Decoys Used in Missile Defense Intercept Tests, 1999-2018

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Summary

Missile defense tests through 2018 (Table 1) have not included realistic decoys and other countermeasures that the system would be expected to face in a real attack—including an attack from North Korea. Contrary to some claims, these tests have therefore not demonstrated that the missile defense system would be successful in intercepting incoming warheads under realistic conditions. This paper discusses the decoys used in all of the intercept tests to date of the US Ground-based Midcourse Defense (GMD) system.

GMD Intercept Tests and Discrimination

Tests IFT-1 (1997) and IFT-2 (1998)[1] were fly-by tests in which the kill vehicle simply observed the objects in the target cluster without attempting to intercept, to collect data on their appearance to the kill vehicle's sensor. The tests found that the kill vehicle was unable to distinguish some of these objects from the mock warhead. Subsequent intercept tests have instead used decoys that do not look like the warhead and are easy to distinguish (Broad 2000).

The first flight intercept test of what has become the Ground-based Midcourse Defense (GMD) missile defense system was test IFT-3 on October 2, 1999. That test and many of the 15 others since then have included decoy balloons. The primary purpose of these tests was to demonstrate "hit to kill," that is, to test the ability of the interceptor to be guided toward an intercept point and for the kill vehicle to home on the target warhead and physically collide with it. A secondary purpose of these tests was for the kill vehicle to use its onboard sensors to attempt to distinguish the mock warhead from the decoy balloons and other objects, such as the upper stage of the missile that launched the warhead.

The sensors on the kill vehicle measure the brightness of the objects in several wavelength bands, and the fluctuation of those signals. The kill

TABLE 1. **Intercept Tests of the GMD System**

Ground-Based Midcourse Defense Intercept Tests		
Test	**Date**	**Designation**
1	**10/2/99**	IFT-3
2	**1/18/00**	IFT-4
3	**7/7/00**	IFT-5
4	**7/14/01**	IFT-6
5	**12/3/01**	IFT-7
6	**3/15/02**	IFT-8
7	**10/14/02**	IFT-9
8	**12/11/02**	IFT-10
Deployment Decision		
9	**12/15/04**	IFT-13C
10	**2/14/05**	IFT-14
11	**9/1/06***	FTG-02
12	**9/28/07**	FTG-03A
13	**12/5/08**	FTG-05
14	**1/31/10**	FTG-06
15	**12/15/10**	FTG-06A
16	**7/5/13**	FTG-07
17	**7/22/14**	FTG-06B
18	**4/30/17**	FTG-15

Green succeeded, red failed.

*The interceptor in FTG-02 hit the target with a glancing blow that did not destroy the warhead. The Missile Defense Agency (MDA) rates this test as a "hit" but not a "warhead kill," and counts it as a success. Since the goal of developing hit-to-kill (HTK) interceptors is to guide the kill vehicle to destroy the warhead, we do not count this as a successful demonstration of the HTK technology.

[1] IFT stands for Integrated Flight Test.

vehicle attempts to use that information to tell which is the warhead and which objects it should ignore. However:

- The decoy balloons and other objects used in the tests have been designed to look very different than the warhead to the kill vehicle's sensor, so they have been easy to distinguish;
- Information about the different appearance of the objects is given to the kill vehicle in advance so that it can recognize which object is which;
- Those decoys found in early tests to be difficult for the kill vehicle to distinguish from the warhead have not been used in subsequent tests.

