How adaptive optics may have won the Cold War

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ABSTRACT

While there are many theories and studies concerning the end of the Cold War, circa 1990, I postulate that one of the contributors to the result was the development of adaptive optics. The emergence of directed energy weapons, specifically space-based and ground-based high energy lasers made practicable with adaptive optics, showed that a successful defense against inter-continental ballistic missiles was not only possible, but achievable in a reasonable period of time.

1. INTRODUCTION

At the end of the Second World War, a stalemate between members of the Allied Powers existed in Europe. The Eastern Bloc under the Warsaw Pact was under the control of the Soviet Union and the Western Bloc remained protected by NATO and the United States. Both the Soviets and the Americans were nuclear armed. Between 1945 and 1947, author George Orwell, financier Bernard Baruch, journalist Herbert Swope, and columnist Walter Lippmann referred to the ongoing conflict as the *Cold War.* For over 30 years, psychological warfare and industrial warfare, such as the space race and the arms race, ensued. The Cuban missile crisis and other events often threatened all-out war again. Breaks in the relative calm were punctuated by proxy wars in Berlin, Korea, the Suez, Vietnam, the Middle East, and Afghanistan

Defense against a nuclear strike was essentially impossible after the development of nuclear carrying submarines and inter-continental ballistic missiles (ICBMs). Technology on the offensive side evolved into thousands of nuclear tipped missiles with the ability to individually attack multiple targets. Defense to the Multiple Independently-targetable Reentry Vehicles (MIRV) was limited. The only practicable defense was to have an offensive counterattack large enough to survive the first strike, thereby assuring the mutual destruction of the aggressor. Out of necessity, both sides began developing systems for defense to gain an upper hand over this policy of mutual assured destruction (MAD).

Layouts of ground-based interceptors near the ICBM facilities progressed during the 1950s and 1960s until radar stealth and multiple warheads showed that the offense would prevail or the defense become too costly.

Attacking the missiles right after launch before they reached mid-course and could MIRV, was studied. Hiding the counterattack missiles on submarines off the enemy coast was a workable although expensive solution.

Putting counterattack weapons in orbit that would overfly the targets made it possible to attack cities or military installations within minutes of a detected aggressor attack. After the Partial Test Ban Treaty of 1963, x-ray, neutron, and gamma-ray sensor systems such as the Vela satellites were launched to detect such an attack or monitor the testing of nuclear weapons. One interesting result from the satellites was the 1967 observation for the first time of a Gamma Ray Burst which results from a supernova and the formation of a neutron star or black hole.

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2. TREATIES

A number of treaties addressed this escalation of offensive nuclear weapons in space. The Outer Space Treaty of 1967 banned the use of nuclear weapons or other weapons of mass destruction in space. The Anti-ballistic Missile (ABM) Treaty of 1972 limited each signatory to one site with no more than 100 interceptor missiles each. The Nuclear Non-proliferation Treaty, in force since 1970, required the parties to "pursue negotiations in good faith" to reduce or eliminate nuclear weapons. Nearly 200 nations have signed the treaty but four nuclear-tipped nations have not or no longer recognize the treaty. So much for "good faith."

3. LASERS

The laser was invented in 1960 and quickly became an interest of the military. If the speed-of-light photon "bullets" could be used to intercept ICBMs, reentry vehicles, aircraft or other delivery systems or sensors, they had to be studied. Being non-nuclear, they could be placed in space and not violate the Outer Space Treaty. It was hotly debated that laser-based satellites or laser-equipped defenses at launch facilities did or did not violate the ABM treaty. After all, did the treaty limit the number of interceptor missiles or the number of shots allowed by a defensive laser?

Throughout the 1970s, researchers began to explore the scaling up of high energy lasers, the deployment of the lasers, the ability to rapidly fire the lasers and control of the laser beam along its path. Although proposed in 1953 as a technique to counter atmospheric turbulence, astronomer Horace Babcock's suggestion eventually evolved into the field of adaptive optics with technological advances in the mid-1970s.

