

Aegis Ballistic Missile Defense (Aegis BMD)

Executive Summary

- The Missile Defense Agency (MDA) conducted three Aegis Ballistic Missile Defense (BMD) intercept flight tests in FY16. Overall, Aegis BMD successfully engaged two ballistic missile targets and one anti-air warfare target and failed to intercept one ballistic missile target.
- The MDA conducted operational flight testing of the Aegis Baseline 9.1 system (i.e., Aegis BMD 5.0 Capability Upgrade) in its Aegis Ashore (Baseline 9.B1) and Aegis destroyer (Baseline 9.C1) configurations with Standard Missile-3 (SM-3) Block IB Threat Upgrade (TU) guided missiles. Additionally, the MDA conducted developmental flight testing of the SM-3 Block IB TU guided missile and Sea-Based Terminal (SBT) capability.
- Although the program completed FOT&E for Aegis BMD 3.6.1 and IOT&E for Aegis BMD 4.0 in FY11 and FY15, respectively, the program continued to use system variants (i.e., Aegis BMD 3.6.3 and 4.0.3) in flight and ground tests and a U.S. Navy Fleet exercise in FY16 to assess element- and system-level engagement capabilities, long range surveillance and track (LRS&T) capabilities, and interoperability with the BMDS and foreign missile defense assets.
- During one of the five live-guided missile tests conducted in FY16, the SM-3 Block IB TU missile failed to launch from the Aegis BMD ship.
- The MDA conducted two developmental flight tests and six design verification and qualification ground test firings of the SM-3 Block IB TU Third Stage Rocket Motor (TSRM) to verify an aft nozzle area re-design that improves missile reliability.
- Testing demonstrated engagement capabilities against short and medium-range ballistic missiles (SRBM/MRBM) in both endo- and exo-atmospheric engagements and against anti-air warfare targets.
- Flight testing, modeling and simulation (M&S), and ground testing have demonstrated Aegis BMD capabilities to perform LRS&T.
- During integration testing of an SM-3 Block IIA flight test round, the Kinetic Warhead's guidance unit experienced a failure.
- Operational Aegis BMD assets and hardware-in-the-loop (HWIL) facilities underwent cybersecurity testing.
- The MDA deployed an Aegis Ashore site to Romania, and the U.S. European Command (USEUCOM) declared it operational.

System

- Aegis BMD is a sea- and land-based missile defense system that employs the multi-mission shipboard Aegis Weapon System, with improved radar and new missile capabilities to



Aegis Cruiser



Aegis Ashore and Vertical Launch System

engage ballistic missile threats. Capabilities of Aegis BMD include:

- Computer program modifications to the AN/SPY-1 radar for LRS&T of ballistic missiles of all ranges
- A modified Aegis Vertical Launching System, which stores and fires SM-3 Block IA and Block IB guided missiles, modified SM-2 Block IV guided missiles, and SM-6 Dual I guided missiles
- SM-3 Block IA and Block IB guided missiles that use maneuverable kinetic warheads to accomplish midcourse engagements of SRBMs, MRBMs, and intermediate-range ballistic missiles (IRBMs)
- Modified SM-2 Block IV guided missiles that provide terminal engagement capability against SRBMs and MRBMs
- SM-6 Dual I guided missiles that provide SBT capability against SRBMs and MRBMs in their terminal phase of flight, anti-ship cruise missiles, and all types of aircraft
- Aegis Ashore (Baseline 9.B1) is a land-based version of Aegis BMD, with an AN/SPY-1 radar and Vertical Launching System to enable engagements against MRBMs and IRBMs with SM-3 guided missiles. The first Aegis Ashore site in Romania is the central, land-based component of the second phase of the European Phased-Adaptive Approach (EPAA) for the defense of Europe.
- Aegis BMD ships and Aegis Ashore are capable of performing missile defense operations and sending/receiving cues to/from other BMDS sensors through tactical datalinks. Aegis BMD ships are capable of performing autonomous missile defense operations while both Aegis BMD ships and Aegis Ashore are capable of performing engagements using remote track data from BMDS sensors.

