The Absurdity of Missile Defense Using Space Based Directed Energy Weapons

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The belief that space-based directed energy weapons (DEW), such as Space-Based Lasers (SBL), can defeat strategic missile threats is totally impractical. This belief unfortunately arises from science fiction shows such as Star Trek and Battlestar Galactica, as well as President Reagan's Strategic Defense Initiative (SDI) of the 1980s, also called Star Wars. It is true that High Energy Lasers (HEL) can destroy missiles over short ranges under clear atmospheric conditions, but are totally impractical over the long ranges of thousands of kilometers required to engage strategic missiles from Low Earth Orbit (LEO). It is also true that modest laser powers can dazzle or damage optical detectors (as well as human eyesight) at long ranges due to the high optical gain of optical telescopes, but such modest lasers will have no effect on strategic missiles. These facts were thoroughly documented in classified and unclassified documents in the 1980s.

As shown in Figure 1, a perfect large hydrogen fluoride (HF) chemical SBL could achieve a soft target kill of 1 kJ/cm^2 in about one second up to about 4000 km range. However, this is a very large satellite that would be deployed at about 1000 km altitude and require many dozens of satellites to ensure global coverage to engage a limited threat (not a massive missile attack). It would have been nice if the calculations indicated that a few SBLs could be deployed at geosynchronous orbit to accomplish the BMD mission, but that would have required a hundred times more laser power to just negate soft targets. Countermeasures to expensive LEO satellites are many, including hardening of ballistic missiles.

