

DIRECTED ENERGY WEAPONS ON THE BATTLEFIELD: A NEW VISION FOR 2025

by

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Author

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Preface & Acknowledgements

In 1996, I had the privilege of participating in a major study effort, requested by General Ronald Fogleman, to look 30 years into the future. Under the leadership of Lieutenant General Jay Kelley, I had a chance to interact with some of the brightest minds and most forward thinkers of this age. The list included Dr. Norman Augustine, President of Lockheed Martin; Alvin Toffler; James Cameron, who later directed the movie *Titanic*; Burt Rutan; General Bernard Schriever; Admiral Bobby Inman; Dr. Gene McCall, then Chairman of the AF Scientific Advisory Board; and Dr. Dan Hastings, who is now Chairman of that same board. These, and roughly 100 others of similar status, taught me and nearly 200 other volunteers in the Air Force 2025 Study, a little about how to look ahead and understand the technological revolutions that will shape our future. To them, and many who remain unnamed here, I will be forever grateful.

This paper is an outgrowth, or perhaps an aftereffect, of that study. My interest in directed energy began in earnest back in 1996 as I was researching and writing the monograph, *The Alternate Futures for 2025*. In 2001, I devoted part of my Air War College year toward an attempt to discern what directed energy technologies might mean on a future battlefield. I am very appreciative of the assistance provided by Drs. Harro Ackerman, Vern Schlie, and Bob Duffner, of the Air Force Research Laboratory's Directed Energy Directorate, who helped me understand a truly phenomenal amount of work, which spans four decades, and brings us to where we are today. Dr. Grant Hammond, Colonel (retired), Ted Hailes, and Lieutenant Colonel Courtney Holmberg, all who work in this Center, helped me better formulate and phrase the ideas I had. I am also thankful for the efforts of Air University's Hyla Pearson and the Public Affairs office in the Air Force Secretariat, for their hard work in ensuring I didn't break any rules in writing this paper. Still, few papers are perfect, and the fault for any errors, remains my own.

Most importantly, I thank my wife, Pier, and daughter Francesca, for their patience, and support for all the writing, trips, and interviews that kept me away from home.

Abstract

Several nations are engaging in development and production of directed energy weapons. Recent scientific advances now enable the production of lethal lasers and high-powered microwaves. The current growth and development in this emerging area strongly suggests that directed energy weapons of lethal power will reach the battlefield before 2010. Since proliferation of lower power laser weapons has already happened, it is likely that proliferation of high power or high energy weapons will occur as well. This paper expands on this development and posits potential impacts on a plausible future battlefield, developed in part from the Alternate Futures of AF 2025, where all comers deploy lethal directed energy technologies. From these impacts, which span doctrine, organization, force structure, and systems design, this paper recommends changes to better posture the United States for this potential future.

I. Introduction

Directed energy technologies are not new. Laser research began in earnest in the United States during the space race of the 1960s, and research in microwave physics can be traced back to the atomic energy program in the late 1930s.¹ What is new is the power and energy output levels being achieved by devices in our laboratories and in the field. Recent developments include megawatt-class (millions of watts) continuous wave lasers that have shot down aerospace vehicles, and a system of lasers at Lawrence Livermore Laboratories that combine to produce a very short laser pulse with a peak power output of five quadrillion (5,000,000,000,000,000) watts.² As the output of directed energy sources continues to increase, so does the potential for desirable battlefield effects. Within the next twenty to thirty years, laser and microwave weapons will place surface, airborne, and space forces at increased risk at greater distances. Lethal ranges for these new weapons will increase to hundreds of kilometers. As a result, laser blinding will rapidly become the least of our directed energy force protection worries.

The purpose of this paper is straightforward and simple: to establish a vision for how directed energy weapons could revolutionize military affairs in the future. To achieve this, the paper will first describe the developments in directed energy technologies that have led us to the crossroads at which we now stand. Specifically, it will examine the development of four types of directed energy technologies: continuous wave lasers, pulsed lasers, continuous wave high power microwaves, and pulsed microwaves. This paper will also examine the trends in the proliferation of these technologies to postulate where the future may lead. From these trends, the paper will examine the battlefield of the future, where the likely impacts of directed energy weapons will be explored. From these impacts it will be clear that changes to our doctrine and equipment will be required to maintain a viable expeditionary force. Many of these changes will be time consuming, difficult, and expensive. Lastly, this paper will offer recommendations as to how the Department of Defense and the Air Force can better position our nation to be ready for the future.

2... Directed Energy Weapons on the Battlefield

II. Directed Energy Technologies

Continuous Wave Lasers

Dr. Charles Townes of Columbia University pioneered Microwave Amplification by Stimulated Emission of Radiation (MASERs) in the mid 1950s. Over the next several years, he worked to extend his MASER concept to the optical regime to generate visible and near-visible radiation. Dr. Townes' work laid the foundation for the creation of the first ruby crystal laser in 1960 by Dr. Theodore Maiman of the Hughes Research Laboratories.³

In his position as Director of Research at the Institute of Defense Analysis, Dr. Townes strongly advocated military research on lasers with the eventual purpose of weaponization. In spite of his unwavering support, he also cautioned that considerable basic research was needed to fully understand the fundamental principles of laser physics before operational systems could be produced. Following Townes' recommendations, the Air Force took the lead in laser research during the 1960s under the auspices of the Air Force Special Weapons Center (AFSWC). In 1962, AFSWC obtained funding from the DOD's Advanced Research Project Agency (ARPA) to begin investigating the vulnerability of military systems to laser radiation and to begin laser device development. The Air Force eventually transferred most of the basic research on lasers from AFSWC to the newly formed Air Force Weapons Laboratory (AFWL). Over the next decade and a half, Air Force laser research efforts focused on the development of laser devices and optical components, including efforts to increase output power, efficiency, and beam quality. By 1966, AFWL researchers had successfully demonstrated a carbon-dioxide (CO₂) gas dynamic laser (GDL) with an output power between 500 and 700 watts. In 1968, a follow-on Experimental Laser Device produced an output beam of 77,000 watts, which reinforced the idea that laser technology could eventually be fielded on airborne systems.⁴ Hence, the quest for laser weapons charged forward.

In 1969, as a result of the early successes in GDLs, the U.S. government made a major commitment to build a one-megawatt (1-MW, or 1,000,000 watts) device by the end of 1971.⁵ While the project

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encountered delays, the laser was eventually finished in 1972 with a demonstrated output power of 0.5 MW. Initially, beam control difficulties resulted in an inability to optimally concentrate the energy on a spot of small size.⁶ While these beam control problems were solved, some of the early high energy lasers encountered engineering challenges associated with power output damaging some internal components. In spite of these challenges, by 1975, several high power lasers had been successfully demonstrated. Pratt and Whitney had developed a GDL with an output power of 500kW (500,000 watts) in 1972, and Northrop developed a laser with between 0.5-1.0 MW of power.⁷

Meanwhile, new experimental efforts to track moving targets had begun. A proof-of-concept demonstration called Project DELTA (Drone Experimental Laser Test & Assessment) integrated Air Force Laser 1, an experimental gas dynamic laser, with a pointing and focusing system. Project DELTA achieved a spectacular success on 14 Nov 1973 when the laser system tracked, engaged, and successfully disabled an aerial drone at the Starfire Optical Range at Kirtland AFB, NM. This achievement resulted in the transition of this technology to the Airborne Laser Laboratory (ALL) onboard an extensively modified NKC-135.

The ALL was built to prove the physics and lethality of lasers in an airborne environment. Equipped with a 400 kW CO₂ GDL, it would demonstrate the potential for directed energy weapons in airborne combat. In May 1983, the ALL acquired, tracked and disabled five Sidewinder air-to-air missiles. That fall, the ALL intercepted three ground-launched Navy drones flying low-altitude profiles over the Pacific Ocean.

In the late 1970s and early 1980s, attention gradually shifted to other devices including hydrogen-fluoride/deuterium-fluoride-based (HF/DF) systems. In 1984, the HF/DF lasers produced a 1MW beam, but like early attempts with CO₂ lasers, the beam quality at high power levels was not optimal.⁸ Development of these systems continued, and in 1988, a new megawatt-class HF/DF laser was successfully tested at White Sands Missile Range in New Mexico.

A second set of lasers was also developed in the late 1970s. In 1977, researchers at the Air Force Weapons Laboratory discovered the Chemical Oxygen Iodine Laser (COIL). This new type of laser substituted a chemical pumping scheme for the more traditional method of optical pumping with flash lamps to excite the lasing species to the meta-stable energy levels required for lasing. This new method proved to be significantly more efficient than flash-lamp pumping and dramatically

increased laser efficiency. By 1988, AF scientists had achieved an output of 35,000 watts using a supersonic flow technique. The success of COIL laser technology led to its selection for integration into the Air Force's Airborne Laser (ABL) Program platform, where multiple 100kW-class COIL laser modules will be combined to create an airborne, megawatt-class chemical laser for theater ballistic missile defense. By 1999, COIL technology had advanced to the point that Boeing had proposed a 100-kW-class laser system for the V-22 Osprey.⁹ Also in 1999, TRW, Inc., had completed testing of one of the Airborne Laser's modules, a multi-hundred kilowatt laser that is the foundation for the multi-megawatt full power demonstration to take place in 2005.¹⁰

While the power outputs of these devices certainly seem large, they are meaningless unless one can describe their effects. The effects of a continuous wave laser on a target are based on the amount of energy the laser deposits onto the target. The deposited energy is a function of the output power of the laser, the length of time the laser power is incident on the target, a transmission number to account for losses between the source and the target, and the spot size of the laser spot on the target. The energy delivered to a target is determined by the following equation: $F = P \Delta t L/A$. F is the energy deposited in Joules per square centimeter; P is the laser output power in watts (or Joules per second); Δt is the duration of the laser pulse in seconds; L is a dimensionless transmission number which delineates the percentage of the laser output that actually reaches the target (often called the Strehl number); and A is the laser spot size on the target. To destroy soft targets (human flesh, fabrics, plastics, etc...) approximately 1000 Joules per square centimeter are required. Extremely hard targets such as tanks might require 100,000 Joules per square centimeter.¹¹ Thus, a 25kW laser with a two-second pulse length and a five-centimeter spot size could kill a person, break an aircraft canopy, or ignite fabrics and materials at distances where transmission is only forty percent effective. The current state-of-the-art high energy lasers described above can maintain this forty percent effectiveness over distances of twenty to forty kilometers. The ABL's multi-megawatt systems are advertised as being able to destroy missiles at distances of over 200 nautical miles (370 km).¹² Based on the American Physical Society analysis above, at close ranges, the ABL's laser would be capable of destroying hard targets.

Pulsed Lasers

In contrast to continuous wave laser devices that produce continuous beams of light, physicists have developed a class of laser systems that produce laser energy in short bursts. For the purposes of this paper, pulsed lasers are defined as those devices that produce less than 0.1 second of laser dwell time before cessation of lasing to produce the next pulse. Some pulsed lasers now in operation produce very short pulses that are on the order of a few hundred quadrillionths of a second.¹³ This is accomplished by compressing the original laser beam via diffraction, reflection, or other methods to cause parts of the original laser beam to travel different distances. These distances are chosen such that all of the original beam energy can be combined and focused at a fixed point at the same time.¹⁴ This results in a pulse that can have many times the peak power output of the continuous wave laser. The process results in a loss of energy in the beam splitting and recombining processes, thus reducing the “average laser output” (an average over time that includes the null periods between pulses). While pulsed lasers can burn through materials, the rate at which they do so is based on their average power output. Since the average output of a pulsed laser is less than the continuous wave system due to losses in creating the pulse, this is generally not an optimum use for pulsed lasers unless the pulsing offers other advantages such as minimizing thermal blooming, or laser beam distortion and expansion due to rapid heating of the atmosphere along the path of the laser beam.

Pulsed lasers can create a unique series of effects caused by the impact of the short-duration high-intensity pulses. The magnitude of these pulses can be impressive. For example, in 1995, a tabletop laser at Lawrence Livermore National Laboratory had a pulsed output of 100 trillion watts. While each pulse was extremely short, each pulse had a peak power output that was twenty times greater than the entire instantaneous electrical generation capacity of the United States of America.¹⁵ The beamlets from this laser, only 400 quadrillionths of a second in duration, act as powerful battering rams when projected against a structure or material. These pulses drive an ultrahigh-pressure shock wave into the material that can cause material failure through fracturing at the atomic level.¹⁶ The magnitude of these shocks is extreme. Tests using smaller devices in 1966 and 1987 yielded point impulse shock pressures

on the order of a few megabars (a few million times atmospheric pressure),¹⁷ which would be equivalent to over 20 million pounds per square inch.¹⁸ Pulsed lasers have also been shown to have considerable ablation properties, which may be helpful in producing structural failures. As the laser pulse impacts the material, it hits with sufficient force to strip away molecules and atoms at the point of impact. While each pulse may not remove a huge number of molecules, some short-pulsed lasers can deliver well over one million pulses per second, which can cause considerable ablation of material in a short time.¹⁹

Because of the extreme intensity of their beams, pulsed lasers can also produce a superheated region of gas, or plasma, at the point of impact.²⁰ Since lasers can be used to create these plasmas at pre-designated points, these effects may have operational utility. In some cases, these laser-induced plasmas may be extremely bright, and this phenomenon may be able to temporarily blind or dazzle optical sensors. The extreme temperatures within the plasma and its effects on the chemical composition of the air in and near the plasma may affect engines.²¹ While this author has been unable to find definitive information on the subject, it certainly seems plausible that the ingestion of plasma at several thousand degrees Fahrenheit could potentially disrupt engine function in aircraft, missiles, and unmanned vehicles.

