Missile Defense

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Missile defense is a critical component of the U.S. national security architecture that enables U.S. military efforts and can protect national critical infrastructure, from population and industrial centers to politically and historically important sites. It can strengthen U.S. diplomatic and deterrence efforts and provide both time and options to senior decision-makers amid crises involving, for example, cruise missiles and hypersonic weapons that fly on ballistic and non-ballistic trajectories.

The Growing Missile Threat

Missiles remain a weapon of choice for many U.S. adversaries who view them as cost-effective and symbols of power compared to other types of conventional weapons.[1] The number of states that possess missiles will continue to increase, as will the sophistication of these weapons as modern technologies become cheaper and more widely available.

Despite U.S. diplomatic efforts, North Korea continues its aggressive pursuit of a nuclear intercontinental ballistic missile (ICBM) program—including a new "monster" ICBM supposedly able to carry multiple warheads and decoys—that will allow it to strike the United States. It also recently tested ground-based and sea-based ballistic missiles and appears to direct its missile advancements toward overcoming U.S. missile defenses.[2]

Iran continues to modernize and proliferate its regional missile systems. Its recent successful solid-fuel rocket launch demonstrates that Iran has the ability to build and successfully launch sophisticated missiles, which implies that it has or is developing the ability to advance to the ICBM level of capability.[3]

China and Russia, in addition to their vast ballistic missile inventories, are investing in new ground-launched, air-launched, and sea-launched cruise missiles that uniquely challenge the United States in different domains and are deploying new hypersonic glide vehicles.[4] China is rapidly building up its missile inventory, to include hundreds of new silo-based ICBMs and road-mobile ICBMs that reportedly can carry 10 warheads, as well as theater-range missiles that can strike U.S. assets with precision.[5] Russia is developing entirely new capabilities, such as a nuclear-powered cruise missile, that are intended to avoid U.S. sensors and missile defenses, and its conventionally armed sea-launched and air-launched cruise missiles can strike strategic nodes within the U.S. homeland, even from Russian territory.[6]

The Strategic Role of Missile Defense

Because they are designed to detect and defeat incoming missile attacks, missile defense systems can save lives and protect civilian infrastructure from damage or destruction. More important, missile defense plays a critical role in strategic deterrence.

The ability to deter an enemy from attacking depends on convincing him that his attack will fail, that the cost of carrying out a successful attack is prohibitively high, or that the consequences of an attack will outweigh the perceived benefit of attacking. A U.S. missile defense system strengthens deterrence by offering a degree of protection to the American people and the economic base on which their well-being depends, as well as forward-deployed troops and allies, making it harder for an adversary to threaten them with missiles. By raising the threshold for missile attack, missile defense limits the option for a "cheap shot" against the United States.

A missile defense system also gives a decision-maker a significant political advantage. By protecting key U.S. assets, it mitigates an adversary's ability to intimidate the United States into conceding important security, diplomatic, or economic interests.

Missile defense systems enable U.S. and allied conventional operations. Adversaries want to deny the United States the ability to conduct offensive operations during a regional conflict, which they can do by targeting U.S. and allied forward-deployed personnel or military assets. In addition, they might try to decouple the United States from defense of its allies by threatening to strike U.S. forces and assets if the United States intervenes in a regional conflict. Missile defenses in place, by making it easier for the U.S. military to introduce reinforcements that can move more freely through a region, can strengthen the credibility of U.S. extended deterrence.

Finally, a missile defense system gives decision-makers more time to choose the most de-escalatory course of action. Without the ability to defend against an attack, U.S. authorities would be limited to an unappealing set of responses ranging from preemptively attacking an adversary to attacking his missiles on launch pads or even acceding to an enemy's demands or actions. By assuring some level of protection from a missile attack, robust missile defense systems would affect the dynamics of decision-making by removing the need to take immediate action.

In other words, missile defense creates additional options and provides more time to sort through them and their implications to arrive at the one that best serves U.S. security interests. This can make them profoundly stabilizing.

The U.S. Missile Defense System

The U.S. missile defense system has three critical physical components:

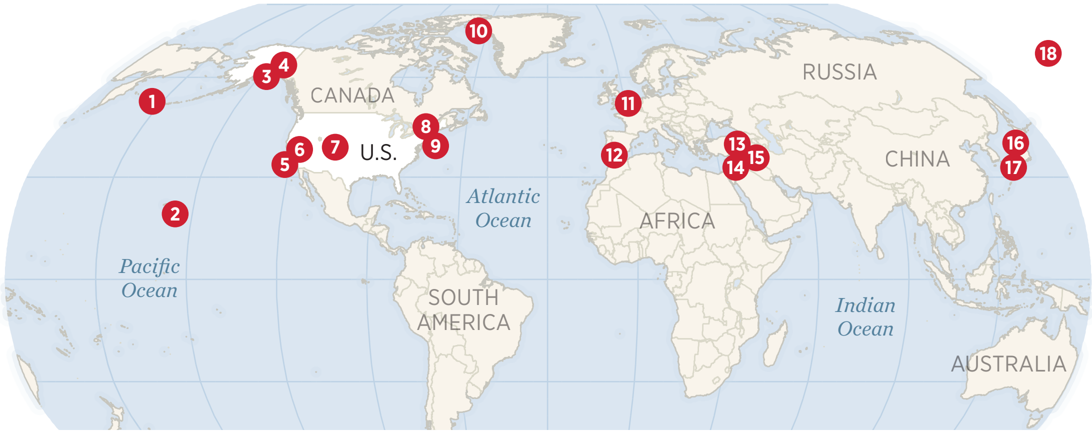
- Sensors,
- Interceptors, and
- Command and control infrastructure that provides data from sensors to interceptors.