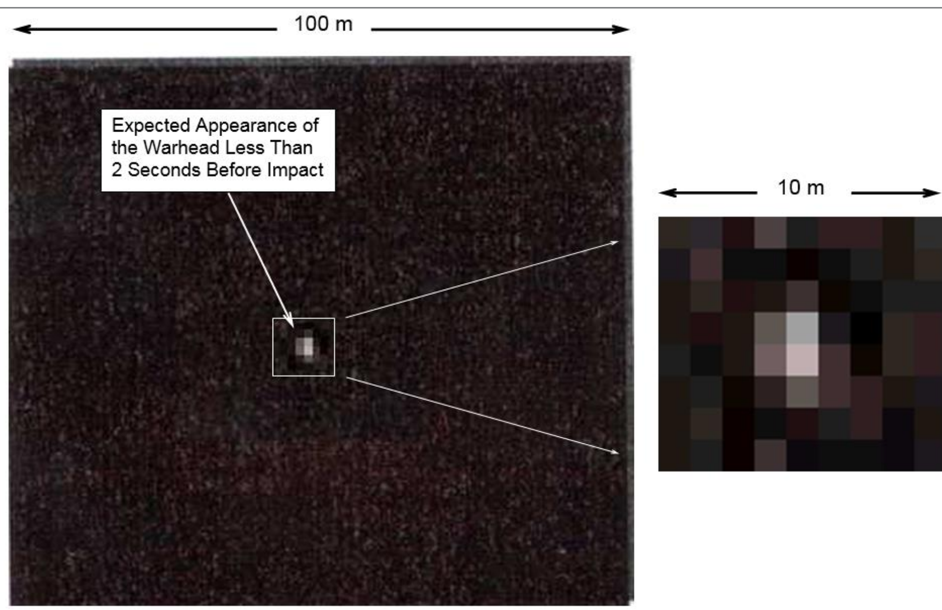
As noted, the discrimination methodology used in the tests assumes that the defense will have detailed information—in advance of an attack—about the appearance of the warheads and decoys used by the attacker. To discriminate, the defense would then compare what its sensors see with the information stored in its computer and attempt to find a unique match that will identify the warhead.[2]

In a real attack, the defense is unlikely to have *a priori* information about the appearance of the objects, which is under the control of the attacker. The attacker might release dozens of lightweight decoy balloons while also disguising the appearance of the warhead, so the defense sensors could not expect to collect information that would allow the defense to identify the warhead.

The intercept tests therefore do not demonstrate the ability of the GMD system to successfully discriminate objects the kill vehicle might see in an actual attack.

[2] The General Accounting Office (GAO) describes this process by noting that the defense is provided with a set of "reference data," which is "a collection of predicted characteristics, or features, that target objects are expected to display during flight." The discrimination software then tries to identify the various target objects "by comparing the target signals collected from each object at a given point in their flight to the target signals it expects each object to display at that same point in the flight" (GAO 2002).

FIGURE 1. **Appearance of Objects to the Kill Vehicle**



This figure illustrates how objects appear to the kill vehicle. It shows a portion of the field of view of the kill vehicle's infrared sensor when the kill vehicle is about 16 km from an object of roughly 2 m size, comparable to a warhead or decoy. Impact would occur in about a second and a half. The small light and dark squares represent the individual pixels of the infrared detector array. Even at this short range, the object only covers a small number of pixels, which appear lighter than the others (a blow-up of the center of the image is shown on the right). This illustrates that the kill vehicle will not be able to get information about the shape of objects in the threat cloud until it is too late to use for discrimination. (The kill vehicle's sensor uses a 256 x 256 element array.) SOURCE: THEODORE POSTOL, MIT

It is important to note that the kill vehicle's sensors do not have the ability to see details of objects, such as shape, until the kill vehicle is very close to the object. The reason for this is that the sensors consist of arrays of individual sensor elements onto which the sensors' optics project an image of the object. The farther away the object is, the smaller its image is and the fewer elements it covers on the array. If the object is distant enough that its image falls on only one or a few elements, the sensor cannot determine the shape of the object, but only detects the overall brightness (Figure 1).

