

**Human Factor Considerations for Outdoor Laser Operations
in the Navigable Airspace**

RATIONALE

This document has been reaffirmed to comply with the SAE 5-year Review policy.

FOREWORD

The SAE G-10T Committee has met over 30 times during the past 4 years with 17 different agencies to identify the issues, technologies, and operational capabilities of outdoor laser shows in navigable airspace. This information was requested by the FAA to assist in developing FAA Order 7400.2D "Recommended Interim Guidelines" (RIGs) and the current development of FAA's Advisory Circular 90-XX, "Laser Operations in the National Airspace System". These two documents, along with the ANSI Z136.6, "Standards for the Safe Use of Lasers Outdoors", document will be interfaced with AS4970, "Laser Operations in Navigable Airspace" to provide in-depth reference documents for outdoor laser operations.

This document will provide recommendations and guidance in the following areas:

1. Flashblindness, afterimage and glare
2. Temporary Vision Loss (TVL) during critical phases of flight causing: distraction, disruption, disorientation and temporary incapacitation
3. Laser flight zone maximum exposure limits for airspace volumes
4. Risk analysis for outdoor operations
5. Laser beam measurement techniques
6. Atmosphere propagation
7. Aircrew laser protocol
8. Laser forms for request of operation, configuration description and measurement tables
9. Automated devices
10. Scientific/research laser operations
11. Airspace diagrams for flight zone limitations

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FOREWORD (CONTINUED)

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INTRODUCTION

In the early 1990s, outdoor laser light shows began to proliferate throughout the USA. While these shows were spectacular and entertaining, some were located near commercial airports and were involved with aircrew laser illuminations. Commercial off the shelf (COTS) and commercial outdoor shows demonstrated a potential hazard to aircraft operations. The threat to aircraft was no longer limited to military-developed laser systems.

The SAE G-10T Laser Hazards subcommittee was formed to address the issues of laser hazards in navigable airspace, and develop guidance standards and procedures to safely operate outdoor laser light shows in proximity of airport operations and other enroute navigable airspace. Other areas of laser operations that address scientific/research operations are included in this document (i.e., satellite tracking/astronomical telescope operation).

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1. SCOPE

This SAE Aerospace Standard (AS) provides a method for protecting the navigable airspace around airports from unwanted laser illuminations and a procedure for proponents to seek approval from regulatory agencies for operations of various classes of laser devices and their applications within this volume of airspace. This document also provides a system of data disclosure deemed necessary for a regulatory agency to determine the potential safety effect of proposed outdoor laser activities upon flight operations within the defined airspace.

1.1 Purpose

The purpose of this document is to establish a standard protocol for safe co-existence of aircraft operations and various types of ground-based laser operations within the navigable airspace. It also provides a method for flight crews to report in-flight illuminations to their respective regulatory authorities.

2. REFERENCES

1. Zimmerman, Sheldon; and Aldrich, Robert; Comparison of Divergence Measurement Techniques for Laser Light Show Application, Proceedings of the Third International Laser Safety Conference, Laser Institute of America, 1997.
2. American National Standards Institute Inc., American National Standard for Safe Use of Lasers, ANSI Z136.1-1993, 5 February 1993.
3. Marshall, W. J., Focused Laser Beam Hazard Calculations. Proceedings of the International Laser Safety Conference, Laser Institute of America 1991: 9-33.
4. Thomas, Robert J.; Maier, Dennis A.; Barsalou, Norman; McLin, Leon; Lambert, LeRoy; and Keppler, Kenneth. Laser Light Show Measurement Techniques.

2.1 Related Reading Material

- 2.1.1 American National Standards Institute (ANSI) Z136.1 American National Standard for Safe Use of Lasers
- 2.1.2 American National Standards Institute (ANSI) Z136.6 Standard for the Safe Use of Lasers Outdoors
- 2.1.3 Federal Aviation Administration (FAA) Order 7400.2 Procedures for Handling Airspace Matters
- 2.1.4 Federal Aviation Administration (FAA) Order 7400.2D Recommended Interim Guidelines (RIGS)
- 2.1.5 Society of Automotive Engineers Aerospace Research Document (ARD 50059)
- 2.1.6 Society of Automotive Engineers Aerospace Recommended Practice (ARP 5290)

3. DEFINITIONS

The terms defined are limited to those actually used in this standard and its appendices and are not intended to constitute a dictionary of terms used in the laser field as a whole.

ABSORPTION: Transformation of radiant energy to a different form by interaction with matter.

ACCESSIBLE EMISSION LIMIT (AEL): The maximum accessible emission power or energy permitted within a particular class.

ACCESSIBLE RADIATION: Optical radiation to which it is possible for the human eye or skin to be exposed in normal usage.

AFTERIMAGE: A reverse contrast shadow image left in the visual field after an exposure to a bright light.

ALIGNMENT MODE: Operation of the laser system at the lowest possible power to enhance safety while conducting beam alignment.

APERTURE: An opening through which optical radiation can pass.

APPARENT VISUAL ANGLE. The subtended angular width of the source at the viewer distance. It is the apparent angular dimension of the source divided by the viewer distance. It is expressed in radians (rad).