Thus, while pulsed lasers may not burn through materials as well as their continuous wave counterparts, they have a number of unique characteristics that may give them military utility in the future.

High Power Microwaves

A variety of sources, including radio frequency oscillators; magnetrons; fast, high power electrical switches; and even nuclear weapon bursts generate microwave radiation. We encounter microwave energy in many varieties every day: radio stations in the FM and Citizen's Bands, airport air traffic control radio detection and ranging (RADAR) equipment, and the ever-popular kitchen appliance that heats the average hot dog in about twenty seconds. The effects that microwave energy has on materials vary dramatically depending upon the characteristics of the materials as well as the power level, pulse length, pulse repetition frequency for pulsed systems, and the frequency of the microwave radiation. This is why an 800-watt (illegal) Citizen's Band radio booster

amplifier at 20 MHz is harmless, but watching one's dinner cook from *inside* an 800-watt (typical) microwave oven would be fatal.²²

While lasers generate tightly focused beams of monochromatic (single frequency) photon energy in the visible and infrared region of the electromagnetic spectrum, high power microwave (HPM) devices generate much less focused beams of energy in the radio frequency range of the electromagnetic spectrum, which spans from around 1 megahertz to around 100 gigahertz.²³ Additionally, the frequency content, or bandwidth, of microwave signals can vary significantly. Narrow band systems emit all their energy within a few tenths of one percent of a central frequency. Wideband and ultra-wideband (UWB) systems can have their energy spread across a spectrum that is as much as twenty-five percent or more of the center frequency. High-altitude nuclear-burst-generated electromagnetic pulses (EMP) may spread across many decades of bandwidth within the microwave range. However, it should be noted that high-altitude nuclear EMP does not have significant energy in frequencies above a few tens of megahertz, whereas narrow band HPM spectra are typically in the few gigahertz to tens of gigahertz range and UWB spectra may contain energy in the frequency range from hundreds of megahertz to a few gigahertz.²⁴ Unlike lasers that operate in the visible and infrared regions of the electromagnetic spectrum, the atmosphere, clouds, or moisture do not significantly affect the propagation of microwave frequencies; thus, microwave weapons can provide all-weather capability.²⁵ The next three sections will examine pulsed microwave radiation from both nuclear and non-nuclear sources as well as continuous wave microwave radiation. The effects that both pulsed and continuous wave microwave energy can generate will also be discussed.

Electromagnetic Pulses

An extremely powerful variant of pulsed electromagnetic energy that results from a nuclear weapon detonation is known as electromagnetic pulse, or EMP. The bandwidth of a nuclear EMP signal is extremely wide, ranging from tens of hertz up through tens of megahertz. Additionally, as one might expect, the peak electric field strength of a nuclear-generated EMP can be exceptionally high.²⁶ Serious study of the effects generated by EMP began in a series of nuclear tests conducted at Johnston Atoll in the Pacific Ocean in 1962.²⁷ Shortly after the Soviet

Union breached a nuclear testing moratorium, the United States detonated a 1.4-megaton nuclear bomb 400 kilometers above the Pacific Ocean approximately 1300 kilometers from the Hawaiian Island of Oahu.²⁸ The experiment was code-named STARFISH. During the experiment, several unusual events happened in Hawaii. Radio stations were shut down, street lighting systems became inoperative due to burned out fuses, cars stopped working due to burned out alternators and generators, and some telephone systems failed. Not every phone, streetlight and car was affected, but these effects were felt as far as 1000 miles from the detonation site.²⁹ While the cause of the widespread disruption was not immediately apparent, over the next two years researchers discovered that the test and these events were somehow linked, and that a yet unknown property of the electromagnetic energy emanating from the blast had wide ranging and potentially useful military effects.³⁰

As both the U.S. and the Soviet Union began to realize the implications of detonating nuclear weapons in space, they drafted the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*. In this treaty, now with over ninety-five signatories, the deployment of nuclear weapons in space was banned.³¹

Still, in their search for asymmetric advantages against the United States, some nations may be willing to violate the Outer Space Treaty above. Senior members of the Russian government have openly admitted to exploring the implications of nuclear detonations in the upper atmosphere or outer space over the United States in the event of war.³² Writings by two senior Chinese Colonels at one of China's military senior service schools talk plainly of "Unrestricted Warfare," where, if China faced the U.S. in war, they would seek major asymmetric advantages and not confine the conflict to effects on military forces.³³

The EMP effects created by a nuclear detonation over the center of the North American continent could be very serious. A multi-megaton weapon exploding over the central United States would spread a peak electrical field of twelve to twenty-five kilovolts per meter over the area within line of sight (from coast to coast) of the nuclear detonation with considerable impact.³⁴ To put this into perspective, electrical field strengths of three to eight kilovolts per meter can cause temporary upset of commercial off-the-shelf equipment, requiring rebooting computer systems to bring them back on line.³⁵ At field strengths above eight kilovolts such upsets become probable. Field strengths between seven and

twenty kilovolts per meter will cause some equipment to be damaged, requiring component repair or replacement before systems can operate again. Above twenty kilovolts per meter this kind of damage becomes probable.³⁶ These effects would be experienced by ground and satellite based systems alike.³⁷ The potential effect of such a detonation has been likened to taking the entire nation and transporting it back in time to the 1890s.³⁸ The burst of electromagnetic radiation could cause motor vehicles, telecommunications, radio, television, computers, water and sewer systems, and electrical generators to all stop working. While such predictions may seem extreme, and while several government agencies have offered more optimistic predictions, these optimistic predictions have been openly discredited due to several methodological flaws in their testing and evaluation procedures.³⁹

Even more disconcerting, steps taken by various agencies to protect themselves from interference by relatively innocuous devices suggest the actual threat may be quite severe. For example, 'we make passengers on aircraft, during takeoff and landing, turn off radios, games, and other electronic devices. Hospitals regularly place signs that electronic devices are not allowed. Many do not want you using your cellular telephones near their computer. Many repair shops require that wristbands attached to the ground be used when opening electronic equipment for repair.'⁴⁰ In the end, while the exact effects of these pulsed microwaves may in some cases be classified, and in others unknowable, the precautions several industries take against very small emissions suggest the vulnerability to our national infrastructure may indeed be significant.

Worse yet, if the U.S. were attacked, the system failures will likely compound each other. For example, if the electrical system repairmen cannot travel to the damage site because their vehicles are inoperative, and cannot get their vehicles repaired because the local repair shop has neither electrical power nor the phone service to order spare parts, then serious delays will result. The problem is further compounded with the electrical repairmen not even knowing a repair is needed because they are unable to communicate with their command center. Thus, the whole recovery process greatly bogs down and becomes slower still. If this problem is expanded to cover nearly an entire continent, then the recovery pace from such an event might best be described as glacial.⁴¹

Pulsed Microwaves

Admittedly, the preceding discussion focuses heavily on the probable nationwide disruption resulting from a (hopefully unlikely) high-altitude nuclear burst EMP. However, the adverse effects caused on electronic equipment by microwave radiation are not unique to nuclear EMP. Air Force laboratories have made substantial progress in developing microwave sources and antennas that are powered by much more mundane power systems than nuclear explosions. Currently available laboratory sources can produce one gigawatt of power for a few nanoseconds from a source weighing only forty-five pounds. A slightly larger 400-pound source can produce 20 gigawatts of power for the same few nanoseconds.⁴² By comparison, the total power production output of the Hoover Dam is only 2 gigawatts.⁴³ These microwave systems can affect electronics in much the same way as described in the EMP discussion above, albeit their effects are significantly more localized.

Unfortunately, the technical expertise and vast resources of U.S. military laboratories are not necessarily required to develop effective microwave weapons. For example, according to some sources, relatively small devices can be built by individuals using parts available at commercial stores or through mail order, placed in a van, and be capable of effecting buildings across a street.⁴⁴ A small suitcase bomb, which destroys all computers within the radius of its “detonation,” has been built in Russia and reportedly has been sold to the Australian military. The price was around \$100,000.⁴⁵ These devices can produce electrical field strengths of up to 100 kilovolts per meter with a tunable pulse rate to ensure maximum effect on the target.⁴⁶ If the claims made by the designers of such devices are even partially accurate, these systems are capable of disabling electronics over predetermined areas, and U.S. systems are currently vulnerable.

Continuous Wave Microwaves

Most people are familiar with the most common effect of continuous wave microwaves. It heats their foods. This heating is due to the microwave energy exciting the water molecules within the food causing its internal temperature to warm. From a physics standpoint, there

is nothing to prevent microwaves being used on living tissue, and research on the biological effects of these waves has been conducted for the past seventy years.⁴⁷

The initial research into the effects of microwaves on living tissue began in 1931 with experiments examining the capacity of radio waves to induce unusual rhythms into the heart.⁴⁸ By the mid 1940s, research expanded to examine possible relationships between microwaves and the unusual incidence of cataracts in the eyes of personnel who worked in the microwave industry.⁴⁹ By 1957, the scope of research expanded further as scientists probed the death of a young military member who died from an apparent overexposure to radar energy.⁵⁰ Research on effects of large doses of microwaves on various human organs continued through the 1950s, 1960s, and 1970s. The exposure of Moscow-based U.S. Embassy personnel to low levels of microwave radiation in the 1970s fostered a new round of research. Scientists began examining the long-term effects of low-level microwave exposure. This research continued to expand, and as of today, there are at least 957 separate open-source research publications on the medical and biological effects of microwave radiation.⁵¹

Throughout this research, scientists have demonstrated a myriad of microwave effects among which are biological changes on the cellular level, changes in brain chemistry and function, changes in cardiovascular function, creation of lesions within the eye, temporary incapacitation, and even death.⁵² Early research in microwaves also showed that low dosages over long periods could cause changes in the formation of cells in lung tissue and decreasing lung function;⁵³ changes in calcium ions affecting brain and cell function;⁵⁴ changes in blood chemistry;⁵⁵ changes in immune system function, some favorable and others adverse;⁵⁶ and increases in histamine production.⁵⁷ In addition, microwaves have been able to produce performance-degrading effects. For example, microwaves have been able to turn alpha waves into beta waves in the brains of some animals, and a recent Pentagon briefing indicated that effects such as using electromagnetic waves to put humans to sleep or heat them up have been explored.⁵⁸ This research seems to have been confirmed by the Marine Corps Electromagnetic Weapons Project in the early 1980s, which discovered that electromagnetic radiation could be used to cause mammals to release eighty percent of the natural opioids in their brains, placing animals in a stupor.⁵⁹ Substantial research has been conducted into the pain-inducing effects of heating the outermost epidermal layers, and the

U.S. Marine Corps has conducted area denial demonstrations with this technology.⁶⁰

Lethal effects are also possible. The *Washington Post* reported in 1987 that the Soviet Union had used radio wave weapons to kill goats at a range of one kilometer.⁶¹ Research conducted at the Oak Ridge National Laboratory was conducted on an electromagnetic gun what would “induce epileptic-like seizures.”⁶² Another was a “thermal gun what would have the operational effect of heating the body to 105 to 107” degrees Fahrenheit. Such effects would bring on discomfort, fevers, or even death.⁶³ The Russians may have even been able to use electromagnetic energy to create a “voice of God” effect.⁶⁴ If true, microwave energy may have uses in the information operations realm as well.

What is even more interesting are the power levels needed to create these potentially debilitating effects. Research by French physicist Jacques Thuery suggests that many of the uses mentioned above can be conducted with only a few milliwatts of energy per square centimeter on target. Even the most extreme uses involved energy of only around 550 milliwatts (slightly more than ½ watt) per square centimeter.⁶⁵ These energy levels are important when compared with the power generation capabilities mentioned above. As a result, continuous-wave radio weapons (microwaves) may have significant military uses as we move into the 21st Century.

14... Directed Energy Weapons on the Battlefield

III. Future Developments in Directed Energy Weapons

The most effective way to cope with change is to help create it.

--L. W. Lynett

Yesterday is not ours to recover, but tomorrow is ours to win or lose.

--Lyndon B. Johnson

Futurists tell us that there are three basic ways to attempt to determine the future. One is to find a highly regarded expert and have him or her predict the future. The second is to use trend extrapolation. This is often used in science where one extrapolates from past developments to predict the future. Moore's Law of computer chip speed is an example. The last method is to use alternative futures.⁶⁶

As stated earlier, the purpose of this paper is to take a realistic look at what impacts directed energy might have on the battlefields of the future. As a result, using an alternative futures methodology to predict scientific advancement is unnecessarily cumbersome. The futures would bound the problem, but the purpose here is not to look at the extreme possibilities but to examine mainstream probabilities. Thus, this section will draw upon the expert testimony in part two, and will generally extrapolate the trends in directed energy developments to posit a state of technology likely to exist in the 2020-2030 timeframe.⁶⁷

Continuous Wave Lasers

Figure 1 details the development of laser power of operational in-the-field devices over the past 30 years. As the chart shows, initial growth in power output was rapid and exponential. The curve has flattened somewhat in recent years. Still, extrapolating these trends to the 2025 timeframe suggests the state of technology will allow deployment of lasers in the five to ten megawatt (MW) range. From these trends, this paper

posits that the technology will exist to field tactically significant lasers on small to medium sized aircraft, and on large ground vehicles by 2025. Larger devices, perhaps exceeding 10 MW, will likely be fielded as fixed ground stations. The effects of such devices would yield fighter aircraft laser systems capable of destroying hardened vehicles at short ranges, destroying surface-to-air missile sites at extended ranges, and destroying enemy fighter aircraft at ranges well beyond 100 kilometers.⁶⁸ The more powerful surface-based systems would have the capability to engage airborne targets at ranges beyond that of the Airborne Laser, and at approximately ten times greater range than the airborne systems mentioned above. These fixed systems will have two advantages in terms of scaling for greater power. They will not need to be miniaturized to fly, and they will be less limited on the amount of chemical or electrical power they to which they will have access.

