Decoys and Discrimination
in Intercept Test IFT-8

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Introduction

The core of the Bush administration's missile defense program is a modified version of the system being developed by the Clinton administration, which would use ground-based interceptors to deliver a kill vehicle that would operate above the atmosphere, attempting to intercept incoming warheads during the midcourse phase of an attacking missile's trajectory. This system, now called the ground-based midcourse defense (GMD) is receiving the vast majority of the funding for long-range missile defense.

The program has conducted seven Integrated Flight Tests (IFTs), and an eighth test is scheduled for Friday, March 15. The first two tests, IFT-1A and 2, were "fly-by" tests intended largely to test the sensors on the kill vehicle; these did not involve an attempt to intercept the mock warhead. The intercept tests began with IFT-3. Of the five intercept tests that have taken place, three resulted in intercepts.

In a previous working paper,[2] we examined the test program through IFT-7. These intercept tests focused largely on the "endgame" of the full intercept process to demonstrate that the kill vehicle can successfully home on a target that it can readily identify (or has been identified for it). We concluded that while the past intercept tests have demonstrated hit-to-kill, they have not done so under conditions that are operationally realistic. For example, the closing speed between the kill vehicle and the target has been much lower—by up to a factor of two—than would be expected for an operational system.

In this working paper, we discuss the decoys that will be used for the eighth flight test, IFT-8, and how the defense will use the kill vehicle's infrared sensors to discriminate these decoys from the mock warhead. All previous intercept tests (IFT-3 through 7) of the ground-based midcourse system included a single large balloon decoy in addition to the mock warhead. The upcoming test will reportedly include two smaller balloon targets in addition to the single large balloon target.

We find that, while increasing the number of decoys will increase the complexity of this test, the additional balloons will not increase the difficulty of the discrimination task. All the balloons to be used will have infrared signals that are significantly different from that of the mock warhead.

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[2] 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, 30 November 2001. Available at http://www.ucsusa.org/security/ift7.html

Specifically, the large balloon will have an infrared signal significantly larger than the mock warhead, and the small balloons will have a significantly smaller signal. No balloons that have a signature similar to the mock warhead are planned for this test. While this may be appropriate for such an early stage in the testing program, it does not represent a significant increase in the realism of the test.

Moreover, as in the previous tests, discrimination will rely on the defense having detailed prior knowledge about how all the objects will appear to the defense sensors—an assumption that is highly unrealistic.

The Discrimination Methodology

As part of the ground-based midcourse defense, the Pentagon plans to use both infrared sensors on the kill vehicle and ground-based radars to discriminate the warhead from other objects. Eventually, the United States plans to add satellite-based infrared and visible sensors as well. Whether these sensors will allow the system to discriminate successfully depends on the measurement capabilities of the various sensors and on the discrimination methodology to be used by the system.

Since warheads and decoys can have a wide range of infrared signals, shapes, and radar cross sections, this is a potentially difficult task.[3]

The most detailed publicly available information about the discrimination process that the GMD system uses to sort warheads from decoys is provided by two General Accounting Office (GAO) reports on fly-by test IFT-1A, which were released in late February.[4] According to the GAO reports, 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."[5] 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."[6]

Thus, 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 will then compare what its sensors see with the data it has stored in its computer and attempt to find a unique match that will identify the warhead.

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[3] See, for example, Andrew M. Sessler *et al*, *Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned US National Missile Defense System*, (Union of Concerned Scientists: Cambridge MA), April 2000, available at http://www.ucsusa.org/security/CM_exec.html
[4] General Accounting Office (GAO), *Missile Defense: Review of Results and Limitations of an Early National Missile Defense Flight Test*, GAO-02-124, February 2002, and General Accounting Office, *Missile Defense: Review of Allegations about an Early National Missile Defense Flight Test*, GAO-02-125, February 2002.
[5] GAO, *Missile Defense: Review of Results*, p. 5, footnote 14.
[6] GAO, *Missile Defense: Review of Results*, p. 20.

