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An Assessment of the Missile Defense Agency's "Endgame Success" Argument

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Executive Summary

The Pentagon's Missile Defense Agency (MDA) is increasingly resistant to providing detailed reports to Congress on the progress of US missile defense programs, and has recently decided to classify more information about its missile defense intercept tests. In such a time of reduced Congressional and independent oversight, it is especially important to understand the extent to which information provided by the MDA is credible and trustworthy.

In this context, we have examined in detail statements made by MDA Director Lt. General Ronald Kadish in recent Congressional testimony, in which he argued that the test record for hit-to-kill missile defenses demonstrates that these missile defense systems will work. Specifically, General Kadish testified that many of the test failures were due to quality control problems that prevented the interceptor from reaching the "endgame" of the intercept attempt, but that when the tests actually reach the endgame, the interceptors have a very high success rate of 88 percent. Moreover, he argued that this high "endgame success" rate shows that the technical feasibility of missile defenses is not in question.

We find that this argument is wrong on several counts: First, the numbers Kadish uses are incorrect; he undercounts the number of endgame failures. Second, he inappropriately combines test data for midcourse and terminal missile defenses, even though they operate quite differently from one another. Third, for both midcourse and terminal systems, the endgame success rate is actually slightly *lower* than the success rate prior to the endgame. Fourth, there is no reason to consider the endgame success rate rather than the overall success rate—since quality control errors can and have occurred in all phases of the tests. Taking into account failures that occur both prior to and during the endgame, the overall success rate for midcourse systems drops to 41 percent. Finally, and most important, all of the hit-to-kill tests conducted to date have—as the MDA itself notes—included numerous "limitations" and "artificialities," so even a perfect test record would say little about the ability of the system to operate under realistic operational conditions.

Our analysis shows that regardless of how the test results are tabulated, they do not indicate anything meaningful about the technical feasibility of the missile defense systems under development. The MDA analysis that Kadish presented to Congress is based on misrepresenting the results of past tests, and its conclusions are wrong and misleading. This raises serious questions about the recent MDA decision to classify information about its future intercept tests, since this will make it nearly impossible to check its claims. It also indicates how important it is that MDA programs be subject to continuing and increased Congressional and independent oversight.

Introduction

In early 2002, Secretary of Defense Rumsfeld restructured the Pentagon's missile defense programs, creating a new Missile Defense Agency (MDA) with more flexibility. Members of Congress and others have argued that the new structure provides inadequate Congressional and independent oversight of the MDA programs.

This summer, the MDA announced that it would no longer publicly provide details about its missile defense intercept tests, despite the fact that these are still early research and development tests.

Critics of midcourse hit-to-kill missile defenses—such as the NMD system developed under the Clinton Administration and the "emergency defense" capability that the Bush Administration plans to put in place in Alaska by 2004—have argued that such defenses are vulnerable to even simple countermeasures, and that the current test program does not include realistic countermeasures. Indeed, the Pentagon's renewed interest in boost-phase defenses reflects just this concern about countermeasures. Moreover, even though the intercept tests have been simplified and have not included realistic countermeasures, such midcourse systems have a rather poor test record, further undercutting the rationale for any deployment by 2004. Of the 27 intercept tests of midcourse hit-to-kill defenses conducted through June 2002, in only 11 have the interceptors actually hit their targets, for a success rate of 41 percent.[1]

Recently, missile defense advocates, most notably Missile Defense Agency (MDA) Director Lt. General Ronald Kadish, have begun to place a different spin on this test record, noting that many of the failures were due to quality control problems that prevented the interceptor from reaching the "endgame" of the intercept attempt. They argue that when the tests actually reach the endgame, the interceptors have a very high success rate, and that this high endgame success rate shows that these missile defense systems will work.

Specifically, General Kadish claimed in Congressional testimony in June that of the 25 intercept attempts in which the interceptor reached the endgame, the target was hit 22 times, for a success rate of 88 percent.[2] In other testimony, he stated "Many of the failures we have encountered to date owe more to challenges in engineering and systems integration than to an inadequate technology base." and argued that

[1] Since General Kadish's testimony, there have been two additional intercept tests of midcourse hit-to-kill systems, one of the Ground-Based Midcourse system and one of the Sea-Based Midcourse system, and both were successful. These results do not change any conclusions of this paper, and only slightly affect the numbers (for example, the overall midcourse success rate would increase from 41% to 45% and the success rate in the endgame would increase from 61% to 65%).

[2] Lt. General Ronald T. Kadish, Special Briefing on Missile Defense, June 25, 2002. Transcript available at www.defenselink.mil/news/Jun2002/t06252002_t0625kadish.html and the slides shown are at www.defenselink.mil/news/June2002/g020625-D-6570C.html .

> …what success in the endgame does show is that the critical technologies we require to counter the ballistic missile threat, to hit a bullet with a bullet, are in hand. In other words, we are not awaiting some technological break-through in order to proceed with missile defense development. The feasibility of missile defense and the availability of technologies to do this mission should not be in question.[3]

MDA Chief System Architect Keith Englander made a similar argument in February 2002,[4] and other missile defense advocates have made similar statements.[5,6]

What is the significance of this "endgame success" argument? Have very high success rates actually been achieved in the endgame? Is the success rate in the endgame more meaningful than the overall success rate? Does either success rate demonstrate anything significant about how the systems would work if used in a real attack?

In this report, we show that the statistics being used in support of the endgame success argument are wrong. In fact, for both terminal and midcourse hit-to-kill systems, a greater proportion of the intercept tests failed in the endgame than in any other phase of the tests.

More importantly, we show that the success rates in these tests reveal very little information about how effective these defense systems would be in a real attack.

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[3] Statement of Lieutenant General Ronald T. Kadish, Director of the Ballistic Missile Defense Organization, before Subcommittee on Military Research and Development of the House Armed Services Committee, June 14, 2001.

[4] During his presentation at the 2002 Annual Meeting of the American Association for the Advancement of Science, Boston, Massachusetts, February 18, 2002, Keith Englander stated that—of the tests conducted to date—when the hit-to-kill interceptor reached the endgame, the success rate was 85%.

