The reason for pursuing negotiations with Moscow is not that the ABM Treaty is sacred but that a formal agreement on defenses would serve U.S. interests. It would reassure Moscow about American intentions. That would greatly increase the odds of agreeing on deep cuts in offensive nuclear weapons as well as other measures designed to reduce nuclear risk, substantially reduce the diplomatic costs of an NMD deployment, improve the prospects for a strong Nunn-Lugar cooperative threat reduction program, and reduce the chances that Russia would seek to undermine the U.S. defense system, for example, by selling countermeasure technologies to countries such as Iran, Iraq, and North Korea. Most U.S. allies are unlikely to object strongly to a U.S. missile defense if Moscow decides to accept it. A modified ABM Treaty may need to be further revised a decade or two from now should the evolution of the ballistic missile threat warrant it. But the United States should cross that bridge only when (and if) it comes to it.

Moscow may prove intransigent on missile defense and leave the United States with no choice but to withdraw from the ABM Treaty. But in doing so, Washington should still seek to allay Russian concerns. At a minimum, it should pursue a tacit arms control policy that keeps Moscow informed of its plans and unilaterally accept intrusive verification procedures on the size and nature of its NMD program. Because China can also make the costs of an NMD deployment exceed the benefits, Washington should pursue a similar policy of transparency toward Beijing.

No one should be under any illusion, however, that tacit arms control will be easy to establish. Not only is treaty withdrawal an inauspicious foundation on which to build a new relationship with Moscow, domestic political support for tacit arms control could prove elusive. Critics will ask why the United States is sharing sensitive information with Russia and China when both countries target American cities. The net result might be no arms control at all. Both Washington and Moscow should keep this in mind as they discuss the future of the ABM Treaty. It would be much more preferable to modify the treaty than to abandon it.

CHAPTER TWO

Missile Defense: Concepts and Systems

THE BASIC IDEAS BEHIND how missile defense systems operate are not particularly complex. But it is important to have a clear mental picture of how ballistic missiles, and technologies designed to counter them, function. This chapter provides that background information, with a number of graphics, illustrating the main concepts.

Basic Elements of Ballistic Missiles

Ballistic missiles are rockets designed to accelerate to fast enough speeds so that they can fly relatively long distances before falling back to earth. They are first accelerated by the combustion of some type of fuel, after which they simply follow an unpowered—or ballistic—trajectory. They consist, most basically, of rocket engines, fuel chambers, guidance systems, and warheads, though the specifics vary a great deal depending on the range and sophistication of the missile.

Missile Parts and Types

For shorter-range missiles, the entire weapons system is generally simple. The missile usually consists of a single stage rocket, which fires until its fuel is exhausted or shut off by a flight-control computer and then ceases functioning for the duration of the flight. The missile body and warhead often never separate from each other, flying a full trajectory as a large, single object.

For longer-range missiles or rockets, the system consists of two or three stages, or separate booster rockets, each with its own fuel and rocket engines. The rationale for this staging is to improve boosting efficiency and thereby maximize the speed of the reentry vehicle or vehicles. Putting all the fuel for a long-range rocket in one stage would make for a very heavy fuel chamber and mean that the rocket would have to carry along a great deal of structural weight throughout the entire phase of boosted flight. That would lower the ultimate speed of the warhead or warheads, reducing their range. With staging, by contrast, much of the structural weight is discarded as fuel is consumed. That makes it possible to accelerate the payload to speeds sufficient to put it on an intercontinental trajectory. Long-range warheads must reach speeds of about 4.5 miles a second (roughly 7 kilometers a second), or almost two-thirds of the speed any object would need to escape the earth's gravitational field entirely (roughly 7 miles, or 11 kilometers, a second). To reach such speeds with existing rocket fuels, efficiency in design—including rocket staging—is essential.

On long-range rockets, warheads are designed so that they can be released from the missile body during flight. Generally, warheads and any decoys are released after boosting but while the rocket is still going up—that is, in the ascent phase of flight.[1] Releasing warheads from the missile is clearly necessary if multiple warheads with multiple aim points are to be used. It is also desirable since large missile bodies are subject to extreme forces on atmospheric reentry that could throw them, and any warheads still attached to them, badly off course.

In fact, warheads do not fly free and exposed. They are instead encased within reentry vehicles. These objects provide heat shields and aerodynamic stability for the eventual return into earth's atmosphere. They protect the warheads from melting or otherwise being damaged by air upon reentry and also maximize the accuracy with which they approach their targets.

Missiles may be powered by solid fuel or liquid fuel. If liquid fuels are used, it is usually considered desirable that they be storable and not require cooling or other special treatment that would involve extensive preparation before launch. Advanced intercontinental ballistic missiles (ICBMs) can use either type of fuel; Russian SS-18s use liquid fuel, for example, whereas modern U.S. missiles use solid fuel.[2]

Missile guidance must be exquisitely accurate. Warhead trajectories are determined by the boost phase, meaning that their course is set hundreds or thousands of miles before they reach their targets. To land within a few hundred feet of a target—or even a couple miles—requires considerable care in how long the rocket motors are fired and in what direction the rocket is directed to take by their firing. Generally, rockets use inertial guidance systems to measure the acceleration provided by the boosters at each and every stage of their burning. Computers then integrate those measurements to plot out a trajectory for the warheads; a feedback loop then corrects any inaccuracies in how the rockets have been firing, so that when they are shut off, the warheads' ballistic flight will take them halfway around the world and land them perhaps within a couple football fields of their designated aim point.

