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MISSILE DEFENSE

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SPECIAL TOPIC

MISSILE DEFENSE

Since the start of the nuclear age, U.S. presidents have sought a peaceful counter to an attack from an Intercontinental Ballistic Missile. President Ronald Reagan popularized the notion of "Star Wars," the ability to hit a bullet with a bullet, safely outside the atmosphere. But for decades, the idea seemed less like a triumph over evil than a black hole into which billions of government dollars were poured. Gradually, however, engineers began notching successes – first with small scale systems to shoot down rockets and mortars – and later to defeat cruise missile threats.

This spring, a test in the U.S. showed for the first time it could defeat an ICBM target. And now, with North Korean missile development picking up pace, the U.S. is responding with increased funding for national missile defense.

The articles in this package look at the threat from North Korea and current efforts to counter their missiles. It includes extensive reporting on the fate of the ground-based missile defense program and an in-depth look at the kill vehicle technology that steers a missile to its target.

This e-book has the latest details on the current, future and far-reaching technologies in development.

Jen DiMascio
Managing Editor, Defense, Space & Security

Raytheon Missile Takes On And Destroys Midrange Target

Raytheon's Standard Missile-6 Dual I has successfully intercepted a medium-range rocket target off the coast of Hawaii in a much-anticipated validation test by the U.S. Missile Defense Agency (MDA) and Navy. The "salvo" launch marks another significant step toward Washington's construction of a multilayered missile shield to thwart new missile technologies being fielded by North Korea and Iran. It is also meant to defeat small-scale or limited strikes by regional superpowers Russia and China, who have far too many missiles in their inventory to knock out all at once.

Having already proven the SM-6 Dual I's capability against short-range ballistic missiles (ranges under 539 nm/1000 km) and cruise missiles, on Dec. 14, the USS John Paul Jones (DDG-53) fired two of the explosive interceptors against a "complex," threat-representing a medium-range target rocket originating from the Pacific Missile Range Facility on the Hawaiian island of Kauai. The Aegis 5.0 (Baseline 9.C1)-equipped destroyer detected, tracked and successfully destroyed the specially designed target in a high-speed, endoatmospheric salvo engagement, MDA says. It released this video of the test:

The agency says the test, designated FTM-27, met its primary objective, and program officials will now comb through telemetry and other data to evaluate overall performance. "The SM-6 missile and the Aegis Weapon System continue to prove that they are critical components of our nation's multilayered, robust ballistic missile defense system," MDA Director Vice Adm. Jim Syring says.

The intercept follows the May 17 flight of a medium-range ballistic missile (MRBM) target from Hawaii, which proved that destroyers outfitted with the latest Lockheed Martin-built Aegis configuration could detect and track midrange threats in the terminal phase using their SPY-1 radars. The May 17 and Dec. 14 target missiles were designed, built and launched by Lockheed Martin's targets and countermeasures group, located in Huntsville and Courtland, Alabama.

Two Raytheon-built SM-6 Dual I missiles were fired against a "complex medium-range ballistic missile target" off the coast of Kauai, Hawaii, after midnight on Dec. 14. Credit: Missile Defense Agency

That test was supported by the Kauai-based Aegis Ashore test complex and a Raytheon TPY-2 transportable surveillance radar, as well as the agency's experimental space-based tracking and discrimination satellite system and command-and-control elements.

RAYTHEON STANDARD MISSILE 6

- Range: 240-370 km (150-230 mi.)
- Targets: Cruise missiles, aircraft, UAVs, terminal-phase short-to-intermediate-range ballistic missiles, ships and land targets (proven)
- Fielded Variants: Block I, IA, Dual I (full operational capability expected by 2018)

At the annual Space and Missile Defense Symposium in August, Syring pointed to FTM-27 as a significant

demonstration of the U.S.'s sea-based terminal defense technology and further proof of the Standard Missile family's versatility, having also been used to sink a ship in January. "We've flown targets that look a lot like the [MRBM] threat and we will intercept a target that looks a lot like the threat in December," he said at the time.

On May 17, MDA flight-tested a medium-range ballistic missile against an Aegis ship as a precursor to the December SM-6 Dual I test. Credit: Missile Defense Agency

At the conference, Raytheon Missile Systems executives told Aviation Week that a successful Dual I intercept would "continue to prove that SM-6 is awesome." They would not say if the target warhead follows a standard ballistic trajectory or is a maneuvering type. "It will demonstrate the robustness of the system against the threat that is out there," said one program official.

SM-6 MILESTONES

- 2013: Block I achieves initial operational capability, arming the USS Kidd
- June 2014: Block I achieves U.S. Navy's farthest-ever surface-to-air intercept
- November 2014: Block IA intercepts cruise missile over land
- July-August 2015: Dual I intercepts first short-range ballistic and cruise missiles
- January 2016: Modified SM-6 sinks USS Reuben James
- February 2016: Two Block Is intercept two cruise missiles simultaneously
- December 2016: Dual I salvo intercepts first medium-range ballistic missile

SM-6 Dual I has improved software and a more powerful processor, giving it the ability to identify, track and intercept threats potentially armed with conventional, nuclear or chemical and biological warheads while descending at high velocity from the upper atmosphere—the most hazardous "terminal phase" of flight just moments before impact. With an active and semiactive radar guidance section borrowed from Raytheon's AIM-120 Amraam, the Dual I variant can also eliminate threatening cruise missiles and aircraft, retaining the same capability as the earlier SM-6 Block I and Block IA variants. Dual I is a lower-cost alternative to Standard Missile-2 Block IV, which was specifically designed for terminal-phase ballistic missile defense.