[5] Raymond F. Askew, Carl T. Bayer, William A. Davis, Jr., Frank Rose, and Alan D. Sherer, **The Facts Behind Missile Defense: A Guide to Two Decades of Proven Technology**, updated August 2001 (no publisher listed) makes a similar argument. The paper states, "When systems reach the endgame, the success rate provides an exceedingly positive sign. In testing since 1984, systems have reached the endgame 18 times, hitting the target 15 times. Only twice has a system reached the endgame and failed." (Note that the statement that "Only twice has a system reached the endgame and failed." is clearly wrong, and may be due to not updating the numbers following the July 2001 PAC-3 test, which failed to intercept its ballistic missile target.) The paper further states: "Reaching the endgame -- technically the terminal homing and intercept phase -- involves a full assessment of the components and software of hit-to-kill missile defense systems." and "This testing experience argues strongly that missile technology works because it involves reliable technological components and known scientific principles. It also shows that evolutionary and incremental testing is much more successful than programs that spring up overnight. Missile defense is not awaiting a revolutionary scientific or technological breakthrough. Instead the challenge today involves integrating systems and technologies that already exist."

[6] Bill Davis, "Guest Perspective: Why Missile Defense Will Work," *Inside Missile Defense*, October 3, 2001, argues that the land-based, midcourse NMD system then currently under development would work since: "The overall 'score' of hit-to-kill intercept tests, including both theater missile defense and national missile defense systems is 15 successes in 33 tests. Significantly, of the 18 intercept tests that have reached the "endgame" of the engagement, the stage when the kill vehicle opens it's eyes, sees the target and begins to home-in for the kill, 15 have been successful. … This latter statistic indicates that when quality control type problems did not preclude testing of the critical 'hit-to-kill' functions, the success rate is over 80%."

Problems with the Endgame Success Argument

The serious problems with the argument about the endgame success rate made by General Kadish and others are discussed below.

Inaccurate statistics
First, the statistics cited by Kadish are simply wrong. Even the relatively limited publicly available information about these tests makes it clear that, under Kadish's own definition of endgame, there are many more intercept attempts that reached the endgame but failed to hit the target than are accounted for in MDA's statistics. As discussed in the next section and the Appendix, we assess that there are six additional endgame failures; once these are taken into account the success rate for all hit-to-kill systems that successfully reached the endgame drops from 88% to 71%.

Midcourse and terminal defenses inappropriately lumped together
Second, General Kadish essentially mixes apples and oranges. His endgame success statistics combine the results for both midcourse systems (which can or must operate above the atmosphere) and terminal-phase systems (which operate within the atmosphere), even though these systems differ from each other in many important respects.

Roughly half of the tests that General Kadish counts as having reached the endgame are of different midcourse systems: Homing Overlay Experiment (HOE); Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS); Light-weight Exo-Atmospheric Projectile (LEAP); Theater High-Altitude Area Defense (THAAD); and National Missile Defense (NMD), now called Ground-Based Midcourse. These interceptors all have a great deal in common. All are midcourse systems designed to operate above the atmosphere against medium to long-range missiles (THAAD is also capable of operating in the upper reaches of the atmosphere). All use a kill vehicle released from a booster rocket. All of the kill vehicles use infrared sensors for homing, and maneuver using divert thrusters. Given that all of these systems operate in the same way, it may make sense to lump them together when looking at the overall success rate in midcourse hit-to-kill systems.

The remaining tests (13 out of 25) that are counted by General Kadish are those of the terminal-phase Patriot PAC-3 interceptor and its developmental predecessors, the ERINT and FLAGE interceptors. While it is true that PAC-3 is a hit-to-kill system, this system differs in essentially every other important respect from the Ground-Based Midcourse system and the other midcourse hit-to-kill systems. PAC-3 is a terminal defense that only operates within the atmosphere, well below the minimum altitude of any of the other systems. Instead of using an infrared sensor for homing, it uses a radar. It maneuvers using atmospheric forces rather than divert thrusters (although it does uses small thrusters to produce rapid attitude changes in order to generate these aerodynamic forces). Thus, in the two key aspects of the endgame—the way the interceptor detects and tracks the target and the way it maneuvers in attempting to hit the target—PAC-3 is completely different from all the other systems discussed above.

It differs in other crucial respects as well. All of the other interceptors release a kill vehicle; the PAC-3 interceptor is a single-stage missile with no kill vehicle. PAC-3 is intended to counter much shorter-range and slower missiles than the other interceptors. While all the other interceptors are purely ballistic missile defenses, PAC-3 is also designed to counter airplanes and cruise missiles. In addition, the types of countermeasures that PAC-3 must be designed to counter are completely different from those for the midcourse systems.

Thus, developing and deploying a highly effective Patriot PAC-3 system would tell you almost nothing about the likely effectiveness of a midcourse hit-to-kill system.

By adding in the better statistics of the terminal-phase hit-to-kill systems, proponents of the endgame success argument are in effect padding the relatively poor test statistics for the midcourse systems. This is very misleading since the policy debate over missile defenses, to which the endgame effectiveness argument is directed, is really only about the midcourse systems. Removing the irrelevant terminal-phase data from the statistics drops the endgame success rate from 71% to 61% for midcourse systems.[7]

Endgame success rate is not higher than pre-endgame success rate

Third, proportionally the success rate in the endgame is actually *lower* than in any other phase of the tests. In 67% of the tests of midcourse systems, the test successfully reached the endgame. However, only 61% of those tests that successfully reached the endgame went on to hit the target, resulting in a slightly lower endgame success rate. (This is also true for the terminal systems; 87% of the tests reached the endgame, but only 85% of these went on to hit the target.)

Endgame success rate is irrelevant

More importantly, the argument that the endgame success rate is more meaningful than the overall success rate is false. There is no merit to the claim that the overall success rate is less meaningful because many of the failures prior to the endgame were simply quality control-type errors (or as General Kadish put it "challenges in engineering and systems integration"). As is shown in the Appendix, quality control problems have also plagued the endgame. In fact, when quality control-type errors are excluded, the hit-to-kill success rate is 100%. Every failure, whether in the endgame or earlier, has been caused by quality control errors or malfunctions in either the interceptor or target. This is because every test has been carefully designed to be successful (i.e., achievable geometries and timelines were used, and detailed information on the nature of target was provided to the kill vehicle). As a result, such tests will always be successful unless there is a malfunction or error of some sort.