ATTENUATION: The decrease in the radiant flux as it passes through an absorbing or scattering medium.

AUTHORIZED LASER OPERATOR. A knowledgeable person, present during laser operation, who has been given authority to operate the laser system in compliance with applicable safety standards, subject to recommendations of the LSO.

AVERAGE POWER. The total energy imparted during exposure divided by the exposure duration.

AVERSION RESPONSE: Closure of the eyelid, or movement of the head to avoid an exposure to a noxious stimulant or bright light. In this standard, the aversion response is assumed to occur within 0.25 s, including blink reflex time.

BEAM: A collection of light rays emitted from a source that may be parallel, divergent, or convergent.

BEAM BACKSTOP: A non-specular material that is opaque to laser radiation of a particular wavelength. An adequate backstop encompasses the entire laser beam and appropriate buffer area.

BEAM DIAMETER: For the purposes of this standard, the beam diameter is the radial distance across the center of a laser beam where the irradiance is $1/e$ times the center-beam irradiance (or radiant exposure for a pulsed laser).

BUFFER ANGLE. An angle added to the beam divergence or intended laser projection field in order to ensure a protection zone.

BUFFER AREA. The projection of the buffer zone around a target, when the ground serves as the beam backstop.

BUFFER ZONE. This volume of air surrounding the laser beam includes all potential locations of the laser beam, including hazardous diffuse or specular reflections, where the MPE or visual interference levels are exceeded. It includes the beam divergence or scanning extent of the laser beam plus the buffer angle, and the full range of the laser beam to the point where the MPE, or any applicable visual interference level is not exceeded. Natural terrain or beam masks may truncate part of this volume.

C_A: A correction factor, which increases the MPE values in the near-infrared spectral band based upon reduced absorption by the retina.

C_C: A correction factor, which increases the MPE values for ocular exposure in the spectral band of 1150 and 1400 nm.

C_E: A correction factor, which increases the MPE for large sources (sources that exceed 1.5 mrad).

C_P: A correction factor, which reduces the MPE for repetitively pulsed exposure.

COLLIMATED BEAM: Effectively, a "parallel" beam of light with very low divergence. See divergent beam.

CONTINUOUS WAVE (CW): The output of a laser that is operated in a continuous rather than a pulsed mode. In this standard, a laser operating with a continuous output for a period >0.25 s is regarded as a CW laser.

CONVERGENT BEAM: See focused beam.

CORNEA: The transparent outer coat of the human eye that covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.

CRITICAL EXPOSURE DISTANCE. The distance along the beam path of a visible laser source beyond which the local effective irradiance falls below the critical level.

CRITICAL LEVEL: The minimum effective irradiance from a visible laser beam that can interfere with critical task performance due to transient visual effects (see 8.3).

CRITICAL FLIGHT ZONE (CFZ): Airspace within a 10 nautical mile (NM) radius of the Airport Reference Point, up to and including 10,000 ft AGL, where a level of laser light is restricted to avoid flash blindness or afterimage effects.

CRITICAL ZONE: Volume of airspace where visual interference by a visible laser beam would compromise safety due to interruption of necessary performance of critical tasks (see Figures E3 and E4). This zone surrounds the laser-free zone.

DEMONSTRATION LASER PRODUCT: Any laser product designed or intended for purposes of visual display of laser beams, entertainment, advertising display, or artistic composition (see 21 CFR 1040.10 (b) 13).

DIAMETER: See beam diameter.

DIFFRACTION: Deviation of part of a beam, determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

DISABLING GLARE. Obscuration of an object in a person's field of vision due to a bright light source located near the same line-of-sight.

DISRUPTION: Interference or interruption of critical tasks.

DISORIENTATION: Losing perspective in the relationship between the direction of travel and surroundings.

DIVERGENCE: The divergence is the increase in the diameter of the laser beam with distance from the exit aperture, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is 1/e times the maximum value.

DIVERGENT BEAM: A laser beam that diverges from the exit port at an angle significantly greater than the diffraction limit of the optics system. A divergent beam does not have an external beam waist (not a focused beam).

EFFECTIVE IRRADIANCE: The actual irradiance multiplied by a factor from Table B5, Appendix B, to correct for visual perception. The effective irradiance can then be compared to the applicable visual interference level. The effective irradiance multiplied by 683 is the illuminance.

ELECTROMAGNETIC RADIATION: The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation. This radiation includes optical radiation and also X-rays and radio waves.

ELECTRONIC MONITORING: A variety of means (other than human observers), such as radar or infrared cameras, for observing the sky to prevent potential illuminations of aircraft by laser beams.

ENERGY: The capacity for doing work. Energy content, generally expressed in joules (J), is commonly used to characterize the output from pulsed lasers.

FLASHBLINDNESS: A visual interference effect, which persists after the source of illumination has been removed.

FLIGHT ZONES: Areas of airspace specifically designed to mitigate the potential hazardous effect of laser radiation. These areas may not be contiguous or concentric with other zones.

FOCAL LENGTH: The distance from the secondary nodal point of a lens to the primary focal point. In a thin lens, the focal length is the distance between the lens and the focal point for a collimated source of light.

FOCAL POINT: The point toward which radiation converges or from which radiation diverges or appears to diverge.