Mission

The Navy can accomplish three missile defense-related missions using Aegis BMD:

- Defend deployed forces and allies from short- to intermediate range theater ballistic missile threats

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- Provide forward-deployed radar capabilities to enhance defense against ballistic missile threats of all ranges by sending cues or target track data to other BMDS elements
- Provide ballistic missile threat data to the Command and Control, Battle Management, and Communications (C2BMC) system for dissemination to Combatant Commanders' headquarters to ensure situational awareness

Major Contractors

- Aegis BMD Weapon System: Lockheed Martin Corporation, Rotary and Mission Systems – Moorestown, New Jersey
- AN/SPY-1 Radar: Lockheed Martin Corporation, Rotary and Mission Systems – Moorestown, New Jersey
- SM-3, SM-2 Block IV, and SM-6 Dual I Missiles: Raytheon Company, Missile Systems – Tucson, Arizona

Activity

- The MDA conducted all testing in accordance with the DOT&E-approved Integrated Master Test Plan.
- In FY16, the MDA conducted operational flight testing of the Aegis Baseline 9.1 system in its Aegis Ashore (Baseline 9.B1) and Aegis destroyer (Baseline 9.C1) configurations with SM-3 Block IB TU guided missiles and conducted developmental flight testing of SBT capability.
- Although the program completed FOT&E for Aegis BMD 3.6.1 and IOT&E for Aegis BMD 4.0 in FY11 and FY15, respectively, the program continued to use system variants (i.e., Aegis BMD 3.6.3 and 4.0.3) in flight tests, system-level tests, and a U.S. Navy Fleet exercise in FY16 to assess element- and system-level engagement and LRS&T capabilities and interoperability with the BMDS and foreign missile defense assets.
- The MDA conducted three Aegis BMD intercept flight tests in FY16. Overall, Aegis BMD successfully engaged two ballistic missile targets and one anti-air warfare target and failed to intercept one ballistic missile target.
 - In October 2015, Aegis BMD participated in At-Sea Demonstration-15, a multi-event fleet exercise conducted in the United Kingdom's Hebrides Missile Range wherein assets from NATO member countries exchanged air and ballistic missile message information across operational communication architectures during cruise missile and ballistic missile engagements. In one of the nine exercise events, an Aegis BMD 3.6.3 destroyer with an SM-3 Block IA guided missile engaged and intercepted a non-separating SRBM target. Participating assets also included an Aegis BMD 3.6.3 laboratory representation, an Aegis 5.3.10 air defense ship, C2BMC, and Allied naval vessels from Great Britain, Spain, Netherlands, Italy, Canada, France, and Norway.
 - In November 2015, an Aegis Baseline 9.C1 destroyer operating in Integrated Air and Missile Defense (IAMD) radar priority mode participated in Flight Test Operational (FTO)-02 Event 2a at Wake Island and the broad-ocean area surrounding it. The MDA and BMDS Operational Test Agency (OTA) designed the test mission to demonstrate a layered BMDS with Aegis BMD and Terminal High-Altitude Area Defense (THAAD) sharing common defended areas and shot opportunities against two threat-representative ballistic missile targets. The primary Aegis BMD test objective was to prosecute a ballistic missile engagement in the presence of non-organic post-intercept debris generated by a THAAD intercept, while simultaneously conducting anti-air warfare against an anti-ship cruise missile surrogate. However, the SM-3 missile failed in flight, preventing a midcourse intercept of the ballistic missile target, while the Aegis BMD ship did successfully engage the cruise missile surrogate with an SM-2 Block IIIA guided missile. The MDA initially attempted to conduct this test in October 2015 as FTO-02 Event 2; however, due to a THAAD target malfunction, the October event was a "No Test."
- In December 2015, the OTA and the MDA conducted FTO-02 Event 1a at the Pacific Missile Range Facility (PMRF) on Kauai, Hawaii. The test intended to demonstrate the operational capability of the EPAA Phase 2 BMDS, anchored by the Aegis Ashore combat system, to defend Europe against MRBMs. In the test, the Aegis Ashore Missile Defense Test Complex at PMRF engaged an air-launched MRBM target with an SM-3 Block IB TU guided missile using data from an AN/TPY-2 (Forward-Based Mode (FBM)) radar located at PMRF. This was the first intercept flight test for Aegis Ashore.
- Aegis BMD participated in two live-target and five live-guided missile test events in FY16. During one of the live-guided events, the SM-3 Block IB TU missile failed to launch from the Aegis BMD ship.
 - In December 2015, the MDA conducted Aegis Ashore Control Test Vehicle-02 (CTV-02), a guided missile-only firing of an SM-3 Block IB TU missile. The MDA conducted this live-fire event as a risk reduction flight for FTO-02 Event 1a.
 - In December 2015, the MDA conducted Standard Missile Cooperative Development CTV-02, a guided missile-only, developmental flight test of the SM-3 Block IIA missile through nosecone deployment and kinetic warhead ejection. This was the second live-fire event for the SM-3 Block IIA guided missile, which is a joint U.S.-Japanese development of a 21-inch diameter variant of the SM-3.
 - In February 2016, the MDA conducted Standard Missile CTV-01, planned to be the first of two guided missile-only firings to verify the re-designed SM-3 Block IB TU TSRM aft nozzle area. The SM-3 Block IB TU missile failed to launch from the Aegis BMD 3.6.3 destroyer.

