A New Approach to Ballistic Missile Defense for Countering Antiaccess/Area-Denial Threats from Precision-Guided Weapons

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Advanced capabilities in a variety of foreign weapon systems have prompted many discussions about antiaccess and area denial (A2AD) over the last decade. Such capabilities, which allow an adversary to apply force at greater ranges or with greater accuracy, will affect many aspects of allied campaign planning. This article addresses one subset of A2AD: the new ballistic missile technologies that an enemy can use to hold even mobile forces at risk at ranges in excess of 1,000 kilometers (km). This involves more than just China's antishipping ballistic missile—and evidence exists that other countries are developing these technologies as well.[1] If successful, they could have a significant effect on planned missile defense systems. In particular, a maneuvering threat will have a higher probability of hitting an undefended target, place more targets at risk, and have less susceptibility to interception.

This is not a revelation—the mechanics of ballistic flight are well known. Less well known is the fact that the Missile Defense Agency (MDA) has chosen to focus nearly all resources for developing missile defense not on the A2AD threat but on the "early intercept" concept that supports the European Phased Adaptive Approach (EPAA). Since 2009 the MDA has committed most of its development efforts to improving the Navy's SM-3 interceptor and supporting sensors. The SM-3 is an established system with a long history of success against purely ballistic targets, but it was not designed for the challenges of a maneuvering threat. Furthermore, the MDA has dedicated nearly all of its recent development to the midcourse phase of flight, where the threat has the greatest freedom to introduce confusion, and has ignored the boost and terminal phases of flight, where the threat remains most identifiable and most vulnerable.[2]

The maneuvering threats presented in this article are based upon foreign research that appears in English in the open technical literature. The article examines the development of simple maneuver schemes to avoid both tracking and interception and of subsequent maneuvers to hit an intended target. Such maneuvers can prove effective against midcourse interceptors with limited agility, but they have negligible effect on an agile interceptor designed for boost-phase intercepts. The analysis presented here shows that increased interceptor agility is more effective than increased speed if the threat maneuvers. It also demonstrates that the Air Force's proposed Airborne Weapons Layer (AWL) could effectively counter these maneuvering threats.[3] Finally, the article discusses whether the military services or a single-function defense agency should make the key decisions that define future operational capabilities in this critical component of air superiority.

The Missile Defense Agency's Current Plans and the Maneuvering Threat

The SM-3 family of systems, cornerstone of the MDA's development plans, was designed to intercept medium- and intermediate-range ballistic missiles in the midcourse phase of flight—assuming that decoys may be present but not maneuvers.[4] At present, the MDA emphasizes improving the SM-3's sensor technology, discrimination algorithms, and divert-system reliability, as well as substantially boosting the interceptor's speed. This approach results in kinetic kill vehicles with low agility—low divert velocity and low lateral acceleration—and a primary concentration on increasing the effective range through higher speeds. It yields attractive, very wide area coverage from a single site but does not solve the underlying discrimination and kill-assessment issues. Moreover, if the threat maneuvers during midcourse as a countermeasure—with or without decoys—performance falls off sharply.

To fully appreciate the issues, one should understand what an adversary must do to attain this maneuvering capability and why maneuverability is so lucrative. A ballistic missile that contributes to A2AD operations must have precision guidance, to either a fixed or mobile target. The former is easier since it does not require real-time tracking, but both demand that the missile know its position (i.e., navigate), determine the difference between its actual and desired flight path (i.e., guidance), and correct to its desired flight path (i.e., control). An Iranian paper on this subject, published in 1991 by the American Institute of Aeronautics and Astronautics, indicated Iranian awareness of precision guidance techniques for intercontinental ballistic missiles (ICBM) and exposed Iran's efforts to apply these techniques to theater ballistic missiles. Iranian researchers have published subsequent papers on this subject in international journals as recently as 2008.[5]

To attack mobile targets, a medium-range ballistic missile (MRBM) (or one with longer range) must maneuver after boost phase to remove the differences in a target's position due to unpredictable motion between time of launch and target impact. Of course, doing so calls for an off-board sensor to provide real-time tracking data on the target, but for now our attention remains on the missile. This same correction maneuver can come into play for avoidance of midcourse interception by allowing an initial flight path toward one location, followed by delayed propulsion toward the intended target. Midcourse interceptors launched at a predicted intercept point determined before the maneuver have limited flexibility to divert once their boost phase has ended. Even if they continued to track the threat through the maneuver, the end-game intercept may exceed the interceptor's divert capability. This was the subject of a Chinese paper presented at a recent guidance and control symposium hosted by the American Institute of Aeronautics and Astronautics, which also included a potentially viable Chinese approach to optimizing defense avoidance.[6]

Finally, a defensive plan that entails shooting one interceptor and assessing its success before firing others obviates the need to fire large salvos of very expensive interceptors. This "shoot-assess-shoot" doctrine led to the MDA's concept of early intercept, emphasizing the first intercept attempt during the first half of the threat's flight path.[7] Unfortunately, such an approach necessitates tracking sensors and interceptor launch sites well forward of the defended area (or in space). This in turn requires persistent presence in the same area to which the adversary is attempting to deny access (or an exceptionally expensive constellation of space-based sensors). However, despite establishing an accurate track soon after the boost phase ends and launching an interceptor for an ascent-phase intercept, a postboost maneuver may evade its seeker acquisition or its divert capacity.