The most mammoth of Raytheon's Standard Missile family is the SM-3 Block IIA, being jointly developed with Japan. Credit: Raytheon

Over four intercepts from July 28-Aug. 1, 2015, SM-6 Dual I engaged a short-range ballistic missile target as well as two types of cruise missile targets: the air-launched, Mach 4-capable AQM-37C

Jayhawk and rail-launched, subsonic BQM-74E Chukar. The Missile Defense Advocacy Alliance reports that SM-6, designated RIM-174, has an approximate range of 130-184 nm (240-340 km).

The Dual I demonstration checks off one of three significant intercept tests MDA has on its books. Next is an intercept test to validate Standard Missile-3 Block IIA, a 21-in.dia. variant cooperatively developed by the U.S. and Japan to destroy enemy missiles in transit on the edge of space. Armed with a nonexplosive lightweight exoatmospheric hit-to-kill projectile, or "silver bullet," SM-3 Block IIA has twice the range of a regular 13.5-in.-dia. SM-3 at 810 nm (1,500 km).

That flight test, designated SFTM-01, was meant to occur in October but has been pushed back. The agency does not think the delay will impact the overall schedule for completing the development phase, due to end in the second quarter of fiscal 2018. On Dec. 8, program officials from the U.S. Navy and Japan conducted the second live-fire flight test of the missile from Point Mugu, California, and meanwhile Raytheon has received more funding for additional engineering work.

The most significant intercept test for homeland defense is FTG-15, which will see the silo-based Ground-Based Interceptor fly against an intercontinental-range ballistic missile target for the first time. The test is meant to validate the reliability improvements to the Boeing/Orbital ATK "Configuration 2" booster and Raytheon-built "Capability Enhancement-II Block 1" exoatmospheric kill vehicle. That test has been pushed back into the second quarter of fiscal 2017 due to missile availability and an extended ground-test period. The interceptor will be launched from Vandenberg AFB in California to strike an ICBM target launched from the Reagan Test Site, Kwajalein Atoll, Marshall Islands.

The Russian Missiles Trained On NATO (Gallery)

The unprecedented rate of long-range missile testing by North Korea has added a new level of urgency to the Trump administration's review of U.S. missile defenses.

Missile defense advocates are no longer comfortable relying on a few dozen silo-based interceptors in Alaska and California to thwart potential attacks on the mainland. They are now appealing to the government to pump billions of dollars into strengthening today's homeland and regional defenses, while investing in future technology for multi-object kill vehicles, laser-carrying unmanned aircraft, defenses against hypersonic weapons and an overlapping web of missile-tracking satellites. There are even discussions about putting lasers and interceptors in space, akin to then-President Ronald Reagan's 1983 Strategic Defense Initiative.

Nearer term, advocates say several lines of effort are crucial for the U.S. Missile Defense Agency (MDA): increasing the reliability and size of the Ground-based Midcourse Defense (GMD) system's interceptor fleet; improving the quality, manufacturability and number of kill vehicles atop those interceptors; adding sensors; and adapting the system to meet hypersonic weapon threats.

NEW THREATS, NEW TECHNOLOGY

- North Korea's missile tests prompt calls for U.S. to construct a missile defense layer in space
- Concerns raised about U.S. pausing homeland defense interceptor fleet at 44 missiles
- U.S. faces kill vehicle production gap
- MDA ramps up prototyping and demonstration campaign to meet future hypersonic threat

The Missile Defense Advocacy Alliance's Riki Ellison and Center for Strategic and International Studies' Thomas Karako want to see an improvement in the overall "capability, reliability and capacity" of the 44-missile Ground-Based Interceptor (GBI) fleet and the procurement of additional spares to hedge against any potential North Korean missile raid, if deterrence fails. The MDA requests $150 million in fiscal 2018 for six additional interceptors and two more silos at Fort Greely, Alaska, but still needs approval and funding from Congress. Some U.S. lawmakers have called for 14-28 spare interceptors.

Kill Vehicle Chasm

The reliability of kill vehicles has been an ongoing sore point for the MDA; six of eight failed GMD tests since 1999 were attributed to malfunctions or separation failure of the Raytheon Exoatmospheric Kill Vehicle (EKV). But efforts to correct the issue appeared to pay off May 30 with the first successful U.S. end-to-end ICBM intercept test using Raytheon's latest "Capability Enhancement-II Block 1" EKV.

Hitting a bullet with a bullet: The Capability Enhancement-II Block 1 Exoatmospheric Kill Vehicle tested on May 30 is to be the final version of Raytheon's EKV hit-to-kill interceptor series until the new Redesigned Kill Vehicle arrives in 2022. Credit: Missile Defense Agency

Ellison and Karako say this variant is an improvement over the version fielded in 2004, but as the

number of missiles capable of reaching the U.S. increases over the next decade, kill vehicles must become more reliable, cheaper and small enough to deploy in clusters.

The MDA's fiscal 2018 program, however, delays testing and fielding of the EKV's replacement, the Redesigned Kill Vehicle (RKV), until 2022, a two-year deferment. It brings forward deployment of the Multi-Object Kill Vehicle (MOKV) to 2025 from the 2029-30 time frame.

Karako applauds acceleration of the MOKV, which will enable a single interceptor to carry several hit-to-kill payloads instead of one EKV or RKV. But he worries about the consequences of delaying the RKV, since the production line and supply chain for the EKV is winding down.

The RKV is engineered to be more reliable and less expensive than the current-generation EKV, which was rushed into service during the George W. Bush administration. The number of manufacturing steps will be reduced by 70%. Raytheon delivers the final eight CE-II EKVs this year, at which point production will end, and the company will focus solely on future product development until the RKV enters production at the turn of the decade. Buying more interceptors and kill vehicles as spares could negate this issue.

"The dirty little secret is: There are no operational and testing spares. None," Karako says. "Every time MDA conducts another test, they'll need to pull one out of the ground from Fort Greely. They're not going to replace it because there's nothing to replace it with. Forty-four interceptors will go down to 40, a 10% reduction, and that's before the delay of RKV became public." Raytheon manufactures the EKVs in Tucson, Arizona, where it has capacity to build more CE-II kill vehicles. Boeing is the prime contractor for the RKV, with Lockheed and Raytheon as major suppliers. Raytheon has 50% of the workshare and is responsible for integration, assembly and testing of the future kill vehicle at its "Space Factory" in Tucson. Boeing attaches the missile-hunting payload to the GBI interceptor.