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- In May 2016, the MDA conducted SM CTV-01a, a re-test of SM CTV-01. An Aegis BMD 3.6.3 destroyer fired an SM-3 Block IB TU guided missile against a simulated test target to exercise a two-pulse firing of the TSRM using a minimum inter-pulse delay between the TSRM axial thrust burns. This was the first SM-3 Block IB firing from an Aegis BMD 3.6.3 ship.
 - In May 2016, the MDA conducted SM CTV-02. An Aegis BMD 3.6.3 destroyer fired an SM-3 Block IB TU guided missile against a simulated test target to exercise a two-pulse firing of the TSRM using a maximum inter-pulse delay between TSRM axial thrust burns.
 - In May 2016, the MDA conducted Flight Test Other-21 (FTX-21), planned to demonstrate the ability of an Aegis Baseline 9.C1-configured destroyer to detect and track an MRBM target within the Earth's atmosphere. The test was a risk reduction exercise for the future Flight Test Standard Missile (FTM)-27 flight test mission, which is planned for 1QFY17.
 - In June 2016, the Navy conducted Pacific Dragon, a Commander, Pacific Fleet-directed exercise. An Aegis Baseline 9.C2-equipped ship performed a simulated SM-3 Block IIA engagement against a separating MRBM target. This exercise served as risk reduction for the future Standard Missile Cooperative Development Project Flight Test Standard Missile-01 (SFTM-01) flight test mission and explored interoperability between U.S. Navy forces and naval assets from Japan and the Republic of Korea.
 - Aegis BMD provided HWIL representations for four BMDS ground tests that provided information on Aegis BMD interoperability and functionality in various regional/theater scenarios:
 - GTD-06 Part 1 in October 2015 examined defense of USEUCOM and U.S. Central Command scenarios, using Aegis Baseline 9.B1 (Aegis Ashore Missile Defense System in Romania), Baseline 9.C1, Aegis BMD 4.0.3, and Aegis BMD 3.6.3.
 - GTI-06 Part 2 in April 2016 examined defense of U.S. Pacific Command and Homeland defense scenarios, using Aegis Baseline 9.C1, Aegis BMD 4.0.3, and Aegis BMD 3.6.3.
 - GTI-Israel-16 in June 2016 studied interoperability between the BMDS and the Arrow Weapon System for maintaining shared situational awareness, using Aegis BMD 4.0.3 and Baseline 9.C1.
 - GTD-06 Part 2 in September 2016 again examined defense of U.S. Pacific Command and Homeland defense scenarios, using Aegis BMD 3.6.3, Aegis BMD 4.0.3, and Aegis Baseline 9.C1.
 - During integration testing of an SM-3 Block IIA flight test round, in preparation for SFTM-01, the MDA discovered a problem with the Kinetic Warhead's Guidance Unit.
 - The Navy's Commander, Operational Test and Evaluation Force (COTF) conducted high-fidelity digital M&S runs using accredited models in support of Aegis Baseline 9.B1 in September 2016.
