Section 5

COUNTERMEASURES TO BOOST-PHASE INTERCEPT

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Countermeasures that limit the effectiveness of traditional ballistic missile defenses—decoys, radar blackout, defense suppression, etc.—are well known. A comparable set of countermeasures, no less daunting for being less familiar, faces the designer of boost-phase defenses.

The need to resort to countermeasures imposes a cost on the offense. This cost is measured in money to build more or specialized offensive hardware, but also in the time needed to do so, in constraints upon the type of attack the offense can incorporate in its nuclear planning, and in the confidence with which it can predict a "successful" outcome of the strike.

Every BMD system actually proposed for deployment would be accompanied, at least ideally, by, first, an analysis of its degradation in the face of an improving Soviet offense and, second, by an analysis of how much it would cost for the United States to improve its defense in such a way as to avoid being overcome.[1]

[1]See *Ballistic Missile Defense,* ed. Ashton B. Carter and David N. Schwartz (The Brookings Institution, 1984), ch. 4.

Figure 5.1

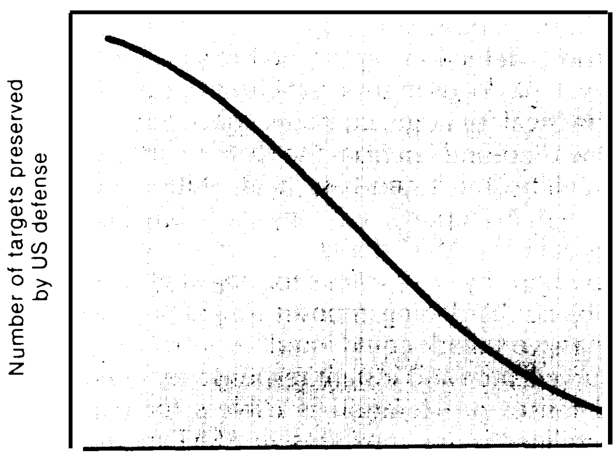

Fig. 5.1. Schematic drawdown curve, showing how the performance of a BMD system degrades as the size and sophistication of the attacking force increase.

Figure 5.2

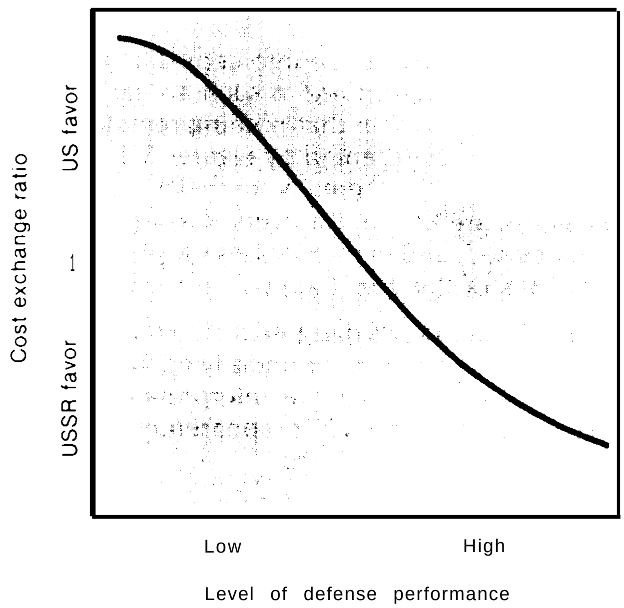

Fig. 5.2. The marginal cost exchange ratio measures the outcome of a race between the Soviet offense to enhance its penetration and a U.S. defense to maintain its level of protection. In general, modest defense goals (e.g., "preserve 40 percent of the targets") are easier to sustain than high goals ("preserve 95 percent of the targets") against improvements in Soviet offensive forces, including deployment of countermeasures.

The first analysis would be expressed in a drawdown curve such as that shown in figure 5.1. The Soviets can overcome the defense and destroy a large number of U.S. targets, but to do so the Soviets must "pay" an "attack price."

