# Defense Against Nuclear-armed Intercontinental Ballistic Missiles, Especially Space-based Missile Defense Prospects- one participant's view

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With the advent of a new U.S. Space Force and new staff in various national security and policy positions in the U.S. government, options for space-based defense against ballistic missiles are once again under consideration. The first round of such advocacy in living memory goes back to the Strategic Defense Initiative launched by President Ronald Reagan's speech of March 23, 1983, that aimed to protect the United States against all of the then-6000-strong Soviet nuclear-armed ICBMs and SLBM warheads. Instead, we have now the existing 44 Missile Defense Agency ground-based interceptors (GBI) deployed nominally against actual or potential proliferant states of North Korea and Iran. In reality, space-based defense goes back to the proposals by RAND in the late-1940s era[1]. The technology of satellite-based directed energy weapons—DEW—was under study by the Defense Advanced Research Projects Agency—DARPA—before the SDI of 1983.

**I am providing a rather loquacious paper, much of which will survive to be shared with colleagues, but only a portion of which, as is my custom, will be displayed in large print for presentation at the meeting.**

**Science and technology in the service of national security.**

With the success of S&T in the United States and Britain in eventually countering military capabilities of Germany and Japan in WW-II, it was both natural and responsible to look at the potential of S&T in meeting the security threats of the post-WW-II world—especially those posed by the potential of the Soviet Union.

In WW-II, England was under bombardment by German aircraft and by V-1 cruise missiles and V-2 short-range ballistic missiles—SRBM. Eventually the United States, with assistance from UK scientists and engineers developed and deployed vast air, naval, and army forces, equipped with newly developed radar and (too late for the war in Europe) nuclear weapons.

Key to these achievements were the major laboratories—the MIT Radiation Laboratory for the development of radar (especially airborne radar), and the Los Alamos Scientific Laboratory—LASL, now LANL—for the design and construction of fission weapons. In addition, there were other laboratories of the Manhattan Project, especially the "Metallurgical Laboratory" at the University of Chicago, where Fermi's first neutron-chain-reacting pile was built.

[1] "Origins of U.S. Space Policy: Eisenhower, Open Skies, and Freedom of Space" by R. Cargill Hall. https://history.nasa.gov/SP-4407/vol1/chapter2-1.pdf

More generally, with the perception of a security threat or the creation of a new institutional element in the armed forces, such as the Space Force of recent months, there is a search for existing technology that can be moved into the new element, and for the creation of new technology. As was the case with the establishment of the Department of Homeland Security following the attack on the World Trade Center on September 11, 2001, there may be inefficiencies as well as productive prospects from such a reorganization, and that is potentially the case for the new Space Force. In mid-February, 2019, President Trump ordered the creation of the Space Force with the U.S. Air Force, rather than as a separate military service. [2]

Case in point: In March-April 1951, I spent a month in South Korea and Japan with a senior colleague from the University of Chicago, in the search for topics for a potential new laboratory (or two) for the newly formed U.S. Air Force Tactical Air Command, and I believe duly provided an informal report advocating developments in fan-jet engines, flexible military radios, pulsed-hydrogen-discharge optical ranging gun sights, night-vision capability from aircraft, and other innovations of the time.

Somewhat later, I was introduced to the Harvard/MIT world of technical defense summer studies and what was to become the President's (Eisenhower's) Science Advisory Committee—PSAC—and a host of opportunities and challenges to learn and to teach.
Although much of my work in the field of space weapons and other space capabilities has been technical on behalf of the U.S. government, I have published some policy papers as well, including this one from the Council on Foreign Relations in 2004.[3]

The concluding paragraph of that paper:

> "A regime that effectively prohibits the deployment of space weapons and the use of destructive ASAT before they can destroy U.S. or other satellites would be a smart, hard-nosed investment in U.S. national security, but would require U.S. leadership. By sacrificing relatively unattractive technical and military options, the United States could move to protect its valuable scientific, civil, and commercial space systems while ensuring the security of crucial U.S. military assets—and the dominant systems and capabilities they enable. Such an approach, more than incidentally, would pay dividends for the entire international space-faring community."

