U.S. Department of Transportation

Federal Aviation Administration

Advisory Circular

SUBJECT: Outdoor Laser Operations

Date: 03/14/19

Initiated by: AJV-P2

AC No: 70-1A

Change:

1. PURPOSE.

a. This Advisory Circular (AC) provides information for those proponents planning to conduct outdoor laser operations that may affect aircraft operations in the National Airspace System (NAS). Also, the AC explains why notification to the Federal Aviation Administration (FAA) is necessary, how to notify the FAA of the planned laser operation, and what action the FAA will take to respond to such notifications.

b. In addition, to assist proponents in providing information to be used by the FAA in its review of outdoor laser operations, the AC includes:

- Appendix 1:
  - Notice of Proposed Outdoor Laser Operation(s) and Instructions;
  - Tables 1 & 2 Maximum Permissible Exposure Limits;
  - Tables 3 Correction Factors;
  - Graphic Examples and Descriptions of Airspace Flight Zones;
- Appendix 2: FAA Service Center Office Addresses;
- Appendix 3: Glossary.

c. The FAA's interest in these types of operations does not supersede or invalidate any existing rules or ordinances promulgated by other Federal, state, county, or local government. The proponent is responsible for compliance with these requirements.

2. AUTHORITY.

a. The FAA has the authority to regulate the safe and efficient use of the navigable airspace (Title 49 U.S.C., Section 40103, Sovereignty and Use of Airspace, and the Public Right of Transit.

3. EFFECTIVE DATE.

This advisory circular becomes effective March 14, 2019.

4. NOTIFICATION FORM.

a. Why is it necessary to notify the FAA?

(1) In recognition of the FAA's role in promoting aviation safety, the FDA requires notice to the FAA as a condition of a variance for entertainment lasers operated outdoors.

(2) Early notice of the planned activity provides the FAA the opportunity to minimize the potentially hazardous adverse effects of laser operations on aircraft operators in the navigable airspace. The possible visual effects are flash blindness and afterimage created when a laser beam interferes with the vision of the pilot or air crewmember, and glare when the laser beam illuminates the windshield of an aircraft.

(3) The FAA recognizes that there are varied demands for the use of airspace, both by aviation and non-aviation interests. While a sincere effort is made to find equitable solutions to conflicts over the use of this national resource, the FAA must give primary consideration to aviation operations.

b. Who should file a Notice?

Any person/proponent who plans to conduct laser operations with visible beams exceeding 50 nW/cm^2 or with non-visible beams that exceed the MPE in the navigable airspace should file notice with the FAA. Navigable airspace is airspace above the minimum altitudes of flight prescribed by regulations including airspace needed for the takeoff and landing of aircraft (49 U.S.C. Section 40102).

c. When should the Notice be Filed?

Notice should be filed at least 30 days before the planned event in order to allow the FAA sufficient time to accomplish an aeronautical study and make a determination regarding the planned activity.

d. Where to File the Notice?

Notice should be filed with the appropriate/applicable FAA Service Center. A list of service center addresses and the states they are responsible for is provided in Appendix 2.

e. What Information should be submitted to the FAA?

The FAA requests the proponent submit the following information:

(1) A completed "Notice of Proposed Outdoor Laser Operation(s)" including a completed "Laser Configuration Worksheet" for each laser.

Note: If proponent is utilizing an electronic protection system in lieu of safety observers, they must use Section 6 of FAA Form 7140-1 to certify that control measures meet the performance criteria in the SAE AS6029 (current edition).

(2) Detailed diagrams depicting the planned laser paths.

United States Geological Survey quadrangle maps are available from:

USGS National Center
12201 Sunrise Valley Drive
Reston, Virginia 22092
(703) 648-5953

or

U.S. Geological Survey
Box 25046 Denver Federal Center
Denver, Colorado 80225
(303) 202-4200

f. What Action will the FAA take regarding this Information?

(1) The Service Center must conduct an aeronautical review of all outdoor proposed laser operations, to be performed in the NAS, to ensure that these types of operations will not have a detrimental effect on air traffic control operations.

(2) The aeronautical study determination will be provided in a Letter of Determination (LOD) to the proponent with respect to the laser activity's effect on users of the navigable airspace.

5. RELATED DOCUMENTS.

a. TITLE 49 U.S.C., Subtitle VII, AVIATION PROGRAMS**,** Part A - (Air Commerce and Safety) & Part B - (Airport Development and Noise)

b. FAA Order 7400.2, *Procedures for Handling Airspace Matters.*

c FDA 225-99-6000, Memorandum of Understanding between the Food and Drug Administration and the Federal Aviation Administration (available on the FDA CDRH web site).

d. **21 CFR Part 1010,** Performance Standards for Electronic Products, and Part 1040, Performance Standards for Light Emitting Products.

e. HHS Publication FDA 86-8262, Laser Light Show Safety – Who's Responsibility? (Available on the FDA CDRH web site).

f. American National Standards Institute (ANSI) Z136.1 & Z136.6 Laser standards.

g. **SAE International (SAE) Aerospace Standard, AS4970**, Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace.

h. **SAE Aerospace Recommended Practice, ARP5290,** Laser Beam Divergence Measurements Techniques Comparison.

i. SAE Aerospace Standard, AS6029, Performance Criteria for Laser Control Measures Used for Aviation Safety.

j. **AC 70-2**, Reporting of Laser Illumination of Aircraft.

6. PAPERWORK REDUCTION ACT STATEMENT.

a. Through use of this AC, the FAA intends to maintain a high level of safety between laser operations and aircraft operations. The FAA is requesting that laser operators submit information on a voluntary basis using the form listed in this AC.

b. It will take the proponent approximately 4 hours to provide the necessary information for the initial system analysis. The time should decrease with subsequent submissions for the use of the same laser system by the same respondent. A person is not required to respond to an information collection request unless it displays a currently valid Office of Management and Budget (OMB) number. The OMB control number assigned to this request is 2120-0662.

//ORIGINAL SIGNED by

Karen K. Gonzales

for Maurice Hoffman
Director, Airspace Service, AJV-1

APPENDIX 1

FAA Form 4140-1, Notice of Proposed Outdoor Laser Operation(s) and Instructions

Tables 1 and 2, Maximum Permissible Exposure Limits

Table 3, Correction Factors

Graphic Examples and Descriptions of Airspace Flight Zones

Form Approved OMB No 2120-0662

Expiration Date: 08/31/2021

Please print or type on this form. Failure to provide all requested information may delay processing of your notice.

This area for FAA use only

U.S. Department of Transportation
Federal Aviation Administration

NOTICE OF PROPOSED OUTDOOR LASER OPERATION(S)

1. GENERAL INFORMATION		
(a) To: *(FAA Service Center)*	(b) From: *(Proponent)*	
(c) Event or facility	(d) Report date	
(e) Customer	(f) Site address	
2. DATE(S) AND TIME(S) OF LASER OPERATION		
(a) Testing and alignment	(b) Operation	
3. BRIEF DESCRIPTION OF OPERATION		
4. ON-SITE OPERATION INFORMATION		
(a) Operator(s)		
(b) On-site phone #1	(c) On-site phone #2	
5. FDA CDRH LASER LIGHT SHOW VARIANCE (if applicable)		
(a) Variance #	(b) Accession #	(c) Expiration date
6. BRIEF DESCRIPTION OF CONTROL MEASURES		
7. ATTACHMENTS		
(a) Number of laser configurations *Fill out one copy of page 2 of this Notice (e.g., items 10-15 on the next page) for each configuration*		
(b) List additional attachments *(including maps, diagrams, details of control measures, and details of calculations or software printouts)*		
8. DESIGNATED CONTACT PERSON *(if further information is needed)*		
(a) Name	(b) Position	
(c) Phone	(d) Fax	(e) E-mail
9. STATEMENT OF ACCURACY **To the best of my knowledge, the information provided in this Notice (both sides) and the attachment(s) is accurate and correct**		
(a) Name *(if different from contact person)*	(b) Position	
(c) Signature	(d) Date	

FAA Form 7140-1

Form Approved OMB No 2120-0662

Expiration Date: 08/31/2021

Please print or type on this form. Failure to provide all requested information may delay processing of your notice.

