Aegis Ballistic Missile Defense (Aegis BMD)

Executive Summary

- The Missile Defense Agency (MDA) conducted five Aegis Ballistic Missile Defense (BMD) intercept flight tests in FY/CY17. Aegis BMD successfully engaged four of the five ballistic missile targets in those tests. During one of these tests, Aegis BMD successfully engaged a complex ballistic missile for the first time. Such missiles pose a challenge in discriminating the target reentry vehicle from other objects. In another test, Aegis BMD intercepted a simple ballistic missile target with a Standard Missile-3 (SM-3) Block IIA missile for the first time.
- Aegis BMD participated in six non-intercept flight test events in FY/CY17 with simulated Standard Missile variants engaging live targets and a live SM-6 Dual I missile engaging a simulated target.
- Aegis BMD provided hardware-in-the-loop (HWIL) representations for two Ballistic Missile Defense System (BMDS) ground tests that provided information on Aegis BMD interoperability and functionality in various regional/theater and strategic scenarios.
- The MDA delivered high-fidelity digital modeling and simulation (M&S) runs-for-the-record results in FY17 to support assessments of Aegis Ashore (Baseline 9.B1) and Aegis Baseline 9.C1 Sea-Based Terminal (SBT) performance for select scenarios.
- DOT&E has lower confidence in SM-3 missile reliability due to recent in-flight failures, coupled with MDA shortfalls in simulating the in-flight environment in its SM-3 ground test program, addressing failures and anomalies identified during flight testing, and implementing a rigorous configuration management and control process for SM-3 production.

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 engage ballistic missile threats. The Aegis BMD includes:
  - Computer program modifications to all Aegis Weapon System elements, including the AN/SPY-1 radar, to support multiple BMDS mission capabilities including long-range surveillance and track, engagement support surveillance and track, and organic engagement with the SM-3, SM-6, or modified SM-2 Block IV missile variants against ballistic missiles of all ranges
  - A modified Aegis Vertical Launching System, which stores and fires SM-3 Block IA, Block IB, and Block IIA guided missiles, modified SM-2 Block IV guided missiles, and SM-6 Dual I guided missiles
  - SM-3 Block IA, Block IB, and Block IIA guided missiles that use maneuverable kinetic warheads to accomplish midcourse engagements of short-range ballistic missiles (SRBMs), medium-range ballistic missiles (MRBMs), and intermediate-range ballistic missiles (IRBMs)
  - Modified SM-2 Block IV guided missiles that provide SBT 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 Cruiser

Aegis Ashore and Vertical Launch System

- Aegis BMD ships and Aegis Ashore are designed to conduct missile defense operations, send/receive cues to/from other BMDS sensors through tactical datalinks, and conduct engagements using remote track data from BMDS sensors. Aegis BMD ships also are designed to conduct autonomous missile defense operations.
- 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 land-based component of the second phase of the European Phased-Adaptive Approach (EPAA) for the defense of Europe.
- The Aegis BMD weapon system configurations currently deployed or under development are summarized below.

WEAPON SYSTEM	AEGIS BASELINE (BL) NOMENCLATURE	PLATFORM	MISSILES
Aegis BMD 5.1	BL 9.C2	Guided-Missile Destroyers (DDGs)	SM-3 Blocks IA, IB, and IIA; SM-6 Dual I and Dual II
	BL 9.B2	Aegis Ashore	SM-3 Blocks IA, IB, and IIA
Aegis BMD 5.0 (Capability Upgrade)	BL 9.C1	DDGs	SM-3 Blocks IA and IB; SM-6 Dual I and Dual II; and SM-2 Block IV
	BL 9.B1	Aegis Ashore	SM-3 Blocks IA and IB
Aegis BMD 4.1	Not Applicable	DDGs and Guided-Missile Cruisers (CGs)	SM-3 Blocks IA and IB; SM-6 Dual I
Aegis BMD 4.0.3			SM-3 Blocks IA and IB
Aegis BMD 3.6.3			SM-3 Blocks IA and IB; SM-2 Block IV

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
- 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 Missiles: Raytheon Company, Missile Systems – Tucson, Arizona