FOCUSED BEAM. A laser beam shaped to narrow at a distance away from the source. Thus, the beam waist is along the beam path in front of the laser. Lasers that have the beam waist inside the laser cavity or behind the laser are not considered focused in this standard.

GAUSSIAN BEAM PROFILE. The profile of a laser beam operating in the lowest transverse mode (TEM₀₀).

GLARE. See disabling glare.

HALF-POWER POINT: The time of either the leading or trailing edge of a laser pulse at which the power is one-half of its maximum value.

HAZARD ZONE. The space within which the level of radiation during operation exceeds the applicable exposure level. This includes: Nominal Hazard Zone (NHZ), Sensitive Flight Zone, Critical Flight Zone, and Laser-Free Flight Zone.

HERTZ (Hz): The unit that expresses the frequency of a periodic oscillation in cycles per second.

ILLUMINANCE: A measure of the irradiance on a surface multiplied by a factor to adjust for human visual sensitivity. Measurement units are foot-candle (lumens per square foot) or lux (lumens per square meter). See effective irradiance.

INCAPACITATION: Inability to continue performing critical tasks.

INCIDENTAL PERSONNEL: Those persons whose work makes it possible (but unlikely) that they will be exposed to laser energy sufficient to damage their eyes or skin.

INFRARED RADIATION: For the purposes of this standard, electromagnetic radiation with wavelengths that lie within the range 0.7 μm to 1 mm.

INTEGRATED RADIANCE: The integral of the radiance over the exposure duration. Also, known as pulsed radiance. Unit: joules per square centimeter per steradian($\text{J}\cdot\text{cm}^{-2}\cdot\text{sr}^{-1}$).

INTERLOCK: A device, which is activated upon entry to a laser laboratory or enclosure, which terminates laser operation or reduces personnel exposure to below the MPE.

INVISIBLE LASER: For the purposes of this standard, an invisible laser has a wavelength either shorter than 0.4 μm or longer than 0.7 μm . This term does not mean that the laser itself is invisible.

IRIS: The circular pigmented membrane that lies behind the cornea. The iris is perforated by the pupil.

IRRADIANCE (at a point of a surface): The quotient of the radiant flux incident (from a particular direction) on an element of the surface containing the point at which irradiance is measured, by the area of that element. Unit: watt per square centimeter ($\text{W}\cdot\text{cm}^{-2}$).

JOULE: A unit of energy. 1 joule = 1 watt second.

LASER: A device that produces an intense, coherent, directional beam of light by stimulating electronic or molecular transitions to lower energy levels. LASER is an acronym for "Light Amplification by Stimulated Emission of Radiation."

LASER SYSTEM: An assembly that includes a laser.

LASER-FREE EXPOSURE DISTANCE: The distance along a visible laser beam path beyond which the laser irradiance is less than the laser-free level.

LASER-FREE LEVEL: The maximum level of visible optical radiation which is not expected to cause any psychological or visual disruption to an individual performing critical tasks (see 8.3).

LASER-FREE ZONE (LFZ): The airspace, up to and including 2000 ft AGL, extending 2 NM in all directions measured from the runway centerline, plus a 3 NM extension along the extended centerline, to include 2500 ft each side of the extended runway centerline for each useable runway surface. The level of laser light is restricted to a level that should not cause any psychological or visual disruption (see Figures E2, E3, and E4).

LASER LIGHT SHOW SYSTEM: A demonstration laser product for producing and redirecting laser beams to produce a visual effect.

LASER OPERATOR: A knowledgeable person, present during laser operation, who has been given authority to operate the laser system in compliance with applicable safety standards, subject to recommendations of the LSO.

LASER PRODUCT: Any manufactured product or assemblage of components that constitutes, incorporates, or is intended to incorporate a laser or laser system. A laser or laser system intended for use as a component of an electronic product shall itself be considered a laser product.

LASER SAFETY OFFICER (LSO): An individual with both the authority and the responsibility to monitor and enforce the control of laser hazards and to effect the knowledgeable evaluation and control of Class 3b and Class 4 laser hazards.

LASER SAFETY SPECIALIST: One who has formal training to calculate or determine laser hazards and appropriate control measures.

LASER SYSTEM MANAGEMENT ORGANIZATION (LSMO): The organization which is responsible for employing and designating a Laser Safety Officer (LSO). This organization may, or may not, own the laser.

LIMITING APERTURE (Df): The circular diameter over which irradiance and radiant exposure is averaged for comparison to MPE. The limiting aperture for the eye for wavelengths between 400 and 1400 nm is 7 mm, simulating the dark-adapted pupil size.

LIMITING EXPOSURE DURATION (Tmax): An exposure duration which is specifically limited by the design or intended use(s).

MAINTENANCE: Performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser or laser system, which are to be performed by the user to ensure the intended performance of the product. It does not include operation or service as defined in this section.

MAXIMUM PERMISSIBLE EXPOSURE (MPE): The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. In general, MPE is expressed as mW/cm² or mJ/cm². Selected MPEs for the eye are listed in Tables A1, A2, and A3.

