U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: Outdoor Laser Operations **Date:** 05/05/2022 **AC No:** 70-1B
Initiated By: AJV-P21 **Change**: 1

This Advisory Circular (AC) provides information to assist proponents planning to conduct outdoor laser operations that may affect aircraft operations in the United States (U.S.) National Airspace System (NAS).

This change clarifies meaning in Appendix A and corrects errors in Appendix B.

PAGE CONTROL CHART

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A-2	02/14/2022	A-2	05/05/2022
B-1 through B-8	02/14/2022	B-1 through B-7	05/05/2022

The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. The intent of this document is to provide clarity to the public regarding existing requirements under the law or agency policies.

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Natasha A. Durkins

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1. PURPOSE

This AC provides additional context for FAA Form 7140-1, Notice of Proposed Outdoor Laser Operations, explains the necessity and requirements of notification, describes the method to notify the Federal Aviation Administration (FAA) of the planned laser operation, and defines what FAA will do with the notification once received. Additionally, this AC provides detailed instructions to assist with the completion of FAA Form 7140-1.

Using this AC, FAA intends to maintain a high level of safety between laser operations and aircraft operations. FAA requests that laser operators submit information as required via FAA Form 7140-1 (available on FAA's website[1]).To assist proponents in providing information for FAA review of the proposed outdoor laser operation, this AC includes the following appendices:

- Appendix A: Instructions for Completing FAA Form 7140-1, Notice of Proposed Outdoor Laser Operation(s)
- Appendix B: Tables and Examples
- Appendix C: MPE and NOHD for a Laser Emitting Multiple Wavelengths from the Same Aperture
- Appendix D: Depictions of Airspace Flight Zones and Graphic Examples
- Appendix E: FAA Service Center Information
- Appendix F: Glossary

NOTE*: 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: The FAA has the authority to regulate the safe and efficient use of the navigable airspace per Title 49 United States Code (U.S.C.) Section 40103, Sovereignty and Use of Airspace, and the Public Right of Transit.

3. EFFECTIVE DATE: February 14, 2022.

4. WHAT THIS AC CANCELS: AC 70-1A, Outdoor Laser Operations, dated March 14, 2019, is canceled.

5. NOTIFICATION

Why is it Necessary to Notify FAA?

In recognition of FAA's role in promoting aviation safety, the Food and Drug Administration (FDA), which regulates lasers per 21 Code of Federal Regulations (CFR) § 1040,[2] requires notice to FAA as a condition of a variance for a laser light show, display, or device operated outdoors that intends to project into open airspace at any time. Early notice of the planned

[1] https://www.faa.gov/regulations_policies/.
[2] https://www.ecfr.gov/current/title-21/chapter-I/subchapter-J/part-1040.

activity provides FAA the opportunity to minimize the potentially hazardous adverse effects of laser operations on aircraft operators in the navigable airspace. Appendix C graphics provide general considerations.

FAA recognizes there are varied demands for the use of airspace, both by aviation and non-aviation interests. While FAA makes a sincere effort to find equitable solutions to conflicts and the use of airspace as a national resource, FAA must prioritize safe aviation operations.

What are the Risks of Laser Light in Navigable Airspace?

The leading risk of a laser striking an aircraft is visual interference with a crewmember. Any form of laser illumination can distract a crewmember. If a pilot experiences a laser illumination, the resulting visual effects could lead to loss of life, especially at critical phases of flight, such as take-off or landing. Laser incidents have disrupted aircraft flights (e.g., go-around or return to airport) and other missions (e.g., search and rescue).

Visual effects can range in severity from glare (e.g., oncoming headlights or inability to see outside the aircraft while illuminated) to temporary flashblindness. Temporary flashblindness can cause an afterimage that may persist from several seconds to several minutes. Other effects of laser illumination can include loss of dark adaptation, disorientation, and eye pain. Additionally, exposure to strong laser light could result in eye injury.

Who Should Submit a FAA Form 7140-1 Notice?

Any person/entity/proponent who plans to conduct outdoor laser operations with visible laser beams, wavelengths of 400 nanometers (nm) to 700 nm,[3] exceeding 50 nanowatts per square centimeter (nW/cm^2) in navigable airspace *or* with any laser beams (visible or non-visible) that exceed the maximum permissible exposure (MPE) in navigable airspace should submit Form 7140-1 to FAA.

Navigable airspace is airspace above the minimum altitudes of flight, including airspace needed for the takeoff and landing of aircraft.[4] If a proponent is unsure whether a proposed outdoor laser operation will remain completely within non-navigable airspace, FAA encourages proponents to contact the applicable FAA service center for guidance.

When to File a Notice?

FAA requests proponents file a notice at least 30 days before the planned event. This allows FAA sufficient time to accomplish an aeronautical study and make a determination.

How to File the Notice?

File a notice with the appropriate/applicable FAA service center for the area that includes the laser operation site. Appendix E provides a list of service center contact information and the areas for which they are responsible. For laser operations that plan to cross service center

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[3] FAA relies upon FDA/Center for Devices and Radiological Health's (CDRH) guidance regarding compliance with IEC 60825-1 Ed. 3 for its definition of the visual spectrum as 400 nm to 700 nm.
[4] *See* 14 CFR 1.1 and FAA Aeronautical Information Manual (AIM).

boundaries (normally airborne operations), file a notice with the FAA service center responsible for the location serving as the predominant site for aircraft basing.

What Information Should a Proponent Submit to FAA?

FAA requests the proponent submit the following information:

- A completed FAA Form 7140-1, Notice of Proposed Outdoor Laser Operation(s). This includes a completed Laser Configuration Worksheet (page two of the form) for each laser configuration.

- Detailed diagrams depicting the planned laser paths (see related documents for resources).

- Any other attachments (e.g., worksheets) requested on the form or within these instructions that require more space than the form allows to provide additional information sufficient for FAA to analyze the proposed laser operation.

NOTE*: If a proponent plans to use an electronic protection system in lieu of safety observers, use section 6 of FAA Form 7140-1 to describe the control measures and provide any additional documentation to certify that the control measures meet the performance criteria in SAE AS6029, Criteria for Laser Control Measures Used for Aviation Safety (current edition).*

What Action Will FAA Take Regarding this Information?

The FAA service center that receives the notice will review the information. If FAA personnel have any questions or need to verify data, FAA will contact the proponent. If FAA has no initial questions for a proponent, FAA will coordinate with parties potentially affected by the proposal as part of its aeronautical review for all proposed outdoor laser operations in the NAS.

The goal of the review is to identify any potential negative effects to aviation safety from the proposed operation. Once complete with the aeronautical review, FAA will issue a letter of determination (LOD) to the proponent. The letter will either state that FAA has no objection to the proposed laser use or that FAA objects and the laser use should not proceed until resolution of objectionable effects.

6. PRINCIPAL CHANGES

The FAA revised this AC to reflect changes to FAA Form 7140-1. The FAA also modified content with the goal of enhancing readability. A summary of changes follows.

- Use of decimal notation to improve ease of use.

- Revised instructions to determine MPE, nominal ocular hazard distance (NOHD), and exposure distances.

- Included examples to assist proponents with form completion based on common applications.

- Updated source notes and glossary to increase clarity.
- Updated graphics products to augment items described in the text.

7. RELATED DOCUMENTS

This AC should contain sufficient instructions for proponents to complete FAA Form 7140-1, Notice of Proposed Outdoor Laser Operation(s). A list of additional resources useful in understanding the general background of laser safety and regulations regarding aviation procedures and laser safety is as follows.

- Title 49 U.S.C., Subtitle VII, AVIATION PROGRAMS, Part A—Air Commerce and Safety and Part B—Airport Development and Noise: FAA's regulatory authority.
- FAA Order JO 7400.2, Procedures for Handling Airspace Matters, Chapter 29: Outdoor Laser Operations: Additional information and process for handling notices.
- FAA Advisory Circular 70-2, Reporting of Laser Illumination of Aircraft: Provides guidance for aircrews and air traffic control on the formal reporting of laser illumination incidents.
- FDA 225-99-6000, Memorandum of Understanding between the FDA/CDRH and FAA (available on the FDA/CDRH website): Defines roles and collaboration between FAA and FDA/CDRH.
- 21 CFR Part 1010, Performance Standards for Electronic Products, and Part 1040, Performance Standards for Light Emitting Products (§ 1040.10 applies to laser products and § 1040.11 applies to specific purpose laser products): FDA regulations.
- FDA/CDRH *Laser Products-Conformance With IEC 60825-1 Ed. 3 and IEC 60601-2-22 Ed. 3.1 (Laser Notice No. 56); Guidance for Industry and Food and Drug Administration Staff; Availability*, 84 FR 20140 (May 8, 2019).
- FDA information on laser light shows (e.g., description, uses, and industry guidance): Available at https://www.fda.gov/radiation-emitting-products/home-business-and-entertainment-products/laser-light-shows.
- International Electrotechnical Commission (IEC) IEC 60825-1 Ed. 3: Safety standards for laser products.
- American National Standards Institute (ANSI) Z136.1 and Z136.6 laser standards: Standards for the safe use of lasers (in general and outdoors); helpful to determine potential hazards and resulting control measures for outdoor laser uses that may have special characteristics or conditions not addressed in Form 7140-1 and/or this document.

