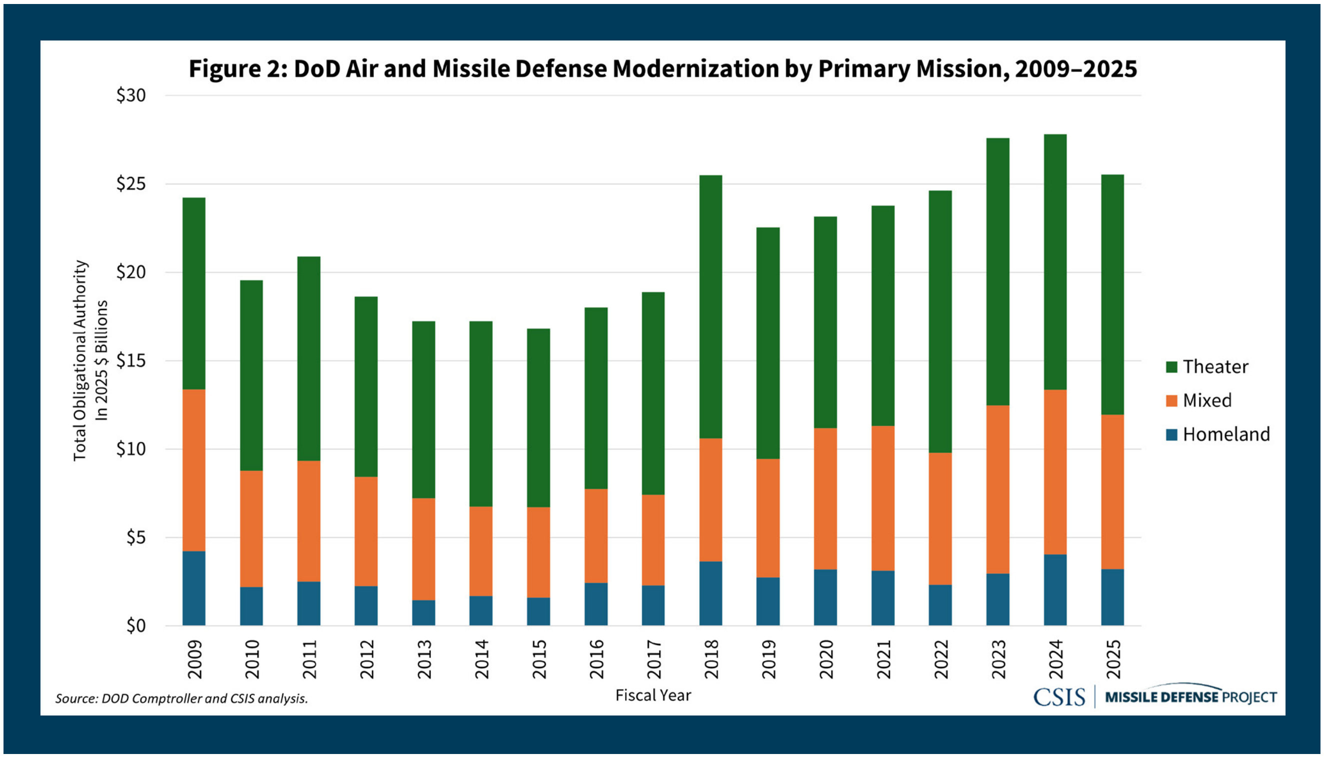
Some might be tempted to find funding for more expansive homeland missile defense projects by reallocating resources from theater defense programs. For example, certain theater defense systems could be repurposed as part of the homeland cruise missile defense architecture or a ballistic missile defense underlay. However, the persistent demand for these assets will constrain the ability to reallocate resources within the missile defense portfolio without incurring strategic risk. The Administration's challenges in redirecting scarce theater missile defense assets from the Indo-Pacific to the Middle East underscores this trade-off.[9] Reallocating theater defense systems to the homeland or reducing investments in their capacity could meaningfully reduce the flexibility of the U.S. to deploy forces in increasingly contested and missile-rich environments. These homeland deployments also could have operational tempo implications for already stretched air and missile defense force structure. To incorporate mature systems like Aegis, THAAD, and their associated elements into homeland defense, DoD should consider a more distributed and disaggregated approach, which could be less manning intensive.[10]