The infrared sensor on the kill vehicle can measure several things: the strength of the signal in three different bands of wavelengths (one optical and two infrared), and the time variation of these signals. However, the sensors on the kill vehicle 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 sensor consists of an array of individual elements onto which the sensor's 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, but only detects the overall brightness.

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 until a few seconds before impact. This is too late for the kill vehicle to be able to change its course by any significant amount.[7]

The Infrared Signal of an Object in Space
The infrared radiation from an object, as measured by an infrared sensor, will be a combination of radiation emitted by the object due to its temperature, and of radiation from the sun and earth that is reflected by the object into the sensor. The infrared signature will depend on many factors. As we discuss in more detail below, these factors include inherent characteristics of the object, such as its physical shape and its surface coating; the time of day; the relative orientation of the sensor and object; and whether the object is tumbling, rotating, or spin-stabilized.

If an object in space is in sunlight, it will have an equilibrium temperature that is determined solely by its shape and the properties of its surface coating.[8] In darkness, objects will tend to cool, with the equilibrium temperature determined by the shape. Thus, the infrared signal that is measured by the sensor will also depend on the time of day and how much of the object's trajectory is in sunlight or darkness. If the equilibrium temperature differs from the initial temperature of the object when it is launched, the temperature of the object will change during part or all of its trajectory. Thus, the infrared radiation measured by the sensor at any given time during the object's trajectory will depend on the initial temperature, and on the surface coating, shape, and mass of the object—which will determine how quickly it heats up or cools down.

Because the infrared signal depends on the shape of the object, a balloon decoy that does not inflate properly will have a different signal from one that does. As was noted in the GAO reports, the ability of the defense to discriminate could be seriously eroded if objects deploy differently than expected.[9] When the balloon decoy used in IFT-5 did not deploy properly, Gen. Kadish,

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[7] This assumes the sensor has a one degree field-of-view and a 256x256 element array, which is likely the case for the kill vehicle's sensor ("Data Boost Confidence in KV Performance," *Aviation Week and Space Technology*, 8 June 1998). In this case, when the kill vehicle is 15 kilometers from an object, each element of the sensor array would see an area one meter by one meter. At closing speeds of 7 to 12 km/s, this distance corresponds to 1 to 2 seconds before impact. If the kill vehicle can achieve a lateral acceleration of 10g's, it could only divert 50 to 200 meters in 1 to 2 seconds. Decoys can be deployed with much greater spacing than this. The spacing between decoys in IFT-6 in the plane seen by the kill vehicle was roughly a kilometer.
[8] In particular, the equilibrium temperature will be determined by two properties of the surface coating: the solar absorptivity averaged over visible wavelengths and its emissivity averaged over infrared wavelengths. For more detail, see Appendix A of Sessler *et al*, *Countermeasures*.
[9] General Accounting Office, *Missile Defense: Review of Results*, p. 30.

director of the missile defense program, said "So the decoy is not going to look exactly like what we expected. It presents a problem for the system that we didn't expect."[10]

Unless the object is spherical and has a uniform surface coating, the measured radiation will also depend on the angle at which the sensor views the object. For example, if the object is cone-shaped, the amount of infrared radiation emitted in the direction of the sensor will depend on whether the sensor views the cone from the side or nose-on. Similarly, if the object is spherical but has two different surface coatings, the measured signature would depend on which part of the object faced the sensor. A rotating object with a non-uniform surface coating would result in a signal that varied with time.[11]

A non-spherical object that tumbled during flight, such as a conical warhead, would also give a signal that fluctuated in time.[12] A spin-stabilized warhead, which is made to spin around its axis of symmetry to prevent it from tumbling, could be precessing or nutating (wobbling around its axis). Such a warhead would also give a fluctuating signal, but the fluctuations would not be as great as for a tumbling warhead.

For the upcoming intercept test, as well as for the past ones, the defense knows the time of day, and the trajectories that will be flown since it determines these in advance. Thus, the reference data provided to the defense during these tests may be valid only for a test at that time of day and with those specific trajectories.

