Laser Weapons

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Chapter 4
Laser Weapons

Laser technology is only 30 years old, but it is much diversified. There are already varieties of military applications, although there are many limitations restricting the use of lasers. Today, the armed forces in most countries routinely use a wide range of laser devices such as laser range finders and designators. In some countries, work is proceeding on more imaginative laser weapon concepts that will eventually fulfill realistic, yet very precise, military requirements. The design of a specific laser weapon is heavily influenced by the characteristics of the intended target. If the desired effect of the weapon is to neutralize aircraft, helicopters, or missiles by burning holes through them or tanks by putting many miniature cracks (crazing) in the glass vision blocks to make them appear to be frosted, a very high-energy laser has to be used with a power output on the order of several megawatts (MW). Such a laser would be a true anti-material weapon. However, if the target is a sensitive electro-optical system or some other type of sensor system, which has to be jammed or destroyed by a laser operating in a countermeasure mode, the choice will be a low-energy laser operating within the frequency bandwidth of the target sensor. This use of a laser can also be considered anti-material. If the target is a soldier, there is one part of his body that is extremely sensitive to laser radiation—his eyes. It is sufficient to use a low-energy laser operating in the visible or near-infrared (near-IR) part of the spectrum to damage the soldier's eyes and, in effect, cause blindness. If the laser is to cause burn injuries to the soldier's skin or to set fire to his uniform, a high-energy laser is required. In either case, if the purpose of the laser is to blind or burn the soldier, it will obviously be antipersonnel.

4.1 Laser as a Weapon

Even before the laser was invented, science fiction writers told of incredible weapons and machines that emitted a bright saber of light, a death ray that disintegrated everything in its path. Even today, science fiction movies and books

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place high emphasis on weapons that use light instead of bullets. The laser beam is popularly thought of as a very powerful death ray which can be fired from a handheld laser gun to vaporize soldiers, demolish building, and burn-through target armors. In reality, the laser is a suitable tool for many military applications and can be turned into a deadly weapon, but there are definitely limitations to what a laser can do. The laser really is a ray weapon, and its light rays can damage some targets in a way that appeals to the most vivid imagination. It is important to take these somewhat speculative factors into consideration when studying the psychological effects of the use of laser weapons on the battlefield. Otherwise, it will not be possible to get a complete and realistic picture of what using a laser really means to the combatants.

4.2 Possible Targets

A discussion of laser weapon applications outlining what laser weapons can really do must start with the destination of the laser beam—the target. The desired effect on the target ultimately decides what is needed from the laser. To a large extent, the interaction between the laser beam that is selected and the target also determines which cost-effective weapons are developed, produced, and deployed into the battlefield.

The sensitivity of the target to laser light determines whether a low-energy or high-energy laser is required. If the target is sufficiently sensitive to low levels of energy within a comparatively broad band of the spectrum, a cheap and cost-effective laser weapon can be designed and mass-produced. If high energy is required, the possibility of designing a usable and affordable laser weapon decreases drastically.

4.3 Energy Level at the Target

One of the basic questions facing the laser weapon designer is what energy level must be absorbed by the target in order to get the desired result. The absorbed energy (E) is some fraction (A) of the product of the power density or intensity (I) present in the laser beam and the emission duration (t). E is measured in energy units, joules (J) or watt seconds per area, usually expressed in square centimeters; I in power units, watts (W) per square centimeter; and the time in seconds in the following equation:

$$E = A(I \times t)$$

This means that if the emission duration is required to be short, as it would be in the engagement of multiple targets, the power density has to be as high as possible. The power density is calculated as the beam power divided by the size of the "beamed" area, which means that a high beam power and a small surface area will give a high power density. How much of the laser power will finally be absorbed by the target in the affected surface area will determine what destructive effect will be achieved. The laser power goes from the laser to the target, suffers transmission losses in the optical system and the atmosphere, and has a further loss when some of the power is reflected from the target surface. The absorbed power is normally no more than 20–60 % of the original emitted laser power.

One parameter that is useful in determining the effectiveness of a Gaussian laser beam is the beam irradiance at the target. For a beam with output power P_0 and cross-sectional A at the target, the peak irradiance I_{p} at the target is

$$I_{\mathrm{p}} = \frac{P_0 \tau}{A}$$

where τ is the atmospheric transmittance.

The effectiveness of a laser beam in causing mechanical damage is, thus, dependent on beam power, pulse duration, wavelength, air pressure, the material, and the finish of the target surface. For example, a painted area has considerably increased energy absorption when compared to an unpainted aluminum plate. The absorption varies widely between different materials and at different wavelengths. The absorption of a ruby laser at 694 nm is 11 % for aluminum, 35 % for light-colored human skin, and 20 % for white paint. The corresponding figures for a CO_2 laser at 10,600 nm are 1.9, 95, and 90 %. This also indicates that one way to counter a HEL weapon is to choose a very reflective material for the target surface. On the other hand, longer wavelengths emitted by the laser can reduce the effects of highly reflective materials and increase the absorption. Every factor in this very difficult pattern combines to determine the degree of target destruction as well as the final energy level that will be needed to produce the desired effect.

It is obvious that the level of energy required to destroy a target varies considerably depending on the circumstances. Therefore, it is not surprising that the required energy level figures quoted in the open literature also show rather large variations. In spite of this, some numbers may be given which indicate the general range of energy levels.

An aircraft, helicopter, or missile could be hit with an HEL weapon in many different ways that in the end would nullify it. Fuel tanks could be ruptured, or the fuel itself could be caused to explode. Windshields could be shattered, and parts of the control surfaces such as elevators or rudders could be destroyed or disturbed enough to make it impossible to continue fighting. The rotor head of a helicopter or the wing of an airplane or missile could be made to fail, resulting in a crash. Sensors, radars, and other navigation aids could be destroyed; if this destruction occurs during a sensitive and crucial moment in the last phase of an attack, it could result in a crash or an aborted mission. Also, in some situations, an HEL weapon could even explode the ammunition carried by an airborne attacker.

To punch through the metal skin of an airplane requires about 700 J/cm^2, although it should be noted that a hole burned in the skin of an airplane may not be sufficient to destroy it in the air or even to make it crash. A more realistic energy level to disable an aircraft may be five to ten times higher, which means that a successful HEL weapon will have to be able to deliver at least 5000–10,000 J/cm^2 on the target.

Optical sensors and radomes (plastic radar domes) are much easier to damage; no more than 10 J/cm^2 needs to be delivered directly on the target. Furthermore, if the laser wavelength is within the sensitive wavelength region of the sensor in question, the energy needed could be extremely low. If the HEL weapon is used as an antipersonnel weapon, that is, as a long-range flamethrower, the energy necessary to burn exposed skin is merely 15 J/cm^2, and damage to the cornea, the clear window into the eye, requires only 1 J/cm^2.

4.4 Absorption and Scattering

The Earth's atmosphere is acting like an absorbing medium. Absorption occurs when a photon of radiation is absorbed by a gaseous molecule of the atmosphere that converts the photon into the molecule's kinetic energy. Hence, absorption is a way and procedure by which the atmosphere is heated, and it is a strong function of laser or radiation of wavelength. For example, propagation of radiation essentially gets eliminated at a wavelength below 0.2 μm due to absorption by O_2 and O_3, while there is very little absorption at the visible wavelengths (0.4–0.7 μm).

Scattering of electromagnetic waves in the visible and IR wavelengths occurs when the radiation propagates through certain air molecules and particles. Light scattering is strongly wavelength dependent, but there is no loss of energy like in absorption. The physical size of the scatters determines the type of scattering:

- *Rayleigh Scattering*—This is named after Lord Rayleigh and caused by air molecules and haze that are small in comparison with the wavelength λ of the radiation (see Fig. 4.1 below). Rayleigh scattering, also called *molecular scattering*, applies only to very clear atmosphere. The scattering coefficient is proportional to λ^{-4}, a relation known as the *Rayleigh law*. For these small air molecules, scattering is eligible at wavelengths greater than roughly 3 μm. At wavelengths below 1 μm, Rayleigh scattering produces the blue color of the sky

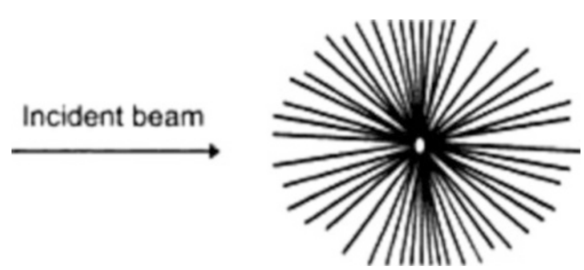


Fig. 4.1 Rayleigh scattering

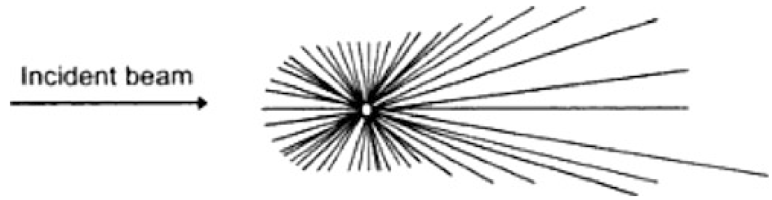


Fig. 4.2 Mie scattering

as a consequence that blue light is scattered much more than other visible wavelengths.

