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Missile Defense Agency successfully conducted flight test of 3-stage Ground-Based Interceptor from Vandenberg Air Force Base

Missile Defense
Follow-on to European Phased Adaptive Approach

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Ballistic missile defense (BMD) is a key component of the strategic military posture of the United States. The latest version is the European Phased Adaptive Approach, initiated by the Obama administration in 2009. It is a regional defense to protect both our European allies and deployed U.S. forces from a missile attack by Iran. It does not protect the U.S. homeland, and is less than robust against sophisticated attack configurations. Current homeland-deployed midcourse and terminal defense systems unfortunately do not provide the missing robustness.

BMD has been under uneven development for more than four decades. It has been configured with nuclear, X-ray, particle beam, high-energy laser (HEL), explosive fragmentation, and, finally, kinetic energy kill mechanisms. It has survived mistaken strategic barriers including a treaty that perpetuated mutual assured destruction (MAD) and the notion that BMD unavoidably promoted first strike instability. It has encountered political hurdles that constrained the use of space for weaponry, even defensive weaponry. Although those impediments have not been entirely overcome, there is encouraging progress rooted both in technological advances and in a somewhat relaxed political environment.

The lack of credible ballistic missile defense shaped strategic nuclear concepts throughout much of the latter half of the 20th century. It led to the MAD strategy, variants of which are still in place. MAD derived from very large nuclear stockpiles, typically 10,000 warheads on opposing sides, is driven by game-theoretic issues of first strike stability, and puts a substantial part of the world's population at risk. Fortunately, following several arms limitation agreements, nuclear stockpiles were reduced by almost an order of magnitude, and concurrently missile defense matured considerably. As missile defenses improve and nuclear stockpiles undergo further shrinkage, the MAD strategy will likely approach obsolescence.[1]

The widespread perception that missile defense had insurmountable drawbacks significantly influenced the emergence of MAD. It included two unsubstantiated notions: (1) that it is impossible to reliably hit a bullet with a bullet, and (2) by incorporating multiple independent reentry vehicles (MIRVs), decoys, and chaff, the offense will always have an overwhelming edge over the defense. Both have been largely debunked. Miniaturized computer circuits, development of optimized (proportional navigation) guidance algorithms, and redundant sensors mounted on speedy, high-acceleration interceptors have enabled consistent single-shot hit probabilities of 0.8

to 0.95, implying 0.992 to 0.9999 levels for three independent shots. MIRV/decoy/chaff issues have been addressed by focusing on the boost phase of the ballistic missile trajectory, where all offensive elements are bundled together allowing a single hit to destroy the entire package. Admittedly, boost-phase intercept approaches are still works in progress and not adequately funded. There are promising concepts, however, and useful results should follow within a decade or so. Moreover, even if the necessary redundancy is not attained solely in the boost phase, backup by ground-based midcourse and terminal phase interceptors can be provided as necessary.

Perversely, the present political climate is not receptive to space-based weapons. If that changes, high-energy lasers and hit-to-kill interceptor constellations—both space-based—have potential. Brilliant Pebbles (discussed below) with hit-to-kill components has exceptional merit for the boost phase as well as for midcourse. Unfortunately, it was discontinued by the Clinton administration for ideological reasons presumably rooted in reluctance to orbit weapons in space. However, if boost-phase attack is ultimately pursued (as it should be), the utilization of space constellations for missile defense merits additional review.

Solid-state lasers of 1,000 kW in low-Earth orbit also have potential. The key to their success is reducing vulnerability to antisatellite weapons using low-cost decoys.

Additionally, aircraft-mounted high-energy lasers warrant further consideration. Multiple-shot solid-state devices also operating at 1,000 kW with standoff of 100 nautical miles (nm) have been postulated. That level of performance has already been demonstrated with chemical lasers but the launch platforms were bulky, vulnerable to air defenses, and generally unsuitable for military use. The transition to high-energy solid-state media is about 10 years in the future.

In what follows, the history of prior BMD is reviewed and the European Phased Adaptive Approach (EPAA) is then summarized. Our analysis sadly indicates that neither currently deployed stateside defenses nor EPAA offers robust prospects for reliable homeland protection. To set the stage for a dependable homeland defense, the fundamental relationships between high-reliability protection and nuclear stockpile quantities are next expounded analytically. Issues concerning first strike stability in the context of MAD are also explored but subsequently dismissed as irrelevant. Finally, several new approaches are suggested for boost-phase BMD as follow-on to EPAA. The expectation is that reliable missile defense can indeed be realized in the long term and, concurrently, nuclear stockpile quantities can go down further by substantial quantities.