Utilizing large surface-based interceptors is not the only way to address this problem. For nearly five years now, the MDA and Air Force have jointly investigated the AWL, demonstrating critical technologies. Indeed, one test (funded by a congressional earmark rather than an MDA decision) actually carried out the MDA's first boost-phase intercept of a surrogate theater ballistic missile. Unfortunately, despite multiple joint studies that determined the concept's technical viability and operational feasibility, the MDA has funded no further development, pursuing the EPAA instead.[8]

But is the EPAA the right concept for an antiaccess environment where threats can conduct exoatmospheric maneuvers? How does performance of the AWL compare to that of the planned EPAA systems if threats maneuver to aid penetration of the defense? What interceptor attributes are necessary for system success when the threat maneuvers? To answer these questions, the author simulated both approaches against two different threats—an exomaneuvering MRBM with terminal guidance and an ICBM capable of lofted trajectories. The following analysis included improvements in both speed and agility to a notional surface-launched interceptor, similar to the planned developments of the SM-3. The resulting performance projections were then compared to the baseline AWL upper-tier interceptor in terms of operational area.

Not surprisingly, the results indicated that the planned speed increases for the EPAA interceptor alone offered little benefit if the threat maneuvers after boost phase. Moreover, enhanced agility produced other benefits, including introduction of a boost-phase intercept capability if the interceptor launched close enough to the threat's launch site. Concurrently, the Defense Science Board's report of September 2011 regarding early intercept criticized the MDA on several accounts but acknowledged that boost-phase intercepts would solve the principal deficiencies of early intercept (discrimination and kill-assessment challenges). The board also acknowledged that boost-phase intercept with today's systems is not currently feasible.[9] However, such intercept *is* feasible with more interceptor agility *and* placement of the interceptor close to the threat's launch area. Again, the key interceptor attribute is increased agility—as well as the critical positioning capability that airpower can supply—the two primary advantages of the AWL.

Finally, given the findings of the Defense Science Board, this analysis, and the MDA's decisions to pursue the EPAA and defer any development of the AWL, one must question whether a single-function defense agency such as the MDA is the proper organization to decide future defense capabilities. Its formation in 2002 from the Ballistic Missile Defense Organization was driven by an administration goal to provide nationwide protection against a North Korean threat as quickly as possible. Is that approach still justified, and is it the best one for future theater challenges? Before addressing that question, I will first describe the analysis and modeling of the maneuvering threat.

Threat Models

The MRBM threat model was roughly based upon "Maneuver Strategy of Evader Considering Detection System," a Chinese paper presented in August 2011 by Yang Guo, Shicheng Wang, Yu Yao, Baoqing Yang, and Peng Zhang at the Guidance, Navigation, and Control Conference sponsored by the American Institute of Aeronautics and Astronautics. These authors suggested multiple methods for evading interception, including single and multiple pulses (fig. 1). They note that "the purpose of maneuver is to change ballistic trajectory instead of evading interceptor directly. On the interception side, estimation and prediction errors of detection system will increase because of Ballistic Maneuver by the flight vehicle. . . . If the errors are large enough, the interceptor either fails to satisfy the launch requirements (such as target location uncertainty, capture zone), or loses the target after launch."[10]

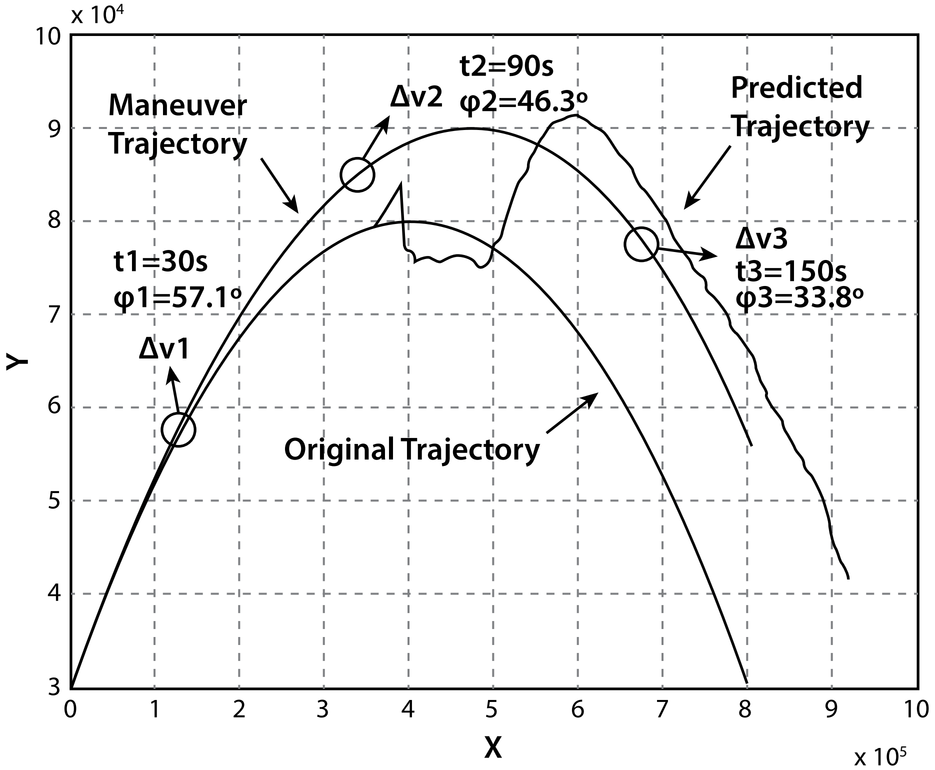


Figure 1. Trajectory of three times maneuver. (From Yang Guo et al., "Maneuver Strategy of Evader Considering Detection System," AIAA 2011-6713 [presentation at the American Institute of Aeronautics and Astronautics Guidance, Navigation, and Control Conference, Portland, OR, 8–11 August 2011].)

The following analysis modeled one- and two-pulse maneuvers for the notional MRBM threat model (fig. 2). The maneuvers, which occur above 200 km in altitude during ascent, are barely noticeable in the following trajectory arcs but do result in the shift in impact points as depicted. For the ICBM, both a minimum-energy trajectory and a lofted trajectory were modeled (fig. 3).