	This area for FAA use only

10. CONFIGURATION INFORMATION

(a) Configuration number______of ________	(b) Name of event/facility	(c) Report date
(d) Brief description of configuration		

11. GEOGRAPHIC LOCATION

(a) Site elevation (Mean Sea Level), in feet: _____________	(e) Latitude:___________degrees,___________minutes,__________seconds
(b) Laser height above site elevation (above ground level), in feet: _____________	(f) Longitude:__________degrees, __________minutes,__________seconds
(c) Overall laser elevation (a) + (b), in feet:_____________Mean Sea Level	(g) Horizontal datum: ☐NAD 27 ☐NAD 88
(d) Latitude and longitude determined by: ☐GPS ☐Map (quad) ☐Other	(h) Vertical datum: ☐NGVD 29 ☐NAVD 88

12. BEAM CHARACTERISTICS AND CALCULATIONS *(check one Mode of Operation only, and fill in only that column)*

MODE OF OPERATION	☐SINGLE PULSE	☐CONTINUOUS WAVE	☐REPETITIVELY PULSED
12(a) LASER AND BEAM CHARACTERISTICS			
Laser type *(example: DPSS, sodium-vapor, etc.)*			
Laser hazard classification			
Power *Watts (W)*	*(not applicable)*	Maximum Power	Average Power
Pulse energy *Joules (J)*		*(not applicable)*	
Pulse duration *Seconds (s)*		*(not applicable)*	
Pulse repetition frequency *Hertz (Hz)*		*(not applicable)*	
Beam diameter at 1/e points *Centimeters (cm)*			
Beam divergence 1/e at full angle *Milliradians (mrad)*			
Wavelength(s) *Nanometers (nm)*			
12(b) MAXIMUM PERMISSIBLE EXPOSURE (MPE) VALUE *(this will be used to calculate the NOHD)*			
MPE *Watts per square cm (W/cm^2)*	*(not applicable)*		
MPE per pulse *Joules per square cm (J/cm^2)*		*(not applicable)*	
12(c) VISUAL EFFECT CALCULATIONS *The following items are for lasers with visible wavelengths (400-700 nm). If the laser has no visible wavelengths, enter “N/A (non-visible laser)” in all blocks.*			
Pre-Corrected Power (PCP) *Watts (W)*	Pulse Energy *(J)* x 4	Maximum Power (from above)	Pulse Energy *(J)* x PRF *(Hz)*, or Average Power
Visual Correction Factor (VCF) *Enter “1.0” or use Table 3*			
Visually Corrected Power *PCP x VCF*			

13. BEAM DIRECTION(S)

(a) Maximum elevation angle *(degrees)*	(c) Magnetic variation *(degrees)*
(b) Minimum elevation angle *(degrees, where horizontal = 0 degrees)*	(d) Azimuth *(degrees)* ☐True ☐Magnetic

14. PROTECTION DISTANCES *(fill in all three columns below)*

	SLANT RANGE (ft)	HORIZONTAL DISTANCE (ft)	VERTICAL DISTANCE (ft)
(a) NOHD *(based on MPE value)*			
The following items are for lasers with visible wavelengths (400-700 nm). If the laser has no visible wavelengths, enter “N/A (non-visible laser)” in all blocks.			
(b) SZED *(for 100 $\mu W/cm^2$)*			
(c) CZED *(for 5 $\mu W/cm^2$)*			
(d) LFED *(for 50 nW/cm^2)*			

15. CALCULATION METHOD

☐Commercial software *(print product name)* ☐Other *(describe method such as spreadsheet, calculator, etc.)*

INSTRUCTIONS FOR COMPLETING NOTICE OF PROPOSED OUTDOOR LASER OPERATION(S)

A single outdoor operation may have a number of lasers or “laser configurations” – power settings, wavelength, pulse modes, divergence, etc. In section 7.(a), of the Notice of Proposed Outdoor Laser Operations form, enter the number of different laser configurations for the outdoor operation. Then, complete one Laser Configuration Worksheet (page 3) for each different configuration.

Through use of the AC the FAA intends to maintain a high level of safety between laser operations and aircraft operations without regulating certain entities that were not previously regulated. The FAA is requesting that laser operators submit information on a voluntary basis by using the forms listed and enclosed in this AC.

It will take the proponent approximately 10 hours to provide the necessary information for the initial system analysis. The time should decrease with subsequent submissions based on use of the same laser system per respondent per request. A person is not required to respond to an information collection request unless it displays a currently valid Office of Management and Budget (OMB) control number. The OMB control number assigned to this request is 2121-0662.

Data sources: This form requires calculations based on data concerning the laser beams characteristics. The data can be obtained from direct measurement, manufacturer specifications, or specialized instruments. Also, data may be derived by making reasonable, conservative assumptions (e.g., that a certain value makes the beam more hazardous than it would be in reality). All data should err on the side of safety. In borderline situations where data accuracy is crucial to compliance, provide additional information on measurement techniques, data sources, and assumptions.

Alternative analysis: This form and accompanying tables must cover a wide variety of laser configurations. They are necessarily simplified, and they make conservative assumptions. Some laser configurations may warrant a more complex analysis. Any such alternative analysis should be based on the American National Standards Institute (ANSI) Z136 series of standards or other established methods. Both the methods and the calculations must be documented.

The information on this form will be used by the FAA Service Center to perform an aeronautical study to evaluate the safety of a proposed laser operation. Provide all information that may be needed to perform the study. If additional details are necessary, list these in the “ATTACHMENTS” section of this form.

1. **GENERAL INFORMATION -** In 1.(a), enter the name, address, telephone, and fax numbers of the FAA Service Center responsible for the area which includes the laser operation site. (A list of Service Centers is available in APPENDIX 3 of this circular.) In 1.(b), enter the proponent's name, address, telephone, fax, and E-mail information. This is the party primarily responsible for the laser safety of this operation. When the proponent is a manufacturer or a governmental agency (e.g., NASA), and the laser is located at a different site, list the proponent here. In 1.(c), enter the event name (for temporary shows) or the facility name (for permanent installations). In 1.(d), enter the date the report is prepared or sent to FAA. It is not the date of the laser operation. - If the laser user is different than the proponent, fill in section 1.(e) Customer; if not, enter “Same as proponent.” In 1.(f) enter the site address.

2. DATE(S) AND TIME(S) OF LASER OPERATION - Enter the dates and times of testing alignment procedures, and operation.

3. BRIEF DESCRIPTION OF OPERATION - The description should be a general overview of the operation. Specific laser configurations of the operation are described in detail using the Laser Configuration Worksheet on page 2. If necessary, attach additional pages.