Taking into account failures that occur both prior to and during the endgame, the overall success rate for midcourse systems drops to only 41%.

[7] One might question whether THAAD should be lumped in with the other midcourse systems, since it is capable of operating in the upper layers of the atmosphere (high endo) and six of its intercept tests were high endo tests. However, as discussed above, unlike PAC-3, THAAD operates in a manner very similar to the other pure midcourse systems. In addition, dropping the six high endo THAAD tests would change our results very little, raising the endgame success rate from 61% to 62.5%.

Intercept tests do not adequately simulate real world usage

Finally, even if it were true that midcourse hit-to-kill missile defense systems had achieved high success rates overall in the tests to date, this would not demonstrate that such systems would work in actual use.

All the midcourse tests conducted to date are research and development (R&D) tests, which are carefully orchestrated and, as the MDA itself notes, include numerous "limitations" and "artificialities."[8] While these limitations may be appropriate for a program at an early stage of development, they mean that the tests say little about the ability of the system to operate under realistic conditions.

A successful R&D test simply shows that it is possible to hit a well-behaved target on the test range, a fact was first demonstrated over 18 years ago in the fourth test of the Homing Overlay Experiment, and that is not in serious dispute. There is no fundamental principle or question being investigated in these tests.

The actual effectiveness of any missile defense system, and of midcourse hit-to-kill systems in particular, will be determined primarily by its ability to deal with countermeasures, such as decoys, employed by attackers in an attempt to defeat the system. The problem of countermeasures has always been the fundamental problem standing in the way of developing effective missile defenses and it remains the fundamental problem today. A 1999 National Intelligence Estimate concluded that countries such as North Korea, Iran, and Iraq could rely on a wide range of available technologies to develop countermeasures, and that "These countries could develop countermeasures based on these technologies by the time they flight test their missiles."[9] A 2000 study by a group of scientists and engineers demonstrated in detail how a number of relatively simple countermeasures could defeat the Clinton administration's planned midcourse NMD system.[10]

In some of the intercept tests of midcourse systems, the warhead target was accompanied by one or two other objects that were called "decoys." However, the physical appearances of the objects used in the tests were designed to look very different from one another as measured by the

[8] Examples of limitations and artificialities in the Ground-Based Midcourse tests to date include the use of a slower surrogate booster and intercepts at closing speeds that are much lower—by up to a factor of two—than would be expected for an operational system. Another example is the use of data sent by the C-band beacon or GPS receiver on the mock warhead, allowing the kill vehicle to be put on a trajectory that is headed essentially straight at the mock warhead. As a result, the kill vehicle does not have to maneuver much to home on the mock warhead and intercept it. In a real attack, the kill vehicle might need to maneuver far more to home on the target, especially if the defense radars had not succeeded in discriminating the warhead from the other objects. For more details, see Lisbeth Gronlund, David Wright and Stephen Young, An Assessment of the Intercept Test Program of the Ground-Based Midcourse National Missile Defense System (Union of Concerned Scientists: Cambridge MA), 30 November 2001, available at www.ucsusa.org/publication.cfm?publicationID=339.

[9] National Intelligence Council, "National Intelligence Estimate (NIE): Foreign Missile Development and the Ballistic Missile Threat to the United States Through 2015," unclassified summary, September 1999.

[10] Andrew M. Sessler, John M. Cornwall, Bob Dietz, Steve Fetter, Sherman Frankel, Richard L. Garwin, Kurt Gottfried, Lisbeth Gronlund, George N. Lewis, Theodore A. Postol, and David C. Wright, Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System, Union of Concerned Scientists/MIT Security Studies Program, March 2000.

various defense sensors. Moreover, in all cases, the defense has been given *a priori* information about the expected appearance of the different objects in advance of the test, an advantage the United States is unlikely to have in a real attack. Thus, the intercept tests reveal very little about the discrimination capabilities of the system.

