Shielded from Oversight

The Disastrous US Approach to Strategic Missile Defense

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Appendix 7: Testing

Union of Concerned Scientists

Rigorous testing is essential both for developing the technology for missile defense as well as for assessing its capabilities in an operational setting. Intercept tests are the by far the most publicly visible aspect of the Ground-based Midcourse (GMD) missile defense program. As such, they are the "pass-fail" exams for the GMD system.

A large number of tests, on the order of dozens, is necessary to gain confidence that the reliability of the system is known (see Appendix 8: "Confidence Levels and Probability"). That many tests, however, are economically infeasible, since GMD tests cost hundreds of millions of dollars each, and can take months to plan, execute, and analyze. While simulations and models can be used to support reliability assessments, they cannot be used to discover failure modes that are previously unknown, such as the sensitivity to vibrations that contributed to the failure of FTG-06a or unburned fuel from the target rocket booster that confused the discrimination radar in FTG-06. And models assume that the elements of the system work as designed and do not fail because of issues such as poor manufacturing quality control, which contributed to the missed intercept in FTG-06 or mechanical failures such as occurred in IFT-5 and IFT-15. Models also are not suited to simulating conditions that have not been tested in live-fire tests, such as a wide range of closing geometries and speeds, targets not illuminated by the sun, or multiple interceptors fired at one target.

Thus, it is important to consider not only the total number of successes and failures, but also the range of conditions under which the tests have occurred, and the prospects that the testing program can support an informed assessment of the GMD system's reliability.

Intercept Tests Using Prototypes

From October 1999 through February 2005, the Missile Defense Agency (MDA) conducted 10 intercept tests involving Ground-Based Interceptors (GBIs) (see Table 1). Known as Integrated Flight Tests (IFTs), these tests did not use production versions of the GBIs. Instead, they used prototype and surrogate components. In all of these IFTs, the GBI was launched from the US missile test range at Kwajalein Atoll. Thus, these tests also could not use the actual sensors, such as the PAVE PAWS Upgraded Early Warning Radar (UEWR) at Beale Air Force Base in California, which would be used by the GMD system to guide the interceptors in an actual intercept, since these radars were over the horizon. Half the prototype intercept attempts failed, including the last three. The causes of the failures were failure of the kill vehicle cooling system, failure of the kill vehicle to separate from the booster rocket (twice), and failure of the interceptor to launch when commanded (twice).

In the first five of these tests, IFT-3 (October 2, 1999) through IFT-7 (December 3, 2001), the threat cloud included two other objects in addition to the conically shaped warhead target: a large (1.7–2.2-meter diameter) balloon decoy, and the final rocket stage used to deploy them.[1] Due to its larger surface area, the balloon had a much larger infrared emission signal than the warhead target, allowing the two to be easily distinguished from each other. In IFT-8 (March 15, 2002), two small balloons with infrared signals much smaller than the warhead target were also added to the threat cloud.

In May 2002, the MDA announced that details about GMD test targets would be classified for all future GMD tests.[2] The intercept test after that announcement, IFT-9 (October 14, 2002) apparently used a threat cloud similar to that of IFT-8, with one large and two small balloons in addition to the target.[3] A Pentagon planning figure

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[1] Wright, D. and L. Gronlund. 2002. Decoys and discrimination in intercept test IFT-8. Working paper. Cambridge, MA: Union of Concerned Scientists. March 14. Online at ***www.ucsusa.org/assets/documents/nwgs/acfxoq64lk.pdf***. Note: All URLs in footnotes to this appendix were accessed June 10–12, 2016.

[2] Gildea, K. 2002. MDA classifies missile defense flight test target countermeasure data. ***Defense Daily***, May 15.

published in ***The New York Times*** in June 2000 indicated that subsequent IFT flight tests would use similar target sets as their threat clouds.[4] In any event, in the three remaining tests in the IFT series (IFT-10, IFT-13C, and IFT-14), the GBI interceptor or its launcher failed before it reached the point at which the kill vehicle would have been able to observe the threat cloud.

TABLE 1. The Integrated Flight Test (IFT) GMD Intercept Tests

Intercept Test	Interceptor Version	MDA Intercept Assessment ✓=success; ×= failure	Comments
IFT-3 (10/02/99)	Prototype	✓	Due to a pointing error, the kill vehicle did not initially detect the target. Eventually it detected a large spherical balloon decoy accompanying the target and subsequently used this detection find the target. According to the Director of Operational Test and Evaluation (DOT&E), "It is uncertain whether the EKV [Exo-atmospheric Kill Vehicle] could have achieved an intercept in the absence of the balloon..."*
IFT-4 (01/19/00)	Prototype	×	The kill vehicle infrared sensor failed because of a cooling failure.
IFT-5 (07/08/00)	Prototype	×	The kill vehicle failed to separate from its booster due to a failure of a data bus in the booster.
IFT-6 (07/14/01)	Prototype	✓	The GBR-P X-band radar at Kwajalein incorrectly reported the intercept attempt as a miss.
IFT-7 (12/03/01)	Prototype	✓	Test was designed to be identical to IFT-06.
IFT-8 (03/15/02)	Prototype	✓	Test was similar to IFT-7, except two small spherical balloon decoys were used in addition to the large spherical balloon.
IFT-9 (10/14/02)	Prototype	✓	Test was similar to IFT-8 except that the target warhead's appearance was somewhat different.
IFT-10 (12/11/02)	Prototype	×	Only night launch of a GMD interceptor. The kill vehicle failed to separate from its booster
IFT-13C (12/15/04)	Prototype	×	Interceptor failed to launch due to a software design error in a diagnostic system check.
IFT-14 (02/14/05)	Prototype	×	Interceptor failed to launch due to a missile support stabilizer in the silo failing to retract.

*Director, Operational Test and Evaluation (DOT&E). 2000. National Missile Defense. In ***FY 2009 Annual Report***. Washington, DC: Department of Defense. February. Online at ***www.dote.osd.mil/pub/reports/FY1999/***, VI-9.

[3] Wright, D. 2002. The target set for missile defense intercept test IFT-9. Technical working paper. Cambridge, MA: Union of Concerned Scientists. October 11. Online at ***www.ucsusa.org/assets/documents/nwgs/ift9.pdf***.

[4] Broad, W. 2000. Antimissile testing is rigged to hide a flaw, critics say. ***The New York Times***, June 9, A1. Online at ***www.nytimes.com/2000/06/09/us/antimissile-testing-is-rigged-to-hide-a-flaw-critics-say.html?pagewanted=all***. The figure is reproduced in Wright 2002.