Appendix 1

4. ON-SITE OPERATION INFORMATION - List names and/or titles of operators. There should be at least one working, direct telephone link to the operator, or equivalent way of quickly reaching the operator (e.g., telephoning a central station that reaches operator via radio). Two telephone numbers are requested on the form; the number in 2.(c) should be used as an alternate or backup.

5. FDA CDRH LASER LIGHT SHOW VARIANCE - List the variance number, accession number, and variance date if the operation uses or is a "demonstration laser" (generally, a laser light show) and therefore, is regulated by the Food and Drug Administration's Center for Devices and Radiological Health.

6. BRIEF DESCRIPTION OF CONTROL MEASURES - Describe the method(s) used to protect airspace; for example, termination on a building (where the beam path is not accessible by aircraft including helicopters), use of observers, use of radar and imaging equipment, physical methods of limiting the beam path, etc. The more the operation relies on the control measures to ensure safety, the more detailed the description should be. If proponent is utilizing an electronic protection system in lieu of safety observers, they must use Section 6 to certify that control measures meet the performance criteria in the SAE AS6029 (current edition).

7. ATTACHMENTS – In 7.(a) list the number of "Laser Configurations" you are submitting with this notice. If a particular setup operates with more than one laser, with different beam characteristics (power settings, pulse modes, divergence, etc.) or has multiple output devices (example: projector heads), then each should be analyzed as a separate Laser Configuration. In 7.(b) list all additional attachments which are included to assist the FAA in sufficiently evaluating the proposal, such as maps, diagrams, and details of control measures.

8. DESIGNATED CONTACT PERSON - Specify the person with whom the FAA will communicate if additional information is needed. This should be the person most knowledgeable about laser safety of this operation. However, the person could also be the laser operation central contact that interfaces with the FAA. The Designated Contact Person should work for or represent the proponent listed in 1.(b).

9. STATEMENT OF ACCURACY - The person having the authority to bind the proponent must sign the form.

10. CONFIGURATION INFORMATION – In 10.(a), enter the number of the specific configuration and the total number of configurations. In 10.(b), enter the name of the event or facility. In 10.(c), enter the date the worksheet is prepared or sent to the FAA. In 10.(d), describe the beam projecting or directing system. Include a description of the site layout. Attach additional sheets if more space is required.

11. GEOGRAPHIC LOCATION – In 11.(a), enter the elevation of the site in feet above Mean Sea Level (MSL). In 11.(b), enter the height of the laser above the site elevation. This value should reflect the total height including any tall structure or building on which the laser may be located. In 11.(c), enter the total height of the laser above MSL (site elevation + height above site elevation). For aircraft or spacecraft operations, attach additional information on the flight locations and altitudes. In 11.(d) and (e), enter the latitude and longitude in degrees, minutes and seconds. Some maps or devices may give this information in "Degrees Decimal" form; convert this value into degrees, minutes, and seconds. In 11.(f), enter the method used to determine the latitude and longitude. In 11.(g), enter the horizontal datum used to determine the latitude and longitude. In 11.(h), enter the vertical datum used to determine the site elevation.

12. BEAM CHARACTERISTICS AND CALCULATIONS - Determine the mode of operation for this configuration: single pulse, continuous wave, or repetitively pulsed. Check the appropriate column and fill out only the Beam Characteristics, MPE Calculations, and Visual Effect Calculations applicable to that column.

> ***Laser Type/Classification*** - Enter the lasing medium, for example, "Argon," "Nd-YAG," "Copper-vapor," "CO_2," and the hazard classification for the laser.

Beam Diameter and Divergence **-** Provide the diameter using the 1/e peak-irradiance points; be sure the diameter is entered in centimeters, not millimeters. The divergence is the full angle given at the 1/e points. If you know the diameter or divergence measured at the $1/e^2$ points instead, multiply by 0.707 to convert to 1/e diameter or divergence.

NOTE - Diameter and divergence measurements can be complex; if necessary, use conservative (smaller diameter/smaller divergence) simplifications.

Wavelength **-** If the laser emits a single wavelength, enter this. If the laser emits multiple wavelengths, each wavelength should be analyzed separately to find the MPEs and NOHDs. There may be one wavelength that is most hazardous (e.g., MPE the smallest, and NOHD the largest) so that subsequent calculations can make a simplifying, conservative assumption by ignoring the less-hazardous wavelengths. For visible multiple-wavelength lasers, a simplifying, conservative assumption can be made when performing Visual Effect Calculations: that the entire beam has the same wavelength as the most visible wavelength (largest Visual Correction Factor). In all cases of multiple-wavelength lasers, you must document your methods and calculations. If you do not analyze all wavelengths in full, then you must explicitly state your simplifying, conservative assumptions.

Repetitively pulsed vs. scanning- "Repetitively pulsed" refers to lasers that naturally emit repetitive pulses, such as Q-switched lasers. The form and tables are not intended for analyzing pulses due to scanning the beam over a viewer or aircraft (examples: graphics or beam patterns used in laser displays; scanned patterns used for LIDAR). Pulses resulting from scanning are often extremely variable in pulse width and duration. Therefore, for a conservative analysis, assume the beam is static (non-scanned). Should you rely on scanning to be in compliance, you must: 1) provide a more comprehensive analysis, documenting your methods and calculations, and 2) document and use scan-failure protection devices.

(a) MAXIMUM PERMISSIBLE EXPOSURE (MPE) CALCULATIONS - Provide the Maximum Permissible Exposure (MPE) calculation results in the applicable block. For convenience, a simplified, conservative method is provided in Tables 1 and 2 of this document. If you require less conservative levels, use the American National Standards Institute (ANSI) Z136 series of standards or other established methods. Both the methods and calculations must be documented. Unintentional exposure on aircraft is expected to be no more than 0.25 s due to natural relative motion between the beam and aircraft related to wind and other stabilization issues. The following analysis applies to laser wavelengths between 400 nm and 1050 nm for exposures less than 0.25 s. This analysis also provides conservative results for wavelengths from 1050 nm to 1400 nm. Additional analysis techniques can be found in the ANSI Z136 series of standards.

Single Pulse **-** Use Table 1 for lasers that produce a single pulse of energy with a pulse width $<$ 0.25 seconds or a pulse repetition frequency $<$ 1 Hz. Fill in the "MPE per pulse" block in the Single Pulse column.

Continuous Wave (CW) - A laser that produces a continuous (non-pulsed) output for a period $\geq$ 0.25 seconds is regarded as a CW laser. Use Table 2 to find the MPE. Fill in the "MPE" block in the Continuous Wave column.

Repetitively Pulsed **-** Pulsed lasers can produce hazards greater than CW lasers with the same average power. Lasers that produce recurring pulses of energy at a pulse repetition frequency (PRF) greater than 13 kilohertz (kHz) for wavelengths from 400 to 1050 nm, or greater than 6.5 kHz for wavelengths between 1050 and 1400 nm, may be treated the same as CW lasers.