Historical Context

The original BMD program was authorized by President Dwight Eisenhower in 1957 and assigned to both the Advanced Research Projects Agency (ARPA) and the U.S. Army. It was ARPA's largest program. When the "Defense" was added to ARPA to create DARPA in 1972, BMD continued as a major research activity emphasizing high-energy lasers.

Concurrently, the Army also undertook BMD development, initially extrapolating from the Nike antiaircraft series. The first program was Sentinel, a two-tiered nuclear configuration containing interceptors operating both within and above the atmosphere. The endo-atmospheric interceptor was the nuclear-tipped Sprint. Supported by the Perimeter Acquisition Radar, it was able to filter out decoys and chaff. The exo-atmospheric interceptor called Spartan employed an X-ray kill mechanism produced by its nuclear warhead. Guided by the Missile Site Radar, it was capable of destroying several reentry vehicles simultaneously. However, critics maintained that the radars would not function adequately in an environment characterized by prior nuclear detonations and blackout. Ultimately, that flaw terminated the program.

In 1969, the Nixon administration changed both the name and the mission of Sentinel. It became Safeguard and the mission was ballistic missile silo defense rather than city defense. Operational in 1975, Safeguard protected 150 Minuteman intercontinental ballistic missiles (ICBMs) deployed in North Dakota. However, it was deactivated after only a few months. America then became completely dependent on MAD and lacked an operational BMD system for the next three decades.

In the 1980s, the Reagan administration refocused BMD under the Strategic Defense Initiative (SDI). The 1972 Anti-Ballistic Missile Treaty had prohibited extensive BMD deployments but constraints on research were ambiguous. SDI research, popularly known as "Star Wars," was broad-based and pushed the limits of knowledge. Its principal elements were:

Space-based X-ray Lasers. The initial focus of SDI was a nuclear explosion–initiated X-ray device. In theory, selected spectra would pump linked laser emitters on nearby satellites so that several incoming ballistic missiles could be targeted and destroyed simultaneously. In subsequent testing, however, nuclear-energized lasers proved unsuccessful.

Chemical Lasers. In 1985, a deuterium fluoride laser known as the Mid-Infrared Advanced Chemical Laser (MIRACL) was conceived. It successfully destroyed a Titan missile in a simulated boost-phase intercept and was the basis for several Army and Air Force follow-on programs. In 2009, a descendent of MIRACL shot down a boost-phase missile in actual flight as part of the Airborne Laser test schedule, and in 2010, it destroyed two rockets in quick succession. The Airborne Laser had a power of several megawatts and was capable of 100-nm standoff. However, it required a large, vulnerable launch platform (of the Boeing 747 aircraft class) and was considered unacceptable by the Air Force. The Airborne Laser program was canceled in 2012 after 16 years of development and an expenditure of $5 billion.

Neutral Particle Beams. An ambitious neutral particle beam weapon for deployment in space was also explored. Neutral particle beams are streams of near light-speed atoms and neutrons emitted by highly energized accelerators and are capable of superheating and catastrophically destroying massive target structures. Particle beam BMD weapons were eventually abandoned because practical space-based versions with the required energy and power were not realized.

When the Soviet Union collapsed and the Cold War ended, the focus of BMD changed. In 1991, SDI was recast as Global Protection Against Limited Strikes (GPALS). GPALS had three components collectively intended to provide robust protection against accidental or unauthorized attacks by Russia or China and limited attacks by rogue nations. They included a space-based defense against boost-phase missiles, a ground-based midcourse phase for homeland defense, and a ground-based terminal defense against theater threats. Its principal programs were:

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Airborne Laser Test Bed final flight as it transitions to long-term storage in Arizona

Brilliant Pebbles. Brilliant Pebbles was a stand-alone space-based constellation of small interceptors primarily focused on boost-phase targets. It was time-durable and survivable. The 6-kilometers per second (km/sec) kinetic energy kill vehicles each weighed about 3 kilograms (kg). Brilliant Pebbles employed a wide field of view infrared camera to detect missile launch, visible and ultraviolet cameras to point toward the target's bright compact plume, and a far-infrared imager in conjunction with a co-focal light detection and ranging (Lidar) sensor to resolve the missile body from its plume. Costs were estimated at $1.1 million per interceptor or roughly $1.1 billion for a constellation of 1,000.[2] Brilliant Pebbles[3] achieved or defined a clear path to most of the GPALS objectives for boost-phase BMD. However, it was canceled both on budgetary grounds and on a reluctance even to put defensive weapons into space.