MIE SCATTERING: Atmospheric scattering by particles larger than those particles that produce Rayleigh scattering. Mie scattering is mostly forward scattering and is less dependent upon wavelength than Rayleigh scattering.

MILLIRADIAN (MRAD): A measure of angle used for beam divergence. A milliradian is 1/1000 of a radian. This is approximately 1/17th of a degree.

NODAL POINT: One of two conjugate points inside a thick lens where the angular magnification is unity.

NORMAL FLIGHT ZONE (NFZ): Airspace not defined by the Nominal Hazard Zone or the Laser- Free, Critical, Sensitive Flight Zones.

NOMINAL HAZARD ZONE (NHZ): The NHZ describes the space within which the level of the direct, reflected or scattered radiation during operation exceeds the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE level.

NOMINAL OCULAR HAZARD DISTANCE (NOHD): The maximum distance from the laser system beyond which the beam irradiance of the laser does not exceed the MPE for that laser.

OPERATION: The use of the laser product over the full range of its intended functions. It does not include maintenance or service.

OPERATOR CONTROLLED SPACE: An area on the ground or volume of airspace where the operator has accepted the responsibility for laser safety.

POINTING ACCURACY: The maximum angle of expected error in beam direction during all projected uses of the device. For automatic tracking systems, the pointing accuracy includes the maximum error that could occur during a loss of track scenario before the laser is disabled.

POWER. The rate at which energy is emitted, transferred, or received. Unit: watts (joules per second).

PRF: Abbreviation for pulse repetition frequency.

PROTECTION DISTANCES: Generic term referring to the distance from the laser along the beam path to the cessation of a biological or visual effect. See laser-free exposure distance, critical exposure distance, sensitive exposure distance, and nominal ocular hazard distance.

PULSE DURATION. The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse.

PULSE REPETITION FREQUENCY (PRF): The number of pulses that a laser produces over an applicable time frame divided by that time frame. For uniform pulse trains lasting over 1 s, the PRF is the number of pulses emitted by the laser in 1 s in Hz.

PULSED LASER: A laser that delivers its energy in individual pulses, lasting less than 0.25 s. See repetitively pulsed laser.

Q-SWITCHED LASER: A laser that emits short (~10 ns to 1 μ s), high-power pulses by means of a Q-switch device.

RADIAN: An angular measurement unit equal to the subtended angle at the center of a circle by an arc whose length is equal to the radius of the circle. $1 \text{ radian} = 57.3^\circ$; $2\pi \text{ radians} = 360^\circ$.

RADIANT ENERGY (Q): Energy emitted, transferred, or received as radiation. Unit: joule (J).

RADIANT EXPOSURE (H): Surface density of the radiant energy received. It is computed from the emitted energy divided by the area of the laser beam. Unit: joules per square centimeter ($\text{J}\cdot\text{cm}^{-2}$).

RADIANT POWER (flux) ($\dot{Q}$): Power emitted, transferred, or received as radiation. Unit: watt (W).

RAYLEIGH SCATTERING: Scattering of radiation during its passage through a medium containing particles whose sizes are very small compared with the wavelength of the radiation.

REFLECTANCE: The ratio of total reflected radiant power to total incident power. Also called reflectivity.

REFLECTED BEAMS: There are two components of reflected beams, as follows:

DIFFUSE: The component of a reflection from a surface which is incapable of producing a virtual image such as is commonly found with flat finish paints or rough surfaces. A diffuse surface will reflect the laser beam in many directions.

SPECULAR: A mirror-like reflection that usually maintains the directional characteristics of the beam.

REFLECTION: Deviation of radiation following an incidence on a surface. Reflections can be either a diffuse reflection or a specular reflection.

REPETITIVELY PULSED LASER: A laser producing multiple pulses of radiant energy occurring in sequence with a PRF $> 1 \text{ Hz}$.

RETINAL HAZARD REGION: Wavelengths between 0.4 and $1.4 \mu\text{m}$.

SAFETY INTERLOCK: A device which is designed to be displaced or moved upon removal of the protective housing in such a way as to prevent human exposure above the MPE.

SAFETY OBSERVER: One who has been given the responsibility for ensuring that people do not enter hazardous laser beams, and the authority to terminate the laser beams when a potential conflict occurs.

SCANNING LASER: A laser having a time-varying direction, origin, or pattern of propagation with respect to a stationary frame of reference.

SCINTILLATION: The rapid changes in irradiance levels in a cross-section of a laser beam produced by atmospheric turbulence. See Appendix C.

SENSITIVE EXPOSURE DISTANCE: Distance along a visible laser beam path beyond which the local irradiance falls below the sensitive level.

SENSITIVE FLIGHT ZONE (SFZ): Airspace outside the Critical Flight Zone(s) that regulatory authorities have identified to be protected from flash blindness or afterimage effects.

SENSITIVE LEVEL: The minimum effective irradiance from a visible laser that interferes with the performance of vision-dependent tasks due to temporary vision impairment. The effects from illumination at this level can often exceed the duration of exposure (afterimages or flash blindness) (see 8.3).

SERVICE: Performance of procedures or adjustments described in the manufacturer's service instructions that may affect any aspect of the product's performance. It does not include maintenance or operation as defined in this section.