Of these, interceptors receive much of the public's attention because of their visible and kinetic nature. Components of missile defense systems can be classified based on the phase of flight during which intercept occurs, although some—for example, the command and control infrastructure or radars—can support intercepts in various phases of flight. Interceptors can shoot down an adversarial ballistic missile in the boost, ascent, midcourse, or terminal phase of its flight. As cruise missiles and hypersonic glide vehicles continue to proliferate, the Missile Defense Agency (MDA) and the services must therefore consider intercept in the boost, glide, or terminal phase of flight.

Another way to classify missile defense systems is by the range of an incoming missile (short-range, medium-range, intermediate-range, or intercontinental-range) that an interceptor is designed to shoot down. An interceptor's flight time determines both the time available to conduct an intercept and the optimal interceptor placement to improve intercept probability. With ICBMs, the United States has "30 minutes or less"[7] to detect the missile, track it, provide the information to the missile defense system, find the optimal firing solution, launch an interceptor, and shoot down the incoming missile, ideally with enough time to fire another interceptor if the first attempt fails. The time frame for intercepting short-range, medium-range, and intermediate-range ballistic missiles is shorter.

MAP 19

U.S. Missile Defense Assets



GBI—Ground-based interceptors
GFC—Fire control center
GMD—Ground-based midcourse defense

IDT—In-Flight Interceptor Communications System (IFICS) Data Terminal

TPY-2—Transportable Radar Surveillance and Control Model 2
UEWR—Upgraded early warning radar

1. **Shemya, AK**
   - Cobra Dane radar
   - IDT
2. **Pearl Harbor, HI (base)**
   - Sea-based X-Band radar
3. **Clear, AK**
   - UEWR
4. **Ft. Greely, AK**
   - 40 GBIs
   - GMD
   - GFC
   - IDT
5. **Vandenberg AFB, CA**
   - 4 GBIs
   - 2 IDTs
6. **Beale AFB, CA**
   - UEWR
7. **Schriever AFB, CO**
   - GFC
8. **Ft. Drum, NY**
   - IDT
9. **Cape Cod, MA**
   - UEWR
10. **Thule, Greenland**
    - UEWR
11. **Fylingdales, UK**
    - UEWR
12. **Rota, Spain (base)**
    - Sea-based Aegis BMD SPY-1 radar
13. **Kurecik AFB, Turkey**
    - TPY-2 radar
14. **Israel**
    - TPY-2 radar
15. **CENTCOM-Middle East**
    - TPY-2 radar
16. **Shariki, Japan**
    - TPY-2 radar
17. **Kyogamisaki, Japan**
    - TPY-2 radar
18. **Outer space**
    - Defense support program satellites
    - Space-based infrared system satellites
    - Space tracking and surveillance system-demonstrator

NOTE: Locations are approximate.

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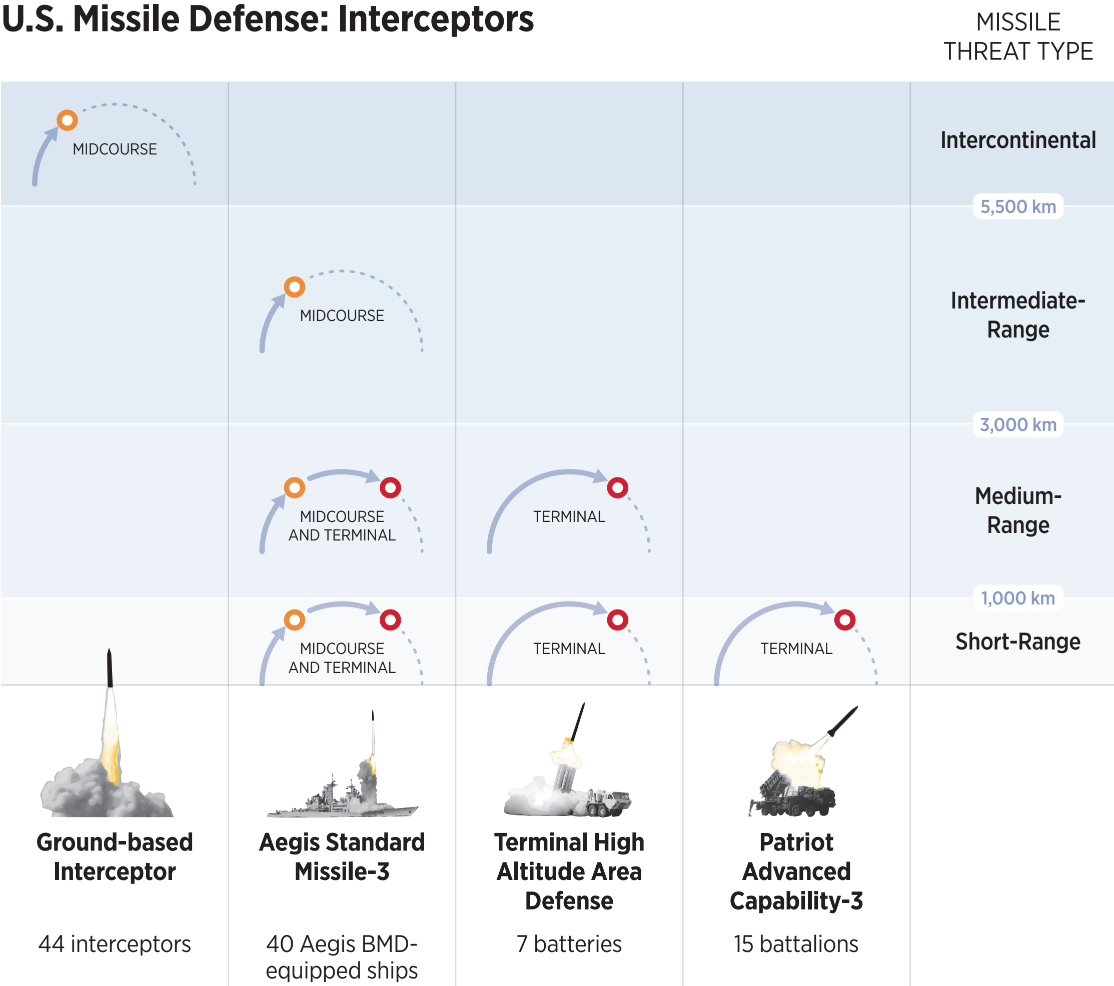
FIGURE 6