Bombs, Bomblets, and MIRVs

Although streaking shards of metal can cause terror, damage, and casualties, it is of course the warhead placed atop a missile that is most feared and most capable of causing serious harm to an enemy.

The standard, simple missile carries a single warhead. It is generally large as warheads go, but not enormous—typically weighing about as much as bombs dropped from aircraft (several hundred pounds up to perhaps a ton in weight).

Both shorter-range and longer-range rockets can also carry large numbers of bomblets instead of warheads. These can carry conventional, chemical, or biological agents in smaller packages, or submunitions, distributing their aggregate effects over a larger area than a single warhead could. They could also carry radiological payloads—basically radioactive waste, designed not to explode but to contaminate, injure, and kill directly.

But one cannot build a nuclear bomblet. Most modern nuclear weapons weigh hundreds of pounds, and crude devices such as the Hiroshima and Nagasaki bombs weigh tons. They weigh so much because they produce critical masses of fissile material not through efficiency of design but rather brute force—meaning large amounts of enriched uranium or plutonium, as well as correspondingly large amounts of conventional explosive to compress that fissile material.

Both warheads and bomblets can be designed to explode on impact, or when reaching a certain altitude, or after a certain time of flight. Bombs designed to explode at a certain altitude or after a certain time may—or may not—explode if they accidentally strike the ground. Much depends on the details of their design; as a rule, modern U.S. warheads would not explode under such circumstances, but simpler weapons could. This fact is relevant to certain types of missile defenses that could destroy a missile but not the warheads it carried.

Long-range missiles can also have multiple independently targetable reentry vehicles, or MIRVs. Britain, France, Russia, and the United States have developed and deployed this technology. It works in the following manner. All warheads are initially within a "bus," or vehicle-sized object that separates from the rocket's third stage at the end of powered flight. The bus has mini-booster rockets of its own, which it can use to modify its own position and speed before releasing a reentry vehicle (RV) containing a warhead (and any decoys or chaff to accompany it). It can then reposition itself before releasing another RV. Based on their minor differences in position and velocity, the warheads can then travel slightly different trajectories. Magnified by the effects of fifteen to twenty minutes of high-speed, long-distance flight, these minor changes in trajectory can translate into impact points distributed throughout a "footprint" perhaps 100 miles by 300 miles in size.[3]

A missile bus may also carry decoys. These are objects designed to resemble warheads, thereby confusing the defense's sensors and preventing them from identifying the true warhead or slowing the defense's response time. In the vacuum of space, even extremely light decoys move at the same speed as heavy warheads, making it particularly straightforward to fool simple sensors during exoatmospheric flight. More advanced sensors that can gauge the size, shape, rotational motion, temperature, or radar reflectivity of an object may be able to distinguish warheads from decoys—unless the decoys become more sophisticated or unless the warheads are camouflaged to make them resemble decoys.

The Trajectory of a Ballistic Missile

Ballistic flight is unpowered flight within the earth's gravitational field. In other words, it corresponds to what is essentially the free fall of a fast-moving object. Once a rocket stops burning, the only forces acting on it—or any warheads or decoys released from it—are because of gravity or air resistance. That makes flight trajectories predictable and essentially parabolic with respect to the earth's surface. But the other details of the trajectories vary greatly and depend on the speed of the rocket when its boosters stop firing, as well as the angle at which the rocket is pointed.

Boost Phase

As figure 2-1 shows, the first, or boost, phase of a ballistic-missile trajectory is a powered flight typically lasting one to five minutes. This boost phase generally lasts about a fifth of a missile's total flight time.

For shorter-range missiles, the boost phase occurs entirely within the earth's atmosphere; for long-range missiles, it generally extends beyond the atmosphere into space. Either way, during boost phase, the missile gains an upward and an outward or horizontal component to its velocity. For an ICBM, the missile will usually be about 200 to 500 miles downrange of its launch point and have reached an altitude of about 125 to 400 miles at the end of its boost phase.[4]