SITE LSO: An LSO for a local facility where lasers are used, who is responsible for approving all uses of the lasers at that facility. The site LSO may delegate this responsibility to the visiting LSO.

SOURCE: A laser or a surface that reflects laser illumination.

SOURCE ANGLE: See apparent visual angle.

SPECULAR REFLECTION: A mirror-like reflection. A specular reflection maintains the collimation of the laser beam.

$T_{\max}$: See limiting exposure duration.

$T_{\min}$: The exposure duration for which the MPE is the same as it is for 1 ns.

TERMINATED BEAM: An output from the laser projector which enters airspace and is confined by a suitable object that blocks the beam or prohibits the continuation of the beam at levels capable of producing psychological or visual disruption.

TRANSMISSION: Passage of radiation through a medium.

TRANSMITTANCE: The ratio of total transmitted radiant power to total incident radiant power.

ULTRAVIOLET RADIATION: Electromagnetic radiation with wavelengths smaller than those of visible radiation; i.e., 0.18 to 0.4 μm for this standard.

VISIBLE LASER: For the purposes of this standard, a laser operating in the wavelength range between 0.4 and 0.7 μm . This term does not mean that the laser itself is either visible or invisible.

VISIBLE RADIATION (LIGHT). Electromagnetic radiation that can be detected by the human eye. This term is commonly used in laser safety standards to describe wavelengths that lie in the range 0.4 to 0.7 μm .

VISUAL INTERFERENCE LEVEL A laser beam irradiance less than the MPE, but which can interfere with aircrews, or other personnel, performing sensitive or critical tasks. This limit varies in accordance with the particular zone where the laser is operating. A generic term for critical level, sensitive level or laser-free level (see 8.3).

WATTS (W): A measurement unit associated with the power output of a laser system. Often a fraction of a watt is prefixed with "milli," "micro," and "nano." One watt is one joule per second

WAVELENGTH. The distance between two successive points on a periodic wave that have the same phase. It is commonly used to provide a numeric description of the color of visible laser radiation.

WIRELESS COMMUNICATION LASER. A point-to-point, through the air, system that transmits communications signals via the use of a laser transmitter and a collection of lenses to produce a highly collimated beam.

4. BACKGROUND

Advanced technologies are making lasers more powerful, more complex and, at the same time, less expensive to own and operate. These developments have been accompanied by an increase in the number of reports of flight crews being illuminated by lasers while engaged in flight operations. Some reports indicate illuminations possibly emanating from outdoor laser light shows. Other reports indicate the source of illumination to be associated with unauthorized laser beams projected near airports or within critical airspace. Unchecked or uncontrolled these illuminations present potential safety hazards to pilots, crews and passengers on aircraft within the navigable airspace.

5. RECOMMENDATIONS

5.1 Control of Lasers and Bright Lights in Airspace

The following language provides recommended guidelines for safe control of lasers and bright lights in airspace. In addition it sets reasonable reporting requirements on both laser and bright light operations, and on pilots flying near such operations.

- 5.1.1 Projection of Laser or Other Directed Bright Light Source at an Aircraft: It is recommended that no person shall intentionally project, or cause to project, a laser or other directed bright light source at an aircraft in such a manner as to create a hazard to aviation safety, damage to the aircraft, crew or passengers.
 - 5.1.2 Regulatory Agency Notification of Outdoor Laser or Directed Bright Light Displays: When using, or planning to use, outdoor lasers or other directed bright light display sources, written notification to the appropriate Regulatory Agency (e.g., FAA, CAA, DOT, JAA, etc.) is recommended, provided that the sources are of sufficient power to cause the potential of an aviation safety hazard.
 - 5.1.3 Pilot Avoidance of Outdoor Laser or Other Directed Bright Light Source: It is recommended that no Pilot-in-Command shall deliberately operate an aircraft into a laser or other directed bright light source, or into an area such sources are in use, unless mutually agreed by the operator of the laser or directed bright light source and the Pilot-in-Command.
- ##### 5.2 Study of Eyewear Effectiveness
- 5.2.1 Further research needs to be conducted on the usefulness of eye protection (e.g., notch filters) for protection, especially for helicopter crewmembers engaged in high-threat environments.

6. LASER SAFETY ANALYSIS METHODOLOGY FOR AIRCRAFT OPERATIONS

6.1 Operational Volume and Hazard Distances

In order to perform an evaluation of the laser systems, the actual spatial volume of operation and power levels of the laser must be determined.

- a. Elevation and Azimuth: Determine ranges of elevation and azimuth that will be used for the proposed system operations. [Many laser systems are fixed, others operate over a range of directions and elevations. The actual elevations and azimuth directions of planned operation need to be defined in order to evaluate air space that will be potentially affected, e.g., the spatial volume of operation.]
- b. Hazard Distances: Determine hazard distances of the proposed laser. Each hazard distance must be addressed for the laser operations. When the NOHD exceeds one of the other distances, it takes precedence. If a laser will operate at varying power levels, the worst case should be addressed. The following distances need to be calculated:
 1. Nominal Ocular Hazard Distance
 2. Laser-Free Distance
 3. Critical Distance
 4. Sensitive Distance

Lasers operating outside of the visible spectrum do not require the distances 2-4.