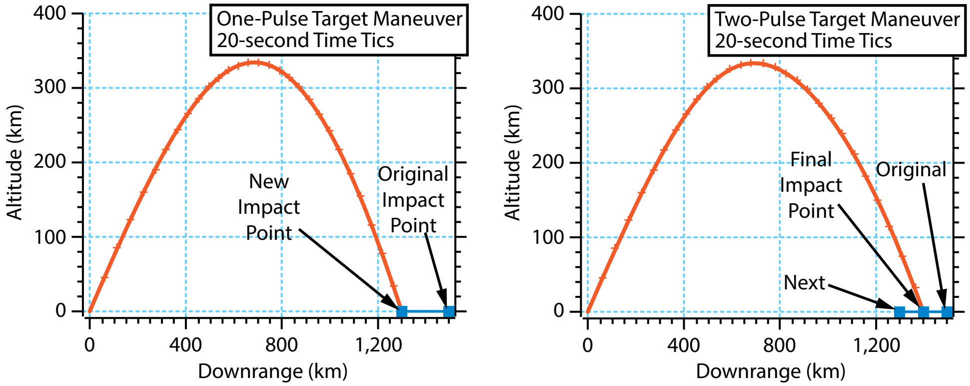


Figure 2. MRBM threat with one- and two-pulse midcourse evasion/precision-targeting maneuver

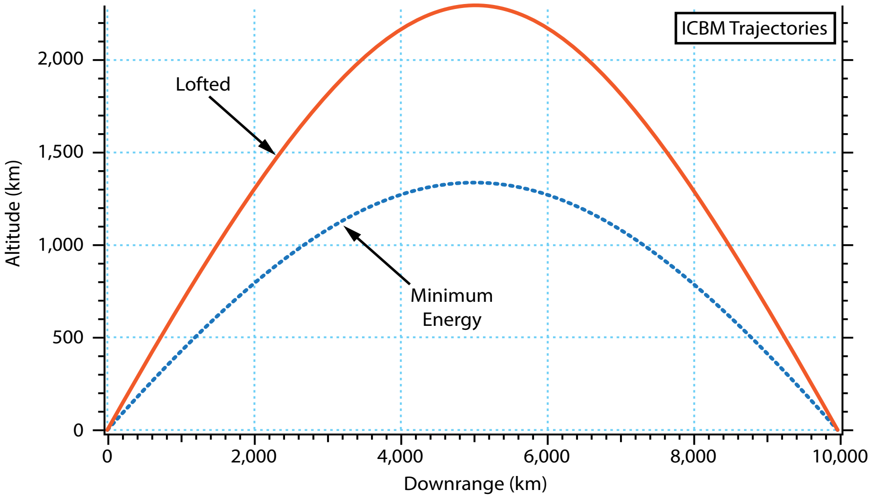


Figure 3. Comparison of minimum-energy and lofted ICBM trajectory

These maneuvers and the lofted ICBM trajectory do not occur without cost, however. An adversary cannot maneuver in flight or fly a lofted trajectory without a performance penalty to either the maximum range for delivering a particular payload or the maximum payload delivered to a particular range. The ICBM could use the additional energy necessary to fly a lofted trajectory to deliver the same payload further on a minimum-energy trajectory. If the weight of the systems needed to execute these threat maneuvers is about 250 kilograms (a reasonable estimate), the additional weight would result in a decrease in the MRBM's maximum range from 3,000 to 2,400 km (about 20 percent). Despite these significant effects on missile range, an enemy may be willing to accept them to put his weapon on the intended target.

Interceptor Models

The notional baseline surface-launch interceptor was modeled with 3.5 km/second burnout velocity, 250 meter/second divert, acceleration of 2 g's, and homing guidance. This was considered nominal performance for a surface-launched interceptor and representative of a low-agility missile intended for midcourse intercepts only (referred to in the figures that follow as the "phased adaptive approach [PAA] surrogate"). I intend the PAA surrogate only as a point of departure for examining the potential performance benefits attainable by increasing the interceptor velocity or the kinetic kill vehicle's agility. It is not one of the variants of the SM-3.

This analysis assumes that planned forward-based radar, airborne infrared tracking systems, and the Precision Tracking Space System are all available and contribute to "perfect tracking" to support the PAA surrogate. This provides a common basis for comparison of interceptor performance but also produces overly optimistic performance estimates. Four notional developments of the PAA surrogate were modeled, with burnout velocities of 5 km/second and 6 km/second (40 percent and 70 percent faster, respectively, but with baseline agility) and with baseline velocity—but with 200 percent and then 400 percent greater agility.

The AWL upper-tier interceptor was modeled, based on employment from an F-35A.[11] In general the upper-tier interceptor has a burnout velocity of 3.5 km/second and a divert capability of 2.0 km/second; moreover, it is capable of 10 g's lateral acceleration. For boost and early ascent-phase intercepts, it relies only on the indigenous F-35

Distributed Aperture System and triangulation from two aircraft operating in formation.

Simulation Results: Operational Area Comparisons

Open sources describe details of the modeling system.[12] Although this article presents only the results, readers are encouraged to fully investigate the simulation methods used and decide for themselves if the methods are adequate. The objective was to determine interceptor attributes necessary for successful intercepts against maneuvering threats. The method consisted of simulating nonmaneuvering threats, adding threat maneuvers, and then examining interceptor velocity and agility enhancements to isolate the most important ones.

Figure 4 depicts the operational area for a notional 3.5 km/second interceptor against a nonmaneuvering MRBM threat. With no threat maneuvers, agility is not a distinguishing factor, and the resulting operational areas remain the same for both the AWL and the PAA surrogate. Interceptors may be launched from behind, abeam, or in front of the intended target for midcourse intercepts. However, if the intercept is constrained to occur prior to apogee (the ascent phase) to support a shoot-assess-shoot doctrine, one sees in figure 4 that for the same threat profile, each interceptor must now be launched from well in front of the defended target impact point.