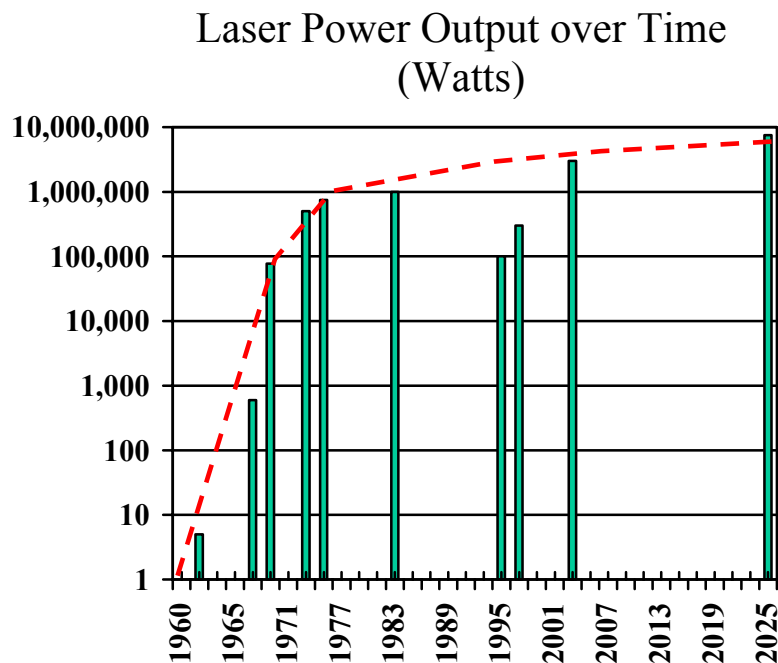


Figure 1: Continuous Wave Laser Power Development Over Time (2025 Extrapolated)⁶⁹

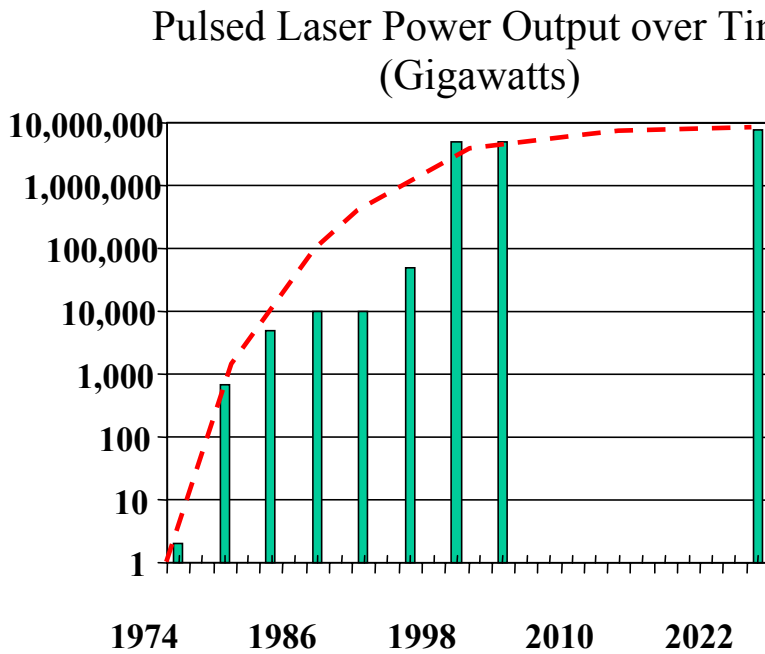


Figure 2 Pulsed Laser Power Output Over Time (2020 Data Extrapolated)⁷⁰

Pulsed Lasers

Like their continuous wave cousins, pulsed lasers have also increased exponentially in power over the past thirty years. Since no weaponization has yet occurred with this type of laser, it is difficult to reasonably extrapolate trends for the future. This paper posits that derivatives from the current level of technology in the laboratory will make it to the field in the next twenty years.⁷¹ Terawatt-class devices may be flying on fighter-like aircraft in the 2020-2030 timeframe.⁷² Due to weight and size constraints, it seems likely that multi-Petawatt pulsed devices will be relegated to ground stations. Still, as the figure below indicates, extremely powerful devices are likely in this timeframe, providing significant military utility. For example, the Lawrence-Livermore 5-petawatt device was capable of generating temperatures at the impact point of several million degrees. Plasma creation, ablation through significant metal thickness, and some all weather capability become possible with lasers of this power.⁷³

Continuous High Power Microwaves

Microwave effects differ from lasers because the effect on the target is only partially dependent on the power output of the microwave device. With microwaves, the specific frequency, bandwidth, and transmission device all have direct bearing on the effects sustained at the target. Nonetheless, power output capability for future microwave weapons will increase in much the same way as the laser devices already explored. With this power production and improved portability, microwaves will enable a very different set of effects-based operations on future battlefields.

As was discussed earlier, continuous wave microwaves can have a variety of potential effects ranging from an intense sensation of heat on a person's skin, to causing incapacitation, to even causing death. The Air Force Research Laboratory has weaponized such a system for non-lethal effects, and it is being tested in conjunction with the Joint Non-Lethal Weapons Directorate.⁷⁴ This paper posits that the development of microwave weapons will continue in the next twenty to twenty-five years. If the United States fails to lead this change, it may be forced to follow the lead of other developed nations.

In the future, continuous wave microwave devices will likely find uses for area denial, force protection, or for non-lethal incapacitation of forces minimizing loss of life.⁷⁵ It is likely this technology will also be developed as a lethal weapon in the form of a "death beam" type device. The wide beam-width of microwave transmission systems, which for some systems are measured in tens of degrees, will enable these effects to become widespread potentially covering large sections of the battlefield.⁷⁶ Thus, microwaves can be viewed as an area weapon. As a result, a different thought process must be used in choosing target sets and setting objectives. Used defensively, the nature of microwaves may reduce the importance of the element of surprise and/or the value of some stealth technologies.

Pulsed Microwaves

In addition to being broadcast as a continuous beam, microwaves can be emitted in short pulses or bursts of short pulses. These pulsed

microwave devices in future warfare will likely come in two basic forms: nuclear driven EMP weapons and conventionally driven pulsed devices.

Nuclear device driven EMP waves will likely change relatively little over the next twenty years. Limitations such as the nuclear test ban treaties will certainly hinder revolutionary advances in this area.⁷⁷ Still, as was shown in part two, peak electric fields of twelve to twenty-five kilovolts per meter will be possible within line of sight of any nuclear detonation. This includes space. Should an adversary launch such an attack, non-EMP hardened electronics would likely be destroyed in an area covering between one million and several million square miles, with severe damage possible out to 1000 miles.⁷⁸

Conventionally driven high power microwave sources will also have a significant effect on future battlefields. These weapons will have long reach, deep magazines, and will be of scalable size. While larger devices will be mounted on ground or air vehicles, some smaller devices will be hand held.⁷⁹ The larger vehicle mounted devices may be capable of interdicting over 100 targets per mission. Further, these weapons will likely have considerable reach. It is not unreasonable, "that a single high power microwave weapon could destroy the entire air defense system," and have a similar impact on the entire command and control network, possibly eliminating the ability to manage military assets.⁸⁰ While it is possible to defend against such attack, it is currently very difficult and quite expensive to harden systems and facilities against microwave attack.

Another area in which additional advancements may occur in pulsed microwave technologies is in the use of wideband pulses. Many microwave and radio transmitters today broadcast on a single carrier frequency, or in only a limited set of frequencies. This has led to programs hardening systems against pulses of a specific frequency. The enhancement of wideband microwave pulse technology will enable the destruction or disabling of those systems hardened against only parts of the electromagnetic spectrum. Thus, only those devices hardened against the entire electromagnetic spectrum will likely survive wideband microwave pulses.⁸¹

The real question is what all these technological developments mean for future warfare. To try to answer this question as completely as possible, we will look at a future scenario in the 2020-2030 timeframe.

IV. The Persian Gulf War of 2025

A moment's insight is sometimes worth a life's experience.

--Oliver Wendell Holmes

The following scenario is for illustrative purposes only. It is designed to raise some of the doctrinal, strategic planning, and operational issues that directed energy weapons will pose. To posit the U.S. as the only owner of these weapons produces a rather uninteresting scenario of rapid U.S. victory. The key challenges to our future warfighting capability will occur when our opponents also possess modern weapons, and when the U.S. is responding in an expeditionary mode. This future picture is murkier, and the outcome is much less certain. The following scenario uses real places, and in some cases real people; however, it is not a prediction of what will happen, only a plausible future of what might happen.⁸² It has its roots in two alternate futures from the Chief of Staff-directed study, *Air Force 2025*, specifically the worlds of "2015 Crossroads," and "King Khan."⁸³

The Rise of China

What was called the American century has given way to the Asian Millennium.⁸⁴ The economies of South East Asia became progressively more intertwined in the early years of the twenty-first century. By the year 2000, over seventy percent of the wealth of Indonesia, Malaysia, Thailand, and Singapore was in the hands of ethnic Chinese.⁸⁵ The trade between the Chinese in the area and the mainland helped the mainland economy grow rapidly.⁸⁶ In late 2000, many estimated the Chinese gross domestic product to be in the neighborhood of \$5.6 trillion, with annual trade with the U.S. at over \$58 billion.⁸⁷ After the economic slowdown in 2002-2004, China's economy continued to grow at around 8 percent per year, and passed the U.S. economy in total size by 2011.⁸⁸ By 2012, Chinese GDP passed \$12 trillion on its way to the \$29 trillion mark in 2025, the same year the United States economy crossed the \$18 trillion threshold.⁸⁹

This robust economic expansion paved the way for China to modernize its military. China increased military spending over 200 percent between 1988 and 1995, and although the pace of growth has slowed somewhat, China's defense spending continues to increase.⁹⁰ China began a restructuring of its military in the late 1990s and continued this during the decade that followed. China began to change a mammoth military equipped with aging and dilapidated equipment into a smaller but more capable force.⁹¹ China purchased *Sovremenny*-class destroyers in the late 1990s,⁹² and began construction of its first aircraft carrier in 2006. The construction of the carrier proved more difficult than expected, and the carrier and its attendant aviation wing were not completed until 2012. Seeking to bolster its force projection capability, China embarked on a program to build a new group every four years until it had seven carrier groups in its fleet. By 2025, four carrier battle groups were in operation. China was also concerned about its ability to project ground forces. A program to build new amphibious vessels was begun in 2005. Today, in 2025, China has sufficient sealift to land three divisions ashore at a point of its choosing.

Well aware of the value of asymmetric weapons, China began investing in directed energy weapons in the late twentieth century. By 2025, China had equipped her naval vessels with 50 TW pulsed laser cannons; pulsed microwave beams capable of inducing kilovolt electric fields in unprotected circuitry at distances of several tens of miles, and continuous wave microwave devices for point defense, area denial, and adversary troop incapacitation. Airborne laser systems, while less powerful, were capable of destroying a tank at ten miles, and engaging an adversary aircraft at more than 100 miles in clear weather. Microwave defense shields were in place around all military assets, capable of disintegrating the circuits of any guided weapon that approached within ten kilometers.⁹³ Aware of the impact of directed energy technologies, and with asymmetric use of these technologies a central theme of their defense plans, China maintains a redundant command and control system with both digital and analog communications. Hardening against use of these devices has been incorporated into all vessels and vehicles built since 2012.

The Rise of Iran

Iran began the twenty-first century in economic crisis. The national GDP had been flat from 1997-1999, and international debt had risen to over ten percent of GDP.⁹⁴ As oil prices rose in the spring of 2000, Iran experienced a balance of payments influx that began to bolster the economy at a rate of over five percent per year.⁹⁵ Iran's economy remained tied to the fortunes of its oil exports, which served the nation well over the period. Iran had over 105 billion barrels of crude oil reserves with many regions of the nation unexplored at the beginning of the century. This was in addition to owning nearly one seventh of the world's natural gas reserves—roughly one quadrillion cubic feet.⁹⁶ As a result of its vast oil wealth, Iran paid off its international debt by 2007, and its economy continued to grow throughout the period. As the economies of Asia grew stronger, and as their demand for oil became greater, trade between Iran and China more than quadrupled in this period. Further, as Iran fulfilled China's need for oil, China acted as Iran's primary supplier for arms and a strategic partnership was formed.⁹⁷

In 2025, Iran has a GDP of approximately \$1.4 trillion (constant 2000 dollars), and a population approaching 120 million.⁹⁸ It has an armed force of over 450,000 with over 400 tanks, half equipped with directed energy weapons, and 400 combat aircraft, including two wings of recently acquired stealthy Chinese fighters. Iran has fielded a submarine fleet of an estimated 100 vessels, several of which are capable of extended silent running, and has constructed several ultra-high-energy laser and high power microwave weapons on the islands in and on the mainland around the Straits of Hormuz.⁹⁹ These weapons have on-site generation capability, and are tapped into the national power grid for augmentation.