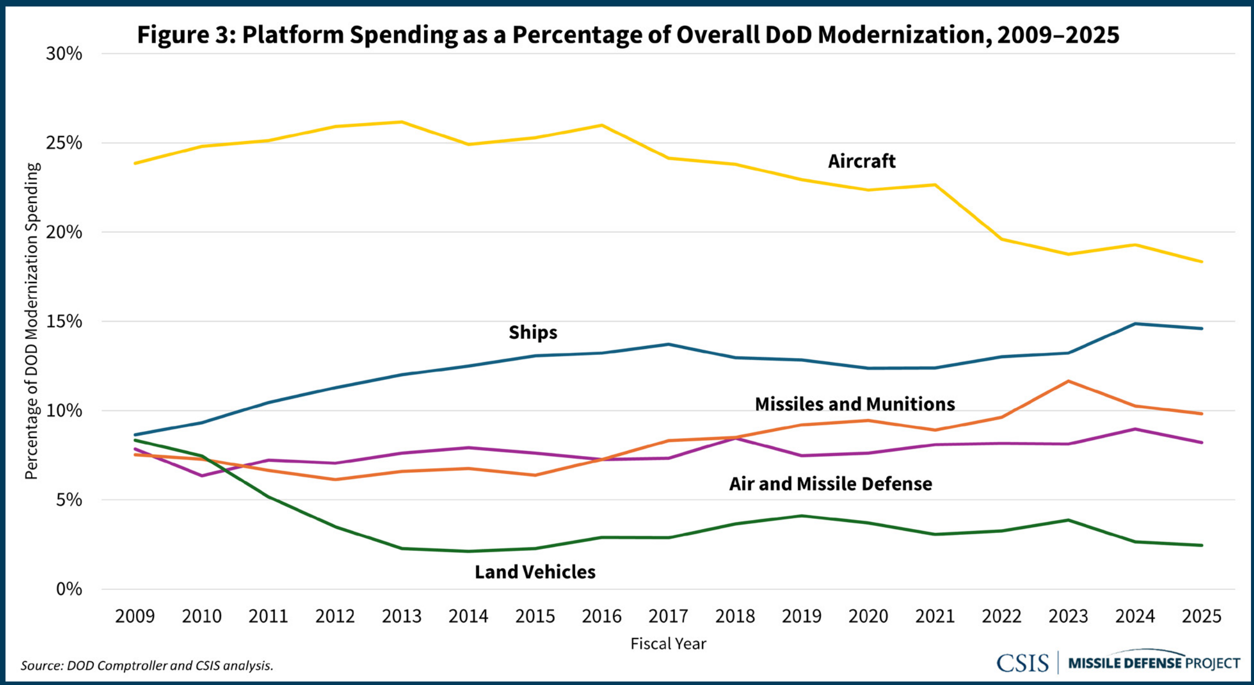
> **Trying to fund Golden Dome through internal reallocations alone would either yield too few resources for the supposedly transformational effort to succeed, or create unacceptable risk to other DoD priorities.**

Golden Dome could also be prioritized within the DoD budget by making trade-offs between the missile defense portfolio and other capabilities. Figure 3 shows that, relative to other capabilities, air and missile defense funding has been prioritized at consistent levels since 2009, accounting for between 7 and 9 percent of modernization spending. If the Pentagon declines to make trade-off within the missile defense portfolio itself, funding for Golden Dome programs might require cuts to other operations or capabilities. Secretary of Defense Pete Hegseth's February memo seeking realignment of $50 billion suggests the Pentagon is already exploring this option.[11]

The largest challenge to resourcing Golden Dome through internal DoD budget reallocation is finding meaningful funding that can be cut easily. Budget exercises conducted by the American Enterprise Institute using the Hegseth memo constraints have required significant cuts to the Army and additional cuts to Air Force programs.[12] Attempts to trim spending on older systems are likely to face congressional opposition, and previous administrations have already picked much of the low-hanging fruit.[13] This suggests that trying to fund Golden Dome through internal reallocations alone would either yield too few resources for the supposedly transformational effort to succeed, or create unacceptable risk to other DoD priorities.

The final lever the White House can pull for Golden Dome is in the U.S. government's overall fiscal policy.