Thus, the objects in the target cluster—the mock warhead, the balloons, and the final stage of the missile that launched them—will all appear to the kill vehicle as points of light (see Figures 3, 4 and 5 below) until just one to two seconds before impact. This is too late for the kill vehicle to be able to change its course by any significant amount.[3]

Decoys in GMD Tests

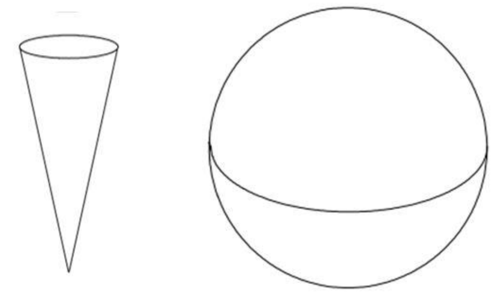
Below we summarize what is known publicly about the decoy balloons and other object used in the GMD intercept tests to date. Quantitative information about the appearance of some of these objects is available as a result of the controversy over the initial integrated flight test, IFT-1a (Wright and Gronlund 2002).

TEST IFT-3 (1999)

In tests IFT-3 through IFT-10, the target missile with the mock warhead was launched from Vandenberg Air Force Base in California, toward Kwajalein Atoll in the Pacific, where the interceptor was launched.

In IFT-3, the reentry vehicle containing the mock warhead was roughly 1.8 meters in length and had a base diameter of roughly 0.75 meters (DoD 2001). The balloon decoy had a diameter of 2.2 meters (Figure 2).

FIGURE 2. **The Reentry Vehicle and Decoy Balloon Used in IFT-3**



SOURCE: SESSLER ET AL. 2000

The balloon appeared about six times brighter than the reentry vehicle to the kill vehicle's infrared sensor.[4] For this reason, the kill vehicle could easily distinguish the two objects and tell which was which. Indeed, a Pentagon briefing about IFT-3 stated that the kill vehicle first saw the balloon by itself and recognized from its appearance that it was the balloon rather than the warhead, so "discrimination" was not based on comparing the signatures of the two objects (DoD 2000).

The other object the kill vehicle might see around the target is the upper stage of the target missile, the Multi-Service Launch System (MSLS), which releases the warhead and decoys. Based on information from the fly-by test IFT-1A, the MSLS appeared about three times brighter than the mock

[3] A National Research Council study (NRC 2012) gives a notional design for an advanced kill vehicle with a lateral acceleration late in flight of 4g (Table 5-2, p. 150). Acting over one second, this acceleration could divert the kill vehicle by only 20 m. The objects may be separated by hundreds of meters or kilometers.

[4] This figure comes from comparing the central values of the predicted one-sigma ellipses for the infrared intensity of the objects for one of the sensor bands, as shown in Figure 5 of the POET Study 1998-5 (Tsai 1998); Theodore Postol, personal communication, February 2002.

warhead to the kill vehicle's infrared sensor, and was therefore also easy for the kill vehicle to distinguish from the warhead.[5]

TESTS IFT-4 AND IFT-5 (2000)

The same set of objects used in IFT-3 were also used for the second and third tests, IFT-4 and IFT-5, both of which were unsuccessful. IFT-4 failed due to problems with the kill vehicle's sensor. In IFT-5 the kill vehicle failed to separate from the interceptor booster.

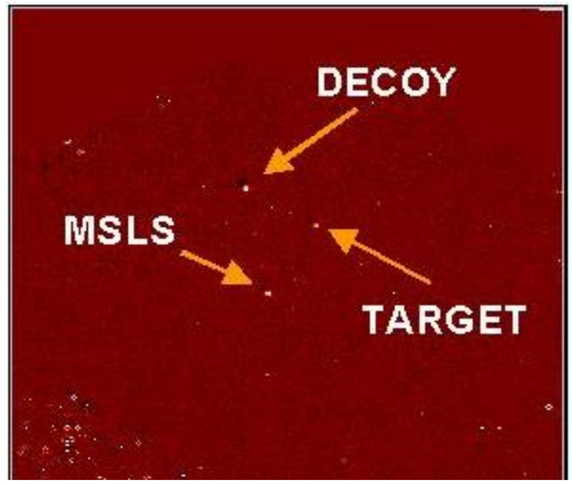
The importance of the kill vehicle having *a priori* information about the appearance of the decoys was underscored by the reaction of Ronald Kadish, director of the Ballistic Missile Defense Organization (BMDO) (the forerunner of MDA)) when he was being filmed for television during the IFT-5 test. When told the balloon decoy did not deploy properly, he responded "The decoy is not going to look exactly like what we expected. This presents a problem for the system that we didn't expect" (Kadish 2000). Since the test failed when the kill vehicle failed to separate from its booster, the test did not provide information on the extent to which this posed a problem for the defense.