The second analysis would be encapsulated in the cost exchange ratio. The marginal cost exchange might be defined as follows: "Assume that in the year 2000 the U.S. defense and Soviet offense have evolved so that each has a certain level of effectiveness. Suppose the Soviets wish to improve their position and the U.S. resolves to maintain the status quo. Which side spends more in the competition?" For example, suppose every time the Soviets add 100 ICBMs to their arsenal, the United States has to add 20 satellites to its defensive constellation to intercept them: Which costs more, 100 ICBMs or 20 satellites?

In general, high levels of defense performance are harder to enforce in the face of offensive improvements than low levels: this important fact is shown schematically in figure 5.2 (see also Section 8.2).

All of the boost-phase intercept schemes discussed in this report are in such an early stage of conceptualization that nothing remotely like the analyses represented by Figures 5.1 and 5.2 can be done for them. Nonetheless, countermeasures are known for every boost-phase system devised, and in many cases simple heuristic estimates of the cost tradeoffs are **suggestive. ,**

Technical experts disagree not so much about the facts and calculations underlying these countermeasures as about the interpretation to be given to them. Should an apparently fatal flaw uncovered at this early stage of study of a defensive concept be decisive, or should work (and the inevitable expectations that accompany it) continue on the chance that a new idea will turn up to rescue the concept? Would the Soviets really resort to a subtle tactic or exotic piece of hardware as a confident basis for their nuclear policy? Some analysts see BMD as a way of "forcing" the Soviets to take a certain direction in their pursuit of the arms race, e.g., away from large, slow-burning MIRVd boosters to single-warhead Midgetman-like boosters. In this view, defeat of the BMD is purchased at the price of a theoretically more stable and desirable Soviet offensive posture. All these questions of judgment loom large in making a final assessment of a given countermeasure.

5.1 ANTI-SATELLITE (ASAT) ATTACK, INCLUDING DIRECTED-ENERGY OFFENSE

All boost-phase intercept BMD concepts have crucial components based in space. Even a pop-up defense would need warning and very probably target acquisition sensors on satellites over the Soviet Union. Ground-based laser defenses would have mirrors and sensors—their most fragile components—in space. Vulnerability of these satellites is a cardinal concern because their orbits are completely predictable (they are in effect fixed targets), they are impractical to harden, conceal, or proliferate to any significant degree, and because successful development of effective directed-energy BMD weapons virtually presupposes development of potent anti-satellite (ASAT) weapons. ASAT is the clear boost-phase analogue of familiar defense suppression tactics against traditional BMDs, where attack is first made upon the defensive deployment (especially fixed radars) and then upon the defended targets.

The interplay of ASAT techniques–missiles (nuclear or conventional), space mines, directed energy—and satellite defense (DSAT) techniques is a complex one, It is difficult to generalize, but in the specific case of large battle stations in low-earth orbit it would seem that the advantage is very likely to lie with ASAT, not DSAT. For one thing, the offense need not destroy a large number of defensive satellites, but only "cut a hole" in the defensive constellation. Second, the traditional military refuges all offer complications: concealment from radar, optical, infrared, and electronic detection, while possibly successful for small payloads in supersynchronous orbits, is impractical for large, complex spacecraft at most a few thousand km from the earth's surface; decoy satellites must generate heat, stationkeep, and give status reports, and they are in any event only useful if the ASAT designer is somehow restrained (perhaps by cost) from shooting at all suspicious objects; hardening imposes weight penalties, and massive shields could interfere with the constant surveillance and instant response required of the defense; proliferation is useless for expensive satellites facing inexpensive ASAT methods, As a consequence, discussions of DSAT for BMD battle stations usually emphasize large keep-out zones around the satellites and active self-defense. A third reason why ASAT is likely to prevail over DSAT is that possession by the offense of the same type of directed energy satellites used by the BMD probably assures successful first strike. Fourth, the Soviets would pick the time and sequence of their attack, and it would occur over Soviet territory.

Two rather novel ASAT threats are worthy of note. The first is the x-ray laser itself. The x-ray laser, if it could be developed, would constitute a powerful space mine. Because of its long range, it could lurk thousands of km from its quarry. The Soviets might also launch x-ray lasers a few seconds before launch of their main attack. Recall that the well-known phenomenon of bleaching (see Section 3.3) would probably allow such x-ray lasers to shoot out of the atmosphere at a U.S. x-ray laser defense, but the U.S. x-ray lasers could not shoot down into the atmosphere at the ascending lasers.