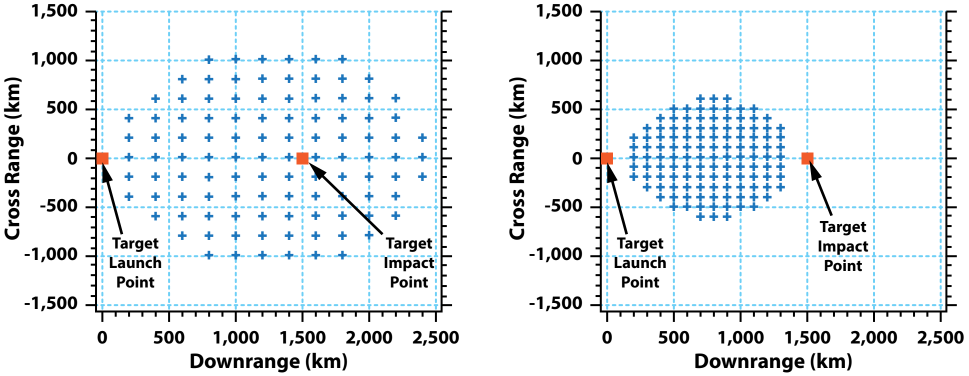


Figure 4. Operational area comparison, no threat maneuvers (left: midcourse intercepts, right: ascent phase)

Introduction of a single-pulse target maneuver significantly reduced the operational area for the PAA surrogate, but the AWL operational area remained relatively unchanged. The two-pulse threat maneuver caused the PAA surrogate to lose all intercept capability in the ascent phase; the AWL interceptor, though, retained over 90 percent of the original operational area (fig. 5, top). The speed of the PAA surrogate interceptor was then increased by 40 percent, thus producing a small operational area relatively close to the target launch point. Boosting the interceptor speed by 70 percent enlarged the operational area marginally (fig. 5, center), but it still required launch points well ahead of the defended target point. Next, the analysis kept the baseline PAA surrogate speed and doubled the agility, producing a limited operational area, which, when doubled again, grew to about 80 percent of the original area (fig. 5, bottom). However, not until the agility was increased six times the original amount did the surface-launch interceptor regain parity with the AWL. The noticeable asymmetry of these operational areas was attributed to the out-of-plane threat maneuvers.

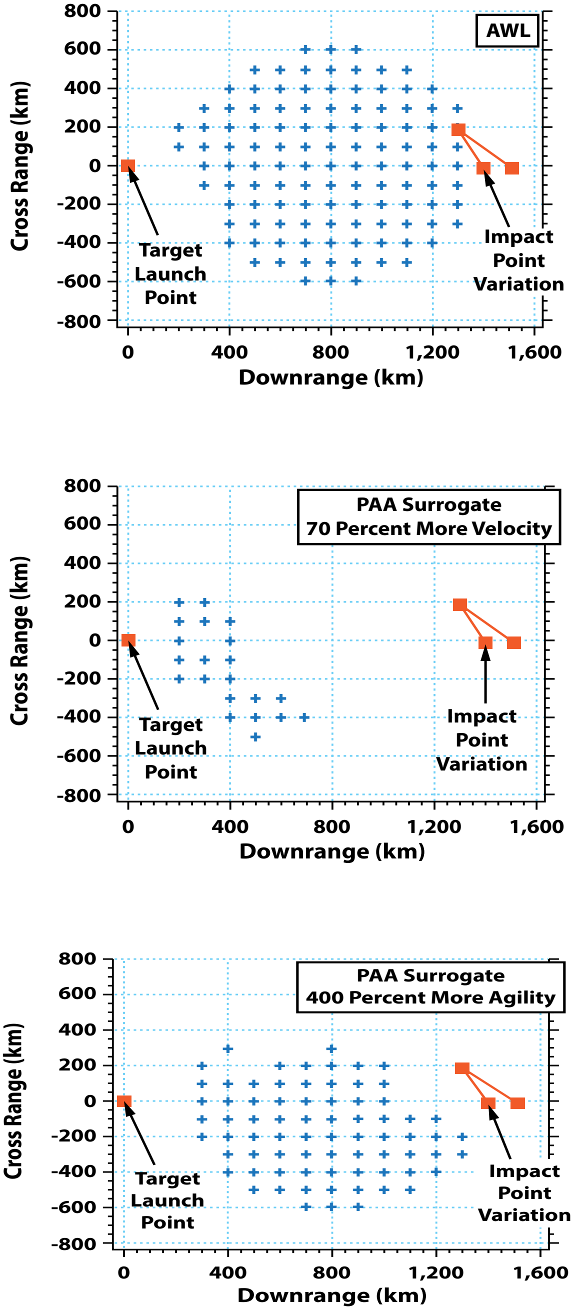


Figure 5. MRBM, two-pulse maneuver, ascent-phase intercepts only (agility versus speed)

ICBM Intercepts

Neither the AWL nor the PAA surrogate—each with a burnout velocity of only 3.5 km/second—has an ascent-phase capability against a 10,000 km ICBM on a minimum-energy trajectory. However, both will retain a descent-phase capability, given adequate tracking support. Note the change in the range scale and the AWL's descent-phase operational area of roughly 1,000 km by 1,500 km (fig. 6). However, this small operational area of the upper-tier AWL interceptor, when combined with air defense alert aircraft, allows a descent-phase layer of protection against ICBMs over the entire continental United States.