Flight and Intercept Tests of Operationally Configured GBIs

Beginning with the non-intercept flight test FT-1 in December 2005, the MDA began testing operationally-configured GBIs, as shown in Table 2. These tests used the Orbital Sciences GBI booster rocket and production version of the Exo-atmospheric Kill Vehicles (EKVs), designated either CE-I or CE-II.

TESTS USING CE-I EKVs

FT-1, December 13, 2005. This was the first flight test of an operationally-configured GBI. The interceptor, with a CE-I kill vehicle, was launched from Kwajalein against a simulated target based on data from previous launches from Kodiak Island, Alaska. This non-intercept test was assessed by the MDA as a success.

FTG-02, September 1, 2006 (FTG = Flight Test Ground Based Interceptor or Flight Test GMD). The target was launched from Kodiak Island, Alaska, and the interceptor from Vandenberg Air Force Base. This was the first launch of a GBI from Vandenberg instead of Kwajalein.[5] The Upgraded Early Warning Radar in California provided tracking data for the intercept attempt. An Aegis SPY-1 radar and the Sea-Based X-band (SBX) radar collected data on the test in shadow mode, in which they collected data but did not forward it to the GMD command system in real time. No balloons or other countermeasures were used in the test. At a press conference following the test, MDA Director Lt. General Henry Obering described the test as "a total success."[6]

However, in December 2006, Obering told ***Aviation Week & Space Technology*** that FTG-02 revealed two problems that needed to be fixed before the next test.[7] One of these problems was with a telemetry component. Although Obering said this problem did not cause a data loss in FTG-02, he said it could cause a loss of telemetry data in future tests if not fixed. However, it subsequently became known that the MDA was unable to collect a full set of kill vehicle data from FTG-02. GMD program officials told the Government Accountability Office (GAO) that while FTG-02 had provided limited intercept data for assessment purposes, these data were incomplete and could not be used to fully validate and verify the models and simulations.[8] In addition, according to the Pentagon's Director of Operational Test and Evaluation (DOT&E), as of 2008 only two GMD intercept tests—FTG-03a and FTG-05—had produced complete interceptor and EKV data.[9] In his December interview, Obering did not give specifics of the second identified problem with FTG-02, but described it as a software issue that could affect the kill vehicle's "performance and reliability."[10]

More than five years after the test, in March 2012, DOT&E J. Michael Gilmore told Congress that, in fact, the intercept attempt in FTG-02 "did not achieve a kill."[11] In his subsequent response to a written question submitted after the hearing, Gilmore stated that in FTG-02, "...the EKV achieved a 'glancing blow'" on the warhead and that subsequent analysis indicated that the glancing blow would not have resulted in a kill.[12] Although the MDA scores this intercept test as a success, in part because it argues an intercept was not a primary objective of the test, we classify it as in intercept failure.

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[5] For range safety reasons, interceptors cannot be test-launched from Fort Greely.

[6] Department of Defense. 2006. DoD news briefing with Lt. Gen. Obering from the Pentagon. September 1. Online at ***http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=3710***

[7] Butler, A. 2006. Dramatic pause: Missile defense test slip could draw scrutiny from new Congress. ***Aviation Week & Space Technology***, December 18, 33.

[8] Government Accountability Office (GAO). 2009. ***Defense acquisitions: Production and fielding of missile defense components continue with less testing and validation than planned***. GAO-09-338. Washington, DC. March. Online at ***www.gao.gov/assets/290/287097.pdf***, 30.

[9] GAO 2009, 93.

[10] Butler 2006.

[11] Gilmore, J.M. 2012. Testimony before the Strategic Forces Subcommittee of the House Armed Services Committee. March 6. Online at ***www.gpo.gov/fdsys/pkg/CHRG-112hhrg73437/pdf/CHRG-112hhrg73437.pdf***.

[12] Gilmore, J.M. 2012. Written response to a question by Representative Loretta Sanchez (member of the Strategic Forces Subcommittee of the House Armed Services Committee). March 6.

TABLE 2. Tests of Operationally-Configured GBIs, Including Non-Intercept Flight Tests through the end of 2015

Test	GBI Type	Intercept Attempt?	Intercept Assessment ✓=success; ✗= failure --- = no intercept attempt	
FT-1 (12/15/05)	CE-I GBI	N	---	First flight test of an operationally configured GBI and CE-I kill vehicle. The MDA assessed it as a success. The test was postponed one day due to weather.
FTG-02 (09/01/06)	CE-I GBI	Y	✗	First intercept test of an operationally configured GBI. The MDA assessed it as a success. DOT&E subsequently assessed it as "a hit but not a kill," since it only achieved a "glancing blow" that would not have destroyed the target.
FTG-03a (09/28/07)	CE-I GBI	Y	✓	An earlier attempt at this test, FTG-03 (05/25/07), was cancelled when the target failed after launch.
FTG-05 (12/05/08)	CE-I GBI	Y	✓	Countermeasures on target failed to deploy. According to DOT&E, an interceptor malfunction, although not preventing an intercept, required subsequent hardware modification. Last successful intercept test of a CE-I GBI.
FTG-06 (01/31/10)	CE-II GBI	Y	✗	First test of new CE-II kill vehicle. Kill vehicle failed to intercept because a "lockwire was not inserted during the EKV manufacturing process," causing a thruster failure. The SBX radar also experienced a significant failure.
BVT-01 (06/06/10)	Two-stage CE-I GBI	N	---	Non-intercept flight test of a two-stage version of the GBI booster. The MDA claims it as a success, although DOT&E states: "A malfunction of the kill vehicle, unrelated to problems associated with FTG-06 above, may have degraded the quality of data collected."**
FTG-06a (12/15/10)	CE-II GBI	Y	✗	High frequency vibrations from kill vehicle thrusters caused a failure in a guidance component. The failed component was not part of the original CE-I kill vehicle. Deliveries of EKVs were suspended following this test.
CTV-01 (01/26/13)	CE-II GBI (with mitigations)	Y	---	Non-intercept test intended to confirm cause of FTG-06a failure. The MDA assessed it as successful.
FTG-07 (07/05/13)	Improved CE-I GBI	Y	✗	Intercept test of CE-I GBI incorporating "24 or 25" improvements.*** MDA attributed failure to leaking battery causing a voltage shift that prevented the EKV from separating from its booster.
FTG-06b (06/22/14)	CE-II GBI (with re-placement part)	Y	✓	Intercept test to confirm operation of CE-II kill vehicle with part that failed in FTG-06a replaced. Deliveries of EKVs resumed following this test.