Midcourse Flight: Ascent, Apogee, and Descent Phases

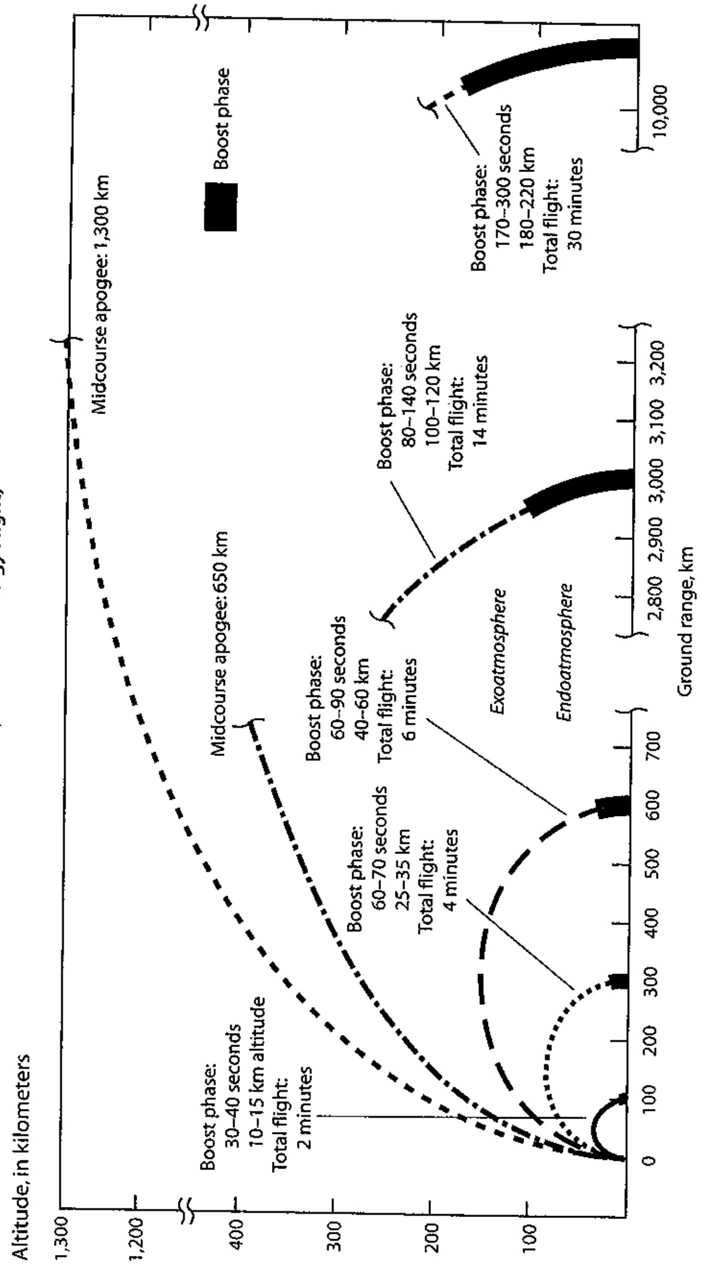
Once boost phase is complete, the remainder of the upward flight is often termed the ascent phase. Upward flight ends at the trajectory's apogee, or highest point above the earth. The missile then begins to accelerate back to earth in its descent phase.

For existing ICBMs, the ascent phase occurs entirely outside the atmosphere. It would be possible for a sophisticated country to build a fast-burn missile that would complete its boost phase within the atmosphere, but that has not yet been accomplished.[5] (The atmosphere is generally considered to end at roughly sixty miles or one hundred kilometers above the earth's surface, even though in fact there is no true cutoff but instead an exponential decline, and some air molecules are found even above one hundred miles.)

Since a long-range missile's apogee and descent phase also occur outside the atmosphere, midcourse flight is also described as the exoatmospheric phase of flight. For ICBMs, most of the missile's total flight time is spent in this exoatmospheric phase.

During exoatmospheric flight, the horizontal element of the velocity of the missile and any warheads or decoys remains constant. The vertical component of velocity is reduced by gravity, eventually slowing to zero and then reversing as the missile and any objects it has released return to earth. The result is, as noted, essentially a parabolic trajectory, as the missile continues in a generally upward motion until gravity turns its trajectory first flat and then downward.

Figure 2-1. ***Trajectories of Ballistic Missiles (for Standard, Minimum-Energy Flight)***



Source: Ballistic Missile Defense Organization, *1993 Report to Congress on the Theater Missile Defense Initiative (TMDI)*, Union of Concerned Scientists.

The Terminal Phase—Atmospheric Reentry

Finally, the missile and any objects it releases, including warheads, bomblets, and decoys, reenter the atmosphere—assuming that they reached a high enough altitude to have left it in the first place. Typically, missiles with ranges of 300 miles (about 500 kilometers) or more leave the atmosphere; those with shorter ranges do not.

Missile bodies, warheads, and decoys slow because of air resistance in a manner that depends on their weight, size, and shape. As a result of this air resistance, descending objects heat up; they are also subject to strong forces that may damage them structurally if they are not well built.[6]