- SAE International (SAE) documents related to outdoor laser operations and aviation safety: Aerospace recommended practices (ARP) and aerospace standards (AS).
    - SAE ARP5290: Laser Beam Divergence Measurements Techniques Comparison.
    - SAE ARP5293A: Safety Considerations for Lasers Projected in the Navigable Airspace.
    - SAE ARP5535: Observers for Laser Safety in the Navigable Airspace.
    - SAE AS4970: Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace.
    - SAE AS6029B: Performance Criteria for Laser Control Measures Used for Aviation Safety.
- United States Geological Survey (USGS): Use the following methods as examples to contact USGS and/or acquire topographical (quadrangle) maps.
    - USGS National Center: 12201 Sunrise Valley Drive, Reston, Virginia, 22092, or (703) 648-5953.
    - https://www.usgs.gov/products/maps/topo-maps or https://store.usgs.gov/map-locator.

Appendix A. Instructions for Completing FAA Form 7140-1, Notice of Proposed Outdoor Laser Operation(s)

A.1. Introduction

This appendix provides detailed instructions to assist those completing FAA Form 7140-1. For additional information on MPE limits or visual correction factors to assist with completing the form, consult Appendix B.

A.2. Submission, Preparation, and Processing

General: Fill out Form 7140-1 completely. If the form requires information that does not apply to the submission (e.g., fax number), enter N/A. Submit any additional information sufficient for FAA to analyze the proposed laser operation via attachments to the form. This additional information may include necessary details that require more space to explain, e.g., diagrams, or worksheets requested on the form or within these instructions. Failure to provide all requested information may delay processing.

Data sources: This form requires calculations based on data concerning characteristics of the laser beam(s). Proponents may obtain data from direct measurement, manufacturer specifications, or specialized instruments. Proponents may also derive data by making reasonable, conservative assumptions, e.g., that a certain value makes the beam more hazardous than it could 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 AC and its tables (see Appendix B) cover a wide variety of laser configurations. They are necessarily simplified and make conservative assumptions. Some laser configurations may warrant a more complex analysis. Use the ANSI Z136 series of standards or other established methods as basis for any such alternative analysis. Document the method(s) and calculations and include them when submitting Form 7140-1 to FAA.

Laser configurations: A single outdoor laser operation may have a number of lasers or “laser configurations.” A laser configuration is a laser, or group of similar lasers, aimed in a given direction or area that needs airspace protection.

If a setup operates with more than one laser, with different beam characteristics (e.g., power setting, pulse mode, divergence, or wavelength), or has multiple output devices (e.g., projector heads) aimed into the airspace, it has multiple configurations and requires analysis as a separate laser configuration. For each configuration, fill out one copy of the Laser Configuration Worksheet (page two of the form). An example and resulting requirements follows.

Example*: At a laser light show, there may be two configurations.*

- *A group of lasers all aimed in the same general direction over the audience, e.g., 10 RGB (red-green-blue) diode laser projectors above a stage, aimed horizontally along an azimuth ranging from 30 to 45 degrees and elevated vertically from 5 to 45 degrees.*

- *A beacon laser pointing straight up.*

In the *group* example above, report all 10 laser projectors and their beam characteristics (power, divergence, and wavelength) to FAA on the form or an attachment. Since, however, all lasers have similar characteristics and are all aimed into the same area of airspace, complete as few Laser Configuration Worksheets as required.

- If the laser with the longest eye hazard distance (NOHD) ***is also*** the laser with the longest visual interference distance (laser-free exposure distance/LFED):
  - Complete one worksheet.
  - Rationale: The other, less-powerful projectors have shorter protection distances that remain within the longest distances needed to protect airspace.

- If the laser with the longest eye hazard distance (NOHD) ***is not*** the laser with the longest visual interference distance (LFED):
  - Complete an additional worksheet for the laser with the longest visual interference distance (LFED).
  - Use the data to determine the other protection distances, e.g., SZED and CZED.
  - Rationale: While this laser is similar to the one in the some group with the longest NOHD, the visual interference value is different. This laser does not remain within the protection distances of the other laser and therefore requires additional analysis to protect airspace.

In the *beacon* example above, a separate beacon laser is aimed straight up (90 degrees vertically). This is another configuration, requiring completion of an additional Laser Configuration Worksheet and associated attachments.

Aeronautical study: FAA service center personnel will use the submitted information to perform an aeronautical study to evaluate the safety of a proposed laser operation. Provide all requested information to FAA to enable service center personnel to perform the study. If a proponent needs to include additional details not requested on the form, list these in cell 7b and include with the submission.

A.3. Section 1. General Information

1a. Enter the FAA service center responsible for the area that includes the laser operation site. For airborne laser operations, enter the service center where the majority of aircraft basing will occur. Consult Appendix E for FAA service center contact information.

1b. Enter the proponent's name and contact information; e.g., address, telephone, fax, and e-mail. The proponent 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's information here then reference cell 1f.

1c. Enter the event name (for temporary shows) or the facility name (for permanent installations).

1d. Enter the date the proponent prepared or sent the report to FAA. The date in this cell *is not* the date of the laser operation.

1e and **1f.** If the laser user is different from the proponent, complete these cells. If not, enter "Same as proponent." Enter the customer and site address in 1e and 1f.

A.4. Section 2. Date(s) and Time(s) of Laser Operation

2a and **2b.** Enter the date(s) and time(s) of the testing, alignment (if applicable), and operation. Include the time zone at the site. Example: May 20, 2021, 7:00 p.m. to 12:00 a.m. (midnight), Central Time.

A.5. Section 3. Brief Description of Laser Operation

Provide a general overview of the operation. Describe specific laser configurations of the operation in detail using the Laser Configuration Worksheet found on page two of Form 7140-1. If necessary for multiple configurations, attach additional copies of the Laser Configuration Worksheet.

A.6. Section 4. On-site Operation Information

List the names and titles (if available) of the laser operators in 4a. Proponents should provide one (or more) working, direct telephone links to the laser operator or an equivalent method of quickly reaching the operator, e.g., telephoning a central station that reaches the operator via radio. FAA provides space for two telephone numbers on the form. List the primary phone number in cell 4b and the secondary/alternate/backup number in cell 4c. The on-site phone numbers in cells 4b and 4c must be U.S. phone numbers.

A.7. Section 5. FDA/CDRH Information

If the operation uses or is a "demonstration laser" (generally, a laser light show) regulated by FDA/CDRH, enter the variance number for the laser light show, the variance expiration date, and the accession number. The accession number may or may not have an "RH" prefix or a suffix, e.g., "-001." At a minimum, enter the seven alphanumeric digits provided by FDA/CDRH.

NOTE*: The variance number may remain valid even if issued in the past. FDA/CDRH may require periodic reports (usually annually) to keep variances active as stipulated in the variance* *if approved. If the report is acceptable, FDA may send an acknowledgement letter that may or not contain a new variance expiration date. The variance number may not change.*

A.8. Section 6. Brief Description of Control Measures

Describe the proposed method(s) to protect airspace from the laser, e.g., termination on a building or surface (where the beam path from the laser origin to the termination point is not accessible by aircraft, including helicopters), use of observers, use of radar and/or imaging equipment, or physical methods of limiting the beam path. As the level of reliance on the control measure(s) to ensure safety increases, FAA expects a commensurate increase in the level of detail used to describe the control measure(s).

***NOTE**: If a proponent is utilizing an electronic protection system in lieu of safety observers, enter the description into Section 6 of FAA Form 7140-1 and provide additional documentation to certify that control measure meets the performance criteria in the SAE AS6029, Criteria for Laser Control Measures Used for Aviation Safety (current edition).*

A.9. Section 7. Attachments

7a. List the total number of laser configurations submitted with this notice (see the example described earlier in paragraph A.2.).

7b. List all attachments/associated file names and the correlation between each attachment (and/or file) and the specific configuration listed in cell 10a. This will assist FAA in evaluating the proposal. Examples of attachments are maps, diagrams, and details of control measures.

A.10. Section 8. Designated Contact Person

Specify the person who FAA may contact for additional information. This contact should be the person most knowledgeable about the laser safety of this operation. The person could also be the laser operation central contact who interfaces with FAA. The designated contact person should work for or represent the proponent listed in cell 1b.

A.11. Section 9. Statement of Accuracy

The person signing the form must have the authority to bind the proponent to follow the control measures described in the submitted notice. This person may also serve as the contact person.

A.12. Section 10. Configuration Information

10a. Enter the configuration number of the specific configuration entered on this Laser Configuration Worksheet. If there is only one configuration, enter “Configuration number 1 of 1.” If there is more than one configuration, enter the number of the specific configuration entered on this page and the total number of configurations submitted. Example: “Configuration number 7 of 9.”

10b. Describe the system that aims and projects the beam(s) into airspace, e.g., fixed mirror, scanning galvanometers, or manually aimed. Include a description of the site layout. Attach additional pages if needed to describe the laser use.

A.13. Section 11. Geographic Location

11a. Enter the ground elevation of the site in feet mean sea level (MSL).