A second ASAT tactic, discussed for many years, imagines the Soviet Union exploding nuclear weapons at high altitudes in peacetime with the intent of shortening the orbital lifetimes of the U.S. defensive satellites, The nuclear bursts inject further radiation into the van Allen belts that circle the earth's equator from about 1,500 to 10,000 km altitude. Satellites (more likely carrying sensors than weapons at these altitudes) passing through the belts accumulate a radiation dose that gradually degrades electronics, sensors, and optical surfaces. This possibility, if taken seriously, would require defensive satellites designed to withstand rather substantial accumulated radiation doses.

A detailed treatment of the ASAT problem is beyond the scope of this Background Paper. The following "parable" illustrates some of the problems encountered in trying to ensure the survivability of a defensive constellation, taking the 20 MW HF lasers of Section 3.1 as an example.

The United States deploys the HF lasers in this hypothetical system in low orbits at 1,000 km altitude. Higher altitude would place them too far from their targets. This is unfortunate: higher altitude (say, between 2,000 km and semisynchronous orbit at 20,000 km) would move the satellites further from ground-based ASAT weapons and put them into lesser-used orbits where staking out a sanctuary would involve less interference with foreign spacecraft.

Suppose the battle station designers have succeeded in the considerable task of making the satellites resilient to multi-megaton nuclear space mines (bombs, not x-ray lasers) as little as 100 km away, To keep all Soviet spacecraft (i.e., all potential mines) at least 100 km away, the United States claims for itself the orbital band between 900 and 1,100 km altitude. Perhaps the Soviets are awarded some other orbital zone for their own military purposes. The United States establishes the following rules in its zone: 1) No foreign spacecraft may transit the zone without prearrangement; 2) All transiting vehicles must remain at least 100 km from all U.S. battle stations, passing through a "hole" in the constellation; 3) Foreign spacecraft failing to obey these rules may be destroyed by the U.S. lasers.

Consider first a Soviet kinetic energy ASAT deployed at 1,100 km altitude, just outside the U.S. keepout zone. Suppose the rocket interceptors on the Soviet satellites have the same propulsive capacity—one km/see—as the proposed High Frontier Global BMD system. The Soviet ASATs are then just 100 seconds away from the U.S. lasers. The U.S. lasers must therefore be very vigilant to avoid surprise attack. Fortunately, at 100 km range the 20 MW laser with 10 m mirror would burn up even a heavily hardened ASAT rocket in short order. Since starting up the main laser for self-defense might be awkward, wasteful of fuel, or time consuming, each U.S. battle station might be escorted by a satellite carrying a smaller laser or rockets for self-defense.

A constellation of Soviet 20 MW, 10 m HF lasers (the same technology as the U.S. lasers) at 1,100 km is another matter. These lasers could attack the U.S. lasers seconds before launch of a Soviet ICBM attack. The United States would have to keep these Soviet spacecraft ***thousands*** of km away from the U.S. constellation. That is, the United States would have to dominate near-earth space. Suppose the United States does so.

Now the Soviets build a fleet of pop-up x-ray lasers. These lasers climb to 100 km or so altitude, where information radioed to them from the ground allows them to point their rods at the U.S. lasers and detonate. The Soviets have had poor success **at building an x-ray laser; theirs are 100 times less bright than the ideal x-ray laser described** in Section 3.3. Nonetheless, by pointing **all its lasing rods at the same target, a Soviet x-ray laser can destroy a U.S. laser battle station** at 10 Mm range. The U.S. chemical lasers attack the Soviet x-ray lasers as they ascend, but at this range long dwell times are required to destroy the Soviet lasers. By launching enough x-ray lasers simultaneously, the Soviets succeed in getting some to 100 km altitude, where they can shoot out through the thin atmosphere, before the U.S. lasers can destroy them. In this way, the Soviets "punch a hole" in the U.S. defensive constellation. (At a minimum, the Soviet ASAT attack consumes precious laser fuel aboard the U.S. battle stations.)

just to make sure, the Soviets also deploy some powerful ground-based excimer or free electron lasers to destroy the U.S. battle stations as they orbit helplessly through space.