Target Suites in Previous Tests

Tests IFT-1A and IFT-2 did not involve intercept attempts, but were "fly-by" tests in which the kill vehicle flew near the target suite and its sensors collected data on them. The target suite in these tests consisted of eight objects in addition to the mock warhead and the "multi-service launch system"(MSLS), or "bus," which is the final stage of the missile that releases the warhead and decoys. The mock warhead is referred to as a "medium reentry vehicle" (MRV), and is "less than two meters in length and less than one meter in diameter across the base."[13]

The eight additional objects in IFT-1A and IFT-2 consisted of three replica decoys, which have a conical shape like the warhead, and five spherical balloons: one large, two medium, and two small (see Figure 1).[14] The only one of these eight objects that has been used in the subsequent intercept tests is the large balloon.

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[10] Sixty Minutes II**,** 31 October 2000.
[11] Some of the spherical balloons used in the testing program have a set of stripes on them to give a varying signal when the balloon rotates.
[12] Some balloons are conical to have a similar shape to the warhead. In addition, a balloon that was intended to be spherical but did not inflate properly could have a non-spherical shape and lead to a non-uniform signal.
[13] Michael Sirak, "Next NMD Flight Test to Feature Less-Complex Target Suite," *Inside Missile Defense*, 29 December 1999. This article states that the mock warhead "will be equipped with motion and attitude control instrumentation, a photonic hit indicator to determine the impact point of the collision with the NMD kill vehicle, and a Global Positioning System translator."
[14] These objects are listed in GAO, *Missile Defense: Review of Results*, p. 25.

Figure 1: Targets for Integrated Flight Tests (May 2000)
This chart shows the planned target suites for tests of the ground-based midcourse system planned by the Pentagon as of May 2000. It appeared in the New York Times in June 2000 (William Broad, "Antimissile Testing Is Rigged To Hide a Flaw, Critics Say," *New York Times*, 9 June 2000, p. A1).

According to this chart, several of the objects used in the fly-by tests—the medium balloons and the medium and small replica decoys—were dropped from all future tests. One possible motivation for removing these targets is that the analysis of IFT-1A showed that the medium balloon could appear to the sensors to be very similar to the mock warhead that is being used in the current tests, and that tumbling replica decoys could appear very similar to a tumbling warhead. Notice in particular that according to the plans in the chart, those tests involving a tumbling warhead, which could lead to large fluctuations in brightness, would contain only spherical decoys, which would be expected to have much smaller fluctuations (if the surface was not uniform) or no fluctuations (if the surface was uniform).

Acronyms:

MRV—Medium Reentry Vehicle (RV)
LB—Large Balloon
CSB—Canisterized Small Balloon
MB—Medium Balloon
MRLR—Medium Rigid Lightweight Replica
SCLR—Small Canisterized Lightweight Replica
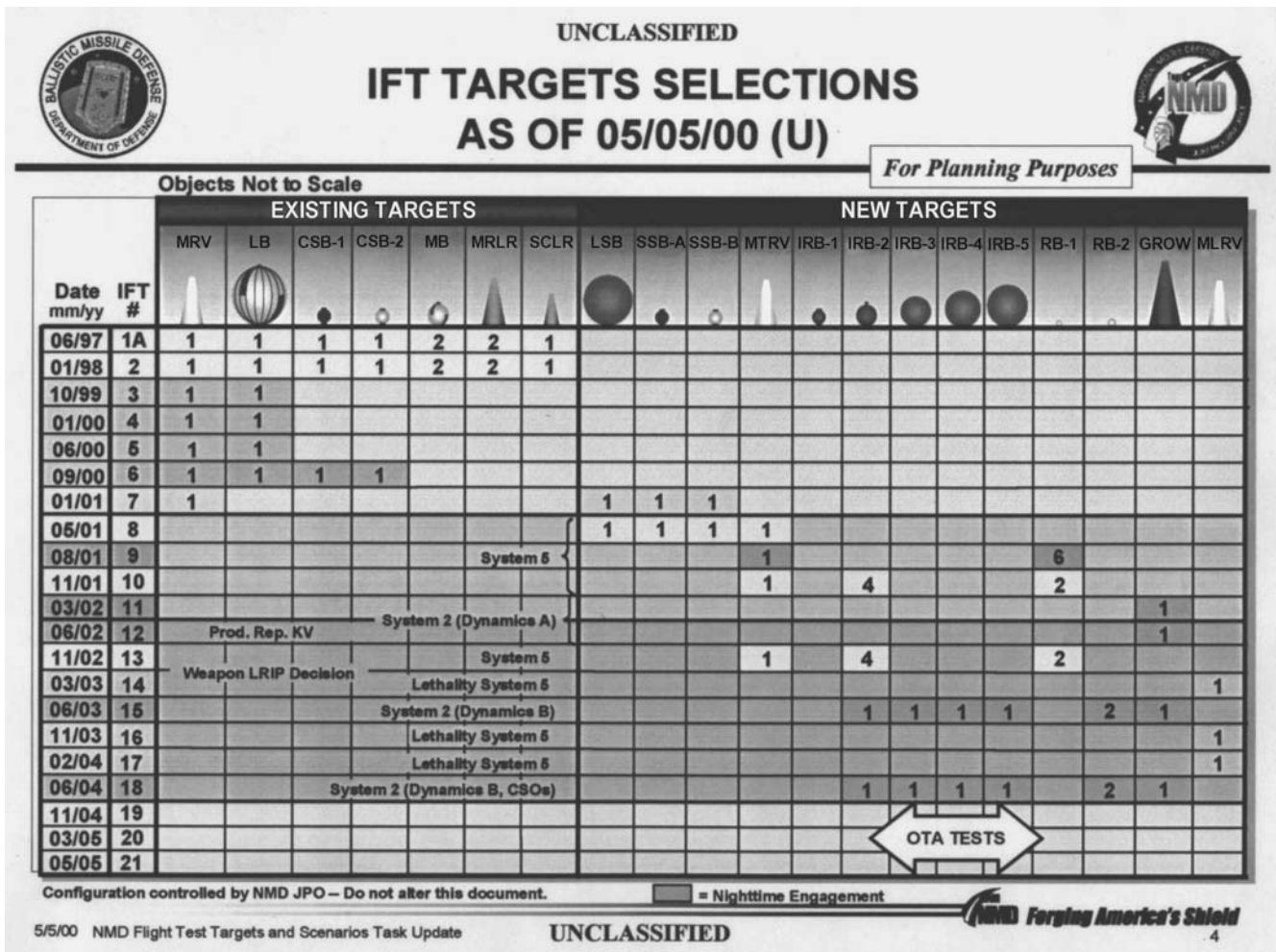LSB—Large Spherical Balloon

SSB—Small Spherical Balloon
MTRV—Medium Tumbling RV
IRB—Infrared Balloon
RB—Radar Balloon
GROW—Generic Rest-of-World RV
MLRV—Medium Lethality RV

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IFT TARGETS SELECTIONS AS OF 05/05/00 (U)

For Planning Purposes

Objects Not to Scale

Date mm/yy	IFT #	MRV	LB	CSB-1	CSB-2	MB	MRLR	SCLR	LSB	SSB-A	SSB-B	MTRV	IRB-1	IRB-2	IRB-3	IRB-4	IRB-5	RB-1	RB-2	GROW	MLRV
06/97	1A	1	1	1	1	2	2	1													
01/98	2	1	1	1	1	2	2	1													
10/99	3	1	1																		
01/00	4	1	1																		
06/00	5	1	1																		
09/00	6	1	1	1	1																
01/01	7	1							1	1	1										
05/01	8								1	1	1	1									
08/01	9					System 5						1						6			
11/01	10											1		4				2			
03/02	11					System 2 (Dynamics A)														1	
06/02	12		Prod. Rep. KV																	1	
11/02	13					System 5						1		4				2			
03/03	14		Weapon LRIP Decision			Lethality System 5															1
06/03	15					System 2 (Dynamics B)								1	1	1	1	2	1		
11/03	16					Lethality System 5															1
02/04	17					Lethality System 5															1
06/04	18					System 2 (Dynamics B, CSOs)								1	1	1	1	2	1		
11/04	19																				
03/05	20												OTA TESTS								
05/05	21																				