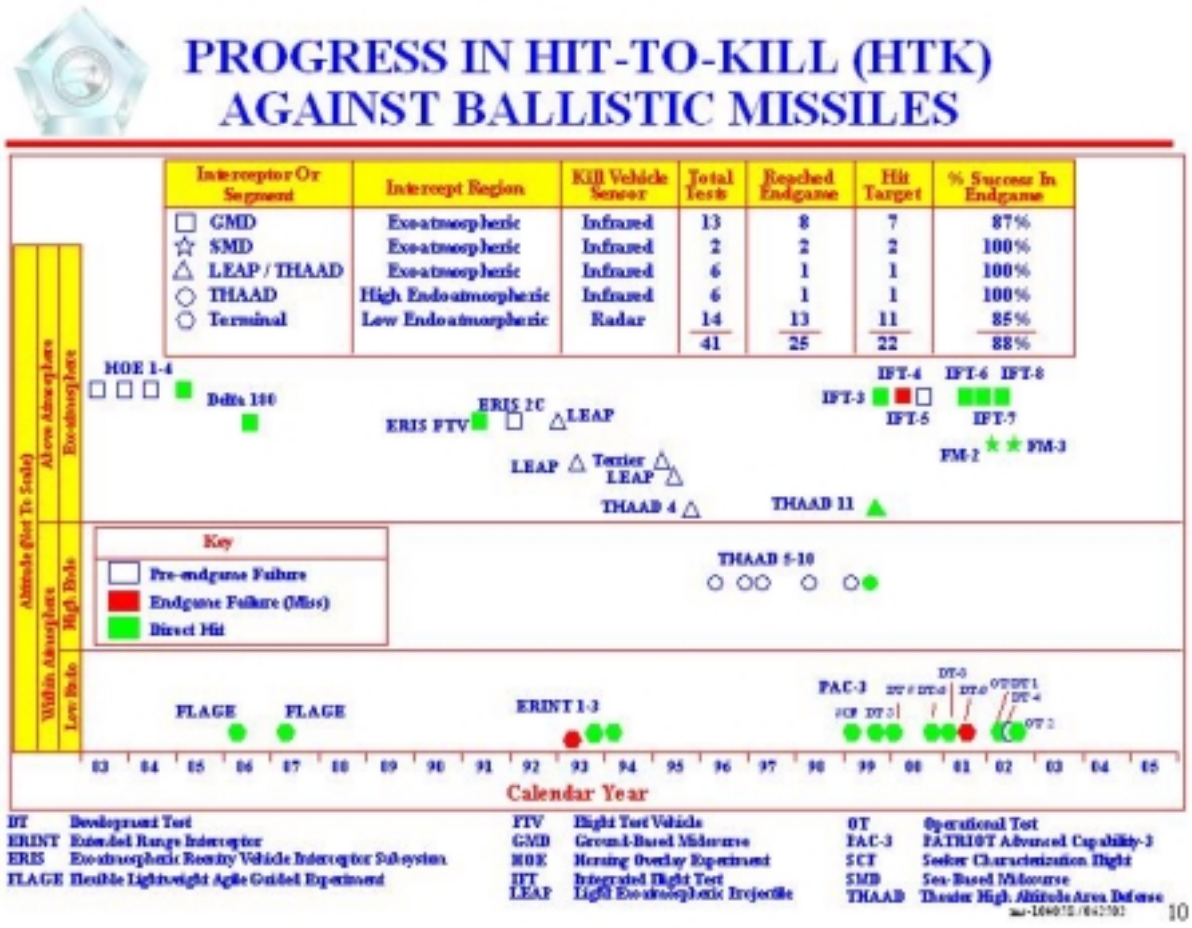
There has never been a midcourse hit-to-kill intercept test against a target employing even minimally credible countermeasures. It is at best unclear if such a test, using countermeasures actually intended to defeat the defense and without providing the defense with complete advance knowledge, will ever be conducted. Certainly no such test will take place until well after many of these midcourse systems are slated to be deployed.

Without realistic tests, there is no way to know with confidence how well a defense will work in actual use. Worse, unrealistic test-range results against cooperative targets, particularly when coupled with the increasing secrecy about the nature of the tests, may lead to inflated expectations about capabilities. The potential discrepancy between test-range and actual results was well demonstrated in the Gulf War when the Patriot system attempted to shoot down modified Iraqi Scuds. Although Patriot had a perfect 17 for 17 record against missile targets on the test range prior to the war it completely failed to destroy the Iraqi Scuds. The reason: the Iraqi Scuds, which broke apart and maneuvered erratically on reentry, were different than the test range targets, which flew slower and on predictable trajectories. The Patriots were defeated by an apparently unintentional Iraqi countermeasure.

A Closer Look at the Numbers

The slide presented by General Kadish during his testimony lays out how the MDA obtained the "22 for 25" figure for the success rate in the endgame (see Figure 1).[11]

Figure 1: MDA slide presented by General Kadish during June 25, 2002 testimony



The five categories of system tests listed on this slide are:

(1) Thirteen tests of ground-based midcourse defenses, comprised of the four Homing Overlay Experiment (HOE) tests, the two Exoatmospheric Reentry Vehicle Interceptor Subsystem (ERIS) tests, the Delta 180 experiment, and the six Ground-Based Midcourse system intercept tests conducted through June 2002

[11] Lt. General Kadish, slides accompanying "Special Briefing on Missile Defense."

(2) Two Sea-Based Midcourse tests using the Light-weight Exo-Atmospheric Projectile (LEAP) kill vehicle conducted in 2002

(3) Four exoatmospheric LEAP tests carried out between 1992 and 1995 and the two exoatmospheric THAAD tests

(4) Six high endoatmospheric THAAD tests

(5) Tests of terminal missile defenses, comprised of 14 tests of the Patriot PAC-3 and its developmental predecessors, ERINT and FLAGE, against ballistic missile targets. (These terminal systems were also tested against aircraft and cruise missile targets, but those engagements are not included in Kadish's statistics)

The figures cited on this slide are summarized in Table 1.

Table 1: Figures on slide presented by Kadish at June 2002 testimony

	Total Tests	Reached Endgame	Hit Target
Ground-Based Midcourse (GMD)	13	8	7
Sea-Based Midcourse (SMD)	2	2	2
LEAP and exo THAAD	6	1	1
high endo THAAD	6	1	1
Terminal	14	13	11
Total	41	25	22

Thus, Kadish's numbers indicate that there have been 41intercept tests, of which 22 were successful (a 54% success rate), but that of the tests that reached the endgame, the success rate is 22 for 25 (88%).

The definition of endgame

In order to assess whether a test reached the endgame, we need to define what the "endgame" is. According to General Kadish:[12]

> The endgame is the final part of an interceptor's flight, when the guidance system on the kill vehicle acquires the target cluster, executes terminal guidance and divert maneuvers, sorts the real targets from the decoys, and then arrives successfully at its aim point and destroys the target by colliding with it.

This statement indicates that the endgame begins when the kill vehicle is released from its booster missile and starts to search for its target, and the endgame continues until the target is either hit or missed. This is a reasonable definition, consistent with the common understanding of the meaning of "endgame," and is the definition we will adopt in this paper.

[12] Statement of General Kadish, June 14, 2001.

General Kadish's testimony later added one additional criteria, that the kill vehicle had to be placed in a "basket" from which it was actually able to detect and maneuver to hit the target. Thus, by this additional criteria, if either the kill vehicle or target was not placed on the correct trajectory so that the kill vehicle could not reach the target, it would not be counted as an endgame failure even if the kill vehicle detected and began to home on the target. We agree that such cases, even though they may meet the definition of endgame above, could reasonably be argued to not be failures in the endgame, and thus we will also not count them as endgame failures.