David Dutcher, Boeing's director of the GBI and RKV programs, says his team has "stood up a capability to produce more interceptors, if needed." The company is also working on the next-generation MOKV. The MDA says the two-year delay for the RKV allows more time for systems engineering, parts and materials screening and hardware qualification, while reducing overlap between development and production. "The additional time reduces program concurrency and will support meeting the program's primary goal—achieving high levels of reliability," the agency says. But without some overlap, Raytheon would have to lay off much of its skilled kill vehicle production workforce until the RKV is approved for production.

Despite the schedule change, Raytheon says it is confident of meeting all RKV testing and fielding requirements, "if funded and resourced properly."

Bruce Jurcevich, Lockheed's director of advanced interceptor systems, says the RKV has been the MDA's No. 1 priority for improving kill vehicle reliability and reducing manufacturing complexity and unit cost. "The previous system had producibility issues," he says. The RKV will introduce "on-demand communications" so kill vehicles can send and receive target updates, discrimination data and hit assessments during spaceflight. This is an initial step toward collaborative intercepts against one or more targets.

Boeing, Lockheed and Raytheon have received contracts worth $50-60 million each to begin developing and prototyping their MOKV concepts. Karako says the government could move more quickly toward MOKV but should not jump to multithreat intercept capability without first finishing the RKV. "The path to MOKV is through RKV," he says. "MOKV requires more of a leap [in technology]; RKV is an evolution."

The MDA believes the MOKV could revolutionize the missile defense architecture by multiplying the number of warheads each interceptor can destroy. Today, the Pentagon would launch two or more multimillion-dollar GBIs against a single incoming warhead. "Instead of a unitary kill vehicle, it's a swarm of them," Karako says.

The agency could also develop a smaller MOKV payload for Raytheon's new 21-in. SM-3 Block 2A, an Aegis exoatmospheric interceptor designed to intercept medium- to intercontinental-range missiles. The missile has failed in one of two intercept tests, possibly delaying low-rate production.

Hypersonic Imperative

Russian and Chinese development of hypersonic cruise missiles, glide weapons and maneuverable reentry vehicles could soon render Western antiballistic missile defenses obsolete. These weapons either skim along the upper atmosphere at high speed or maneuver in unpredictable ways to outplay traditional missile shields. Congress directed the MDA to address this challenge and develop plans and programs to counter hypersonic threats due to enter service in the next few years. The agency's answer is a series of demonstrations involving "radars, high-altitude drones and a space layer" as well as new weapon concepts, it told Congress in June.

For detection, the MDA is evaluating new electro-optical/infrared and laser rangefinding sensors in space and on high-flying drones. Because of their speed, hypersonic missiles have strong heat signatures, which makes detection easier from certain vantage points. Directed-energy weapons on drones or in space could knock out targets from above at the speed of light but probably not from below, due to a plasma layer.

In 2015, the agency even expressed interest in adapting high-speed conventional interceptors such as the Terminal High-Altitude Area Defense system and SM-6 to knock out hypersonic threats. The MDA is also assessing the utility of high-speed projectiles, such as Mach 3-capable hypervelocity powder guns and electromagnetic rail guns that fire rounds at six times the speed of sound.

Many industry analysts see space as the "ultimate high ground" for sensing and intercept of hypersonic threats.

The MDA says it is establishing a "three-phase limited contingency capability" for real-time hypersonic missile warning across "the majority of the threat profile." This includes a mix of overhead persistent infrared sensors—airborne and space-borne—but also terrestrial sensors.

The agency has been maturing stereoscopic tracking and range-finding of ballistic and hypersonic threats using two customized General Atomics Aeronautical Systems MQ-9 Reaper UAVs with chin-mounted Raytheon Multispectral Targeting System (MTS-C) turrets. The MDA is also exploring ground-based MTS-C sensor sites.

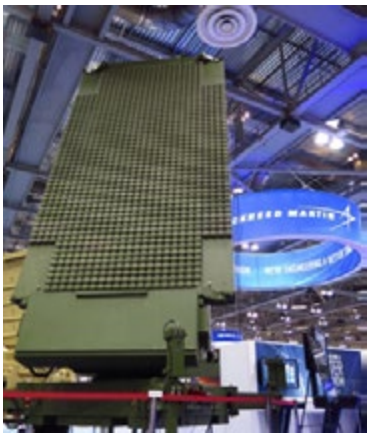
For the space layer, the agency wants many small, inexpensive satellites and hosted payloads instead of billion-dollar behemoths, and its budget includes funding for an "overhead miniature sensor" experiment. A $21 million contract for space sensor concept development is due to be awarded this year.

Kingston Reif of the Arms Control Association cautions that establishing even a limited defense against hypersonic weapons would be wildly expensive and cost-prohibitive. The better answer might be to prevent the capability from "coming out of the bag" in the first place, through arms control.

"We can see the point where Russia, the U.S. and China are all fielding these systems," he says.

How will Washington respond to North Korea's missile threat?

The 19th annual Space & Missile Defense Symposium is underway in Huntsville, Alabama, as saber rattling by North Korea puts U.S. allies in the Asia-Pacific region on edge. Pyongyang conducted its fourth underground nuclear test in January and is stepping up short- and intermediate-range ballistic missile testing; nine trials have occurred since May, including one submarine launch. Meanwhile, the U.S. is continuing to expand the ballistic missile shield to protect against Russia in Europe under its so-called Phased Adaptive Approach. The first Aegis Ashore site recently started operations in Romania; one in Poland will follow in 2018. Along with the traditional showing of missile interceptors and targets, radar-makers such as Lockheed Martin, Raytheon and Northrop Grumman are pushing a new breed of gallium nitride-based active, electronically scanned array radars. The technological advance comes as the U.S. Army looks to upgrade or replace its Patriot radar inventory and as the Air Force settles its disputed Three-Dimensional Expeditionary Long-Range Radar development contract. Cooperation with Israel is also on show, with models of the Israel Aerospace Industries/Boeing Arrow 3 and Rafael/Raytheon Stunner missile interceptors on display.