The MIT Radiation Laboratory and the Los Alamos Scientific Laboratory of WW-II had a short feedback time from the aggressive search for problems, to the actual solution to those problems—however imperfect. This is very different from the situation in the United States today, where hyperbole and the ignoring of fundamental vulnerabilities and deficiencies in military-oriented technology are common.

It is natural for people newly entering a field to ask,

> "With all the progress in computing and miniaturization and technology in general, why hasn't the cost of launch-to-space gone down according to Moore's Law? Why don't we have space-based laser weapons lethal at a range of thousands of km to nuclear weapons traveling through space on ballistic trajectories? Why don't we have space-based capabilities for destroying hypervelocity glide vehicles—HGV (perforce traveling in the upper atmosphere above all clouds)—which can apparently defeat existing ballistic missile defense—BMD—capabilities?"

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[2] https://www.nytimes.com/aponline/2019/02/19/us/politics/ap-us-trump-space-force.html, Trump Orders Creation of Space Force, but Within Air Force

[3] "Space Weapons: Crossing the U.S. Rubicon," Bruce M. DeBlois, Richard L.Garwin, R. Scott Kemp and Jeremy C. Marwell, *International Security*, Vol. 29, Issue 2 - Fall 2004, pp. 50 – 84. (At https://fas.org/rlg/041100-rubicon.pdf )

These are good questions and deserve to be addressed in both technical and policy terms. Some answers are unwelcomed to one or another element in the debate. Particularly unwelcome is the fundamental truism—"occasionally one must take the adversary into account." That is, you don't get to choose how the adversary responds to an initiative on your part. The history of military technology and confrontation is that of action and response—from the sword to the shield to the cross-bow to improved armor, to armor-piercing weapons such as shaped-charge warheads, and the like.

The 2019 Missile Defense Review was published 01/18/2019 by the U.S. Department of Defense, and the Executive Summary is available[4]. I discuss here the proposal to emphasize space-based weapons against offensive ballistic and cruise missiles, both strategic and shorter range, as indicated here,

"…against possible missile attacks on the homeland posed by the long-range missile arsenals of rogue states, defined today as North Korea and Iran, and to support the other missile defense roles identified in this 2019 MDR. This force-sizing measure for active U.S. missile defense will require the examination and possible fielding of advanced technologies to provide greater efficiencies for U.S. active missile defense capabilities, including space-based sensors and boost-phase defense capabilities. It calls for a missile defense architecture that can adapt to emerging and unanticipated threats, including by adding capacity and the capability to surge missile defense as necessary in times of crisis or conflict." The text is ambiguous as to where the adjective "space-based" refers to more than "sensors," but a review of the problems and potential of space-bases weaponry can't hurt.

[4] "2019 Missile Defense Review," Office of the Secretary of Defense, Executive Summary. (At https://www.defense.gov/Portals/1/Interactive/2018/11-2019-Missile-Defense-Review/The%202019%20MDR_Executive%20Summary.pdf )

Traditionally and logically, one can interfere with the delivery of a nuclear explosive by ballistic (or for that matter, long-range cruise) missile during the interval of launch, while the rocket from a high-thrust rocket propulsion is operating (boost-phase intercept—BPI) or while the warhead is freely falling through the vacuum of space (mid-course intercept), or while the warhead in its reentry vehicle is penetrating the 1 $kg/cm^2$ mass density of the Earth's atmosphere, on its way to explode within lethal range of its intended target on the surface. These have the well-known benefits and deficiencies:

**Boost phase intercept.**
The United States has long had the ability from satellites in GEO or HEO (high-Earth orbit) to observe the launch of any significant ballistic missile, anywhere on Earth. On the other hand, the full force must be brought against the missile within its ~250 s powered flight, before it becomes invisible to that openly disclosed capability. The thrusting rocket is very vulnerable under the acceleration stress of boost. On the other hand, basing the intercept means close enough to the launch sites so that they can destroy the missile while it is boosting poses difficulties and vulnerabilities in midcourse intercept.