Assessment of whether tests reached the endgame

Based on the definition of endgame discussed above, we can review the publicly available data on the midcourse intercept attempts to see how many of the tests can be assessed as reaching the endgame. The Appendix lists each of the 27 midcourse hit-to-kill intercept tests, and for each intercept failure provides additional publicly available information about the test. We find that in addition to the one failed midcourse test acknowledged by General Kadish to have reached the endgame, six additional tests were endgame failures (the 1st, 2nd, and 3rd HOE intercept tests; 2nd ERIS intercept test; 4th LEAP intercept test; and 3rd THAAD intercept test).

It is also worth noting that four additional failed intercepts clearly entered the endgame, but failed either because the target or interceptor was incorrectly positioned (2nd and 3rd LEAP and 1st THAAD intercept tests), or because the kill vehicle did not receive expected information about the target (1st LEAP test). We do not count these as endgame failures. These tests are nonetheless interesting examples of how a deviation from the preplanned "script" of the test will lead to failure.

Some of the six additional endgame failures we identify above so obviously failed in the endgame that is very difficult to understand how supporters of the "endgame success" argument could justify not counting them as endgame failures. For example, in the first HOE test, the kill vehicle's sensor cooling system did not work correctly, and the sensor was too warm to work correctly. This is remarkably similar to the one midcourse endgame failure acknowledged by General Kadish—the second NMD intercept test, in which the sensor cooling system also failed—and is clearly an endgame failure. The other two HOE failures similarly provide very clear examples of endgame failures. In the second HOE test, the kill vehicle reportedly successfully demonstrated homing but then missed because of a failure in the kill vehicle's guidance electronics. In the third HOE test, homing was again reported to have been successfully demonstrated, but the intercept failed because of a software error in the kill vehicle computer.

The assessment here of whether or not an intercept attempt entered the endgame is necessarily based on public, unclassified information. It is possible that, with access to the classified information, we might obtain a somewhat different count of how many intercept attempts reached the endgame. However, the examples discussed in the previous paragraph make it very clear that, unless the publicly released information about the intercept attempts is completely inaccurate, many more midcourse intercept attempts reached the endgame than the single one acknowledged by General Kadish.

Comparison of results

For ease of comparison, in Table 2 we have included the numbers used by Kadish and, where they differ, our own numbers. The lightly shaded box shows the endgame success rate that General Kadish argues is relevant, with his inaccurate figure of 88% and our corrected figure of 71%. The darkly shaded box shows the overall midcourse success rate of 41%.

Table 2: A Comparison of the Numbers Used by Kadish and the Authors

System Tested	Total Tests		Reached Endgame		Hit Target	Pre-Endgame Success Rate		Endgame Success Rate		Overall Success Rate	
	K	A	K	A		Kadish	Authors	Kadish	Authors	Kadish	Authors
Ground-Based Midcourse	13		8	12	7						
Sea-Based Midcourse	2		2		2						
LEAP and exo THAAD	6		1	2	1						
high endo THAAD	6		1	2	1						
Subtotal Midcourse	27		12	18	11	12/27 = 44%	18/27 = 67%	11/12 = 92%	11/18 = 61%	11/27 = 41%	
Terminal	14	15	13		11	13/14 = 93%	13/15 = 87%	11/13 = 85%		11/14 = 79%	11/15 = 73%
Total	41	42	25	31	22	25/41 = 61%	31/42 = 74%	22/25 = 88%	22/31 = 71%	22/41 = 54%	22/42 = 50%

We note that General Kadish's figures completely omit one failed PAC-3 test. Thus, while he includes a total of 41 tests, of which 14 were tests of terminal defenses, we include a total of 42 tests, with 15 tests of terminal defenses. His chart shows PAC-3 test DT-4 as a single test in which the endgame was not reached. In fact, DT-4 consisted of two PAC-3 interceptors that were to be fired at two separate missile targets. The US Army initially reported that one of the interceptors had destroyed its missile target, but subsequently announced that the interceptor "made contact with the target, but failed to destroy it" and thus the engagement was not counted as a success.[13] The fact that the PAC-3 actually hit the target strongly indicates that this was a failure in the endgame. The other PAC-3 interceptor failed to launch. Thus, neither target was destroyed, and this test appears to consist of one failure during the endgame and one prior to the endgame.

[13] Emily Hsu, "Army Officials: Last PAC-3 Missile Test 'Intercept' Won't Count," *Inside Missile Defense*, May 29, 2002.

Finally, it is worth observing that of the 27 midcourse tests, 18 (67%) successfully reached the endgame. Of these 18, only 11 (61%) actually hit their targets. Thus on a percentage basis, more tests failed in the endgame than in all the other phases combined.

Appendix:
Chronology and Assessment of Midcourse Hit-to-Kill Intercept Tests

This appendix lists each of the 27 intercept tests of midcourse hit-to-kill missile defense systems that took place prior to General Kadish's June 2002 testimony, indicating whether or not it resulted in a successful intercept of the target. For those tests that failed, we

(1) provide a description of the test based on publicly available information;
(2) indicate whether General Kadish assessed the failure to have occurred prior to or in the endgame; and
(3) provide our own assessment of whether the failure was an endgame failure.

Homing Overlay Experiment

First Intercept Test, February 7, 1983
The kill vehicle missed the target. The miss was attributed to problems in the infrared sensor cooling system. These problems caused the interceptor's infrared sensor to be warmer than expected, producing noise that saturated the flight computer on the kill vehicle. In the three subsequent Homing Overlay tests, the sensor's detection threshold was raised in order to eliminate the noise, and the target was also heated.[14]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Endgame failure
It is unclear from press reports whether the kill vehicle ever acquired or tracked the target, but the failure occurred in the infrared sensor that was used for endgame homing, so this was clearly a failure of the kill vehicle's ability to perform the endgame. This failure was similar in nature to the one midcourse endgame failure acknowledged by General Kadish—the January 18, 2000 NMD test, in which the sensor cooling system also failed.

Second Intercept Test, May 28, 1983
The kill vehicle again missed its target. Shortly after the test, Army officials said that the kill vehicle had completed the flight sequence required to intercept the target, but that the intercept did not occur.[15] The interceptor reportedly demonstrated successful homing, but missed due to a "random" failure in the guidance electronics.[16]

Kadish assessment: Not an endgame failure

[14] David A. Fulghum, "Army Officials Deny Rigging SDI Test," *Aviation Week and Space Technology*, August 30, 1993, p. 25.