5.2 FAST-BURN BOOSTERS

Shortening the boost time and lowering the burnout altitude is easily accomplished at little sacrifice in useable ICBM payload (see Section 2). Shorter boost time increases the number of lasers needed for space-based laser or ground-based laser systems to handle simultaneously launched boosters. Short burn time makes rocket-propelled kinetic energy systems impractical, since the radius of action of each satellite becomes too small. Short burn time, together with low burnout altitude, would severely compromise the effectiveness of x-ray lasers popped up even from subs near Soviet shores. Low burnout altitude nullifies the neutral particle beam, which cannot penetrate very far into the atmosphere.

Fast-burn boosters would therefore be a potent, even decisive, countermeasure against almost all concepts for boost-phase intercept.

5.3 COUNTER C^3I TACTICS

Countermeasures to the crucial functions of target sensing and command and control are a relatively unexplored, but probably key, problem area for directed energy BMD. In the case of terminal and midcourse defenses, the issues of decoy discrimination, confusion caused by chaff and aerosols, radar blackout and infrared redout, radar jamming, and traffic handling have always been and remain central limitations, It is likely that analogues will be found for boost-phase systems. Devising countermeasures requires a degree of specificity about the nature of the defense system which cannot be provided in the present conceptual stage. There follow a few examples of C^3I countermeasures, by no means an exhaustive list.

A first point to note is that sensors are likely to be the most vulnerable part of a defensive satellite. A laser shined into an optical sensor can daze or injure the focal plane elements, though viewing in frequency bands absorbed by the atmosphere offers protection from ground-based lasers. Mirrors would be very susceptible to damage from a Soviet x-ray laser. A Soviet neutral particle beam could disrupt electronic circuits on U.S. satellites. Radiation pumped into the van Allen belts by nuclear bursts would affect sensors and electronics.

A single nuclear burst causes the upper atmosphere to glow brightly over areas 100 km in radius for over a minute. Calculated radiances[2] are large enough to cause background problems for MWIR tracking sensors.

[2] S. D. Drell and M. A. Ruderman, *Infrared Physics,* Vol. 1, p. 189 (1962).

Some directed-energy weapons produce spots only meters wide at the target, requiring target sensing to commensurate precision via laser radar (see Section 4.1). Laser radars sense laser light reflected from the target. A small corner reflector affixed to the target would produce a bright glint of reflected light, as would other corner reflectors launched on sounding rockets, ejected from the target, or attached to the target by expendable booms. These proliferated corner reflectors might force the beam weapon to attack them all.

The homing sensor of a kinetic energy interceptor could be susceptible to spoofing, depending on its type.

Jamming satellite-to-satellite communications crosslinks is probably ***not*** an effective offensive tactic, since the links would have narrow beamwidths, requiring the jammer to locate itself directly between the two satellites; and wide bandwidths, requiring high jammer power.

5.4 SHIELDING

A degree of shielding from lethal effects is practical for ail but the kinetic energy weapons but involves in each case different methods suited to the different physical principles at work. At the same time, large uncertainties plague all lethality estimates, and further testing and study will be needed before firm answers can be given for any of the systems. For thermal kill with a laser, a solid booster designed with some attention to a laser threat can probably easily be made to withstand 10 kJ/cm^2. Application of a gram or so of heatshield material on each square centimeter of booster skin can probably triple this hardness, and spinning the booster enhances hardness by another factor of three. Heatshield material is ablative, meaning that when heated it burns off, carrying away the heat in the combustion gases rather than conducting it through to the missile ski n underneath. A factor of nine increase in hardness requires the defensive laser to dwell on the booster nine times as long or to approach within a third of the range, Though hardening a new booster from scratch is clearly easiest, there is no serious impediment to retrofitting ablative coatings on existing boosters. Applying a gram per square centimeter of ablative material to the entire body of the MX missile would require removing several RVs from the payload, since the coating would weigh well over 1,000 kg.