The Theocratic Government of Saudi Arabia

The reign of King Fahd came to an end in late 2011 as a result of an uprising by the religious clergy within the kingdom. Efforts by CENTCOM Commander to maintain an American presence over the first ten years of the century received support at home and were begrudgingly accepted by King Abdullah as a continuing counterbalance to Iraq, and later to Iran.¹⁰⁰ The continued presence of Americans on what was

considered “Holy Ground” by most Muslims in the region continued the downward trend of stability within the Saudi Kingdom.¹⁰¹ Feeling “more is better” the plans to jointly exercise U.S. and Saudi forces developed by the CENTCOM staff only exacerbated the problems.¹⁰² As a result, uprisings began in 2012, which the Saudi military forces were hard-pressed to control. In the end, the unwillingness of the Saudi army to kill their countrymen and esteemed religious clerics resulted in the toppling of the government in March 2013. The religious theocracy that came to power requested all non-believers leave Saudi soil not later than October of that year, and permanent American military presence came to an end. While the Saudi economy remains intact, and the standard of living continues to slowly improve for the Saudi people, American presence on Saudi territory appears unwelcome unless Saudi Arabia faces imminent invasion of their own territory.

The United States

The United States began the new century as the world’s one and only superpower. The tax cut package implemented in 2002, combined with increased military and homeland security spending, resulted in an end of the budget surpluses that characterized the 1990s.¹⁰³ Pro business lobbying and a generally conservative congress resulted in no movement within the U.S. in development of a national energy policy, or the development of more energy efficient infrastructure. The U.S. ended the year 2000 importing forty-nine percent of its domestic oil needs.¹⁰⁴ It enters 2025 importing more than sixty percent of the oil needed to run the economy and fuel its cars, trucks, motorcycles, and aircraft.

The economy continued to grow throughout the period. The GDP rose from just under \$9 trillion in 2000 to a 2025 level of nearly \$19 trillion.¹⁰⁵ Despite the robust economy, a series of tax cuts kept federal revenues relatively steady. Thus, while there was a recovery from the post cold war military drawdown, this recovery has been slow. The U.S. enters 2025 with ten full aerospace expeditionary forces, which contain the F-22, JSF, and more than twenty airborne laser attack platforms each.¹⁰⁶ The Army has succeeded in implementing much of the Joint Vision 2020 capabilities, but has only started the conversion to what was known in 2000 as the Army after Next. The Navy is back to thirteen carrier battlegroups with each major combatant ship and submarine having high

energy laser and high power microwave weapons. Powered by nuclear plants, the weapons on the aircraft carriers and submarines are on par with larger fixed ground stations. Stealthy cruise missiles and stealthy aircraft predominate the air component of each of the services.

The Trigger Events

Worldwide oil production finally plateaued in 2025, peaking at 118 million barrels per day.¹⁰⁷ Global demand continued to increase, however, and now stood at nearly 126 million barrels per day.¹⁰⁸ The result was that on February 1, 2025, oil hit a price of ninety dollars per barrel (constant 2000 dollars) and threatened to reach \$130 by midyear.

The economies of the world's great powers were greatly strained with China and the United States facing the same basic problem. Both desired continued unimpeded economic growth--China for stability; the United States for prosperity.¹⁰⁹ The Chinese leadership feared a breakup and fragmentation of the country if cheap oil sources for their economy could not be secured. The leadership decided to leverage its long-standing relationship with Iran to further Chinese economic needs while providing for the attainment of Iran's long-term goal of becoming the Middle East's greatest regional power. Similarly, the United States sought to leverage its alliances to maintain U.S. access to vital world oil supplies.

In early February, the Chinese Premier conducted a summit with the Iranian President and the leading Iranian clergy to enlist their support for continued Chinese economic growth. This summit included covert discussions of Chinese support to an Iranian attempt to increase their control over all oil flow in the Middle East. In return, Iran promised China sufficient oil to maintain their economic growth. As the summit concluded, three Chinese aircraft carrier battlegroups, nineteen major amphibious troop carriers with over 20,000 combat troops, and over fifty submarines began to steam toward the Straits of Hormuz.

On February 19, Iran announced that it would use all of its resources to supply oil solely to China. World spot market oil prices rose overnight by fifty dollars per barrel. Qatar and the United Arab Emirates indicated they would sell only to the West on February 21. Iran responded by seizing all islands in the Straits of Hormuz, and declaring that they would exercise the rights to determine which vessels may pass through the narrow straits, which they defined as the sovereign waters of Iran. Iran

immediately deployed its entire submarine fleet (estimated at 100 vessels), and powered its directed energy network along its coastline.

U.S. Deployment

The President ordered a freedom of navigation exercise through the Hormuz straits. The American aircraft carrier Independence sailed through the straits the next day. The carrier was attacked by Iranian laser stations, which destroyed the carrier's laser emitter. The carrier also sustained laser-induced gashes along the entire port side of the vessel. The gash was thirteen inches wide and stretched from stem to stern only fourteen inches above the water line. Minutes later, the Independence was attacked by at least six submarines. While the subs did not sink the vessel, their torpedoes caused the carrier to take on water. As the carrier sank further, water poured through the gash along the entire length of the vessel. Four hours later, with its pumps unable to keep up with the flow of water, the quick-thinking captain ran the carrier aground off the coast of Oman to prevent the vessel from sinking. The carrier sat there, useless, listing twenty-two degrees to port. Three other major combatants also sustained severe laser induced damage and steamed out of the straits back into the Gulf of Oman. Preparations were being made to tow these vessels back to the U.S. for repair. In the aftermath, the American people and congress reacted angrily. For the first time in nearly eighty-five years, Congress declared war. Three nights later, special operations forces attacked the Iranian laser station involved. In response, Iran and China launched a massive search and destroy mission against all U.S. forces in the Gulf region.

The Secretary of Defense issued deployment orders for the 9th and 10th AEFs to the region, and activated stages I and II of the Civil Reserve Air Fleet. Within twenty-four hours, units from the 1st and 27th Fighter Wings and the 92d Air Reserve Wing arrived in theater.¹¹⁰ Some bases in the region were deemed unusable due to the extended reach of the Iranian laser weapons. All facilities within seventy miles of these sites were determined to be at unacceptable risk.¹¹¹ The Saudi government denied other bases, as they did not perceive a threat to their sovereignty. Unaware of any threats near the bases, the heavy airlift began to arrive in theater. However, clandestine Iranian operatives used portable directed energy weapons to cause one C-17s and two civil reserve air fleet aircraft

to crash while landing.¹¹² The weapons were used to incinerate the pilots and their clothing on short final, resulting in a loss of aircraft control. In two cases, the aircraft crashed into parts of the base infrastructure. All total, more than 700 Americans died on that day alone.¹¹³ Host nation forces began to scour the countryside to find the Iranian operatives, but were able to find only one team in the following three days. The U.S. was faced with a difficult decision: whether to risk further deployments without finding all the Iranian teams, or whether to place the time phased force deployment on hold. Because the major airlines were not convinced that their assets could be adequately protected, all withdrew their fleets from the CRAF.¹¹⁴

The first aircraft and equipment arrived in Theater on February 27. Before and during the deployment process, Iran and China launched numerous stealth HPM UAVs that targeted each potential U.S. deployment base and port with periodic HPM pulse bursts. Despite host-nation attempts to fend these off, many of the microwave attacks were successful. The attacks caused damage to commercial-off-the-shelf computer equipment that now formed nearly every workstation used for administrative functions, command, and control. Aircraft on the field and near the aerodromes suffered damage as well, including two jets lost on landing. Others suffered computer systems failures because they were hit by the HPM pulses while taxiing after landing. In the end, much of the U.S. equipment arrived in theater damaged, and substantial repair and replacement of equipment was going to be necessary before an effective command and control system would be established. Fully operable base defenses including directed energy weapons finally put an end to the microwave attacks on 7 Mar, and the CFACC's command and control network was repaired and operational one week later. As a partial solution to the microwave attacks, the CFACC initiated setup of a laser based inter-theater communications system.¹¹⁵

Employment – War

The CFACC ordered a naval cruise missile and UAV strike against the Iranian defenses. Iranian laser weapons destroyed the high altitude UAVs at a range of nearly seventy miles from their targets. Only a few missiles penetrated the laser detection network.¹¹⁶ Pulsed HPM signals emanating from Iranian installations caused over ninety percent of the

cruise missile systems that defeated the laser network to fail enroute to their targets. While no casualties were sustained, only one major enemy directed energy weapon site sustained damage. The AF was left in a quandary as to how to engage fixed defenses whose firepower was in excess of anything that could be carried in the air.

In retaliation for the CFACC attempted strike, Iran turned its lasers skyward. As polar orbiting satellites passed within two degrees of latitude and longitude of a fixed Iranian laser site, the weapon was used to disable and destroy satellite components. In the first twenty-four hours, twelve U.S. satellites were destroyed or had their optical sensors rendered permanently inoperative. The U.S. president and secretary of defense threatened an overwhelming response, but were initially at a loss as to how to conduct it.

U.S. Special Forces were deployed to the theater in large numbers. Assisted by groups of “indigenous warriors” special forces teams began studying how to take down the Iranian integrated directed energy defense system.¹¹⁷

While Iranian proxies opposed the deployment and continued to conduct sporadic attacks, the Iranian forces made no further land advances. Iranian directed energy weapons effectively closed the Straits of Hormuz to all shipping not desired by Iran. The Navy regained submarine superiority in early May.

U.S. Navy Special Forces mounted a coordinated attack on the Iranian coastal directed energy defenses. With air power unable to breach the laser defenses just inland of the Iranian coastline, underwater vehicles were used to insert Special Operations Forces. These teams targeted the directed energy installations near the Straits of Hormuz for destruction. The teams used portable HPM weapons to disrupt installation security systems, and sensor networks, used portable infrared lasers to kill at distances, and successfully breached the installations’ perimeters.¹¹⁸ Explosives were planted in each facility and were detonated by the retreating teams. The teams believed all coastal installations were destroyed. Destruction of laser batteries deep inside Iran using these tactics was not possible due to the limited range of the Special Forces’ insertion vehicles. Despite the American victory, the spot market continued to increase in price, and had doubled to \$180 per barrel. The U.S. tapped the strategic petroleum reserve, which kept the U.S. economy afloat, but global stock markets were falling in the uncertain atmosphere.

The deployment of forces continued for over two months. By early May, the U.S. and China each had three carrier battle groups in the region with the associated combat support vessels. The U.S. Air Force had two AEF equivalents in theater, opposed by a recently modernized Iranian Air Force, augmented by the Chinese, with a combined six fighter wings of second-generation stealth aircraft. The Army had the 82d Airborne Division, and one heavy division in theater with a sixty-day supply of combat arms. The Marines had a single MEU-SOC off shore being protected by one of the carrier battle groups. As of the fifteenth of May, neither the U.S. nor Iran had any low earth orbiting space assets left in service.

The CFACC's first concern was gaining air supremacy. There were two problems facing him. First, many of his fighter aircraft were severely damaged in the Iranian microwave attacks during deployment, resulting in an initial mission capable rate of less than fifty percent. In many cases, avionics and flight control wiring and computer systems had to be pulled and replaced. These repairs were not only manpower intensive, but they required cannibalization of aircraft assigned to units not deploying to provide the spare parts needed to return the two AEFs to combat ready status. The second problem was how to attack the Iranian interior defenses and the Iranian Air Force, when their ground systems had a greater reach than the CFACC's fighter resources.

This left the CFACC two options. Settle for temporary air superiority when U.S. ground forces attempt landings, or engage in what would likely be a very expensive war of attrition against the directed energy systems of Iran. The CFACC opted initially to provide air superiority over U.S. ground forces and not take on the entire Iranian defense forces.

The next phase of the CFC's plan involved taking Iranian island and coastal territory to ensure the Straits of Hormuz were not threatened by repaired Iranian defenses the Special Operations Forces destroyed. The 82d Airborne Division attempted a landing at Abu Musa and the MEU-SOC attempted an amphibious landing at Salakh.¹¹⁹ The CFACC provided fighter and Airborne Laser cover for the operation. As the C-130s laden with the 82d Airborne troops approached Abu Musa, Iranian ground forces equipped with transportable laser systems lased the cockpits on approach. As with the initial deployment, two aircraft were downed on final approach before the fighter cover could react. Lasers and kinetic kill weapons were fired from the fighter cover, destroying the ground lasers as

they were detected. During this engagement, a squadron of Iranian fighter aircraft also engaged friendly forces using laser and other devices. In the end, the USAF downed twenty Iranian aircraft, but sustained the loss of fourteen, including five C-130s.