U.S. Missile Defense: Interceptors



SOURCE: Lieutenant General Daniel L. Karbler, USA, Commanding General, U.S. Army Space and Missile Defense Command, and Commander, Joint Functional Component Command for Integrated Missile Defense, statement on "Fiscal Year 2022 Authorization Request for Missile Defense" before the Subcommittee on Strategic Forces, Committee on Armed Services, U.S. Senate, June 9, 2021, pp. 18 and 19, https://www.armed-services.senate.gov/imo/media/doc/Karbler%20Written%20Statement%20to%20SASC%206-091.pdf (accessed August 17, 2021).

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Finally, missile defense can be framed by the origin of interceptor launch. At present, U.S. interceptors are launched from the ground or from the sea. In the past, the United States explored possible ways to launch interceptors from the air or from space, but efforts on that front have been limited since the U.S. withdrawal from the Anti-Ballistic Missile Treaty in 2002.[8]

The current U.S. missile defense system is a result of investments made by successive U.S. Administrations. President Ronald Reagan envisioned the program—the Strategic Defense Initiative (SDI)—as a layered ballistic missile defense (BMD) system, including BMD interceptors in space, that would render nuclear weapons "impotent and obsolete."[9] These layers would have boost, ascent, midcourse, and terminal interceptors, including directed-energy interceptors, providing the United States with more than one opportunity to shoot down an incoming missile.

The United States stopped far short of this goal, even though the SDI program generated tremendous technological advances and benefits.[10] Instead of a comprehensive layered system, the U.S. has no boost-phase ballistic missile defense systems and no defense against the advanced ballistic missile threats from China or Russia. The volatility and inconsistency of priority and funding for missile defense by successive Administrations and Congresses—Administrations and Congresses controlled by *both* major political parties—have yielded a system that is numerically and technologically limited and incapable of defending against more sophisticated or more numerous long-range missile attacks.

Beginning with the National Missile Defense Act of 1999, it was U.S. policy to protect the homeland only from a "limited ballistic missile attack."[11] The National Defense Authorization Act (NDAA) for Fiscal Year 2017 dropped the word "limited" even as it continued to focus on ballistic missiles.[12] Then the 2020 NDAA made it a matter of policy to rely on nuclear deterrence to defend against "near-peer intercontinental threats" and focus on improving missile defense against "rogue states."[13] In the future, as technological trends progress and modern technologies become cheaper and more widely available, North Korean or Iranian ballistic missiles may rival, in sophistication if not in numbers, those of Russia or China. Consequently, the U.S. must remain aware of how such threats are evolving and alter its missile defense posture accordingly.

In January 2019, the Trump Administration published its congressionally mandated Missile Defense Review (MDR), a statement of policy intended to guide the Administration's missile defense programs. The 2019 MDR addresses the dangerous threat environment that has evolved since the previous MDR in 2010 and advocates a comprehensive approach to all missile threats—no longer only ballistic—that integrates offensive capabilities, active defenses, and passive defenses. It acknowledges that the United States is no longer vulnerable only to ballistic missiles and recognizes that future missile defense systems must defend against cruise and hypersonic missiles as well.[14]

For fiscal year (FY) 2022, the Biden Administration requested $8.9 billion for the MDA,[15] a decrease from the FY 2021 budget request's projection of $9.1 billion[16] and a decrease of $1.6 billion from the FY 2021 enacted budget of $10.5 billion.[17]

Interceptors

Interceptors are one major component of the U.S. missile defense system. Different types of interceptors that respond to different missile threats have been emphasized over the years, and the composition of today's U.S. missile defense reflects these choices.

While the United States is working to improve its ability to strike down cruise missiles and hypersonic glide vehicles, the primary mission of its fully operational missile defense systems today is to intercept ballistic missiles. In particular, missile defense interceptors are designed to intercept ballistic missiles in three different phases of flight.

- **The boost phase** extends from the time a missile is launched from its platform until its engines stop thrusting.
- **The midcourse phase** is the longest and thus offers a unique opportunity to intercept an incoming threat and, depending on other circumstances like the trajectory of the incoming threat and quality of U.S. tracking data, a second shot if the first intercept attempt fails.
- **The terminal phase** is less than one minute long, occurring as the missile

plummets through the atmosphere toward the target, and offers a very limited opportunity to intercept a ballistic missile threat.

Boost-Phase Interceptors. The United States currently has no capability to shoot down missiles in their boost phase. Technologically, boost-phase intercept is the most challenging option because of the very short time frame in which a missile is boosting, the missile's extraordinary rate of acceleration during this brief window of time, and the need to have the interceptor close to the launch site.[18] This phase, however, is also the most beneficial time to strike. A boosting ballistic missile is at its slowest speed compared to other phases; it is therefore not yet able to maneuver evasively and has not yet deployed decoys that complicate the targeting and intercept problem.

In the past, the United States pursued several boost-phase programs, including the Airborne Laser, the Network Centric Air Defense Element, the Kinetic Energy Interceptor, and the Air Launched Hit-to-Kill missile. Each of these programs was eventually cancelled because of technical, operational, or cost challenges. The current MDR discusses the option of incorporating the F-35 initially as a sensor platform and later as an interceptor platform for boost-phase intercepts. However, this effort has not progressed.