Lasers with a PRF of 1 Hz or faster are considered to be repetitively pulsed. These can produce an additional hazard above that of a single pulse or continuous wave laser. The MPE is adjusted for repetitively pulsed lasers based on its pulse repetition frequency and is designated as MPE_{PRF}. The MPE_{PRF} can be determined using either the per-pulse energy or the average power. This document provides a simplified method for calculating the MPE_{PRF} for average power with wavelengths in the visible and infrared region. (ANSI Z136 series can provide a less conservative value in some cases.) Although designated MPE_{PRF}, the values should be placed in either the "MPE" or "MPE per pulse" blocks of the repetitively pulsed column. Following are the simplified methods for determining the MPE_{PRF} for:

(1) Ultraviolet wavelengths: Reference the American National Standards Institute ANSI Z136 series.

(2) Visible and infrared wavelengths up to 1050 nm: For PRF greater than 13 kHz,use Table 2 to determine the MPE in $W{\cdot}cm^{-2}$. For PRF less than 13 kHz, use Table 1 to determine the MPE in $J{\cdot}cm^{-2}$ Fill in the "MPE" block in the Repetitively Pulsed column.

(3) Infrared wavelengths from 1050 nm to 1400 nm: For PRF greater than 6.5 kHz, use Table 2 to determine the MPE in $W{\cdot}cm^{-2}$. For PRF less than 6.5 kHz, use Table 1 to determine the MPE in $J{\cdot}cm^{-2}$ Fill in the appropriate "MPE" block in the Pulsed column, indicating whether the MPE is in $J{\cdot}cm^{-2}$ or in $W{\cdot}cm^{-2}$.

(4) Infrared wavelengths greater than 1400 nm: For repetitive pulse exposure at these wavelengths, a PRF of just a few hertz results in the CW MPE being more restrictive than the pulsed MPE. The MPE which indicates the greatest hazard determines the MPE. Fill in the appropriate "MPE" block in the Pulsed column, indicating whether the MPE is in $J{\cdot}cm^{-2}$ or in $W{\cdot}cm^{-2}$.

NOTE - For Repetitively Pulsed lasers. The simplified methods of Table 2 use the Average Power to determine the MPE in W/cm^2. It is possible with other methods to use the Pulse Energy to determine the MPE per pulse in J/cm^2. Only one of the two MPEs is required.

(b) VISUAL EFFECT CALCULATIONS - If the laser has no wavelengths in the visible range (400-700 nm), enter "N/A (non- visible laser)" in these blocks and go to the next section. For visible lasers, the FAA is concerned about beams that are eye-safe (below the MPE) but are bright enough to distract aircrews. The FAA has therefore established "Sensitive," "Critical" and "Laser-Free" areas where aircraft should not be exposed to light above $100\mu W/cm^2$, $5\mu W/cm^2$, and $50nW/cm^2$ respectively. Because apparent brightness varies with wavelength – green is more visible than red or blue – a visual effect correction factor can be applied if desired. This has the effect of allowing more power for red and blue beams than for green beams. For any visible laser, you must submit Visual Effect Calculations:

First, determine the Pre-Corrected Power.

(1) Single Pulse - Multiply the Pulse Energy (J) by 4, and enter in the form.

NOTE - This technique averages the pulse's energy over the 0.25 sec maximum pulse duration, and is a conservative approximation of the visual effect of a pulse. If you use less conservative calculations, you must document your methods and calculations.

(2) Continuous Wave - Use the Average Power (W) block already entered on the form.

(3) Repetitively Pulsed - For repetitively pulsed lasers, it is necessary to determine the maximum number of pulses (MNP) that could occur in 0.25 s. MNP is determined by multiplying the PRF by 0.25 s and then rounding up to the next whole number. The Pre-Corrected Power is then the pulse energy multiplied by (4 x MNP).

Next, decide on how precise you want to be:

For the simplest, most conservative analysis - Assume no correction factor at all, enter "1.0 (assumed)" for the Visual Correction Factor, and the Pre-Corrected Power found above for the Visually Corrected Power.

For a single-wavelength beam use Table 3 to find the Visual Correction Factor. Multiply this by the Pre-Corrected Power to find the Visually Corrected Power.

For a beam with multiple wavelengths, choose one method:

a. <u>Make a simplifying, conservative assumption</u>. Use Table 3 to determine which wavelength has the largest Visual Correction Factor (is the most visible). Multiply this Visual Correction Factor by the Pre-Corrected Power of the laser (all wavelengths) to find the Visually Corrected Power.

   NOTE - You must attach data and calculations showing how you arrived at the Visually Corrected Power.

b. <u>Analyze each wavelength separately, then sum them</u>. First, determine the Pre-Corrected Power for each wavelength. Next, use Table 3 to find the Visual Correction Factor for each wavelength. Multiply each wavelength's Pre-Corrected Power by its Visual Correction Factor, to find the Visually Corrected Power (VCP) for that wavelength. Add all the VCPs together to determine the total VCP. Enter the total VCP in the "Visually Corrected Power" block of the form.

   NOTE – You must attach data and calculations showing how you arrived at the Visually Corrected Power.

13. BEAM DIRECTION(S) – Enter the maximum and minimum elevation angles. Also, provide the pointing directions and elevation angles (minimum and maximum) of the beam projections for this configuration only:

If the beam is moved horizontally during the operation, enter the movement range under "Azimuth." For example, "20° to 50°." Make sure you give the range going clockwise, otherwise your data will be interpreted as directing the beam everywhere but where you intend. Specify if azimuth is in true or magnetic readings. Provide the magnetic variation for the location if this is known (this *must* be done if you mark the "Magnetic" check box or if you are using a compass as part of your control measures).

For some configurations, additional information concerning the beam direction may be needed. For example, lasers that are very widely separated at the Geographic Location listed on page 2 of the Notice Of Proposed Outdoor Laser Operation(S) form or a laser used on an aircraft or spacecraft which is moving and/or shoots downward.

14. PROTECTION DISTANCES (From above data) - There are four protection distances that are important in evaluating the safety of outdoor operations. The NOHD is based on the risk of a permanent injury to the eye and the other three distances are related to temporary visual effects that could interfere with a person's performance of critical tasks. Brief definitions of these distances are as follows:

Nominal Ocular Hazard Distance (NOHD) - The beam is an eye hazard (is above the MPE), from the laser source to this distance.

Sensitive Zone Exposure Distance (SZED) - The beam is bright enough to cause temporary vision impairment, from the source to this distance. Beyond this distance, the beam is 100µW/cm^2 or less.

Critical Zone Exposure Distance (CZED) - The beam is bright enough to cause a distraction interfering with critical task performance, from the source to this distance. Beyond this distance, the beam is 5 µW/cm^2 or less.

"Laser-Free" Exposure Distance (LFED) - Beyond this distance, the beam is 50 nW/cm^2 or less – dim enough that it is not expected to cause a distraction.

Visible/non-visible determination - Determine whether one or more of the laser wavelengths are visible (in the range 400-700 nm). If the laser is outside the visible range, enter "N/A (non-visible laser)" in all SZED, CZED, and LFED blocks. If the laser is visible, then perform the SZED, CZED, and LFED calculations.

IMPORTANT - For some visible pulsed lasers, the SZED, CZED, and LFED may be calculated to be less (shorter distance) than the NOHD. If this is the case, for safety reasons *do not* enter the distance numbers in the applicable block. Instead, you *must* enter that the distance is "Less than NOHD." This is because in this case, the NOHD (eye-damage distance) would be the most important for calculating safety distances and airspace to be protected.