- c. Operational Volume: Illustrate the site, operational volume and hazard distances on the Visual Flight Rules (VFR) map. VFR maps are maps typically used by pilots. They provide airport locations and other important flight data. By overlaying the projected area of the operational volume and hazard distances on a VFR map, a "picture" of the potentially affected volume can be obtained.

6.2 Local Airports and Hazard Zones

[In conjunction with the paragraph above, the hazard zones (laser-free, critical and sensitive) are identified around the airports in Figure E1.]

Using the FAA VFR map from all airports near the proposed laser site, identify the laser-free, critical, and sensitive zones around each of the identified airports. See Figures E3 through E5. Illustrate the hazard zones on the VFR map for each area airport.

Airport zones beyond the greatest distance identified in Figure E1 need not be considered. Airports with zones that do not overlap the respective hazard distances and operating volumes identified in Figure E1 do not need to be considered further.

NOTE: The NOHD is not zone specific. If the laser will produce an eye hazard within navigable airspace, the hazard to air traffic must be evaluated.

6.3 Air Traffic Patterns and Densities

If an airport hazard zone is impacted by the laser operation or an NOHD will penetrate navigable air space, air traffic patterns and densities should be determined to evaluate the magnitude of potential impact.

Request assistance of the appropriate regulatory agency for:

1. Historical aircraft patterns, for a one-year period, near the proposed laser site. [Consideration should be given to density changes based on time of day and seasonal air traffic activities. Air traffic densities shall also be considered outside of airport related activities for laser operations producing an NOHD.]
2. Aircraft landings and takeoffs for the airports identified in 6.5. This information can be coordinated with standard approach and departure routes to estimate flight path densities.

6.4 Relative Risk of Airspace

The objective of this step is to identify defined volumes of airspace that have higher or lower risk levels as a result of hazard zones, patterns and densities. This information can be useful in determining control techniques and methodologies.

Evaluate the airport hazard zones identified in 6.5 and the air traffic patterns and densities identified in 6.6.

Identify the relative risk levels of the airspace based on the evaluation. This can be illustrated on a basic graph, Figure 1.

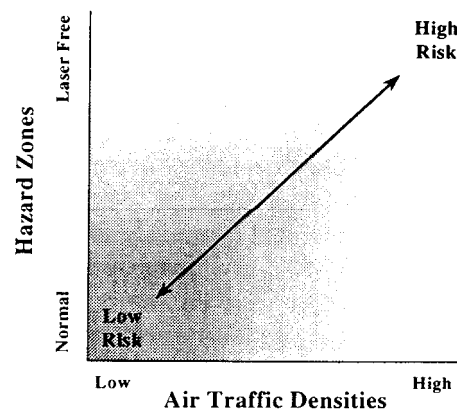


FIGURE 1 – RELATIVE RISK BASED ON AIR TRAFFIC DENSITIES AND HAZARD ZONES

6.5 Define Laser Operations

It is necessary to further define the actual lasing activity (see Appendix A, Figure A1, Page 2).

- a. Determine duration (minutes, hours, etc.) of the proposed laser event.
- b. Define when the events will occur.
 1. Time of day or night
 2. Days per week and which days of the week
 3. Time of the year
 4. Required or allowable weather conditions for a laser event (e.g., clear weather, cloudy weather, etc.)
- c. Determine how the transmitted laser beam will propagate through the atmosphere during the event (e.g., sweep an arc, vertical stationary beam, etc.).

6.6 Relative Risk of the Laser Operations

The objective of this step is to balance the hazards presented by the laser (hazard distances) with the time, duration and conditions of the operations (e.g., a laser with short hazard distances fired in a fixed direction for only 2 min a month would be a very low hazard, where as, a laser with long hazard distances fired in a variety of directions and continuously over a month would be a high hazard).

Evaluate the hazard distances determined in 6.1 and the laser operations defined in 6.5.

Identify the relative risk of the laser operations.

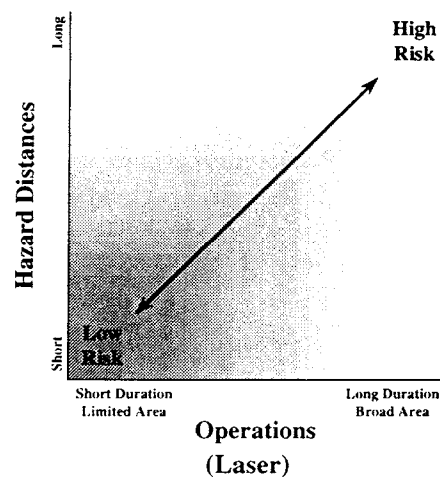


FIGURE 2 – RELATIVE RISK BASED ON LASER OPERATIONS AND HAZARD DISTANCES

6.7 Relative Risk of Laser Operations Versus Air Space

Evaluate the combination of 6.5 and 6.6 to provide a qualitative risk level for the proposed laser operations at the proposed site. When combined with the hazard distance relative to the at-risk air space/hazard zones and the operational requirements and limitations of the laser operations, this qualitative risk level assists in identifying the types and levels of protection required. [Combine Figures 1 and 2 to provide a combined picture.]