Midcourse-Phase Interceptors. Intercepting missiles in their midcourse phase offers more time for intercept and presents fewer technological challenges than intercept in the boost phase presents, but it also allows the missile time to deploy decoys and countermeasures that are designed to complicate interception by confusing sensors and radars. The United States deploys two systems that can shoot down incoming missiles in the midcourse phase of flight:

- The Ground-Based Midcourse Defense (GMD) system and
- The Aegis defense system.

The Ground-Based Midcourse Defense system is the only operational system capable of shooting down a long-range ballistic missile headed for the U.S. homeland. It consists of 40 Ground-Based Interceptors (GBIs) at Fort Greeley, Alaska, and four at Vandenberg Air Force Base, California. A GBI consists of a multi-staged rocket booster and an Exoatmospheric Kill Vehicle (EKV), which intercepts the incoming missile with hit-to-kill technology. In March 2019, the MDA conducted a groundbreaking and successful "salvo" GMD test against an ICBM target during which one GBI intercepted the target and a second intercepted the biggest piece of debris from the exploded target.[19]

To increase the probability of an intercept, the United States has to shoot multiple interceptors at each incoming ballistic missile. At present, because its inventory of interceptors is limited, the United States can shoot down only a handful of ballistic missiles that have relatively unsophisticated countermeasures.

In 2017, Congress approved a White House request to increase the number of GBIs from 44 to 64 to keep up with the advancing ballistic missile threat, particularly from North Korea. Construction of 20 new silos has been underway, but they remain empty.[20] The MDA intended to produce a Redesigned Kill Vehicle (RKV) to top 20 additional GBIs to fill these silos, but this program was canceled in 2019 because of technological difficulties. The MDA instead initiated the Next Generation Interceptor (NGI) program to build an entirely new interceptor that would add both capacity and capability to the GMD system. NGIs will begin to fill the 20 empty silos in 2028 and eventually will replace at least some of the existing 44 GBIs, the result of which will likely be a mixed fleet of interceptors. Unlike the GBIs, the NGI will feature multiple kill vehicles, enabling a single NGI to shoot at multiple objects ejected from one incoming missile.[21]

Contracts to develop the NGI were awarded to Lockheed Martin and a Northrop Grumman–Raytheon team in March 2021.[22] The FY 2022 budget request includes $926 million for

NGI to support these two competing designs through Preliminary Design Review.[23]

The Aegis defense system is a sea-based component of the U.S. missile defense system. It is designed to address the threat of short-range, medium-range (1,000–3,000 kilometers), and intermediate-range (3,000–5,500 kilometers) ballistic missiles. It utilizes different versions of the Standard Missile-3 (SM-3) depending on the threat and other considerations like ship location and quality of tracking data. The Aegis system also has capability against aerial threats and cruise missiles.[24]

"Under the FY2021 budget submission," according to the Congressional Research Service, "the number of BMD-capable Navy Aegis ships is projected to increase from 48 at the end of FY2021 to 65 at the end of FY2025."[25] The increase reflects an increase in demand for these assets.

The Aegis Ashore system in Romania and another being deployed to Poland will relieve some of the stress on the fleet because missile defense–capable cruisers and destroyers are multi-mission and are used for other purposes, such as wartime fleet operations and even anti-piracy operations. These Aegis Ashore sites will help to protect U.S. allies and forces in Europe from the Iranian ballistic missile threat.

Two Aegis Ashore batteries were being built in Japan to help protect U.S. allies and forces in the Indo-Pacific from the North Korean and Chinese threats, but the Japanese canceled the project in June 2020 because of costs and technical issues.[26] Instead, Japan will build two additional destroyers to deploy SM-3 interceptors.[27]

Moreover, the former Commander of U.S. Indo-Pacific Command (INDOPACOM), Admiral Philip Davidson, has testified that "the most important action we can take to increase the joint force's lethality [in the region] is to introduce a 360-degree, persistent, air and missile defense capability on Guam (Guam Defense System (GDS))," a capability that only the Aegis Ashore system can provide.[28] The FY 2022 budget request includes $78.3 million to support the continued assessment of systems to defend Guam as well as $40 million to begin procuring components for a missile defense system.[29]

In November 2020, the U.S. Navy and the MDA shot down an intercontinental-range ballistic missile using the SM-3 interceptor class Block IIA against an ICBM target.[30] The test, FTM-44, was the first step in a plan to use SM-3 Block IIAs as an "underlay" to the GMD system to defend the homeland, with GBIs taking the first shot at an incoming target and SM-3 interceptors taking a second shot if the GBIs miss.[31] Deploying such an underlay would require a concept of operations that includes optimal locations for the deployment of SM-3 interceptors on Aegis ships or at Aegis Ashore sites across the United States.

The November 2020 test was against a simple ICBM target; the next step will be to test against a more complicated and realistic ICBM target that could be armed with decoys or other missile-defense countermeasures. The FY 2022 budget request supports the continued pursuit of a layered homeland defense (LHD) approach with funding for continued assessment of the SM-3 Block IIA against ICBMs.[32]

Terminal-Phase Interceptors. The United States currently deploys three terminal-phase missile defense systems:

- Terminal High Altitude Area Defense (THAAD);
- The Patriot missile defense system; and
- Aegis BMD.

A THAAD battery is capable of shooting down short-range and intermediate-range ballistic missiles inside and just outside of the atmosphere.[33] It consists of a launcher, interceptors, the Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2) radar, and fire control.[34] The system is transportable and rapidly deployable.