LOCKHEED MARTIN NEXT-GENERATION LONG-RANGE RADAR

RAFAEL/RAYTHEON STUNNER

ORBITAL ATK AIR-LAUNCHED INTERMEDIATE-RANGE BALLISTIC MISSILE TARGET

DYNETICS SMALL GLIDE MUNITION

BOEING PHANTOM EYE

LOCKHEED MARTIN THAAD AND PAC-3

Missile defense chief says U.S. is capable of shooting down North Korean missiles

When it comes to the North Korean threat, the U.S. can respond offensively or defensively, top military officials say.

America's ballistic missile defense system is ready to handle a ballistic missile raid by North Korea, according to the director of the Missile Defense Agency, Air Force Lt. Gen. Samuel Greaves. And though he won't discuss details, Defense Secretary Jim Mattis acknowledges plans exist for an allied military response.

TWO U.S. AIR FORCE B-1B BOMBERS FLY WITH JAPANESE F-2S. CREDIT: COURTESY PHOTO

The statements come as leaders in Washington and Pyongyang amp up their rhetoric. After President Donald Trump told North Korea its threats will be met with "fire and fury like the world has never seen," North Korea responded by revealing plans to strike U.S. military installations on Guam with a Hwasong-12 intermediate-range ballistic missile, a single-stage, liquid-fuel rocket.

The U.S. would have several opportunities to intercept such a missile. American and Japanese Aegis Ballistic Missile Defense ships could fire Raytheon Standard Missile-3 exoatmospheric interceptors. An Army Terminal High-Altitude Area Defense (THAAD) battery, stationed on Guam since 2013, could also finish off any targets. If North Korea tried to strike Alaska or Hawaii with the new intercontinental ballistic missile (ICBM) that it fired twice in July—the two-stage liquid-fuel Hwasong-14—the U.S. would attempt an intercept with its flight-ready Ground-Based Interceptors at Fort Greeley, Alaska, and Vandenberg AFB, California.

Greaves expresses confidence that the missile defense architecture installed over the past two decades is ready. Nevertheless, Trump is now pledging to increase funding for missile defense by billions of dollars.

In addition to being able to defend against an attack and use diplomacy, the Pentagon is making sure that its words are backed by military might. "The combined allied militaries now possess the most precise, rehearsed and robust defensive and offensive capabilities on Earth," says Mattis. North Korea's "actions will continue to be grossly overmatched by ours, and it would lose any arms race or conflict it initiates."

Counter-UAS Rules

Classified guidance sent by the Pentagon to certain U.S. military bases detailing how to counter small unmanned aircraft systems (UAS) appears aimed at addressing concerns over whether and how personnel can deal with the growing threat posed by commercial drones. "When it comes to UAS or drones operating over military installations, the new guidance does afford us the ability to take action to stop those threats," Pentagon spokesman Navy Capt. Jeff Davis says. The guidance may clear up confusion over how the Defense Department can counter drones without violating FAA rules.

Congress, in the fiscal 2017 National Defense Authorization Act, gave the Defense and Energy depart-

ments authority to protect nuclear deterrence, missile defense and national security space installations from drones. The Pentagon issued a classified policy in early July on how to counter drones at such locations, and guidance issued on Aug. 4 instructs installation commanders to communicate with local officials and publicize the prohibition of operating drones over the bases.

Action allowed under the new guidance includes tracking, disabling and destroying drones, depending on the circumstance and type of installation where UAS activity is detected, Davis says. The FAA is coordinating with the other agencies.

Restricted Airspace

Trump's 17-day visit to his Bedminster, New Jersey, golf club is putting the squeeze on nearby airports and aviation-related ventures. A bipartisan handful of New Jersey and Pennsylvania lawmakers are appealing to the Secret Service, the FAA and the Transportation Security Administration for changes to flight restrictions for the 20-plus general aviation airports within the zone affected by Trump's vacation.

In a June letter to Secret Service Director Randolph Alles, the lawmakers, led by Rep. Leonard Lance (R-N.J.), noted there are 28 flight schools and 10 flying clubs in the restricted zone that generate their biggest sales during the summer season. Their economic output amounts to $2.4 billion a year, say Lance and his home-state colleagues Rodney Frelinghuysen (R), Josh Gottheimer (D), Bill Pascrell (D) and Donald Payne, Jr. (D) along with Rep. Brian Fitzpatrick (R-Pa.).

Somerset and Solberg-Hunterdon airports, the letter says, have been operating since the 1940s but have had to shut down because of the flight restrictions. Andover Flight Academy cannot provide its weekend classes and Van Sant Airport and Skydive Jersey have also felt the effects, the lawmakers say.

The congressmen seek procedures accorded to the District of Columbia that allow vetted pilots to fly into and out of the restricted area. No answer yet, midway through Trump's stay.

—With James Drew, Lara Seligman and Graham Warwick in Washington

Editor's note: The photo caption was updated to correct the designation of the Japanese fighter.

Pentagon adds dollars for missile defense, Raytheon pitches SM-3s as ICBM killers

After a series of North Korean ballistic-missile launches, President Donald Trump in August vowed his administration would boost funding for missile defense by "billions of dollars."

Already in the midst of a ballistic missile defense review expected to wrap up by year-end, the Pentagon was directed to look at what could be done in the near term. The first results of president's push are now visible, with Congress approving the transfer of $367 million from other programs to a number of missile defense efforts.