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Activity

- The MDA conducted all FY/CY17 testing in accordance with the DOT&E-approved Integrated Master Test Plan.
- The MDA conducted five Aegis BMD intercept flight tests in FY/CY17. Overall, Aegis BMD successfully engaged four of the five ballistic missile targets in those tests:
  - In December 2016 during Flight Test Standard Missile-27 (FTM-27) Event 1, an Aegis Baseline 9.C1 destroyer engaged a complex MRBM target with a salvo of two SM-6 Dual I missiles. FTM-27 Event 1 was the first demonstration of Aegis BMD SBT capability against complex ballistic missile targets.
  - In February 2017 during SM-3 Block IIA Cooperative Development Project Flight Test Standard Missile-01 (SFTM-01), an Aegis Baseline 9.C2 destroyer intercepted a simple-separating MRBM target with an SM-3 Block IIA missile. This was the first intercept with the SM-3 Block IIA missile, which the United States and Japan are developing cooperatively to defeat MRBMs and IRBMs.
  - In June 2017 during SFTM-02, an Aegis Baseline 9.C2 destroyer attempted to intercept an MRBM target with an SM-3 Block IIA missile. The destroyer detected, tracked, and engaged the target with an SM-3 Block IIA missile, although SFTM-02 did not achieve the planned intercept. Aegis Ashore received track data from the Aegis Baseline 9.C2 destroyer and conducted the first successful simulated engagement on the MRBM remote track.
  - In August 2017 during FTM-27 Event 2, an Aegis Baseline 9.C1 destroyer engaged a complex MRBM target with a salvo of two SM-6 Dual I missiles. The test, which was a follow-on from FTM-27 Event 1, further demonstrated aspects of the Baseline 9.C1 SBT engagement capability.
  - In October 2017 during the fourth event of the multi-event Formidable Shield-17 (FS-17) Navy fleet exercise, an Aegis BMD 4.0.3 destroyer engaged and intercepted an MRBM target with a production-representative SM-3 Block IB Threat Update (TU) missile. As part of the scenario, some of the participating NATO naval assets intercepted three anti-air warfare (AAW) targets as part of a complex multinational integrated air and missile defense (IAMD) exercise that validated the NATO Smart Defense concept. This event satisfied one of the requirements for

a Full-Rate Production decision for the SM-3 Block IB missile.

- Aegis BMD participated in six non-intercept flight test events in FY/CY17 with simulated Standard Missile variants engaging live targets and a live SM-6 Dual I missile engaging a simulated target:
  - In March 2017 during FTX-30, an Aegis Baseline 9.C2 ship operating in IAMD mode conducted a simulated SM-3 Block IIA engagement of a live simple-separating SRBM target and SM-2 missile engagements against multiple subsonic and supersonic anti-ship cruise missiles.
  - In July 2017 during FTX-32, Aegis Ashore, configured with Baseline 9.B2, detected, tracked, and engaged a complex MRBM target with associated objects with a simulated SM-3 Block IIA missile. Aegis Ashore also reported track data via Link 16 to an Aegis BMD laboratory conducting a simulated engagement on the remote track.
  - In September 2017 during FTX-31, an Aegis Baseline 9.C1 ship and Aegis Ashore detected and tracked a complex-separating SRBM target with associated objects. The ship conducted a simulated engagement against the SRBM and two AAW targets. Aegis Ashore, configured with Baseline 9.B2, reported these track data via Link 16 to an Aegis BMD laboratory, which conducted a simulated engage on remote engagement against the SRBM remote track using a simulated SM-3 Block IIA missile.
  - In September and October 2017 during Events 1 and 2 of FS-17, Aegis BMD 4.0.3 and Aegis Baseline 9.C1 destroyers conducted simulated engagements of ballistic missile targets using remote data. NATO maritime assets transmitted the remote track data through C2BMC and a NATO communications gateway. In each event, NATO maritime assets, not participating as BMD assets, fired simulated or live missiles and engaged four AAW targets.
  - In October 2017 during Standard Missile Controlled Test Vehicle-03 (SM CTV-03), an Aegis BMD 4.1 destroyer detected, tracked, and engaged a simulated ballistic missile target with a live SM-6 Dual I missile. The missile firing supports certification of the Aegis BMD 4.1 upgrade to include hosting the SBT capability into Aegis BMD 4.0.
- Aegis BMD provided HWIL representations for two BMDS ground tests that provided information on Aegis BMD interoperability and functionality in various regional/theater and strategic scenarios:
  - Ground Test Integrated-07a (GTI-07a) in June 2017 explored defense of U.S. Pacific Command and homeland defense scenarios in a HWIL environment. Aegis Baseline 9.C1 and Aegis BMD 4.1, 4.0.3, and 3.6.3 participated in the test as firing assets or long-range surveillance and tracking support ships.
  - Ground Test Distributed-07a (GTD-07a) in September and October 2017 examined BMDS defense capabilities and interoperability in U.S. Pacific Command and homeland defense scenarios using operational assets and communications in a distributed environment. Aegis Baselines 9.C1 and 9.C2 and Aegis BMD versions 4.1, 4.0.3, and 3.6.3 participated as firing assets and long-range surveillance and tracking units.
- The MDA delivered high-fidelity digital M&S runs-for-the-record results in FY17 to support assessments of Aegis Ashore and Aegis Baseline 9.C1 SBT performance for select scenarios. The Navy Commander, Operational Test and Evaluation Force (COMOPTEVFOR) accredited the SBT M&S run set for performance in May 2017. COMOPTEVFOR's accreditation of the Aegis Ashore M&S run set is still in progress.