- *Mie Scattering*—(named after Gustav Mie) scattering by particles comparable in size to the radiation wavelength (also called *aerosol scattering*). Unlike Rayleigh scattering, scattering by particles comparable in size to or greater than the radiation wavelength is concentrated in the forward direction (see Fig. 4.2). Scattering losses decrease rapidly with increasing wavelength, eventually approaching the Rayleigh scattering case. Mie scattering is the reason why sunset appears red.

A term that is sometimes used to describe atmospheric visibility is the visual range, which corresponds to the range at which radiation at 0.55 μm is attenuated to 0.02 time that is a transmitted level. Rayleigh scattering by molecules implies a visual range of approximately 340 km (or 213 miles) [2].

Absorption and scattering are often grouped together under the topic of *extinction*, defined as the reduction or attenuation in the amount of radiation passing through the atmosphere. The *transmittance* (also called *atmospheric transmission*) of laser radiation that has propagated a distance L is related to extinction as described by Beer's law, which can be written as [1, 2]

$$\tau = \exp[-\alpha(\lambda)L] \quad \text{unitless}$$

where $\alpha(\lambda)$ is the extinction coefficient and the product $\alpha(\lambda)L$ is called the *optical depth*. The extinction coefficient is composed of two parts:

$$\alpha(\lambda) = A_a + S_a \quad [\text{m}^{-1}]$$

where A_a is the absorption coefficient and S_a is the scattering coefficient. Absorption and scattering are deterministic effects that are fairly well known.

Software packages like LOWTRAN, FASCODE, MODTRAN, HITRAN, and PcLnWin (most of these codes are available from Galaxy Advanced Engineering) are commonly used by both government and private industry to predict transmittance (attenuation) effects as a function of wavelength λ, based on a variety of conditions—meteorological range, latitude (tropical, mid, arctic), altitude, etc. A typical output from MODTRAN for rural aerosols with meteorological range of 23 km is shown in Fig. 4.3 as a function of wavelength over 1–10 μm.

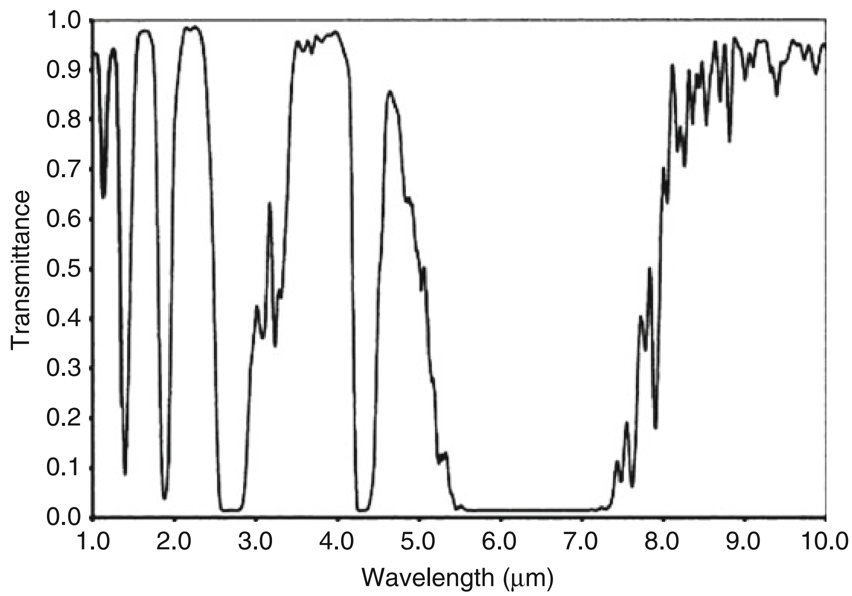


Fig. 4.3 Typical atmospheric transmittance for a horizontal 1-km path. The height above ground is 3 m with no rain or clouds

4.5 Atmospheric Structure with Altitude

The atmosphere is a gaseous envelope that surrounds the Earth and extends to several hundred kilometers above the surface. Over 98 % of the atmosphere by volume is comprised of the elements nitrogen and oxygen. The major constituents of the atmosphere are water vapor, carbon dioxide, nitrous oxide, carbon monoxide, and ozone. Based mostly on temperature variations, the Earth's atmosphere is divided into four primary layers (Fig. 4.4):

- *Troposphere*—extends up to 11 km and contains roughly 75 % of the Earth's atmospheric mass. Maximum air temperature occurs near the surface of the Earth, but decreases with altitude to −55 °C. The *tropopause* is an isothermal layer extending 9 km above the troposphere where air temperature remains constant at −55 °C. The tropopause and troposphere together are known as the *lower atmosphere*.
- *Stratosphere*—the layer above the tropopause, which extends from 20-km up to 48-km altitude. The air temperature is roughly constant in the very lowest part of the stratosphere but then increases with altitude because the ozone gas in this layer absorbs ultraviolet sunlight, thereby creating heat energy. The ozone layer, which protects life from harmful ultraviolet radiation, is concentrated between 10 and 50 km. Separating the stratosphere from the mesosphere is the stratopause, another isothermal layer at approximately −3 °C.
- *Mesosphere*—extends from the stratopause to roughly 80 km. The temperature here generally decreases at a constant rate down to −90 °C, which is the coldest temperature in the atmosphere. The *mesopause* is the third isothermal layer,

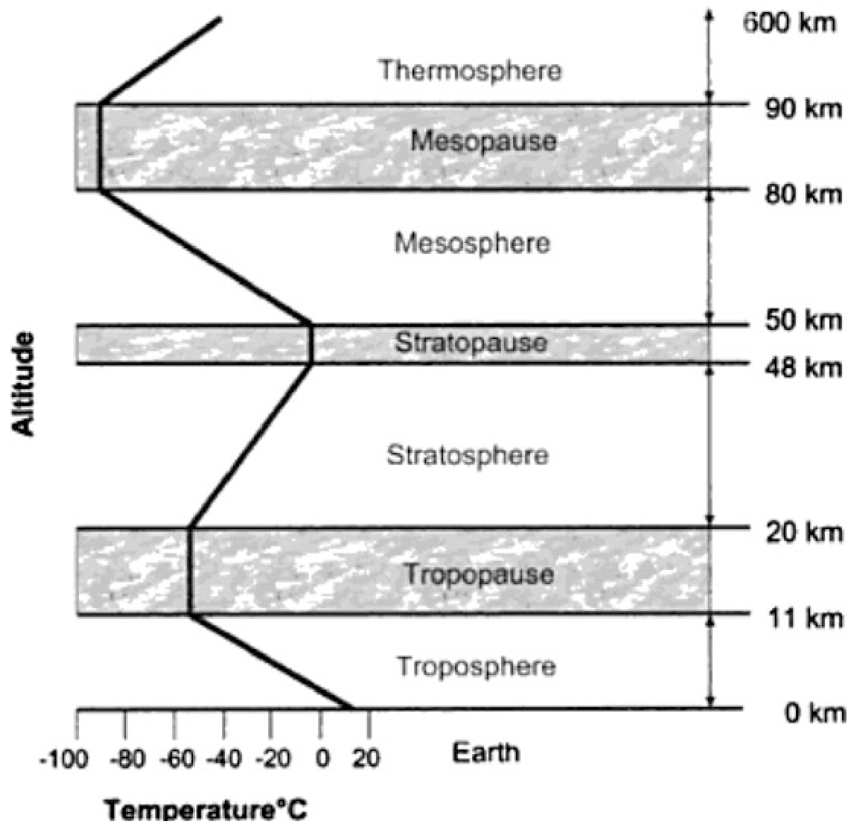


Fig. 4.4 Diagram depicting various atmospheric layers and air temperature

separating the mesosphere, along with the stratopause and mesopause, constituting what is commonly called the *middle atmosphere*.