[15] "Army Evaluates Homing Vehicle Test Failure," *Aviation Week and Space Technology*, June 13, 1983, p. 119.

[16] Clarence A. Robinson, Jr., "BMD Homing Interceptor Destroys Reentry Vehicle," *Aviation Week and Space Technology*, p. 19.

Lewis/Gronlund assessment: Endgame failure
The kill vehicle had begun homing but failed to hit the target due to a failure in the guidance electronics.

Third Intercept Test, December 1983
The kill vehicle again missed its target. Homing was successfully demonstrated, but a software error in the on-board computer prevented the conversion of homing data into steering commands causing the miss distance to be too large to be successful.[17]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Endgame failure
A software error affected the homing process, causing the kill vehicle to miss its target.

Fourth Intercept Test, June 10, 1984
The kill vehicle hit the target.

Delta 180 Experiment

Intercept Test, September 5, 1986
In this experiment, two satellites were maneuvered to collide with each other. In the final phase of the experiment, one satellite successfully homed on and hit the other.

ERIS (Exo-atmospheric Reentry Vehicle Interceptor System) Tests

First Intercept Test, January 28, 1991
The ERIS kill vehicle hit its target.

Second Intercept Test, March 13, 1992
The ERIS failed to hit the target, which was accompanied by a single balloon "decoy," reportedly missing by "several meters."[18] The decoy and target were separated by about 20 meters and the kill vehicle flew between them.[19] The miss was apparently a result of two factors: a greater than anticipated separation between the decoy and target and a later than expected detection (by about 0.2 second) of the target relative to the decoy. The kill vehicle was programmed to initially fly to the midpoint between the target and decoy, while collecting data on them for a one-second period. Because it initially detected only the decoy, the first part of its divert was directed towards the decoy rather than the midpoint. Combined with the greater than expected separation, this left the kill vehicle unable to divert to the target in time. According to

[17] Robinson, "BMD Homing Interceptor," p. 20.

[18] Vincent Kiernan and Debra Polsky, "SDI Interceptor Fails to Hit Target," *Defense News*, March 23, 1992, p. 8.

[19] Private communication from David Wright, based on meeting with Lockheed officials, April 3, 1992.

Project Manager James B. Katechis, following the one-second data collection period, mission planners had allowed 0.8 seconds for the kill vehicle to make its divert, but at least 0.9 seconds were actually needed.[20]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Endgame failure
The miss was a result of several errors in the endgame, including a late detection of the warhead, an insufficient amount of time allowed for maneuvering, and a mispositioning of the "decoy" (not the target). While it appears likely that without the data collection interval an intercept would have occurred, the test had been designed to produce an intercept even taking into account the data collection period. This test illustrates that even small deviations from a carefully scripted intercept test can lead to failure.

LEAP (Light-weight Exo-Atmospheric Projectile) and Sea-Based Midcourse Tests

LEAP 2 Intercept Test, June 19, 1992
The LEAP successfully acquired and tracked the target, but failed to hit it.[21] The target was supposed to transmit data on its position and speed to the kill vehicle. This position and speed data was to be used by the kill vehicle to initialize the Kalman filter used in its guidance system.[22] When it did not receive this data, the LEAP used default values, resulting in the miss. According to Lt. Col. Stephen G. Kee, the Army Strategic Defense Command Manager for the Hughes LEAP, without the position and speed data from the target, "there is little chance of success." The miss distance was about 25 meters.

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
The kill vehicle was apparently delivered to a position from which it should have been able to hit the target. However the data provided on the target position and speed was incorrect. This is perhaps analogous to a kill vehicle being given incorrect target information by the defense's radar. Thus the fault here appears to lie with the systems supporting the kill vehicle and not the kill vehicle itself.

LEAP 3 Intercept Test, June 22, 1993
The LEAP missed its target. According to the Ballistic Missile Defense Organization's LEAP Program Manager, the target was released about 1 kilometer beyond its intended location. As a

[20] "SDI Experimental Interceptor Misses Dummy Warhead in Final Flight Test," *Aviation Week and Space Technology*, p. 21.

[21] Michael A. Dornheim, "Loss of Position and Velocity Data Makes SDI LEAP Interceptor Miss Target," *Aviation Week and Space Technology*, June 29, 1992, p. 66.

[22] Paul Baker, Buster Kelley, and Anne Avetissian, "Lightweight exo-atmospheric projectile (LEAP) Space Flight Test, June 1992, Performance Validation," 2nd Annual AIAA and SDIO Interceptor Technology Conference, Albuquerque, New Mexico, June 6-9, 1993, AIAA Paper 93-2696.

result, when the interceptor homed on the target, it ran out of fuel due to the longer flight time to the target, and missed the target by seven meters.[23]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
Although the kill vehicle was clearly in the endgame, the target was apparently deployed out of the LEAP's range.

FTV-3 Intercept Test, March 4, 1995
First intercept attempt for LEAP/Upper Tier, launched from the USS Turner. LEAP failed to hit the target because a programming error in its guidance system during the second stage caused the missile to fly too high, putting the kill vehicle in a position from which it could not make an intercept.[24] According to then BMDO Director Lt. General Malcolm O'Neill, "All stages of flight were demonstrated, including guidance by the new third stage and target tracking and homing by the LEAP kill vehicle."[25]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
The kill vehicle apparently reached the endgame, but the error in the second stage booster put it in a position from which it could not reach the target.

FTV-4 Intercept Test, March 28, 1995
The LEAP failed to hit the target, apparently because a battery in the LEAP failed.[26] The intercept proceeded normally up to the point at which the kill vehicle was ejected from the missile, and the LEAP apparently saw the target before it was ejected from the missile. However, the LEAP had no electrical power after release, and missed the target by 167 meters.[27]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Endgame failure
It could be argued that it is unfair to count this as an endgame failure, since the kill vehicle had no power after release. However, the kill vehicle was apparently released in the right place for detecting and intercepting the target. It apparently failed to do so

[23] Ben Iannotta, "Target Error Again Gets Blame in 2nd LEAP Test Failure," *Defense News*, July 12-18, 1993, p. 20.