NOHD (Slant Range) – Extensive methodology on determining hazard distances is contained in the ANSI Z136 series of standards. For beams with a small beam diameter (< 1 cm), equations 6.1 through 6.3 provide a simplified method. To determine the Nominal Ocular Hazard Distance slant range (SR) in feet, use Equation 6.1 for Single Pulse or Repetitively Pulsed less than 13 kHz (6.5 kHz for 1050 to 1400 nm). Use Equation 6.2 for Continuous Wave or Repetitively Pulsed greater than 13 kHz (6.5 kHz for 1050 to 1400 nm).

Equation 6.1

$$NOHD = \frac{32.8}{\phi} \times \sqrt{\frac{1.27 \times Q}{MPE_H}}$$

Where:
φ = Beam Divergence (mrad)
Q = Pulse Energy (J)
MPE_H = MPE per pulse in J/cm^2
32.8 = Conversion factor used to convert centimeters into feet, and radians into milliradians.

Equation 6.2

$$NOHD = \frac{32.8}{\phi} \times \sqrt{\frac{1.27 \times \Phi}{MPE_E}}$$

Where:
φ = Beam Divergence (mrad)
Φ = Average Power (W)
MPE_E = MPE in W/cm^2
32.8 = Conversion factor used to convert centimeters into feet, and radians into milliradians (0.0328 ft/cm)

Example: A 40-watt CW laser has a beam divergence of 1.5 milliradians
Given:
φ = 1.5 mrad
Φ = 40 W
MPE_E = 0.0026 (2.6 mW/cm^2, from Table 2)

Appendix 1

Solve Equation 6.2:

$$NOHD = \frac{32.8}{\phi} \times \sqrt{\frac{1.27 \times 40}{0.0026}} = 21.87 \times \sqrt{19536} = 21.87 \times 140 = 3{,}061.8\,\text{ft.}$$

Visual Effect Protection Distances (PDs) - If the laser has no wavelengths in the visible range (400-700 nm), enter "N/A (non- visible laser)" in all blocks under "Visual Effect Distances." For a visible laser, to calculate the visual protection distance in feet you must calculate equation 6.3 three times, using different values of EL (exposure level) each time. These distances are then the SZED, CZED, and LFED.

Equation 6.3

$$PD = \frac{32.8}{\phi} \times \sqrt{\frac{1.27 \times \Phi_{\text{VCP}}}{EL}}$$

Where:

φ = Beam Divergence (mrad)

Φ_{VCP} = Visually Corrected Power (from form)

32.8 = Conversion factor used to convert centimeters into feet, and radians into milliradians (0.0328 ft/cm)

EL = 1.0×10^{-4} W/cm^2 (100 μW/cm^2) when calculating slant range for Sensitive Zone Exposure Distance (SZED)

EL = 5.0×10^{-6} W/cm^2 (5 μW/cm^2) when calculating slant range for Critical Zone Exposure Distance (CZED)

EL = 5.0×10^{-8} W/cm^2 (50 nW/cm^2) when calculating slant range for Laser Free Exposure Distance (LFED)

Source: The equations above are derived from ANSI Z136.1 and have been re-expressed to a simpler form as follows: Beam divergence (φ) is entered in milliradians, making the first ANSI fraction 1,000/φ instead of 1/φ. The radical (square root) sign is used instead of raising to a power of 0.5. Under the radical, the expression 4/π is reduced to 1.27, while beam diameter (a^2) is not used since its contribution to the overall slant range distance is negligible. ANSI results are in cm; to convert to FAA's desired feet, a conversion factor of 0.0328 is used (1 cm = 0.0328 ft). There are now two numeric constants, 1,000 (from the milliradians fraction) and 0.0328, which are multiplied into a single constant, 32.8, to give results in feet. For results in cm, use "1,000" as the constant; for results in meters, use "10."

HORIZONTAL DISTANCE is the distance along the ground. For example, if a beam's power drops to 100 μW/cm^2 at 1,000 feet, and the beam is elevated at 30° above horizontal, the ground distance where 100 μW /cm^2 is reached is 866 feet (1,000 x cos (30°)). Note that the horizontal distance uses the *minimum* elevation angle.

Calculate the horizontal distance using the equation:

HD = PD x (cos(Minimum Elevation Angle))
HD = Horizontal distance. The units are the same as for the Slant Range. If SR is in feet, then HD will also be in feet.
SR = Calculated Slant Range for NOHD, SZED, CZED, and LFED respectively.
Minimum Elevation Angle = Minimum elevation angle of laser beam as provided on form.

VERTICAL DISTANCE is the distance above the ground. In the example above, the beam's power drops to100 µW /cm2 at 500 feet (1000 x sin(30°)) above the ground. Note that the vertical distance uses the *maximum* elevation angle. Calculate the vertical distance using the equation.

VD= PD x (sin (Maximum Elevation Angle)).
VD = Vertical distance. The units are the same as for the Slant Range(feet).
SR = Calculated Slant Range for NOHD, SZED, CZED, and LFED respectively.
Maximum Elevation Angle = Maximum elevation angle of laser beam as provided on form.

15. CALCULATION METHOD - List the method by which the calculations were performed.

TABLE 1. SINGLE PULSE SELECTED MAXIMUM PERMISSIBLE EXPOSURE (MPE) LIMITS

Wavelength (nm)	Exposure Duration (sec)	MPE (J/cm^2)
Ultraviolet		
180 to 400	10^{-9} to 10	Reference American National Institute Standard (ANSI) Z136 series
Visible		
400 to 700	$<10^{-9}$ 10^{-9} to 5×10^{-6} 5×10^{-6} to 10	Reference ANSI Z136 series 0.2×10^{-6} $1.8 \times t^{0.75} \times 10^{-3}$
Infrared		
700 to 1050	$<10^{-9}$ 10^{-9} to 5×10^{-6} 5×10^{-6} to 10	Reference ANSI Z136 series $0.2 \times C_A \times 10^{-6}$ $1.8 \times C_A \times t^{0.75} \times 10^{-3}$
1050 to 1400	$<10^{-9}$ 10^{-9} to 13×10^{-6} 13×10^{-6} to 10	Reference ANSI Z136 series $2.0 \times C_C \times 10^{-6}$ $9 \times C_C \times t^{0.75} \times 10^{-3}$
1400 to 1500	$<10^{-9}$ 10^{-9} to 10^{-3} 10^{-3} to 4 10	Reference ANSI Z136 series 0.3 $0.56 \times t^{0.25} + 0.2$ 1.0
1500 to 1800	$<10^{-9}$ 10^{-9} to 10 10	Reference ANSI Z136 series 1.0 1.0
1800 to 2600	$<10^{-9}$ 10^{-9} to 10^{-3} 10^{-3} to 10 10	Reference ANSI Z136 series 0.1 $0.56 \times t^{0.25}$ 1.0
2600 to 10,000	$<10^{-9}$ 10^{-9} to 10^{-7} 10^{-7} to 10 10	Reference ANSI Z136 series 10×10^{-3} $0.56 \times t^{0.25}$ 1.0

To find C_A:
For wavelength = 700 to 1050nm, $C_A = 10^{0.002\ (\text{wavelength}-700)}$
Example 1
Laser wavelength is 850nm; $C_A = 10^{0.002(850-700)} = 10^{0.002*150} = 10^{0.3} = 1.995$
Example 2
Laser wavelength is 933nm; $C_A = 10^{0.002(933-700)} = 10^{0.002*233} = 10^{0.466} = 2.924$
To find C_C:
For wavelength = 1050 to 1150nm, $C_C = 1.0$
For wavelength = 1150 to 1200nm, $C_C = 10^{0.018\ (\text{wavelength}-1150)}$
For wavelength = 1200 to 1400nm, $C_C = 8.0$
Example 3
Laser wavelength is 1175nm; $C_c = 10^{0.018(1175-1150)} = 10^{0.018*.25} = 10^{.25} = 2.8$
To find t: "t" is the pulse duration in seconds.