THAAD batteries have been deployed to such countries as Japan, South Korea, Israel, and the United Arab Emirates. The United

States temporarily deployed a THAAD battery to Romania in support of NATO ballistic missile defense in the summer of 2019 as Romania's Aegis Ashore system was being updated[35] and signed a deal in 2020 to deliver THAAD to Saudi Arabia.[36] In FY 2022:

> [The MDA will also] continue to evaluate a new Terminal High-Altitude Area Defense (THAAD) interceptor prototype to support Contiguous United States Defense as part of the LHD effort. This effort will result in a series of technology demonstrations allowing for expansion of engagement options and coverage areas for the THAAD weapon system culminating in a flight test in FY 2023.[37]

Patriot is an air-defense and short-range ballistic missile defense system. A battery is comprised of a launcher, interceptors, AN/MPQ-53/65 radar, an engagement control station, and diesel-powered generator units. The Patriot family of missile defense interceptors has been upgraded over time, from the initial Patriot Advanced Capability-1 (PAC-1) deployed in Europe in 1988 to the PAC-3 configuration deployed around the world today. The most recent Patriot upgrade, the PAC-3 Missile Segment Enhancement, expands the lethal battlespace with an advanced solid rocket motor.[38] The system is transportable, and the United States currently deploys it in several theaters around the world.[39]

Assessment. Interceptor strength is difficult to assess because, while deploying more interceptors to increase capacity or defend more targets would always be better, deploying more short-range to medium-range interceptors to unprotected locations or increasing interceptor capacity *ad infinitum* is simply not feasible. Congress provided funding in FY 2021 to procure additional PAC-3, SM-3, and THAAD interceptors, and the FY 2022 budget continues this effort for PAC-3 and SM-3 interceptors. However, the FY 2022 budget sharply reduces support for THAAD interceptor procurement.[40]

To increase the defended battlespace, the MDA is also pursuing the Patriot Launch-on-Remote (THAAD) capability, which integrates the PAC-3 and THAAD systems by enabling a PAC-3 launch using a THAAD AN/TPY-2 radar. Launch-on-Remote is an important capability that can help to increase the defended area by spreading out missiles.[41] The MDA conducted two flight tests for this capability in 2020, and both failed.[42] However, the test failures do not necessarily indicate lack of progress; the MDA can now use the test data to proceed with development of this capability. The Army plans to field this capability "across all Patriot battalions beginning in Fiscal Year 2023."[43]

In addition, Congress provided funding for an eighth battery that appeared on the Army's unfunded priorities list. Nine THAAD batteries have long been required, but sufficient funds have not been available to support more than seven.[44]

One way to improve interceptor capability would be to fully fund an Aegis Ashore system on Guam using SM-3 interceptors in FY 2022. Such a system for Guam has appeared on the INDOPACOM unfunded priorities list for the past three years, but efforts to build the system have yet to begin. This year's budget includes funding to study a missile defense architecture on Guam and begin procuring components that would be common to any missile defense system. However, the budget does not commit to any specific system that will be built on Guam. Congress could move this critical capability forward by providing the additional $231.7 million requested for the Guam Defense System on INDOPACOM's FY 2022 unfunded priorities list.[45]

In terms of capacity and capability to defend the homeland, the Commander of U.S. Northern Command (NORTHCOM), General Glen VanHerck, recently stated that he is "comfortable with my ability to defend the homeland, including Hawaii, against a limited state actor such as DPRK, which the system is designed for, for the foreseeable future" but that we need "to maintain the timeline of no later than 2028 for NGI, to ensure that we maintain capacity and capability to defend against a ballistic missile threat."[46] Among General VanHerck's specific concerns are the increasing capacity of North Korean ballistic missiles to strike the U.S. homeland and North Korea's ability to deploy decoys.[47]

The recent NGI contract award follows a delay in schedule of more than a year. Fortunately, both competitors have been challenged to meet or exceed the schedule of 2028 for an operational capability.[48] This program also seems to enjoy bipartisan support in Congress.

In addition to accelerating the NGI program, Congress provided additional funds in both FY 2020 and FY 2021 for a GMD service life extension program (SLEP). The GMD system was largely built in the early 2000s, and many parts—like the GBI kill vehicles and boosters—are subject to degradation from aging. Regardless of how quickly NGI can be delivered, GBIs will likely remain a part of the fleet of interceptors beyond this decade.

Moreover, it is important to distinguish between GBIs, which are the interceptors themselves, and GMD, which is the entire homeland defense system that encompasses other components like silos, fire control, and even training methods for personnel. The MDA has begun to replace aging boosters on the GBIs, for instance, but as MDA Director Admiral Jon Hill has stated, "It's not just about the GBIs but it's also about the weapon system and its support."[49] Since the NGI will be integrated into the GMD system for the long term, upgrading the entire GMD system to last beyond the fielding of NGI will remain critical.

In FY 2020, to compensate for the delay in adding 20 additional interceptors to the fleet, the Trump Administration proposed that an underlay using SM-3 Block IIA and THAAD interceptors be developed. General VanHerck agreed to the value of an underlay, stating that "an underlayer would give us additional capacity and capability" to address threats to the homeland, but he also specified that an underlay should focus on more than just ballistic missiles, to include other threats like cruise missiles or unmanned aerial vehicles.[50]

Despite the MDA's original plan to field an underlay quickly as U.S. forces await NGI, the Department of Defense (DOD) has yet to specify a concept of operations for employing the SM-3 Block IIA and THAAD for homeland defense, as requested by Congress. The FY 2022 budget request states that homeland underlay systems "could begin fielding as early as 2025" but does not address where in the United States those systems could be deployed or how many would be required.[51] The utility of exploring the use of SM-3 and THAAD interceptors for ICBMs can also extend beyond an underlay for the continental United States, as they can also work for other missions or defended assets like Hawaii, Alaska, and Guam. Therefore, using SM-3 and THAAD interceptors to defend against ICBMs is a worthwhile effort, but the DOD will eventually need a more specific deployment plan.