11b. 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.

11c. Enter the overall laser elevation (site elevation plus height above site elevation). This number is the total height of the laser in MSL. For laser operations from aircraft or spacecraft operations, attach additional information on the flight locations and altitudes.

11d. Select global positioning system (GPS), map (e.g., USGS topographical or quadrangle), or other as the method used to determine data in section 11. If selecting "other," describe the method (e.g., application or software name, program, or service) to FAA in cell 10b (Brief description of configuration) and mention cell 11d in the description.

11e and **11f.** Enter the latitude and longitude in degrees, minutes, and seconds. Some maps or devices may provide this information in "decimal degrees" form. If the source provides decimal degrees, convert this value into degrees, minutes, and seconds. The Federal Communications Commission furnishes a website with a converter (https://www.fcc.gov/media/radio/dms-decimal).

A.14. Section 12. Beam Characteristics and Calculations

Determine the laser's mode of operation (single pulse, continuous wave [CW], or repetitively pulsed). Check the appropriate column header and complete *only* that column for section 12.

For the purposes of this form, use these characteristics:

- "Continuous wave" refers to a laser that produces a continuous (non-pulsed) output for a period greater than 0.25 seconds.
- "Repetitively pulsed" refers to a laser with a pulse repetition frequency (PRF) of equal to or greater than one hertz.

NOTE: Repetitively pulsed versus scanning lasers

"Repetitively pulsed" refers to lasers that naturally emit repetitive pulses, such as Q-switched lasers.

The intent of the design of the form and the tables within this Advisory Circular does not include safety analysis of pulses of a beam scanned over a viewer or aircraft, such as graphics or beam patterns used in laser displays, or scanned patterns used for light detection and ranging (LIDAR).

Pulses resulting from scanning are often extremely variable in pulse width and duration. For a conservative analysis, assume the beam is static (non-scanned). If a proponent relies on scanning to remain in compliance, they must provide a more comprehensive analysis that *documents methods and calculations, <u>and</u> must document and use scan-failure protection devices.*

A.14.1. Considerations for Multiple Visible CW Laser Beams Aimed Within the Same Area

For a configuration that aims multiple lasers in the same direction, all of which emit visible wavelengths (from 400 nm to 700 nm), consider the following before completing cell 12a.

Example: Multiple lasers on a stage projecting over the audience into the same area of airspace requiring protection.

- **Simplest, most conservative analysis.**
    - In cell 12a, enter the data for the laser with the highest power. All other lasers will have a shorter hazard distance.
    - In cell 12c, enter "1" as the Visual Correction Factor (VCF).
    - Notes for this approach follow.
        - The pre-corrected power (PCP) and the Visually Corrected Power will be the same as the power from the highest-power laser.
        - Because of no allowance for the beams' visibility, the SZED, CZED, and LFED distances will be longer than analyzing each laser separately.
- **Analyze each laser separately:** This analysis will determine which laser beam has the longest NOHD, and which has the longest LFED.
    - For each laser projector, determine the NOHD, SZED, CZED, and LFED. Attach documentation showing the data and calculations. See Appendix B for an example.
    - Cells 12a and 14a: Enter the data for the projector with the longest NOHD.
    - Cells 12c, 14b, 14c, and 14d: Enter the data for the projector with the longest LFED.

A.14.2. Section 12a. Laser and Beam Characteristics

Laser type: Enter the lasing medium, e.g., CO_2, copper-vapor, diode, or Nd-YAG.

Laser hazard class: Enter the hazard class for the laser, e.g., Class 2, Class 3R, Class 3B, or Class 4.

Power: If a continuous wave laser, enter the maximum power in watts (W). If a repetitively pulsed laser, enter the average power in watts (W).

Pulse energy: If a single pulse or repetitively pulsed laser, enter the pulse energy in joules (J).

Pulse duration: If a single pulse or repetitively pulsed laser, enter the pulse duration in seconds (s).

Pulse repetition frequency: If a single pulse or repetitively pulsed laser, enter the pulse repetition frequency in hertz (Hz).

Beam diameter and divergence: Provide the diameter using the 1/e peak-irradiance points in centimeters (*not millimeters*). The divergence is the full angle given at the 1/e points in milliradians (mrad). If measuring the diameter or divergence at the $1/e^2$ points instead of 1/e, 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 or smaller divergence) simplifications.*

Wavelength(s): Based on the number of wavelengths and their relation to the visible spectrum, use the following information to assist with determining what information FAA requires.

- **Single-wavelength laser beam**: For a laser emitting a single wavelength:
    - Enter the wavelength in nanometers (nm) in 12a.
    - If the emitted wavelength is:
        - Within the visible range (400 nm to 700 nm): Enter “2.6” as the MPE value in 12b and enter the results of the visual effect calculations in cell 12c.
        - Not within the visible range: Determine the MPE value as described in paragraph A.14.2. and enter the value into cell 12b. Enter “N/A (non-visible laser)” in all cells of the applicable column of section cell 12c.
- **Multiple-wavelength laser beam**: For a laser simultaneously emitting multiple wavelengths in the same beam (from the same aperture), see Appendix C.

A.14.3. Section 12b. Maximum Permissible Exposure (MPE) Value

Provide MPE calculation results in the applicable cell, expressed in milliwatts per square centimeter (mW/cm^2) or joules per square centimeter (J/cm^2). For convenience, the tables in Appendix B provide simplified, conservative MPE values. If a proponent requires less conservative values, use the ANSI Z136 series of standards or other established methods. If using a method other than the values in Appendix B, document and attach the approach and results when submitting the form.

NOTE: Exposure duration

Unintentional laser exposure to the eye of a person in an aircraft is not estimated to last more than 0.25 seconds based on various factors including the human aversion response (for visual lasers) and the natural relative motion between the beam and aircraft related to wind and other *stabilization issues. The analysis in this document applies to laser wavelengths between 400 nm and 1050 nm for exposures less than 0.25 seconds. This analysis also provides conservative results for wavelengths from 1050 nm to 1400 nm.*

If the potential exposure may last for an increased duration or a proponent desires to complete a more precise analysis (e.g., wavelengths from 1050 nm to 1400 nm), refer to the ANSI Z136 standards for additional analysis techniques. Document and include the standards' MPE exposure limits and calculations with the submission.

A.14.3.1. MPE: Single Pulse Laser

Use Table 1 for lasers that produce a single pulse of energy with a pulse width less than 0.25 seconds. Enter the MPE per pulse value in joules per square centimeter (J/cm^2) in cell 12b.

A.14.3.2. MPE: Continuous Wave Laser

Determine if all wavelengths of a continuous wave laser beam are in the visible spectrum (400 nm to 700 nm).

- If all wavelengths are in the visible range, enter "2.6" in cell 12b.
- If one or more wavelengths are not within the visible range:
  - Record all wavelengths on a separate document per A.14.1., Section 12a, Laser and Beam Characteristics.
  - Use Table 2 to find the MPE for each wavelength.
  - Calculate the NOHD for each wavelength per A.16.2.1., Slant Range (NOHD).
  - Enter the MPE value for the wavelength with the longest NOHD in 12b, and use this MPE value for the visual effect calculation values in 12c and the remainder of section 14a.

A.14.3.3. MPE: Repetitively Pulsed Laser

Some repetitively pulsed lasers can produce hazards greater than CW lasers with the same average power. Treat the following lasers as CW lasers, use the instructions in A.14.2.2, and enter the MPE value in the repetitively pulsed column:

- 400 nm to 1050 nm: PRF greater than 13 kilohertz (kHz).
- 1050 nm to 1400 nm: PRF greater than 6.5 kHz.

NOTE: *The most restrictive MPE for a repetitively pulsed laser is determined from choosing the most conservative MPE considering Tables 1 and 2. The PRF values provided only apply for a 0.25 s exposure with individual pulse widths less than 5 µs for wavelengths from 400 nm to 1050 nm and less than 13 µs for wavelengths from 1050 nm to 1320 nm.*

For the purposes of this form, a laser with a PRF of equal to or greater than one hertz is a repetitively pulsed laser. These lasers can produce an additional hazard greater than that of a single pulse or continuous wave laser. The MPE calculation for repetitively pulsed lasers uses its PRF, designated MPE_{PRF}. Determine the MPE_{PRF} 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}, enter the value in either the "MPE" or "MPE per pulse" cells of the repetitively pulsed laser column (FAA only requires one of the two MPEs). Use the following simplified methods to determine the MPE_{PRF}.

- **Ultraviolet wavelengths less than 400 nm**: Reference the ANSI Z136 series. Enter the MPE value in cell 12b ("MPE per pulse" row).

- **Visible and infrared wavelengths up to 1050 nm**. For a laser with a PRF:

    - Less than 13 kHz: Use Table 1 to determine the MPE per pulse in J/cm^2 and enter the value in cell 12b ("MPE per pulse" row).

    - Greater than 13 kHz: Evaluate as if a CW laser. Use Table 2 to determine the MPE in mW/cm^2 and enter the value in cell 12b ("MPE" row).