TABLE 2. CW MODE MAXIMUM PERMISSIBLE EXPOSURE (MPE) LIMITS

Values are for selected wavelengths for unintentional viewing.

Wavelength (nm)	MPE **(W/cm²)**
Ultraviolet	
180 to 400	Reference American National Standards Institute ANSI Z136 series
Visible	
400 to 700	$2.6\text{x}10^{-3}$
Infrared	
700 to 1050	$(2.6\text{x}10^{-3})$ x C_A
1050 to 1150	$13\text{x}10^{-3}$
1150 to 1200	$(13\text{x}10^{-3})$ x C_C
1200 to 1400	.1
1400 to 10,000	0.1

See Table 1 for correction factors of C_A and C_C.

Example 1

Laser wavelength is visible; MPE = 0.0026 W/cm^2

Example 2

Laser wavelength is 850nm;

$$C_A = 10^{0.002(\lambda-700)} = 10^{0.002(850-700)} = 10^{0.3} = 1995$$

$$MPE = 2.6\times10^{-3}\times C_A = 2.6\times10^{-3}\times1.995 = 5.2\times10^{-3}\ \mathrm{W\cdot cm^{-2}}$$

"Unintentional viewing": Unintentional exposure on aircraft is expected to be no more than 0.25 s due to natural relative motion between the beam and aircraft related to wind and other stabilization issues.

Source: ANSI Z136.1 Tables 5 and 6.

TABLE 3. VISUAL CORRECTION FACTOR FOR VISIBLE LASERS

Use for visible lasers only (400-700 nm).

Laser Wavelength (nm)	Visual Correction Factor (VCF)	
400	4.0×10^{-4}	
410	1.2×10^{-3}	
420	4.0×10^{-3}	
430	1.16×10^{-2}	
440	2.30×10^{-2}	
450	3.80×10^{-2}	
460	5.99×10^{-2}	
470	9.09×10^{-2}	
480	1.391×10^{-1}	
490	2.079×10^{-1}	
500	3.226×10^{-1}	
510	5.025×10^{-1}	
520	7.092×10^{-1}	
530	8.621×10^{-1}	
540	9.524×10^{-1}	
550	9.901×10^{-1}	
555	1.0×10^{0}	(VCF=1)
560	9.901×10^{-1}	
570	9.524×10^{-1}	
580	8.696×10^{-1}	
590	7.576×10^{-1}	
600	6.329×10^{-1}	
610	5.025×10^{-1}	
620	3.817×10^{-1}	
630	2.653×10^{-1}	
640	1.751×10^{-1}	
650	1.070×10^{-1}	
660	6.10×10^{-2}	
670	3.21×10^{-2}	
680	1.70×10^{-2}	
690	8.2×10^{-3}	
700	4.1×10^{-3}	

To find the Visually Corrected Power (VCP) for a specified wavelength, multiply the Visual Correction Factor (VCF) for the wavelength (from the table above) by the Average Power. If the laser's wavelength falls between two table entries, use the more conservative (larger) value of the two resulting VCFs.

Example 1: A frequency-doubled YAG laser emits 10 watts of 532nm continuous wave light. From the table, 532 is between 530 and 540; use the more conservative (larger) Visual Correction Factor of 540nm: 9.524×10^{-1}. Multiply the VCF of 0.9524 by the Average Power of 10 watts, to obtain the Visually Corrected Power of 9.524 watts.

TABLE 3. VISUAL CORRECTION FACTOR FOR VISIBLE LASERS (Continued)

Example 2: An 18-watt argon laser emits 10 watts of 514nm light, and 8 watts at 488nm light, both continuous wave. Calculate each wavelength separately, and then add the resulting Visually Corrected Powers together.

10 watts at 514nm: From the table, 514 is between 510 and 520, use the more conservative (larger) VCF of 520nm: 7.092×10^{-1}. Multiply the VCF of 0.7092 by the Average Power of 10 watts to obtain the Visually Corrected Power of 7.092 watts.

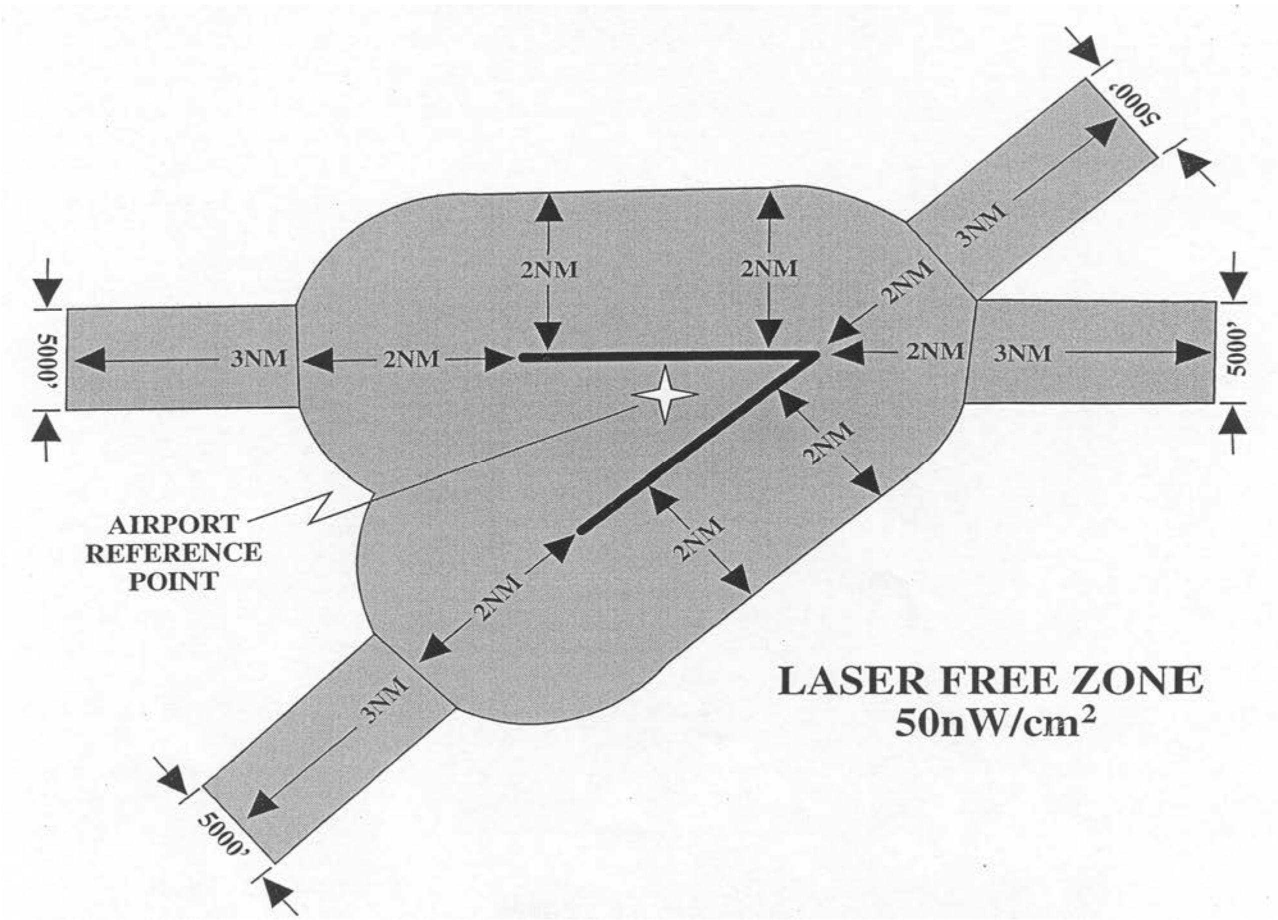
8 watts at 488nm: From the table, 488 is between 480 and 490; use the more conservative (larger) VCF of 490nm: 2.079×10^{-1}. Multiply the VCF of 0.2079 by the Average Power of 8 watts, to obtain the Visually Corrected Power of 1.6632 watts.