The cruise missile threat to the homeland, for which the United States does not have a dedicated missile defense system, is also advancing. That Russia can strike key strategic nodes in the U.S. homeland from its own territory is of particular concern. To address the cruise missile threat, General VanHerck has emphasized improving domain awareness, because early identification of a threat allows for options like left-of-launch operations or diplomacy to avoid having to shoot down cruise missiles in the U.S. homeland.[52] Ensuring that the NORTHCOM Commander has the capabilities needed to address this advancing threat will therefore be important.

The Army's Indirect Fire Protection Capability (IFPC) Increment 2 program has been moving very slowly but has seen recent improvement. The IFPC 2 would defend against short-range rockets, artillery, and mortars, as well as cruise missiles, against which the United States, as noted, lacks a sufficient defensive capability.[53] As a system, IFPC would fill the gap between short-range tactical air defense and ballistic missile defense like PAC-3 and THAAD.

In response to a congressional requirement to field an interim cruise missile defense capability in response to the increasing cruise missile threat, the Army purchased two Iron Dome batteries manufactured by the Israeli company Rafael.[54] Despite prior concerns about integrating Iron Dome as part of an enduring IFPC solution, the Army is preparing the Iron Dome systems for operational deployment and integration into its future missile defense command and control system.[55] In April 2021, the Army issued the solicitation for its own enduring IFPC 2 system, to reach combat capability by 2023.[56]

Overall, the United States has multiple capable interceptors, but there is much room for improvement. The most important step for the near future will be on-time or early delivery of the NGI to ensure protection of the homeland from North Korea.

Sensors

The sensor component of the U.S. missile defense system is distributed across the land, sea, and space domains and provides the United States and its allies with the earliest possible warning of a launch of enemy missiles in addition to missile tracking and discrimination. These sensors can detect a missile launch, acquire and track a missile in flight, and even classify the type of projectile, its speed, and the target against which the missile has been directed. They relay this information to the command and control stations that operate interceptor systems like Aegis (primarily a sea-based system) or THAAD (a land-based system).

Land-Based. On land, the major sensor installations are the upgraded early warning radars (UEWRs), which are concentrated along the North Atlantic and Pacific corridors that present the most direct flight path for a missile aimed at the United States. They include the phased array early warning radars based in California, the United Kingdom, and Greenland that scan objects up to 3,000 miles away.[57] Two additional sites—one in Cape Cod, Massachusetts, and the other in Clear, Alaska—are being modernized for use in the layered ballistic missile defense system, but their certifications have been delayed.[58] These sensors focus on threats that can be detected in the missile's boost or launch phase when the release of exhaust gases creates a heat trail that is "relatively easy for sensors to detect and track."[59] A shorter-range (2,000-mile) radar called the Cobra Dane is based in Shemya, Alaska.[60]

The United States also deploys mobile land-based sensors, called AN/TYP-2s. These sensors can be forward deployed for early threat detection or kept in terminal mode to provide tracking and fire control support for the THAAD interceptors.[61] Of the United States' 12 AN/TPY-2 systems, five are forward deployed with U.S. allies.[62]

In cooperation with the Republic of Korea, the United States deploys a THAAD missile system accompanied by an AN/TPY-2 on the Korean Peninsula. Despite China's long-standing opposition to a U.S. radar deployed so close to its homeland, the THAAD system is critical to countering the North Korean threat.[63]

To fill a gap in missile discrimination capability for tracking North Korean missiles over the Pacific, the MDA is developing the Long Range Discrimination Radar (LRDR) in Northern Alaska to improve coverage in the northern Pacific. There had been plans to develop the Homeland Defense Radar-Hawaii (HDR-H) as well to fill a tracking and discrimination gap over Hawaii. In its FY 2021 budget request, the Trump Administration omitted funding for HDR-H because of budget constraints, but Congress provided the full funding needed to proceed with the radar. The FY 2022 budget does not include funding for HDR-H, so this radar's future again lies with Congress.

Sea-Based. There are two types of sea-based sensors. The first is the Sea-Based X-band (SBX) radar, which is mounted on an oil-drilling platform and can be relocated to different parts of the globe as threats evolve.[64] SBX is employed primarily in the Pacific. The second radar is the SPY-1 radar system, which is mounted on all U.S. Navy vessels equipped with the Aegis Combat System and therefore is able to provide data that can be utilized for ballistic missile missions. Of these ships, 40 are BMD-capable vessels that carry missile defense interceptors.[65]

Space-Based. Finally, U.S. missile defense sensors operate in space. From the ultimate high ground, space-based sensors can detect and track missile launches from almost any location from boost to terminal phase, compared to ground-based radars that are limited in their tracking range.[66] The MDA, the U.S. Space Force, and the Space Development Agency (SDA) all control aspects of the space missile defense sensor system.

Of the systems that contribute to the missile defense mission, the oldest is the Defense Support Program (DSP), a constellation of satellites that use infrared sensors to identify heat from booster and missile plumes. The DSP satellite system has gradually been replaced by the Space-Based Infrared Radar System (SBIRS) to improve the delivery of missile defense and battlefield intelligence.[67] For instance, SBIRS can scan a wide swath of territory while simultaneously tracking a specific target, making it a useful means for observing tactical, or short-range, ballistic missiles.[68]

The Air Force and Space Force have launched five SBIRS satellites out of a planned total of six.[69] The Air Force originally planned to launch eight SBIRS satellites, but due to congressional funding delays, it decided to end production of SBIRS early and move on to development of its replacement, the Next-Generation Overhead Persistent Infrared (Next-Gen OPIR) satellite, in 2017.[70] The seventh and eighth SBIRS satellites will be switched to Next-Gen OPIR satellites, the first of which is to be delivered "no later than FY 2025."[71] The Next-Gen OPIR satellites are designed to be more survivable against cyber and electronic attacks.