EXTENDED RANGE

- Pentagon begins transfer of $367 million in funds to missile defense efforts
- Optical sensor from Raytheon's SM-3 Block 2A forms basis of Redesigned Kill Vehicle
- Block 2A interceptor could be used to defeat ICBMs

The transfers fund pursuit of a so-called "left-of-launch" capability to defeat mobile missiles while they are still on the ground—whether using a missile fired from a fighter, a ship-launched weapon or an attack by special forces. They also provide funding to start the effort of creating 20 new missile-defense silos at Fort Greely, Alaska, as well as for upgrades to a sea-based X-band radar and additional testing of the SM-3 Block 2A interceptor.

THE SM-3 BLOCK IIA IS IN LIMITED PRODUCTION, AND TESTING ON THE INTERCEPTOR CONTINUES. CREDIT: RAYTHEON

Raytheon has been pitching the latest Block 2A version of its SM-3 air-defense missile, which is being cooperatively developed by the U.S. and Japan to destroy medium- and intermediate-range missiles in space during the midcourse stage of their flight and is to be used against even longer-range missiles.

The enlarged, 21-in.-dia. missile already has the speed, range and altitude performance needed to defeat ICBMs. By design, the optical seeker developed for the SM-3 Block 2A's enlarged hit-to-kill Kinetic Warhead is also the centerpiece of the Redesigned Kill Vehicle (RKV). By 2022, it will begin replacing legacy kill vehicles on the new Ground-Based Interceptors (GBI) in Alaska.

The RKV is being developed by a Boeing-led industry consortium, including Lockheed Martin and Raytheon. Raytheon says that with a few software tweaks ported across from the RKV, the SM-3 Block 2A could be used against ICBM targets.

"On the RKV program, we're developing algorithms to improve the performance capability of that sensor. It's nothing more than software and firmware," explains Rondell Wilson, Raytheon's lead engineer for air and missile defense products. "That goes directly back into SM-3 Block 2A, and now you have an ICBM-killer capability."

The SM-3 Block 2A will be the primary armament of the U.S. Aegis Ashore site being activated in Poland next year. Raytheon says similar land-based installations could be set up in Hawaii or on the U.S. East or West Coasts as a redundant second layer of defense against potential missile attacks.

If billions of additional dollars are unlocked for missile defense, Wilson says, the supersized SM-3 Block 2A and lower-altitude Block 1B would provide the greatest capability faster. "We can provide SM-3 Block 2A ashore as an under-layer capability for GBI, thereby maximizing the magazine depth of those high-value GBIs," he says. "We can do that immediately."

The SM-3 Block 2A is in testing and has already entered limited production. Raytheon's principal supplier is Japan's Mitsubishi Heavy Industries, which provides the second- and third-stage boosters and nose cone.

The missile has completed two successful flight tests, and it knocked out its first ballistic missile target in February. But the second intercept test, in June, failed, reportedly because a sailor on the USS John Paul Jones pressed the wrong button and the missile self-destructed after launch. "We know it wasn't the interceptor," Wilson says.

For threats within the atmosphere, Raytheon is also proposing land-based SM-6 interceptors for the Army. It is the U.S.'s longest-range air defense weapon, typically carried by Aegis-equipped guided-missile destroyers.

Dean Gehr, Raytheon's director for the Land-Based Standard Missile, says the SM-6 has been demonstrated against aircraft, cruise missiles and even ships. It can also intercept missile warheads as they reenter the atmosphere and after any decoys have burned up.

"You've got a lot of capability in the SM-3 and SM-6, so why not bring that capability ashore?" Gehr says. "It already is ashore as part of Aegis Ashore, but bring it into a form factor where we can integrate it with existing Army systems, then you've got layered defense."

Raytheon has proposed different launcher options for SM-6, such as the M1120 HEMTT Load-Handling system used with Lockheed Martin's Terminal High-Altitude Air Defense (Thaad) system. Fire control for the Army could be provided by Northrop Grumman's Integrated Air and Missile Defense Battle Command System.

Raytheon also wants the Pentagon to adopt its long-range radar systems, specifically the Thaad system's X-band TPY-2 and the S-band SPY-6 Air and Missile Defense Radar under development for the Navy.

Can Congress stop missile defense kill-vehicle production from flatlining?

At Raytheon's Space Factory, nestled in the Sonoran Desert, engineers are building some of the world's most complex and sensitive military devices: Exoatmospheric Kill Vehicles, or EKVs, designed to protect the U.S. homeland from the world's deadliest weapons.

In a room designed to filter out nearly all dust particles from the air, two EKVs—dubbed Payload 70 and 71 —are nearing the end of their assembly. These two payloads, one of which is the Block 1 variant, are scheduled to be launched on Ground-Based Interceptors to snuff out a mock intercontinental ballistic missile (ICBM) in an upcoming operational test.

They are among the last of the Capability Enhancement II (CE-2) series of EKVs being delivered by Raytheon. Production is winding down, since the U.S.'s current plan calls for fielding just 44 interceptors by year-end. The question now is whether more will be required to replace the ones that will be lost to testing, such as Payloads 70 and 71, or whether the entire Boeing-led Ground-Based Midcourse Defense (GMD) fleet will grow beyond 44.

"Hit To Kill"

- Support builds for U.S. Missile Defense Agency to expand the number of Ground-Based Interceptors beyond 44
- Raytheon lobbying for "a handful" more CE-2 Block 1 Exo-atmospheric Kill Vehicle orders to bridge production gap
- Ballistic Missile Defense Review will inform size of Boeing-built Ground-based Midcourse Defense enterprise

Growth seems likely. Support for an expanded fleet includes members of Congress and even the Chairman of the Joint Chiefs of Staff Marine Gen. Joseph Dunford. "We do think an increase is warranted," he says.