- **Infrared wavelengths from 1050 nm to 1400 nm**. For a laser with a PRF:

    - Less than 6.5 kHz: Use Table 1 to determine the MPE per pulse in J/cm^2 and enter the value in cell 12b ("MPE per pulse row").

    - Greater than 6.5 kHz: Evaluate as if a CW laser. Use Table 2 to determine the MPE in mW/cm^2 and enter the value in cell 12b ("MPE" row).

- **Infrared wavelengths greater than 1400 nm**: For an exposure to a repetitively pulsed laser at these wavelengths, a PRF of just a few hertz results in a more restrictive CW MPE than the pulsed MPE. The MPE that indicates the greatest hazard determines what MPE to enter into cell 12b. Fill in the appropriate "MPE" cell in the Pulsed column, indicating whether the MPE is in J/cm^2 or mW/cm^2.

***NOTE**: The simplified methods of Table 2 use the average power to determine the MPE in mW/cm^2. Using other methods, it is possible to use the pulse energy to determine the MPE per pulse in J/cm^2.*

A.14.4. Section 12c. Visual Effect Calculations

Non-visible lasers: If the laser has no wavelengths within the visible range (400 nm to 700 nm), enter "N/A (non-visible laser)" in all three cells of the appropriate column of section 12c and proceed to section 13.

Visible lasers: For any laser emitting wavelengths within the visible range (400 nm to 700 nm), proponents must submit visual effect calculations to assist FAA with its evaluation of laser beams bright enough to distract or interfere with a crewmember's vision, e.g., glare or afterimage. To reduce the risk of distraction or interference, FAA established the following areas wherein crewmembers should not encounter light greater than the values listed.

- Sensitive Flight Zone: 100 microwatts per square centimeter ($\mu W/cm^2$).
- Critical Flight Zone: 5 $\mu W/cm^2$.
- Laser-Free Zone: 50 nanowatts per square centimeter (nW/cm^2).

Because perceived brightness varies with wavelength (e.g., a green laser appears brighter to the human eye than a red or blue laser of the same power), proponents can apply a visual effect correction factor if desired. This correction factor has the result of allowing more power for red and blue beams than for green beams of equal power and divergence.

A.14.4.1. Determine the Pre-corrected Power (PCP).

The PCP is the total power (sum) of all visible wavelengths. The PCP calculation method depends on the laser's mode of operation.

- **Single Pulse**: Multiply the pulse energy (in joules) stated in cell 12a by four and enter the value.

***NOTE**: This technique averages the pulse's energy over the 0.25-second maximum pulse duration, and is a conservative approximation of the visual effect of a pulse. If proponents use less conservative calculations, they must document and attach the methods and calculations.*

- **Continuous wave**: Enter the total power (sum) of all visible wavelengths. If the laser emits only visible wavelengths, this will be the same as the maximum power entered in cell 12a.
- **Repetitively pulsed**: Multiply the pulse energy (in joules) by the pulse repetition frequency (hertz) stated in cell 12a and enter the value.

A.14.4.2. Determine the Visual Correction Factor and Visually Corrected Power.

Use one of the following methods to provide the VCF and the Visually Corrected Power of the laser.

- **Simplest/most conservative analysis**.
  - VCF: Assume no correction factor and enter "1.0 (assumed)."
  - Visually Corrected Power: Enter the same value as the PCP.
- **Single-wavelength beam**.
  - VCF: Enter the appropriate value from Table 3.
  - Visually Corrected Power: Multiply the VCF by the PCP and enter the resulting value.
- **Multiple visible wavelengths**: Choose one of the two following methods and enter the resulting value.
  - Make a simplifying, conservative assumption.
    - VCF: Use Table 3 to determine which wavelength has the largest factor (is the most visible), and enter the value.
    - Visually Corrected Power: Multiply the VCF by the PCP (the sum of all visible wavelengths) and enter the resulting value.
  - Analyze each wavelength's power and VCF individually to find the overall VCF and the visually corrected power. There are two methods to perform this calculation.
    - **Software calculation**: Use laser safety software with the ability to enter separate wavelengths and powers for a single laser beam. The software should provide a total VCF calculation for the combined wavelengths and the Visually Corrected Power calculation for the beam.

NOTE*: Include attachments (and list in cell 7b) of screenshots or printouts showing the wavelength and power inputs and the software's resulting VCF and visually corrected power values. Ensure completion of section 15, listing the software name and version.*

- **Manual Calculation**: Attach a spreadsheet or worksheet showing the steps of the following calculations:
  - For each visible wavelength, list the power at that wavelength. Sum the listed wattages and enter than number as the PCP in cell 12c.

- For each visible wavelength, consult Table 3 and list the VCF of the wavelength.
- For each visible wavelength, multiply that wavelength's power by the VCF of the wavelength. This provides the visually corrected power for that wavelength.
- Add all visually corrected powers for all wavelengths together and enter this as the visually corrected power in cell 12c.
- Divide the visually corrected power by the PCP to obtain the overall VCF for the laser beam. Enter this as the VCF in cell 12c.

NOTE*: Include attachments (and list in cell 7b) showing the wavelength and power inputs and the resulting VCF and visually corrected power values. Ensure completion of section 15, describing the method used.*

Example*: Manual calculation*

- ***For each visible wavelength, list the power at that wavelength. Sum the listed wattages and enter that number as the PCP in cell 12c.***
  - *A laser has three visible wavelengths: 8W of 630 nm (red), 4W of 520 nm (green), and 10W of 450 nm blue.*
  - *The laser has a total power of (8 + 4 + 10) 22W of visible light. Enter "22" in cell 12c as the PCP.*
- ***For each visible wavelength, consult Table 3 and list the VCF of the wavelength.***
  - *630 nm has a VCF of 0.2653, 520 nm has a VCF of 0.7092, and 450 nm has a VCF of 0.0380.*
  - *Document the VCF for each wavelength.*
- ***For each visible wavelength, multiply that wavelength's power by the VCF of the wavelength. This provides the visually corrected power for that wavelength.***
  - *Red: 8W × 0.2653 = 2.1224 visually corrected watts*
  - *Green: 4W × 0.7092 = 2.8368 visually corrected watts*
  - *Blue: 10W × 0.0380 = 0.380 visually corrected watts*
- ***Add all visually corrected powers for all wavelengths together and enter this as the visually corrected power in cell 12c.***

- *Add the three visually corrected watts results together (2.1224 + 2.8368 +0.38) to obtain the visually corrected power of 5.3392 watts.*
- *Enter "5.3392" in cell 12c for visually corrected power.*
- *Explanation: Although the laser in this example outputs 22 total watts, the human eye perceives the laser to have the same brightness as a 5.3392 watt laser emitting at the 555 nm wavelength (perceived as brightest by the human eye).*

- ***Divide the visually corrected power by the PCP to obtain the overall VCF for the laser beam. Enter this as the VCF in cell 12c.***
    - *Divide the visually corrected power by the PCP (5.3392 / 22) to obtain the overall VCF for all visible wavelengths of 0.2427.*
    - *Enter "0.2427" in cell 12c for VCF.*

A.15. Section 13. Beam Direction(s)

Use Section 13 to enter the beam(s) elevation angle(s), direction(s)/azimuth(s), and specify the azimuth source.

If the beam can move to multiple locations (for example, it rotates or is scanned) or if there are multiple lasers emitting beams in similar directions and angles (e.g., a laser show from an outdoor concert stage), FAA can evaluate the possible beam locations as a single configuration. Enter the maximum and minimum elevation angle of the beams, and the widest spread in azimuth of the beams. FAA will evaluate the entire area of this configuration as protected airspace where any beam could project at any time.

If lasers are widely separated at the geographic location listed on page one of the form (reflected in section 11) or there are lasers aimed in different/non-overlapping directions, each laser or group of lasers is a different/separate configuration. Complete a Laser Configuration Worksheet (page two of the form) for each configuration.

13a and **13b.** Enter the beam projections' minimum and maximum elevation angles (pointing directions) in degrees of the beam projections *for this configuration only*.

13c. Azimuth and type of north

- **Azimuth**
    - **Fixed beam**: Enter the azimuth on which the beam will project.
    - **Moving beam (e.g., rotating, scanned, or aimed)**: If the beam will move horizontally during the operation, enter the movement range in degrees; e.g., "20° to 50°."

NOTE: Moving beams

FAA considers east as 90°, south as 180°, west as 270°, and north as 360°. Enter degrees from smallest to largest moving clockwise, otherwise FAA will interpret the beam rotating everywhere except where intended. Example: An entry of 10° to 350° means the proponent plans to rotate within a total of 340°. If planning to rotate within 10° (either side) of north, enter 350° to 10°.

For some configurations, FAA may need additional information concerning the beam direction, e.g., the laser is mounted on a moving aircraft or spacecraft and/or the beam projects downward.

- **Type of north**: Select true or magnetic north.
  - **Using a compass:** If a proponent determines the azimuth degrees **or if** control measures will use a compass, check the "Magnetic north" box in cell 13c.
  - **Not using a compass:** If a proponent determines the azimuth degrees using a map or other method **and if** control measures do not use a compass, check the "True north" box in cell 13c.