The MDA also operates the Space Tracking and Surveillance System-Demonstrators (STSS-D) satellite system. Two STSS-D satellites were launched into orbit in 2009 to track ballistic missiles that exit and reenter the Earth's atmosphere during the midcourse phase.[72] STSS-D satellites provide operational surveillance and tracking capabilities and have the advantage of a variable waveband infrared system to maximize their detection capabilities. Data obtained by STSS-D have been used in ballistic missile defense tests and are now providing risk reduction to support a future space tracker. After more than a decade of serving risk reduction efforts, the MDA recently announced its plans to deorbit the STSS-D satellites within "the next couple [of] years."[73]

In addition, the United States is developing a system of satellites capable of providing global detection, tracking, and discrimination of any missile launch. Dating back as far as President Reagan's Strategic Defense Initiative, successive Administrations have called for a proliferated layer of sensing satellites in space to track the flight of any type of missile—not just ballistic—from birth to death.

A layer of space-based sensors can be particularly useful in tracking hypersonic vehicles, which fly at lower altitudes than ballistic missiles and can maneuver during their trajectories. Comparatively, the DSP and SBIRS systems were designed for ballistic missiles and can lose track of missiles flying at lower altitudes. Since many new threats are not flying on ballistic trajectories, the Trump Administration paid close attention to developing this space sensor layer as endorsed by the MDR.

As a result, the SDA, in conjunction with the MDA, is developing a space Tracking Layer of satellites proliferated in Low-Earth Orbit (LEO) as part of the SDA's National Defense Space Architecture. According to the SDA:

> Once fully operational, the SDA Tracking Layer will consist of a proliferated heterogeneous constellation of Wide Field of View (WFOV) space vehicles (SVs) that provide persistent global coverage and custody capability combined with the Missile Defense Agency (MDA) Hypersonic and Ballistic Tracking Space Sensor (HBTSS) Medium Field of View (MFOV) SVs that provide precision global access capability.[74]

Once deployed, the Tracking Layer will be able to detect, track, and discriminate among any types of missile launches throughout the entirety of the missiles' flights. The SDA is also exploring the ability of space sensors to provide fire control information directly to weapon platforms like the NGI (as opposed to the data's going through a ground station).

Last year, Congress provided $130 million—about $30 million above the President's budget request—for the HBTSS and affirmed that the MDA, not the SDA, would develop the system.[75] It also fulfilled the President's request for $48 million for the SDA.[76] This year's budget request includes $256 million for the HBTSS to enable an on-orbit demonstration for two contractors in FY 2023.[77]

Assessment. Senior defense leaders have stated repeatedly that the most important way to advance sensor capability is to deploy sensor satellites to space in order to track missiles from the high ground throughout their entire flight. According to Admiral Charles Richard, Commander of U.S. Strategic Command (STRATCOM):

> Future space-based sensors may be able to provide birth-to-death detection, tracking, and discrimination of hypersonic glide vehicle, cruise missile, and ballistic missile threats globally. These abilities cannot be fully achieved with the current or future terrestrial-based radar architecture due to the constraints of geography and characteristics of future missile threats.[78]

Fortunately, the U.S. government has progressed in the space-based sensor effort despite a slow start. In FY 2019, FY 2020, and FY 2021, the program was plagued by insufficient funding requests and bureaucratic infighting over whether the SDA or MDA would develop the HBTSS.[79] These issues seem to have been resolved as clear roles for the SDA and MDA have been defined. The space-based sensor effort must continue to be fully funded, especially in view of commanders' urgent need for improved missile tracking as well as the technological challenges associated with developing a sensor that can perform in LEO.[80]

Development of land-based sensors to fill the missile discrimination capability gap over the Pacific has progressed slowly. Development of the LRDR has been delayed by at least a year.[81] The HDR-H project resumed in FY 2021, but local opposition to its development threatens to create delays.[82] Because the DOD originally proposed the HDR-H to fill the critical discrimination gap identified over Hawaii, the lack of funding for HDR-H again in the FY 2022 budget also demonstrates a disconnect with DOD priorities. Additionally, the Pentagon initially planned to build a radar elsewhere in the Pacific (HDR-Pacific), but the FY 2021 budget request excluded this program, and Congress did not restore its funding. If NGI is the solution to a strong homeland missile defense, the NORTHCOM Commander must have the sensor coverage necessary to execute the mission.

With respect to Next-Gen OPIR, Congress fulfilled the FY 2021 budget request, which should keep the program on schedule, and this year's budget request continues to fund the program.[83] The Army is also progressing quickly on development of the Lower-Tier Air and Missile Defense System radars that will provide 360-degree threat coverage for PAC-3 and other regional missile defense batteries; the current Patriot radar can scan only one-third of the sky at a time.[84]

Fortunately, the space-sensor project is now on track compared to previous years. It is important that land-based radar coverage move forward in order to stabilize the future sensor architecture.

Command and Control

Command and control of the U.S. ballistic missile defense system requires bringing together data from U.S. sensors and radars and relaying those data to interceptor operators so that they can destroy incoming missile threats against the U.S. and its allies. The operational hub of missile defense command and control is the Joint Functional Component Command for Integrated Missile Defense (JFCC IMD), a component of STRATCOM housed at Schriever Air Force Base, Colorado. JFCC IMD brings together Army, Navy, Marine Corps, Space, and Air Force personnel and is co-located with the MDA's Missile Defense Integration and Operation Center (MDIOC). This concentration of leadership from across the various agencies helps to streamline decision-making for those who command and operate the U.S. missile defense system.[85]

Command and control of the GMD system to defend the homeland utilizes the Ground-based Midcourse Defense Fire Control (GFC) system, which consists of a suite of hardware, software, and personnel located in Fort Greeley, Alaska, and Vandenberg Air Force Base, California.[86] The system involves collecting data on missile movement from sensors and radars to inform the launch of GBIs.