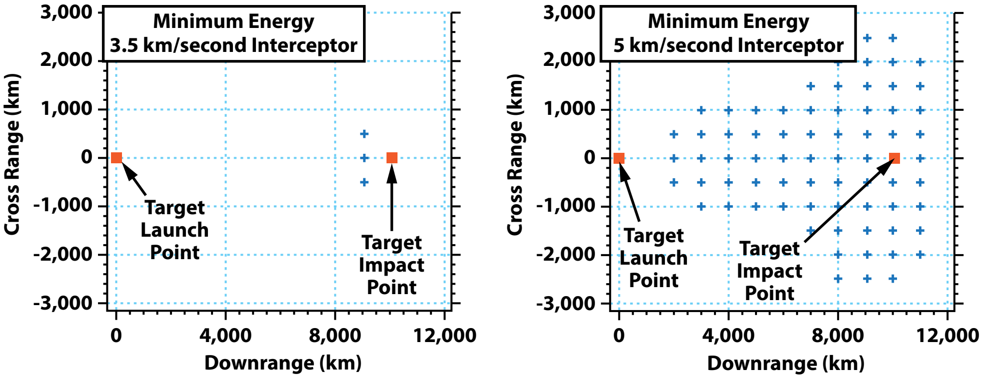


Figure 6. ICBM minimum-energy profile (comparison of 3.5 km/second interceptor to 5 km/second interceptor)

Increasing the PAA surrogate's speed by 40 percent to 5 km/second enables ICBM engagement throughout the ascent and midcourse phases, but again this assumes perfect tracking. Although this large operating area looks attractive, it only indicates that 5 km/second is sufficient kinematics to intercept a nonmaneuvering ICBM throughout the midcourse phase. Unfortunately, all problems associated with providing that perfect tracking, along with midcourse discrimination and kill assessment, remain. When the same interceptors were compared against an ICBM on a lofted trajectory, both retained descent-phase capability, but the ascent-phase capability of the 5 km/second interceptor disappeared.

Examining the same threat for boost-phase intercept showed that the AWL will provide an operationally useful intercept capability with a significant operational area. The analysis also revealed a very limited boost-phase intercept capability for the PAA surrogate interceptor with baseline agility although that is due to the continuous guidance assumed for this analysis. If one assumes guidance initiation similar to that of today's systems, the capability vanishes. One should also note that the MDA has made no claims of a boost-phase intercept capability for the planned PAA systems. Increasing the PAA surrogate's agility by 200 percent or its speed by 40 percent did give it a limited capability for boost-phase intercepts. However, even though the size of the operational area expanded, it remained relatively close to the threat's launch point with limited cross-range capability.

A lofted ICBM trajectory reduced the AWL's boost-phase operational area by a small amount (fig. 7, left side), as well as that of the PAA surrogate with increased agility. Note that even with a burnout velocity of 6 km/second but without significantly enhanced agility, the operational area for the surrogate remains relatively close to the threat launch area and again provides very little cross-range capability (fig. 7, right side). This clearly shows that even significant augmentation of interceptor velocity does not appreciably increase the distance of the operational area from the threat's launch point. Realization of the operational limitations implied by this fact represented one of the principal factors that led to the demise of the kinetic energy interceptor program.

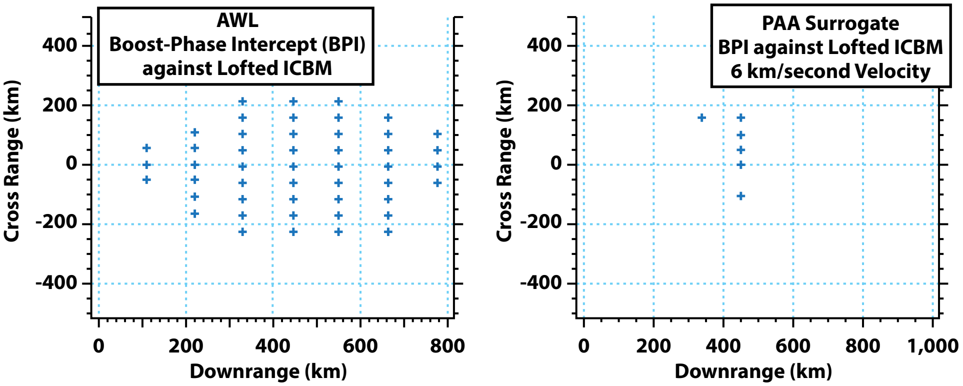


Figure 7. ICBM lofted trajectory, boost-phase intercept (comparison of the AWL to the 6 km/second PAA surrogate)

It may not be feasible to deploy surface-launched interceptors where necessary for boost-phase intercepts, but the same limitation does not apply to air-launched interceptors. Low-observable aircraft operating within 600–900 km of a suspected Iranian ICBM launch area would be feasible, commensurate with heightened tensions. Granted, maintaining persistent boost-phase intercept coverage for all potential ICBM launch sites in a country like Iran for an extended period would become overwhelming, but our forces could do so for brief periods while strike operations destroyed the launch sites.

What Does This Mean?

Gains in operational area derived from increases in interceptor speed alone fall apart quickly if the threat maneuvers. In fact, as mentioned above, all ascent-phase intercept capability disappeared with the MRBM two-pulse maneuver for the PAA surrogate. Raising the speed by 40 or 70 percent regained some marginal capability but did not restore the original operational area associated with a nonmaneuvering threat.

For ascent-phase intercepts against a maneuvering threat, the analysis indicates that defense performance, as depicted by operational area, increased much faster with improvements to the interceptor's agility rather than to its speed. The interceptor performance needed to engage an ICBM robustly for an ascent-phase intercept will demand substantially greater interceptor velocity than the proposed SM-3 family of systems (approaching that of the originally planned European ground-based midcourse defense [GMD] deployment) and must still address the problem of effective exoatmospheric discrimination and kill assessment. For MRBM engagements with a high-speed interceptor, ascent-phase intercepts would necessitate launch areas well forward of defended areas. For ICBM ascent-phase engagements, assuming availability of a very-high-speed interceptor, the limited operational area could rule out deployment to friendly host countries or access from the sea. Further, European deployments of such an interceptor would generate concern and opposition in Russia. In contrast, the AWL retains a boost-phase capability against ICBMs from Iran and other countries, featuring an operational area that low-observable aircraft could obtain during periods of heightened tension—this in addition to a capability of autonomous terminal defense provided by the same aircraft and weapons.