13d. Magnetic declination (degrees)

- If a proponent checked the "Magnetic north" box in 13c, enter the geographic location's magnetic declination (or magnetic variation) in degrees from true north, e.g., 11°west.
- If a proponent checked the "True north" box in 13c, enter "N/A" (not applicable).

A.16. Section 14. Protection Distances[i]

There are four important distances to consider when evaluating the safety of a proposed outdoor laser operations. Each of these calculated distances enhances safety by minimizing the potential exposure of crewmembers to laser light.

NOTE*: The ANSI Z136 series of standards contains extensive methodology on determining hazard distances. FAA, in collaboration with SAE International, derived all equations from ANSI Z136.1.*

The NOHD relates to the potential risk of permanent physical injury (e.g., the eye). The other three distances relate to temporary visual effects that could distract a person or interfere with a person's performance of critical tasks. A brief definition of each follows, with additional explanation found in the glossary (Appendix F).

Nominal Ocular Hazard Distance (NOHD)

- Distance (from the laser source to this defined distance) over which it is necessary to protect the safety of a crewmember's eyes.
- Considered for all lasers projected into navigable airspace regardless of whether or not the beam is visible.

Visual interference distances: Protection distances considered in addition to NOHD for planned use of visible lasers. The distance included for each calculation begins at the laser source and ends at the defined distance. The distance term and primary hazards for each are as follows.

- Sensitive Zone Exposure Distance (SZED): Flashblindness and afterimage.
- Critical Zone Exposure Distance (CZED): Glare.
- Laser-free Exposure Distance (LFED): Not expected to cause a distraction beyond this distance.

NOTE*: Visual distraction may also occur within the SZED and CZED.*

A.16.1. Protection Distance Considerations

- **Visible/non-visible determination**: Determine whether one or more of the laser wavelengths are visible (within 400 nm to 700 nm).
  - If the laser has no wavelengths within the visible range:
    - Enter "N/A (non-visible laser)" in all nine SZED, CZED, and LFED cells (14b through 14d).
    - Calculate only the three NOHD distances for section 14a.
  - If the laser has one or more visible wavelengths, proceed to calculate all twelve exposure distances (cells 14a through 14d).
- **Exposure distances less than the NOHD**: For some visible lasers, the SZED, CZED, and LFED calculations may result in a value less than (a shorter distance) the NOHD. If this is the case, for safety reasons:
  - Do not enter the distance value in the applicable cell and, instead, enter "Less than NOHD."
  - Rationale: The NOHD (distance potentially damaging to the eye) is the most important for calculating safety distances and the protection of commensurate airspace.

A.16.2. Slant Range Calculations

For lasers with a small beam diameter at the output aperture (less than one centimeter),[5] use the equations 70-1.1 through 70-1.3 as examples of a simplified method and enter the data in the first column of section 14. Perform the calculation and round up to the next whole number.

A.16.3. Slant Range (NOHD)

To determine the NOHD slant range (SR) in feet:

- Use Equation 70-1.1 for a single pulse or repetitively pulsed laser with a frequency less than 13 kHz (less than 6.5 kHz for 1050 nm to 1400 nm).
- Use Equation 70-1.2 for a continuous wave or repetitively pulsed lasers with a frequency greater than 13 kHz (greater than 6.5 kHz for 1050 nm to 1400 nm).
- Complete the calculation and enter the result in cell 14a (slant range column).

Equation 70-1.1: Calculating NOHD slant range with pulse energy and MPE in J/cm²

$$NOHD_{SR} = \frac{32.8}{mrad} \times \sqrt{\frac{1.2732 \times J}{MPE}}$$

Equation Term	Explanation
$NOHD_{SR}$	NOHD slant range (feet)
32.8	Conversion factor used to convert centimeters into feet and radians into milliradians (0.0328 feet per centimeter)
mrad	Beam divergence (milliradians)
1.2732	4/π (derived from the original ANSI equation)
J	Pulse energy (joules or J)
MPE	MPE per pulse (joules per square centimeter or J/cm^2)

[5] For lasers with beam diameters larger than one centimeter at the output aperture, use the appropriate NOHD calculations in ANSI Z136.6, Appendix B. and submit calculations to FAA as a separate attachment.

Equation 70-1.2: Calculating NOHD slant range with average power and MPE in mW/cm²

$$NOHD_{SR} = \frac{32.8}{mrad} \times \sqrt{\frac{1273.2 \times W}{MPE}}$$

Equation Term	Explanation
$NOHD_{SR}$	NOHD slant range (feet)
32.8	Conversion factor used to convert centimeters into feet and radians into milliradians (0.0328 feet per centimeter)
mrad	Beam divergence (milliradians)
1,273.2	4/π (derived from the original ANSI equation) then divided by 0.001 to express the value in milliwatts for this equation (original equation uses watts)
W	Average power (watts)
MPE	MPE (milliwatts per square centimeter or mW/cm^2)

NOHD calculation example

What is the $NOHD_{SR}$ for a 40-watt CW visible laser with a beam divergence of 1.5 milliradians?

Given:

mrad: 1.5 milliradians

W: 40 watts

MPE: 2.6 mW/cm^2 (from Table 2)

Solution:

$$NOHD_{SR} = \frac{32.8}{1.5} \times \sqrt{\frac{1273.2 \times 40}{2.6}} = 21.87 \times \sqrt{19588} = 21.87 \times 140 = \mathbf{3,062\ ft}$$

A.16.4. Slant Range (SZED, CZED, and LFED)

SZED slant range: To calculate the SZED slant range ($SZED_{SR}$) distance, use Equation 70-1.3. Complete the calculation and enter the value in cell 14b (slant range column).

Equation 70-1.3: Calculating SZED (slant range) exposure distance

$$SZED_{SR} = \frac{32.8}{mrad} \times \sqrt{12732 \times W_{VCP}}$$

Equation Term	Explanation
$SZED_{SR}$	SZED slant range (feet)
32.8	Conversion factor used to convert centimeters into feet and radians into milliradians (0.0328 feet per centimeter)
mrad	Beam divergence (milliradians)
12,732	4/π (derived from the original ANSI equation) then divided by the SZED exposure level of 0.0001 W/cm^2 in the denominator
W_{VCP}	Visually corrected power (watts from cell 12c.)

CZED slant range: To calculate the CZED slant range ($CZED_{SR}$) distance, multiply the $SZED_{SR}$ by 4.47. Enter the product in cell 14c (slant range column).

Equation 70-1.4: Calculating CZED (slant range) exposure distance

$$CZED_{SR} = SZED_{SR} \times 4.47$$

LFED slant range: To calculate the LFED slant range ($LFED_{SR}$) distance, multiply the $SZED_{SR}$ by 44.7. Enter the product in cell 14d (slant range column).

Equation 70-1.5: Calculating LFED (slant range) exposure distance

$$LFED_{SR} = SZED_{SR} \times 44.7$$

A.16.4.1. Horizontal and Vertical Distance Calculations

Using the calculated slant ranges, calculate the distances for the horizontal and vertical columns. These distances assist FAA personnel in determining the distance along the ground and the altitudes that require protection. The equations use the cosine (cos) and sine (sin) functions and the minimum and maximum elevation angles entered in cells 13a and 13b, respectively.

***NOTE**: Because FAA requires (and formulas in this AC provide) the slant range in feet, the horizontal and vertical distances will also be in feet.*

A.16.4.2. Horizontal and Vertical Distances for NOHD

Using the previously calculated NOHD slant range ($NOHD_{SR}$) and the previously entered maximum and minimum elevation angles (cells 13a and 13b), use the following formulas to calculate the horizontal and vertical distances for the NOHD. To obtain the sine (sin) and cosine (cos) of the angles, use a scientific calculator or a table of sine and cosine values. Enter the calculated values in the appropriate columns of section 14a.

Equation 70-1.6: Calculating NOHD horizontal distance

$$NOHD\ horizontal\ distance = NOHD_{SR} \times cos(minimum\ elevation\ angle)$$

Equation 70-1.7: Calculating NOHD vertical distance

$$NOHD\ vertical\ distance = NOHD_{SR} \times sin(maxmium\ elevation\ angle)$$

NOHD vertical and horizontal distance calculation example

What are the NOHD horizontal and vertical distances for the following laser?

Given:

$NOHD_{SR}$: 1000 feet

Minimum elevation angle: 15 degrees

Maximum elevation angle: 45 degrees

Solutions (rounded to the nearest foot):

$$NOHD\ horizontal\ distance = 1000 \times cos(15) = 1000 \times 0.9659 = \mathbf{966\ ft}$$

$$NOHD\ vertical\ distance = 1000 \times sin(45) = 1000 \times 0.7071 = \mathbf{707\ ft}$$

A.16.4.3. Horizontal and Vertical Distances for SZED, CZED, and LFED

Using the previously calculated slant ranges for the $SZED_{SR}$, $CZED_{SR}$, and $LFED_{SR}$ and the previously entered minimum and maximum elevation angles (cells 13a and 13b); use the following formulas to calculate the horizontal and vertical distances for the SZED, CZED, and LFED.

To obtain the sine and cosine of the angles, use a scientific calculator or a table of sine and cosine values. Enter the calculated values in the appropriate columns of sections 14b, 14c, and 14d.