Prior to the MEU-SOC landing, and unknown to the Americans, the Iranian coastal defense authorities were able to get one laser defense installation back on line on a hill near Bander-e-Dulub, slightly more than twenty kilometers from the MEU-SOC landing site. As the landing force came within firing distance, the Iranian Air Force engaged the remaining protective air cover with lasers and beyond visual range missiles. Both sides sustained heavy losses. As the landing force approached the shore, the newly recommissioned laser battery fired on the remaining protective air cover, downing several aircraft, which caused the others to scatter. It then turned its firepower on the landing force. Within only a few minutes, the MEU's combat power was effectively neutralized. The Marine force sustained nearly thirty percent casualties; many were vaporized or burned beyond any hope of recognition. A hastily arranged strike by several dozen missiles overwhelmed the site's ability to defend itself and again took the laser site out of commission. The Marines gathered their dead; over 500 body bags were filled. More challenging for mortuary affairs was what to do approximately 220 Marines who were killed but whose disintegration left no remains.

In retaliation for the landing, the Iranian defense force launched a 300-kiloton nuclear weapon and detonated it approximately sixty-five miles over Kuwait City.¹²⁰ The detonation caused virtually no damage at the surface and though a brief burst of neutron radiation was detectable, it fell well below lethal limits. However, the detonation sent a current through every electrical wire within several hundred miles of the detonation site. Virtually every computer component within the Middle East Theater that was not located in a hardened site was destroyed. The Expeditionary Air Force units, who deployed to bare bases in tent like facilities, suffered near total loss of all computer and communications capabilities. Much of the theater command and control center was effectively destroyed, though the laser piece of the communications system remained operative. Most allied aircraft sustained damage to their computer-controlled systems. More than seventy percent of the aircraft in theater were non-mission capable, but due to the command and control difficulties, the leadership in the U.S. remained unaware of the extent of the problem for nearly a day.

The U.S. responded with the Carrier Task Force from the Far East. It arrived four days later and was able to launch retaliatory strikes on Iran. Meanwhile, the Chinese carrier groups now also in the Middle East launched attacks on the U.S. Carrier Groups, only to be shot down at great range by the directed energy weapons on-board the U.S. ships.

The U.S. began with a nuclear EMP detonation over the center of Iran, and then followed up the attack with a series of cruise missile attacks on the directed energy installations.¹²¹ This attack was successful since the Iranian systems were down due to the EMP strike. Air Force and Naval fighter and attack assets then began a slow parallel takedown of the Iranian electrical generation capacity, which was a key node in their directed energy defenses. With Iran's defensive directed energy technologies now reduced, a parallel warfare program was launched against the Iranian leadership and their communications, commensurate with the available combat ready assets in theater.

In response to the U.S. attack, Iran and China began an all out assault with what was left of their submarine fleet. This minor battle took on a more traditional and conventional flavor. It took only three weeks for the U.S. forces to locate and destroy the Iranian submarines. Before that occurred, the Iranians and Chinese managed to sink four more surface combatants and severely damage one more aircraft carrier. In the end, the U.S. succeeded in eliminating the Iranian submarine threat and partly reopened the Straits of Hormuz. By the end of July, over 35,000 Americans had died, and another 47,000 were injured. Worse, the major shipping lanes were awash in obstacles as a result of the sinking of the vessels. By this point, the American people were frustrated and the anti-war protest movement was clearly gaining momentum. Material losses in the Department of Defense had already exceeded \$35 billion, operations costs were over \$90 billion, oil prices were still rising, and American servicemen were coming home in body bags by the thousands.

During the submarine wars, Iran began to put its power generation capacity back on line. They began in the Teheran region, but concealed the actual status by leaving the power grid un-powered.¹²² With the two laser batteries guarding the capital repaired, on September 2, the lights in Teheran came back on. The Iranians used these batteries to keep enemy aircraft from attacking within a seventy-mile radius of the capital. Near the borders of this circle, the Iranian military constructed new laser batteries, and extended the power supply system, gradually expanding the area under the laser umbrella. While the CFACC attempted to attack these

batteries, bi-static radars, and laser sensors enabled detection of the attacking systems. Dozens of cruise missiles, UAVs and bomber aircraft were destroyed in the attempts to keep the Iranians from reconstructing their defense network. Within three months, the original defense network was restored, and laser batteries on mountains overlooking the Straits of Hormuz were occasionally operational once again. In the New Year, the war degenerated into a quasi-stalemate. While the U.S. had the upper hand, Iran used directed energy weapons to wage a campaign of terror against vessels transiting the straits. While the straits remained “open,” many ship captains were unwilling to attempt passage.

Over one year after the start of the conflict, the administration felt it was losing the support of the American people. Saudi Arabia offered to broker a cease-fire between the U.S. and Iran. There was no peace, only a cease-fire...and Iran still insisted on selling all its oil to China. In the end, the incumbent administration elected to create a comprehensive energy policy aimed at achieving energy independence at home.

V. Implications and Recommendations

When one has finished building one's house, one suddenly realizes that in the process one has learned something that one needed to know in the worst way – before one began.

--Friedrich Nietzsche

This paper has sought to raise the awareness of DOD on several key issues regarding directed energy weapons in the future. These issues should be thoroughly considered as we build our forces for the future.

The Primacy of the Defense

Since fixed sites can be constructed to make maximum use of large power sources, and since the range of a directed energy weapon is directly related to the power available, fixed directed energy sites will have greater range than portable systems. This will likely cause an increase in the primacy of defense. These defensive sites produce an enormous conundrum for an expeditionary attack force. If the deployment base is within the range of the fixed site, deployment may not be possible until after the site is destroyed. If the deploying force is fully expeditionary, the destruction of the site may not be possible via conventional means until deployment is achieved. Even if this problem is solved, a second challenge remains. Advances in bi-static radar and other sensor technologies likely in the next twenty to thirty years will make surprise very difficult to achieve, if it is achievable at all. Thus, future attack operations against fixed sites will carry extreme risk and may require the use of special operations forces with specialized skills and advanced, portable, directed energy equipment. In any event, the utility of conventional attack against such installations as it is now conceived, becomes extremely problematic.

The Need for Advanced Stealth – Almost Everywhere

To the extent conventional attack remains possible, the need for surprise becomes a need for stealth. However, this will require much

better stealth technology than is currently embodied in the F-117 or the B-2. New passive radars using bi-static technology will enable detection of all aircraft that do not absorb electromagnetic emissions across the entire spectrum. Laser sensors, which will send out laser pulses and look for reflections, will detect anything that reflects light.¹²³ Once these laser sensors make it to the battlefield, the minimum threshold for effective stealth will be a system invisible to radars, passive electronic signal collectors, and reflected light or laser beams. This is an extremely high threshold for success, which if achievable will likely be extremely expensive. The cost of not having this technology will be much worse – irrelevance in a world with sophisticated, highly effective directed energy weaponry on both sides of the battlefield.

This level of stealth technology will be needed on all platforms that come within the lethal range of these directed energy systems. Some of these systems could potentially have ranges of several hundred kilometers, which means some transport and specialized aircraft such as the AWACs, JSTARs, Commando Solo, refueling aircraft and Airborne Laser platforms will need to incorporate advanced stealth technology just to perform their basic missions. The lack of stealthy airlift and tanker platforms in this timeframe will necessitate the creation of either stealth air refueling aircraft, or new stealth fighters with greatly extended range similar to the former F-111, or current B-1.

This need for stealth is not limited to aircraft or the Air Force. Naval vessels will need to be harder to detect or they will increase their vulnerability to long range directed energy systems and reduce their relevance in ‘brown-water’ conflict. Ground-based systems will need to incorporate camouflage and tactical deception to avoid attack. In short, the development of lethal directed energy weapons with advanced detection systems will result in a need for increased emphasis on detection avoidance in all the armed services.

Challenges for an Expeditionary Force

The advent of high power microwave weapons may create serious problems for unhardened facilities. The expeditionary mindset of DOD will need to include methods of ensuring communications and computer systems are not vulnerable to electromagnetic attack, especially early in the deployment phase. There are two possible methods to do this.

There is substantial evidence that a combination of fiber optics and laser communications may provide at least a partial solution to this problem.¹²⁴ Combining these technologies with optical switches currently being researched by the Naval laboratories would clearly enable a robust inter theater communications system. This will not solve the problem of hardening the automation technology, nor does it fully secure the communications between the forward headquarters in theater and continental U.S.-based activities. To be totally effective in eliminating the transient currents in communications and computer devices, total abandonment of metal-based connectors, wires, circuits, and computer chips may be necessary.¹²⁵

Alternatively, a major construction program of electromagnetically hardened facilities at all potential expeditionary forward operating locations may also be a potential solution. To maximize readiness, these facilities should be constructed to house all operational units, command and control facilities, vehicles, and aircraft. These facilities will require periodic maintenance and the permanent basing of a small cadre of support personnel. Unless the automation technology on which DoD depends is hardened against all bands of RF energy signals, hardened facilities may be the only way to guarantee operability of the technology on which our operations currently depend.

If the construction of Cold-War like hardened facilities at all prospective forward bases is perceived to be too expensive, there may be another method of protecting combat capability from electromagnetic attack. If all systems, vehicles, and aircraft are designed such that all computer circuits were located in a module that is rapidly accessible and replaceable, then hardened facilities need be constructed only to hold these modules. After a microwave attack, maintenance personnel would then remove and dispose of the old aircraft/vehicle modules and install the new ones. While this may also be expensive and will certainly require substantial stockpiling of spare electronics parts, it may prove less costly than constructing large numbers of electromagnetically-hardened facilities.

The disruptive nature of directed energy weapons also places a premium on the ability to defend the base during the earliest stages of deployment. Since the ability to defend against directed energy weapons is directly dependent on the range of the defensive weapon, consideration should be given to building robust defenses at the installations overseas to which we would deploy. If directed energy defenses are used, the range of

the systems will be dependent on the power output of the respective systems, which, in turn, is directly related to the available input power. As such, permanent or fixed-site systems will have greater range than transportable systems, and would provide a better defense of forward operating bases, enabling expeditionary deployments to succeed. These systems, like any permanent hardened facilities, would require continuing maintenance by a cadre of assigned support personnel. The combinations of these two future potential requirements result in a need for reestablishing a minimally manned but robust overseas basing structure. This alone will take considerable time and diplomatic effort to achieve.

Hardening of Commercial Systems

Commercial off-the-shelf systems will likely need hardening also. Substantial research is being done in places like The Army Space and Missile Center at Huntsville, AL, and this research has led to “eighty percent” solutions against specific microwave frequencies. Unfortunately, this does not address the wider range of frequencies likely to be encountered in the future. Still, these technologies hold promise that may protect systems from damage from attacks by some future weapons.¹²⁶ However, if protection technologies do not mature sufficiently, then one of two strategies must be pursued. Either DOD will need to procure specially designed desktop computer systems hardened to a sufficient level of protection, or backup systems such as Plexiglas boards and grease pencils will need to be kept in reserve for command and control should the computer systems fail. The latter option above will be workable if staffs and aircrews are trained in manual methods of planning, executing, commanding and controlling missions. However, this type of training is no longer conducted, and we are rapidly creating a generation of officers who lack the skills to efficiently conduct operations without automation.

Force Protection

Personnel protection will need to be enhanced. DOD’s present mindset on laser eye protection is myopic. The real laser protection issues for the future have to do with being able to keep our people from being burned or vaporized by laser beams powerful enough to do so. Current materials like Nomex can provide a couple of seconds of protection but

are inadequate to protect against even modest laser exposure.¹²⁷ Additionally, personnel protection against microwave weaponry will also be needed. This may be possible by building a protection into outer garments that will keep microwave energy from penetrating further, much like a Faraday cage prevents microwaves from leaking from a household appliance.¹²⁸

Lastly, protective measures for combatant systems need to be explored. The question of whether it is even possible to protect a satellite, aircraft, tank, or naval vessel against high-energy lasers must be researched. While reflective coatings may work against continuous wave lasers (i.e., reflecting the laser using a polished silver surface), such materials may be less effective at pulsed lasers that tend to ablate material off of a surface. Protection against a combination of the two types of lasers (pulsed laser ablates the surface causing it to be non-reflective, continuous wave laser then makes the kill) may also need to be investigated.¹²⁹

Doctrine

Doctrine and tactics will need to be revised. With detection and aiming systems good enough to kill missiles at distances of several hundred kilometers, the primary doctrinal principle in this environment is “He who shoots first, wins!” The corollary to this is that he who has the longest-range weapons, wins, since the one with longest range is the one who has the ability to shoot first. This may require rethinking national policies dealing with shows of force and preemptive strikes.

Shows of force and freedom of navigation exercises will be high-risk operations, and as such may lose their value to diplomats and the nation’s civilian leadership. Long-range attack from fixed-site directed energy weapons will have the ability to cause significant damage to surface combatants or to deploying forces. Freedom of navigation exercises, especially in narrow passages such as the Straits of Malacca, Straits of Hormuz, and the South China Sea, may become “turkey shoots” to determined adversaries, placing thousands of U.S. forces at risk. Further, the cost-benefit calculus may benefit the adversary. If he attacks and succeeds the adversary can potentially sink or heavily damage vessels worth billions of dollars and cause casualties numbering in the thousands. If the adversary loses the engagement, he may lose a weapon worth a few

million dollars and the lives of a few operators. This change in calculus may force re-thinking of U.S. foreign policy and doctrinal alternatives short of conflict.

Because of the combined potential of accuracy and lethality of directed energy weapons, preemptive strikes may be one of the few viable options. As discussed earlier, an adversary equipped with fixed-site directed energy weapon systems could engage in several effective anti-access strategies. If these systems remain active during deployment, the casualty costs to the U.S. could be high. Preemptive attacks against these sites, while risky, may be the only way to prevent large losses early in a conflict. As such, Special Operations Forces may be a key enabler for future regional contingencies.