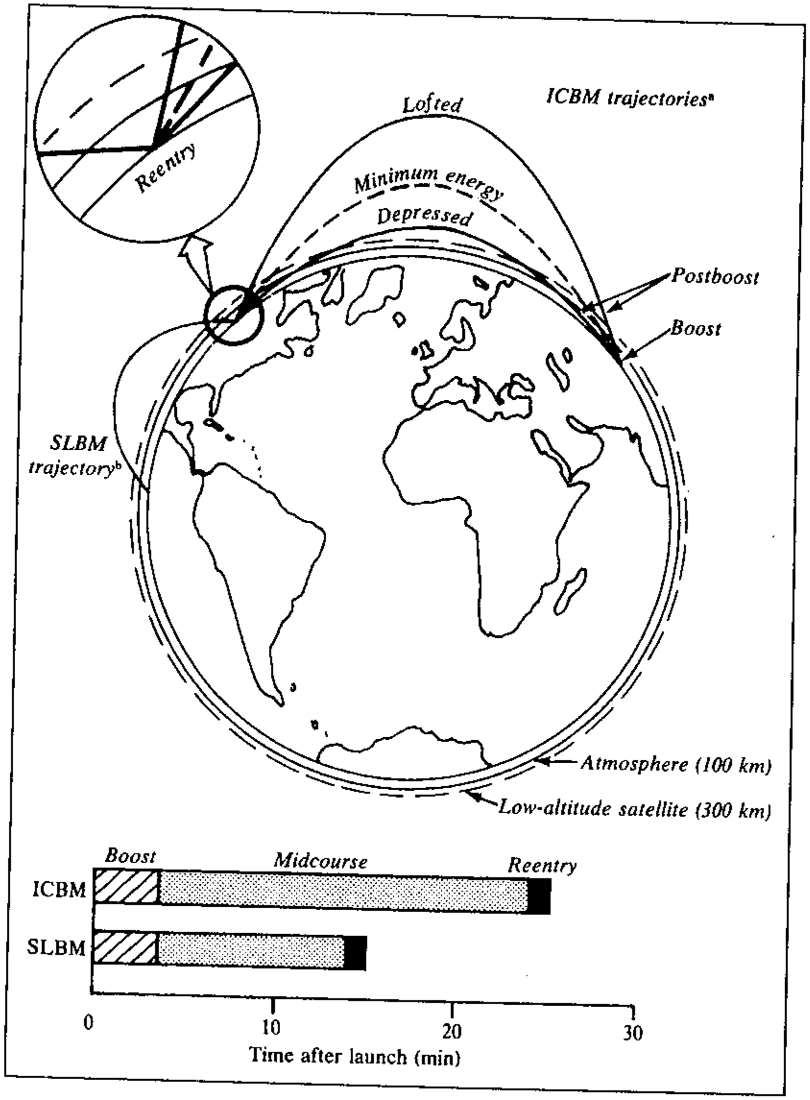
Minimum-Energy, Lofted, and Depressed Trajectories

As figure 2-2 shows, missiles may also be flown on several different types of trajectories. A missile that flies a minimum-energy trajectory will travel the maximum distance given the speed at which its rocket burns out. But missiles may also fly on what are known as lofted or depressed trajectories for certain purposes. These names are fairly self-explanatory. Lofted trajectories are those on which the rocket's flight attains a higher altitude than a minimum-energy trajectory for the same horizontal range. Depressed trajectories, by contrast, stay closer to the earth's surface than is normal for long-range flight.

Missiles and warheads on lofted or depressed trajectories require extra energy, and extra speed, to cover a given distance. But there are advantages to such flight profiles. Depressed trajectories can help missiles and reentry vehicles avoid radar detection. By staying close to earth they are shielded from the view of distant radars due to the planet's curvature. For shorter-range rockets, they can also keep a ballistic missile within the earth's atmosphere at all times—rendering them invulnerable to those types of missile defenses that must work outside the atmosphere.

Lofted trajectories also have their uses for an attacker. A missile or reentry vehicle on such a flight profile would come back to earth at a greater speed than one traveling a standard trajectory. That means the objects would reach earth more quickly in its final descent, and with greater speed and energy. It also means that they would be within the earth's atmosphere only a relatively short time during the terminal phase of flight, giving certain kinds of missile defenses less time to try to shoot them down.

Figure 2-2. *Trajectory Phases*



Source: Ashton B. Carter and David N. Schwartz, eds., *Ballistic Missile Defense* (Brookings, 1984), p. 51.
a. Range of intercontinental ballistic missiles is 10,000 km in this example.
b. Range of submarine-launched ballistic missiles is 5,000 km in this example.

Missile Types

Missiles are sometimes given the rather arbitrary designations of short range, medium or intermediate range, and long or intercontinental range (the last also being known in the cold war superpower context as strategic). The corresponding acroynms are SRBM, IRBM, and ICBM. In the standard U.S. lexicon, theater missile defenses generally cope with SRBMs and IRBMs, and national missile defenses try to destroy ICBMs (though they may also at times go after IRBMs). Table 2-1 shows the basic flight characteristics of IRBMs and ICBMs.

Most Scuds are SRBMs. Iranian Shahabs, North Korean NoDongs, and Indian Agni missiles are IRBMs. Superpower strategic systems such as the Minuteman, MX, SS-18, and SS-25 are ICBMs.

Most short-range missiles have ranges of up to about 300 miles (500 kilometers), meaning that all or virtually all of their trajectories are within the atmosphere. However, the category of SRBMs also generally includes missiles with ranges up to roughly 600 miles or 1,000 kilometers. Medium-range and intermediate-range missiles can travel 600 miles to 3,500 miles (1,000 to 5,500 kilometers, roughly speaking). ICBMs have ranges up to 6,000 miles (roughly 10,000 kilometers) or even more.

Submarine-launched ballistic missiles, or SLBMs, are generally of intercontinental range (that is, they are generally ICBMs). But they are sometimes only capable of shorter flight—and sometimes are flown on shorter flights, regardless of their maximum ranges, if the launching submarine is reasonably close to its targets when missiles are fired.

These various range distinctions can become confusing because some authors define them in different ways. But the idea of three distinct categories is useful, since there are three different classes of missiles in terms of sophistication, cost, and prevalence around the world.

Basic Types of Missile Defenses

Missile defenses can be categorized by the range of the offensive missile they are designed to defeat. Actual defenses do not always fall neatly into one category or the other, but most do. This is the approach the Pentagon generally takes and is the approach that we use. The main categories of interest are theater missile defense (TMD) and national missile defense (NMD).