Finally, add the two VCPs together: 7.092 + 1.6632 = 8.7552. The 18-watt laser in this example has a Visually Corrected Power of only 8.7552 watts.

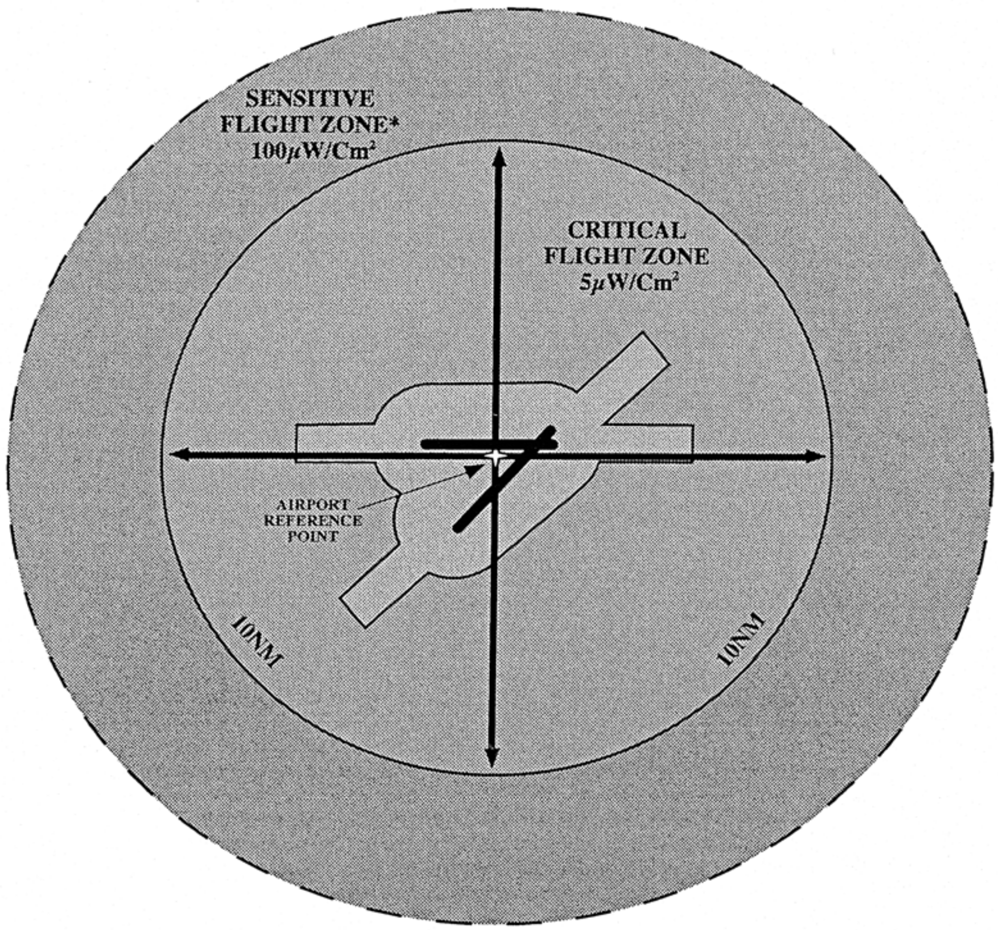
Note: *Example 1 is the 10-watt YAG which appears brighter to the eye (9.5 W_{VCP}) than an 18-watt argon (8.8 W_{VCP}).*

<u>Source</u>: The Visual Correction Factor used in this table (C_F) is the CIE normalized efficiency photopic visual function curve for a standard observer. The illuminance ($lm \cdot cm^{-2}$) is the measured irradiance multiplied by C_F and 683. The effective irradiance is the actual (measured) irradiance multiplied by C_F. The effective irradiance ($W \cdot cm^{-2}$) multiplied by 683 $lm \cdot W^{-1}$ is the illuminance ($lm \cdot cm^{-2}$).

LASER FREE ZONE



AIRSPACE FLIGHT ZONES



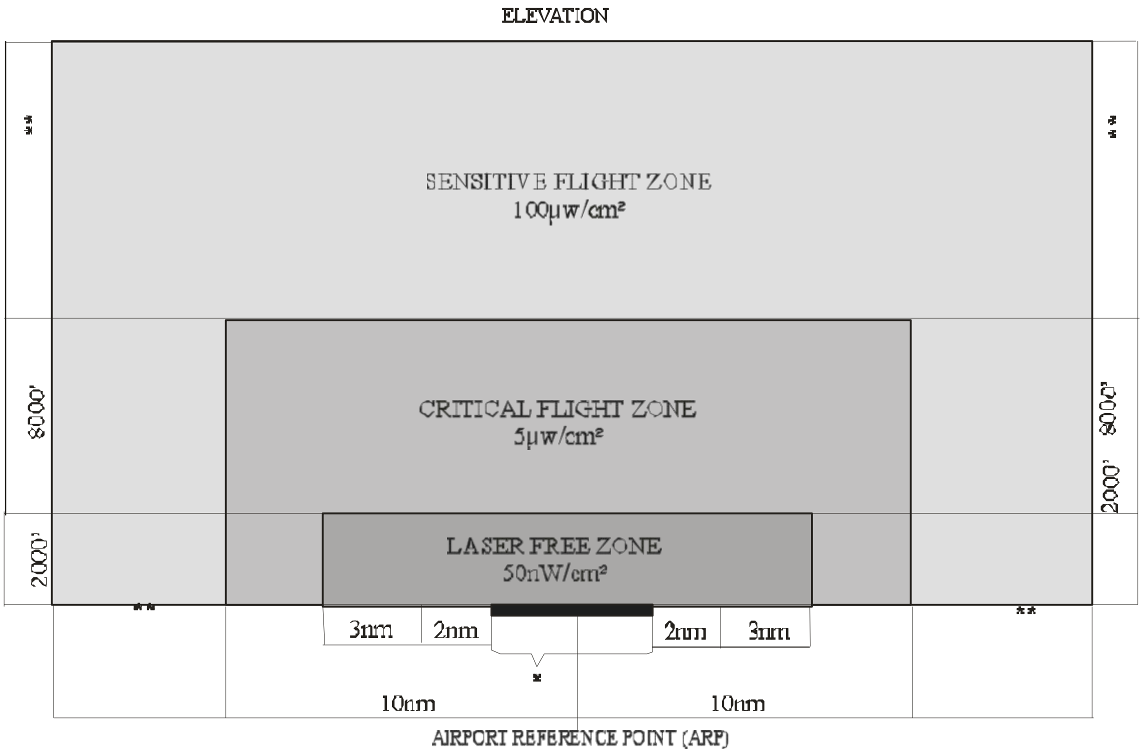
1. Laser Free Zone (LFZ): Airspace in the immediate proximity of the airport, up to and including 2,000 feet AGL, extending 2 nautical miles in all directions measured from the runway centerline. Additionally, the LFZ includes a 3nm extension, 2,500 feet each side of the extended runway centerline, up to 2,000 feet AGL of each useable runway surface. The level of laser light is restricted to a level that should not cause any visual disruption.