That could help Raytheon bridge what would otherwise be a five-year production gap, before the EKV's successor payload, the Redesigned Kill Vehicle (RKV), comes online about 2022.

Raytheon officials say the government should at least buy additional rounds to replace those boosters and kill vehicles expended during testing to maintain a flight-ready fleet of 44 interceptors.

"We have options. We can provide the government with several more," says Rondell Wilson, Raytheon's lead engineer for air and missile defense products. "We're offering the government ways to ramp up the quantities. That will keep the numbers at 44 for a longer period of time until the next kill vehicle [RKV] comes online."

The Space Factory opened in 2002, and the first generation of EKVs went into operational service two years later. The original EKV was essentially a hand-made prototype, leading to well-documented reliability issues and intercept test failures. However, Raytheon says hard-earned lessons from past problems have been incorporated into this latest variant, the CE-2 Block 1.

In May, a CE-2 Block 1 EKV destroyed a mock ICBM for the first time in the program's history. The next step is the GMD system's first operational trial against an ICBM target. It will be the most complex and realistic test yet.

The Senate version of the fiscal 2018 defense authorization bill would provide up to 28 new interceptors, of which half would be operationally activated, bringing the total to 58. The other 14 would be kept in storage as spares. The House's markup of the bill would approve $351 million to "increase Ground-Based Interceptor (GBI) magazine capacity" and purchase three additional kill vehicles and seven three-stage, solid-fuel GBI boosters.

RAYTHEON'S KILL VEHICLES ARE PRODUCED AT ITS "SPACE FACTORY" NEAR TUCSON, ARIZONA. DESIGNED TO INTERCEPT NUCLEAR-ARMED REENTRY VEHICLES IN THE VACUUM OF SPACE, THEY MUST BE ASSEMBLED WITH EXTREME PRECISION. CREDIT: RAYTHEON

In addition, Congress has recently approved the transfer of funding in fiscal 2017 to create 20 new silos in Alaska to house additional GBIs that are expected to use the RKV, eventually bringing the total number of interceptors to 64.

Rep. Mike Rogers (R-Ala.), chairman of the House subcommittee on strategic forces, has been advocating for up to 100 GBI rounds, including standing up an East Coast missile defense site. "I'm happy we're going to add 20 more interceptors, but it should be 60 more," he says. "We really don't have enough, and we need to recognize that fact and get after it more aggressively."

Rogers says the U.S. should never have paused GBI production as it did in the past and should not do so now.

"If the last kill vehicle rolls off the line this year, that gives you approximately 44 or 45 kill vehicles in the fleet. As you test those kill vehicles, you're dropping below 44 after a period of time," Wilson explains. "Time is of the essence to get those additional quantities out there. If you turn EKV off, it's harder to turn it back on."

As Raytheon works to sell additional EKVs, a team including Boeing, Lockheed Martin and Raytheon are proceeding with development of the RKV.

The Boeing-led program, which completed a preliminary design review in March, is valued at $5.8 billion. It brings together experts from across the U.S.' missile defense community in a national effort to increase the "reliability, producibility, testability and cost-effectiveness" of kill vehicles, according to the U.S. Missile Defense Agency (MDA), which is responsible for the program.

The RKV will begin replacing original CE-1 and CE-2 EKV variants, but not newer, more reliable CE-2 Block 1s.

The program remains one of the MDA's top priorities, despite work being slowed in the agency's latest

budget request. The RKV was set to begin replacing EKVs starting in 2020, after testing, but the latest schedule delays several key tests by 1-2 years to begin fielding the weapon system in 2022.

MDA Director Lt. Gen. Samuel Greaves says he is confident in the GMD system's ability to counter new threats from North Korea. Although he was referring to the current generation of GBIs and EKVs, he says the RKV is the necessary next step in the improvement and evolution of kill-vehicle technology.

"RKV is an improved single-shot capability," Greaves explains. "The first step is to deliver RKV, to build the confidence in the warfighter's mindset and improve tactics, techniques and procedures."

THE REDESIGNED KILL VEHICLE (PICTURED) IS DESIGNED WITH FEWER PARTS AND WIRES THAN THE CURRENT-GENERATION EXO-ATMOSPHERIC KILL VEHICLE, THEREBY BRINGING DOWN THE UNIT COST AND REDUCING THE LIKELIHOOD OF COMPONENT FAILURE. CREDIT: RAYTHEON

Boeing is responsible for the overall RKV program, and Lockheed and Raytheon are major suppliers. Raytheon is handling more than 50% of the workshare, including eventual production in Tucson, Arizona, in its specialized Space Factory.

The team is working toward a critical design review, after which actual hardware will start coming together for testing. Raytheon is confident the RKV can be delivered sooner than the latest time line without compromising engineering.

Wilson says the legacy EKVs were rushed into production and fielded to meet urgent national requirements. The drivers then, as now, are North Korea and Iran.

"People liken [the EKV] to a prototype vehicle that was prepped for service, and that's not too far from the truth. It's a very complex vehicle to build," Wilson says. "It's taken several iterations of manufacturing experience to build it properly. I think it's a very reliable vehicle; however, the lessons learned on how difficult it is to produce that vehicle have been rolled into the Standard Missile-3 family and RKV."

The new RKV uses the same seeker developed for the newest SM-3 Block 2A exoatmospheric interceptor. The industry team completed a seeker requirements review with the government last year and is now developing software updates for better tracking and target discrimination of rogue warheads, as well as algorithms to distinguish real warheads from decoys and penetration aids.

The RKV's communication system is being improved to receive targeting information updates throughout most of the flight, instead of intermittently. The government has also reinstated key survivability requirements to overcome advanced enemy tactics such as blinding by nuclear explosion. The number of unique parts required to build the RKV will also come down dramatically to reduce cost and streamline assembly.

"[RKV is] a capability that's needed by the warfighter," Wilson says. "It's easier to produce, and if something needs to be modified or updated on the kill vehicle, it's out of commission for weeks instead of months at a time."