Adaptive optics is a series of technologies to correct beams of light that are distorted. Conventional systems include a wavefront sensor to determine the disturbance, a deformable mirror with actuators to bend the surface to match the disturbance, and high-speed computer controllers to operate it. The beam can be light from a distant star coming into an astronomical telescope where the atmosphere disturbs the wavefront up to kHz rates or the beam can be an outgoing laser with a distorted wavefront and other distortions in the optics or the atmospheric beam path to the target.

4. WEAPONIZATION AND ADAPTIVE OPTICS

In the late 1970s, the U.S. Air Force, Navy, and DARPA initiated a series of classified programs to develop high-energy lasers and the supporting technology to weaponize them. Large beam control systems (the SeaLite Beam Director) were developed by the Navy, principally as a speed-of-light defense against cruise missiles. Other large optics for space surveillance imaging and beam propagation were under way.

Chemical lasers in the multi-kilowatt range had been developed by 1976 and tested on short range targets. Plans for putting the chemical lasers in space culminated in three programs: Alpha, the Large Optics Demonstration Experiment (LODE), and Talon Gold. These programs operated throughout the 1980s, managed by a changing administration structure in the Department of Defense and demonstrated results by the early 1990s.

Megawatt class power levels were first achieved by the Mid-Infrared Advanced Chemical Laser (MIRACL) originally sponsored by the Navy. This laser was optimized for sea-level operation and was unsuitable for space operation. By 1991, the Alpha laser demonstrated that megawatt space-compatible lasers could be built and operated. Figure 1 shows the scale of the laser gain medium. The Alpha laser gain medium could consist of

Hydrogen-Fluoride for 2.7 μm radiation in space or Deuterium-Fluoride for 3.8 μm radiation for an atmospheric window.

Figure 1. Checkout of Alpha laser components.

After the beam is produced, it must be readied for transmission toward the target. Two related programs were constructed to demonstrate the optical system necessary for the space-based weapon. The Large Advanced Mirror Program (LAMP) built a lightweight, segmented 4 m diameter mirror on which testing was completed in 1989. The size was governed by the ability of the Space Shuttle to deliver it to orbit. Tests verified that the surface optical figure and quality desired were achieved, and that the mirror was controlled to the required tolerances by adaptive optics adjustments. The mirror consisted of a 17 mm thick facesheet bonded to fine figure actuators that are mounted on a graphite epoxy supported reaction structure. Even though the operation of the space-based laser did not have to correct for the atmosphere, the wavefront of the high power Alpha laser was far from ideal. Adaptive optics are needed to dynamically correct for the vibration-induced figure errors of the optical train as well as the wavefront errors of the laser. The telescope, using LAMP as the primary mirror, had a hole in the center of the secondary mirror. (Fig. 2) Etched gratings at various places across the primary would diffract a very small portion of the laser light into the hole where a wavefront sensor, buried in the secondary mirror structure, would decode the wavefront. Corrections were applied to actuators of the primary mirror, actuators of a deformable mirror in the beam train, and fast steering mirrors to correct for beam tilt and jitter. The LODE program developed the technology of the adaptive optics and the Alpha-LAMP Integration (ALI) program put the pieces together for full power demonstrations.

Figure 2. The 7-segment 4-meter diameter LAMP mirror.

To make everything work as an integrated weapon system, target acquisition, tracking, and beam pointing technologies were needed. By 1985, the Talon Gold brassboard demonstrated subscale versions of separate pointing and tracking apertures, a target illuminator, an inertial reference gyro system, fire control mode logic, sensors and trackers.

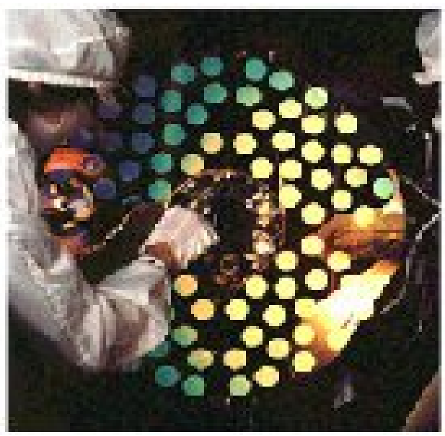

Figure 3. Testing the diffraction gratings on a scale primary mirror for LODE.