Ground-based Midcourse Defense. GMD is a deployed BMD system to protect the U.S. homeland. Interceptors were emplaced in Alaska and California, totaling 30 missiles by the end of 2010, with the objective of adding 14 more by 2017. Further plans to put missiles in Poland and radars in the Czech Republic were subsequently canceled by the Obama administration. GMD is a three-stage interceptor with a solid-fuel booster and an exo-atmospheric kinetic energy kill vehicle (EKV). The 64-kg EKV has a speed of 10 km/sec and an infrared seeker to discriminate reentry vehicles from decoys and chaff. The EKV has its own guidance divert propulsion, discrimination algorithms, and computers.

Terminal High-Altitude Area Defense System. THAAD is a U.S. Army system to destroy ballistic missiles in their final phase. THAAD employs an enhanced kinetic energy kill mechanism. Two batteries (48 missiles) were activated in Texas in 2008 and two additional batteries are planned for 2013. Some of these missiles will be deployed in Guam in response to North Korean threats. The launchers, together with eight missiles, are truck-mounted. Each missile weighs 900 kg, the range is greater than 200 km, and the speed is 2.8 km/sec. Guided by the Army Navy/Transportable Radar Surveillance (AN/TPY-2) X-band radar, THAAD is similar to the Patriot PAC-3 and is designed to hit with a small explosive warhead that enhances the kill. The U.S. Navy has a complementary sea-based system—the Aegis Ballistic Missile Defense System—that uses the Standard Missile 3 (SM-3).

New BMD Approaches

In September 2009, the Obama administration decided to cancel GMD deployments planned for Poland and the Czech Republic and instead undertook the European Phased Adaptive Approach. According to the National Research Council,[4] EPAA is specifically intended to protect European allies and deployed U.S. forces against an Iranian midcourse missile attack. It is not a defense against an attack by Russia or China.

EPAA was planned in four phases to begin in 2011 and end after 2020. The deployment includes SM-3s with Blocks IA/IB/IIA/IIB, in which velocities increase progressively from 3 to 5.5 km/sec and in which seeker optics are upgraded from one-color to two-color. Initially, the system uses sea-based AN/SPY-1 and AN/TPY-2 radars, and the latter radar was deployed in 2011 in Turkey. A total of 32 Aegis ships, each capable of tracking one hundred targets simultaneously, will be delivered along with 409 SM-3s. In 2015, some of those SM-3 interceptors will also be deployed on land in Romania, and possibly by 2018 in Poland. The United States will additionally develop the Airborne Infrared Sensor platforms capable of tracking hundreds of targets simultaneously.

The SM-3 Block IIB was scheduled to be deployed in Phase 4. The intent was to provide "limited" capability to counter ballistic missiles in the boost phase. However, a 2011 Defense Science Board study asserted that goal was unrealistic and Phase 4 was subsequently canceled in 2013.

A number of deployments in Phase 1 are currently in place to defend against first-generation Iranian missile launches (that is, those that are not augmented with extensive MIRVs and decoys). Existing EPAA deployments are capable of effective midcourse engagements only until such time as Iran inevitably fields more capable countermeasures.

Several X-band radars oriented toward Iran are currently stationed in Turkey, the Negev Desert in Israel, and the Island of Qatar. Patriot PAC-3 Missiles are collocated with the radars. Standard Missiles on Aegis Missile Defense Ships are also deployed in both the Mediterranean Sea and Persian Gulf.[5] The deployment is such that ballistic missile launches directed toward the Middle East or Europe can be detected and responded to with redundancy. The short- and medium-range missiles in Iran's inventory have large radar cross-sections, and Standard Missiles deployed on Aegis ships and land-based Patriot PAC-3 Missiles have a promising record for engaging such targets. They do not have enough range and speed to engage them in the boost phase, however.

Beyond EPAA

A solid-state HEL mounted on an aircraft is a long-term alternative to EPAA and would be capable of multiple lethal shots from standoff distances of 100 nm. The required laser power is 1,000 kW. The currently achieved maximum power level is 105 kW, reached in 2009, with the Northrop Grumman Joint High Power Solid-State Laser (JHPSSL). JHPSSL leveraged seven 15-kW laser units synchronized to produce the total output. It is conceptually scalable to achieve even higher power.