Table 2-1. ***Flight Characteristics of Ballistic Missiles***

Range	*Initial angle of trajectory relative to earth's surface*[a]	*Missile speed at rocket burnout*	*Time of flight (approximate)*
Short-range ballistic missiles (SRBMs)			
600 miles (1,000 km)	43°	1.8 miles/second (2.9 km/ second)	7 minutes
Intermediate-range ballistic missiles (IRBMs)			
1,000 miles (1,600 km)	41°	2.4 miles/second (3.0 km/second)	10 minutes
2,000 miles (3,200 km)	38°	3.2 miles/second (5.1 km/second)	16 minutes
Intercontinental ballistic missiles (ICBMs)			
5,000 miles (8,000 km)	27°	4.3 miles/second (6.9 km/second)	27 minutes
6,000 miles (10,000 km)	23°	4.5 miles/second (7.2 km/second)	31 minutes

Source: Albert D. Wheelon, "Free Flight of a Ballistic Missile," *ARS Journal* (December 1959), pp. 916, 917, 919.

a. Information shown is for minimum-energy trajectories—that is, trajectories that provide maximum range for a given rocket burnout speed. Conversions to kilometers are rounded off to two significant figures.

Theater Missile Defense versus National Missile Defense

The distinction between TMD and NMD is not perfect, but for a country like the United States located far away from possible threats, and given most current defense technologies, the distinction works fairly well. Technologically, TMD defends against shorter-range missiles—SRBMs and IRBMs—and NMD defends against long-range threats or ICBMs as well as most SLBMs and many IRBMs. Conceptually, for the United States, that means TMD systems would protect American troops deployed abroad, as well as the territories of friendly countries near potential conflict zones, whereas NMD systems would protect U.S. territory (or allies a long distance from likely threats). NMD is sometimes also described as strategic missile defense.

These latter distinctions between TMD and NMD obviously fail for U.S. allies located near potential combat zones. For them, TMD systems are what would provide national defense. For the United States, TMD could have national defense implications as well, if offensive missiles were fired from a ship near U.S. territory, or from the northern half of Latin America. It could also have NMD relevance if the TMD systems also had the capability to intercept longer-range systems. In general, TMD interceptors are not sufficiently fast or maneuverable to hit high-speed warheads; moreover, if they had only been tested against slow-moving threats, their owner would probably not have confidence that they would work against faster objects even if that was theoretically possible. There may be exceptions to these broad generalizations, however.

To avoid confusion, we use the term NMD only to mean defense against long-range missile threats—ICBMs, SLBMs, and some longer-range IRBMs. We apply it to all technologies that could provide such protection, ranging from the Clinton administration's proposed system (which, lacking a proper name of its own, is also confusingly called NMD as if that were its actual designation rather than simply its mission) to boost-phase concepts to more advanced, futuristic approaches. We also note any situations where TMD systems would be likely to have NMD capabilities.

In fact, the United States and Russia have attempted in recent years to clarify the distinction between TMD and NMD. As defined in a 1997 U.S.-Russian accord known as the demarcation agreement, TMD systems are considered those capable of working against missiles with ranges not exceeding 3,500 kilometers (roughly 2,100 miles). In addition, that agreement defines TMD systems as those whose interceptor missiles do not exceed 3 kilometers per second in speed, and those that are tested only against offensive missiles with speeds below 5 kilometers per second.[7] The reason speed is so important is that faster intercepts require greater maneuverability in order to ensure that the interceptor collides with the streaking warhead in the short time available for terminal homing. Systems designed for slower flight are unlikely to have the necessary high acceleration and maneuverability. Missile defense systems with faster interceptors that are tested against longer-range, faster threats are defined as NMD. Missile defenses exceeding some but not all of the ceilings for TMD are in a legally ambiguous state.

Alas, even the technical distinction between TMD and NMD can break down for certain types of systems. That is especially the case for boost-phase defenses that would intercept an enemy rocket in its first phase of flight, while its engines were still firing. Defenses that were capable of hitting a medium-range missile in its powered flight might well be intrinsically capable of hitting a long-range rocket in that phase of flight as well, since there is much less difference among SRBMs, IRBMs, and ICBMs in their initial phases of flight than in subsequent phases. It is also possible that other weapons designed and tested for TMD may be capable of being upgraded to work as NMD, perhaps by linking them to advanced sensor networks, if their interceptors were given sufficient maneuverability to hit fast-moving objects as well.

Eventually, these facts may make it impractical to limit NMD without also limiting at least certain types of TMD. But for the near-to-medium-term future the distinction between the two types of defenses can probably be maintained for most purposes. Moreover, very capable TMD systems can be designed without exceeding most or all of the above speed and range restrictions from the TMD/NMD demarcation agreement. In particular, the Navy theater-wide system should have tremendously wide coverage, and it is doubtful that greater coverage would be needed for theaters of special concern to the United States such as East Asia and the Persian Gulf.