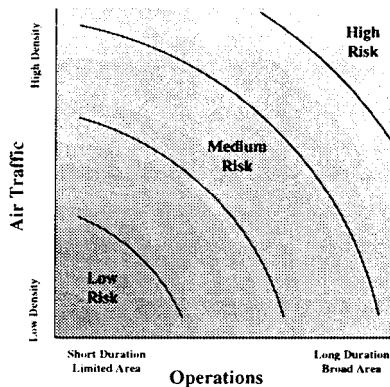


FIGURE 3 – RELATIVE RISK BASED ON A COMBINATION OF LASER OPERATIONS AND AIR TRAFFIC

7. PREVENTIVE METHODS

Following are some examples of preventive measures that have been successfully used to protect airspace.

7.1 Aircraft Detection

Observer

Authorized Laser Operator - Control of access to beam by operator (operator located outdoors)
Aircraft Spotter - Dedicated person looking for aircraft outdoors
Aircraft Spotter Team - Multiple persons with communications looking for aircraft outdoors
Vision Enhancement - Vision aids to enhance detection range: (a) Night vision (light amplifiers)
(b) Infrared vision (8 to 12 μm)

Camera Observer

CCD Camera with motion analysis - Automated systems of aircraft detection
Infrared Camera (8 to 12 μm) - Infrared spectrum to allow cloud and fog penetration
Multiple Cameras - Cameras covering multiple fields of view

Radar Observer

Remote Monitor - Remote radar feed to an onsite monitor
Bore-sighted Radar - Radar system whose transceiver is coaxial with the transmitted laser

Other Technologies

Transponder Receiver – Detects signals from aircraft
Scanning - Reduction in average power through scanning of the transmitted laser
LIDAR - Laser radar

7.2 Preventive Techniques and Associated Ranges

A variety of factors influence the actual effective range of preventive techniques. The following are basic distances that have been achieved by previous applications.

TABLE 1 - REASONABLE CONTROL TECHNIQUES FOR LASERS WITH VARIOUS HAZARD RANGES AND ALSO OBSCURATION CONDITIONS

Hazard Range (feet)	Reasonable Control Technique
Less than 1000 ft	Operator Control
1000 to 15,000 ft	Aircraft Spotter
15,000 to 30,000 ft	Vision Enhancement, Spotter Teams
30,000 to 100,000 ft	Radar or Camera System
> 100,000 ft	Contact Space Command (SPADOC)
Cloud or Fog Obstruction	Infrared Camers

7.3 Aircraft Illumination Avoidance Method

The choice of preventive technique(s) should be based on the level of hazard presented by the laser operations. The above analysis provides information to be used in the determination.

1. Identify, in detail, all methods, procedures, systems, hardware, software, etc., which will be used to avoid the illumination of aircraft with the transmitted laser beam.
2. Document and maintain on file all analyses and approvals.
3. Re-evaluate the analysis and preventive techniques whenever the system or operational parameters are modified or approximately every five years if no changes are made.

8. NAVIGABLE AIRSPACE CONTROL MEASURES

8.1 Airspace Flight Zones

All volumes of airspace must be protected against hazardous beams. For non-visible lasers, the NOHD value is the sole consideration. For visible lasers, in addition to the NOHD, visual disruption must also be considered.

Airspace volumes have been designated as normal flight zones, sensitive flight zones, critical flight zones, and laser-free zones, where visible laser beams should not interfere with a pilot's vision, even if the MPE is not exceeded. These volumes of airspace correspond to the visual interference zones outlined in 8.3. The normal flight zone comprises all airspace that may contain an aircraft and is not included in any of the other visual interference zones. Figures E1, E2, and E3 illustrate these visual interference zones as applied to aircraft.

In addition to retinal hazards, particular zones of critical activity involving tasks which would create safety problems from dazzle, startle, or distraction from visible laser beams can be established during reduced ambient illumination (night operations) by the LSO. The beam from a visible laser shall not enter any visual interference zone when the irradiance is greater than the corresponding visual interference level unless adequate protective means are employed to prevent personnel exposure.

Figures E4 and E5 describe the zones established for aircraft in navigable airspace. Protective means shall be used to protect personnel and pilots when a visual interference level is exceeded. Redundant systems are advisable in locations noted for heavy air traffic.

8.2 Control of Navigable Airspace

Lasers with beam irradiances less than the MPE, but exceeding the sensitive level or critical level may be operated in the sensitive zone or critical zone, respectively, if adequate means are used to prevent aircraft from entering the beam path. Electronic means (accepted by the FAA during an aeronautical study) is the preferred solution, although safety observers may be used to provide such prevention for short-duration operations (less than 1 h). Any affected air traffic control facility should be able to directly communicate with the authorized laser operator to terminate the laser beam when these levels are exceeded.

A variety of electronic means may be used to monitor aircraft and automatically terminate the laser beam when aircraft could be exposed. The type of electronic monitoring shall be accepted by the respective regulatory agency before it is used to protect aircraft. When aircraft could be potentially exposed above the MPE, multiple methods for observing airspace are advisable. Section 8 describes some possible electronic monitoring methods.