- *Thermosphere*—extends from the mesopause to roughly 600 km. Air temperature in the thermosphere increases quite strongly above 90 km due to the sun's energy. Most of the *ionosphere* and the *exosphere* are included in the thermosphere. The ionosphere starts around 70 or 80 km up to an indefinite height (~1000 km) and is so named because it is sufficiently ionized by solar ultraviolet radiation that the concentration of free electrons in this layer affects the propagation of radio waves.

4.6 The Major Laser Weapon Concepts

There is generally more than one laser weapon alternative for each proposed laser weapon mission on the battlefield. It is quite possible to vary the laser properties and energy level, the tracking system, and the fire control equipment according to the military requirements for each specific mission. Environmental influences will also have a very strong impact on the final choice of laser weapon applications. For example, hydrogen fluoride (HF) laser is not the best choice for long-range use within the atmosphere, because its wavelength is strongly absorbed by the atmosphere. Every laser weapon that is designed to operate within the atmosphere over any great range, whether ground-based laser (GBL), sea-based laser (SBL), or air-based laser (ABL), must use wavelengths at which the atmosphere absorption and scattering are as small as possible [2].

To be effective, the wavelength of a laser weapon must be short, at least in the visible band, but preferably in the ultraviolet or X-ray band. The greatest difficulty in designing short-wavelength lasers is power—the shorter the wavelength, the more energy that is required. Optical (visible or ultraviolet) lasers work by heating the skin of the target. The beam must remain at the same spot for several seconds until the skin is hot enough to do internal damage to the target. This is tough because the typical ballistic missile travels in excess of 6 miles per second. Imagine focusing on the same 2′ or 3′ spot over a distance of 50,000 ft, and you have an idea how accurate such a laser weapon must be.

In addition to the problems of accuracy, laser weapons of any power tend to be monstrous, and there are many technical obstacles that the designer should overcome. The SBL is using relay mirrors to direct the beam to the target. ABLs are using turbine-powered chemical jets, and they are placed aboard of aircraft, but the wavelength of the light is long—6–10 μm—far in the infrared region. This makes laser relatively inefficient at destroying their targets unless certain atmospheric and environmental condition met for target engagements.

X-ray lasers, still wrapped in secrecy, emit an extremely high-powered beam that can literally destroy a missile in mid-flight. X-rays can't be deflected by mirrors, however, which means that the weapon must be easily aimed and in a direct line of sight to the target. Fortunately, X-ray lasers can be built small, experts say, making them suitable for space-based operation. The biggest disadvantage to X-ray lasers is that they use an internal nuclear explosion to work, so they are essentially one short device.

A relative newcomer to this laser weapon scene is the free-electron laser, which is being developed at the several national laboratories and universities. The free-electron laser (FEL) uses a stream of electrons that is made to emit photons of light after being oscillated by giant electromagnetic. Free-electron lasers (FELs) have been built and they do work. However, if put into production, an actual antiballistic missile FEL would take up a huge field such as football field or more to function. Obviously, such a device would be useful only as a stationary ground-based laser (GBL) weapon with its present technology.

Laser weapons may be used within an army's air defense against aircraft, helicopters, and missiles. The desired effect on the target may either be to burn holes or destroy key structures, to blind or trick the sensors, or to blind the crews temporally or permanently. The high-energy air defense laser may use all three effects at the same time if the target is within reach of the main effects of the laser. At longer distances, only the anti-sensor and anti-eye capability will be possible. The low-energy air defense laser will use enough energy to be effective against sensors and eyes. It is also possible to field a laser with the main purpose of blinding or flash blinding the crews. Flash blinding will be most effective in the dark when the eye is dark adapted and much more sensitive to overload by bright flashes [2].

4.7 Small-Scale Weapons Using Lab-Type Lasers

So far part of this report has covered high-energy weapons, designed to counter a major military conflicts and attack. Laser guns in the movies are often handheld devices or, at most, small enough to prop on a vehicle. Lasers powerful enough to inflict damage, but small enough to be carried, have developed, but they are not used in any current military application. It's relatively easy, for example, to build a handheld ruby laser that puts out bursts of large amounts of light energy. When focused to a point, the light from a ruby laser can cut through the paper, cloth, skin, or even thin metal.

Ruby crystals are poor conductors of heat, so ruby lasers emit only short pulses of light to allow the crystal to cool between firings. Nd:YAG lasers operate in a similar fashion as ruby lasers, but they can produce a continuous beam. Making a handheld Nd:YAG laser is no easy feat either; however the Nd:YAG crystal must be optically pumped by another high-powered laser or by an extremely bright flash lamp or light source. Though the power output of an Nd:YAG laser is extremely high, considering the current state of the art, a handheld model is impractical. However, such a weapon could be built as a "laser canon," transported on an armored vehicle or on a towed trailer.

CO_2 lasers are often used in industry as cutting tools. This type of laser is known for its efficiency—30 % or more compared to the 1–2 % of most gas and crystal lasers. A pistol-sized CO_2 laser would probably be difficult to design and manufacture because the CO_2 gas mixture (which includes helium and nitrogen) must be constantly circulated through the tube. What's more, the laser requires a hefty electrical power supply. Still, such apron could be built in an enclosure about the same size as a personal rocket launcher. These are designed to be slung over a shoulder and fired when standing in an upright position [3].

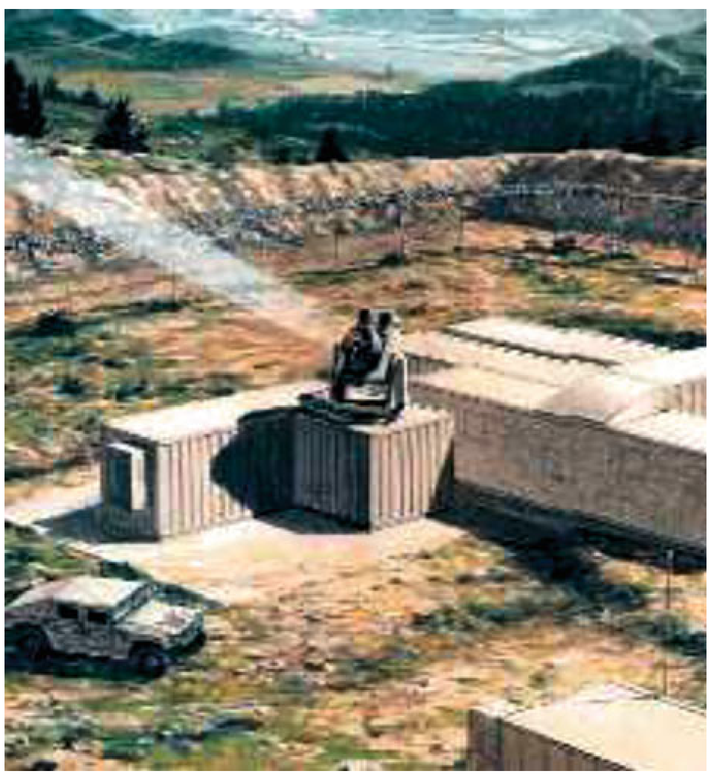
4.8 High-Energy Lasers as Weapons

An air defense HEL weapon designed to shoot down airplanes, helicopters, and missiles successfully must have the ability to keep a very powerful beam at one point on the target for a long enough time to deliver at least 5000 J/cm^2. This requires a laser in the megawatt range. If the shot is to be successful, it must be directed to a certain part of the target that is limited in size and very sensitive and then kept there until the desired effect is reached. Thus, the laser beam must track and follow a target if any great length of time is needed to achieve the desired effect.

Many parts of an aircraft or helicopter are highly resistant to an HEL weapon, but there are still enough thin-skin parts and sensitive areas to produce a devastating effect or destruction if hit precisely. On the other hand, it is obvious that at battlefield ranges even an extremely high-energy laser weapon cannot penetrate the heavy armor on a tank or other armored vehicles and thus an HEL weapon is of no use for destroying resistant ground targets in the battlefield. However, sensors, optics, and related devices are still valid targets wherever they appear on the battlefield, even in a tank.

4.9 High-Energy Laser (HEL) Safety Program

As high-energy lasers move from the safe confines of the laboratory into the outdoor domain, new problems arise in dealing with laser safety. The Tri-Service Laser Bioeffects program at Brooks AFB will be examining the safety aspects of the new technologies and weapon systems to be employed in the future. Several new high-energy laser systems are now scheduled for deployment in the immediate future.



The Tactical High-Energy Laser (THEL) will be a ground mobile system which will use a chemical laser to destroy low-flying threats. Currently under development in a cooperative program with Israel, the THEL conducted test firing in FY1998 and continues several test phases at White Sands Missile Range today.