Report of the Defense Science Board Task Force on the Missile Defense Agency's "Early Intercept" Concept

In December 2009, the undersecretary of defense asked the Defense Science Board to examine the science and technology issues of early intercept ballistic missile defense. Completing its review in September 2011, the board offered the following conclusions:

- "[Early intercept] in and of itself is not a useful objective for missile defense in general or for any particular missile defense system," highly dependent on the development of a *very high-speed* regional interceptor and "predicated on an ability to discriminate (in the exo atmosphere) the missile warhead(s) from other pieces of the offensive missile complex, such as rocket bodies, miscellaneous hardware, and intentional countermeasures. The importance of achieving reliable midcourse discrimination cannot be overemphasized."[13]

- One of the objectives of the early intercept concept—reduced depletion of interceptor inventory by using shoot-assess-shoot doctrine to avoid salvo launches—calls for near-perfect kill assessment. Calculations revealed it would prove ineffective, given a probability of a false-positive kill assessment greater than 2 percent. The board concluded that, "unfortunately, the ability to make kill assessments with such small probabilities of false positive has yet to be demonstrated."[14] The findings also acknowledged that boost-phase intercept (assessed as currently not feasible) is a fundamental counter to the use of penetration aids or the early release of submunitions.[15]
- The MDA, in coordination with current service efforts, should develop future plans for "more advanced technology for regional missiles with the proper balance between higher velocity, lateral movement capability [i.e., agility], payload weight and shorter burn time and with the potential to be deployed both on land and at sea."[16]

However, the Defense Science Board did not consider the implications of a maneuvering threat.

The National Research Council's (NRC) report entitled *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S Boost-Phase Missile Defense in Comparison to Other Alternatives* was released on 11 September 2012. An unclassified letter to the chairman of the House Armed Services Committee summarized the report's findings, however:

- Phase IV of the EPAA is "not necessary for theater defense and is at best less than optimal for homeland defense. . . . With regard to . . . homeland defense, a significantly faster interceptor than needed for theater defense would be needed to avoid a forward-located homeland defense being overflown."[17]

- "The committee [found] no valid justification for pursuing PTSS [Precision Tracking Space System]. . . . It is too far away from the threat to provide useful discrimination data. . . . PTSS would cost 2 to 3 times as much as MDA estimates."[18]
- The report determined that "boost-phase intercept was not feasible, except in very limited cases," one of which was air-launched interceptors based upon tactical aircraft "in conflict situations in which the U.S. had air supremacy, so that [these aircraft] could safely operate close to or over enemy basing areas."[19]
- It recommended that the MDA focus on improving the interceptor and sensors of the GMD system—a recommendation challenged by others who believe that the report erred in its assessment of the radar cross-section of the warhead.[20]

However, the NRC Committee also did not consider the implication of maneuvering threats.

Increased interceptor speed alone is not enough if the target maneuvers. Agility, rather than speed, then becomes the essential interceptor attribute. Agility also enables boost-phase intercepts if the interceptor can be positioned close enough to the threat launch area. This, in turn, relieves the requirement to achieve near-perfect exo-atmospheric discrimination and kill assessment necessary for a shoot-assess-shoot doctrine.

Given the same agility and speed, an air-launched interceptor and a ground-launched interceptor can both counter a maneuvering threat, but only an air-launched interceptor provides the flexibility of launch location to carry out boost-phase intercepts as well. Additionally, the AWL offers a survivable, flexible, and scalable capability, quickly deployable to a theater.

Agile kill vehicles constrained by insensitive munitions requirements represent unique but not insurmountable development challenges. Previous MDA efforts had identified promising technologies that could meet the agility objectives, but the agency terminated these efforts in 2009 to concentrate on "early intercept" and the EPAA.

Despite claims by many critics that midcourse intercepts in the presence of decoys are difficult, if not impossible, the MDA has directed most of the current development funding to enhancements to midcourse systems. The potential introduction of maneuvering threats poses even greater challenges to the systems planned for the EPAA.

Multiple studies have asserted both the technical viability and operational feasibility of the AWL, which represents an alternative to an SM-3-centered concept not hindered by midcourse discrimination concerns and brings with it the potential for significant, additional capabilities in air superiority.[21] A lower-tier AWL interceptor is the same size and weight as an advanced medium-range air-to-air missile (AMRAAM) but potentially twice as fast (and capable of intercepting at twice the range) because it doesn't carry a warhead and relies on the kinetic energy of the impact for the kill mechanism.

The government of Israel, which understands the synergy possible with air superiority systems, is considering the development of Rafael's future air-to-air missile, based upon the upper stage of the Stunner interceptor of the Israeli David's Sling missile defense system.[22] The Stunner itself had been derived from the Python air-to-air missile, and now this proposed program would apply the hit-to-kill technology to an air-to-air missile that would likely have kinematics superior to those of the AMRAAM. Since 2006 the MDA and Israel have jointly managed the David's Sling program, and the US Congress has appropriated more than $400 million for its development.[23]

An AWL upper-tier interceptor roughly the size of a 2,000-pound bomb would provide approximately the same operational-area performance as the much larger SM-3 Block 2 but without the necessary surface infrastructure. Further, it would not demand a presence on the ground in difficult regions without basing options; neither would it need forward sensors and data communication links required by the EPAA. Nevertheless, this concept receives little support from the MDA.