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Large Balloon
The large balloon used in the fly-by tests and the first three intercept tests (IFT-3 through IFT-5) was 2.2 meters in diameter. In these tests, this balloon appeared about six times brighter than the mock warhead did to the kill vehicle's infrared sensor.[15] For this reason, the kill vehicle could easily distinguish the balloon from the reentry vehicle. Indeed, a Pentagon briefing about IFT-3 stated that the kill vehicle first saw the balloon by itself and recognized that it was the balloon rather than the warhead, so "discrimination" was not even based on comparing the signatures of the two objects.[16]

This balloon apparently had a set of stripes on its surface so that its brightness would fluctuate as it rotated (see Figure 1). Such fluctuations are apparently intended to appear similar to those that would arise from the motions (such as nutation or precession) of a spin-stabilized warhead. For all of the tests conducted so far, the mock warhead has been spin-stabilized.

For tests IFT-6 and 7, the 2.2 meter balloon was replaced with one having a slightly smaller diameter (1.7 meters).[17] Unlike the 2.2 meter balloon, this one apparently has a uniform surface rather than stripes (see Figure 1). If this balloon had the same average surface properties as the original balloon, then based on the ratio of cross-sectional areas 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 mock warhead.

Multi-Service Launch System (MSLS)
Based on information from the fly-by test IFT-1A, the MSLS appears about three times as bright as the mock warhead to the kill vehicle's infrared sensor, and is therefore also easy for the kill vehicle to distinguish from the warhead.[18]

Medium and Small Balloons
Two types of smaller spherical balloons were also used in the fly-by tests.

From information on the IFT-1A test, the medium balloons are seen to have essentially the same brightness as the mock warhead.[19] If these balloons had roughly the same surface properties as the 2.2 meter balloon, then the fact that they were one-sixth as bright would suggest they had a diameter of about 0.9 meters. These balloons therefore appear to have a diameter very similar to the base diameter of the mock warhead. Like the 2.2 meter balloon, these balloons had stripes on their surfaces (see Figure 1).

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[15] 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 (M-J. Tsai, L. Ng, G. Light, C. Meins, "Independent Review of TRW Discrimination Techniques, Final Report"); Theodore Postol, personal communication, February 2002.

[16] Special Defense Department Background Briefing on Upcoming National Missile Defense System Test Launch, 14 January 2000.

[17] The 2.2 meter balloon was an existing decoy that BMDO had in its inventory, and BMDO reportedly intended to switch to this new 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.

[18] Figure 5, POET Study 1998-5 (see footnote 15).

[19] Figure 5, POET Study 1998-5 (see footnote 15).

The smallest balloons used in the fly-by tests, called the canisterized small balloons (since they were released from canisters), were 0.6 meters in diameter.[20] They were one-half to one-third as bright as the mock warhead in IFT-1A.[21] The two balloons apparently had different surface coatings from one another (see Figure 1) and stripes on their surfaces to create a fluctuating signal.

Two of these small balloons were originally intended to be part of the target suite in the IFT-4 intercept test in January 2000. These targets were dropped, however, in part at the recommendation of the Welch panel, which argued against complicating the early tests.[22]

Decoys for IFT-8

The next intercept test (IFT-8), currently planned for March 15, will include two additional balloon targets along with the large balloon target used in the previous tests.

The additional targets will reportedly be two small balloons like those that were used in the fly-by tests IFT-1A and IFT-2.[23] This choice of objects is not surprising, for several reasons.

First, the Pentagon might be expected to use balloons similar to the ones used in the fly-by tests, since those are the objects on which it has collected data in flight. As discussed above, having such data is important since the discrimination method used by the kill vehicle is to match what it sees in the test to data it has been given in advance about the appearance of the objects it will see.