The GMD system is the largest and most costly element of the U.S. ballistic missile defense architecture, requiring billions of dollars in funding each year. Since 2002, the MDA has received approximately $123 billion from Congress to develop that architecture, which includes money for GMD, Terminal High-Altitude Area Defense, Aegis and dozens of other interceptors, launchers, sensors and command-and-control systems. The MDA will require $37 billion more through fiscal 2021 to continue those efforts, says the U.S. Government Accountability Office.

Raytheon warns against 'short-changing' MOKV developmen

The Holy Grail of the U.S. Missile Defense Agency (MDA) has long been the Multi-Object Kill Vehicle (MOKV), which would allow one interceptor to tackle several incoming nuclear warheads hurtling toward the U.S.

The realization of this technology could make today's interceptors look rather primitive and wasteful, since operators must currently fire two or three multimillion-dollar Ground-Based Interceptors (GBI) at each warhead they detect to maximize the chances of success.

The fleet of interceptors located at Fort Greely, Alaska, and Vandenberg AFB, California, might take on 20 incoming warheads at most when armed with the single-target Exoatmospheric Kill Vehicle (EKV). But what happens if each incoming missile carries multiple warheads, plus decoys and other penetration aids? That is where MOKV would excel.

FUTURE INTERCEPTOR

- Raytheon warns against accelerating MOKV at the expense of RKV
- U.S. shouldn't "short-change" risk reduction in race to develop MOKV
- Boeing, Lockheed Martin want greater share of kill vehicle market

The MDA has hired Boeing, Lockheed Martin and Raytheon to begin maturing the advanced sensor, guidance, propulsion and communication technologies required for the MOKV payload, essentially a cluster of tiny, wirelessly networked kill vehicles.

Support for the program has been increasing in the wake of new missile tests by North Korea and Iran, which U.S. President Donald Trump singled out as rogue nations from the U.N. podium Sept. 19, where he emphasized that the countries are two of the most serious threats to U.S. national security.

To counter the potential threat of a missile raid by one of these countries, the MDA has proposed accelerating MOKV by about five years for deployment in the latter half of the 2020s.

But while contractors involved in MOKV would happily speed up development of their competing concepts with the infusion of additional funds, they do not want the acceleration to come at the expense of the nearer-term Redesigned Kill Vehicle (RKV) being developed by Boeing along with Lockheed and Raytheon.

"The importance of RKV cannot be overstated," says Rondell Wilson, Raytheon's lead engineer for air and missile defense products. "There is no new science here. None. It is really about engineering and integration. MOKV, while that capability is needed based on where the threat is going, that technology is further out. It is not as mature."

Wilson also was involved in this kind of work when Lockheed and Raytheon first developed MOKV-like concepts under the MDA's Multi-Kill Vehicle (MKV) program, which was terminated by Defense Secretary Robert Gates in 2009. The cancelation of MKV came not long after Lockheed conducted a simulation of its kill-vehicle concept operating in space at the National Hover Test Facility at Edwards AFB, California, in

December 2008.

The competing systems from Lockheed and Raytheon were dubbed MKV-L and MKV-R, respectively, and would have armed the GBI, SM-3 Block 2A air-defense missile and the MDA's now-defunct Kinetic Energy Interceptor. After several years in limbo, the initiative resumed in 2015 under MOKV.

The three companies involved are reticent to discuss their concepts because much of the work is classified. But each mini kill vehicle will be independently targetable with its own sensor for object identification, tracking and discrimination using advanced algorithms. They will also communicate with each other via data link for collaborative swarming.

THE MULTI-OBJECT KILL VEHICLE PROGRAM WAS RESURRECTED BY THE OBAMA ADMINISTRATION, WHICH HAD TERMINATED AN EARLIER EFFORT CALLED MULTIPLE KILL VEHICLE (MKV). RAYTHEON AND LOCKHEED MARTIN HAD BEEN MATURING COMPETING CONCEPTS (LOCKHEED'S PICTURED) FOR MKV PRIOR TO ITS CANCELATION IN 2009.
CREDIT: MISSILE DEFENSE AGENCY

Wilson anticipates strong support for MOKV from the Trump administration. In fact, the MDA's budget proposal for fiscal 2018 would accelerate the program, with the goal of achieving "demonstrated capability in the 2025 time frame."

The agency's new acquisition strategy compresses the risk-reduction and product-development phases to shave about five years off the schedule. Wilson says the competing kill-vehicle teams were awarded contracts earlier this year for the initial 30-month technology maturation phase. That period will be followed by a two-year proof-of-concept phase prior to the source-selection decision for development, production and fielding.

"With what is going on in the world today, I would like to see an acceleration of MOKV," he says. "[But] we should not rush to MOKV at the expense of RKV.

"Some of those cutting-edge technologies are not at the appropriate technology readiness level. Based on my 26-plus years of experience in kill vehicles, I want to make sure we do not short-change risk reduction for MOKV," Wilson stresses.

The MDA's fiscal 2018 budget proposal includes $253 million for MOKV-related technology development, including development and testing of a small solid-propellant divert and attitude control system. Spending on MOKV will average $230 million per year through fiscal 2022 to complete technology maturation and begin development.

At Raytheon, the MOKV program is being run by its Advanced Missile Systems innovation cell. It is the company's sixth distinct kill-vehicle product.

Boeing and Lockheed are leveraging their work on past initiatives and the ongoing RKV program to grow

their in-house kill-vehicle teams and challenge Raytheon.

David Dutcher, Boeing's director of GBI and RKV programs, says the company has the "knowledge and experience" to produce kill vehicles and will be gunning to win a prime position for MOKV development and production. He points to Boeing's contributions to the Raytheon Standard Missile-3 and Lockheed Patriot Advanced Capability-3 interceptors and extensive experience pairing Raytheon's EKV with GBI booster stacks.