The director of that agency testified before Congress on 7 March 2012 regarding the details of the president's budget for fiscal year 2013 (FY 13), which again emphasized future development of the previously planned EPAA.[24] Despite the findings of the Defense Science Board and the NRC, the MDA plans to continue to pursue the early intercept concept and to proceed with the proposed enhancements to the SM-3. It requested no funds to support technology development for enhanced interceptor agility, the AWL, or any specific counters to A2AD threats.

The MDA has no incentive (and some would even argue that it has no authority) to pursue systems with ancillary capabilities beyond missile defense. Its charter strictly limits the agency's authority to missile defense, regardless of the benefits of multiple-mission systems. The MDA's record indicates a willingness to use the capabilities of other systems (Aegis-equipped ships, the space-based infrared system, early warning radars, etc.) that support missile defense, but it applies development resources only to purely missile-defense functions. Dual-role systems such as Patriot and the Aegis SM-2 Block IV trace their development to decisions predating the MDA.

Even if a missile defense development would contribute significantly to the air superiority mission, the MDA has no incentive to pursue it; in fact, it would have to overcome impediments to seeking such a solution. Imagine the difficulty of a decision involving a trade-off that improved a non-missile-defense function to the detriment of a missile defense function. From the developer's perspective, the "stovepipe" single-function approach is much easier to deal with. But is this the best solution from a war fighter's perspective? Perhaps decisions with an operational impact should be left to the services rather than an engineering and development agency such as the MDA.

Conclusion

The Ballistic Missile Defense System, the world's largest single defense acquisition program, has allocated the majority of its resources in FY 12 on midcourse interceptor systems.[25] This excludes the development of technology that could support interceptor agility necessary for boost-phase intercepts, or possible ancillary use in a system capable of contributing to both missile defense and air superiority.[26] As the military departments work toward a future of predominantly multirole systems, the Department of Defense should consider whether that same way of thinking should apply to missile defense. Regarding the acquisition of weapon systems, is a single-function development agency still preferable to the military departments?

Air Force doctrine clearly includes ballistic missile defense within both offensive counterair and defensive counterair mission areas, but the necessary Air Force capabilities do not exist following the launch of a ballistic missile. At that point, all active defense capability lies only with surface-launched systems, most of which rely on midcourse intercepts. Accepting that posture entails significant risk—without a layered defense and without boost or mobile terminal-phase intercept capabilities—as threat capabilities advance. Unfortunately, the MDA program does not address that risk.

Diverting only 1 percent of the MDA's obligation authority in 2013 would establish a foundation for initiating an Air Force or joint AWL program office. Increasing that diversion over a five-year period to no more than 10 percent of that agency's annual obligation authority would enable the efficient development and acquisition of both upper- and lower-tier interceptors, as well as full integration of the F-35 for the Air Force, Navy, and Marine Corps.[27] By the end of the decade, active missile defense capability could become fully integrated into air superiority operations within the combat air forces, giving us the tools we need to match the doctrine of integrated air and missile defense.

Time and again, the services have proven that they can balance the needs of the moment with those of the future. They have the capability to direct resources in an environment of competing requirements and can apply the needs of the war fighter to the acquisition of weapon systems. The Department of Defense's senior leadership should give them the opportunity to guide the development of the AWL with missile defense resources.

Doctrine, in general, also acknowledges that despite our best attempts, we don't always get it right the first time: "A defining element in military effectiveness lies in the ability to recognize when prewar visions and understanding of war are flawed and must change."[28] If the long-term viability of midcourse intercepts is in doubt, then we should consider alternatives that avoid that liability or at least mitigate the risk. Some resources should focus on developing reasonable choices and providing decision makers with a true analysis of them. Placing the AWL under service leadership is an excellent way to begin—and the time to act is now. ✪

Notes

1. For published foreign research into the defensive maneuvering of ballistic missiles, see Yang Guo et al., "Maneuver Strategy of Evader Considering Detection System," AIAA 2011-6713 (presentation at the American Institute of Aeronautics and Astronautics Guidance, Navigation, and Control Conference, Portland, OR, 8–11 August 2011) (accepted for publication as "Maneuver Control Strategies to Maximize Prediction Errors in Ballistic Middle Phase" in the AIAA's *Journal of Guidance, Control, and Dynamics*); J. Z. Ben-Asher, "The Influence of a Maneuvering Target RV on Radar Predictions" (paper presented at the 7th International Conference on Missile Defence: Challenges in Europe, Spain, May 2011); and Erez Druckmann and J. Z. Ben-Asher, "Optimal In-Flight Trajectory Modifications for Ballistic Missile and Free Rockets," *Journal of Guidance, Control, and Dynamics*, 2013, forthcoming. Additionally, nontechnical open-source literature refers to maneuvers for defense avoidance by India's Prahaar system and Pakistan's Shaheen 1, 1A, and 2. See *Wikipedia: The Free Encyclopedia*, s.v. "Prahaar (missile)," http://en.wikipedia.org/wiki/Prahaar_%28missile%29; and *Wikipedia: The Free Encyclopedia*, s.v. "Shaheen-1," http://en.wikipedia.org/wiki/Shaheen-I.

2. The MDA budget request has included funds for laser research with the remnants of the Airborne Laser (ABL) program and some promising but nascent technology development. However, since the ABL program was terminated because of the lack of a viable boost-phase-intercept concept of operations, among other reasons, it is a dubious claim that the continued research addresses development of the boost and terminal-intercept phase.

3. The AWL operational concept is thoroughly described in the author's previous articles with Paul Zarchan. See Col Mike Corbett and Paul Zarchan, "The Role of Airpower in Active Missile Defense," *Air and Space Power Journal* 24, no. 2 (Summer 2010): 57–71; and Corbett and Zarchan, "The United States Should Develop a Missile Defense System That Builds Confidence," *Air and Space Power Journal* 25, no. 3 (Fall 2011): 74–90.