 - COTF conducted a cybersecurity Adversarial Assessment of Aegis Baseline 9.B1 in June 2016 at the Aegis Ashore Missile Defense Facility in Romania. The Adversarial Assessment was the first cybersecurity assessment conducted on the Aegis Ashore Missile Defense System.
 - USEUCOM declared the Aegis Ashore Missile Defense System in Romania operational in July 2016.
- ### Assessment
- The Aegis BMD 4.0 system, which is the latest, widely deployed version of Aegis BMD and the primary sea-based firing asset for EPAA Phase 2, participated in HWIL and distributed ground test events in FY16 primarily to demonstrate LRS&T improvements in support of Ground-based Midcourse Defense (GMD) with the Aegis BMD 4.0.3 update.
 - Prior IOT&E flight testing and supporting M&S demonstrated that Aegis BMD 4.0 has the capability to engage and intercept non-separating, simple-separating, and complex-separating ballistic missiles in the midcourse phase with SM-3 Block IB guided missiles. However, flight testing and M&S are not yet sufficient to assess the full range of expected threat types, ground ranges, and raid sizes. Details on Aegis BMD 4.0 performance can be found in the classified December 2014 Aegis BMD 4.0 IOT&E Report.
 - In FY16, Aegis Baseline 9.B1 and Baseline 9.C1 underwent operational flight testing of those systems' remote engagement capabilities with SM-3 Block IB TU guided missiles using data from an AN/TPY-2 (FBM) radar (during FTO-02 Events 2a and 1a). The successful intercept in FTO-02 Event 1a by the Aegis Ashore Missile Defense Test Complex at PMRF demonstrated an MRBM defense capability relevant to EPAA Phase 2. During FTO-02 Event 2a, the SM-3 failed in flight; however, this event contributed tracking and engagement processing data relevant to an assessment of Aegis BMD's remote engagement capabilities. Similar to previous tests with remote engagements (FTM-15 in FY11 and FTM-20 in FY13), the system did not use remote AN/TPY-2 (FBM) radar data throughout the engagement. Instead, the firing assets consummated the engagement using local AN/SPY-1 radar data. Although Aegis BMD HWIL, distributed ground testing, and unaccredited high-fidelity M&S have demonstrated all remote engagement modes, the lack of a flight test demonstration of a fully remote engagement reduces certainty in that capability. High-fidelity digital M&S run results using accredited models in support of Aegis Baseline 9.B1 will be available 1QFY17 to support future assessments.
 - In FTO-02 Event 2a, the SM-3 Block IB TU guided missile failed early in flight due to a faulty G-switch in the guidance section of the missile. The malfunctioning G-switch precluded the separation of the missile's second stage from the first stage. A failure review board (FRB) determined that the G-switch malfunctioned due to mechanical failure caused by abnormally high sticking in the component's lubricant. The program implemented improved testing and screening of the G-switch