"We certainly believe we're capable of being in the kill-vehicle product line," he says.

Bruce Jurcevich, Lockheed's director of advanced interceptor systems, says his company is committed to the MDA's two-phase approach of building RKV and then MOKV. Lockheed's RKV team is based in Huntsville, Alabama, and its MOKV group operates from Sunnyvale, California.

Jurcevich says a significant number of lessons learned from Lockheed's earlier MKV program will be applied to MOKV development, with the aim of enabling each interceptor to take out multiple incoming threats.

The latest round of contracts for MOKV was awarded to Lockheed and Raytheon in April and Boeing in May. They are valued at $53-60 million each, with a period of performance scheduled to run through early 2020.

Anatomy Of U.S. Missile Defense Agency's Key Systems

Anatomy of a Ground-Based Interceptor
Key Suppliers:

- Exoatmospheric Kill Vehicle: Raytheon and Aerojet Rocketdyne
- Integrated Boost Vehicle: Boeing and Orbital ATK

Oversight:

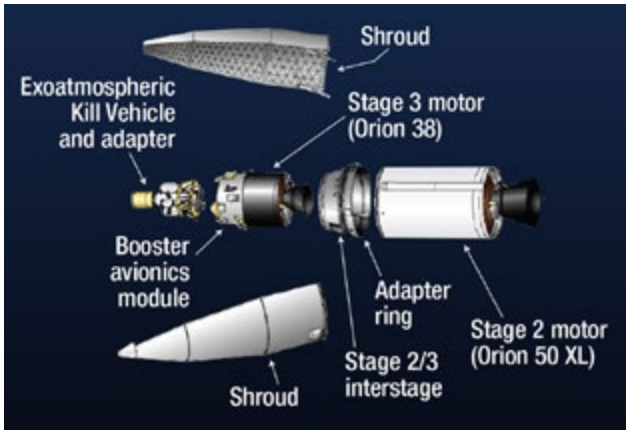
- Missile Defense Agency GMD Joint Program Office

Source: Orbital ATK

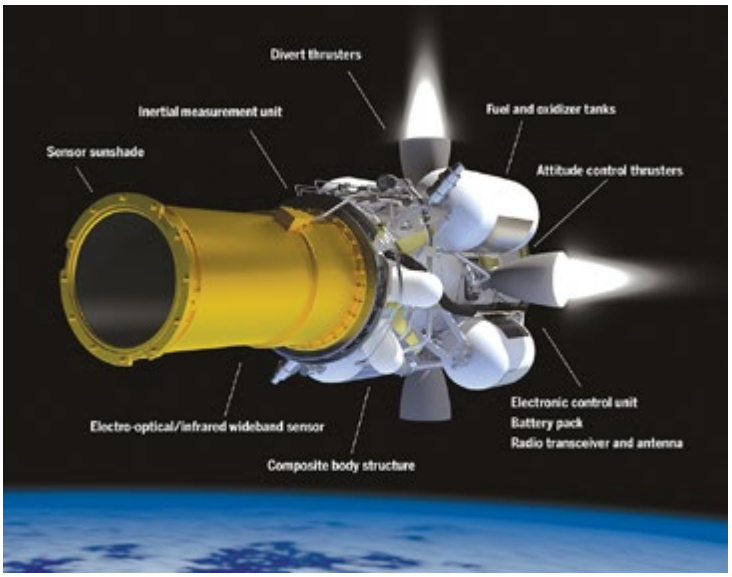
The Ground-Based Interceptor (GBI) is the central flight component of the Boeing Ground-based Midcourse Defense (GMD) system, standing 54.5 ft. tall and measuring 50 in. in diameter with a liftoff mass of 49,567 lb. It is the only operational U.S. interceptor built specifically to destroy intercontinental ballistic missiles in space before their deadly payloads can reenter the atmosphere. The three-stage rocket is based on three solid-fuel Orion motors drawn from Orbital ATK's Pegasus, Taurus and Minotaur families of space launch vehicles. The Orion motors are produced in Utah and then integrated by Boeing at Vandenberg AFB in California. The missile is topped by Raytheon's exoatmospheric hit-to-kill interceptor, which seeks out and extinguishes target reentry vehicles. The GBI booster has gone through three iterations, each adding new capabilities and reliability enhancements, including an inertial measurement unit, onboard batteries as well as environmental protection and ignition safety features. In future versions, operators will be able to select whether to fire all three stages or just two, depending on the range of the intended target. The Missile Defense Agency (MDA) has also announced plans for a next-generation, multi-stage Common Boost Vehicle for deployment around 2024.

Anatomy of the Exoatmospheric Kill Vehicle

The culmination of decades of research, testing and refinement of hit-to-kill interceptor technology, the Exoatmospheric Kill Vehicle (EKV) is designed to intercept payloads of high-speed ballistic missiles in the midcourse or exoatmospheric phase of flight in space. A prototype EKV successfully intercepted its first missile target in 1999 and was put into production in 2003 to meet the George W. Bush administration's requirement for a homeland missile defense capability.



Source: Missile Defense Agency



SOURCES: RAYTHEON AND THE MISSILE DEFENSE AGENCY

The EKV acquires and tracks targets using a highly sensitive infrared sensor, with target updates provided by terrestrial and space-based sensors and radars. The EKV uses advanced discrimination algorithms to differentiate between target reentry vehicles and decoys or space debris. Within the next five years, the EKV will be replaced by the more modular, reliable and lower-cost Redesigned Kill Vehicle (RKV) being developed by Boeing with Lockheed Martin and Raytheon. By 2025, the Missile Defense Agency plans to demonstrate the next-generation Multi-Object Kill Vehicle, which would carry several tiny kill vehicles on a common maneuvering payload bus. Each miniature kill vehicle will have its own seeker and two-way communications data link for collaborative discrimination and targeting.