Section 4

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The previous section treated only the defensive weapon itself, the so-called "kill mechanism. But if beam weapons ever evolve to the point where deployment is a serious possibility, other elements of the overall defensive system will emerge as equally important determinants of cost and level of protection. After all, the interceptor missile in traditional BMDs has not been the central focus of attention or technical debate since the 1950's, when it became clear that a "bullet could hit a bullet. " Discussion of BMD at that point passed to the difficult issues of radar performance, data processing capability, and vulnerable basing of defensive components—issues that had nothing to do with the kill mechanism. In a similar manner, the other essential elements of a boost-phase intercept system will figure more prominently in discussion of boost-phase BMD if and when the kill mechanisms—lasers, mirrors, accelerators—are in hand. These other essential elements introduce their own technological problems and opportunities for offensive countermeasures. If traditional BMDs are any guide, provision of a kill mechanism will be just the beginning of making an efficient, robust defensive system.

4.1 TARGET SENSING

Locating and tracking an ICBM booster with enough precision to aim a directed-energy weapon is not as straightforward as is sometimes supposed. it is true that booster motors emit hundreds of kilowatts of power at short- and medium-wave infrared (SWIR and MWIR) wavelengths of a few microns. Sensors can detect these plumes at great distances from the earth. Plume sensing is used today for early warning of missile attack to support launch of bombers and airborne command posts and launch under attack of ICBMS.

To be useful for directed-energy BMD, however, the sensor must localize the booster within an area as small as the beam spot. Otherwise the beam would have to sweep wastefully back and forth over the area of uncertainty. Small divergence beams must therefore be accompanied by sensors with small angular resolution.

Diffraction limits the angular resolution of a sensor in the same way it limits the divergence angle of a laser. A large infrared telescope with 5 m diameter mirror observing MWIR booster emission at 4 micron wavelength would have angular resolution no more precise than a micro radian. Such a sensor affixed to each battle station in a defensive constellation would localize ascending boosters to within a spot 5 m wide at 5 Mm range. At this range, the (illustrative) systems described in Section 3 have spot sizes: 1.5 m for the H F laser, 0.6 m for the ground based laser, 10 m for the neutral particle beam, and 100 m for the x-ray laser. Even a large infrared sensor on each battle station would therefore be inadequate for directing the laser beams at a point source of MWIR light, marginal for directing the neutral particle beam, and adequate for directing the x-ray laser. The actual situation would be worse still, since the booster is not a point source. The booster plume would be larger than the laser or particle beam spots, and the booster body would need to be located in relation to the plume to avoid wasting beam time attacking the plume.

For directed-energy weapons with small divergence angles, therefore, sensing the conspicuous rocket plume is inadequate. Another kind of sensor must be introduced into the BMD system. For finer angular resolution one looks to shorter wavelengths, in the visible or ultraviolet. At these wavelengths the sensor must provide its own illumination. A so-called laser radar or ladar is the only practical solution. In a ladar, a low-power visible or ultraviolet laser shines on the booster body, and a telescope on board the battle station senses the reflected light.

Besides the annoyance of a new laser and new sensor, the necessary introduction of ladar into the boost-phase system creates opportunities for the defense to spoof and blind the offensive sensor.

Kinetic energy systems do not need precision long-range sensing, since the rocket or guided projectile homes on the target when it comes within short range. The terminal homing might involve deducing the location of the booster body in relation to its MWIR plume, homing on low-power laser light shined from a defensive satellite and reflected from the target, or some other method. These homing methods are susceptible to countermeasures.

Though this Background Paper treats only intercept of the booster proper, it is worthwhile pausing to consider tracking of the post boost vehicle or bus. The low thrust levels of the post boost vehicles's rocket motors, their intermittent operation, the possibility of dimming them with propellant additives, and the possibility of building decoys with small rocket motors all suggest that MWIR plume sensing is not practical for post boost intercept. The alternatives are ladar or radar, suggesting again many opportunities for countermeasures.

4.2 AIMING AND POINTING

The directed-energy beam must be aimed and stabilized as accurately as it is collimated. If the beam waves around too much, the effective divergence increases, and the beam wastes energy missing the target. The mirrors or other mechanism steering the beam must be stabilized despite vibrations in the battle station caused by the beam's large power source.