** Director, Operational Test and Evaluation (DOT&E). 2010. Ground-Based Midcourse Defense (GMD). In ***FY 2010 Annual Report***. Washington, DC: Department of Defense. Online at ***www.dote.osd.mil/pub/reports/FY2010/pdf/bmds/2010gmd.pdf***, 234.
*** Syring, J. 2013a. Testimony before the Subcommittee on Strategic Forces of the House Armed Services Committee. May 8. Online at ***www.gpo.gov/fdsys/pkg/CHRG-113hhrg82459/pdf/CHRG-113hhrg82459.pdf***.

FTG-03a, September 28 2007. This test was similar to the previous FTG-02 and was described by the MDA as a successful intercept. The test was originally planned for December 2006, but was delayed until May 2007 to address the problems identified in FTG-02. An attempt to conduct the test in May 2007 (FTG-03) was cancelled when the target malfunctioned and the interceptor was therefore not launched. FTG-03a did not use any decoys or other countermeasures, but following the test, MDA Director Lt. General Obering said that given its success, countermeasures would be used on the next GMD test.

FTG-05, December 5, 2008. This test was described by the MDA as a successful intercept. (FTG-04 was cancelled in May 2008 due to problems with a telemetry card in the EKV.) As in the previous two tests, the target was launched from Kodiak Island and the interceptor from Vandenberg Air Force Base. Data from the UEWR in California, the SBX radar, two Aegis radars, and a TPY-2 X-band radar near Juneau, Alaska, were used for tracking.

FTG-05 was to be the first test of an operationally-configured GBI against a target accompanied by countermeasures. However, the countermeasures did not deploy from the target booster. MDA Director Lt. General Patrick O'Reilly said that there were to have been "two countermeasures" of a type that "we've used in the past."[13] (Some of earlier tests of GBI prototypes involved deploying spherical balloons either larger or smaller than the warhead as countermeasures.) In addition, according to the DOT&E, "An interceptor malfunction, although not affecting achievement of test objectives, resulted in a hardware change to mitigate the risk of a similar GMD interceptor malfunction."[14] As of the May 2016, FTG-05 was the last successful intercept test of a CE-I GBI interceptor.

BVT-01, June 6, 2010. A non-intercept test (BVT = Booster Verification Test) using a two-stage version of the GBI. Following the GBI launch from Vandenberg Air Force Base in California, the CE-I kill vehicle separated from the booster and carried out a series of preplanned maneuvers. The test was described as a success. However, a malfunction of the kill vehicle may have degraded the quality of the data collected.[15] This is the only flight test of a two-stage GBI to date. The next planned test of a two-stage GBI, although possibly with a different booster configuration than this one, is a non-intercept flight test scheduled for 2018, with an intercept test to be held in 2019.

FTG-07, July 5, 2013. This was first, and so far only, intercept test using the refurbished version of the CE-I EKV. As discussed in Shielded from Oversight Chapter 3. More Consequences: The Story of the Ground-Based Interceptors, in 2007, the MDA established a refurbishment program for existing CE-I EKVs; according to MDA Director Vice Admiral James D. Syring, the EKV used in FTG-07 had received 24 or 25 improvements relative to the originally deployed CE-I EKVs.[16] The primary purpose this test was to test these many changes.

However, the intercept attempt failed when the EKV did not separate from its rocket booster. According to Syring: "While the GBI was in flight, a voltage shift caused by battery electrolyte leakage shut down the flight computer and prevented EKV separation."[17] In its 2014 annual report, the Pentagon's deputy assistant secretary of defense for developmental test and evaluation DASD (DT&E) expressed skepticism that the cause of the failure had been definitively identified, suggesting there may be a more systematic problem with the booster. It said that:

> ...the July 5, 2013, GBI battery failure was not duplicated during ground test and evaluation causing DASD(DT&E) to question this as a definitive cause of failure. DASD(DT&E) recommends more relevant ground test and

[13] Department of Defense. 2008. DoD news briefing with Lt. Gen. O'Reilly from the Pentagon. News Transcript. December 5. Online at ***http://archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=4327***.

[14] Director, Operational Test and Evaluation (DOT&E). 2009. Ground-Based Midcourse Defense (GMD). In ***FY 2009 Annual Report***. Washington, DC: Department of Defense. December. Online at ***www.dote.osd.mil/pub/reports/FY2009/pdf/bmds/2009gmd.pdf***, 246.

[15] DOT&E 2010.

[16] Syring 2013a.

[17] Syring, J. 2015. Statement before the Subcommittee on Strategic Forces of the House Armed Services Committee. March 19. Online at ***www.mda.mil/global/documents/pdf/ps_syring_031915_hasc.pdf***.

evaluation prior to and after flight test events to provide the needed information to better assess design strengths and weaknesses.[18]

In this test, the LV-2 target booster was launched from Kwajalein and the GBI from Vandenberg Air Force Base. The target was tracked initially by an Aegis radar and then by the SBX radar. Although in 2011 MDA then-Director Lt. General Patrick O'Reilly told Congress that all future GMD tests would include countermeasures, the MDA has not directly stated whether or not FTG-07 included any countermeasures.[19] In 2013, MDA Director Syring described the target as presenting "a representative ICBM [intercontinental ballistic missile] target scene," and that the target met all of its requirements during the test.[20] He also said that the failure was not due to an inability to discriminate the warhead.[21] According to a director with the Government Accountability Office (GAO), Christina Chaplain, the test was "against a complex target," which also suggests that some countermeasures were deployed.[22]

TESTS USING CE-II EKVs

FTG-06, January 31, 2010. This was the first intercept test (and also the first flight test) of a CE-II kill vehicle. The target was launched from Kwajalein and the GBI from Vandenberg Air Force Base. The target included "simple countermeasures" that were successfully deployed; however, the intercept attempt failed due to a quality control problem with the kill vehicle.[23] A problem with the SBX radar may also have contributed to the intercept failure.

This was the first test for which the SBX radar was responsible for tracking the target and guiding the interceptor. (The UEWR in California observed the test, but did not actively participate.) It was also was the first test using an LV-2 booster, which is based on the first and second stages of a Trident I C4 submarine-launched ballistic missile, for the target missile. "Chuffing" of material out of the solid-fuel rocket booster near or following the end of its burn time created a more complex scene than was anticipated, causing the SBX radar to shut down. [24]

Reportedly, the EKV's sensor had already acquired the warhead target before the SBX radar failed.[25] However, the kill vehicle itself also suffered a failure of its thruster system due to a connector problem, and the intercept failed. According the GAO, "a lockwire was not inserted during the EKV manufacturing process."[26]

FTG-06a, December 15, 2010. This was the second flight and intercept test using a CE-II EKV. FTG-06a was similar to FTG-06, although with a forward-based TPY-2 X-band radar on Wake Island providing tracking data in addition to the SBX radar. However, the EKV failed shortly before the intercept was expected to take place. The EKV failure in FTG-06a was due not to a quality control failure but was instead caused by a design flaw in a component that was new to the CE-II version of the EKV. According to the GAO, the problem was with the CE-II EKV's inertial measurement unit in its guidance system and this unit needed "redesign and additional development."[27]

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[18] Department of Defense Developmental Test and Evaluation (DT&E). 2015. ***FY 2014 Annual Report.*** Washington, DC. March. Online at ***http://www.acq.osd.mil/dte-trmc/docs/FY2014_DTE_AnnualReport.pdf***. 63.