**Mid-course intercept**
The reentry vehicle spends about 30 minutes in freefall (Keplerian orbit), with lots of time available for a ground-based missile to strike the warhead. With non-nuclear interceptors, though, intercept can be defeated by readily available countermeasures—simulation by a decoy or, better, "anti-simulation" in which the warhead itself is "dressed" to resemble a light, easily replicated and deployed decoy, and the warheads are accompanied by ten or more decoys with a range of observable parameters.

For certain hit-to-kill interceptors, a large enclosing balloon will conceal the warhead from observation in the visible or infrared or from radar and may be all that is needed.

There is a countermeasure game to be played, and counter-countermeasures, and C-C-CM that thus far has persuaded essentially all independent technical observers that hit-to-kill intercept in mid-course cannot be performed. Unfortunately, the MDA mid-course intercept system has not demonstrated the ability to discriminate dressed warheads from suitable decoys—especially *antisimulation* decoys  A good treatment of these problems is in the year-2000 volume, *Discrimination*[5].

See, in particular, the 2012 NAS Missile Defense Study.[6]

**Terminal intercept**

As the reentry vehicle begins to reenter the sensible atmosphere, balloon decoys and ultimately radar decoys are stripped away, initially simply beginning to lag behind the heavy warhead.  But a defense based on such terminal-area intercept is vulnerable also to anti-simulation—in this case to very small retrorockets that slow the RV a bit according to a program or sensor, in order to more or less match the effects of drag of the very tenuous upper atmosphere on the very light RVs.  This can deny the intercepting rockets crucial seconds and distance of warning.

Furthermore, adversaries with few nuclear-armed ICBMs cannot hope to disarm the United States by destroying its retaliatory capability, and must be acting either in a "deterrent mode" or nihilist mode; the success of terminal defense requires one  to deploy defense everywhere there is a significant city or other target, and the adversary will know what is defended and what is not.

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[5] "Countermeasures," A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System, (Executive Summary and full text) UCS-MIT Study, A.M. Sessler (Chair of the Study Group), J.M. Cornwall, R. Dietz, S.A. Fetter, S. Frankel, R.L. Garwin, K. Gottfried, L. Gronlund, G.N. Lewis, T.A. Postol, and D.C. Wright, April 2000 http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/cm_all.pdf

[6] "Making Sense of Ballistic Missile Defense, An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives( 2012)" https://www.nap.edu/catalog/13189/making-sense-of-ballistic-missile-defense-an-assessment-of-concepts

The Strategic Defense Initiative Organization—SDIO—was initially dedicated to the goal of countering every one of the 6000 Soviet ICBMs or submarine-launched ballistic missiles—SLBMs—by deploying a system of space-based weapons that could destroy the Soviet missile, once launched, in every stage of their flight. As now, these included hit-to-kill (kinetic) space-based interceptors—SBIs, but also weapons that travel at or near the speed of light—space-based lasers (SBL) and neutral-particle beams (NPBs). Because of the presence of the solid Earth and its marginally less solid atmosphere extending sensibly to 100-km altitude or so, even space observation requires many satellites. Nevertheless, U.S. satellites in GEO have long detected every launch of a significant rocket anywhere on Earth, and will continue to do so, so long as those satellites exist. But responding with a lethal directed energy weapon—DEW-- against an ICBM or SLBM is another matter.

I comment here first on the potential space-based weapons that reappear in the 2019 MDR and also because it must be assumed that the Space Force will have a role.

The MDR is a highly aspirational document. It sees no negatives to missile defense—only benefits in reducing the threat, deterring launch, reassuring allies, and the like.

With all of the evolution of technology and the deployment of many capable systems in space, why has the capability for missile defense lagged? Indeed, some problems in realizing benefits of technology are organizational, or regulatory or run counter to powerful, entrenched organizations, as is the case with some aspects with healthcare in the United States. But some problems are just technically difficult. Indeed, the cost of launch to orbit has recently been reduced by dependence on private organizations in the United States, rather than on NASA or government-procured boosters. Some of the commercial organizations such as Space-X with its reusable boosters, automatically landing on a floating platform or on a land-based launch site, should further significantly reduce the cost of space-based systems.