Boost-Phase, Midcourse, and Terminal Defenses

One can further subcategorize defenses by considering where in an offensive missile's trajectory the defense would try to destroy a threat and what technologies the defense would use to find, track, and destroy a threat. The main categories based on the offensive threat's trajectory are as follows:

—Terminal defenses that would work as warheads reentered the earth's atmosphere (if they had left it) but in any case in the final minutes of an offensive missile's flight;

—Midcourse defenses that would work while enemy warheads were outside the atmosphere (with some defense systems focusing on the ascent phase, relatively early in the exoatmospheric flight, and others on the descent phase); and

—Boost-phase defenses that would work in the first few minutes of the offensive missile's flight.

Finally, the different technologies used in missile defense range from land- and sea-based interceptor missiles to air-based or space-based interceptor missiles to various types of lasers. Within each of these main areas of technology, there are also other variations, depending on how any interceptor would physically destroy a threat and how it would be guided toward that threat.[8]

The following discussion uses the above taxonomy. At the broad level, defenses are broken down into TMD and NMD categories—that is, systems that would intercept SRBMs and most IRBMs, on the one hand, and those designed primarily against ICBMs on the other.

Types of Theater Missile Defenses

Most theater missile defenses today operate in either the midcourse or terminal phases. Some operate in both, so the following discussion considers those categories together. But they can be subcategorized by how they destroy a target. In addition, there is at least one boost-phase concept being considered for TMD.

Terminal and Midcourse Defenses

These defenses are of two main types, depending on how they destroy a warhead.

TRADITIONAL EXPLOSIVES. Most theater missile defenses that have been built or developed to date work in a fairly straightforward and similar fashion, and a way not so different from the way a radar-guided surface-to-air missile works against an airplane. First a defense battery is "told" of a missile launch, usually by communication from an early-warning satellite that senses the heat or infrared signal from the offensive missile's booster rockets. The defense battery's radar then begins to scan the sky looking for the incoming threat. Once it locates and begins to track the threat, and the incoming object is at the proper distance, an interceptor missile is launched. Its trajectory is chosen to put it in the right place to meet the incoming threat; a computer linked to the radar makes the necessary computation.

From that point on, the defense battery radar does double duty, tracking the incoming threat and the outgoing defensive interceptor missile. The interceptor missile may have a radar receiver that allows it to pick up radar echoes from the target. (Placing a radar receiver on the interceptor missile allows for more precise tracking; it is referred to as semiactive homing.) At the proper moment, a ground control station sends a radio signal to the interceptor, causing it to detonate a conventional-explosive warhead. The explosion then creates shrapnel that, if sufficiently close to the incoming warhead, should destroy that warhead. This is the basic way the existing Patriot missile defense system, known as the Patriot PAC-2, functions.[9]

HIT-TO-KILL INTERCEPTORS. More advanced theater missiles, such as the next generation of the Patriot (or PAC-3), the Army's theater high-altitude area defense (THAAD), and the Navy's area defense and theater-wide programs, use more advanced interceptors. Patriot PAC-3 may be deployed in 2001; Navy area defense by 2003; and THAAD and Navy theater-wide (NTW) by 2007 or so. Equipped with many miniature boosters, they are intended to maneuver so well that they can collide directly with incoming threats, obviating the need for (and weight of) explosives. They generally also will use either their own radar (as with Patriot PAC-3) or advanced infrared sensors (both Navy systems and THAAD) for the final homing, having first been steered to the general vicinity of a target by radar. These approaches are known as hit-to-kill technology.

Hit-to-kill technologies generally operate when an enemy missile or warhead is in its descent phase or terminal phase of flight. However, the NTW system is designed to work anywhere outside the atmosphere, be it in the ascent or descent phase. Theoretically, it may even be able to work against missiles still in boost phase. However, it can only work outside the atmosphere, and many shorter-range missiles do not have boost phases that continue beyond the atmosphere. In addition, it is not clear that the NTW missile has sufficient maneuverability to hit a target that is still accelerating.

Boost-Phase Defenses

Boost-phase defense may provide TMD as well, less so against SRBMs (given their very short boost phases) than against IRBMs. Such boost-phase defenses could be either interceptor rockets or lasers.

For example, a laser based on an airplane may ultimately be used to shoot a high-energy beam at a burning rocket, rupturing its metal skin and causing it to explode. A current program exists to develop such a laser, known as the ABL (for airborne laser); the Pentagon hopes to have it operational by 2010. Eventually, and with much work, such lasers could eventually also be based in space. Alternatively, small interceptor rockets could be based on airplanes or in a low orbit in space a few hundred kilometers above the earth's surface. Larger interceptors on land or at sea could also perform this mission, as we discuss in a moment.

Types of National Missile Defense

As is true of TMD, NMD systems can work at various places along an incoming warhead's trajectory.

Terminal Defenses

Terminal defenses are useful for defending small or high-value targets. They are poorly suited to national missile defense for a large country like the United States, however. Since they only work against incoming threats during the last minute or so of flight, and their interceptor missiles can realistically fly no more than fifty to one hundred miles in that time, they must be based near the city or small region they are designed to protect. More than one hundred defense batteries—and perhaps even two or three times that number—would be needed to defend an area the size of the United States in this way.

It may, however, eventually be possible to combine the advantages of terminal defense with those of midcourse defense. An interceptor missile could theoretically leave the atmosphere, fly hundreds or thousands of kilometers to where an incoming threat was headed, then reenter the atmosphere to conduct an intercept. It would need a local radar to guide the final approach to its target, but would not need to be based near the region it was defending.[10]

Midcourse Defenses

Midcourse missile defenses generally have fifteen to twenty minutes to work against ICBMs, which is one of their appeals. During that time, interceptor missiles could travel thousands of miles, meaning that in theory it is practical to defend an entire land mass such as the United States with a single base or two of missiles.