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before acceptance for installation to address the problem.

The MDA implemented the new process changes prior to the successful SM CTV-01a and -02 flight tests.

- The MDA demonstrated the efficacy of the SM-3 Block IB TU re-designed TSRM aft nozzle area, to improve missile reliability following the FTM-16 Event 2 (FY11) and FTM-21 (FY13) failures during two flight tests (SM CTV-01a and -02) and six design verification and qualification ground test firings.
- Additional SM-3 Block IB component anomalies have occurred in recent flight and lot acceptance testing, one resulting in a failed SM-3 launch.
 - Low TSRM Attitude Control System cold gas regulator (CGR) pressures were observed in FTM-25 (FY15) and during lot acceptance testing. The CGR anomaly in FTM-25 did not preclude the target from being intercepted; however, the cold gas pressure observed was much lower than that commanded. If the regulated pressure from the CGR is too low, the Attitude Control System may not function properly. The Prime Contractor (Raytheon Missile Systems) established an FRB, which determined that now-defunct tooling procedures caused the FTM-25 CGR anomaly. The FRB determined that changes to the CGR C-seal's spring dimensions, additional inspections, and an enhanced acceptance test process addressed the low pressure anomalies from the lot acceptance tests.
 - A second anomaly was observed during SM CTV-01 when an SM-3 Block IB TU failed to launch due to the missile failing a pre-launch booster nozzle response built-in test designed to ensure safe missile egress from the firing ship. An FRB determined that random minor voltage glitches in guidance section components caused short-duration (tens of milliseconds) corrupted commands to be sent to the booster nozzle, which resulted in a failure of the built-in test. To address the problem, the program developed software that mitigates the possibility of failure by introducing logic to re-send commands up to two additional times. The new software was successfully flown in SM CTV-01a and -02, and will be installed on new production rounds.
 - Third, lot acceptance testing revealed a number of SM-3 Block IB TU kinetic warhead guidance units that were unresponsive at power up. An FRB established the root cause to be related to memory management during boot up. The MDA has implemented a minor change to the kinetic warhead's guidance unit software to correct the anomaly. These two software changes will be loaded on all Block IB TU missiles at their 4-year recertification periods.
- The successful simulated engagement in the Pacific Dragon Fleet exercise demonstrated the organic engagement capabilities of the Baseline 9.C2 system.
- The FTX-21 flight mission demonstrated the endo-atmospheric tracking capabilities of the Aegis Baseline 9.C1 system, which are relevant for the SBT engagement mission; however, no SBT engagements were attempted in FY16. To date, intercept testing of the Baseline 9.C1's SBT capabilities consists of the first two multi-mission warfare events in FY15. These events demonstrated that SM-6 Dual I and SM-2 Block IV missiles can be used to conduct SBT engagements against non-separating SRBMs, but high-fidelity M&S analyses conducted using models accredited by the BMDS OTA have not yet occurred, so SBT engagement performance cannot be quantitatively evaluated. Completion of a subset of the SBT M&S analyses is expected in 1QFY17.
- The MDA demonstrated Aegis Baseline 9.C1 system's IAMD capabilities to a limited degree in FTO-02 Event 2a, when the firing ship performed a remote ballistic missile engagement with the system operating in IAMD radar priority mode while conducting an anti-air warfare engagement against a single cruise missile surrogate. The demonstration of IAMD capabilities in FTO-02 Event 2a was not stressing, even less so than during FTM-25 (FY15), where a raid of two cruise missiles and a single ballistic missile target were simultaneously engaged in an organic engagement.
- Reliability, maintainability, availability, and supportability (RMA&S) data collected during Aegis Baseline 9.1 BMD-related testing through FY15 show that the system has lower than desired software stability. Also, the data show that the system does not currently meet its requirements for availability and mean time to repair hardware, mostly due to a series of early Aegis Display System failures and an AN/SPY-1 radar coolant leak that downed the system for an extended period of time. The majority of the Aegis Display System problems have since been addressed with the installation of new console graphics cards. DOT&E will reassess RMA&S once the MDA completes FTM-27 planned for December 2016.
- ASD-15 demonstrated Aegis BMD 3.6.3 retention of Aegis BMD 3.6.1 midcourse engagement capabilities against non-separating SRBMs, when an Aegis BMD 3.6.3 ship detected, tracked, and intercepted an SRBM using an SM-3 Block IA guided missile. ASD-15 also demonstrated that Aegis BMD can interoperate with NATO defenses and exchange air and ballistic missile message information across operational communication architectures during cruise missile and ballistic missile engagements. The MDA further demonstrated Aegis BMD 3.6.3 capabilities in FY16 during SM CTV-01a and -02, when an Aegis BMD 3.6.3 destroyer fired SM-3 Block IB TU missiles for the first time. Aegis BMD 3.6.3 is the only variant of the Aegis BMD 3.6 system that can fire SM-3 Block IB missiles.
- The MDA continues to utilize Aegis BMD assets and HWIL representations in ground test events and warfighter simulation exercises during operational flight test campaigns (e.g. FTO-02), which has helped to refine tactics, techniques, and procedures (TTPs) and overall interoperability of the system with the BMDS. However, the test events routinely demonstrated that inter-element coordination and interoperability need improvement. The tests highlighted multiple classified suitability and effectiveness shortfalls.
- The MDA continues to participate in tests of opportunity like the Pacific Dragon exercise, which provide a venue to explore interoperability between Aegis BMD assets and foreign ballistic missile defense assets. In Pacific Dragon, Aegis BMD

successfully exchanged data with Allied units from Japan and the Republic of Korea.