The airborne laser (ABL), with its megawatt-class laser systems, will engage tactical ballistic missiles during boost phase at altitudes over 40,000 ft. Its lasers will be test fired in FY2003, with Engineering and Manufacturing Development scheduled to begin soon after that. The high-power chemical oxygen iodine laser will have nominal eye-safe distances in the order of thousands of miles and will produce reflection patterns off targets that also have the potential for causing eye damage at very large distances.

Combining these laser characteristics with the planned usage of these weapon systems involving moving targets and possibly moving sources results in a complex series of laser safety calculations to allow safe testing and usage of high-energy lasers outdoors. The Air Force Research Laboratory, Optical Radiation Branch, is developing new tools and techniques for calculating laser hazard areas which include computer modeling of the interaction of high-energy lasers and moving targets and the use of probabilistic methods to augment deterministic calculations.

One of the Missile Defense Agency's highest priority programs involves putting a weapon-class laser aboard a modified Boeing 747-400 series freighter aircraft and using that laser to destroy ballistic missiles shortly after launch. The program is called the airborne laser, and its development could forever change the way that nations wage war.

4.9.1 Airborne Laser (YAL-1A)

Destroying ballistic missiles is a complicated process, one that is confounded even more by the revolutionary use of a directed energy device as a weapon rather than as a targeting or range-finding apparatus. To be successful, ABL must:

- Be housed aboard a stable platform that can stay aloft for hours on the end above weather systems whose clouds could refract its laser beams and nullify its effectiveness.
- Be equipped with sensors able to locate a ballistic missile shortly after launch and hold the track long enough for other system elements to swing into operation.
- Be implemented with a sophisticated computer system capable of keeping track of dozens of missiles and prioritizing them so that the most threatening is targeted first.
- Have a highly developed optical system capable of measuring the amount of thermal disturbance between the aircraft and the target; then be capable of directing a beam of energy that self-compensates for the clear-air obstacles.
- Possess the ability to focus the killer beam on a rapidly rising target, which may be traveling at a speed of Mach 6 or more; then keep the shaft of energy in place long enough to burn a hole in the missile's metal skin.
- And lastly, be provided with a laser powerful enough to prove lethal at a distance of hundreds of kilometers.

Some of those requirements already have been tested:

- The first ABL aircraft—YAL-1A—made its virgin flight over the western Kansas on July 18, 2002, staying aloft for 1 h and 22 min before returning to the Boeing modification facility in Wichita. Between then and the time it transitioned to its new temporary home at Edwards Air Force Base, California, in December, YAL-1A made an additional 13 flights logging more than 60 flight hours.
- As part of a Missile Defense Agency test over the Pacific Ocean in December 2002. ABL's infrared trackers successfully detected a Minuteman booster rocket as soon as it broke the clouds, holding a lock until the rocket's engines burned out 500 km downrange.
- Its battle management (computer) system was flight tested in late summer and early fall of 2002 to verify internal crew communications and the V/UHF radios, plus the data acquisition system and high-definition VHS.

- The six infrared search and track sensors were successfully flight tested.
- The first COIL module that will be installed on YAL-1A tested at 118 % of anticipated power during a shakedown run at TRW's facility in San Juan Capistrano, Calif., in January 2002. Shortly afterward, it was disassembled and shipped to Edwards Air Force Base.

In December 2002, YAL-1A was pulled into a hangar at Edwards' Birk Flight Test Facility where it will be grounded, while the lasers and optical components can be tested and installed.

The goal of the Missile Defense Agency, which has overall management responsibility for the program, and the Airborne Laser System Program Office at Kirtland Air Force Base, N.M., is to have YAL-1A ready to shoot down a threat-representative ballistic missile by December 2004. Currently, the missile is scheduled to be launched from Vandenberg Air Force Base, Calif., with the shootdown to take place over the Pacific.

Construction and testing of YAL-1A (prototype attack laser, model 1A), the first aircraft in a proposed fleet of so-far undetermined size, are the results of an effort by MDA, the program office, the Air Force, and three major contractors—Boeing, Lockheed Martin, and Northrop Grumman Space Technologies (formerly TRW). In addition, the US Air Force's Aeronautical Systems Center, headquartered at Wright-Patterson Air Force Base, Ohio, has provided office personnel. The Air Combat Command, headquartered at Langley Air Force Base, Va., will assume control over the plane once it is declared operational and transferred back to the Air Force.

The ABL program office was formed in 1993. Three years later, in November 1996, the Air Force awarded a $1.1 billion contract to the Boeing Defense Group of Seattle, Wash.; TRW Space and Electronics Group of Redondo Beach, Calif.; and Lockheed Martin Missiles & Space of Sunnyvale, California.

Boeing built the aircraft in Everett, Wash., and modified it in Wichita. The company also developed the hardware/software used in the battle management system and is managing the integration of the main components. TRW built the megawatt-class COIL laser that produces the knockout punch to ballistic missiles, and Lockheed Martin is responsible for the optical system.

Another key organization is the Air Force Research Laboratory's Directed Energy Directorate, also at Kirtland Air Force Base, N.M., where the COIL was invented in 1977. For a quarter of a century, the Laboratory has been conducting research into a myriad of technologies needed to make a laser-carrying aircraft a reality. Besides the COIL, the Laboratory also developed the technologies that will increase the distance laser light can travel through the atmosphere to destroy attacking missiles.

The Aircraft—The Air Force bought a 747-400F straight off the Boeing Commercial Aircraft assembly line and flew it to Wichita, Kan., in January 2000. Boeing workers virtually rebuilt the aircraft, installing miles of wiring, grafting huge sheets of titanium to the plane's underbelly to protect the exterior from the heat of the laser exhaust, and, most importantly, adding a 12,000-lb bulbous turret on the front of the aircraft to house the 1.5-m telescope through which the laser beams will be fired. Company officials said it was the largest military modification to a commercial aircraft that Boeing had ever attempted.

Acquisition, Tracking, and Pointing—In addition to a powerful laser, an airborne laser system also must be able to find and hit its targets. Numerous tests have been conducted at the White Sands Missile Range in southern New Mexico, both with lab-type instruments and with the actual aircraft, to demonstrate the system's ability to identify and follow a potential target.

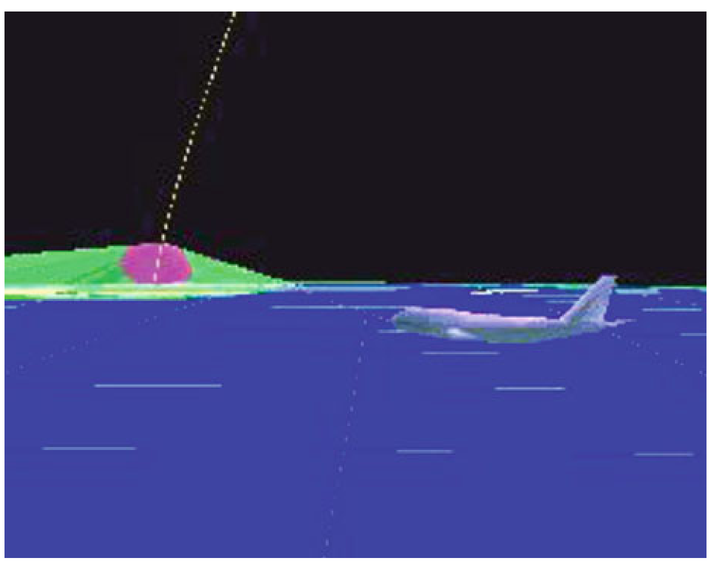
The Lasers—Central to this system is the COIL. As a laser that generates its energy through chemical reaction, it has advantages over solid-state lasers, most notably in the amount of energy it can produce. COIL energy is produced by chemical reaction when oxygen and iodine molecules are mixed. A tremendous additional advantage is that the laser propagates at 1.315 μm in the infrared (invisible) spectrum. This wavelength travels easily through the atmosphere and has greater brightness—or destructive potential—on the target. There are three other important lasers aboard the aircraft: the Active Ranger System, which provides preliminary tracking data; the Track Illuminator Laser, which produces more refined data; and the Beacon Illuminator Laser, which measures the amount of atmospheric disturbance.

Correcting For Atmospheric Turbulence—The ability to find and track a boosting missile would be meaningless without a corresponding ability to lock onto and destroy the intended target. Since air, like water, is made up of many layers, scientists needed to find a way to compensate for these disturbances in the atmosphere in order to focus a high-energy beam on the target and hold the beam in place long enough for it to complete the destruction process. The system that will be installed on YAL-1A is the result of more than 15 years of research conducted by scientists at the Laboratory's Directed Energy Directorate and the Massachusetts Institute of Technology's Lincoln Laboratory. Working out of astronomical facilities at the Starfire Optical Range in the southeastern corner of Kirtland Air Force Base, researchers made revolutionary breakthroughs using lasers, computers, and deformable optics.