A parallel effort is the High Energy Liquid Laser Area Defense System (HELLADS) being developed by General Atomics with sponsorship from DARPA. The goal is to synchronize three 50-kW lasers to produce a total output of 150 kW.

Note that neither JHPSSL nor HELLADS is intended to engage ballistic missile targets. They nevertheless are judged to be appropriate technology for scaling up to a usable antiballistic missile weapon.

High-energy lasers can also be deployed from space. Solid-state devices of 1,000 kW are again envisioned. Target selection and acquisition would have to be provided by a space-based array such the Airborne Infrared Sensor configuration. Assuming only one laser will be involved, the engagement by necessity would be shoot-look-shoot. Space-based HELs have been investigated by DARPA for many years but have not been realized as weapons because of their vulnerability to antisatellite weapons. Note, however, that survivability can be increased very substantially by embedding the HEL platform in a constellation of decoys. Improvements in invulnerability by a factor of 10–100 can be achieved at modest cost.

An HEL with capability against boost-phase ballistic missiles includes 10 100-kW lasers synchronized to produce a 1,000-kW output. The system includes an adaptive optics module to compensate for a turbulent atmosphere.

A key technology for successful HELs involves dissipating large quantities of waste heat. Typically, a HEL has about a 10 percent thermal efficiency, so a 1,000-kW laser produces 900 kW of waste power, the heat from which must be dealt with. ARPA is supporting efforts to increase the HEL efficiency to 30 percent.

As mentioned previously, one of the more promising approaches for providing multiple shots in the boost phase is Brilliant Pebbles. Brilliant Pebbles expends small, relatively inexpensive projectiles at moving targets. This encourages multiple defensive attempts either simultaneously or in quick shoot-look-shoot succession. Since the Brilliant Pebbles projectiles are stand-alone with independent target acquisition and tracking, the multiple engagements should be statistically independent.

An additional boost-phase BMD initiative could be based on stealthy armed aerial drones. Target selection and acquisition would be self-contained using passive infrared sensors. If the drones operated within roughly 50 nm of the launch site, they could attack large, initially slow-moving ballistic missiles with conventional air-to-air missiles using explosive warheads. Drones of the MQ-9 Reaper class are currently being considered for boost-phase target acquisition but not for attack. Reapers can stand off hundreds of nautical miles but they are not stealthy.

Focus on the Boost Phase

Reliable defenses for protection of the homeland are in disarray programmatically. Current and planned deployments do not deal with a sophisticated attack and focus only on the midcourse and terminal phases. Boost-phase defenses were developed to a significant level in the SDI and GPALS activities. Although now dormant, they could be restored relatively quickly since the principal political constraint—the Anti-Ballistic Missile Treaty—has been removed.

The focus of an efficient defense should be in the boost phase because the MIRVs, decoys, and chaff are still bundled together, and a single energetic hit will destroy them all. If the attack is delayed until the midcourse or terminal phases, it will be necessary to engage numerous entities for reliable operations. Currently deployed defenses deal only with midcourse and terminal threats.

Analytical Modeling

Arms limitation agreements between the United States and Soviet Union/Russian Federation have reduced respective strategic nuclear stockpiles substantially: from 10,000 to 6,000, from 6,000 to 3,500, and then to 2,200. The New Strategic Arms Reduction Treaty negotiations, which reduce levels to 1,500–1,675, have recently been completed and ratified by the U.S. Senate. These smaller stockpiles help to enable effective missile defense. This can be shown analytically by calculating surviving strategic reentry vehicles as a function of the number of attackers and the effectiveness of the defense.

Attacks varying from 10,000 to 10 are of interest. Missile defense consists of three independent attempts against each threat since individual missile defense effectiveness is not perfect and varies from 80–95 percent. The significant finding is that surviving warheads are substantially less than 1 if the defense effectiveness is 95 percent for attacks of 1,000, and also for attacks of 100 at effectiveness levels of 80–90 percent.[6] It is not unreasonable to anticipate opposing stockpiles of 1,000 and defense effectiveness at 95 percent within a decade or so.

Strategic and First Strike Stability

The implications of both strategic stability[7] and first strike stability[8] have been studied intensively. Strategic stability arguments are highly subjective and have been used by Russian analysts to justify opposition to a wide set of U.S. military programs including space weapons, precision-guided weapons, drone reconnaissance, drone weapons, and ballistic missile defense. Since the end of the Cold War and the downsizing of the Soviet Union, the United States has outstripped the Russians in all these categories and they, not surprisingly, have

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Command, Control, Battle Management, and Communications is combatant command's interface to fully integrated Ballistic Missile Defense System

depicted each as "destabilizing." Obviously, the United States does not agree to those characterizations.