2. Critical Flight Zone (CFZ): Airspace within a 10-nautical-mile (nm) radius of the Airport Reference Point (ARP), up to and including 10,000 feet AGL, where a level of laser light is restricted to avoid flashblindness or afterimage effects.

3. Sensitive Flight Zone (SFZ): Airspace outside the Critical Flight Zone(s) that authorities (e.g., FAA, local departments of aviation, military, etc.) have identified that must be protected from flashblindness or afterimage effects.

4. Normal Flight Zone (NFZ): Airspace not defined by the Laser Free, Critical, or Sensitive Flight Zones.

AIRSPACE FLIGHT ZONES



* *Runway length varies per airport. AGL is based on published airport elevation.*
** *To be determined by regional evaluation and/or local airport operations.*

Appendix 2: FEDERAL AVIATION ADMINISTRATION SERVICE CENTER ADDRESSES

Attn: Manager, Operations Support Group Eastern Service Center, AJV-E2 1701 Columbia Ave. College Park, GA 30337 9-ATO-ESA-OSG-Lasers-Searchlights@faa.gov	NY, WV, VA, MD, PA, NJ, DE, WASH. DC, RI, MA, CT, VT, NH, GA, AL, MS, FL, KY, TN, NC, SC, ME
Attn: Manager, Operations Support Group Central Service Center, AJV-C2 10101 Hillwood Parkway Fort Worth, TX 76177 9-ASW-Operations-Support-Lasers@faa.gov	IA, NE, KS, MO, OH, MI, IL, IN, MN, WI, ND, SD, TX, AR, OK, NM, LA
Attn: Manager, Operations Support Group Western Service Center, AJV-W2 1601 E. Valley Road Renton, WA 98057 9-ATO-WSA-OSG.Lasers@faa.gov	AK, WA, OR, ID, MT, WY, UT, CO, CA, NV, AZ, HI

GLOSSARY

a) **Afterimage** – A reverse contrast shadow image left in the visual field after an exposure to a bright light that may be distracting and disruptive, and may persist for several minutes.

b) **Center for Devices and Radiological Health (CDRH) –** An office of the FDA concerned with enforcing compliance with the Federal requirements for laser products including laser light shows.

c) **Demonstration** – Any laser product designed or intended for purposes of visual display of laser beams, for artistic composition, entertainment, and /or advertising display (see 21 CFR 1040.10(b) 13). Any demonstration laser in excess of 5 mW requires a variance from the CDRH.

d) **Divergence** – The increase in the diameter of the laser beam with distance from the exit aperture. Divergence is an angular measurement of the beam spread, expressed in milliradians (mrad). In laser safety calculations, divergence is defined at the points where the irradiance is 37% of the peak irradiance.

e) **Flashblindness** – Generally, a temporary visual interference effect that persists after the source of illumination has ceased.

f) **Flight Safe Level** – An estimate of the maximum exposure of radiant light energy emission (irradiance value) allowed to illuminate an aircraft within specific flight zones.

g) **Flight Zones** – Airspace areas specifically intended to mitigate the potential hazardous effect of laser emissions. These areas may not be contiguous or concentric as the other zones. There are several types of flight zones:

1. Laser Free Zone (LFZ) – Airspace zone where the level of laser light is restricted to a level that should not cause any visual disruptions.

2. Critical Flight Zone (CFZ) – Airspace zone where a level of laser light is restricted to avoid flashblindness or afterimage effects.

3. Sensitive Flight Zone (SFZ) – Airspace zone outside the critical flight zones that authorities (e.g., FAA, local departments of aviation, military) have identified that must be protected from the potential effects of laser emissions.

4. Normal Flight Zones (NFZ) – Airspace zone not defined by the Laser Free, Critical, or Sensitive Flight.

h) **Irradiance** – Irradiance is a means of expressing the intensity of the beam per unit area, expressed in watts per centimeter squared (W/cm^2).

i) **Joule** (J) – The International system unit of energy, equal to the work done when a current of one ampere is passed through a resistance of one ohm for one second.

j) **Laser** – An acronym for light amplification by stimulated emission of radiation. A laser is a device that produces an intense, directonal, coherent beam of visible or invisible light.

k) **Laser Manufacturer** – A term that refers to persons who make laser products, including those who are engaged in the business of design, assembly, or presentation of a laser light show.

l) **Laser Safety Officer (LSO)** – A designated person who has authority to monitor and enforce the control of laser hazards and affect the knowledgeable evaluation and control of laser hazards.

m) **Laser Operator** – A laser operator should be 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 direction of the laser safety officer.

n) **Local Laser Working Group (LLWG)** – A group that, when necessary, is convened to assist the regional air traffic division in evaluating the potential effect of laser emissions on aircraft operators in the local vicinity of the proposed laser activity.

o) **Maximum Permissible Exposure (MPE) –** The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological change in the eye or skin. In general, MPE is expressed as mW/cm^2 or mJ/cm^2.

p) **Milliradian (mrad)** – A measure of angle used for beam divergence.

q) **Nominal Ocular Hazard Distance (NOHD)** – The maximum distance from the laser system beyond which the laser-beam irradiance does not exceed the MPE for that laser.

r) **Radiant Exposure** – A means of expressing the intensity of the beam. This is generally expressed as J/cm^2.

s) **Reflections**– reflections can be either diffuse or specular.

1. Diffuse Reflection - The component of a reflection from a surface commonly found with flat finish paints or rough surfaces. A diffuse surface will reflect the laser beam in many directions.
2. Specular Reflection – A mirror-like reflection that usually maintains the directional characteristics of the beam.

t) **Safety Observer** - A designated person who is responsible for monitoring the safe operation of a laser and who can immediately terminate the laser beam if necessary to ensure safety. Normally, a safety observer will view airspace in the vicinity of a laser beam to identify any potentially unsafe condition.

u) **Slant Range –** The distance directly along the beam (e.g., “slant range” does not vary depending on beam elevation angle).

v) **Terminated Beam** - A laser beam that is blocked from entering navigable airspace.

w) **Unterminated Beam** - A laser beam that is directed or reflected into navigable airspace. The proponent should provide sufficient evidence to the FDA and the FAA that users of the NAS are not affected.

x) **Variance** - Permission from FDA for a laser manufacturer and/or operator to deviate from one or more requirements of 21 CFR 1040 when alternate steps are taken to provide equivalent level of safety.

y) **Watts** - A unit of measurement associated with power output. Often the wattage of a laser system is prefixed with milli (mW), micro (μW) and nano (nW). One watt is one joule per second.