The ABL Integrated Test Force—Actually a complex of buildings located at the historic Birk Flight Test Facility at Edwards Air Force Base, Calif. The gem of the ITF is the System Integration Laboratory (SIL), an 18,000-square-foot building housing a surplus 747-fuselage test stand that will serve as a laser template for the ABL aircraft. The six modules that compose the COIL component initially will be tested in the SIL. Once those tests have been completed, the modules will be disassembled and then reassembled on YAL-1A. Other resources in the ITF complex include a ground-pressure recovery assembly (GPRA), which will enable simulation of ABL's anticipated cruising height, and a mixing area for basic hydrogen peroxide, a vital ingredient to the main laser's chemical reaction process.

History—Almost 20 years ago, the Air Force Research Laboratory and its predecessor units completed a project that showed the potential for an airborne laser. A KC-135A tanker airplane (a military version of the Boeing 707) was modified and equipped with a gas dynamic laser. This aircraft shot down a low-flying drone and five air-to-air missiles, proving the concept was possible. Later tests also were conducted at White Sands Missile Range aimed at finding out how effective a laser would be. For these tests, the nation's most powerful laser, the Mid-Infrared Advanced Chemical Laser, was used. In every case, scale models of typical targets were easily destroyed.

The System—Computer simulations indicate that an airborne laser would be very effective under battle conditions. Currently, the program will provide the United States with its only near-term boost-phase missile defense, that is, the ability to find and destroy a missile between the time it is launched and its booster rockets burn out.



The laser range safety tool (LRST) is being developed to permit range safety officers to properly assess hazards and configure test scenarios such that these new weapon systems can be tested in a safe manner. For any given scenario, the tool assists in the evaluation of reflection patterns resulting from targeting various types of moving targets and predicts hazard zones and appropriate "keep-out" areas. The tool is based on the ANSI Z136.1 standard for eye safety calculations along with new bioeffect data for the specific wavelengths associated with the new high-powered laser systems. Moreover, new risk assessment techniques using probabilities associated with the various aspects of exposure and injury will provide more realistic predictions for use by the range safety officers, as well as the operational users.

4.9.2 Tactical High-Energy Laser for Air Defense

The US Army Space and Strategic Defense Command (SSDC) is working on a new active defense weapon system concept to combat the threat to our forces from so-called dumb munitions. The command's mobile Tactical High-Energy Laser or THEL weapon system will provide an innovative solution for the acquisition and close-in engagement problems associated with these threats not offered by existing systems and give the air defense commander an option that he does not currently have. It will significantly enhance the force protection for combat forces and theater-level assets for the Force XXI Army.

For the past several years, SSDC has been pursuing this concept that could provide new air and missile defense capability in force protection missions. Numerous Department of Defense high-energy laser development programs over the last 20 years have proven and demonstrated the laser beam generation and beam-pointing technologies for the THEL concept. Force XXI advancements in the area of real-time situational awareness now make it possible to capitalize on the attributes of a THEL in operational scenarios.

A THEL will be able to rapidly fire for close-in engagements where timelines are very short and cost only a few thousand dollars per kill or less with a deep magazine to counter saturation attacks. Not only can THELs destroy, but they can also degrade, disrupt, or damage to enhance operational flexibility and effectiveness against a wide variety of air threats. This system can, therefore, operate as an effective new weapon node in the short- to medium-range air defense architecture.

The effectiveness of high-energy lasers against short-range rockets was tested and demonstrated in the "Nautilus" program, an outgrowth of Project Strong Safety, in collaboration with Israel. The program was conducted primarily at SSDC's High-Energy Laser Systems Test Facility or HELSTF at White Sands Missile Range, N. M., and utilized a fraction of the power of the HELSTF Mid-Infrared Advanced Chemical Laser (MIRACL) to emulate the THEL weapon concept performance.

The MIRACL is a megawatt-class deuterium fluoride chemical laser that has been operational at HELSTF since the early 1980s. After a series of static and dynamic tests, the program successfully destroyed a short-range rocket in flight on February 9, 1996. This success triggered the next development in the SSDC THEL effort.

In April 1996, the Prime Minister of Israel, Shimon Peres, met with President Clinton and Secretary of Defense William Perry. During the meeting, the United States made a commitment to assist Israel in the development of a THEL Advanced Concept Technology Demonstrator by the end of 1997, based on the success of the Nautilus program, to defeat the threat posed by Katyusha and other short-range rockets against the cities in northern Israel.

In July 1996, a contract was awarded by SSDC to TRW, Inc., of Redondo Beach, Calif., for the design, development, and fabrication of a THEL demonstrator, which will be a transportable, tactical-sized deuterium fluoride chemical laser. Approximately 18 months will be required to design and build the system, followed by 12–18 months of testing.

If successful, the demonstrator may pave the way for future development of a THEL for use in US peacekeeping/contingency operations. The US Army Air Defense Artillery School in Fort Bliss, Texas, already officially designated as the proponent for THEL by the Training and Doctrine Command, is planning to develop a mission need statement and operational concept that could lead to an operational requirement for a THEL system.

Evolving high-energy laser, beam control, and digital battlefield information technologies promise to combine into a highly effective force protection THEL weapon system for the Force XXI Army.

Prepared September 1996 by John J. Wachs, Weapons Directorate, MDSTC, SSDC High-Energy Lasers Weapons

4.10 Lasers for Air Defense

In its 1984 directed energy plan, SDIO planned to develop an acquisition, tracking, pointing, and fire control (ATP/FC) subsystem for directed energy weapons by fiscal year 1990 for $1298 million. Through fiscal year 1993, SDIO allocated $1634 million to this program, accomplishing some but not all of the program objectives. SDIO estimated that it will cost $180 million and take 3 years to resolve the majority of the remaining technical issues. For another $100 million, the ATP technology could be demonstrated in space.

All directed energy weapons need an ATP/FC system. In general terms, the system must quickly engage a large number of targets by placing a directed energy beam on the aimpoint of each target. These time and accuracy constraints dictate a rapid succession of handovers from one sensor to another. Each successive sensor in the system has a smaller field of view and greater accuracy.

The system locks onto the infrared signature of a missile (acquisition), calculates the flight path of the missile (tracking), calculates an aimpoint on the missile and directs the beam to the aimpoint (pointing), and assesses the results and selects the next target (fire control). Depending on the mission of the directed energy system, the ATP/FC system must perform these functions when ballistic missiles are in their boost, post-boost, and/or midcourse phases of flight.

The basic goal of the program was to resolve the technical issues sufficiently to support a space test of a directed energy weapon by 1990. The overall technology performance objectives in the 1984 plan were as follows:

- Reduce the effect on the accuracy of pointing and tracking devices of vibrations caused by operation of the spacecraft and laser to less than 4 in. on the target.
- Develop the capability to rapidly retarget the laser beam from one target to another in less than 2 s.
- Develop the capability to track targets at ranges of 2600–3100 miles at an accuracy of about 4 in.
- Develop fire control computer software to handle more than 100 targets at a rate of more than one target per second. The fire control functions are missile plume to missile hard-body handover, tracking of multiple targets, target identification, aimpoint selection, and damage assessment.

The plan specified that $1298 million would be required from focal years 1986 through 1990 to develop the system components and to fly space experiments to resolve integration and space operation issues. Experiments would permit the space test of a directed energy weapon in 1990.

SDIO met the plan's objectives for pointing and tracking technology and rapid retargeting technology for directed energy weapons. It did not meet the objectives for developing long-range fine tracking and fire control software. While not meeting all objectives, SD10 believes it has met the basic program goal of resolving technical issues sufficiently to support a space test of directed energy technology. Through fiscal year 1993, SDIO spent about $1684 million developing ATP/FC technologies. This amount is about $286 million more than what SD10 estimated was needed to accomplish the objectives. A majority of the funding was spent on a series of space- and ground-based experiments. All major space tracking experiments were canceled before completion due to a lack of funding. However, two space pointing experiments were completed.

At a cost of about $262 million, SDIO reported that it completed the Relay Mirror Experiment and the Low-Power Atmospheric Compensation Experiment, which were focused on resolving issues related to the ground-based laser program. Each was placed in a separate orbit by one Delta booster in 1990. The Relay Mirror Experiment successfully demonstrated high-pointing accuracy, laser beam stability, and long-duration beam relays. The Low-Power Atmospheric Compensation Experiment successfully demonstrated low-power technology to compensate for laser beam distortions, which occur when beams go through the atmosphere from ground to space.