The interceptors could be fired as soon as an enemy launch was noticed by an infrared-detection satellite. More likely, they would be launched after radar picked up the missile following a few minutes of flight. The United States presently has radars for such purposes on its own continental coasts, in Alaska, in England, and in Greenland. These types of radars have long wavelengths that are optimal for long-range detection. A different type of radar, generally using shorter wavelengths and thus having less range but more accuracy, would then track the threatening objects. It would guide interceptors toward targets until the interceptors were close enough to pick up the threats with their own sensors. In the final approach, such sensors would provide much more accurate readings of the location of the threats than distant radars could.[11]

Several interceptors might be launched more or less simultaneously at a single threat, to account for the possibility of random failures. Alternatively, if time were sufficient, a first interceptor could be launched, and then a second or third would be launched if previous efforts had failed. This latter technique is called "shoot-look-shoot" defense.

In fact, it could take four or five interceptors to reliably shoot down a single warhead, not only for midcourse NMD but for most types of missile defense using interceptor rockets. That is the reason why the Clinton administration advertised its proposed one-hundred-interceptor system as capable of destroying only a couple dozen warheads.[12] Several problems could cause a given interceptor to miss. Rocket boosters can fail; for example, during the cold war, superpower ICBMs were generally considered to have no more than 80 to 85 percent reliability.[13] Or the so-called kill vehicle could miss its target, because of random error, a manufacturing defect, or some other cause. Even if the overall interceptor reliability were as high as 80 percent, very high reliability is needed against a nuclear weapon. To obtain 99 percent confidence of a successful intercept, in this example, three interceptors would be needed per warhead. Even more might be required if several interceptors could fail for the same reason (that is, if their probabilities of failure were not simply random, and independent from each other, but linked and systemic). Since there is not a great deal of time in which to intercept warheads, moreover, it might be impractical to attempt one intercept before firing a second and third and perhaps a fourth and fifth interceptor just in case they were needed. In other words, "shoot-look-shoot" defensive tactics may not be possible, necessitating a launch of several interceptors at once against a given warhead.

Boost-Phase Defenses

Boost-phase defenses that worked against theater-range missiles (SRBMs and IRBMs) would generally also work against longer-range missiles (notably, ICBMs). In fact, since the latter begin at the same speed as short-range rockets and burn longer and higher into the atmosphere and beyond, they are generally easier to intercept in this initial phase of missile flight than are shorter-range missiles.

A major difficulty with boost-phase defenses is that they must be based near the enemy missile launch point. That could be on land, at sea, or in the air—but it would need to be near the enemy missile launch points in any case. Since boost phase lasts only three to five minutes, or less for shorter-range missiles, an interceptor does not have much time and cannot cover much distance. As a result, it must begin its flight near its target. This problem is not serious if the potential missile threat comes only from small countries that border U.S. allies or international waterways. But it makes boost-phase defense generally impractical against missiles launched from countries with large land masses, like Russia or China.

The exception to this rule would arise if a boost-phase defense were based in a low orbit in space. Even then, however, a space-based interceptor would need to be in the right place at the time a missile was launched, since it would not have much time to complete the intercept before the offensive booster stopped burning. So the defender would need to put interceptors in many different orbits, spacing them so that some would be in the correct position at all times against plausible threats (the interceptors would be in constant motion relative to the earth's surface). A simple calculation shows that only one out of several dozen interceptors might be, by chance, in the right place at the right time to intercept a given ICBM. So even to have the capacity to intercept five to ten enemy missiles, several hundred interceptors could be needed.[14]

Even lasers, which produce beams traveling at the speed of light, would need to be located near missile launch points. Otherwise, their beams would be too weakened by the atmosphere, or by the inevitable spreading of a light beam that occurs over distance (known as diffraction) even in the vacuum of space. The beams could also simply be blocked by the earth's curvature.

Boost-phase defenses, as well as other types of TMD and NMD, would generally be alerted about the launch of an enemy missile by infrared-detection satellites high above the earth. The satellites would see the strong heat signature of the rocket. Although such signals have occasionally been confused with forest fires and other hot emissions from earth over the years, the combination of experience, more sensitive satellites, and better computers makes such confusion less likely all the time. U.S. early-warning satellites are "parked" in geosynchronous orbit about 22,000 miles (or roughly 36,000 kilometers) above the earth's surface. At that height, an object orbiting the earth completes a full revolution once every twenty-four hours—the same speed at which the earth's surface rotates. As a result, the satellite remains above the same region of the planet continuously.

Decoys and Other Countermeasures

Clearly, intercepting a missile or warhead moving at up to several miles per second is a daunting task. To date, the United States is capable of carrying out this task only for lower-speed warheads that are no more than a couple dozen miles away from a defense battery. Its capability is improving with time, however, and will continue to do so—the test failures that occurred in 2000 notwithstanding.