An interesting possibility, requiring further study, would involve injecting into the atmosphere or producing from atmospheric gases, either throughout the ICBM flyout corridors or in the vicinity of individual boosters, smoke or laser absorbing molecules. Likewise, dust clouds raised by ground burst weapons (delivered by cruise missiles or by ICBMs that “leak” through the defense) might cause serious propagation problems for the ground-based laser scheme,

Hardening to an x-ray laser involves quite different physical principles. Recall that the x-ray energy is deposited in a paper-thin layer of the booster skin. The superheated layer explodes, applying an impulsive shock to the booster. Obviously a paper-thin shield between the booster and the laser will stop x-rays from reaching the booster wall. But the problem then becomes the debris from the exploding shield. One can easily show by calculation that the debris applies virtually the same impulse to the wall of the booster as would result from direct impinging of the x-rays! A number of schemes can be devised to divert the debris from striking the booster, but these require more study to implement in practice. One factor acting in favor of the shield designer is that the booster is not vulnerable to x-ray attack until it leaves the atmosphere. The lightweight shields therefore do not have to be designed to suffer large drag forces.

The neutral particle beam presents a third distinct type of hardening problem. The energetic beam particles penetrate into the target, and several centimeters of lead would be required to stop them. Since the beam cannot penetrate very far into the atmosphere, only the upper booster stages need be hardened. But if the third stage, say, of the MX were covered with a few grams per square centimeters of lead, the shielding alone would weigh as much as several RVs. On the other hand, if the neutral particle beam is only designed to disrupt or damage sensitive electronics, but is not powerful enough to do damage to other parts of the missile, only the sensitive components need be shielded. The weight penalty then becomes small.

It is possible that the offense can extend the protection of the upper atmosphere against the neutral particle beam by exploding a few nuclear weapons at moderate altitudes before the beam can reach them. The detonations heat the air, which rises, effectively elevating the altitude at which the neutral beam is stripped of its remaining electron and bent in the geomagnetic field. This phenomenon is called atmospheric heave. It is as yet unresolved whether atmospheric heave will loft enough air to make a difference to the engagement altitude of the x-ray laser.

5.5 DECOYS

There is no way for a decoy booster to mimic closely the hot exhaust plume of an ICBM booster except by burning a similar rocket stage. One can add chemicals to the propellants to brighten a small booster's plume and dim the ICBM's, but as a first approximation a faithful decoy must be another booster.

Decoy tactics are therefore not as attractive for boost-phase intercept systems that use plume sensing as they are for midcourse and reentry defenses, where large numbers of cheap, lightweight decoys can be carried with negligible offload of RVs. Still, the usefulness of a decoy depends not on how expensive the decoy is, but on how the cost of the decoy compares to the cost of the defense that intercepts it. Booster decoys **would not be nearly as expensive as true** ICBMs, since they carry no warheads or precision guidance system, they need not be highly reliable, and they might **not need to be based in** underground silos but can be deployed above ground next to the ICBM silos.

Some of the boost phase intercept systems must grow in the number of their deployed battle stations in direct proportion to the number of Soviet boosters. Deploying one decoy (with a dummy payload) next to each of the 1,400 Soviet ICBM silos might cause the United States to have to double the number of battle stations overhead (and thus worldwide, multiplying by the absentee ratio) to handle the extra traffic. If the defensive battle stations were at all expensive, this would bean unpleasant prospect for the United States.

Many directed energy schemes would not rely on plume sensing alone (see Section 4.1). Decoy tactics against laser radars (including corner reflectors; see Section 5.3) might be much easier for the offense to implement than mimicking the booster plume.

5.6 SALVO RATE

The worst-case attack for all the boost-phase intercept schemes is massive, simultaneous launch of all Soviet ICBMs. The defensive satellites over the Soviet silo fields at the moment of launch then have to handle the entire attack.

A more leisurely salvo rate would allow laser and particle beam defenses that have to dwell on their targets more time to handle more targets. Slow attack also allows pop-up defenses to climb to intercept position. An attack drawn out 10 minutes or longer allows fresh defensive satellites to move along their orbits into position overhead, replacing depleted satellites. The orbital period of satellites in low earth orbit is about 90 minutes. If there are 8 to 10 satellites in each ring of the defensive constellation, satellites replace one another every 10 minutes or so.

An exception to this simultaneous-launch worst-case analysis is the x-ray laser, which delivers all its energy in an instant.

There would seem to be few military penalties for the Soviet Union to adopting plans to launch all their ICBMs in large attack within a few minutes. Indeed, if one of their objectives is to destroy U.S. ICBMs in their silos, rapid attack would be the best Soviet choice. Some, though not all, of the successful attacks that could be mounted on Closely Spaced Basing (Densepack) for MX involve very slow or intermittent salvo rates, however.