TESTS IFT-6 AND IFT-7 (2001)

These two tests included a 1.7 meter diameter balloon with a more reliable deployment mechanism in place of the 2.2 meter balloon used previously.[6] If this balloon had the same average surface properties as the original balloon, then based on the size ratio of the two balloons it would still appear more than three times brighter than the mock warhead, and would therefore still be easy for the kill vehicle to distinguish from the warhead.

[5] Figure 5, POET Study 1998-5 (Tsai 1998).
[6] The 2.2-meter balloon was an existing decoy that the BMDO had in its inventory, and the BMDO reportedly intended to switch to the new 1.7-meter balloon when it depleted its inventory of the old one. In the original plans, the new balloon was to have been used first in IFT-7. However, the 2.2 meter balloon used in IFT-5 did not inflate properly, and BMDO may have decided not to use the last balloon of this size because of reliability concerns.

FIGURE 3. **The Objects in ITF-6 as seen by the Kill Vehicle's Sensor, Roughly 90 Seconds Before Impact**



Until about two seconds before impact, the objects simply appear as points of light to the kill vehicle. The kill vehicle is able to recognize each object based on stored information it has about the objects' brightness and fluctuation.

SOURCE: NANCE 2001

The difference in brightness of these objects can be seen in Figure 3, which shows the objects in ITF-6 as seen by the kill vehicle's sensor. The mock warhead is noticeably less bright than the other two objects. Test IFT-7 included the same objects as IFT-6.

TEST IFT-8 (2002)

This test included two small additional balloons along with the large balloon used in the previous tests. (Wright and Gronlund 2002) These balloons, called canisterized small balloons, were 0.6 meters in diameter, and were reportedly like those used in the fly-by tests IFT-1A and IFT-2. (Lehner 2002)

While the additional objects increased the complexity of the test, they did not increase the difficulty of the discrimination task since all the balloons in the test had infrared signals that were significantly different from that of the mock warhead. In particular, the small balloons appeared one-half to one-third as bright as the mock warhead to the kill vehicle's infrared sensor in IFT-1A[7] and so would also have been much less bright than the warhead in this test. Both the large balloon and final missile stage appeared about three times a bright as the mock warhead in these tests.

TEST IFT-9 (2002)

This test included the same three balloons as IFT-8, but a modified warhead described as slightly smaller than in previous tests. Based on information from previous tests, it appears the large balloon and final missile stage appeared several times brighter than the mock warhead and the two small balloons were considerably less bright than the warhead, so the kill vehicle could easily distinguish the warhead from the other objects (Wright 2002).

TESTS IFT-10 (2002), IFT-13C (2004), AND IFT-14 (2005)

The next three tests all had problems with the interceptors early in the test and never reached the final engagement.

TESTS FTG-02 (2006) AND FTG-03A (2007)

These were the first tests using interceptors launched from Vandenberg, which was accompanied by a new numbering system. These two tests did not include decoy balloons. Since the tests were flown on a different geometry than previous tests MDA decided not to use decoys for these tests. In earlier tests the targets were launched from Vandenberg and the interceptors from Kwajalein; in these tests the targets were launched from Kodiak, Alaska.

TEST FTG-05 (2008)

This test was intended to have decoys, but the balloons did not deploy because of problems with the fairing panels that protect them before deployment.

[7] Figure 5, POET Study 1998-5 (Tsai 1998). If these balloons had roughly the same surface coating as the 2.2-meter balloon, then their brightness relative to that balloon would suggest they had a diameter of 0.5-0.6 meters, in good agreement with their actual size.