To avoid placing the heavy high-energy lasers in space, a ground-based concept was studied. The idea consisted of having a number of secure and protected sites in the United States that could produce high energy beams. A constellation of relay satellites would orbit the Earth to direct the beams to the available targets, typically assumed to be boost phase missiles shortly after launch. While the technology to produce the lasers was slightly easier than a space-qualified version, the propagation of the beams through the atmosphere to the relay satellites required large telescopes and considerably complex adaptive optics. Another technological problem was the requirement for a wavefront beacon to sense the distortion of the atmosphere.

Placing a beacon on the cooperative relay satellite seemed like a simple fix, but the movement of the satellite during the millisecond a propagation time required the tracker and pointer angles to be slightly ahead of the relay satellite. What was needed was an artificial beacon that could be placed anywhere that it was required.

The Air Force Maui Optical Station (AMOS), originally called the ARPA Mid-course Optical Station, began construction in 1961 and was essentially completed by 1967 for the purpose of tracking midcourse satellites, re-entry vehicles, and decoys in the optical and infrared wavelengths. By 1982, AMOS had the Compensated Imaging System (CIS) which was a working adaptive optics system on a telescope to compensate for the atmosphere in its surveillance imaging. For a wavefront beacon, CIS used glints (Sun reflections) from the target object. By the late 1970s, the Air Force Starfire Optical Range (SOR) near Albuquerque, NM, had telescopes with adaptive optics. By the summer of 1982, SOR confronted the problem of the artificial beacon and began experimenting with lasers that would produce Rayleigh backscatter in the atmosphere and act as a beacon which could be accurately placed anywhere in the sky. The concept of the laser guide star remained classified until 1991.

Besides the directed energy laser weapons, by 1989, neutral particle beam accelerators were being developed for space. And further, kinetic kill was still in the game. Throwing unguided dumb rocks at the targets is the first phase. The second phase is giving them a guidance system so that they become smart rocks. And then, making them very smart and much smaller evolved into Brilliant Pebbles, (1988-1994) soccer ball size kinetic kill space interceptors. The Brilliant Pebbles would use Brilliant Eyes as sensor system for theater ballistic missiles in mid-course.

Figure 4. Artist's concept of a ground-based high-energy laser antimissile system with on-orbit relays.

5. PRESIDENT REAGAN AND THE COLD WAR

After Ronald Reagan became president in 1981, a series of confrontations with Soviet leaders began. With mistrust of the Soviet Union, in 1983 Reagan had labeled the Soviet Union "the evil empire." Two years later, after the first arms summit in Geneva, Reagan said of Gorbachev, "There was warmth in his face and his style, not the coldness bordering on hatred I'd seen in most senior Soviet officials I'd met until then."

Not to downplay the drama and debates of the testing of x-ray lasers powered by nuclear explosions, the prodding of Dr. Edward Teller convinced the President that technology advances were possible. After discussions of the x-ray laser and other briefings about our current and projected technology, President Reagan made a speech to the nation on March 23, 1983. In it he said: [1]

> "What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack; that we could intercept and destroy strategic ballistic missiles before they reached our own soil or that of our allies?"

"I know this is a formidable technical task, one that may not be accomplished before the end of this century. Yet, current technology has attained a level of sophistication where it is reasonable for us to begin this effort. It will take years, probably decades, of effort on many fronts. There will be failures and setbacks just as there will be successes and breakthroughs. And as we proceed we must remain constant in preserving the nuclear deterrent and maintaining a solid capability for flexible response. But isn't it worth every investment necessary to free the world from the threat of nuclear war? We know it is!"

"Tonight, consistent with our obligations under the ABM Treaty and recognizing the need for closer consultation with our allies, I am taking an important first step. I am directing a comprehensive and intensive effort to define a long-term research and development program to begin to achieve our ultimate goal of eliminating the threat posed by strategic nuclear missiles. This could pave the way for arms control measures to eliminate the weapons themselves. We seek neither military superiority nor political advantage. Our only purpose - one all people share - is to search for ways to reduce the danger of nuclear war."