Assessment

- With one exception, the MDA completed its planned flight testing with the SM-3 Block IB TU missile as documented in the Integrated Master Test Plan. The lone exception is FTM-24, a planned engagement against a complex MRBM target that the MDA delayed until FY20. The legacy SM-3 Block IB missile (i.e., without the TU) completed its flight testing in November 2014.
- DOT&E has lower confidence in SM-3 missile reliability due to recent in-flight failures, coupled with MDA shortfalls in simulating the in-flight environment in its SM-3 ground test program, addressing failures and anomalies identified during flight testing; and implementing a rigorous configuration management and control process for SM-3 production.
- The MDA missile ground test program may not adequately simulate the in-flight environment:
  - Contractors introduced a software design flaw into the SM-3 Block IB that was not present in the SM-3 Block IA. The MDA did not discover this flaw during ground testing, but instead discovered this flaw during a failed SM CTV-01 launch in 2016 and subsequent investigation after the EPAA Phase 2 capability declaration.
  - During the course of routine production testing, Raytheon discovered a rare condition that could cause the SM-3 Block IB Kinetic Warhead Guidance Unit Guidance Unit to fail. The MDA halted deliveries of SM-3 Block IB missiles for approximately 5 months while it identified a root cause. The MDA corrected the problem with Block IB software build 6.404, released in August 2016.
  - The SM-3 Block IB electromagnetic interference test and subsequent ground tests have not been compliant with Military Standard 461F, did not evaluate the self-compatibility of SM-3 Block IB electrical and software systems, and did not reflect in-flight electrical grounding, including electrical isolation and grounding shifts due to stage separations.
- The MDA did not thoroughly address, prior to flight testing, the software flaws that were present during recent flight testing:
  - The MDA did not correct the software design flaw that led to the SM CTV-01 failure before conducting the test. The MDA did not correct this problem before retesting the SM-3 during SM CTV-01a, but rather employed patches in a non-tactical software build to conduct the test.

  - Another software design flaw that caused kinetic warhead guidance units to be unresponsive was observed during contractor acceptance testing, but was not addressed prior to conducting five subsequent flight tests. Although the flaw did not adversely affect the flight tests, it represented an unmitigated risk to SM-3 reliability. The root cause of this flaw appears to be the MDA configuration and control process for SM-3, discussed below.
- The SM-3 program may need to improve configuration management and control:
  - The software design flaw that caused the failed SM CTV-01 launch was associated with a change to the software boot-up processes and not related to capability upgrades. The MDA's continuing efforts to improve the SM-3 Block IB could introduce other unintended consequences.
  - The MDA discovered the software design flaw associated with kinetic warhead guidance units (also discussed above) when it observed a performance difference in one of the circuit cards in 2016. This performance difference resulted from an approved manufacturing tooling change made in 2011. The MDA did not evaluate the potential for software performance problems caused by the tooling change until it conducted the SM CTV-01 failure investigation 5 years later.
  - The MDA did not discover an unapproved manufacturing process change in 2014 associated with wiring harnesses until one failed a hardware inspection over a year later. Failures associated with this change had the potential to prevent stage separation during SM-3 Block IB missile operational use.
- Results from flight testing, high-fidelity M&S, and HWIL and distributed ground testing demonstrate that Aegis BMD 4.0 and Baseline 9.1 firing assets can engage and intercept non-separating, simple-separating, and complex-separating ballistic missiles in the midcourse phase with SM-3 Block IB and Block IB TU 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.
- The SM-3 Block IIA guided missile has flown in two developmental intercept flight tests, the first achieving a successful intercept. The second attempt, during SFTM-02, was unsuccessful because a sailor onboard the firing ship inadvertently pushed a button that caused the Aegis Weapon System to break engagement and initiate a message commanding the SM-3 Block IIA missile to destruct, destroying the missile in flight. DOT&E attributes this flight test failure to a design deficiency that allows an operator to break a ballistic missile engagement with the push of a button, without having to confirm the action. After conducting a Failure Review Board (FRB), the MDA provided a number of recommendations to the Navy that, if implemented, would preclude this type of failure from reoccurring.
- Two intercept flight tests in previous fiscal years and accredited high-fidelity M&S demonstrated that the Aegis Baseline 9.C1 system's SBT capability can successfully engage select SRBMs with SM-6 Dual I and SM-2 Block IV missiles. The SBT flight tests in FY17 demonstrated the ability to engage select MRBMs in the terminal phase of flight with SM-6 Dual I missiles, but the MDA has not yet performed M&S analyses with accredited models. The MDA plans to conduct M&S studies for select MRBM threats in FY19 and COMOPTEVFOR plans to accredit the M&S in the same timeframe.
- SM CTV-03 in October 2017 demonstrated the capability of the Aegis BMD 4.1 upgrade to fire an SM-6 Dual I missile. The BMD 4.1 build incorporates Baseline 9.C1 capabilities into the BMD 4.0 baseline.
- SM-6 Dual I and SM-2 Block IV missiles have been reliable in SBT flight tests. Missile reliability estimates for these missiles meet the specification, but not with statistical confidence due to the limited number of firings. To date, the MDA and Navy have conducted nine firings of the SM-6 Dual I or SM-6 Processor Replacement Program missile, and five firings of the SM-2 Block IV missile after modification for the SBT mission.
- Reliability, maintainability, availability, and supportability (RMA&S) data that the MDA collected during Aegis Baseline 9.1 BMD-related testing through FY17 show that the system's availability is less than desired due to large repair and logistics delay times. However, the DOT&E estimate of availability is consistent with the specification.
- The MDA demonstrated the Aegis Baseline 9.C1 system IAMD capabilities to a limited degree in flight testing. IAMD flight test engagements to date have included at most two cruise missile surrogates and a single ballistic missile target.
- MDA ground test events routinely demonstrated that inter-element coordination and interoperability need improvement to increase situational awareness. The tests also highlighted an Aegis BMD problem related to track management when it operates with other elements of the BMDS.
- The FS-17 fleet exercise demonstrated the ability of Aegis BMD 4.0.3 to interoperate with NATO partners over operational communication architectures during cruise missile and ballistic missile engagements, and to use remote data provided by NATO partners to prosecute remote engagements.