8.3 Visual Interference

Serious injury may result indirectly from laser exposure. These effects are most pronounced when a person is exposed at night or in a dark environment. Generally, a higher power laser will produce a comparable effect during the daytime. However, during the daytime, the laser irradiance must approach the MPE for a laser to produce hazardous visual interference effects.

However, even low power lasers, such as laser pointers or laser scopes for rifles, can produce visual interference at dusk or night. Therefore, only responsible people should use products. The indiscriminate use of laser rifle sights or laser pointers to illuminate police or other individuals may be considered assault in some districts.

8.4 Visual Interference Levels

Visual interference levels have been established for each of the flight zones described in 8.1, in terms of effective irradiance:

Sensitive level ($100 \mu\text{W}/\text{cm}^2$)

Critical level ($5 \mu\text{W}/\text{cm}^2$)

Laser-free level ($50 \text{ nW}/\text{cm}^2$)

The effective irradiance of the laser is the actual laser irradiance multiplied by a correction factor, matching the eye's photopic (daytime) visual response, based on laser wavelength. The visual correction factors are listed in Table B5, Appendix B.

These visual interference levels depend on the eye's visual response rather than injury potential. These levels are often exceeded even when the MPE is not exceeded.

The levels are compared to the effective irradiance of the laser averaged over a potential exposure duration of 0.25 s. For exposures less than 0.25 s., the visual interference level is exceeded if the combined radiant exposure of the laser during a 0.25-s period exceeds the radiant exposure of the visual interference level during a 0.25-s exposure duration. The corresponding radiant exposure (J/cm^2) of any visual interference level (W/cm^2) is that level multiplied by 0.25 s.

8.5 Flight Zones

- 8.5.1 Sensitive Zone ($100 \mu\text{W}/\text{cm}^2$): The sensitive zone encompasses the area on the ground or volume of airspace where exposure to intense visible beams would interfere with critical tasks, but not jeopardize safety (see Figures E3, E4, and E5).
- 8.5.2 Critical Zone ($5 \mu\text{W}/\text{cm}^2$): The critical zone encompasses the area on the ground or volume of airspace where interference with critical visual tasks, such as operating an automobile or aircraft at night, would jeopardize safety (see Figures E3, E4, and E5).
- 8.5.3 Laser-Free Zone ($50 \text{ nW}/\text{cm}^2$): When laser beams in this zone exceed the laser-free level, redundant layers of protective mechanisms are advisable, since visual interference by a laser beam in this zone would be very serious (see Figure E4).

8.6 Laser Safety Methods

- 8.6.1 Laser Safety Observers: Safety observers may be employed to observe airspace for aircraft when laser irradiance levels exceed visual interference levels. Safety observers shall be properly trained. Observation times should be limited (perhaps 1 h on and 1 h off). The safety observer shall have the capability and authority to terminate laser beams immediately when an aircraft approaches, and before a potential conflict occurs.

The safety observer shall only be relied upon when conditions permit the detection of aircraft. The safety observer shall not be expected to see aircraft at a distance of more than 3 miles, except in remote locations. For multiple beams, multiple observers may be necessary.

- 8.6.2 Other Beam Control Methods: Co-aligned Radar and other laser safety methods are listed in Section 7.

8.7 Responsibilities

- 8.7.1 Laser Safety Officer (LSO): For Class 3b and Class 4 outdoor operations, an individual shall be designated as the LSO with both the authority and the responsibility to monitor and enforce the control of laser hazards, and to effect the knowledgeable evaluation and control of laser hazards.

The LSO shall be responsible for the following:

1. Classifying or verifying classification of laser systems under the LSO's jurisdiction.
 2. Hazard evaluation of laser work areas including establishment of hazard zones.
 3. Assuring that the prescribed control measures are in effect.
 4. Recommending or approving substitute or alternate control measures when the primary ones are not feasible or practical.
 5. Periodically auditing the functionality of the control measures in use.
 6. Approving standard operating procedures.
 7. Recommending or approving protective equipment and assuring that protective equipment is audited periodically to ensure proper working order.
 8. Approving the wording on area signs and equipment labels.
 9. Approving laser installation facilities and laser equipment prior to use.
 10. Ensuring that the safety features of the laser installation facilities and laser equipment are audited periodically to assure proper operation.
 11. Assuring that adequate safety education and training are provided to laser area personnel.
 12. Ensuring that proper medical surveillance is provided for workers.
- 8.7.2 Laser Safety Specialist: When the LSO does not have the knowledge or training to determine necessary laser control measures, the LSO may act on the recommendations of a laser safety specialist. The laser safety specialist has formal training to calculate and determine laser hazards, and to recommend appropriate control measures. With this formal training, the LSO or authorized laser operator may also be a laser safety specialist.
- 8.7.3 Authorized Laser Operator: Operators of outdoor lasers shall:
1. Follow SOPs for safe work practices, considering the hazards to their fellow workers and the general public.
 2. Direct the beam at a height and location to prevent hazardous exposure to personnel or occupied areas.
 3. Have a general knowledge of the operation and basic maintenance of the laser systems being used.
 4. Have a general knowledge of the laser bioeffects.
 5. Have an understanding of the laser hazard evaluations for the on site conditions.