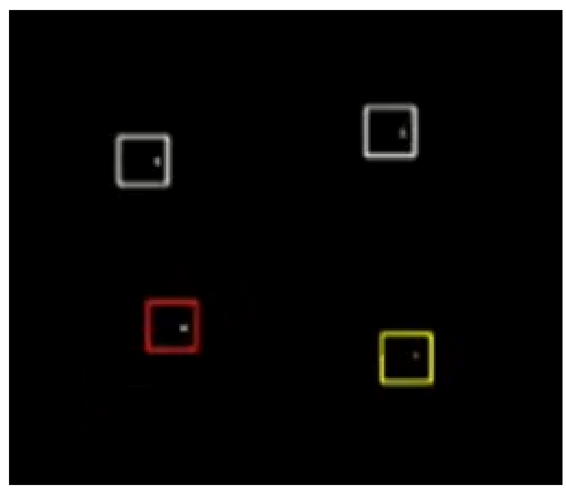
TESTS FTG-06 (2010), FTG-06A (2010), AND FTG-07 (2013)

These three tests were intended to include decoys, but all three tests failed: FTG-06 and FTG-06A failed due to problems with the kill vehicle, and FTG-07 failed when the kill vehicle did not separate from the interceptor booster. (Gilmore 2015, Table 3-4)) These were the first tests to have the target missile launched from Kwajalein with the interceptors launched from Vandenberg.

TEST FTG-06B (2014)

Few details are available about the decoys on this test, but the video from the kill vehicle's sensor appears to show two decoys and the final missile stage along with the mock warhead (Figure 4).

FIGURE 4. **Target Cluster of FTG-06B**



A still from a video showing the objects in the target cluster of FTG-06B as seen by the kill vehicle's sensor (1:26 into video). The decoys are in the light blue squares, the missile stage is in the yellow square, and the mock warhead is in the red square

SOURCE: RAYTHEON 2014

The MDA report on this test, however, indicates that the objects did not present a difficult discrimination test for the kill vehicle, since it rates the "discrimination" task of this test as comparable to previous tests and near the "minimum" level (Figure 5).

FIGURE 5. **Table 2-1 from MDA's Report to Congress on FTG-06B**

Critical Engagement Conditions and Empirical Measurement Events	FTG-06b Test Outcome	Assessment
Primary		
Long Time of Flight	FTG-06b Minimum Previous Data collects Maximum	**Met**
Closing Velocity	FTG-06b Minimum Previous Data collects Maximum	**Met**
Exo-atmospheric Kill Vehicle Discrimination	FTG-06b Minimum Previous Data collects Maximum	**Met**
▲ - met △ - not met or limited data collect		

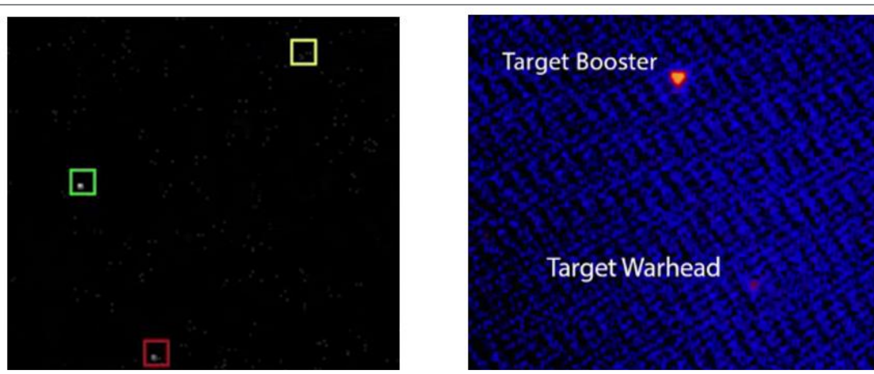
SOURCE: MDA 2014

More generally, in evaluating the "Operational Realism Criteria" established for missile defense tests, a Pentagon report stated that none of the tests from 2010 to 2014 (including this one) involved complex countermeasures, which includes the "use of target dynamics and penetration aids." (Gilmore 2015, Table 4-3) "Target dynamics" includes tumbling or spiraling (nutating) of the warhead (see below).