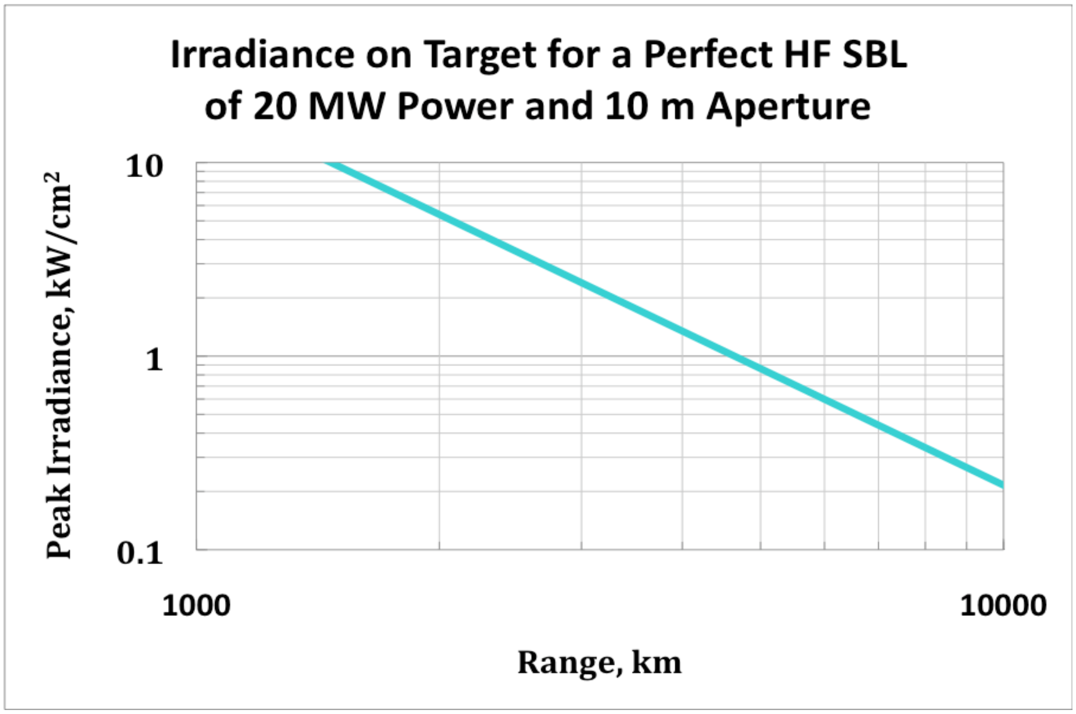

Figure 1. Laser Flux on Target for a Large SBL as a Function of Range

Politicians and newcomers to this subject frequently return to this fantasy and waste time and money on this fruitless endeavor. I analyzed and tested satellite and missile vulnerability and hardening at Martin Marietta Denver in the 80s and 90s. Most of this work is published in classified and unclassified limited distribution reports, which are not available to the public. However, there are some unclassified reports by Binnendijk (1986), available from the U.S. Superintendent of Documents, as well as detailed reviews by Bloembergen et.al. (1987), that will be used to show how ridiculous it is to place DEWs in space for ballistic missile defense (BMD). This is confirmed by numerous independent studies by scientists, but those reports tend to become complicated and voluminous.

Binnendijk (1986) states that chemical lasers would require a telescope aperture of tens of meters (p 26), while Bloembergen et.al. (1987) [pS64] estimates that an order of magnitude improvement is needed in megawatt class chemical lasers, i.e., over 10 MW in order to achieve an absorbed kill fluence of 1 kJ/cm^2 for soft targets to 100 kJ/cm^2 for hard targets [p S35]. A soft kill in one second would therefore require 1 kW/cm^2 on target from thousands of kilometers away, shown previously in Figure 1.*

Equations

Figure 1 is based on the following equations. The peak irradiance on target from an SBL is:

$$I_p = \frac{P_o \tau}{2\pi(\sigma R)^2} \tag{1}$$

where P_o is the laser power, τ transmittance, R target range, and σ the one sigma beam spread due to diffraction, jitter, and atmospheric turbulence, often taken as the root square sum (RSS) of these three terms:

$$\sigma = \sqrt{\sigma_d{}^2 + \sigma_j{}^2 + \sigma^2{}_{turb}} \tag{2}$$

The best that can be done is diffraction limited performance, setting jitter and turbulence to zero, leaving the one sigma, Gaussian approximation beam spread due to diffraction:

$$\sigma_d = (\sqrt{2}/\pi)\,\lambda\, BQ/D_o \tag{3}$$

where λ is the wavelength, BQ the beam quality, and D_o the telescope aperture, or in most cases the primary mirror diameter. At this one sigma point, the irradiance will drop to 61% of peak. The irradiance drops to 60%, close to 61%, at a $\lambda/D_o = 0.45$ for a Fraunhofer distribution which

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* It is common practice for laser analysts to mix MKS and CGS units, so one must check units very carefully. One can also divide kilometers by 1.6 to get statute miles, or 1.85 to get nautical miles, as just using miles is often confusing at rocket and missile museums.

is also the one sigma point for a Gaussian distribution, yet laser outputs are rarely uniform.

As a side note, the one-sigma spot size, where the irradiance will fall off to 61% of peak, can be calculated from two times the one-sigma spot radius:

$$\text{Spot Diameter} = 2\sigma R \tag{4}$$

Figure 1 assumed the highest possible flux on target with no transmission loss, no vibration induced jitter losses, no turbulence effects, and perfect beam quality. There have been more detailed computer models using modulation transfer functions (MTF) and wave optics approaches developed under Air Force Weapons Lab (AFWL) funding, but these models are not needed for this system level analysis.

Figure 1 also assumed a laser output of 20 MW with a 10 m aperture SBL intended to destroy a ballistic missile during boost phase from LEO. Such a satellite is far more complicated and much larger than NASA's James Webb Space Telescope (JWST) that cost about 10 billion dollars ($10B US) for just one JWST. Probable target ranges from LEO to a ballistic missile are approximately 1000 to 4000 km, and many dozens of these large satellites would be required to ensure global coverage against a limited number of missile launches from one location, due to the fact that LEO satellites cannot hover over one Earth location. Currently, only a few minutes are available to take action against the boost phase of a ballistic missile, and multiple launches from a similar location make this timeline challenging.