SDIO had spent about $684 million from fiscal years 1985 through 1991 planning, designing, and fabricating hardware for four ATP/FC space experiments that were canceled before completion for the following reasons:

- Talon Gold was intended to demonstrate precision tracking and pointing in space for targeting satellites and boosters. After spending about $26 million on Talon

Gold, SDIO canceled the experiment because the cost estimates for integration and launch had increased an additional $600 million.

- Pathfinder was started in September 1986 and was canceled in 1987 because it was too expensive. SD10 had spent about $40 million on this experiment, which was to address plume phenomenology using a sensor array on the space shuttle.
- The Starlab space experiment was intended to demonstrate precision tracking and would have used the space shuttle to accomplish the experiment. After spending about $603 million developing Starlab, SDIO canceled this experiment in part because the Challenger accident led to nearly a 3-year delay in the launch date, greatly increasing the overall cost. This coupled with changing priorities in the directed energy program led to changes in requirements and increased costs, which made the experiment too expensive to complete.
- Altair, which was canceled after SDIO had spent about $16 million in development costs, was intended to demonstrate the same types of technologies as Starlab, and was planned to use some of the hardware developed for Starlab. An SDIO official estimated that it would have cost $330 million to complete Altair.

SDIO replaced the Altair space experiment with a nonspace ATP/FC experiment called High-Altitude Balloon Experiment. This experiment was intended to achieve most of the same objectives as Altair but at a much lower estimated cost of $76 million. Balloons were used to carry AW/FC devices to an altitude of about 30 km where these devices will be used to acquire and track missiles in the boost phase. SDIO's program manager for ATP/FC expected this experiment to yield from 80 to 90 % of the data that would have been obtained from a space experiment.

SDIO designed and constructed a Rapid Retargeting/Precision Pointing [R2P2] simulator that emulated the dynamics of a large spacecraft (e.g., motion and vibration). Using this facility, SDIO developed and tested techniques for ensuring the stability, accuracy, and precision of a simulated directed energy weapon's pointing device under rapid retargeting situations. This project demonstrated, within the limits of a ground laboratory, that ATP/FC techniques should work in space at the levels established in the original program plan. SDIO will have spent about $42 million on this project from fiscal years 1986 through 1993.

Two other projects also demonstrated ATP/FC techniques. The Space Active Vibration Isolation project developed and tested ATP/FC techniques for negating the effects of spacecraft and weapon vibrations on the pointing device. This project produced hardware and technology that have improved the pointing stability of directed energy devices to below the program goal of less than 100 nanoradians or about 4 in. from a distance of 1000 km. This project was followed by the Space Integrated Controls Experiment, which improved the pointing stability even further. SDIO spent about $37 million on these two projects from fiscal years 1986 through 1993.

As of 1993 SDIO estimated that it would cost $180 million and take three more years to resolve the vast majority of the ATP/FC technical issues and perform integrated ATP experiments against real targets from the High-Altitude Balloon

Experiment platform. This would substantially complete the objectives of the 1984 plan. An additional $100 million would be needed to demonstrate operation in space, assuming that it would be done as part of another directed energy space experiment such as Star LITE, the experiment planned for the chemical laser. The major technical issues to be resolved from 1993 through 1996 included long-range fine tracking, fire control, integrated ATP/FC, and additional concept development.

For long-range fine tracking, the Solid-State Baser Radar Source program produced two laser illuminators. They still need to be tested in realistic target environments to determine their effectiveness in changing conditions and against a wide variety of targets. In addition, their capabilities must also be developed to support aimpoint selection and maintenance and damage assessment.

Fire control decision software had been demonstrated in computer simulations, but its practicality and robustness had yet to be tested in an integrated field operation. Each of the individual fire control decision algorithms needs to be tested with several sets of scene conditions with real data. Functional integration with sensors and autonomous operation must also be demonstrated. SDIO plans to test the operation of the software on the High-Altitude Balloon Experiment platform against boosting targets at the White Sands Missile Range Test.

4.10.1 Target Acquisition for Combat Operations

This section will be discussing target acquisition, tracking, and combat operation by directed energy weapon systems.

4.10.2 Overview

The goals of this sub-thrust can best be described in three major categories:

1. The measurement of atmospheric parameters on space and time scales required to support Air Force and directed energy weapon system and its missions in Global Reach–Global Power
2. The prediction of the future evolution of the atmosphere from a few hours to a few days
3. The assessment of weather impact on Air Force and directed energy weapon systems and operations

4.10.3 Description

Theater Specification for Dominant Maneuvers sub-thrust conducts R&D programs to better understand the physical and dynamic processes of the lower atmosphere in order to design, develop, test, and transition remote sensing instrumentation, retrieval algorithms, and models in support of air and space warfighters.

Real-Time Measurements of Atmospheric Parameters from Satellites: The measurement goal emphasizes the application and interpretation of satellite sensor data, but also includes in-situ sensor development as part of the program. Measurement emphasis is on the three-dimensional determination of cloud cover at the highest spatial and temporal resolution to develop the models to support global surveillance and tactical warfare.

Atmospheric Optical Turbulence Measurements and Modeling: The technical objective is to specify and predict the atmospheric optical turbulence degradation to ground-, air-, and space-based laser systems. Optical turbulence is highly variable from site to site, season to season, and day to day; however, as yet there are no good predictive models. In a program initiated in FY96, supported by the airborne laser (ABL) SPO, Phillips Lab is obtaining optical turbulence data in theaters of interest to the SPO.

Tactical Remote Sensing: The technical objective is to provide from aircraft and satellite platforms remote sensing of battlefield gases and emissions. The PL/GPOR LIDAR remote sensing program is set up to measure several atmospheric boundary layer parameters in high spatial resolution, including wind profiles, aerosol content, and size distribution, as well as the detection of trace elements, both natural and man-made. Current assets include the following:

- 10.6-μm CO_2 Doppler range-resolved wind profiler, dual tunable 9–11-μm CO_2 Doppler range-resolved wind profiler, and DIAL system to obtain range-resolved water vapor and trace gas profiles
- 1.574-μm portable, environmental, eye-safe LIDAR (or LADAR) for range-resolved aerosol and cloud profiles in addition to cloud depolarization features

New assets soon to be on hand include a coherent, tunable UV DIAL system for water vapor and ozone detection, a mechanical turbulence LIDAR or LADAR for wind shear detection, and a refractive turbulence remote sensor to measure turbulence along a path.

The Theater Forecast for Precision Engagements FTA develops tailored weather products to support combat mission planning and execution worldwide.

Prediction of Clouds and Severe Weather: The prediction goal emphasizes the data fusion of satellite and indigenous data sources in the battlefield where data denial may be a factor. The resulting analysis fields will then be tested in theater-scale prediction models on time and space scales appropriate to tactical weapon delivery.

Virtual Weather: The goal of this program is to produce computer simulations of the atmosphere, with high physical fidelity, valid as a function of location, season, time of day, and geometry. In order to address these requirements, simulation models must be developed that produce three-dimensional structure—the major shortfall of current capability. Initial efforts involve improving the physical reality of current cloud simulation models. Other projects include development of rain, fog, wind, humidity, lightning, and turbulence models. A strong emphasis is placed on physically correct visualization and the generation of radiometrically correct atmospheric scenes.