Once a missile is launched, data from the U.S. global network of sensors and radars travel through secure satellite communications and ground-based redundant communications lines to the Command Launch Equipment (CLE) software that can task GBIs to fire at the incoming missile. Then, once the NORTHCOM Commander—who becomes the supported commander during GMD execution—in consultation with the President has determined the most effective response to a missile threat, the CLE fire response option is relayed to the appropriate GBIs in the field.[87] When the selected missiles have been fired, they maintain contact with In-Flight Interceptor Communications System (IFICS) Data Terminals (IDTs) to receive updated flight information that helps to guide them to their target.[88]

To prepare for and execute GMD operations, the NORTHCOM Commander can also utilize situational awareness data from the Command and Control, Battle Management and Communication (C2BMC) system. Through its software and network systems, C2BMC helps to process and integrate sensor information to provide a more complete picture of the battlespace.[89] The GMD Fire Control system acts as the primary decision aid for GMD execution, and the C2BMC system provides integrated battlefield awareness information before and during GMD operations.[90] It also provides information to other missile defense systems like THAAD and Patriot. Dozens of C2BMC workstations are distributed throughout the world at U.S. military bases.

C2BMC has undergone multiple technical upgrades, called "spirals," since 2004 to bring more missile defense elements into the network. In 2019, the MDA completed an upgrade that will help to expand Aegis missile defense coverage by enabling Aegis Weapons Systems to engage on remote.

Regional missile defense systems like THAAD, PAC-3, and Aegis are equipped with their own individual fire control systems to command and control the launch of their interceptors. The C2BMC system can also provide tracking information to individual missile defense batteries from other regional sensors. Aegis BMD systems have onboard command and control governed by the Aegis Combat System, and they can provide their sensor data to the GMD system through C2BMC.[91]

C2BMC connects sensors and shooters around the world to a global network, but there is no comparable system to link sensors and shooters in a single region. The Army is developing the Integrated Air and Missile Defense (IAMD) Battle Command System (IBCS) to provide this capability. Once fielded, IBCS would connect all sensors and shooters in a region to a single fire control network.[92] Like IFPC, IBCS would also link defenses against smaller threats with ballistic missile defense.

Assessment. A strong global command and control system is critical to missile defense because linking information from sensors can increase domain awareness and decision time, thereby improving the probability of intercept. According to General VanHerck, "Decision space starts with that domain awareness." With more information about the threat, decision-makers can move "further left" to engage a target sooner.[93] For instance, it was recently reported that the MDA provided U.S.

Indo-Pacific Command with a hypersonic missile defense capability, largely as a result of C2BMC improvements that allow sensors to see the threat sooner.[94] Future spirals that are planned will continue to increase the integration of ballistic missile defense elements across the world.

The MDA planned to complete another upgrade to incorporate the LRDR into C2BMC in FY 2021, but this upgrade has been delayed, primarily by the COVID-19 pandemic.[95] Domain awareness can also allow decision-makers to use other tools to deescalate conflict before missiles are launched. This option is especially important in dealing with cruise missile threats to the homeland, for which the U.S. does not have a comprehensive interceptor capability.

The United States will need a more advanced command and control capability as global missile threats shift to include cruise and hypersonic missiles in addition to ballistic missiles. The DOD is currently developing a Joint All Domain C2 (JADC2) system to integrate non-compatible sensors across all domains into a single network so that it can respond to the complex threat more efficiently. Missile defense command and control will strengthen as the services begin to field JADC2 capabilities.

North American Aerospace Defense Command is also pursuing a program called Pathfinder that "ingests data from multiple sources, infuses that data and uses machine learning and intelligence capabilities to process and share in real time."[96] Sensor information can tend to exist in stovepipes, and if it is not integrated, the result can be failure to detect a threat.[97] Pathfinder's use of artificial intelligence can help to ensure that the commander receives a full data picture.

IBCS will also provide an important improvement in regional missile defenses. The system will link all missile defense sensors and interceptors to one fire control center, as opposed to today's more stovepiped approach in which each unit operates its co-located sensor and launcher independently. By permitting air and missile defenses to function as a joint kill web rather than as a linear kill chain, IBCS will be able to determine the best shooter to take down an incoming missile, in turn increasing the defended battlespace.

IBCS was originally scheduled to reach initial operating capability in FY 2019, but it was delayed to FY 2022 because of technical issues.[98] The program remains on this new schedule today and successfully engaged two targets during a limited user test conducted last year.[99] Advancements underway in missile defense command and control will become increasingly necessary to enable defense against the growing missile threat.

Conclusion

By successive choices of post–Cold War Administrations and Congresses, the United States does not have in place a comprehensive set of missile defense systems that would be capable of defending the homeland and allies from robust ballistic missile threats. U.S. efforts have focused on a limited architecture that protects the homeland and on deploying and advancing regional missile defense systems.

Although the United States has in place multiple types of capable interceptors, a vast sensor network, and a command and control system, many elements of the missile defense system need to be improved to defend against today's threat more efficiently. At the same time, the development of missile threats, both qualitative and quantitative, is outpacing the speed of missile defense research, development, and deployment to address those threats. Senior leaders continue to stress the importance of U.S. missile defense, but if the nation is to realize the strategic benefits that missile defense provides, Congress must make sure that the funding of critical programs like NGI, space sensors, and JADC2 is commensurate with that importance.

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