[19] O'Reilly, P. 2011. Testimony before the Subcommittee on Strategic Forces of the House Armed Services Committee. March 31. Online at ***www.gpo.gov/fdsys/pkg/CHRG-112hhrg65803/pdf/CHRG-112hhrg65803.pdf***, 103.

[20] Syring, J. 2013c. Ballistic missile defense overview. Slides from 16th Annual Space and Missile Defense Symposium. August 14. Online at ***https://mostlymissiledefense.files.wordpress.com/2013/09/syring august2013smdc.pdf***, slides 6 and 7.

[21] Syring, J. 2014. Ballistic missile defense overview. Presented at the 2014 Annual Space and Missile Defense Conference. August 13. Online at ***www.ucsusa.org/sites/default/files/attach/2014/11/slides-jd-syring-symposium.pdf***, slide 29.

[22] Capaccio, T. 2013. U.S. to attempt first missile intercept test since 2008. ***Bloomberg News,*** July 2. Online at ***www.bloomberg.com/news/articles/2013-07-02/u-s-to-attempt-first-missile-intercept-test-since-2008***.

[23] Gilmore, J.M. 2011. Testimony before the Subcommittee on Strategic Forces of the House Armed Services Committee. March 31. Online at ***www.gpo.gov/fdsys/pkg/CHRG-112hhrg65803/pdf/CHRG-112hhrg65803.pdf***, 108.

[24] Butler, A. 2010. Diverted attention. ***Aviation Week and Space Technology.*** April 12. 26.

[25] Butler 2010.

[26] Government Accountability Office. 2012. Missile defense: Opportunity exists to strengthen acquisition by reducing concurrency. GAO-12-486. Washington, DC. April. Online at ***www.gao.gov/assets/600/590277.pdf***, 74.

[27] GAO 2012, 74.

MDA Director Syring subsequently explained that vibrations caused by the firing of the EKV's divert thrusters were sensed by the kill vehicle's inertial measurement unit, which in turn led to a "Track Gate Anomaly (Pointing Error)."[28] This problem was first detected in IFT-06 in 2001, and evidence for it had been seen in nine tests through the end of 2010, but it was initially believed to be due to electromagnetic interference. The vibrations responsible for the problem occurred at frequencies too high to be detected or replicated using existing test facilities at the time they were first associated with track gate anomaly and Boeing built a new high-frequency test bed to help confirm the problem.[29] The inertial measurement unit in the CE-II kill vehicle was more sensitive than the one in the CE-I kill vehicle, making it more vulnerable to problems caused by vibration.

As with FTG-06 before it and FTG-07 after it, it appears that some countermeasures were deployed along with the warhead in FTG-06a. According to Vice Admiral Syring, the failure "…was not associated with an inability to properly discriminate the most lethal object."[30]

CTV-01, January 26, 2013. CTV-01 (CTV = Controlled Test Vehicle) was a non-intercept flight test of a GBI with a CE-II EKV. This test was intended to verify that the problem that had caused the failure of FTG-06a had been effectively mitigated. This test used a CE-II EKV with mitigations to address the suspected problem. The test, in which the EKV carried out a series of preplanned maneuvers, was reportedly successful, and cleared the way for an intercept test (FTG-06b) using a CE-II EKV with a replacement for the defective component.

FTG-06b, June 22, 2014. FTG-06b was intended to further demonstrate both that the track gate anomaly had been solved and to achieve the first successful intercept with a CE-II GBI. The EKV used in this test incorporated a new vibration isolation cradle for the inertial measurement unit, and the kill vehicle successfully intercepted the target.

As in FTG-06 and FTG-06a, the target was launched from Kwajalein and the interceptor from Vandenberg. According to Syring, the test "involved a target missile that approached ICBM speeds and included countermeasures."[31] An Aegis radar provided tracking data on early parts of the target trajectory and the SBX radar provided later tracking and discrimination data.

CTV-02, January 28, 2016. A non-intercept flight test of a CE-II kill vehicle modified by replacing its divert thrusters with new alternate divert thrusters that MDA intends to deploy on its new CE-II Block 1 kill vehicles. The primary purpose of this test was to assess the performance of the new thrusters and MDA described the test as successful. The test also involved a demonstration of new discrimination technology.

CONSEQUENCES OF THE FTG-06 AND SUBSEQUENT TEST FAILURES

Problems with the CE-II kill vehicle and the FTG-06 and FTG-06a test failures delayed demonstration of a CE-II intercept capability by more than six years.[32] According the GAO, the total cost to demonstrate a CE-II intercept capability and to repair the CE-II EKVs already built and deployed is now at least $1.98 billion.[33]

The problems have also resulted in CE-II GBIs being deployed more than five and a half years ***before*** a successful demonstration of their intercept capability rather than after such a demonstration, as was originally planned. The MDA began developing the CE-II version of the EKV in 2004–2005 due to obsolescence issues with components of the CE-I version then being deployed. As of September 2006, the MDA plans called for FTG-06, the first intercept test of a CE-II GBI, to be conducted in the last quarter of 2007 with deployment of CE-II GBIs then to begin in early 2008.[34] However, ground test failures in the CE-II kill vehicle's inertial measurement unit resulted in FTG-06 being delayed

[28] Syring 2014, slide 16.
[29] Norris, G. 2012. Valuable vibrations. ***Aviation Week & Space Technology***, December 3, 28.
[30] Syring 2014, slide 29.
[31] Syring 2014, slide 28.
[32] Government Accountability Office (GAO). 2015. ***Missile defense: Opportunities exist to reduce acquisition risk and improve reporting on system capabilities***. GAO-15-345. Washington, DC. May. Online at ***www.gao.gov/assets/680/670048.pdf***, 63.
[33] GAO 2015, 63.
[34] GAO 2009, 43.

until January 2010.[35] In the meantime, deployment of CE-II GBIs began in October 2008.