[24] David Hughes, "Software Errors Fixed for Next Leap Test," *Aviation Week and Space Technology*, March 27, 1995, p. 45.

[25] Prepared Statement of Lt. General Malcolm O'Neill, Department of Defense Appropriations for Fiscal Year 1996, Subcommittee of the U.S. Senate Committee on Appropriations, June 27, 1995. p. 606.

[26] "Navy Theater Wide (NTW) Defense," Director, Operational Test and Evaluation, FY 1998 Annual Report (available at www.fas.org/spp/starwars/program/dote98/98ntw.htm).

[27] O'Neill testimony, June 27, 1995, pp. 606-607.

because of an internal failure of a vital component of the kill vehicle (in a sense, no different than a failure of the seeker or a divert thruster that would clearly be regarded as a failure in the endgame) and thus clearly is an endgame failure.

FM-2 (Flight Mission-2), January 25, 2002
The LEAP hit its target. Although the LEAP hit its missile target, several facts about this test are worth noting. First, an intercept was not an official objective for this test, so that if it had not hit the target, it would not have counted as a miss. Second, the LEAP apparently hit near the middle of the Aries target missile, which was over 10.5 meters long. Thus, not only was the target much larger than a typical missile warhead, but if this had been a real attacking missile, the warhead might well have survived the intercept.

FM-3, June 13, 2002
The LEAP hit its Aries missile target, again apparently near the middle of the missile.

THAAD (Theater High Altitude Area Defense) Tests

First Intercept Test, December 13, 1995
This was an exoatmospheric test. The THAAD kill vehicle failed to hit its target due to a software error which caused the interceptor to "over correct" during the first in-flight update from the ground based radar.[28] The system subsequently tried to correct for this error, but the additional maneuvers required caused it to run out of divert fuel before the last maneuver, and thus it missed the target. The flight met all test objectives, except that the interceptor missed the target.

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
Although the kill vehicle clearly reached the endgame, failure to hit the target was the result of a problem with the first in-flight update from the ground-based radar, which almost certainly would have taken place well before the endgame.

Second Intercept Test, March 22, 1996
This test took place in the high endoatmosphere. The THAAD kill vehicle did not respond to commands following separation from its booster, and did not hit its target.[29] The publicly available information about the problem that occured is somewhat contradictory. The failure was attributed to a broken cable connecting the kill vehicle with its supporting electronics

[28] Department of Operational Test and Evaluation, FY 1995 Annual Report, "Theater High Altitude Area Defense (THAAD) System." (Formerly available at www.dote.osd.mil/reports/FY95/thaad.html ; it is no longer available on the DOT&E website, but can be requested from their office). The THAAD GBR was reportedly used only in a "shadow" mode during this test, so the ground based radar referred to here was likely the White Sands range radar that was used as the primary radar in this test.

[29] Michael A Dornheim, "THAAD Pressing On After Intercept Failure," *Aviation Week and Space Technology*, April 1, 1996, pp. 28-29.

module.[30] General Kadish stated that the failure occurred about 20 seconds after launch, which was before the kill vehicle could have separated from its booster. However, the FY 1997 DOT&E annual report stated that the failure was the result of "a catastrophic failure of a data umbilical cable during kill vehicle/booster separation" and the FY 1998 DOT&E report said the failure occurred because "one of four separation connectors failed to disconnect."[31]

Kadish assessment: Not an endgame failure.

Lewis/Gronlund assessment: Not an endgame failure.
The available evidence indicates that the failure was a result of a malfunction in the process of separating the booster from the kill vehicle.

Third Intercept Test, July 15, 1996
This was also a high-endoatmospheric test. The THAAD kill vehicle failed to hit its target, although program officials said the kill vehicle came within "a matter of yards of the target."[32] The failure was reportedly caused by a seeker problem. According to BMDO Director Lt. General Lester Lyles, the seeker lost power in part of its focal plane array.[33] It appears that the precise cause of the seeker failure could not be conclusively determined, with the leading suspect being loose connection between the electronics boards and the seeker.[34] The seeker had detected the target prior to its failure.[35] According to the FY1998 DOT&E annual report, "A problem with either the seeker electronics or a contaminated dewar in the infrared seeker caused one half of the focal plane array to saturate. This overloaded the onboard signal processor, which precluded designation of the target, and resulted in no closed-loop guidance of the kill vehicle."[36]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Endgame failure
A failure of the seeker prevented the target from being identified.

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[30] Daniel G. Dupont, "Army Hopes to Speed THAAD Fielding Following DoD Cuts," *Inside Missile Defense*, April 3, 1996, p. 3.

[31] Theater High Altitude Area Defense (THAAD), FY 1997 and FY 1998 Annual Reports, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote97/97thaad.htm and www.fas.org/spp/starwars/program/dote98/98thaad.htm

[32] Joseph C. Anselmo, "THAAD Fails Third Intercept," *Aviation Week and Space Technology*, July 22, 1996, p. 31.

[33] Joseph C. Anselmo, "New BMDO Chief: Next THAAD Must Score Hit," Aviation Week and Space Technology, October 14, 1996, pp. 68-69.

[34] Lucius Outlaw, " Program Officials Say Loose Connectors Could Explain THAAD Seeker Failure," *Inside Missile Defense*, October 16, 1996, pp. 1, 18-19.

[35] Daniel G. Dupont, "THAAD Program Officials Verify Seeker Caused Third Miss in as Many Tries," *Inside Missile Defense*, July 24, 1996, pp. 11-13.