4. Ronald O'Rourke, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress*, CRS Report for Congress (Washington, DC: Congressional Research Service, 18 March 2012), 3–5.

5. Mohammad-Ali Massoumnia, *Q-Guidance in Rotating Coordinates*, AIAA-91-2784-CP (Reston, VA: American Institute of Aeronautics and Astronautics, 1991).

6. Yang Guo et al., "Maneuver Strategy."

7. Defense Science Board, *Defense Science Board Task Force Report on Science and Technology Issues of Early Intercept Ballistic Missile Defense Feasibility* (Washington, DC: Defense Science Board, September 2011), 9–12, http://www.acq.osd.mil/dsb/reports/ADA552472.pdf.

8. *Unclassified Statement of Lieutenant General Patrick J. O'Reilly, Director, Missile Defense Agency, before the House Armed Services Committee Subcommittee on Strategic Forces Regarding the Fiscal Year 2013 Budget Request, Tuesday, March 6, 2012*, http://armedservices.house.gov/index.cfm/files/serve?File_id=6fc80696-e878-49cb-b429-7a5b72fca2d4.

9. Defense Science Board, *Defense Science Board Task Force Report*, 9.

10. Yang Guo et al., "Maneuver Strategy."

11. Corbett and Zarchan, "Airpower in Active Missile Defense," 57–71.

12. Paul Zarchan, "Kill Vehicle Guidance and Control Sizing for Boost-Phase Intercept," *Journal of Guidance, Control, and Dynamics*, March–April 2010, 513–21.

13. Defense Science Board, *Defense Science Board Task Force Report*, 33, 8.

14. Ibid., 11.

15. Ibid., 9.

16. Ibid., 34.

17. L. David Montague, cochair; and Walter B. Slocombe, cochair; NRC Committee on an Assessment of Concepts and Systems for US Boost-Phase Missile Defense in Comparison to Other Alternatives, to Rep. Michael R. Turner, chairman, Strategic Forces Subcommittee, House Armed Services Committee, letter, 30 April 2012, 2, http://hosted.ap.org/specials/interactives/documents/nas_response.pdf.

18. Ibid., 2, 3.

19. Ibid., 4, 5.

20. George N. Lewis and Theodore A. Postol, to Rep. Michael R. Turner, chairman, Strategic Forces Subcommitte, House Armed Services Committee, and Rep. Loretta Sanchez, ranking member, House Armed Services Committee, letter, 20 August 2012.

21. Corbett and Zarchan, "Defense System That Builds Confidence," 77.

22. Bill Sweetman, "Real Money," *Aviation Week and Space Technology* 174, no. 11 (19/26 March 2012): 70.

23. Jeremy M. Sharp, *U.S. Foreign Aid to Israel*, CRS Report for Congress (Washington, DC: Congressional Research Service, 12 March 2012), 15, http://assets.opencrs.com/rpts/RL33222_20120312.pdf.

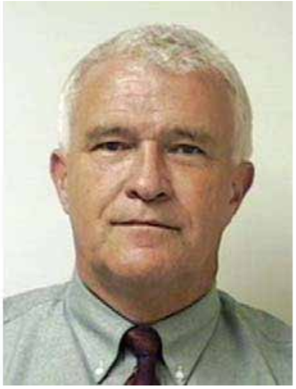
24. *Unclassified Statement of Lieutenant General Patrick J. O'Reilly.*

25. Government Accountability Office, *Missile Defense: Actions Needed to Improve Transparency and Accountability*, GAO-11-555T (Washington, DC: Government Accountability Office, 13 April 2011), 1, http://www.gao.gov/assets/130/126047.pdf.

26. "MDA Fiscal Year 2012 Budget Outline," accessed 3 December 2012, http://www.mda.mil/global/documents/pdf/budgetfy12.pdf; and "Missile Defense Agency (MDA) Fiscal Year 2013 Budget Outline," accessed 3 December 2012, http://www.mda.mil/global/documents/pdf/budgetfy13.pdf.

27. The MDA's total obligation authority in FY 12 was $8.419 billion, 1 percent of which ($85 million) would support establishment of a joint program office and initial technology development. Increasing the annual allocation to 10 percent ($850 million) over the next five years would provide funding that has proven sufficient to develop systems of similar size and complexity. Eugene L. Fleeman's *Tactical Missile Design* (Reston, VA: American Institute of Aeronautics and Astronautics, 2001) shows the actual cost of 21 different system design and development phases for tactical missiles (p. 285). However, precise development costs would remain a rough estimate until the completion of preliminary designs.

28. Air Force Doctrine Document 1, *Air Force Basic Doctrine, Organization, and Command*, 14 October 2011, viii, http://www.e-publishing.af.mil/shared/media/epubs/afdd1.pdf.



Col Mike Corbett, USAF, Retired

Colonel Corbett (BS, Oregon State University; MS, Purdue University; MS, Auburn University–Montgomery) served as the assistant system program director for the Geostationary Operational Environmental Satellite R-Series (GOES-R), a $10.86 billion weather satellite acquisition program of the National Oceanic and Atmospheric Administration prior to his retirement in October 2012. From 2006 through 2009, he served as the Missile Defense Agency's (MDA) director for advanced technology weapons, leading a small staff in support of kinetic- and directed-energy technology development for advanced ballistic missile defense systems. He led the air-launched hit-to-kill concept development and the MDA's evaluation of the Net-Centric Airborne Defense Element, a congressionally directed program to develop a new missile defense interceptor using an existing air-to-air missile seeker. Colonel Corbett joined the MDA in 2005 following his retirement from the Air Force. His military experience includes command positions at various levels within Air Combat Command and the Air National Guard, and over 5,000 hours in a variety of aircraft, predominantly fighters.

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