In the 15 milliseconds the beam takes to travel from the battle station to a booster 5 Mm away, the booster moves about 50 m. A narrow beam must therefore lead the target. In one second of dwell time, the target moves several km; the beam must remain on the target, sweeping through the sky at the necessary angular rate while still maintaining its aim and jitter control.

4.3 INTERCEPT CONFIRMATION

A desirable, though perhaps not essential, function of BMD systems is confirmation that an attempted intercept succeeded. This function is sometimes called "kill assessment. " Intercept confirmation would allow the beam to move onto subsequent boosters with more than a statistical estimate that its previous task was accomplished. Structural damage to the booster would presumably be revealed by an erratic course or burn pattern, though it might be difficult to say in advance exactly what the sensor's view of the wounded booster would be. Subtle damage inflicted by a particle beam or microwave generator might not be visible. Damage to a bus would be difficult to assess and interpret if the debris, including RVs (perhaps arranged by the offense to separate from the bus under extreme circumstances), continue on their ballistic course to the continental United States.

Related to intercept confirmation, and ultimately more serious, is the question of determining whether the beam is missing the target (perhaps by slight misalignment of sensor and beam boresights, miscalibration of aiming mechanisms, etc.) and, if so, by how much and in what direction. It might be possible to observe a glowing column of air where a laser beam passes through the atmosphere. Some clever but elaborate schemes have been devised to track a neutral particle beam. Obviously each new complication added to the defensive system potentially creates new opportunities for offensive countermeasures.

4.4 COMMAND AND CONTROL

The crucial infrastructure of command and control of a complex system is always the last to take shape, since it integrates the workings of all the separate components. It is easy to ignore the difficulty of accomplishing this last step at this early stage when the other components of a boost phase system are not yet remotely in hand. The command and control system of a boost-phase intercept system would comprise communications links among its far-flung components, data processing to support sensors and battle station operations, and "battle management" software incorporating all the instructions and decisions needed to run the defensive engagement and to coordinate the defense with U.S. offensive forces.

Communications and data processing are two areas of technology where there is the least pessimism—looking two or so decades into the future when boost-phase systems could presumably be deployed–that technology will be able to meet the needs of directed-energy defenses. Compact, lightweight, and rapid data processing hardware is virtually assured, though interesting questions attend on hardening, reliability, and lifetime in space. Software would be expensive and would introduce issues of reliability and security from programmer sabotage. Satellite-to-satellite communication via extremely high frequency radio and laser offers high data rates and virtual immunity to jamming from earth or from space.

Command and control for BMD does introduce two interesting issues to which technology cannot provide an answer. The first is the impossibility of testing the whole defense system from end to end in a realistic wartime setting. Unlike the air defense systems of World War 11, which learned through attack after attack to exact kill rates of several percent, the BMD system would have to work near perfectly the very first time it was used. The second issue is the likely need for the defense to activate itself autonomously, since there would be no more than a minute for human decision,

4.5 SELF-DEFENSE

Consideration of anti-satellite (ASAT) attack (see Section 5.1), and analogy with traditional BMD systems (where vulnerability of key radars, data processors, and other components is usually the chief limitation on defense performance) suggest that self-defense mechanisms could well end up being a large part of the defense system. These mechanisms could include shields, escort weapons, and countermeasures to ASAT sensors. Unless and until a credible overall approach to satellite survivability is found, one cannot specify the needed hardware.

Ground-based BMD lasers and pop-up x-ray lasers would obviously need to be protected from precursor attack by cruise missiles and other delivery systems. ‘

4.6 POWER SOURCES

Chemical lasers, x-ray lasers, and rocket-propelled kinetic-energy interceptors have power sources integral to the weapon, but excimer lasers, free electron lasers, neutral particle beams, and rail guns would need sources of electrical power and the equally important means to convert electricity into a form usable by the weapon ("power conditioning"). Space basing obviously complicates the task. Large commercial power plants on the ground produce about 1,000 MW of power, and directed energy weapons might require hundreds of MW. On the other hand, the power plants on defensive satellites need not work reliably for many years but only once for a short time, and they need not be very highly efficient. The three alternatives for space power are fuel burning, explosives, and nuclear power. Starting up a large power source in seconds from a condition of dormancy poses some interesting design issues.