Following the failure of FTG-06 in January 2010, the MDA essentially repeated the test as FTG-06a in December 2010. Following the failure of this second test, the MDA suspended deliveries of CE-II equipped GBIs until the cause of the failure could be determined and a successful intercept test of a CE-II GBI carried out. However, by this time 10 CE-II GBIs had already been deployed in silos. Deliveries and deployments of CE-II GBIs remained suspended for about three and half years until test FGT-06b was successfully conducted in June 2014, after which they were resumed.[36]

Limitations of the Testing Program So Far

NO TEST OF AN OPERATIONALLY CONFIGURED GBI AGAINST AN ICBM-RANGE TARGET

The GMD system is a defense of US territory against ICBMs. However, so far it has only been tested against shorter-range missiles. As of mid-2016, the first intercept test against an ICBM-range target was planned to take place in FTG-15, scheduled for late 2016.[37]
An ICBM is defined as having range of greater 5,500 km, although many ICBMs have significantly greater ranges. Part of Alaska and the westernmost part of the Hawaiian Island chain lie within 5,500 km of North Korea, but all of the contiguous 48 states are more than 7,000 km from either North Korea or Iran.

In all seven of the intercept tests of operationally configured GBIs, the interceptor was launched from Vandenberg Air Force base in California. In the first three tests, the target was launched from Kodiak Island, about 3,500 km away. In the last four intercept tests, the target was launched from Kwajalein, about 7,800 km away. However, the intercept took place roughly midway between the launch points, so that the range covered by the target was less than that of an ICBM. Moreover, three of the four intercept attempts failed.

This lack of testing against ICBM-range targets has significant operational implications, because the speed of a missile increases with its range. As a result of the shorter than realistic range of the targets used so far, the closing speed at the intercept attempt has been lower than that could occur against an ICBM target. Moreover, three of the four successful intercept tests, FTG-02, FTG-03a, and FTG-05, were not only conducted with a target launched from Kodiak but employed intercept geometries with large crossing angles (see Figure 1), which give much lower closing speeds than geometries that are more nearly head-on.

NO SALVO MODE TESTING

The basic operating mode of the GMD system involves salvo firing of interceptors, in which several interceptors are fired at a target before the outcome of the first intercept attempt is known. Given the timelines involved and the low reliability of the interceptors, such a mode of operation is necessary just to have a possibility of obtaining high system effectiveness against even a simple target. However, the GMD system has never been tested in a salvo mode. The first salvo test is now planned to be FTG-11, in which a CE-I and CE-II interceptors will be fired at a single target.[38] As of mid-2015, this test was scheduled for the first quarter of FY 2018.[39]

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[35] Government Accountability Office (GAO). 2013. ***Missile defense: Opportunity to refocus on strengthening acquisition management***. GAO-13-432. Washington, DC. April. Online at ***www.gao.gov/assets/660/654233.pdf***, 86.

[36] Shalal, A. 2014. Raytheon to resume production of warhead after successful test. ***Reuters***, June 23. Online at ***http://www.reuters.com/article/usa-military-raytheon-idUSL2N0P411M20140623***.

[37] Syring, J.D. 2016. Testimony before the Strategic Forces Subcommittee of the Senate Armed Services Committee. April 13. Online at ***http://www.mda.mil/global/documents/pdf/FY17_Written_Statement_SASC_SFS_MDA_VADM_Syring_13042016.pdf***.

[38] Director, Operational Test and Evaluation (DOT&E). 2011. Ground-Based Midcourse Defense (GMD). In ***FY 2011 Annual Report***. Washington, DC: Department of Defense. Online at ***www.dote.osd.mil/pub/reports/FY2011/pdf/bmds/2011gmd.pdf***, 264. See also Gilmore 2012.

[39] Director, Operational Test and Evaluation (DOT&E). 2015. Ground-Based Midcourse Defense (GMD). In ***FY 2014 Annual Report***. Washington, DC: Department of Defense. January. Online at ***www.dote.osd.mil/pub/reports/FY2014/pdf/bmds/2014gmd.pdf***, 312.