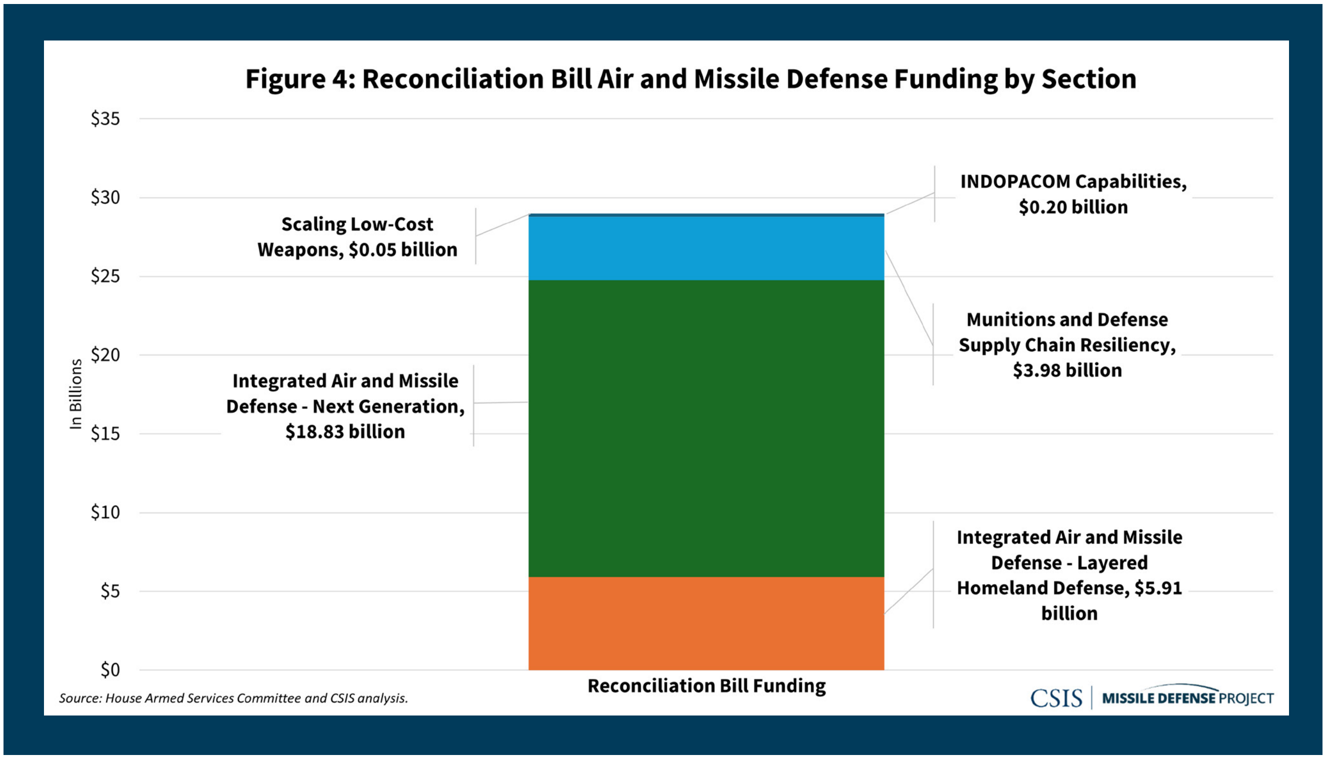


Historically, the total size of the defense budget has had the largest effect on missile defense resourcing, as evidenced by its relative consistency as a percentage of modernization spending (Figure 3) compared to the variation in real dollar terms (Figure 1). The Trump administration has been somewhat inconsistent in its approach to the defense top line, alternately suggesting deep cuts to defense spending and, more recently, submitting a nominally $1 trillion budget request.[14]

At such a level, defense spending must be considered in comparison to other national priorities like economic policy and domestic spending programs. A historical study of the economic burden of defense spending suggests room for top line growth compared to recent years.[15] Congress' budget resolution, which includes an additional $150 billion for defense, is an important marker of intent. Across its various sections, the House Armed Services Committee mark-up of the reconciliation bill includes nearly $30 billion of air and missile defense funding, nearly 20 percent of the defense reconciliation funds (Figure 4). The bill shows Congress' clear support for prioritizing space-based missile defenses. Its two largest line items are $7.2 billion for space-based sensors and $5.6 billion for space-based and boost phase intercept.

The larger challenges here will be the mechanics of the appropriations process and broader economic factors. While the reconciliation bill seems to have momentum, many hurdles to a final bill remain.[16] Even with broad agreement about the defense spending portion of the bill, disagreements about tax cuts and other spending cuts could threaten the whole package. The White House "skinny budget," which counted $113 billion of the reconciliation bill's funding towards its fiscal year 2026 DoD

> **Budgets are about prioritization. Because resources are finite, spending must be prioritized and, where priorities conflict, trade-offs are required.**



budget request, calls into question the magnitude of the actual defense spending increase.[17] Broader economic policies (like tariffs) could also affect Golden Dome implementation, as price increases in key materials could eat into DoD buying power.[18]

Reorienting American missile defense policy on the scale envisioned by Golden Dome will require significant decisions at multiple levels of government. Each of these decisions build upon one another. The more expansive the Golden Dome architecture becomes, the greater its need for budget share within the missile defense portfolio. If sufficient funding cannot be found within missile defense programs, it would require trade-offs with other defense capability areas. If resources cannot be found there, then it will necessitate greater overall defense funding, which could constrain broader fiscal and economic policy. Navigating these budget prioritization decisions will determine whether the Trump administration will have greater success in its second attempt to build a next-generation missile defense than it did the first time.

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