Equation 70-1.8: Calculating SZED horizontal distance

$$SZED\ horizontal\ distance = SZED_{SR} \times \cos(minimum\ elevation\ angle)$$

Equation 70-1.9: Calculating SZED vertical distance

$$SZED\ vertical\ distance = \ SZED_{SR}\ \times \sin(maximum\ elevation\ angle)$$

Equation 70-1.10: Calculating CZED horizontal distance

$$CZED\ horizontal\ distance = \ CZED_{SR}\ \times \cos(minimum\ elevation\ angle)$$

Equation 70-1.11: Calculating CZED vertical distance

$$CZED\ vertical\ distance = \ CZED_{SR}\ \times \sin(maximum\ elevation\ angle)$$

Equation 70-1.12: Calculating LFED horizontal distance

$$LFED\ horizontal\ distance = \ LFED_{SR}\ \times \cos(minimum\ elevation\ angle)$$

Equation 70-1.13: Calculating LFED vertical distance

$$LFED\ vertical\ distance = \ LFED_{SR}\ \times \sin(maximum\ elevation\ angle)$$

A.17. Section 15. Calculation Method

Select the method used to perform the calculations. If using commercial software, enter the software product name and the version. If using a method other than commercial software (e.g., spreadsheet or calculator), describe the method in this section.

***NOTE**: Software may use slightly different MPE values than FAA specifies. For example, some software uses 2.55 mW/cm^2 as the MPE for visible-light wavelengths from 400 nm to 700 nm, while FAA uses 2.6 mW/cm^2. This can create a small difference of a few percent in determining hazard distances. For FAA protection purposes, such small differences are acceptable.*

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[i] Source note: ANSI Z136.1 is the source of the equations derived above, re-expressed to a simpler form as follows.

- Beam divergence (mrad): Used milliradians, making the first ANSI fraction 1,000/mrad instead of 1/mrad.
- Radical/square root sign: Used instead of raising to a power of 0.5.
- Under the radical, reduced the expression of 4/π to 1.2732. For equations that use MPE in milliwatts, multiplied 1.2732 by 0.001 as the original ANSI equation uses watts.
- Did not use beam diameter (a2) under the radical since its contribution to the overall slant range distance is negligible. For beams with diameters at the output aperture more than 1 cm, do not use the equations but instead refer to ANSI Z136, Appendix B. to determine protection distances NOHD and (if visible) SZED, CZED, and LFED.
- Distance (centimeters and feet): ANSI expresses the results of its equations in centimeters whereas FAA requires expression in feet.
  - Equations use a conversion factor of 0.0328 (1 cm = 0.0328 ft).
  - There are now two numeric constants: 1,000 (from the milliradians fraction) and 0.0328.
  - The product of the two constants is a single constant (32.8) to provide results in feet.
  - Note: For results in centimeters, use “1,000” as the constant. For results in meters, use “10.”
- SZED, CZED, and LFED equations
  - Found by using the SZED exposure level of 0.0001 W/cm^2 as the denominator under the radical.
  - The quotient of dividing 1.2732 in the numerator by 0.0001 in the denominator results in a constant of 12,732.
  - There is a fixed relationship between the three distances; the CZED is always 4.47 times the SZED, and the LFED is always 44.7 times the SZED.

Appendix B. Tables and Examples

B.1. Maximum Permissible Exposure (MPE) Limits

Use Tables 1 and 2[ii] along with any associated calculations to determine MPE. For any value (wavelength or exposure duration) that falls exactly on a high or low end of a range within the tables, use the more conservative (smaller) MPE. For repetitively pulsed lasers, the MPE is determined from the more restrictive MPE considering Table 1 for a single pulse and Table 2 for the average power.

Table 1 – Single Pulse Laser MPE Limits

Wavelength (nm)		Pulse Width t (seconds [s])	MPE
Visible	400 to 700	1 ns to 5 µs	0.2 µJ/cm^2
		5 µs to 0.25 s	$1.8 \times t^{0.75}$ mJ/cm^2
Infrared	700 to 1050	1 ns to 5 µs	$0.2 \times C_A$ µJ/cm^2
		5 µs to 0.25 s	$1.8 \times C_A \times t^{0.75}$ mJ/cm^2
	1050 to 1320	1 ns to 13 µs	$2.0 \times C_C$ µJ/cm^2
		13 µs to 0.25 s	$9.0 \times C_C \times t^{0.75}$ mJ/cm^2
	1400 to 1500	1 ns to 1 ms	0.3 J/cm^2
		1 ms to 0.25 s	$(0.56 \times t^{0.25} + 0.2)$ J/cm^2
	1500 to 1800	1 ns to 0.25 s	1.0 J/cm^2
	1800 to 2600	1 ns to 1 ms	0.1 J/cm^2
		1 ms to 0.25 s	$0.56 \times t^{0.25}$ J/cm^2
	2600 to 10000	1 ns to 0.1 µs	10.0 mJ/cm^2
		0.1 µs to 0.25 s	$0.56 \times t^{0.25}$ J/cm^2

Table notes

- For wavelengths or a pulse width not included in the table, refer to ANSI Z136.1.
- For clarity, FAA used metric prefixes (symbols) in place of scientific notation.
    - m represents milli or 1×10^{-3} or 0.001, example 1 ms = 1×10^{-3} s.
    - µ represents micro or 1×10^{-6} or 0.000001, example 1 µs = 1×10^{-6} s.
    - n represents nano or 1×10^{-9} or 0.000000001, example 1 ns = 1×10^{-9} s.

- Correction factors C_A and C_C derived from ANSI Z 136.1. C_A is a correction factor that increases the MPE in the near-infrared region (700 nm to 1400 nm), based on reduced absorption properties of the skin and eyes. C_C is a correction factor that increases the MPE for ocular exposure based on pre-retinal absorption of radiant energy in the spectral region (1150 nm to 1400 nm).

- *t*: Pulse duration in seconds

MPE C_A correction factor

For lasers with a wavelength of 700 to 1050 nm, use the following equation:

$C_\mathrm{A} = 10^{0.002(wavelength-700)}$

Example 1

- *Laser wavelength: 850 nm*

- $C_\mathrm{A} = 10^{0.002(850-700)} = 10^{0.002(150)} = 10^{0.3} = 1.995$

Example 2

- *Laser wavelength: 933 nm*

- $C_\mathrm{A} = 10^{0.002(933-700)} = 10^{0.002(233)} = 10^{0.466} = 2.924$

MPE C_C correction factor

- For lasers with a wavelength of 1050 nm to 1150 nm, use a C_C of 1.0.

- For lasers with a wavelength of 1150 nm to 1200 nm, use the following equation:

- $C_\mathrm{C} = 10^{0.018(wavelength-1150)}$

- For lasers with a wavelength of 1200 nm to 1320 nm, use the following equation:

- $C_\mathrm{C} = 8.0 + 10^{0.04(wavelength-1250)}$

- For lasers with a wavelength of 1320 nm to 1400 nm, refer to ANSI Z136.1.

Example 3

- *Laser wavelength: 1175 nm*

- $C_\mathrm{C} = 10^{0.018(1175-1150)} = 10^{0.018(25)} = 10^{0.45} = 2.8$

Table 2 – Continuous Wave Laser MPE Limits (0.25 s Maximum Exposure Duration)

Wavelength (nm)	MPE (mW/cm^2)
Ultraviolet	
180 to 400	Reference ANSI Z136.1
Visible	
400 to 700	2.6
Infrared	
700 to 1050	$2.6 \times C_A$
1050 to 1150	12.75
1150 to 1320	$12.75 \times C_C$
1320 to 1400	Reference ANSI Z136.1
1400 to 1500	2384
1500 to 1800	4000
1800 to 10000	1584

Table notes

- See Table 1 for C_A and C_C correction factors.
- Values are for selected wavelengths assuming unintentional viewing.[6]

Example 1

- Laser wavelength: Visible
- MPE: 2.6 mW/cm^2

[6] An unintentional laser exposure to the eye of a person in an aircraft is expected to last no more than 0.25 seconds based on various factors including the human aversion response (for visible wavelengths) and the natural relative motion between the beam and a moving aircraft related to wind and other stabilization factors. If the potential exposure may last for an increased duration or a proponent desires to complete a more precise analysis (e.g., wavelengths from 1050 nm to 1400 nm), refer to the ANSI Z136 standards for additional analysis techniques. Document and include the standards' MPE exposure limits and calculations with the submission.

Example 2

- Laser wavelength: 850 nm
- $C_A = 10^{0.002(wavelength-700)} = 10^{0.002(850-700)} = 10^{0.002(150)} = 10^{0.3} = 1.995$
- $2.6 \times C_A = 2.6 \times 1.995 = 5.187$ mW/cm^2

B.2. Visual Correction Factors

To find the Visually Corrected Power (W_{VCP}) for a specified wavelength, multiply the Pre-corrected Power (PCP) by the VCF for the laser's wavelength (from the table below).