Some of the enthusiasm for space weapons arises from ignorance and the victory of hope over experience. In this I point to the excellent report of the American Physical

Society on boost-phase intercept.[7] Beginning in 1999[8], I advocated vigorously the development and deployment of a system for BPI against ICBMs launched from North Korea, proposing the deployment of a system that would destroy the second-stage booster while still in powered flight and highly visible and vulnerable to ground- (or sea-) based interceptors stationed nearby.

This would take advantage of the DSP ("Defense Support Program") satellites in GEO that since the 1970s had reported launches of large missiles anywhere on the surface of the Earth, with a scan time of 10 s, and a precision on the order of 1 km. Even with a delay of as much as 50 s after booster ignition, it is practical to assign a powered kill vehicle launched by a boost-phase interceptor—BPI—that would destroy the booster within an assumed 250 s of powered flight, and the required mass and velocity-gain are readily estimate, as I did in the cited speech of 1999 to the Army Ballistic Missile and Space Command in Huntsville, AL.

For instance, for launches against the continental United States, at 250 s from launch the ICBM is typically ~500 km from its launch site, and a collision must take place within some tens of seconds before second-stage burnout. If one assumes a distance-to-travel from GBI launch of 600 km, and a short-burn GBI booster (but not too short, because it is difficult to penetrate the 1 ton/m$^2$ thickness of the atmosphere at near-orbital speed), in the allotted 200 s flight time, the GBI must travel at an average speed of 3 km/s, and, after that, it must maneuver to direct itself to collide with the booster, which may be a vulnerable area of 10-20 m$^2$.

In fact, I proposed in these early papers a ground-based boost-phase interceptor (G-B BPI) that would achieve 8.5 km/s. The interceptors would be deployed on military cargo ships in international waters east of NK or of Russia. I proposed, in fact, that Russia might be interested in providing a joint interceptor base in the small portion of Russia abutting the northeast edge of North Korea. But it would also be possible, of course, to base the BPI in individual silos in South Korea, or on ships in the East China Sea, west of NK.

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[7] "Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense: Scientific and Technical Issues." David K. Barton, Roger Falcone, Daniel Kleppner, Frederick K. Lamb, Ming K. Lau, Harvey L. Lynch, David Moncton, David Montague, David E. Mosher, William Priedhorsky, Maury Tigner, and David R. Vaughan, Rev. Mod. Phys. 76, S1 – Published 5 October 2004; Errata Rev. Mod. Phys. 76, S425 (2004); Rev. Mod. Phys. 76, 1307 (2005). (At https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.76.S1 )

[8] "Missile Defense Policy and Arms Control Issues," by R.L. Garwin, presented at Second Annual U.S. Army Space & Missile Defense Conference, Huntsville, AL, August 26, 1999. (At https://fas.org/rlg/082799MDPA%20Huntsville_AL.pdf )

I had just completed or was involved with six months of service on the Rumsfeld Commission[9] to Assess the Missile Threat to the United States, and so I was acutely aware of the relative difficulty of BPI against an eventual North Korean ICBM, vs. one from Iraq or Iran, considering the basing possibilities and the area of the countries involved—0.12, 0.44 and 1.65 million $km^2$ respectively.

Despite my insistence that BPI was quite feasible against NK and that the development and deployment of such a system (even initially against liquid-fueled missiles with a typically longer burn time) would serve the function of likely delaying the acquisition of any ICBM capability by NK, there was no receptivity to this proposal. Ultimately, the American Physical Society performed a capable study of this possibility, although the GBI it considered had burnout speeds of 6.7 km/s and 10 km/s, missing a sweet spot at 8.5 km/s.