[36] Theater High Altitude Area Defense (THAAD), FY 1998 Annual Report, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote98/98thaad.htm

Fourth Intercept Test, March 6, 1997
This was a high-endoatmospheric test. THAAD missed its target. The failure was attributed to THAAD's divert and attitude control system (DACS), which is part of the kill vehicle but is also used before the endgame, and which had worked in previous tests. After the interceptor leaves its launch tube, the six attitude control and four divert thrusters are supposed to fire briefly to remove nozzle covers and prime the DACS system. In this case, only two attitude control thrusters fired, and then the DACS failed. Although the missile seeker was activated, because of the DACS failure the missile could not roll to point the seeker at the target, and the target was not detected. The interceptor missed the target by several hundred meters.[37] The failure was due to contamination on the missile battery interface, resulting in poor electrical contact that prevented the DACS from operating.[38]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
The interceptor's DACS system failed shortly after launch.

Fifth Intercept test, May 12, 1998
This was a high-endoatmospheric test. The THAAD interceptor failed shortly after launch and dove into the ground.[39] The failure occurred as the missile was performing an energy management maneuver designed to reduce its speed and consume fuel so it would remain within the confines of the missile test range.[40] According to the FY 1999 DOT&E annual report, "The failure is attributed to an electrical short circuit due to foreign object debris in the high-voltage connector in the thrust vector control that steers the booster.[41]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure

Sixth Intercept Test, March 29, 1999
This was a high-endoatmospheric test. THAAD missed its target. The miss distance was initially said to be 10-30 meters, but was subsequently reported to be much less.[42] However, analysis of

[37] Michael A. Dornheim, "THAAD Second Source Unlikely, Army Says," *Aviation Week and Space Technology*, "March 24, 1997, p. 33.

[38] Theater High Altitude Area Defense (THAAD), FY 1999 Annual Report, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote99/99thaad.htm

[39] Daniel G. Dupont and Brian Berger, "THAAD Missile Fails Early in Fifth Intercept Attempt," *Inside Missile Defense*, May 13, 1998.

[40] Michael C. Sirak, "THAAD Failed as Missile Attempted Range Control Maneuver," *Inside Missile Defense*, May 27, 1998; Daniel G. Dupont, "Analysis of Last THAAD Failure is Slow Going," *Inside Missile Defense*, July 8, 1998.

[41] Theater High Altitude Area Defense (THAAD), FY 1999 Annual Report, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote99/99thaad.htm.

[42] Thomas Duffy and Michael C. Sirak, "THAAD Missile Got 'In the Basket' Before Failing To Intercept Target," *Inside Missile Defense*, April 7, 1999; Daniel G. Dupont, "Army: 'Most Experts' Think THAAD Seeker Was Working, But Data Still Hard To Come By," *Inside Missile Defense*, April 21, 1999.

the miss was hampered by a loss of telemetry data that began early in the flight and was never regained. Following the test, Army and Pentagon officials attributed the miss to a failure of a valve or nozzle in the THAAD's divert and attitude control system (DACS). It was subsequently reported that BMDO had determined that the seeker was not tracking the target during the endgame, because a faulty nozzle was causing so much vibration that the seeker could not have operated.[43] According to the FY 1999 DOT&E annual report: "Although the kill vehicle came within meters of intercepting the target, no endgame data was collected because the telemetry system was damaged during interceptor fly-out. Both failures—the missed intercept and the loss of telemetry—resulted from the very high internal environments in the kill vehicle which occurred after an attitude control system nozzle was torn from its bracket approximately 23 seconds into flight."[44]

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure
The kill vehicle was apparently put into position to make an intercept had the DACS been working properly. However, the DACS system failed before the beginning of the endgame.

Seventh intercept test, June 10, 1999
This was a high-endoatmospheric test. The THAAD interceptor destroyed a Hera target.[45] Although the target was a missile rather then a warhead or reentry vehicle, the kill vehicle hit "within the specification aimpoint limits on the warhead region of the target."[46]

Eighth intercept test, August 2, 1999
This was an exoatmospheric test. The THAAD interceptor destroyed a reentry vehicle target launched on a Hera missile at an altitude above 80 kilometers.

National Missile Defense (Ground-Based Midcourse) System Tests

First Intercept Test (IFT-3), October 2, 1999
The kill vehicle hit its target.

Second Intercept Test (IFT-4), January 18, 2000
The kill vehicle missed its target due to a failure in the cooling system for its infrared sensors. According to BMDO Director Lt. General Kadish, the failure was caused by obstructions in the small orifices through which the krypton gas used for initial cooling of the infrared sensors

[43] Michael C. Sirak and Daniel G. Dupont, "Jubilant THAAD Program Officials Set Sights on Next Flight Test of Missile," *Inside Missile Defense*, June 16, 1999.

[44] Theater High Altitude Area Defense (THAAD), FY 1999 Annual Report, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote99/99thaad.htm.

[45] Sirak and Dupont, "Jubilant THAAD Program Officials."

[46] Theater High Altitude Area Defense (THAAD), FY 1999 Annual Report, Director, Operational Test and Evaluation. Available at www.fas.org/spp/starwars/program/dote99/99thaad.htm.

flows.[47] The kill vehicle detected the target using its visible light sensor. However, only the two infrared sensors are used for the terminal homing, beginning about 6 seconds before the expected intercept, and because these failed the kill vehicle could not hit the target.

Kadish assessment: Endgame failure

Lewis/Gronlund assessment: Endgame failure
This is the only midcourse endgame failure acknowledged by supporters of the "endgame success" argument.

Third Intercept Test (IFT-5), July 8, 2000
The test failed 136 seconds after the interceptor was launched, when the booster malfunctioned, cutting off communication between itself and the kill vehicle.[48] As a result, the kill vehicle did not separate from the booster.

Kadish assessment: Not an endgame failure

Lewis/Gronlund assessment: Not an endgame failure

Fourth Intercept Attempt (IFT-6), July 14, 2001
The kill vehicle hit its target.

Fifth Intercept Attempt (IFT-7), December 3, 2001
The kill vehicle hit its target.

Sixth Intercept Attempt (IFT-8), March 15, 2002
The kill vehicle hits its target.

[47] Michael C. Sirak, "Next NMD Test Slipped to June, Deployment Review to July," *Inside Missile Defense*, March 22, 2000.

[48] Michael Sirak, "NMD Program Chief Says IFT-5 Demonstrated System Integration," *Inside Missile Defense*, August 23, 2000.