Table 3 – Visual Correction Factor (VCF) for Visible Lasers (400 nm to 700 nm)[iii]

Wavelength (nm)	VCF	Wavelength (nm)	VCF
400	0.0004	495	0.2653
405	0.0008	500	0.3226
410	0.0012	505	0.4126
415	0.0026	510	0.5025
420	0.0040	515	0.6059
425	0.0078	520	0.7092
430	0.0116	525	0.7857
435	0.0173	530	0.8621
440	0.0230	535	0.9073
445	0.0305	540	0.9524
450	0.0380	545	0.9713
455	0.0490	550	0.9901
460	0.0599	555	1.0 (VCF = 1)
465	0.0754	560	0.9901
470	0.0909	565	0.9713
475	0.1150	570	0.9524
480	0.1391	575	0.9110
485	0.1735	580	0.8696
490	0.2079	585	0.8136

Table 3 – VCF for Visible Lasers (Continued)

Wavelength (nm)	VCF	Wavelength (nm)	VCF
590	0.7576	650	0.1070
595	0.6953	655	0.0840
600	0.6329	660	0.0610
605	0.5677	665	0.0466
610	0.5025	670	0.0321
615	0.4421	675	0.0246
620	0.3817	680	0.0170
625	0.3235	685	0.0126
630	0.2653	690	0.0082
635	0.2202	695	0.0062
640	0.1751	700	0.0041
645	0.1411	—	—

If the laser’s wavelength falls between two table entries, use one of the two methods below to find the VCF.

- **Conservative approach**: Use the more conservative (larger) of the two given values from the table.
- **Use laser safety software**: If using software to calculate the VCF for a wavelength, submit a screenshot or printout showing the entered wavelength and the software’s resulting VCF value.

Visually Corrected Power (W_{VCP}) examples

Example 1: A frequency-doubled YAG laser emits 10 watts of 532 nm continuous wave light. From the table, 532 nm is between 530 and 535 nm. Use the more conservative (larger) VCF of 535 nm. Multiply the VCF of 0.9073 by 10 (watts) to obtain a Visually Corrected Power of 9.073 watts.

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

10 watts at 514 nm

- From the table, 514 nm is between 510 and 515 nm. Use the more conservative (larger) VCF of 515 nm.
- Multiply the VCF of 0.6059 by 10 (watts) to obtain the Visually Corrected Power of 6.059 watts.

8 watts at 488 nm

- From the table, 488 nm is between 485 and 490 nm. Use the more conservative (larger) VCF of 490 nm.
- Multiply the VCF of 0.2079 by 8 watts to obtain the Visually Corrected Power of 1.6632 watts.

Total visually corrected power

- Add the two VCPs together: 6.059 + 1.6632 = 7.722.
- The 18-watt laser in this example has a visually corrected power of only 7.722 watts.

Overall VCF

- Divide the total VCP by the PCP to obtain the overall VCF (7.722 / 18 = 0.4290).
- Enter "0.4290" as the VCF in cell 12c.

***NOTE**: These two examples show that the 10-watt YAG laser in Example 1 appears brighter to the eye (9.073 W_{VCP}) than the 18-watt argon laser (7.722 W_{VCP}) in Example 2.*

B.3. Multiple Visible-Light Projector Example[7]

Example data and calculations provided for multiple visible-light laser projectors

Where: 1) All laser modes of operation are continuous wave, 2) Each projector emits one or more wavelengths, 3) All wavelengths are visible (400 nm to 700 nm), 4) All beams from the same projector have the same divergence, and 5) All projectors' beams aim at the same area to be protected (same configuration).

Row	Data source	Parameters and Calculations	Projector 1 example	Projector 2 example	Projector 3 example	Projector 4 example
		LASER PARAMETERS				
1	*Proponent*	**Laser type**	Diode	Diode	Diode	Argon-ion
2	*Proponent*	**Laser hazard class (1, 2, 3R, 3B, or 4)**	4	4	4	4
3	*Proponent*	**Total power (watts)**	10	22	10	5
4	*Proponent*	**Beam divergence (milliradians)**	1	1	0.5	0.5
		NOHD CALCULATION				
5	*Calculate, using data in rows 3 and 4. (Note: The equation is valid for the visible MPE of 2.6 mW/cm² for a 0.25 s exposure)*	**Nominal ocular hazard distance (NOHD) (feet)** $32.8/\text{mrad} \times \sqrt{490 \times W}$	**2,296**	**3,406**	**4,592**	**3,247**
		WAVELENGTH CALCULATIONS				
6	*Proponent*	**Wavelength 1 (nanometers)**	633	630	445	514
7	*Proponent*	**Wavelength 1 power (watts)**	4	8	10	2
8	*Table 3. If between rows, use the larger VCF of the two rows*	**Wavelength 1 Visual Correction Factor** (from Table 3)	0.2653	0.2653	0.0305	0.5852
9	*Calculate, using data in rows 7 and 8*	**Wavelength 1 Visually Corrected Power** W1 power x W1 VCF	**1.0612**	**2.1224**	**0.305**	**1.1704**
10	*Proponent*	**Wavelength 2 (nanometers)**	532	520	(none - single wavelength)	488
11	*Proponent*	**Wavelength 2 power (watts)**	1	4	n/a	3
12	*Table 3*	**Wavelength 2 Visual Correction Factor** (from Table 3)	0.9073	0.7092	n/a	0.1941
13	*Calculate, using data in rows 11 and 12*	**Wavelength 2 Visually Corrected Power** W2 power x W2 VCF	**0.9073**	**2.8368**	**n/a**	**0.5823**
14	*Proponent*	**Wavelength 3 (nanometers)**	445	450	(none - single wavelength)	(none - two wavelengths)
15	*Proponent*	**Wavelength 3 power (watts)**	5	10	n/a	n/a
16	*Table 3*	**Wavelength 3 Visual Correction Factor** (from Table 3)	0.0305	0.038	n/a	n/a
17	*Calculate, using data in rows 15 and 16*	**Wavelength 3 Visually Corrected Power** W3 power x W3 VCF	**0.1525**	**0.38**	**n/a**	**n/a**
18	***BE SURE TO ADD ROWS IF MORE THAN 3 WAVELENGTHS***	**... add more rows for any additional wavelengths ...**				
19	*Calculate, adding the VCPs previously calculated (total of rows 9, 13, 17)*	**Total of all wavelengths' Visually Corrected Power** (total will be W_{VCP})	**2.12**	**5.34**	**0.31**	**1.75**
20	*Calculate, using data in rows 19 and 3*	**Total VCF for this laser** W_{VCP} / total power	**0.2121**	**0.2427**	**0.0305**	**0.3505**
		PROTECTION DISTANCES CALCULATIONS				
21	*Calculate, using data in rows 4 and 19*	**Sensitive Zone Exposure Distance (SZED) (feet)** $32.8/\text{mrad} \times \sqrt{12732 \times W_{VCP}}$	**5,390**	**8,552**	**4,088**	**9,800**
22	*Calculate, using data in row 21*	**Critical Zone Exposure Distance (CZED) (feet)** SZED x 4.47	**24,094**	**38,227**	**18,273**	**43,804**
23	*Calculate, using data in row 21*	**Laser-Free Exposure Distance (LFED) (feet)** SZED x 44.7	**240,935**	**382,268**	**182,730**	**438,040**

Longest NOHD
Fill in cells 12a* and 14a using the data and calculations for this projector

Longest SZED
Fill in cells 12a*, 14b, 14c, and 14d using the data and calculations for this projector

[ii] Source note: ANSI Z136.1 (2014) Tables 5 and 6.

[iii] Source note: The VCF (C_F) used in Table 3 is the Commission Internationale de l'Éclairage (CIE) normalized efficiency photopic visual function curve for a standard observer. The illuminance (lm), expressed in lm/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/cm^{-2}) multiplied by 683 lm/W^{-1} is the illuminance (lm/cm^{-2}).

[7] Notes (* for NOHD and SZED) for this example.

- Instance when the longest NOHD *and* longest SZED do not come from a single projector.
- Record the data from the projectors with the longest NOHD and SZED then annotate (parentheses used here) which data aligns to the projector with the longest SZED.
- For this example, complete 12a as follows:
  - Laser type: Diode (Argon-ion).
  - Laser hazard class: 4 (4).
  - Power: 10 (5).
  - Beam divergence: 0.5 (0.5).
  - Wavelength(s): 445 (514, 488).
- List this attachment in cell 7b and submit this information to FAA with the form.

Appendix C. MPE and NOHD for a Laser Emitting Multiple Wavelengths from the Same Aperture

C.1. Introduction

Some lasers emit multiple wavelengths from the same aperture (beams are coaxial and superimposed). For example, an RGB laser mixing three colors to make a single white beam, or a DPSS (diode-pumped solid-state) laser emitting both visible and infrared light in the same beam. To submit information for a laser that emits multiple wavelengths from the same aperture, follow the steps below.

Complete section 12a.

- Enter “See attached” in the “Laser type” cell.
- List all emitted wavelengths in 12a.
- Create a separate document to record the remainder of the laser’s (12a) characteristics and resulting calculated values for each wavelength. Determine some of these values by completing the following steps.
- Attach the document to the submission, and list the document as an attachment in cell 7b.