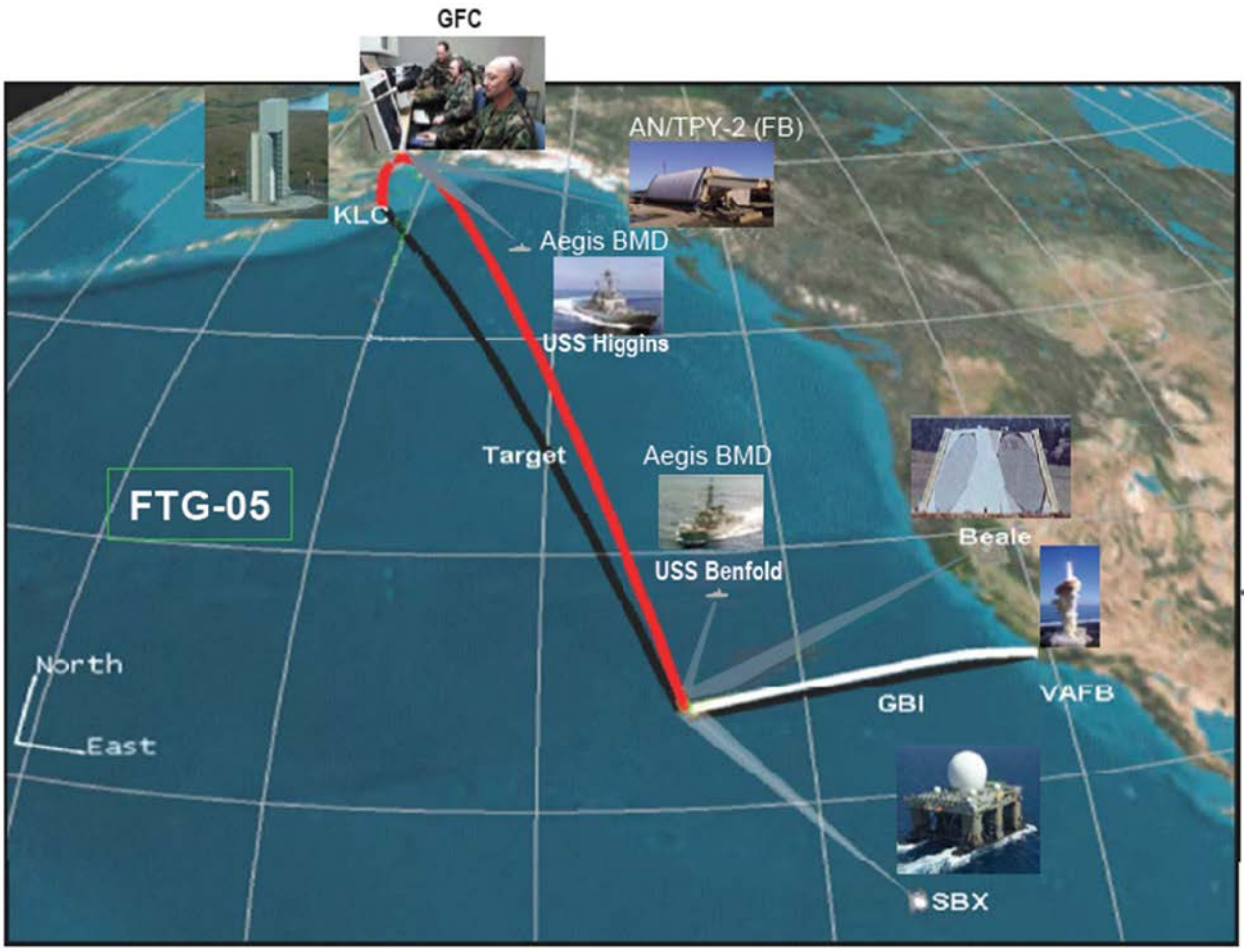
NO TEST AGAINST MULTIPLE TARGETS

The GMD has also never been tested against more than a single target missile. FTO-04, currently planned for the third quarter of FY 2021, will include the first GMD test against two near-simultaneous targets. In this operational test, two GBI interceptors (a CE-I and a CE-II) will attempt to intercept two targets with IRBM (intermediate-range ballistic missile) and ICBM ranges.[40]

REFURBISHED CE-I NOT DEMONSTRATED

Some or all of the CE-I kill vehicles have been refurbished to address issues identified in testing, at a

FIGURE 1. Geometry of FTG-05 in December 2008.† Because of the large crossing angle, the closing speed between interceptor and target was relatively low. The next four intercept tests used more of a head-on geometry, with launches from Kwajalein Atoll, but three of them failed.



†Figure from O'Reilly, P. FTG-05 flight overview. Missile Defense Agency. December 5. Available online at ***http://www.ucsusa.org/sites/default/files/attach/2016/07/FTG-05-Flight-Test-Overview.pdf***

[40] Butler, A. 2014. Pentagon plans three ambitious GMD "firsts." ***Aviation Week & Space Technology***, December 18. Online at ***http://aviationweek.com/defense/pentagon-plans-three-ambitious-gmd-firsts*** (subscription required).

cost of roughly $14–$24 million per CE-I GBI. The refurbishment involved at least two dozen modifications to the kill vehicle. However, the only intercept test (FTG-07) using one of these refurbished GBIs failed in July 2013. This failed test was also intended to "demonstrate CE-I EKV performance under more challenging threat engagement conditions" than in previous tests.[41] The Pentagon's Director of Operational Test & Evaluation (DOT&E) has called for the MDA to repeat FTG-07, but the MDA currently has no plans to test another CE-I GBI until the first quarter of FY 2018.

LIMITED TESTING CONDITIONS

According to the Pentagon's Director of Operational Test & Evaluation (DOT&E), the GMD system "...has not been demonstrated sensor performance throughout the expected range of adverse natural environments."[42] At a minimum, his statement indicates that no GMD intercept test has ever been conducted in which the target was not illuminated by the sun. The westward-moving targets from Vandenberg were illuminated by the setting sun, and the eastward moving targets from Kwajalein were illuminated by the rising or mid-day sun. The only GMD night time intercept test was IFT-10 in 2002. This test, using a prototype EKV, failed when the kill vehicle did not separate from its booster. For the times at which GMD intercept tests were conducted see Table 3.

ONLY A SINGLE SUCCESSFUL TEST AGAINST COUNTERMEASURES

The most difficult problem facing any midcourse defense system is dealing with countermeasures—the actions an adversary takes to defeat the missile defense system, such as decoys which the system must either discriminate from the warhead or otherwise engage all objects. The most recent GMD test, FTG-06b in June 2014, is the only successful intercept test of an operationally-configured interceptor against a target employing even the simplest of countermeasures. The five successful prototype-phase intercept tests (IFT-3, IFT-6, IFT-7, IFT-8 and IFT-9) of GBIs involved one or a few balloon decoys with appearances significantly different than that of the target.[43] The MDA tried to use decoys in four other intercept attempts of operationally-configured GBIs (FTG-05, FTG-06, FTG-06a and possibly FTG-07). However, in the first of these intercept tests, the decoys failed to deploy, and in the other three the kill vehicles failed.

It seems probable that the countermeasures deployed in FTG-06b were no more complex than simple balloon decoys with different shapes and/or sizes than the simulated warhead. A chart published in ***The New York Times*** in June 2000 showed the targets and countermeasures then planned (as of May 5, 2000) for the entire 18 test development sequence of the GMD system.[44] None of the planned tests involved any countermeasure that physically resembled the conical warhead target. Whether that is still the case today cannot be confirmed from public sources since the MDA now classifies any specific information about the countermeasures it uses in tests. For example, the MDA is even unwilling to admit publicly whether or not it has tested the GMD system against a warhead that is tumbling rather than spin-stabilized.[45]

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[41] Director, Operational Test and Evaluation (DOT&E). 2014. Ground-Based Midcourse Defense (GMD). In ***FY 2013 Annual Report***. Washington, DC: Department of Defense. January. Online at ***www.dote.osd.mil/pub/reports/FY2013/pdf/bmds/2013gmd.pdf***, 312

[42] Director of Operational Test and Evaluation. 2009. 2008 Assessment of the Ballistic Missile Defense System (BMDS). Washington, DC: Department of Defense, January, 45. Online at ***http://www.ucsusa.org/sites/default/files/attach/2016/07/2008-BMDS-Assessment.pdf***.

[43] For details of targets and decoys used in these tests, see Wright and Gronlund 2002; Wright 2002.

[44] Broad 2000. The chart is reproduced in Wright 2002. The first two tests on the chart were non-intercept tests.

[45] Syring, J. 2013b. Testimony before the Defense Subcommittee of the Senate Appropriations Committee. July 17. Online at ***www.gpo.gov/fdsys/pkg/CHRG-113shrg39104550/html/CHRG-113shrg39104550.htm***. The testimony contains this exchange: Senator Durbin. "Has the system ever been tested against a tumbling warhead?" Admiral Syring. "Sir, in a classified environment, I'd be happy to answer that."

TABLE 3. Launch times and locations for targets and interceptors in GMD intercept tests extracted from the MDA's press releases and from news reports. Intercepts claimed as successful are in black and failed intercept attempts are in red. Except for IFT-10, in all cases, the target has been illuminated by the sun.