TEST FTG-15 (2017)

Few details are available about the decoy used in FTG-15, but information is available from a video that shows what the kill vehicle's sensor saw during the test, as well as the view from a second sensor (Figure 6). The video appears to show that the test included one decoy that was significantly less bright than the mock warhead, along with the upper stage of the target booster, which was significantly brighter than the warhead.

FIGURE 6. **Target Cluster of FTG-15**



Stills taken from a video showing the objects in the target cluster of FTG-15 as seen by the sensor on the kill vehicle (left, 1:30 into video, rotated by 180 degrees) and by a sensor on a second platform (right, 2:05 into video). In the image on the left, the decoy is in the yellow square (too dim to be seen in this image), the booster stage is in the green square, and the warhead is in the red square. The image on the right shows only the booster and warhead. The images indicate that the three objects appear different to the sensors.

SOURCE: MDA 2017

Other Artificialities of the Tests

SPIN-STABILIZED WARHEAD

The video of FGT-15 also shows another artificiality in the target used for this test. In particular, the mock warhead has been carefully spin stabilized for the test, so that it presents a non-fluctuating signal for the kill vehicle on home on (see 1:50 – 1:57 in video). A spiraling (nutating) or tumbling warhead would produce a fluctuating signal for the kill vehicle to home on, which could make hitting the target much more difficult.

Not only would warheads from North Korea be expected to spiral or tumble, but Pyongyang might intentionally cause them to tumble since doing so would complicate the job of the kill vehicle. While a tumbling or spiraling warhead would reduce the accuracy of the missile somewhat, the accuracy of North Korean missiles is already expected to be low enough that this addition would not be significant.

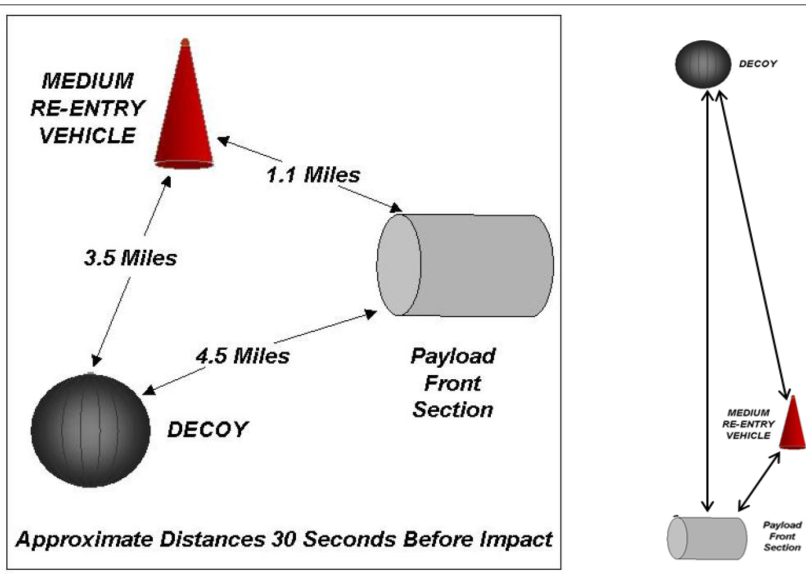
Early BMDO testing plans called for the missile defense system to be tested against a tumbling warhead (MTRV) in several tests in 2001-2. However, to date the system has still not been tested against such a target. (See Figure 1 in Wright and Gronlund 2002.)

OBJECTS IN TARGET CLUSTER SIMULTANEOUSLY IN KILL VEHICLE FIELD OF VIEW

The Pentagon briefing on IFT-6 (Nance 2001) provided information about the relative locations of the warhead, decoy balloon, and missile stage as they approached the kill vehicle. Figure 7 shows the slide from the briefing on the left, and the actual arrangement of the objects based on their separations, on the right.