U.S. deployment of BPI capability against North Korea would have violated the 1972 ABM Treaty with the Soviet Union, that essentially banned U.S. and Soviet defense against ICBMs, but I saw little reason why Russia would not agree to a specific exception to develop a technology that would have been in no way threatening to its own deterrent against U.S. nuclear weapons and that might have been helpful to it in countering some future threats on its borders.

More recently, I have paid more attention to the prospect of air-launch of BPI, as proposed by Dean Wilkening in 2004.[10] Ted Postol and I have posted in 2017 and 2018 two technical papers and have circulated more recently another one that identifies the General Atomic MQ9 "Reaper" drone aircraft (many of which are in service with the U.S. forces, observing in conflict theaters) to carry air-launched interceptors for destroying boosters within view of the launching aircraft.

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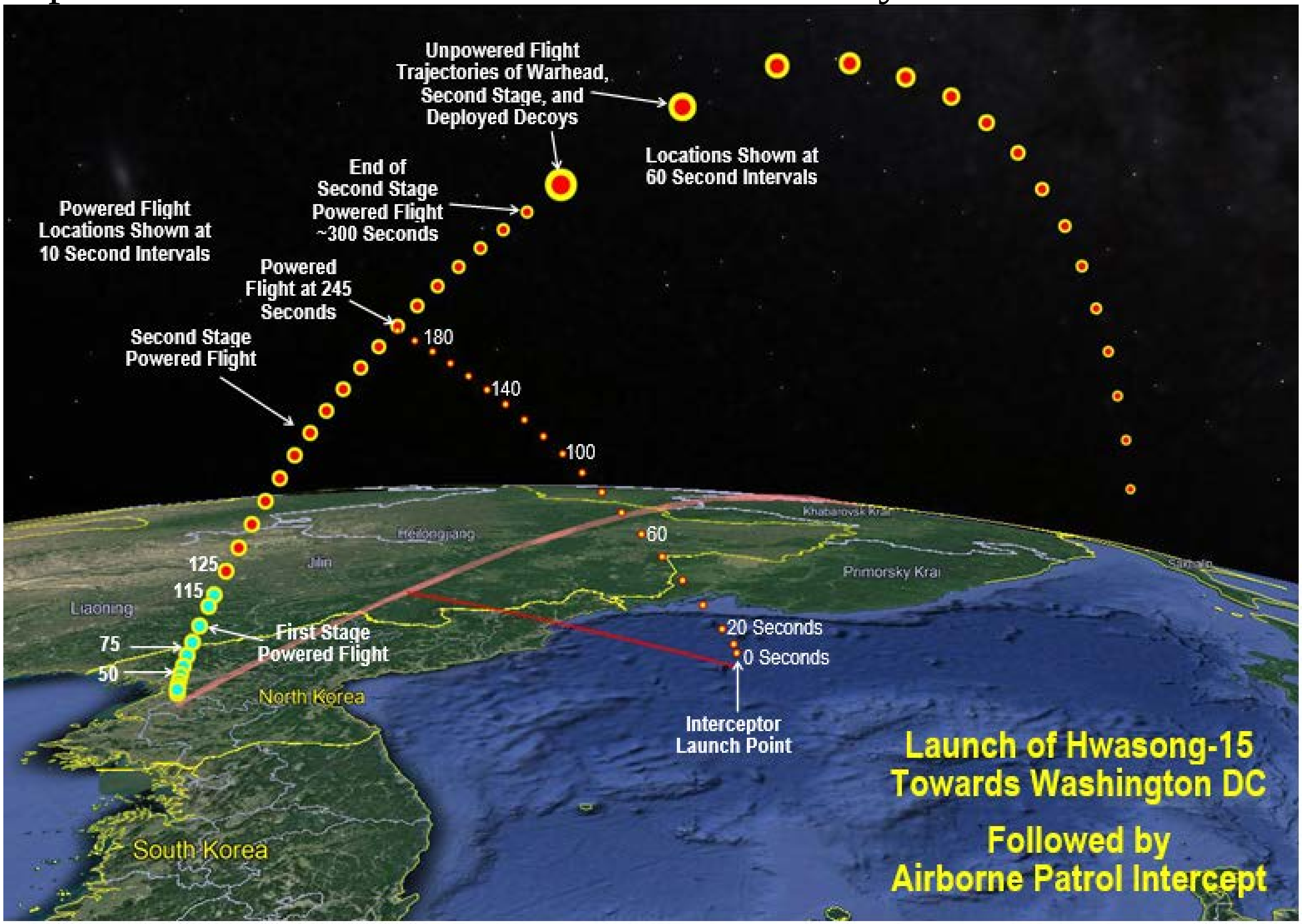
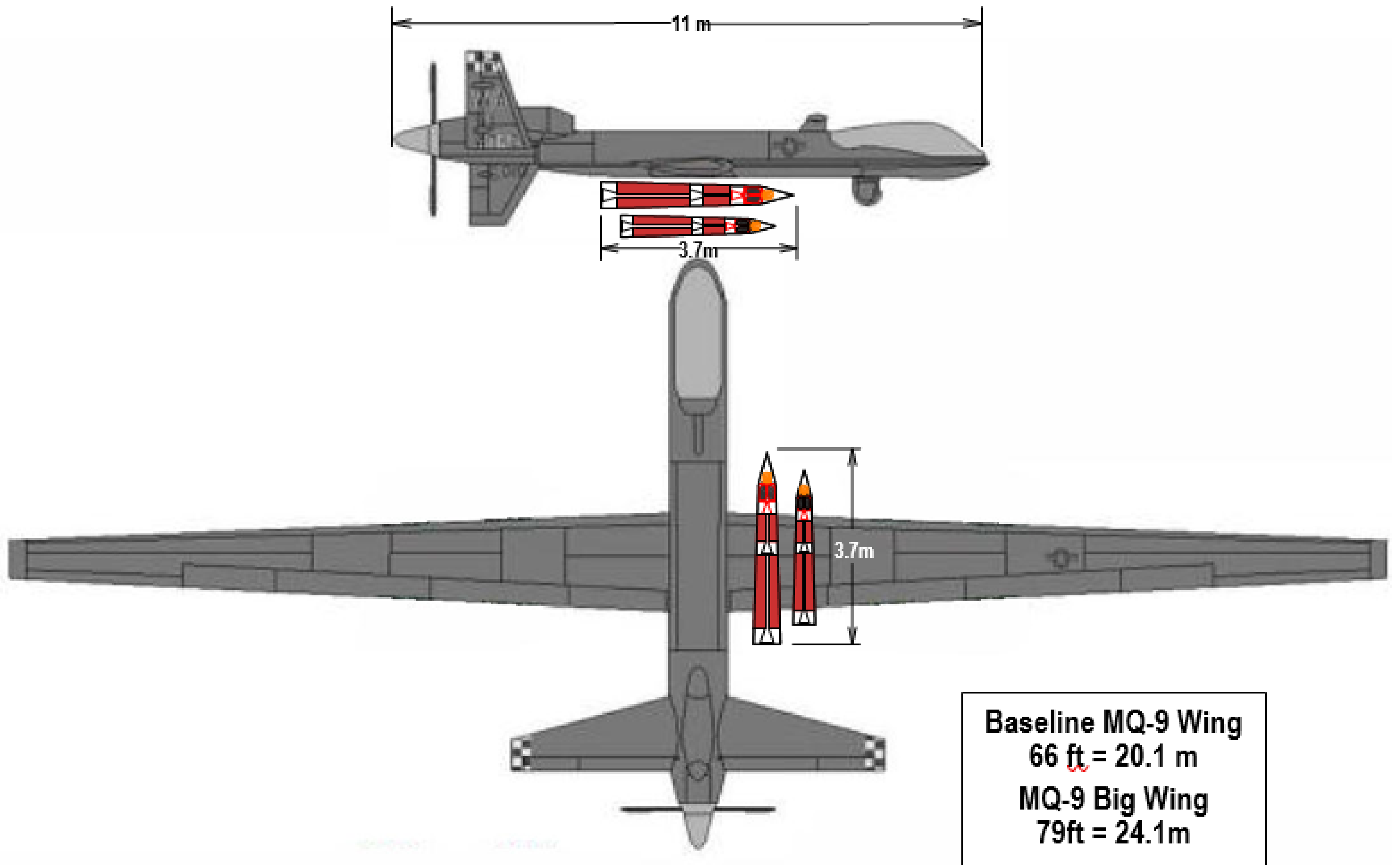
[9] "Executive Summary of the Report of the Commission to Assess the Ballistic Missile Threat to the United States", by B.M. Blechman, Lee Butler, R.L. Garwin, W.R. Graham, W. Schneider, Jr., L.D. Welch, P.D. Wolfowitz, R.J. Woolsey, and D.H. Rumsfeld (Chairman), July 15, 1998. 307 page Report is Secret. One Secret Appendix and one unclassified Appendix. (At https://fas.org/irp/threat/bm-threat.htm )