Weather Impact Decision Aids (WIDAs): The WIDA program is developing software technology for operationally predicting the impact of weather on the performance of airborne electro-optical navigation and weapon targeting systems. The program presently has four major ongoing and/or planned components: (1) Night Vision Goggle Operations Weather Software (NOWS), which will predict the impact of weather on night vision goggle detection range for AFSOC and ACC; (2) IR Target Scene Software (IRTSS), which is developing software that will determine the impact of weather on air-to-ground target scenes in the infrared and produce an IR scene visualization for transition to the Air Force Mission Support System (AFMSS); (3) Weather Automated Mission Planning Software (WAMPS), a new start in FY97 to develop software to automatically incorporate weather impacts on airborne EO systems during theater mission planning in Theater Battle Management Core Systems (TBMCS); and (4) Target Acquisition Weather Software (TAWS), a new start in FY97, will provide a major upgrade to the current operational Electro-Optical Tactical Decision Aid (EOTDA) used by Air Force Weather (AFW) support personnel to provide weapon lock-on and acquisition ranges for EO weapon systems used by ACC:

1. **User Impact**:
   None.
2. **User Impact**:
   Concept/technology.
3. **Images**:
   None.
4. **Related Initiatives**:
   - **Target Acquisition for Combat Operations** (see Sect. 5.1).
   - **Target-Background Discrimination for Surveillance** (see Sect. 5.2)
5. **Related Requirements**:
   None.
6. **Related Categories**:
   Optical Surveillance Effects and Battle-Space Operations
   The importance of maintaining a reduced nuclear force and the emerging conventional ballistic force as a combat and cost-effective weapon is recognized by Air Force Space Command (AFSPC) mission area plans and Space and Missile Systems Command (SMC) development plan having the technology needs in advanced guidance technologies and astrodynamics.
   - **The goals of advanced guidance are:**
     - Global Positioning System (GPS) Range Standardization/Safety Technology
     - Development of new miniature systems to lower range costs 30 % by replacing radar systems and enhance safety with greater accuracy and reliability by FY01
     - GPS accuracy enhancements

  - To increase cost effectiveness, missile navigation, and testing accuracy with improved GPS/INS coupling by FY98
  - Development of precision fiber optic gyroscope (PFOG) with low-loss integrated optics and fiber couplers and flexured mass accelerometer (FMA) with open-loop, two back-to-back microwave resonant cavities by FY99
  - To decrease the reliance on high-cost, high-precision inertial measurement systems with micromechanical updates on accelerometers and gyros by FY01
  - To fly the Missile Technology Demonstration III (MTD III) during FY01 to gain data on multiple penetrator warheads delivered on an ICBM
  - To develop anti-jam antennas
  - To integrate plasma physics with design
  - To develop and test materials for antenna windows

- **The goals of astrodynamics are to:**

  - Improve differential correction (DC) accuracy 90 %.
  - Improve propagation accuracy at the end of the prediction period by 90 %.
  - Demonstrate integrated performance of high-accuracy lasers and astrodynamics algorithms to precisely locate and illuminate spacecraft.
  - Demonstrate next-generation initial orbit determination, DC, and propagation for space surveillance.
  - Show deficiencies in current operational DC and propagation which could be eliminated.
  - Demonstrate capability to maintain independent high-accuracy catalog of selected satellites (20–30 objects).

4.11 Target-Background Discrimination for Surveillance

The following sections will apply for this purpose.

4.11.1 Overview

Space-based surveillance, tracking, and interceptor systems must accurately and reliably discriminate target IR and optical signatures from the atmospheric and celestial IR and optical emissions against which the targets are viewed. When sensor specifications are optimized against realistic, accurate simulations of the atmospheric and celestial emissions in the sensor's field of view, then operational performance is significantly enhanced, and system overdesign is minimized, thereby making DOD space-based systems much more affordable. The sub-thrust goals are to develop and demonstrate integrated background clutter mitigation technologies for SBIRS-High and SBIRS-Low and next-generation hyperspectral surveillance and threat warning systems and to integrate clutter suppression technologies into hardware simulators to provide high-resolution spectral and spatial scene data of atmospheric, cloud, terrain, and celestial background clutter to support system designs.

This sub-thrust:

1. Defines the impact of optical and infrared backgrounds on surveillance and threat warning, theater and national missile defense, and intelligence, surveillance, and reconnaissance systems
2. Measures atmospheric and celestial infrared, ultraviolet, and visible backgrounds using satellite and rocket-borne sensors
3. Models atmospheric and celestial optical and infrared backgrounds for the full range of operational conditions and system design trade space
4. Provides real-world background scenes, global background statistics, and reliable background scene models to support system engineering trade studies
5. Measures and models in-flight infrared signatures of aircraft and missiles
6. Distributes and provides online access to background phenomenology data
7. Defines optical and infrared background requirements for surveillance systems and battle-space simulations

4.11.2 Description

This sub-thrust defines the impact of optical and infrared backgrounds on surveillance and threat warning, theater and national missile defense, and intelligence, surveillance, and reconnaissance systems and measures atmospheric and celestial infrared, ultraviolet, and visible backgrounds using satellite and rocket-borne sensors. The two main project areas of this sub-thrust are backgrounds and target phenomenology and background clutter mitigation.

The goals of the backgrounds and target future technical architecture (FTA) are to provide high-resolution spectral and spatial scene data of atmospheric, cloud, terrain, and celestial background clutter to support SBIRS designs; provide high-throughput data processing, analysis, and distribution of background phenomenology data for SBIRS, BMDO, and other DOD programs; measure in-flight infrared signatures of aircraft and missiles; and develop models capable of predicting the infrared characteristics of all aircraft, particularly in the design and development stages. A major task under this FTA is to construct infrared atmospheric and celestial background scenes from the superb data measured by the MSX satellite and atmospheric scenes from the highly successful MSTI-3 satellite mission. The combined data set will be used to upgrade models for the design of the new SBIRS surveillance system.

The goals of the background clutter mitigation FTA are to (1) characterize and predict atmospheric, cloud, and terrain infrared background clutter for the full range of SBIRS operational conditions and system design trade space and (2) assess the impact of background clutter on SBIRS performance and mission capabilities. Spatial and temporal structure in atmospheric, cloud, and terrain backgrounds produces clutter against which infrared and optical sensor systems must detect and track theater ballistic missiles, cruise missiles, and aircraft threats as well as perform technical intelligence missions.

Under this program, tasks are being performed to:

1. Provide background clutter codes to extrapolate measured background data to the full SBIRS design trade space and all SBIRS operational conditions.
2. Provide background model uncertainty bounds.
3. Assess and upgrade background clutter codes for SBIRS using MSX and MSTI-3 data.
4. Develop dynamic, statistical background clutter models to support adaptive hyperspectral imaging.
5. Provide expert user interface for code applications:

1. **User Impact**:
   None.
2. **User Impact**:
   Concept/technology.
3. **Images**:
   None.
4. **Related Initiatives**:

   - **Space-Based Infrared System—Low Earth Orbit (SBIRS-Low)**
     The space-based infrared system (SBIRS) is in response to the US military forces increasing the need for accurate and timely warning of tactical missile attack. SBIRS will replace the current Defense Support Program (DSP) designed to meet US infrared space-based surveillance and warning needs through the next two to three decades. SBIRS improves support to theater CINCs, US deployed forces, and allies by providing detailed information in the four mission areas of missile warning, missile defense, technical intelligence, and battle-space characterization. SBIRS will provide significant performance enhancements over DSP by improving quality and timeliness of missile warning data. SBIRS should enhance information superiority and support the Joint Vision 2010 operational concepts of full-dimensional protection and precision engagement, by providing this data directly to theater commanders in a timely, survivable manner, thus enabling US forces' immediate reaction to threat.

     The SBIRS space segment includes a high and low component. The high component comprises six satellites: four in geosynchronous (GEO) Earth orbit and two hosted payloads in highly elliptical orbit (HEO). The low component includes approximately 24 low Earth orbit (LEO) satellites. The SBIRS high component will meet a subset of the operational requirements, including all key threshold requirements. The SBIRS low component will provide a unique, precision, midcourse tracking capability critical for effective ballistic missile defense, as well as enhanced capability in support of other SBIRS missions. SBIRS-High, complemented by SBIRS-Low satellites, will meet all of its operational requirements.

The SBIRS ground segment includes a continental US CONUS-based Mission Control Station (MCS), a MCS backup (MCSB), a survivable MCS (SMCS), overseas relay ground stations, Multi-Mission Mobile Processors (M3Ps), and associated communication links. The SBIRS ground segment will be delivered incrementally. The first increment, scheduled to be operational in FY99, consolidates DSP and Attack and Launch Early Reporting to theater ground stations into a single CONUS ground station and will operate with DSP satellite data. The second increment, scheduled for FY02, will provide the necessary ground segment functions required for the new high-altitude SBIRS satellites and the residual DSP satellites. Included in the second increment will be mobile terminals capable of fulfilling the Army Joint Tactical Ground Station in-theater and SBIRS strategic processing requirements. A third increment, which will be operational in FY03, will add the necessary ground segment functions for the first LEO satellite scheduled to be deployed in FY04.

Background Information:
SBIRS was initiated in 1995 as a replacement for the Follow-on Early Warning System acquisition, which was canceled due to cost and requirement problems. Since SBIRS satellites need to be completed before the last DSP satellite is launched, it was placed on an accelerated schedule and selected as a lead program for acquisition reform. Much of the traditional required documentation was reduced or consolidated into a Single Acquisition Management Plan, and emphasis was placed on direct involvement through Integrated Product Teams (IPTs) rather than traditional documentation reviews.

The SBIRS high component entered the EMD phase following a Milestone II DAB review in October 1996. This decision was supported by an OA conducted by AFOTEC and reviewed by DOT&E.