Although there have been detailed mission analysis models to examine force numbers, simply take the circumference of the Earth (or more correctly the circumference of an orbit at 1000 km altitude), spacing the satellites in a near-polar orbital ring by 8000 km (2X 4000 km), and see how many satellites are needed in one orbital ring. Then multiply by the number of orbital rings needed to ensure coverage, spaced by about 8000 km at the equator, assuming a possible SLBM launch from near the equator. This will result in requiring many dozens of very large spacecraft.

Chemical lasers are the only practical HELs for space basing, as solar arrays would be too big as a practical power source. The International Space Station (ISS) uses solar arrays about half the area of a football field that only provide about 100 to 200 kW of electrical power (a hundred times less than a 10 MW SBL, and actually several hundred times less due to inefficiencies in generating laser power from electricity). Generating gigawatts of electricity from ground-based power plants exist today, but doing so on a satellite is totally impractical.

Chemical atomic iodine lasers (COIL) were developed which could provide $(2.8\ \mu\text{m}/1.3\ \mu\text{m})^2$ or about 4X more laser irradiance on target for the same output power as an HF laser, but demonstrated output powers are not close to that from HF or DF chemical lasers. The same issues of hardened targets and countermeasures exist for a COIL SBL.

Space based lasers will also be ineffective to destroy a nuclear-armed cruise missile at strategic ranges. Cruise missiles are virtually impossible to detect from space because of their low signatures, and fly much slower at low altitudes where atmospheric absorption, scattering, and clouds would greatly reduce laser irradiance on target.

Other DEWs have similar problems with power requirements, weight and size limitations. These are discussed in detail by Bloembergen et.al. (1987). One really ridiculous idea was huge ground-based lasers (GBL), which are subject to thermal blooming and turbulence beam spread degradation, shooting up off large LEO relay mirrors to hit ballistic missiles.

Countermeasures Against an SBL

There are numerous countermeasures that can be employed against a SBL system, that I was tasked to document under contract to Lockheed in 1985 during my second employment at Martin Marietta, but I will only mention a few unclassified cases. Martin Marietta Denver was under contract to design a Zenith Star demonstration SBL, with Lockheed providing the telescope and TRW providing a multi-megawatt chemical laser. I was previously tasked to analyze the detection of a fast burn ballistic missile, which would complete its boost phase prior to identifying it as a threat, under contract to Boeing during my first employment at Ball Aerospace in 1983. A modest amount of missile hardening would render a 20 MW, 10 meter SBL ineffective as discussed by Bloembergen et.al. (1987). A solid propellant missile, with a much thicker skin to survive combustion chamber pressures, is much more laser hard than an unhardened liquid propellant missile with a thin painted skin (in this context referring to laser hardening, not nuclear hardening). Additionally, LEO satellites can be destroyed by relatively low cost ground-to-space interceptors, as the USAF demonstrated in a 1985 test using a small ASAT missile launched from an F-15 jet to take out a Ball Aerospace P78-1 satellite, and as the Navy demonstrated in 2008 using an SM-3 ship-launched missile taking out a failed NRO satellite. Also, a single megaton class nuclear explosion in LEO can render LEO satellites inoperable in weeks to months due to radiation from an enhanced (not saturated) Van Allen radiation belt (as the U.S. demonstrated in the 1962 Starfish nuclear test); this radiation field will vary with altitude. Snyder et.al. (2025) published a recent paper on the effects of space detonations on LEO satellites, but these effects are not limited to non-military satellites. Conrad et.al. (2010) has a more detailed review of all effects, despite its title. Nuclear-hardened satellite vulnerability is a matter of degree to which they are hardened – they cannot survive a direct nuclear attack or radiation levels from a saturated Van Allen belt.

Unclassified References, Available to the Public

Binnendijk, Hans (1986), Strategic Defense in the 21st Century, Foreign Service Institute, U.S. Department of State.

Bloembergen et.al. (1987), Report to the American Physical Society of the Study Group on Science and Technology of Directed Energy Weapons, Review of Modern Physics, Vol 59, #3.

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