The kill vehicle's sensor can only see a small region, called the field-of-view. If the kill vehicle were approaching the objects so that it saw the view on the right, it would not be able see all three objects at the same time once the kill vehicle was within about 500 kilometers or 70 seconds of impact (the closing speed in this test was 7.4 km/s). In order for the kill vehicle's sensor to collect data on all three objects, it would have to continually maneuver to shift the field of view between the objects.

FIGURE 7. **Pentagon Briefing on IFT-6**



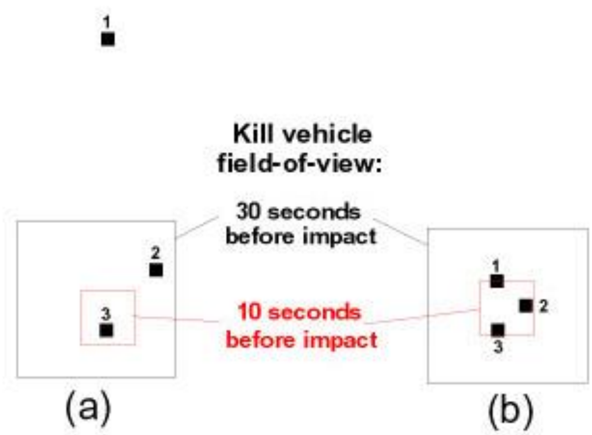
The diagram on the left is from the Pentagon briefing on IFT-6 (the "payload front section" is the upper booster stage that released the warhead and balloon). SOURCE: Nance 2001. The diagram on the right shows the actual separation of the objects in the plane that contains them.
SOURCE: UCS

However, the image in Figure 3 shows that the objects appear to have been released in precise way so that all three objects remained simultaneously in the kill vehicle's field of view until very late in homing process. In other words, it appears that the upper stage was programmed to release the warhead and balloon so that the three objects were all roughly lined up along the direction of sight of the kill vehicle's sensor, so that they appeared to the sensor to be much closer together than they actually were.

This special arrangement simplifies the job of the kill vehicle and allows it to collect data on all the objects for a longer time (Figure 8). The Pentagon has not released information about the locations of the objects in the target cluster for the other tests, so we do not have evidence that the objects were arranged this way in those cases. However, doing so has a clear advantage. Because every aspect of these tests is carefully controlled, it is likely that the test was designed so that this would be the case.

This situation could obviously not be expected in general. Indeed, in an actual attack, one might expect that the attacker would consciously try to separate some of the objects in the target cluster far enough to make observing them more difficult for the kill vehicle. This problem becomes more severe at the higher closing speeds appropriate to an operational system, since the kill vehicle would then have less time to collect data on the objects in the target cluster.

FIGURE 8. **Arrangement of Objects in the Target Set in Test IFT-6 from Two Different Directions**



This figure shows the same arrangement of objects in the target set in test IFT-6 from two different directions. Object 1 is the balloon decoy, Object 2 is the mock warhead, and Object 3 is the booster stage that released them. The kill vehicle is approaching the objects in the direction you are looking at the figure. In part (a), the kill vehicle sees the objects in the orientation shown in the right side of Figure 6. In this case, the objects appear so widely spaced that the kill vehicle's sensor could not see the objects simultaneously as it approached impact. This is illustrated in the figure by the fact that the field-of-view of the kill vehicle's sensors (shown by the red and blue squares) cannot contain all of the objects at the same time. In IFT-6, the objects were instead released so that the kill vehicle approached them from the top in part (a). From this direction, the objects are lined up with one another and appear to the kill vehicle to be much closer together, as shown in part (b) of the figure. As a result, they all remain simultaneously in the kill vehicle's field of view until very late in the homing process. This figure assumes a one-degree field of view for the kill vehicle's sensor and a closing speed of 7.4 km/s, which was the speed in IFT-6.

SOURCE: UCS

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