The first phase of IOT&E will be conducted in 1999 to verify the performance of the Increment 1 ground station. Due to the critical role SBIRS plays in Integrated Tactical Warning and Attack Assessment (ITW/AA) of attack on the CONUS, DOT&E has become involved in this program early. DOT&E works closely with AFOTEC, the program office, and all users to ensure that the acquisition strategy fosters an operationally effective and suitable system while maintaining cost effectiveness. DOT&E has supported SBIRS acquisition reform through heavy involvement in IPTs, early involvement in combined developmental and operational tests, and consolidation of developmental and operational test plans into a single integrated T&E plan.

The SBIRS test program includes a combination of OAs, combined DT/OT testing, and dedicated IOT&E. These OT&E events will progress in a building block manner beginning with analyses, modeling, and validated simulation and ending with hardware-in-the-loop (HWIL) test-beds and field tests. Modeling, simulation, and test-beds will be used to assess those areas in which field testing cannot be conducted, such as actual missile attacks and operation in nuclear environments. SBIRS operational effectiveness and suitability will be assessed on the basis of IOT&Es of each of the three major increments, which will include fixed and mobile assets.

Test and Evaluation Activity:

In 1998, DOT&E approved an initial TEMP that defined the top-level test strategy and mapped it into the overall acquisition strategy. DOT&E also continued its oversight of the following areas (each of which could impact schedule, cost, and system performance):

– Progress toward Increment 1 IOT&E
– HWIL test-bed definition and dynamic effect modeling for Increment 2
– Risk reduction efforts for Increment 3
– Testability of SBIRS/NMD requirements for Increment 3

Progress toward Increment 1 IOT&E was assessed by an AFOTEC (OA) that addressed four areas: (1) major issues potentially affecting effectiveness and suitability, (2) programmatic voids, (3) testability of user requirements, and (4) ability of the program to support operational testing. DOT&E has specific program concerns about SBIRS Increment 1: (1) immature ground system software and delays in requirement performance verification, (2) delays in procuring high-reliability communication links from the overseas ground stations to the Mission Control Station, and (3) adequate hardware for crew training. The program office is addressing many of these findings through specific risk reduction efforts to ensure readiness to enter IOT&E for the Increment 1 ground system in April 1999. There are still testability concerns involving the difficulty of testing SBIRS/NMD operational requirements within an acceptable confidence limit.

Test and Evaluation Assessment:

Year 2000 (Y2K) testing for SBIRS is well underway, and there are no anticipated problems with the system. Due to extensive use of commercial software and close cooperation between the contractor team and the Air Force, an adequate verification program is in place. Final Y2K testing will be complete prior to the start of IOT&E for the Increment 1 ground station in April 1999.

The major near-term challenge for the SBIRS program is to ensure a seamless transfer of operations from the current DSP ground stations to the new SBIRS Increment 1 MCS. This demanding task is complicated by the compressed timeline and issues associated with shared use facilities at the overseas relay ground stations. Additionally, there have been significant delays in validating software performance of the Increment 1 ground system. Other near-term challenges for the SBIRS program include the adequacy of test-bed design and the scope of models and simulations needed to validate the stressing requirements for the SBIRS-High satellites and MCS Increment

2 and the significant technical risks associated with accelerated deployment of the low component by FY04. The demanding SBIRS-High requirements are a significant improvement over DSP's demonstrated performance and require extensive testing to validate and assure the system's performance. For HWIL test-beds, continued attention must be given to ensure that the test-beds are adequate to support OT&E, including the need to portray dynamic backgrounds that accurately portray the Earth's background as seen from space.

DOT&E's assessment is that the SBIRS compressed schedule to achieve "online in '99" remains high risk, and delays in software integration and testing pose an increased risk in a "zero margin" schedule leading to Increment 1 IOT&E scheduled for April 1999. The primary challenge for Increment 1 is the verification of software performance and reliability. There have been significant delays in verifying software performance and reliability, as well as delays in hardware installation at the remote ground stations. While this type of problem is not unusual, many systems interfacing with the SBIRS MCS are 1970's legacy reporting systems, whose interfaces may not be adequately documented. Delays in starting the testing of these interfaces put an inordinate amount of pressure on the first opportunity success. The "never fail" nature of ITW/AA systems requires extensive "online" testing to validate reliable Increment 1 operations and a period of parallel operations prior to declaration of IOC. Any significant delays to IOT&E would lead to "ripple effect" delays in the Increment 1 IOC date and further delay the IOC dates for subsequent ground system increments. Also, there is a concern that the SBIRS Increment 1 ground system includes voids in areas of fault detection and isolation, operator training, and manpower.

SBIRS Increment 2 (both space and ground elements) remains on schedule, but faces continued challenges in the areas of simulation and test-bed development. For Increment 2, progress has been made in identifying real-world, dynamic effects in the short and medium wavelengths detected by the greatly improved SBIRS-High sensors. The operational impact of these effects must be quantified and the SBIRS-High sensor design shown to be robust enough to handle these natural phenomena. The resolution of these issues can be best accomplished by incorporation of adequate testing processes into the baseline sensor ground-testing program. Until this testing is completed, the capabilities of the SBIRS sensor and signal processing to operate in the space environment remain a major concern.

Continuing significant technical problems with the SBIRS-Low, PDRR satellites demonstrate the wisdom of an extensive PDRR test phase before entering EMD to start the construction of operational SBIRS-Low satellites. The current schedule of events is very compressed and does not allow full evaluation of the PDRR satellites' performance. The current baseline SBIRS-Low schedule requires successful completion of many difficult activities proceeding in parallel toward a successful FY04 first launch, thus violating recommendations outlined in the recently completed Welch report on missile defense systems. Any additional delays in the PDRR competing contractors' programs will require starting the EMD prior to completion of PDRR to meet the congressional goal of an FY04 first launch. DOT&E is concerned that the baseline schedule, which includes the Flight Demonstrations System and the Low Altitude Demonstrations System, will be delayed, presenting very few opportunities to collect "real-world" performance data on contractor designs to assess their ability to meet draft performance requirements. This period of evaluation of PDRR results is critical since "lessons learned" from PDRR test activities form the foundation for the government and contractor teams to perform cost as an independent value satellite design trades. Any significant problems encountered during the PDRR phase (given the compressed schedule) may lead to premature launching of inadequately designed and tested satellites to maintain the FY04 initial deployment date.

To support Milestone II decisions, DOT&E has worked closely with the AFOTEC, the program office, and the user community, to ensure that the acquisition strategy throughout the acquisition cycle fosters an operationally effective and suitable system, while maintaining cost effectiveness. This early involvement included active membership in IPTs, fostering combined developmental and operational tests, early validation of software maturity, and consolidation of developmental and operational test plans into a single integrated T&E plan.

5. **Related Requirements**:
   None.
6. **Related Categories**:

   - **Contributing Sensors**
     These sensors provide observation data on satellites to USSPACECOM on a contributing basis, but are not directly under the operational control of USSPACECOM. Both mechanical radars and electro-optical systems are included in this category.
   - **Satellite Operations**
     The DoD procures, operates, and maintains a myriad of satellite systems to support national and tactical communications, missile warning, nuclear detonation detection, navigation, weather, and environmental monitoring. DoD's satellite operations include the Defense Satellite Communications System (DSCS), Milstar, Fleet SATCOM (FLTSATCOM) system, UHF Follow-on (UFO) system, the Defense Support Program (DSP), the Nuclear Detonation Detection System (NUDET), the Global Positioning System (GPS, also referred to as POSNAVTIME or position, navigation, and time), and the Defense Meteorological Satellite Program (DMSP) systems that are included in this category.
   - **Space-Based Warning System**
     This category addresses space systems and sensors that have a surveillance and warning mission, which are operational, in development, or being studied.

- **DoD Space Surveillance Programs**
  A constant and vigilant surveillance of potentially hostile military threats is critical in preserving the operational effectiveness of our armed forces around the world. Naval Space Command manages two distinct surveillance efforts in support of Fleet and Fleet Marine Forces: tracking satellites in orbit and monitoring over-the-horizon threats from sea and air forces.
  Over one million satellite detections, or observations, are collected by this surveillance network each month. Data gathered is transmitted to a computer center at Naval Space Command headquarters in Dahlgren, where it is used to constantly update a database of spacecraft orbital elements. This information is reported to Fleet and Fleet Marine Forces to alert them when particular satellites of interest are overhead. The command also maintains a catalog of all Earth-orbiting satellites and supports USSPACECOM as part of the nation's worldwide Space Surveillance Network.

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