	Date	Target Launch	Interceptor Launch	Additional Information
IFT-3	10/02/99	VN 7:01 pm	KW 2:22 pm	
IFT-4	01/19/00	VN 6:19 pm	KW 2:39 pm	
IFT-5	07/08/00	VN 9:19 pm	KW 4:39 pm	
IFT-6	07/14/01	VN 7:40 pm	KW 3:02 pm	
IFT-7	12/03/01	VN 6:59 pm	KW 3:19 pm	
IFT-8	03/15/02	VN 6:11 pm	KW 2:31 pm	
IFT-9	10/14/02	VN 7:00 pm	KW 2:22 pm	
IFT-10	12/11/02	VN 12:26 am	KW 8:46 pm	Interceptor night launch
IFT-13c	12/15/04	KD 8:45 pm	KW 6:01 pm (launch failed)	KW sunset = 6:33 pm
IFT-14	02/14/05	KD 9:22 pm	KW < 6:42 pm (launch failed)	KW sunset = 6:58 pm
FTG-02	09/01/06	KD 9:22 am	VN 10:39 am	
FTG-03a	09/28/07	KD 12:01 pm	VN 1:18 pm	
FTG-05	12/05/08	KD 11:04 am	VN 12:23 pm	
FTG-06	01/31/10	KW 11:40 am	VN 3:46 pm	
FTG-06a	12/15/10	KW <8:00 am	VN 12:03 pm	
FTG-07	07/05/2013	KW ~6:40 am	VN ~11:30 am	One of these times is off by an hour
FTG-06b	06/22/2014	KW 8:51 pm	VN 12:57 pm	

Location Key: VN = Vandenberg Air Force Base, California
KD = Kodiak, Alaska
KW = Kwajalein Atoll.
All times are local (either standard or daylight savings, whichever is in effect).
Kodiak is four hours behind east coast time.
Kwajalein does not use daylight saving time and is 17 hours ahead of EST and 16 ahead of EDT.

TESTS HAVE INCLUDED DETAILED ADVANCE KNOWLEDGE ABOUT TARGETS AND DECOYS

In at least the tests performed when the interceptors were still prototypes, the defense was provided in advance with detailed knowledge of the characteristics of the target and decoys, and used this information to pick out the target. The discrimination process, as described in a 2002 GAO report, is similar to a template-matching exercise. "Reference data are a collection of predicted characteristics, or features, that target objects are expected to display during flight. The software identifies the warhead from the decoys by comparing the features displayed by the different target objects to the reference data."[46]

Using such detailed advance information about the appearance of the targets and decoys is not unreasonable in early intercept tests; however, such tests do not demonstrate a real-world discrimination capability. As noted above, because the MDA classifies all details about countermeasures used in GMD intercept tests, it cannot be said with certainty that such advance information was used in June 2014's FTG-06b test, the only successful intercept test of an operationally-configured GBI that was described as having included countermeasures. However, given the highly scripted nature of the GMD intercept tests, the use of at least some advance information seems likely.

RATE OF TESTING

One key issue with the GMD testing program is the relatively slow rate at which testing, and intercept testing in particular, has proceeded. Coupled with its relatively low success rate in tests, this low rate of testing has severely limited the circumstances under which the GMD system has been demonstrated; it also has allowed deployment to get out well ahead of testing. Both the CE-I and CE-II versions of the GBIs began deployment at least two years before they were successfully intercept-tested. Under current plans, even assuming that all future tests are successful, developmental testing of the GBIs will not be completed until at least 2022, well after all 44 planned GBIs will be deployed.[47]

Since the beginning of intercept testing in October 1999, the MDA has carried out 17 intercept tests, a rate of about 1.05 intercept tests per year (17 in 195 months, as of the end of 2015). During the prototype testing phase, up to February 2005, the MDA conducted 10 intercept tests in 5.4 years, or about 1.9 tests per year. However, since testing of operationally-configured interceptors began in September 2006, the pace has slowed considerably, to seven intercept tests in 112 months, or about 0.75 intercept tests per year. The next intercept test is scheduled for the first quarter of FY 2017, more than two years after the most recent one.

The MDA has argued that due to the complexity of the GMD tests, a rate of testing of about one intercept test per year is appropriate, and has even argued that testing more frequently would be detrimental to the GMD program: In April 2012, then MDA Director Lt. General Patrick O'Reilly told a Senate committee that "conducting flight tests at a pace greater than once a year prohibits thorough analysis of pre-mission and post-mission flight test data and causes greater risk of further failure and setbacks to developing our homeland defense capability as rapidly as possible."[48] The Pentagon's DOT&E supported this position in March 2012 testimony:

> ***The flight test pace of about one per year is the best that we have been able to do on average over about a decade. That is because these tests are extremely complex. There is over a terabyte of data that is collected during these tests that has to be analyzed. I am all for testing at the most rapid pace possible, but you have to assess and analyze the results of the tests in order to learn from them. It takes a good deal of time to learn from these tests and to plan them. And as I said, they are extremely complex.***[49]

However, the argument that an intercept test rate of about one a year is optimal is a relatively recent one. As

[46] General Accounting Office. 2002. ***Missile defense: Review of results and limitations of an early national missile defense flight test***. GAO-02-124. February. Online at ***www.gao.gov/new.items/d02124.pdf***, 6.

[47] GAO 2013, 89.

[48] O'Reilly, J. 2012. Testimony before the Subcommittee on Strategic Forces of the Senate Armed Services Committee. April 25. Online at ***www.mda.mil/global/documents/pdf/PS_SASC_Oreilly_042512.pdf***.

[49] Gilmore 2012.

of August 2001, the MDA planned to conduct four intercept tests per year for the following five years, for a total of 20 intercept tests, in addition to the four it had already conducted, by the end of FY 2006.[50] The Program Executive Officer for the GMD system, Major General Willie B. Nance, Jr., stated in 2001 that it took about 45 days to analyze the data from a GMD test.[51] The MDA fell far short of its 2001 testing plan objective, conducting only seven intercept tests by the end of 2006, including two in which the interceptor failed to launch. Even so, as late as the end of FY 2006, MDA still planned to average at least three GMD intercept tests per year. Table 4 below shows the MDA's plans for intercept testing of operationally-configured GBI interceptors as of September 2006. The table shows that the MDA planned to carry out intercept tests at a much higher rate than one per year—eight in 30 months, or 3.2 per year. However, due to problems identified both in ground and flight testing, failed target launches, lack of backup hardware (FTG-04) and other reasons, the MDA was unable to come close to achieving this objective. The MDA actually carried out only three tests in that period, with an average spacing between them of over 13 months.

The MDA does not plan to increase the rate of GMD testing, at least not through the next decade. In August 2014, MDA Director Syring stated that "Between now and 2024 there are 7 tests against ICBM targets with countermeasures – the first is planned for FY2016."[52] It is unclear if the seven tests include the planned first two intercept tests of the Redesigned Kill Vehicle planned for 2019 and 2020. An intercept test against an intermediate-range ballistic missile is scheduled for 2020, bringing the total to eight to ten in the 10-year span. However, this schedule assumes no test failures or other setbacks which, based on past performance, seems very optimistic.