More importantly, in many circumstances the Soviets might wish to launch only a traction of their ICBM force. A U.S. defense deployment too small to intercept all boosters in a massive attack would still be able to handle a small attack. A light defense might therefore establish a "threshold" of attack intensity below which Soviet boosters would face intercept. This prospect is discussed further in Section 9.

5.7 OFFENSIVE BUILDUP

The most straightforward way for the offense to compete with the defense is to grow in size. If for every new ICBM added to the Soviet arsenal, the U.S. defensive satellite constellation must be augmented at comparable or greater cost, the Soviets could challenge the United States to a spending race to their net advantage. On the other hand, if the defensive buildup is cheaper than the offensive buildup, the defense forces the offense either to accept limitations on its penetration or to resort to qualitative changes in its arsenal.

As an illustrative example of such a cost trade-off, consider the hypothetical H F chemical laser system described in Section 3.1. Each laser in that system requires 1.7 seconds of dwell time to destroy a booster. During the 200 seconds of boost, each laser overhead can therefore destroy 120 boosters. But for each laser overhead, 32 are needed worldwide. Suppose now that the Soviets deploy, in one region of the U. S. S. R., 1,000 Midgetman missiles at a cost of 10 to 20 billion U.S. dollars (see Section 2). The U.S. defense now needs to be "beefed up" with addition of (1 ,000)X (32)/120 = 270 laser battle stations. A tradeoff of more than one complex U.S. satellite, launched and maintained on orbit, for every 4 Soviet boosters (or decoy boosters) deployed on the ground would certainly appear to be a losing proposition for the United States. This is true even though the hypothetical HF laser system represents a very favorable outcome of laser technology.

Note that Soviet deployment of new ICBMs in one region of the Soviet Union, within coverage of only a single U.S. satellite, gives them the best leverage in the cost exchange.

5.8 NEW TARGETING PLANS

Truly efficient ICBM defenses would presumably force upon the superpowers a stricter attention to targeting priorities. With thousands of warheads in today's arsenals able to be literally lobbed into any target area unimpeded, the superpowers have less need to be discriminating or parsimonious in their nuclear targeting. Such a shift might have both desirable and undesirable

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consequences. For example, the offense might decide that in view of the cost of countermeasures it could no longer afford to threaten the other side's ICBM silos. The warheads "freed up" from the countersilo mission might then be dedicated to heavier targeting of other aim points (per**haps cities) as a hedge against poor penetration.** How the superpowers would greet these hypothetical defenses is not clear, but it is probably quite wrong to imagine future defenses acting against offensive forces targeted according to the war plans of today.

5.9 OTHER MEANS OF DELIVERING NUCLEAR WEAPONS

One additional Soviet response to an efficient defense against their ICBMs would be increased emphasis on submarine-launched ballistic missiles (SLBMs), bombers, cruise missiles, and whatever novel methods time and ingenuity might in the future devise for introducing nuclear weapons to the United States. As defenses forced up the cost-per-delivered-warhead of ICBM forces, these other methods would become relatively more attractive. Though they would sidestep the BMD, these delivery means have higher pre-launch survivability than ICBMs, and bombers and cruise missiles have longer times of flight, These attributes are usually seen as "stabilizing." Shifting the emphasis of the arms competition away from ICBMs is therefore sometimes viewed as adequate payoff for the BMD effort.

SLBMs would obviously be vulnerable to the same boost-phase weapons as ICBMs. The same worldwide coverage, reflected in the absentee ratio, that plagues the anti-ICBM cost exchange means that orbiting boost-phase defenses threaten SLBMs the world over. However, midcourse and terminal tiers of a layered defense would in general have much less capability against SLBMs, because of the latter's short time of flight, possibly depressed trajectory, and uncertain direction of attack. Thus SLBMs could conceivably enjoy greater penetration of a layered defense than ICBMs.

If one takes an optimistic view of emerging defensive technologies, or if one contemplates technological "breakthroughs," it is at least conceivable that such developments will spawn new ways of delivering or aiding the delivery of nuclear weapons as well as new ways of interdicting them.