Recommendations

- Status of Previous Recommendations. The MDA:
  1. Partially addressed the second recommendation from FY13 to conduct operationally realistic testing that exercises Aegis BMD 4.0's improved engagement coordination with Terminal High-Altitude Area Defense (THAAD) and Patriot, when it conducted Flight Test Operational-02 (FTO-02) Event 2a (FY16) using an Aegis Baseline 9.C1 destroyer and THAAD firing assets. This flight test did not include Patriot. The MDA plans to include Patriot in FTO-03 Event 2 in FY18.
  2. Partially addressed the third recommendation from FY14 to ensure that the Aegis Baseline 9.C1 system conducts sufficient flight testing to allow for verification, validation, and accreditation (VV&A) of the M&S suite to cover the

full design to Aegis BMD battlespace. The MDA has collected sufficient flight test data to allow the BMDS Operational Test Agency (OTA) to accredit the high fidelity M&S suite over a portion of the engagement battlespace for Aegis Baseline 9.B1. The MDA and the BMDS OTA plan to conduct VV&A over the remaining battlespace for Baseline 9.C1 in FY18.

3. 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 simultaneous engagement of multiple ballistic missile and anti-ship cruise missile threats.
4. Has not addressed the first recommendation from FY16 to conduct high-fidelity M&S runs-for-the-record for Aegis Baseline 9.B2 and 9.C2 to assess performance across the expected engagement battlespace in all Combatant Command areas of responsibility and develop an appropriate M&S VV&A plan to support that effort. The MDA developed a VV&A plan, but it will not perform Aegis Baseline 9.2 runs-for-the-record until FY20.
5. Has not addressed the second recommendation from FY16 to conduct a live-flight test demonstration of a fully remote engagement. The MDA plans to conduct this type of engagement in FY18 during FTM-29.
6. Partially addressed the third recommendation from FY16 to include BMDS OTA RMA&S data collectors in all flight test missions to improve the accuracy and statistical confidence of future suitability assessments. COMOPTEVFOR works with the program to have data collectors present at each flight test event. However, the MDA has not always funded data collectors for follow-on system-level flight tests like FTO-02 Event 1a and FTO-02 Event 2a.

- FY17 Recommendations. The MDA should:
  1. Conduct an in-depth review of SM-3 missile reliability to ensure ground testing is adequately simulating the in-flight environment as observed during recent test failures.
  2. Implement processes to fix failures and anomalies identified during SM-3 ground testing prior to flight testing.
  3. Ensure that SM-3 production configuration management, manufacturing control processes, and reporting requirements are adequate.
  4. Conduct high-fidelity M&S analysis of the performance of an Aegis Baseline 9 variant ship operating in IAMD radar priority mode when simultaneously engaging multiple ballistic missile and AAW threats.
  5. Work with the Navy to implement recommendations from the SFTM-02 FRB report, including the implementation of fail-safe software designs, to preclude future inadvertent operator actions from breaking engagements against hostile ballistic missile tracks.