Directed Energy Weapons—Are They Weapons of Mass Destruction?

Directed energy weaponry will clearly increase the ability to wage war. As such, one of the most important implications is whether directed energy devices will be considered to be weapons of mass destruction. As power outputs for these weapons improve, they will be capable of engaging forces at extremely long ranges, and causing casualties at a rapid pace. The issue as to whether directed energy is a new form of mass destruction weapon will not be resolved with finality in this paper, however, it is appropriate to examine directed energy weapons with respect to the characteristics historically attributed to the other forms of weapons of mass destruction.

The phrase “weapon of mass destruction” has been in our lexicon for so long, that it has become almost synonymous with nuclear, biological, and chemical (NBC) weapons.¹³⁰ Despite this, there are a series of characteristics that NBC weapons possess, that could form a litmus test as to whether directed energy devices fit this category.

Historically, WMD are juxtaposed from conventional munitions by virtue of their ability to compress the time and effort needed to kill, injure or incapacitate.¹³¹ Further, these weapons have the ability to inflict death and injury over wide areas, with the prospect for considerable collateral damage.¹³² Other sources refer to WMD as “weapons that are capable of a high order of destruction and/or being used in such a manner as to destroy large numbers of people.”¹³³ In general, it seems that weapons that cause

large numbers of casualties, and that have the capacity for large levels of collateral damage or indiscriminate killing are called WMD.

Figure 3 compares the characteristics of NBC and directed energy weapons. Of the three NBC weapon types, each has a high ability to produce casualties, a high rate of producing casualties, and is indiscriminant in its application. Laser and microwave weapons, as described in earlier sections, are somewhat different. While both weapon types can be used indiscriminately, in normal operation neither fits the criteria for WMD. Microwaves can be totally non-lethal, and both lasers and microwaves have beams that can be aimed to reduce the potential for collateral damage. However, like many conventional munitions, indiscriminate use of lasers or lethal microwaves can produce widespread collateral damage and WMD-like effects similar to the conventional munitions used on Tokyo and Hamburg during World War II. While such indiscriminate use would likely violate the laws of armed conflict, this author contends that neither lasers nor microwaves should be considered a form of WMD.

Others may reach different conclusions, and this may affect their response to directed energy use. For example, if weaponization of lethal microwaves occurs, then a future adversary may see this as a form of WMD. For example, if an enemy officer comes across his soldiers lying dead with no bullet holes or outward signs of what caused their death or incapacitation, this adversary may conclude a chemical attack had occurred. As a result, the adversary may respond as if WMD were used. This is especially possible if the adversary is unfamiliar with the directed energy technologies and their effects. Thus, even if we have used a directed energy weapon in a precise attack, how we use it may have profound implications for others' interpretations as to whether WMD have been used and how they will respond. Should the U.S. ever move toward weaponizing these technologies, these implications must be considered.

	Casualty Level	Casualty Speed	Collateral Damage Potential
Nuclear	Very High	High	Indiscriminant
Chemical	High	High	Indiscriminant
Biological	High	Medium to High	Indiscriminant
Laser	High	High	None*
Microwave	High/Low	High	Medium*

* Using laser or microwave in a “scanning” role can yield collateral damage of an indiscriminant nature.

Figure 3: Weapon of Mass Destruction Characteristics

VI. Conclusion

Technologies for directed energy weapons are here today. They will be considerably more widespread, more available, more powerful, and more lethal on the battlefields of tomorrow. As such, the Air Force and DOD must grapple with the strategic implications of these weapons, and that struggle must begin today.

It currently takes approximately twenty years to bring new major weapon systems from conception to production. Once procured, these systems often remain with us for over thirty years. Thus, the plans and programs of our Air Force today are building our Air Force and Department of Defense force structure that will be on the front lines in 2050...twenty-five years beyond the date of the conflict posited in this paper. As a result, for some systems in the procurement pipeline, it may already be too late to ensure their viability on future battlefields.¹³⁴

Responsible stewardship of taxpayer-provided resources demands that we ensure our future systems are adaptable to a directed energy environment. Aircraft such as the F-22, JSF, and Special Operations M-X, must be able to survive and continue to perform their mission even in the presence of intense microwave and laser radiation. While protective systems are not currently developed, these aircraft must be built in such a manner that it will be easy to integrate new, more survivable technologies as they become available. The optimum mix of manned and unmanned combat systems must also be identified and achieved. It is likely that the increased risks associated with future operating environments will significantly change this optimum mix, and that these changes ought to impact current and near-term procurement priorities.

Of longer strategic concern are the mindset changes that may accompany the arrival of directed energy weapons to the battlefield. The ability of these weapons to destroy tent cities in seconds may require a more hardened basing concept than is currently used. It is likely that we will need to use bases with an in-place defense and electromagnetically hardened support structure to which expeditionary air forces deploy. This may require a permanent overseas base-support presence in all regions in which the U.S. has vital interests. This in turn may require a larger overall force structure, and the re-gaining of basing rights in areas where we have already relinquished them as part of the post-cold-war drawdown. None

of these proposals will be easy, and most will be expensive and require long lead-times. Planning in these areas may need to start soon.

The most troubling implications are those that cannot now be divined. The technology trends suggest directed energy weapons and their associated computer tracking and firing systems will become nearly 100 percent lethal—eventually on both sides of conflicts. If this is true, and casualty aversion remains as it is now, then if fixed sites have an advantage over mobile forces, it may not be politically feasible to wage war unless the survival of the state is at stake. A serious examination of the doctrinal implications is needed. Further, if stealth technology cannot be substantially improved, then the survivability of all surface, airborne, and space forces is rapidly called into question. This could lead to a new era of attrition warfare, such as those in the 1860s and 1910s. If true, then there are also major implications for force structure.

This author claims no prescience of the future. This publication is merely an attempt to begin a crucial debate within our Air Force and within DOD on how best to prepare for the world that lies ahead. What seems clear is that we have only five to ten years before earnest preparations to meet these challenges will need to be underway. Even with the most concerted of efforts, it will take us that long to select a path on which to proceed. This debate is important, because directed energy weapons promise to transform the battlefield at least as much as the rifled barrel, and at least as much as the aircraft...maybe even more. As such we have a choice to be proactive and lead that transformation, or be left behind as the world changes around us. At stake is the future of the United States and the world in which we live.

Notes

¹ Walling, Eileen M., Colonel, *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology, Air University Press, 2000, p. 1

² Powell, Howard T., *Keeping Laser Development on Target for the National Ignition Facility*, available at <http://www.llnl.gov/str/Powell.html>, 20 Oct 00, p. 2 and Shifan, Ji, *Development of Tactical Air Defense Laser Weapons at Home and Abroad: An Outline*, National Air Intelligence Center, Wright Patterson AFB, OH, 1996, p. 4

³ Ackerman, Dr. Harro, Chief Laser Division, Air Force Research Laboratories Directed Energy Directorate, personal email, 23 Jan 2002. This author is indebted to Dr. Ackerman for several suggestions that greatly improved the accuracy of the history section of this paper. For a full discussion of the history of directed energy technologies, see also: Duffner, Robert and Mark, Hans, *Airborne Laser – Bullets of Light*, Perseus Publishing Company, Cambridge, Massachusetts, January 15, 1997, 398 pp.

⁴ Ibid.

⁵ Powell, Howard T., *Keeping Laser Development on Target for the National Ignition Facility* and Shifan, Ji, *Development of Tactical Air Defense Laser Weapons at Home and Abroad: An Outline*

⁶ These problems were solved and this laser went on to be a successful demonstrator at significantly higher power levels. Ackerman, Harro, personal email.

⁷ Ackerman, Harro, personal email

⁸ Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, p. 54

⁹ Boeing Aerospace Representatives in discussions at their display at the Directed Energy Society Symposium, Albuquerque NM, November 1999.

¹⁰ Talbot, John P., *Laser History—Airborne Star Wars Laser*, available at <http://www.achilles.net/~jtalbot/history/starwars.html>, October 19, 2000, 4pp and “Airborne Laser Fact Sheet,” Missile Defense Agency, Washington DC, April 2003, available at: <http://www.acq.osd.mil/bmdo/bmdolink/pdf/laser.pdf> as of April 4, 2003.

¹¹ Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, pp. 54-56. Pake covers both the derivation of the mathematical formulas as well as defining the amount of energy required to destroy these targets.

¹² Discovery Channel—Canada, *Airborne Laser Assault From the Skies*, world wide web article available at: <http://exn.ca/starwars/superlaser.cfm>, October 25, 2000

¹³ Moss, William C., *Taking Short Pulse Laser Energy to New Peaks*, Science and Technology Review, September 1995, p. 35

¹⁴ Ibid. Moss discusses a method using diffraction of the light beam to accomplish this task.

¹⁵ Powell, Howard T., “*Keeping Laser Development on Target for the National Ignition Facility*,” Available at the National Ignition Facility website at <http://www.llnl.gov/str/Powell.html>, 20 October 2000, p. 2. Here Powell compares the final generation capacity of the laser of 500 trillion watts to the national generation

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capacity. The reference in the text uses his relationship to extrapolate the appropriate power output for the smaller 100 Terawatt tabletop device.

¹⁶ Moss, William C., *Taking Short Pulse Laser Energy to New Peaks*, Science and Technology Review, September 1995, p. 35, and Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, pp. 256-267

¹⁷ Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, p. 258.

¹⁸ Standard atmospheric pressure of 14.7 pounds per square inch is equivalent to 1013 millibars or 1.013 bars. Thus a megabar would equate to a pressure of 14,700,000 pounds per square foot. The reader should note three things here, however. First, this pressure exists in only the small area covered by the beam and exists for such a short time span that the structural effects are smaller (though still significant) than one normally imagines. Lastly, while the tests in 1987 did record this pressure, the results measured in most experiments seem to be on the order of only a few hundred thousand bars, which is why the lower number of 1 million pounds per square inch is used in the text.

¹⁹ Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, pp. 243-300. Pake et al, describes various devices that were tested in the late 1980s for ballistic missile defense. Among the most effective pulsed lasers were those producing several pulses spaced several hundred nanoseconds apart. This created not only considerable ablation but also a phenomenon known as impulse loading, which greatly contributes to the structural failure mechanism discussed in the text immediately above.

²⁰ Ibid.

²¹ This is speculation by the author based on the discussion of plasma effects in Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, pp. 249-266. Pake et al discusses the plasma region reaching temperatures of over 5000 degrees Kelvin (approx. 8,500 degrees Fahrenheit). The author proposes that a sudden 8000-degree increase in temperature of the gas inside most jet engines would likely cause operational problems.

²² Description of effects taken from Jahn, Joseph, *Microwaves*, available at <http://playspoon.com/microwaves/>, 23 October 2000, pp. 1-2,

²³ Jahn, Joseph, *Microwaves*, available at <http://playspoon.com/microwaves/>, 23 October 2000, pp. 1-2, and Walling, Eileen M., *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology Occasional Paper 11, Maxwell AFB, AL, p. 1

²⁴ Merritt, Ira W., *Proliferation and Significance of Radio Frequency Weapons Technology*, Joint Economic Committee Hearing on Radio Frequency Weapons and Proliferation, February 25, 1998, available at <http://www.dallas.net/~pevler/jec.htm#Merrit>, 38 pp.

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²⁵ Ibid., p. 7

²⁶ Smith, Gary, Dr., Director of John Hopkins University Applied Physics Laboratory in testimony before the House of Representatives, available at http://commdocs.house.gov/committees/security/has197010.000/has197010_1.htm

²⁷ Wood, Lowell, *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, Prepared Statement, pp. 1-3; acquired through <http://ehostvgq11.epnet.com>

²⁸ Bernardin, Michael P., *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, Prepared Statement, pp. 2-4, available at: http://commdocs.house.gov/committees/security/has280010.000/has280010_0.HTM

²⁹ Wood, Lowell, *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, Response to questions from Representative Roscoe G. Bartlett (R-MD); acquired through http://commdocs.house.gov/committees/security/has280010.000/has280010_0.HTM

³⁰ Wood, Lowell; Graham, William; Bernardin, Michael; Jakubiak, Stanley J.; *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, pp. 120 available at http://commdocs.house.gov/committees/security/has280010.000/has280010_0.HTM as of April 7, 2003

³¹ *Treaty on Principles Governing the Activities of States in Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, also known as *The Outer Space Treaty*, was drafted in 1967. Full text of the treaty and current signatory status is available at <http://www.permanent.com/archimedes/LawLibrary.html>

³² Weldon, Curt (R-PA), Chairman House Armed Services Subcommittee on Military Research and Development during a hearing entitled *Effect of Electromagnetic Pulse Attacks*, 7 October 1999, 120 pp. The congressman referred to the speeches of the Chairman of the International Affairs Committee of the Russian Duma. Proceedings available at: http://commdocs.house.gov/committees/security/has280010.000/has280010_0.HTM

³³ Liang, Qiao and Xiangsui, Wang, *Chao Xian Zhan (tr. Unrestricted Warfare)*, Beijing, China, February 1999, 173 pp.

³⁴ Bernardin, Michael P., Prepared Statement, pp. 2-4, and Wood, Lowell; Graham, William; Bernardin, Michael; Jakubiak, Stanley J.; *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, 120 pp. available at: http://commdocs.house.gov/committees/security/has280010.000/has280010_0.HTM

³⁵ Jakubiak, Stanley J., Prepared Statement, pp. 2-4

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³⁶ Ibid. Recent commercial off-the-shelf material testing has confirmed these general field strength figures.