[10] "Airborne Boost-Phase Ballistic Missile Defense, "Dean A. Wilkening, *Science & Global Security*, 12, no. 1-2, (2004): 1-67. https://pdfs.semanticscholar.org/f59d/be1ce52c93758ea0bf35607f40f331d992c1.pdf

A typical "orbit" of the airborne BPI drone aircraft to be resident 24/7 with two interceptors present for each ICBM in the NK inventory:






**The workhorse MQ-9 "Reaper" from General Atomics Aeronautical Systems Inc. The "Big Wing" version is stated to have an endurance of almost 24 hours at 500 km from its operating base, patrolling at an altitude of about 35,000 feet.**

Here the evolution of hit-to-kill air-defense vehicles has a significant impact on reducing the mass of the necessary airborne powered kill vehicle, as shown in this Table from Wilkening's 2004 paper, with a final column added now:

**Table 4:** Airborne interceptor designs.

| Property | Baseline exo-KKV | Advance exo-KKV | Garwin/Postol 2018 |
|---|---|---|---|
| Total ABI mass (kg) | 1,500 | 1,500 | **283** |
| Ideal velocity (km/sec) | 5.4 | 6.1 | **5.0** |
| ABI length (m) | 5.5 | 5.6 | **2.9** |
| Maximum acceleration (g) | 56 | 67 | **33.35** |
| Total burn time (sec) | 20 | 20 | **25** |
| **Payload** | | | |
| KKV mass (kg) | 86.5 | 48.3 | **25** |
| Shroud mass (kg) | 8.1 | 9.2 | Not Applicable |
| **Second Stage** | | | |
| Stage mass (kg) | 232 | 197 | **57** |
| Propellant mass fraction | 0.81 | 0.81 | **0.85** |
| Isp (sec) | 280 | 280 | **285** |
| Stage ΔV (km/sec) | 2.35 | 2.7 | **2.5** |
| Thrust (kN) | 52 | 44 | **11** |
| Stage burn time (sec) | 10 | 10 | **12.3** |
| **First Stage** | | | |
| Stage mass (kg) | 1173 | 1245 | **201.15** |
| Propellant mass fraction | 0.85 | 0.85 | **0.85** |
| Isp (sec) | 280 | 280 | **275** |
| Stage ΔV (km/sec) | 3.0 | 3.4 | **2.5** |
| Thrust (kN) | 274 | 291 | **36.7** |
| Stage burn time (sec) | 10 | 10 | **12.6** |

As emphasized in the APS study, and in other technical analyses, the absentee ratio of LEO Directed Energy Weapons requires an enormous investment against even a small number of ICBMs. In the case of the SBL and the NPB, these very large satellites would be readily tracked, and ICBMs or SLBMs could be fired while no DEW was in range. Even for the case of space-based boost-phase interceptors—S-B BPI, an ICBM could be fired through a "hole" in the LEO constellation, and such a hole could be produced on demand at low cost and high reliability by the aggressor.