After this speech, the Strategic Defense Initiative (SDI) was formed to pursue the necessary research. Early funding was on the order of 4 billion dollars per year. A large and public debate ensued. Some argued that a fully functioning defense against ballistic missiles would allow that nation to perform a successful first strike. To that end, a first strike by the opponent could be instituted prior to the completion of SDI systems. Under all scenarios, the buildup of offensive weapons and the research and construction of a viable defense would be very expensive.

In the 1985 Geneva summit, progress on arms control had foundered over Gorbachev's insistence on scrapping SDI, and Reagan's commitment to its development.

The summit between Reagan and Gorbachev in Reykjavik, Iceland, in October 1986, also ended in a stalemate. At this second summit, Reagan still refused to budge on SDI, and Gorbachev refused to make further concessions without compromise. But at the third summit, in Washington, DC, in December 1987, Gorbachev yielded to Reagan's terms. The USSR was in dire economic straits, and Gorbachev needed a respite from the arms race.

When Reagan and Gorbachev signed the INF Treaty in Washington, in 1987, the first treaty to reduce the number of nuclear weapons, the United States and Western Europe rejoiced. Later when they called each other "friend" in Moscow, many saw it as "the ratification of their mutual desire for peace." At that time, many thought or at least hoped for the end of the Cold War. Was countering SDI so expensive for the Soviet Union that it began to collapse? First it allowed the Soviet republics to demand independence which ultimately resulted in the dissolution of the Soviet Union on December 25, 1991.

6. FURTHER SCIENTIFIC ACHIEVEMENTS

In parallel with the political wrangling, technology development for space and ground-based laser weapons moved along. Some of the adaptive optics and beam control technologies that advanced the field included the High-Precision Tacking Experiment (HPTE) on space shuttle Discovery. The shuttle was tracked (6/21/85) and a low-power laser in Hawaii bounced a laser off the HPTE mirror. In February 1990, the Relay Mirror Experiment (RME) demonstrated stabilization, tracking, and pointing. A laser was sent from the ground to a 60-cm mirror in low Earth orbit and relayed back to the ground at to another location. On the same launch as RME was the Low-power Atmospheric Compensation Experiment (LACE) which included measurements of atmospheric distortion of lasers and real-time adaptive optics compensation for the distortion. It also included experiments in target discrimination against background radiation and Ultra-Violet Plume Imaging (UVPI).

Throughout the 1980s work continued in the development and perfection of a workable artificial wavefront beacon. One concept, presented in about 1981 by Julius Feinleib, evolved into the laser guide stars that are used today throughout the world. In 1981 though, it was critical to the development of ground-based high energy lasers and improved imaging for surveillance telescopes. The concept and development of it was classified. Researchers primarily at SOR and MIT Lincoln Laboratory developed and demonstrated systems where a projected laser formed a useful wavefront beacon in the lower atmosphere. By the late 1980s, new telescopes and systems within the military were employing the technique. However, in 1985, a paper published by two French astronomers, Renaud Foy and Antoine Labeyrie accurately described a laser concept to do precisely the same thing. [2] Funding for the civilian development of laser guide stars was sought. By 1991, with the fall of the Soviet Union and the accompanying reduction in that threat, the military changed focus from defending the continental United States to theater missile defense. The concept of the laser guide star was made public and the Air Force declassified much of the research. Astronomers around the world would not have to spend countless hours and funds to replicate the technology.

At the 78th meeting of the American Astronomical Society in Seattle, Washington, in May 1991 Robert Q. Fugate, technical director of SOR famously revealed to the world, “Ladies and gentlemen, I am here to tell you that laser guide star adaptive optics works!” [3]

7. ANSWERING THE QUESTION

Did adaptive optics spur the end of the Cold War, or did the end of the Cold War spur adaptive optics?

Or one might conclude that it was not adaptive optics itself that led to the end of the Cold War, but the very expensive nature of adaptive optics that did. [maybe 4]

REFERENCES

In addition to my own fallible recollections, I referred to a number of sources:

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