³⁷ Graham, William, *Effect of Electromagnetic Pulse Attacks*, Testimony before the House of Representatives Committee on Armed Services Subcommittee on Military Research and Development, 7 October 1999, 120 pp., acquired through <http://ehostvgq11.epnet.com>

³⁸ Wood, Lowell; Graham, William; Bernardin, Michael; Jakubiak, Stanley J. pp. 1-120

³⁹ Testing on EMP effects has been conducted by the U.S. Army, the Office of the National Communications System, AT&T, Bell Laboratories, and the National Laboratory of Los Alamos. In all cases, Wood argues that three fundamental flaws occurred in testing. First, since the largest EMP and microwave effects travel through wires into the systems, tests should be conducted with uncoiled wires exposed to the EMP effects. Due to the size of the testing facilities, wires were either not connected or were coiled out of range of the EMP pulses. As a result, systems were never exposed to the likely voltages. Second, microwaves and EMP effects use internal system energies like the electricity flowing through circuits to affect disruptions. The tests above were conducted without power on, resulting in test results that are likely more favorable than the real world environment. Third, the microwaves and EMP frequencies that have the greatest effect on systems were often not tested against the systems, further resulting in overly favorable results. Since the results of these tests are the basis for more optimistic predictions regarding microwave and EMP effects, and since these tests are not valid, Wood, Bernardin, Graham, and this author conclude that the potential impact of microwave bursts on U.S. systems in their present configuration could be very serious. ³⁹ Wood, Lowell; Graham, William; Bernardin, Michael; Jakubiak, Stanley J., pp. 1-120

⁴⁰ Shriner, David, *The Design and Fabrication of a Damage Inflicting RF Weapon by "Back Yard Methods,"* Joint Economic Committee Hearing on Radio Frequency Weapons and Proliferation, February 25, 1998, 6 pp.

⁴¹ Wood, Lowell; Graham, William; Bernardin, Michael; Jakubiak, Stanley J.

⁴² Walling, Eileen M., *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology Occasional Paper 11, Maxwell AFB, AL, p. 8

⁴³ *Hoover Dam—How It All Works*, January 4, 1999, available at <http://www.hooverdam.com/workings/main.html>. Admittedly, Hoover Dam produces its 2 gigawatt power output continuously, 24 hours per day compared to the microwave sources nanosecond pulse timescale; however, the comparison is certainly an interesting one.

⁴⁴ Shriner, David, *The Design and Fabrication of a Damage Inflicting RF Weapon by "Back Yard Methods,"* Joint Economic Committee Hearing on Radio Frequency Weapons and Proliferation, February 25, 1998, 6 pp.

⁴⁵ Merritt, Ira W., *The Design and Fabrication of a Damage Inflicting RF Weapon by "Back Yard Methods,"* Joint Economic Committee Hearing on Radio Frequency

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Weapons and Proliferation, February 25, 1998, available at <http://www.dallas.net/~pevler/jec.htm>, 38 pp.

⁴⁶ Ibid.

⁴⁷ Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 443-444.

⁴⁸ Ibid. pp. 444-5

⁴⁹ Daily, L., Wakim, K., Herrick, J., and Parkhill, E., "Effects of Microwave Diathermy on the Eye," *American Journal of Physiology*, Number 155, 1948, p. 482 cited in Ibid.

⁵⁰ MacLaughlin, J., "Tissue Destruction and Death from Microwave Radiation (RADAR)," *California Medicine*, Vol. 86, 1957, pp. 336-339 cited in Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 445

⁵¹ A listing of 955 sources is available in Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 506-552. Thuery points out his list is not complete. This author has found sources outside Thuery's listing.

⁵² Ibid. pp. 444-552

⁵³ Chen, K., and Lin C., "A System for Studying Effects of Microwaves on Cells in Culture," *Journal of Microwave Power*, Volume 11, 1976, pp. 140-141. Cited in Ibid. pp. 449

⁵⁴ Baldwin, S., Caczmarek, L., and Adey, W., "Effects of Modulated Very High Frequency Fields on the Central Nervous System," in Tyler, P., *Ann. New York Academy of Sciences* Vol. 247, 1975, pp. 74-81 and Arber, S., "The Effect of Microwave Radiation on Passive Membrane Properties of Snail Neurons," *Journal of Microwave Power*, Vol. 16, No 1, 1981, pp. 21-3. Both cited in Ibid., pp. 456-468.

⁵⁵ Ivanov, A., and Cuhlovin B., Etat fonctionnel des leucocytes d'un organisme expose aux micro-ondes. In: Gigena truda I biologiceskoje djeystvije electromagnitnyh voln radiocastot SV. Materialov, III. Vsesimpoz., Moskva, 1968, pp. 62-63 cited in Ibid. pp. 450-452

⁵⁶ MacRee D., "Soviet and Eastern European Research on Biological Effects of Microwave Radiation," *Proceedings of the IEEE*, Vol. 68, No 1, 1980, pp. 84-91

⁵⁷ Ibid.

⁵⁸ Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 474-475 and Pasternak, Douglas, "Wonder Weapons; The Pentagon's Quest for Nonlethal Arms is Amazing. But is it Smart?" *U. S. News and World Report OnLine*, available at <http://www.usnews.com/usnews/issue/970707/7weir.htm>, 23 October 2000, p. 1

⁵⁹ Ibid., p. 5. Events reported by Byrd, Eldon, researcher at the Armed Forces Radiobiology Institute in Bethesda, MD. Mr. Byrd believed that weaponization of this technology was only one year away in 1983 when the program was stopped. See also Siniscalchi, Joseph, *Non-Lethal Technologies, Implications for Military Strategy*,

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Occasional Paper Number 3, Center for Strategy and Technology, Air War College, Maxwell AFB, AL, March 1998, p. 7

⁶⁰ Gandhi, O., and Riazi, A., "Absorption of Millimeter Waves by Human Beings and Its Biological Implications," *IEEE Trans. Microwave Theory and Technology*, Vol. 34, No 2., 1986, pp. 228-235. Michaelson, S., "Cutaneous Perception of Microwaves," *Journal of Microwave Power*, Vol. 7, No 2, 1972, pp. 67-73. Mac Afee, R., "Physiological Effects of Thermode and Microwave Stimulation of Peripheral Nerves," *American Journal of Physiology*, Volume 203, 1962, pp. 347-378. Justesen, D., Adair E., Stevens J., and Bruce-Wolf V., "A Comparative Study of Human Sensory Thresholds: 2450 MHz Microwave vs. Far-infrared Radiation," *Bioelectrimagn.*, Vol. 3, 1982, pp. 117-125. Cited in Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 477-482

⁶¹ Pasternak, Douglas, "Wonder Weapons; The Pentagon's Quest for Nonlethal Arms is Amazing. But is it Smart?" *U. S. News and World Report OnLine*, available at <http://www.usnews.com/usnews/issue/970707/7weir.htm>, 23 October 2000, p. 4

⁶² Ibid. Event reported by a Mr. Clay Easterly, a researcher in the Health Sciences Research Division of the Oak Ridge National Laboratory

⁶³ Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 476-477 and Pasternak., pp. 4-5.

⁶⁴ Pasternak, Douglas, "Wonder Weapons; The Pentagon's Quest for Nonlethal Arms is Amazing. But is it Smart?" *U. S. News and World Report OnLine*, available at <http://www.usnews.com/usnews/issue/970707/7weir.htm>, 23 October 2000, p. 4. Thuery mentions that microwaves have a demonstrated ability to create the illusion of sound in the ear. See Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 478-479

⁶⁵ Thuery, Jacques, *Microwaves: Industrial, Scientific, and Medical Applications*, 1992, Artech House Publishing, London, England, pp. 444-502

⁶⁶ Schwartz, Peter, *The Art of the Long View*, Doubleday Publishing Group, New York, New York, 1991, pp. 3-124. The author distills the methods of future prognostication from the first half of Schwartz's text. See also, Spulak, Robert G., Briefing to the USSOCOM Future Concept Working Group, February 1999.

⁶⁷ The reader should note that the history drawn upon contains a variety of types of directed energy devices, and the graphs that follow will be from this variety of systems. In the past, when the power output of one laser device plateaued, other technologies were developed to push the power outputs further. The assumption in this section is that this development process will continue, in the same manner it has proceeded in the past.

⁶⁸ This analysis is based on the damage thresholds contained in Pake, George E., et al., *Science and Technology of Directed Energy Weapons: Report of the American Physical Society Study Group*, New York, New York, 20 April 1987, 422pp. The figures in the text are extremely conservative. Rogers, Mark E., *Lasers in Space: Technological Options for Enhancing U.S. Military Capabilities*, Center for Strategy and Technology Occasional Paper 2, Maxwell AFB, AL, November 1997, cites two other studies on fluence levels needed to damage targets. In both, the damage threshold is one-tenth that

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used in the above analysis. The result is that the capabilities of the systems in the text above may be a full order of magnitude greater than depicted.

⁶⁹ Derived largely from multiple sources cited in part 2. Data from 1978 estimated based on open source data of first COIL test. Data from 1997 based on Boeing proposal for 100kw laser for V-22 Osprey based on demonstrated technology. Proposal was unveiled in unclassified vendor display at the Directed Energy Professional Society Annual Symposium in October 1999 in Albuquerque, NM. Data for 2003 is based on an unclassified briefing on the ABL given by Dr Earl Good, Air Force Research Laboratories, Directed Energy Directorate, September 2000, where he indicated the ABL laser strength was between 2 and 8 megawatts. A figure of 3 MW was used to build the chart.

⁷⁰ Chart data comes from Perry, Michael, et. al., "Taking Short Pulse Laser Energy to New Peaks," *Science and Technology Review*, September 1995, pp. 35-39.

⁷¹ Powell, Howard T., *Keeping Laser Development on Target for the National Ignition Facility*, available at <http://www.llnl.gov/str/Powell.html>, 14pp, 20 Oct 00. It should be noted that while the technology to produce an output of 5 quadrillion watts exists, the time distance between pulses is excessive, and on the order of hours due to cooling concerns. This paper posits that advances to reduce this time to less than 1 second will occur in the next 20 years.

⁷² Perry, Michael, et. al., "Taking Short Pulse Laser Energy to New Peaks," *Science and Technology Review*, September 1995, pp. 35-39. The article reviews the 100 terawatt tabletop device that is a precursor to the 5 quadrillion watt device above.

⁷³ Laser energy can penetrate through clouds. While some clouds are optically opaque, and will block virtually all laser energy, other cloud formations allow some transmission. For specifics, see Woodford, Rich, *Cloud Characteristics: Impact on High Energy Laser Use*, Briefing to Tactical High Energy Laser Technical Interchange Meeting 2, 19 Jan 2000. The 5 petawatt laser is capable of transmitting over 5 gigawatts through some clouds of 1000 meters thickness, and may be able to transmit terawatt levels of power through rain beneath a cloud base.

⁷⁴ "High Power Microwaves," Air Force Research Laboratory, Directed Energy Directorate, Fact Sheet, September 2002, available at: <http://www.de.af.mil/Factsheets/HPM.html> as of April 7, 2003 and Hess, Pamela, "U.S. Non-Lethal Weapons Being Developed," Washington Post, 31 October 2002, available on-line at: <http://www.washtimes.com/upi-breaking/20021030-063607-9176r.htm> as of April 7, 2003

⁷⁵ Siniscalchi, Joseph, *Non-Lethal Technologies, Implications for Military Strategy*, Occasional Paper Number 3, Center for Strategy and Technology, Air War College, Maxwell AFB, AL, March 1998, p. 7

⁷⁶ Walling, Eileen M., *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology Occasional Paper 11, Maxwell AFB, AL, p. 6. Colonel Walling's description of the beam width of typical microwave emitters suggests that given sufficient range, a battlefield area could be totally

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covered with only a few of these weapons. As a minimum, a lethal point defense system could be erected.

⁷⁷ Bunn, George, et al, *White Paper on the Comprehensive Nuclear Test Ban Treaty*, 1999, 87pp. Available at http://www.lawscns.org/speeches/ctbt_whitepaper.pdf and "Senate Votes Down Nuclear Test Ban Treaty," CNN Report on 13 Oct 00 available at <http://www.cnn.com/ALLPOLITICS/1999/10/13/testban/>

⁷⁸ Bernardin, Michael P., Prepared Statement, pp. 2-4, and Jakubiak, Stanley J Prepared Statement, pp. 2-4

⁷⁹ Walling, Eileen M., *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology Occasional Paper 11, Maxwell AFB, AL, p. 7.

⁸⁰ Walling, Eileen M., *High Power Microwaves; Strategic and Operational Implications for Warfare*, Center for Strategy and Technology Occasional Paper 11, Maxwell AFB, AL, pp. 17-18.

⁸¹ *Ibid.*, pp. 21-24

⁸² The value of plausible scenarios is described at length in Schwartz, Peter, *The Art of the Long View*, Doubleday Publishers, New York, New York, 1991, 257 pp.

⁸³ Englebrecht, Joseph A.; Bivins, Robert L.; Condray, Patrick M.; Fecteau, Merrily D.; Geis, John P. II; and Smith, Kevin C.; *Alternate Futures for 2025*, Air University Press, Maxwell AFB, AL, September 1996, 236pp.