What has always limited my enthusiasm for space weapons is that they are highly visible and, especially in LEO, can be shot down at far less cost than required to maintain such a constellation. Naturally, supporters of space weapons counter such arguments with concepts such as "Brilliant Pebbles," and I reply that if I saw some potential adversary beginning to launch a persistent constellation of S-B BPI, for instance, that I would "shoot them down" (destroy them) individually, at my leisure, as they came over the horizon of one of my defensive launching sites for a fleet of tiny GBIs.

This is a totally different matter from BPI of ICBMs, where the timing of the required intercept is determined by the offensive weapon and not by the possessor of the anti-satellite system. The S-B BPI must be put into orbit at an altitude of perhaps 250 km with a booster capable of something like 8 km/s velocity gain. On the other hand, simply to *reach* that altitude and, incidentally, a cross-range distance of 400 km, requires a velocity gain of only 2.8 km/s, furthermore, the actual intercept can be aided by ground-based radar in a semi-active mode.  Another option is to launch a ton of sand not into orbit, but to an apogee of 200 km, at the right time to disperse, "hang there" (falling 125 m in 5 seconds—so a hang time of 10 s within +/- 62 m of the target altitude) for a few seconds of uncertainty in arrival time, destroying the orbiting weapon.  There would be no hazard to other satellites, because the sand would fall back into the atmosphere within a minute.

Of course, a constellation of SBLs or NPBs would be an even more attractive target, and I would shoot it down as well.

Another option is the development (but not deployment) of space mines, which, unlike naval mines, are not stationary in space relative to its quarry, but would be assigned to orbit always within lethal distance of perhaps 1 km, ready to destroy or disable the orbiting space weapon within a fraction of a second.  Of course, as with the proverbial fleas which can have "littler ones to bite 'em; and so on, *ad infinitum*," one needs to think carefully about this, and it is to avoid these impotent-because-vulnerable weapons in space and the arms race to make them so, that we published our "Rubicon" paper.

Why boost-phase intercept? The United States in recent decades has stated that it is developing and now deploying and operating BMD under the Missile-Defense Agency of the Defense Department ("MDA") specifically not for countering ballistic missiles from Russia or China, but only from "rogue states" in which category it puts North Korea and Iran. Iran has no nuclear weapons and no ICBMs, but it might at some future time. North Korea has both, and happens to be a very small country of 120,000 square kilometers area, making it feasible to base BPI hit-to-kill interceptors on land in South Korea or in nearby Russian territory or on ships in, or drone aircraft over adjacent international waters. Neither surface-based interceptors specialized for BPI, nor airborne BPI based on long-endurance drones poses any threat to Chinese or Russian ICBMs against the United States.

In 1999 I proposed surface-based interceptors specifically against North Korea and still believe that would have been a useful and stabilizing expenditure. Over the last couple of years, I have advocated drone-based interceptors as detailed in the following several slides.

One concern with the Airborne Alert is vulnerability of the orbiting drone aircraft. The orbits are beyond the range of the normal Russian-supplied SA-5 air-defense interceptor, but the drones would be vulnerable to NK fighter aircraft or to short-range SAMs fired from surface ships based in the deployment area or sent there on a killer mission. One would anticipate that the airborne patrol would be under close U.S. observation, and any attempts to destroy it/them would be observed in detail by the United States and countered with a wartime response, not necessarily involving nuclear weapons.

Because North Korea would not launch a single ICBM in the absence of Airborne Alert and certainly would not launch a single one in the presence of Airborne Alert, the Airborne Alert fleet on station would have to number approximately double the number of ICBMs that might be launched simultaneously—perhaps ten, and negating Airborne Alert would require the destruction of most of these loitering drones and the near-simultaneous firing of the ICBMs.

For this reason, although I advocate development and deployment of the Airborne Alert fleet, it may be necessary to supplement it with interceptors based in small silos in South Korea.[11]

[11] Placing even small GBI interceptors in silos in South Korea, which might weigh as much as one ton in order to emerge from the atmosphere with the speed of some 8 km/s, will demand some transparency to the international community in order for these to be seen as strictly oriented for intercept of North Korean ICBM launches.