Eventually, a nation that could put a man on the moon in the 1960s can probably figure out how to hit a bullet with a bullet, or with a laser beam. But that may not be good enough. The moon was not trying to get out of the way or confuse us as to its true location. By contrast, even relatively unsophisticated enemies would do everything in their power to make a defense's job as hard as possible—and they would probably have some fairly simple ways to do so.

One approach would be to fire more missiles than the defense has interceptors, simply saturating the defense and ensuring that some offensive weapons could not be intercepted. If the attacker had MIRV technology, saturating a midcourse or terminal defense would be even easier and require even fewer missiles.

Decoys against Midcourse Defenses

Against defenses that can only work outside the atmosphere, in the vacuum of space, an attacker could choose to fly its shorter-range missiles on trajectories that would never leave the atmosphere. Some defenses only work in outer space (or in the very high parts of the atmosphere) because they depend on sensitive infrared detectors to home in on a target—and such detectors can be blinded by the heat generated by air resistance, particularly if an interceptor missile is traveling at high speed. Keeping trajectories within the atmosphere would require an attacker to shorten the range of many of its missiles. But for many scenarios that would not be a steep price for an attacker to pay. Rather than flying its missiles on

depressed trajectories, an attacker might also move its missiles as close as possible to their target (for example, Chinese missiles aimed at Taiwan could be placed near the Taiwan Strait before launch, as indeed they have been by Beijing). In that case, their natural trajectories would be lower and their durations of flight would be reduced—preventing some defenses from having enough time to intercept them.

Against any defense that must work in the vacuum of outer space, the attacker has its greatest range of options.[15] In this exoatmospheric or midcourse region, a warhead would generally have separated from its missile—or could be designed to do so almost immediately after boosting was complete. (As noted, an advanced country could design even its long-range missiles to complete their boosting while within the atmosphere, though a less sophisticated country might not be able to.)[16]

Outside the atmosphere, air resistance will not separate out the generally lighter decoys from the heavier warheads (as it would do for the Patriot and other TMD systems that operate within the atmosphere).[17] In outer space, even extremely light decoys would fly the same trajectory as true warheads, so speed could not be used to distinguish the real from the fake. To mimic the infrared heat signature of a warhead, thereby fooling sensors that measure temperature, decoys could be equipped with small heat generators, perhaps weighing only a pound. To fool radars or imaging infrared sensors, warheads and decoys alike could be placed inside radar-reflective balloons that would make it impossible to see their interiors.[18] Decoys could also be spun by small motors so that the balloons surrounding them rotated at the same speed as real warheads, in case the defense's radar was sensitive enough to pick up such motion.

There is some chance that lighter decoys could be distinguished from heavier warheads based on how they moved away from the bus. If pushed away by something like springs, lighter decoys would tend to move faster than heavy warheads, assuming springs of similar force. But detecting such differences in motion would require extremely precise sensors. The attacker might also compensate by releasing chaff just prior to releasing decoys and warheads—to prevent radars from seeing what happens during the release—or by designing a more sophisticated release mechanism that makes decoys and warheads indistinguishable even at the moment of separation from the bus. It is for these reasons that the decoy problem is acute, and possibly not solvable for the foreseeable future, in the case of midcourse defenses.

Decoys like those mentioned above are not trivial to make, however—and might work only if repeatedly flight tested. Balloons need to be inflated in outer space. Some type of mechanism needs to physically separate each decoy from its host vehicle as well—easy to do for Russia (or the United States, Britain, or France), the countries that have mastered MIRV technology, but a bit harder for one that has not. (Most states of concern to the United States are highly unlikely to have MIRV technology anytime soon; even China does not have MIRVs today.) The associated technology is fairly simple, but making it work in the laboratory is not the same as making it work at high speed in outer space, after a high-acceleration trajectory through the earth's atmosphere.

Decoys against Terminal Defenses

Making decoys work *within* the atmosphere is what is truly hard, however. It can be done, but it requires decoys that can overcome the effects of air resistance so as not to slow down more quickly than real warheads would.

Decoys that could mimic warheads within the atmosphere therefore might need small booster rockets. Alternatively, they could be made small and dense, so that they would fly the same trajectories as heavier but larger warheads (since the rate of slowing from air resistance increases with an object's size as well as its weight), though in that case their radar signatures might give them away.

Countermeasures against Boost-Phase Defenses

Against boost-phase defenses, countermeasures are also possible, though they are relatively difficult to make. As noted, boost phases could theoretically be shortened to minimize the time a defense would have to home in on the hot rocket booster. Against interceptors that would track a rocket's plume, contaminants could be put in the rocket fuel to make its plume asymmetric and potentially lead interceptors that home in on the midpoint of the plume astray (unless the interceptors also had an additional sensor). Against lasers, a rocket could be rotated, or given a shiny external surface that would reflect most incoming light. Finally, rockets could also be launched from remote locations and launched on cloudy days when infrared detection satellites might not detect their heat signatures immediately—reducing the time when boost-phase defenses could work.

In short, the missile defense job involves not only very advanced technologies but a complex interaction between offense and defense. Moreover, the tools available to each side are different, and in many cases advantageous to an attacker, meaning that even a less sophisticated attacker may be able to compete successfully with a technologically advanced defender. The broad message, picked up again in chapter 4, is that one must ask about the likely offensive countermeasures that could be deployed against each and every different type of defense. Missile defense is not pure science; it is an interactive, competitive, action-reaction process.