⁸⁴ The term "American Century" was coined by LeFeber, Walter in *The American Century: American Foreign Policy Since the 1890s*. See LeFeber, Walter, *The American Age: United States Foreign Policy at Home and Abroad Since 1750*, W. W. Norton Publishers, New York, New York, 1898, 759 pp.

⁸⁵ Large amounts of Chinese populate these countries. For specifics, see Hook, Brian and Twitchett, Denis, *The Cambridge Encyclopedia of China*, Cambridge University Press, Cambridge, England, 1991, p. 86. Chinese own 70-75 percent of the non-governmental assets in Indonesia, and over 90 percent in Thailand and Taiwan. Yanan, Ju, "China: The Fourth Power," *The Officer*, December 1994, p. 31

⁸⁶ Selimuddin, Abu, "China: The Biggest Dragon of All?" *USA Today*, September 1994, p. 175

⁸⁷ Morrison, Wayne, M., Congressional Research Service, *IB98014: China's Economic Conditions*, September 21, 2000, available at http://www.cnle.org/nle/inter-10.html#_1_11

⁸⁸ *Ibid.* Morrison extrapolates China's current growth rate which causes it to pass the United States in total size in the 2007-08 timeframe. It is important to note that China's economy is projected to do this at an 8-9 percent annual growth rate, which is nearly triple, the growth rate of the American economy. In this scenario, the author has adjusted the date by a few years to account for the economic slowdown underway at the time of publication, even though this slowdown seems to be affecting the U.S. more than it is China.

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⁸⁹ This projection is based on a *slowing* of the Chinese economic growth rate to an average of only 8 percent over this timeframe. If the U.S. can sustain its current growth rate of 3.5 for this same period, the U.S. GDP in 2025 will be \$19.6 billion.

⁹⁰ Chanda, Nyan, "Fear of the Dragon," *Far Eastern Economic Review*, 13 April 1995, p. 24

⁹¹ Nolt, James H., *The China-Taiwan Military Balance*, Taiwan Security Research, January 2000, available at <http://taiwansecurity.org/IS/IS-012000-Nolt.htm>

⁹² Ibid.

⁹³ Howard, Russell D., *The Chinese Peoples Liberation Army: "Short Arms and Slow Legs*, Institute for National Security Studies Occasional Paper No. 28, September 1999 Available at <http://www.fas.org/nuke/guide/china/doctrine/ocp28.htm>. Howard talks about current Chinese defense policy as emphasizing modernization especially in areas such as C3I and directed energy. The level of development in these fields is an extension of the rationale in parts 2 and 3 of this paper, based on the emphasis levels Howard details.

⁹⁴ *Iran, Islamic Republic at a Glance*, World Bank, 2000, available at http://www.worldbank.org/data/countrydata/aag/irn_aag.pdf and *Iran's Economy*, available at Iran online: <http://www.iranonline.com/iran/iran-info/economy/> 25 Nov 2000.

⁹⁵ Iran's economy is growing at an annual rate of 5.1 percent per year as of October 2000. For specifics see *Iran* at <http://www.eia.doe.gov/emeu/cabs/iran.html>, 24 Nov 2000.

⁹⁶ Ibid.

⁹⁷ Department of Energy Report EIA-0484, *World Oil Markets*, March 31, 2000 available at <http://www.eia.doe.gov/oiaf/ieo/oil.html>. The report projects increased ties between the Middle Eastern nations and China as China's energy consumption grows through the period.

⁹⁸ GDP computed based on 1999 figure of \$347.6 billion in purchasing power parity taken from *CIA World Factbook 2000*, available at <http://www.odci.gov/cia/publications/factbook/geos/ir.html>. This was extrapolated toward 2000 at a constant growth rate of 5.1 percent, which is the Department of Energy's projected growth rate for Iran over the near term. See also *Iran*, Background Paper by the Department of Energy, October 2000. Available at <http://www.eia.doe.gov/emeu/cabs/iran.html>

⁹⁹ This includes the disputed islands of Tunb al Kubra, Abu Musa, and Tunb As Sughra.

¹⁰⁰ *Background Notes: Saudi Arabia, September 1998*, State Department Notes available at http://www.state.gov/www/background_notes/saudi_0998_bgn.html. The State Department indicates King Fahd is in failing health and Crown Prince Abdullah is likely to take complete control of the government shortly.

¹⁰¹ Ibid. The State Department mentions areas of instability within Saudi Arabia in its 1998 Fact Sheet. American presence continues to be a source of disenfranchisement among the religious of the region.

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¹⁰² A senior flag officer and Pentagon strategic planner, under the rubric of academic non-attribution, stated that without exception, Theater Combatant Commanders today view “More is Better” as the theme for Theater Engagement. This speaker further indicated that little thought is given to the quality of the engagement or its long-term effects in many cases. Lecture presented to the AWC Class of 2001 in November 2000.

¹⁰³ This is based on the Republican tax cut proposals put forth in the 2000 election campaign. The Office of Management and Budget believes that federal spending caps will not remain for the 2000-2010 timeframe. Based on that assumption, deficits of \$47 billion will be accrued over this ten-year period if the tax cuts are passed. The result will be a continuation of the constraints over U.S. defense spending. For more information see: “New Democrats Oppose Fiscally Irresponsible Tax Cut,” available at <http://www.house.gov/dooley/msg7-19-99.html>, p. 1, 12 Dec 2000

¹⁰⁴ “Petroleum and Natural Gas: Prospects Through 2005,” available on the Office of Energy Statistics page at: http://www.eia.doe.gov/emeu/finance/usi&to/Up_98.html, Tables 1 and 3, 12 December 2000

¹⁰⁵ Figure of \$20 trillion is a slightly generous extrapolation from U.S. government projections of a GDP of \$15.775 trillion in 2020. Table of GDP growth is available from “International Gross Domestic product, Population, and General Conversion Factors,” available at http://www.eia.doe.gov/oiaf/ieo/tbla1_a8.html#a3, 12 December 2000. Extrapolation of current growth rates yields a 2025 GDP of \$19.6 trillion.

¹⁰⁶ This paper posits the same AEF organization structure will exist in 2025 as exists today, though the AEFs of 2025 will be equipped with more modern weapon systems.

¹⁰⁷ Figure arrived at through extrapolation of statistics from the Department of Energy statistical forecasts. See table 1 at http://www.eia.doe.gov/oiaf/aeo/aeotab_1.htm, 12 Dec 2000

¹⁰⁸ Derived from a 2020 estimate from the International Energy Agency’s publication *World Energy Outlook*, Executive Summary, available at <http://www.iea.org/weo/execsum.pdf>. The 2020 estimate was adjusted to 2025 by the mean growth rate of 1.9 percent.

¹⁰⁹ Wong, John, *China’s Economy in 1998: Maintaining Growth and Staving off the Asian Contagion*, April 1999, 48pp. Wong raises the specter of inadequate growth in China could cause a breakdown in stability.

¹¹⁰ Units in accordance with the current Expeditionary Aerospace Force Detail Concept Paper available at <http://www.af.mil/eaf> and the lead wings as currently assigned.

¹¹¹ The Iranian lasers are posited to be line of sight weapons. The curvature of the earth is approximated by the formula $d^2/8R$ where d is the distance across the surface of the earth and R is the radius of the earth. Using this formula, at 100 miles distance (approximately the width of the Persian Gulf), an Iranian ground based laser would be able to hit and destroy all aircraft flying at altitudes above 1650 feet.

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¹¹² This is postulated as a near simultaneous attack (within an hour or so of each other), and it takes at least this much time for the U.S. coalition forces to ascertain how the aircraft were attacked.

¹¹³ Figure derived from 2 Boeing 747s worth of military personnel deploying into theater, crew of the C17, and more than 100 ground casualties caused by aircraft crashing into the base proper.

¹¹⁴ Title 10 Section 9511-9513 details the law on Civil Reserve Air Fleet aircraft. While these aircraft are under contract to the federal government, the only penalty specified in this code for withdrawal of aircraft from the fleet is a reimbursement to the government for contract money received with an additional penalty. Given the poor survivability of the CRAF missions in this scenario, airlines could view these losses as a breach of contract and the Title 10 code that states that safety of the CRAF fleet is a top priority.

¹¹⁵ Laser communication is not new. Several companies have undertaken the development of laser based communications. A recent web search revealed over 100 on line. Discussions with Paul Westmeyer, Chief Systems Engineer in NASA Goddard's Earth Program Office indicates that miniaturized laser communications will be possible before the 2020 timeframe; that these devices will be able to be networked together to provide reliable in theater communications and these devices will be relatively immune to microwave effects.

¹¹⁶ Lasers here are envisioned to be a primary sensor. A laser device can be used to conduct a multi-bar raster scan looking for targets. This scan is conducted by moving the laser rapidly back and forth across the sky looking for reflected light returns. Only those vehicles that are stealthy in the visible spectrum (no such vehicles in service or planned as of Dec 2000) will be able to defeat such a sensor system. Resolution of such a system could easily exceed the best synthetic aperture radars. Such a sensor system is what enables the airborne laser laboratory to detect and identify missiles only a couple of feet across at distances of several hundred kilometers. Identification of aircraft, which have cross sections, ten times larger, would thus be possible at several thousand kilometers distance. Cruise missiles would easily be detectable out to line of sight.

¹¹⁷ Indigenous Warriors is a USSOCOM Future Concept Working Group (FCWG) concept. The basic idea is that special forces will deliberately recruit persons of various ethnic backgrounds and train these people to a high degree of cultural and language proficiency for the countries of their ancestry. When necessary, these troops can use this knowledge to enhance their chances for survival in combat situations.

¹¹⁸ The use of IR lasers here has two purposes. First, an infrared band laser cannot be seen, even at night, with the unaided eye. Some IR lasers will not be visible, even with advanced night vision devices. This enables a silent lethal shot, taken at long range, which would contribute to a special operations team remaining undetected. Sensor technology, posited to improve over the next 20 years will likely reduce the use of more traditional SOF tactics such as gun silencers, throat slitting, etc...

¹¹⁹ Both locations are strategic is lands in the Persian Gulf very close to the transit lanes through the Straits of Hormuz

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¹²⁰ Iran's first attempt was shot down by the theater air defense system. Iran's second attempt saturated the system with over 20 missiles, in order to get one "leaker" through.

¹²¹ The reader may wonder why this tactic was not pursued earlier. Among the assumptions in this scenario, and the AF 2025 study on which it was based, is that the U.S. would not escalate to nuclear weapons use, unless an opponent used WMD. Thus, the President would not likely approve the tactic of a nuclear airburst over Iran unless Iran first used some form of weapon of mass destruction against allied forces.

¹²² Iran did this as a countermeasure to future attacks based on the concept of "Effects-Based Targeting" put forth by Major General Dave Deptula, USAF.

¹²³ Zust, Eric, *Tactical High Energy Laser Tactical Interchange Meeting CD-ROM*, November 2000.

¹²⁴ Conversations and emails with Paul Westmeyer, Chief Systems Engineer in NASA Goddard's Earth Program Office

¹²⁵ Ibid.

¹²⁶ Brown, Mark, Merritt, I., Altgilbers, L., *Program to Develop RF Mitigation Technologies for Missile Defense Electronics*, U.S. Army Space and Missile Defense Command, Advanced Technology Directorate, Huntsville, AL, 9 February 1999, 6 pp.

¹²⁷ "Racing Apparel," Dupont Corporation Information Even with several thicknesses, the NOMEX suits used by the Formula I drivers depicted in the information sheet is said to provide only a few "valuable seconds" of protection. Available at http://www.dupont.com/nomex/racing_main.html, 28 November 2000

¹²⁸ For the effect of Faraday Cages on the transmission on Microwaves see, Bloomfield, Louis A., *How Things Work: Microwave Ovens*, available at http://rabi.phys.virginia.edu/HTW//microwave_ovens.html

¹²⁹ The implications of this technique are discussed in Pake, George E., et al, *Science and Technology of Directed Energy Weapons – Report of the American Physical Society Study Group*, New York, New York, April 1987, pp. 1-457

¹³⁰ In a literature search on weapons of mass destruction, this author reviewed abstracts and the text of over 200 articles and publications on WMD. Only three contained a discussion of the characteristics of weapons of mass destruction. Of those, only one attempted to actually define the phrase. The remainder, almost 99 percent of those sources examined, used WMD and NBC (nuclear, chemical, and biological weapons) interchangeably, as if the two terms meant the same thing.

¹³¹ Office of Technology Assessment, *Proliferation of Weapons of Mass Destruction*, Washington DC, 1993, p. 11 quoted in Spiers, Edward M., *Weapons of Mass Destruction: Prospects for Proliferation*, St Martins Press, Inc., New York, New York, 2000, p. 2

¹³² Spiers, Edward M., *Weapons of Mass Destruction: Prospects for Proliferation*, St Martins Press, Inc., New York, New York, 2000, p. 2

¹³³ Department of Defense, *Dictionary of Military and Associated Terms*, Government Printing Office, Washington, DC, November 1997, p. 412 quoted in Hays, Peter L.; Joidoin, Vincent J.; and Van Tassel, Alan R.; *Countering the Proliferation and*

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Use of Weapons of Mass Destruction, Primis Custom Publishing, New York, New York, 1998, p. 2

¹³⁴ The author views the current emphasis on ‘spiral development’ as a positive development. However, if systems being fielded now are not designed to be easily hardened, or have new types of “stealth” technology easily incorporated, then the needed updates may be cumbersome or too expensive to apply.

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