COMPARISON WITH AEGIS BMD TESTING

A point of comparison is the intercept testing program for the Aegis Ballistic Missile Defense (BMD) system, which began in January 2002. Table 5 summarizes a comparison between the GMD and the Aegis test programs. As with the GMD system, the Aegis BMD uses an exo-atmospheric, hit-to-kill infrared homing interceptor. Like the GMD testing program, the Aegis BMD program has progressed from testing prototype interceptors to intercept tests of two types of operationally-configured interceptors (the SM-3 Block IA and SM-3 Block IB). However the intercept testing rate for Aegis BMD is more than twice that of the GMD

TABLE 4. GMD Intercept Tests Planned as of September 2006. The first nine planned intercept tests of operationally-configured GBIs and when they were actually carried out, cancelled, or postponed.****

Test	GBI Type	Planned (FY)	Conducted/Cancelled (FY)
FTG-2	CE-I	4Q 2006	4Q 2006
FTG-3	CE-I	1Q 2007	4Q 2007, as FTG-03a
FTG-4	CE-I	3Q 2007	Cancelled 3Q 2008
FTG-5	CE-I	4Q 2007	1Q 2009
FTG-6	CE-II	1Q 2008	2Q 2010
FTG-7	CE-I	2Q 2008	Cancelled (FTG-7 designation reused 4Q 2013)
FTG-8	CE-I	4Q 2008	Cancelled or postponed
FTG-9	CE-I CE-II	1Q 2009	Cancelled or postponed

**** Source for planned dates is GAO 2009, 43.

system, and for operationally configured interceptors it is more than three times greater. Because of the significantly higher success rate of the Aegis BMD intercept tests (80% compared to 47%), the advantage of the Aegis BMD in rate of ***successful*** intercept testing is even greater (4.1 times greater than the GMD system for all tests, 7.2 times for operationally configured tests).

Notably, even though intercept tests for Aegis failed in both 2011 and 2012, the MDA conducted five successful intercept tests of Aegis SM-3 interceptors between February 2013 and October 3, 2013, a period of fewer than eight months.

COMPARISON WITH THAAD TESTING

Although a less directly analogous system, the testing program for the Terminal High Altitude Area Defense (THAAD) system is also a useful point of comparison. THAAD underwent a period of developmental testing in which seven intercept tests were conducted from December 1995 to August 1999. The first five failed and the last two succeeded.

THAAD intercept testing resumed in July 2006. Since then, the MDA has conducted 13 intercept attempts, all successful. Three additional intercept tests were cancelled when the target missile failed before the THAAD interceptor could be launched. The MDA characterizes all of the intercept tests since 2006 as tests of operationally configured interceptors. Thus THAAD has been tested at a rate of 13/114 months = 1.37 operationally configured intercept tests per year; since all tests were successful, this is the same rate for successful tests.[53] The single operationally configured version of the THAAD interceptor has had 4.3 times more successful intercepts than the CE-I and CE-II versions of the GBI combined.

TABLE 5. Comparison of Intercept Tests of the GMD System and Aegis BMD. Month count includes month of first test through 12/2015 inclusive. Any tests in which the interceptor was not launched due to a target failure are not included.

	Ground-Based Midcourse		Aegis BMD	
	All Tests	Operationally Configured	All Tests	Operationally Configured
Months Since First Test (as of end of 12/2015)	195	112	168	131
Number of Tests	17	7	35	30
Successful Intercepts	8	3	28	25
Testing Rate (per year)	1.05	0.75	2.50	2.75
Successful Testing Rate (per year)	0.49	0.32	2.00	2.29

[53] Two of the eleven intercept tests involved two separate intercept attempts, giving a total thirteen intercept attempts.

The more significant point is that the first THAAD battery was activated at Fort Bliss, Texas, in May 2008. At that time, THAAD had completed six consecutive successful intercept tests, including four of operationally configured interceptors. Its first operational deployment was to Guam in April 2013 (it had briefly been deployed in a test mode to Hawaii in 2009), at which point it was supported by data from 12 consecutive successful intercept attempts, including 10 of operationally configured interceptors. This intercept-before-you-buy-and-deploy record contrasts strongly with that of the GMD system, in which both the CE-I and CE-II GBIs were deployed years before they were successfully intercept-tested even once.

COST OF TESTING

One contributing factor to the low GMD testing rate may simply be the large (and increasing) costs of the tests. Table 6 below summarizes some estimates of the cost of recent GMD tests. Even the simplest of GMD intercept tests now appears to cost at least $200 million. These costs can increase greatly, to $300 million or more, if a test fails, due to the cost of determining and responding to the cause of the failure. For example, the $360 mission total shown for FTG-06a includes at least $119 for failure review efforts. On the other hand, the $214 million cost for FTG-07 does not include any failure review costs (because these were not available at the time the estimate was made). Moreover, the delays caused by failures impose additional costs by delaying subsequent tests. According to the GMD program manager, each month of delay in carrying out FTG-06b increased its total cost by about $3 million.[54] Thus, conducting multiple GMD intercept tests per year may simply be infeasible due to cost, given the MDA's current budget.

TABLE 6. Cost of Recent GMD Tests. Sources: Cost data from the MDA, some from the GAO, unless indicated otherwise. DCMA = Defense Contract Management Agency.

Test	Cost (million $)	Comments
FTG-05 (12/2008)	> 210 (DCMA)	
FTG-06 (01/2010)	> 236 > 310 (DCMA)	
FTG-06a (12/2010)	360	Including $119 million in failure review costs.
CTV-01 (01/2013)	171	Non intercept test
FTG-07 (07/2013)	214	Costs through 07/2013
FTG-06b (06/2014)	269	

Sources: GAO 2013, 90; GAO 2012, 75; Government Accountability Office (GAO). 2011. ***Missile defense: Actions needed to improve transparency and accountability***. GAO-11-372. Washington, DC. March. Online at ***www.gao.gov/new.items/d11372.pdf***, 87; Government Accountability Office (GAO). 2010. ***Defense acquisitions: Missile defense transition provides opportunity to strengthen acquisition approach***. GAO-10-311. Washington, DC. February. Online at ***www.gao.gov/assets/310/301067.pdf***, 21; Hennigan, W. 2013. Problem-plagued missile defense system fails in $214-million test. ***Los Angeles Times***, July 5. Online at ***http://articles.latimes.com/2013/jul/05/business/la-fi-mo-missile-defense-test-20130705***; Sherman, J. 2014. DOD delays key missile defense test from fall to March 2014. ***Inside the Pentagon***, July 25.

[54] GAO 2013, 90–91.