First strike stability is substantially quantitative however, and we focus on it instead of strategic stability. During the height of the Cold War, BMD was considered by both the Soviet Union and the United States to be highly destabilizing; that is, the Russians maintained that construction of missile defenses would negate their nuclear deterrent encouraging a first strike even before the program was complete. The United States agreed. To mitigate that danger, the 1972 Anti-Ballistic Missile Treaty was negotiated and ratified by both sides. However, nuclear arms limitation in the last two decades has largely eliminated those concerns, at least on the part of the United States, and the 1972 treaty has since been nullified.

In the past several decades, nuclear stockpiles on both sides have decreased substantially. *Analysts agree that as opposing stockpiles approach 1,000, first strike stability becomes insensitive to missile defenses.* This follows because at reduced stockpile levels a large fraction of the U.S. capability is on submarines and bombers, and both are substantially invulnerable to a first strike. As the U.S. stockpile is drawn down to the vicinity of 1,000, mostly submarine and bomber forces will be left because they are the least vulnerable and under those circumstances BMD cannot have a meaningful effect on first strike stability.

Summary and Recommendations

Ballistic missile defense has been under development, albeit in fits and starts, for more than four decades. It has continued through numerous design iterations that included nuclear, X-ray, particle beam, high-energy laser, explosive fragmentation, and, finally, kinetic energy kill mechanisms. It has survived mistaken strategic barriers including a treaty that perpetuated MAD, and the notion that BMD promoted first strike instability. It has also faced political hurdles that constrained the use of space for weaponry, even defensive weaponry. Although these impediments have by no means been overcome completely, there is reasonable hope the obstacles will be removed in the long term.

The current emphasis is on the European Phased Adaptive Approach. EPAA is regional and is not oriented for boost-phase operations. EPAA does not include space weaponry and does not encompass high-energy lasers. EPAA is capable only of coping with primitive ballistic missiles in the midcourse phase; that is, it cannot deal with MIRVs or decoys. Note that both the existing GMD and THAAD deployments in the homeland have been thus far left in place and added to but they too have only primitive capability against MIRVs and decoys.

If America is to have a robust BMD capability against sophisticated ballistic missiles, it must resort to a boost-phase defense. Brilliant Pebbles, standoff and space deployed high-energy lasers, and stealthy drones armed with air-to-air missiles are all promising approaches for achieving such a boost-phase capability. These concepts presently violate a misplaced reluctance to put weapons in space, and/or are budget busters. However, as stockpiles of the nuclear powers decrease to levels of 1,000, current political and fiscal constraints could and should be relaxed so that robust security can be achieved. **JFQ**

NOTES

[1] It is of course conceivable that the United States and China may eventually confront each other with a new version of mutual assured destruction even at reduced stockpile levels.

[2] Gregory H. Canavan, *Missile Defense for the 21st Century* (Washington, DC: The Heritage Foundation, 2003); the assumed cost for low earth orbit was $20,000 per kilogram in 2003 dollars.

[3] Although final parameters were not established, a typical Brilliant Pebbles constellation orbits at an altitude of 1,000 kilometers with a speed of 7.5 kilometers per second. Assuming 1,000 interceptors packaged in 333 mini-satellite containers spaced 139 kilometers apart, on the average, 3 interceptors can be delivered in 18.7 seconds or less to any point in the orbit.

[4] National Research Council (NRC), *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, DC: NRC, September 11, 2012).

[5] Adam Entous and Julian E. Barnes, "Pentagon Bulks Up Defenses in the Gulf," *The Wall Street Journal*, July 17, 2012.

[6] The calculation is at a basic level: $S = N\{1-(1-P_k)^3\}$ where S is the number of surviving warheads and N is the size of the attack. P_k is the effectiveness of individual defense layers.

[7] Derek F. Schin, "The Impact on Strategic Stability of Ballistic Missile Defense in Eastern Europe" (Master's thesis, U.S. Army Command and General Staff College, 2009); Alexei Arbatov et al., *Strategic Stability After the Cold War* (Moscow: Institute of World Economy and International Relations, Russian Academy of Sciences, 2010).

[8] Glenn A. Kent and David E. Thaler, *First Strike Stability: A Methodology for Evaluating Strategic Forces,* Reports, R-3765 (Santa Monica, CA: RAND, August 1989).