Second, adding these small balloons was the next step in the target selection plan that was developed in mid-2000. The chart in Figure 1 shows that the first four intercept tests (IFT-3 through 5) were intended to use a mock warhead and a single large balloon, as they in fact did. For IFT-6, the chart shows that the plan was to add to the target suite the two small balloons that were used in the fly-by tests. However, the kill vehicle did not separate from the interceptor booster in IFT-5, and the test was repeated as IFT-6, so the two small balloons were not used in that test. Subsequently, BMDO announced that to increase confidence in the technology, the next test would be a repeat of IFT-6, so IFT-7 again used only a single large balloon in addition to the mock warhead.

Thus, the next step would be to use in IFT-8 the target suite originally planned for IFT-6 (with the 2.2 meter balloon replaced by the 1.7 meter balloon, as discussed above).

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[20] Sirak, "Next NMD Flight Test." Unlike the large balloon, the small balloons reportedly contain "sophisticated instruments that collect flight data."
[21] Figure 5, POET Study 1998-5 (see footnote 15). 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.
[22] Sirak, "Next NMD Flight Test."
[23] Lt. Col. Rick Lehner, personal communication, March 2002.

Third, because these small balloons are expected to appear several times less bright than the mock warhead to the kill vehicle's infrared sensor, the kill vehicle should have a relatively easy time distinguishing them from the mock warhead. One would expect that the Pentagon wants to keep the discrimination problem relatively simple at this early stage of testing.

The Pentagon was unlikely to use the medium balloons in the upcoming test for two reasons. First, it reportedly has concerns about the reliability of the medium balloons used in the fly-by tests. According to the recent GAO reports, a December 1997 study by Boeing and TRW "noted that the medium balloons had been in inventory for some time and had not deployed as expected in other tests, including Integrated Flight Test 1A. In that test, one medium balloon only partially inflated and was not positioned within the target cluster as expected." The GAO report also notes that "Boeing said that the risk increased significantly that the exoatmospheric kill vehicle would not intercept the mock warhead if the target objects did not deploy from the test missile as expected."[24]

Second, as noted above, the brightness of the medium balloons and the mock warhead used in the fly-by tests appear to be very similar. This could make discrimination of the warhead more difficult, since discrimination would have to be based on something other than brightness, such as the fluctuation of the brightness or the relative brightness in the two infrared bands. Of course, the brightness of the medium balloons could be changed by modifying their surface coatings.

Future Target Suites

While it is not clear if the chart in Figure 1 reflects current thinking about what targets will be used in future tests, it is nonetheless interesting to see what the test plans were for the subsequent few tests.

The chart shows that the balloons originally intended for IFT-7 (which now might be conducted in IFT-9) were the 1.7-meter large balloon[25] and two new small balloons, which appear to have uniform surfaces. These objects would be flown with the mock warhead used in all the previous tests. If the surface properties of the small balloons were similar to those of the small balloons used in the fly-by tests, they would again be significantly less bright than the warhead, and should be relatively easy for the kill vehicle to discriminate.

A key purpose of this test may be to collect data on the appearance of these new balloons in order to use this data in subsequent tests. The chart in Figure 1 shows that the test following this one was intended to use these small balloons and the 1.7 meter balloon in conjunction with a new mock warhead that tumbles during flight. This warhead could show significant fluctuations in the brightness of its infrared signal as it tumbled, while the spherically symmetric balloons (i.e., with no stripes) would produce minimal fluctuations, as long as they inflated properly so that they were spherical. Notice that the chart shows that no conical replica decoys, which could produce

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[24] GAO, *Missile Defense: Review of Results,* p. 27.
[25] As noted above, the new large balloon was actually first used in IFT-6 rather than IFT-7, possibly due to the malfunction of the old balloon in IFT-5.

large fluctuations in brightness similar to a tumbling warhead, are intended to be included in tests involving a tumbling warhead.