- Following the integration testing failure of an SM-3 Block IIA flight test round, the MDA initiated a Failure Investigation Team process and developed a fault tree. The flight test round will be disassembled and will undergo further analysis to determine the root cause of the failure.
- Cybersecurity testing results from the Adversarial Assessment of the Aegis Ashore Missile Defense Facility in Romania will be included in DOT&E's classified 2016 BMDS Annual Report to Congress.
- Testing has uncovered a number of classified survivability problems, which will be discussed in DOT&E's classified 2016 BMDS Annual Report to Congress.

Recommendations

- Status of Previous Recommendations. The program:
 1. Addressed the first recommendation from FY13 to conduct flight testing of the Aegis BMD 4.0 remote engagement authorized capability against an MRBM or IRBM target using SM-3 Block IB guided missiles, when it conducted FTO-02 Events 1a and 2a using Aegis Baseline 9.1 (BMD 5.0 Capability Upgrade) firing assets.
 2. Partially addressed the second recommendation from FY13, to conduct operationally realistic testing that exercises Aegis BMD 4.0's improved engagement coordination with THAAD and Patriot, when it conducted FTO-02 Event 2a using an Aegis Baseline 9.C1 destroyer and THAAD firing assets. This flight test did not include Patriot.
 3. Addressed the second recommendation from FY14, to determine the appropriate LRS&T TTPs for the transmission and receipt of Aegis BMD 4.0 track data for GMD use. GTI-06 Part 3 (FY15), GTI-06 Part 2, and GTD-06 Part 2 demonstrated that GMD can use data provided by Aegis BMD 4.0.3.
 4. Partially addressed the third recommendation from FY14, to ensure that sufficient flight testing of the Aegis Baseline 9.C1 system is conducted to allow for verification, validation, and accreditation (VV&A) of the M&S suite to cover the full design to Aegis BMD battlespace. Flight testing conducted in FY15 and early FY16 provided additional VV&A data, but the BMDS OTA has not yet accredited the high fidelity M&S suite.
- 5. Addressed the fourth recommendation from FY14, to conduct sufficient ground and flight testing of the redesigned insulation components in the SM-3 Block IB TSRM nozzle to prove the new design works under the most stressing operational flight conditions. This occurred when the program completed a series of six design verification and qualification ground test firings and the SM CTV-01a and CTV-02 flight tests.
- 6. Addressed the first recommendation from FY15, to use an industry-led FRB process to identify the root cause of low cold gas pressure anomalies observed in lot acceptance testing of the SM-3 Block IB CGR, and determine the appropriate corrective actions needed to ensure proper functioning. The FRB process determined that changes to the CGR C-seal's spring dimensions, additional inspections, and an enhanced acceptance test process were required and a follow-on study is underway to investigate the possibility of re-designing the CGR seal.
- 7. Has not addressed the second recommendation from FY15, to conduct stressing simultaneous air and ballistic missile defense engagements with the Aegis Baseline 9.C1 system operating in IAMD radar priority mode, with multiple ballistic missiles and anti-ship cruise missile threats being simultaneously engaged.
- 8. Has not addressed the third recommendation from FY15, to perform high-fidelity M&S analysis over the expected Aegis Ashore engagement battlespace for EPAA Phase 2 to allow for a broad quantitative evaluation of engagement capability. The MDA plans to complete the high-fidelity M&S analysis in FY18.
- FY16 Recommendations. The MDA should:
 1. Conduct high-fidelity M&S runs-for-the-record for the Aegis Baseline 9.2 system (Aegis BMD 5.1) to assess performance across the expected engagement battlespace in all Combatant Commands' Areas of Responsibility and develop an appropriate M&S VV&A plan to support that effort.
 2. Conduct a live-flight test demonstration of a fully remote engagement.
 3. Include BMDS OTA RMA&S data collectors in all flight test missions to improve the accuracy and statistical confidence of future suitability assessments.

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