Determine the laser’s MPE and NOHD: Given the wavelengths of the laser, use Table 1 and/or Table 2 to determine the MPE for each wavelength with the following steps.

NOTE: *Each table groups wavelengths that have the same MPE into rows.*

- If all emitted wavelengths are within the same row of Table 1 or Table 2 (they all have the same MPE):
    - Enter the value into the MPE cell of section 12b.
    - Add the power (W) or energy per pulse (J) of each wavelength together. Use this total power for the calculation in section 16.2.1, Slant Range (NOHD).
    - Return to Appendix A to assist with completing the remainder of the form.
- If the emitted wavelengths are in different rows of Table 1 and/or Table 2 (different MPEs):
    - For each row where the laser emits one or more wavelength(s), add the power (W) or energy per pulse (J) of each wavelength together in the row to find the total power or total energy per pulse for that row. Enter the MPE for that row and the total power or energy per pulse into the separate document.

- For each row, use the total power or total energy per pulse and the MPE to determine the slant range NOHD as per section 16.2.1., Slant Range (NOHD), and enter it into the separate document.

- After determining the slant range NOHD for each wavelength or groups of wavelengths within a row, determine which of these are in the retinal hazard range of 400 nm to 1320 nm, and which wavelengths are in the corneal hazard ranges of <400 nm or >1320 nm.[8]

- Repeat the following steps once for all slant range NOHDs ($NOHD_{SR}$) of the wavelengths within the retinal hazard range (if any), and once for all $NOHD_{SR}$ of the wavelengths within the corneal hazard range (if any).

  - Square each of the $NOHD_{SR}$ values.

  - Add all squared slant range NOHDs.

  - Take the square root of the total to obtain the slant range NOHD of the combined (C) wavelengths ($NOHD_{SRC}$) within the given hazard range (retinal or corneal).

Equation 70-1.14: Calculating $NOHD_{SRC}$ [iv]

$$NOHD_{SRC} = \sqrt{((NOHD_{SR})^2 + (NOHD_{SR})^2 + (NOHD_{SR})^2 + \cdots)}$$

- On the separate document, enter the $NOHD_{SRC}$ for the retinal hazard wavelengths (if any) and the $NOHD_{SRC}$ for the corneal hazard wavelengths (if any). For each $NOHD_{SRC}$ listed, indicate whether the NOHD is for retinal or corneal hazards.

- In the MPE row of section 12b, enter "N/A – multiple wavelength ranges."

- In the slant range column of cell 14a:

  - If the laser has wavelengths *only* in the retinal hazard range or *only* in the corneal hazard range, enter the $NOHD_{SRC}$ in feet.

  - If the laser has wavelengths in the retinal *and* corneal hazard ranges, enter both slant range $NOHD_{SRC}$ values and delineate (e.g., circle, bold, or underline) the longer value. Example: "**<u>1303 ft retinal</u>**, 83 ft corneal."

NOTE*: FAA will use the longer value as the eye protection distance for aeronautical review.*

- Enter the MPE value and the $NOHD_{SRC}$ value(s) on the separate document.

- Return to Appendix A to assist with completing the remainder of the form.

[8] Source note: ANSI Z136.1.

C.2. Example 1: All Wavelengths within the Same Row of MPE Table

Given a continuous wave RGB laser emitting 8W of 633 nm red, 4W of 532 nm green, and 8W of 445 nm blue in a single "white-light" beam of 1 mrad divergence, find the MPE, total power, and slant range NOHD.

- Consult Table 2 to determine if all wavelengths are within a single row.
- Since all three are within a single row (400 nm to 700 nm), the MPE for all wavelengths is 2.6 mW/cm^2.
- Enter "2.6" in 12b and on the separate document described earlier in this appendix.
- Because all wavelengths are in the same row, have the same divergence, and have the same MPE, add the power of the individual wavelengths together to determine the total power of 20W.
- Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 20W, 1 mrad beam is 3246 ft.
- Enter 3246 ft in the slant range column of cell 14a and on the separate document.

C.3. Example 2: Wavelengths in Different Rows of the MPE Table

The wavelengths in this example represent different hazards (some retinal and some corneal).

Given a multiple-wavelength CW laser with a single aperture whose beam combines 1W of 532 nm green and 2W of 633 nm red (both with a 1 mrad beam divergence), 10W of 1064 nm infrared (with a 3 mrad beam divergence), and 20W of 1540 nm infrared (with a 1 mrad beam divergence), find the slant range NOHD.

- Consult Table 2 to determine if all wavelengths are within a single row.
- Since not all wavelengths are in the same row, group the wavelengths by those wavelengths within the same row.

NOTE: *Grouping by row is only valid when the wavelengths in the same row also have the same divergence. See Example 3 as an example where wavelengths within the same row have different divergences.*

- The 532 nm and 633 nm wavelengths fall within the same Table 2 row for 400 nm to 700 nm and they have the same divergence (1 mrad).
  - There is a total (1W + 2W) of 3W of power for the two wavelengths within this row's range.
  - The MPE for this row is 2.6 mW/cm^2.

        - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 3W, 1 mrad beam is **1257 ft**.

    - The 1064 nm wavelength falls within the Table 2 row for 1050 nm to 1150 nm.

        - There are 10W of power for the single wavelength within this row's range.

        - The MPE for this row is 12.75 mW/cm^2.

        - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 10W, 3 mrad beam is **345 ft**.

    - The 1540 nm wavelength falls within the Table 2 row for 1500 nm to 1800 nm.

        - There are 20W of power for the single wavelength within this row's range.

        - The MPE for this row is 4000 mW/cm^2.

        - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 20W, 1 mrad beam is **83 ft**.

- Determine which wavelengths are retinal hazards (400 nm to 1320 nm) and which wavelengths are corneal hazards (<400 nm or >1320 nm).

    - The 532, 633, and 1064 nm wavelengths are retinal hazards: Use Equation 70-1.14 to calculate the combined retinal slant range $NOHD_{SRC(Retinal)}$.

NOTE (Rationale)*: The combined hazard from both wavelengths is greater than either individual wavelength.*

$$NOHD_{SRC(Retinal)} = \sqrt{(1257^2) + (345^2)} = \sqrt{1580049 + 119025} = \sqrt{1699074} = \mathbf{1304\ ft}$$

    - The 1540 nm wavelength is a corneal hazard.

        - Since this is the only wavelength in this range, it is not necessary to use Equation 70-1.14.

        - If there were more than one wavelength, repeat Equation 70-1.14 to calculate $NOHD_{SRC(Corneal)}$.

        - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 20W, 1 mrad beam is **83 ft**.

- Determine which slant range NOHD is longer.

    - Compare the combined slant range NOHD of the retinal hazard (1304 ft) and corneal hazard (83 ft) wavelengths to determine which combined slant range NOHD is longer.

- In this example, the $NOHD_{SRC}$ for the retinal hazard wavelengths is the longer value.

- Record all information that informed the calculations and determination on the separate document.

  - For this example, list the slant range NOHD for each wavelength or group of wavelengths, combined slant range NOHD for the retinal hazard wavelengths, and the slant range NOHD for the corneal hazard wavelength.

  - Delineate (e.g., circle, bold, or underline) the longer NOHD: "**1304 ft retinal**, 83 ft corneal" on the separate document.

- In the MPE row of section 12b of the form, enter "N/A – multiple wavelength ranges."

- In the slant range column of cell 14a, enter the retinal and corneal $NOHD_{SRC}$ values and delineate (e.g., circle, bold, or underline) the longer $NOHD_{SRC}$: "**1304 ft retinal**, 83 ft corneal."

C.4. Example 3. Wavelengths in the Same Row of an MPE Table with Different Divergences

Given a multiple-wavelength CW laser with a single aperture whose beam combines 1W of 633 nm red (with a beam divergence of 1 mrad) and 1W of 532 nm green (with a beam divergence of 2 mrad), find the slant range NOHD.

- Consult Table 2 to determine if all wavelengths are within a single row.

- While the wavelengths of both beams fall within the same row of Table 2 (400 nm to 700 nm), they have different divergences. Therefore, proponents cannot group these wavelengths and must calculate the $NOHD_{SR}$ of each wavelength separately.

- For the 633 nm beam, the MPE is 2.6 mW/cm^2 and the divergence is 1 mrad.

  - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 1W, 1 mrad beam is **726 ft**.

- For the 532 nm beam, the MPE is 2.6 mW/cm^2 and the divergence is 2 mrad.

  - Using Equation 70-1.2 from section A.16.2.1, the calculated $NOHD_{SR}$ for a 1W, 2 mrad beam is **363 ft**.

- Because both wavelengths in this example are in the retinal hazard range of 400 nm to 1320 nm, there is no need in this example to consider a corneal hazard.

- Use Equation 70-1.14 to calculate the $NOHD_{SRC}$.

$$NOHD_{SRC} = \sqrt{(726^2) + (363^2)} = \sqrt{527076 + 131769} = \sqrt{658845} = \mathbf{812\ ft}$$

- Record all information that informed the calculations and determination on the separate document. For this example, list the slant range NOHD for each wavelength and the combined slant range NOHD (812 ft) for the two wavelengths.

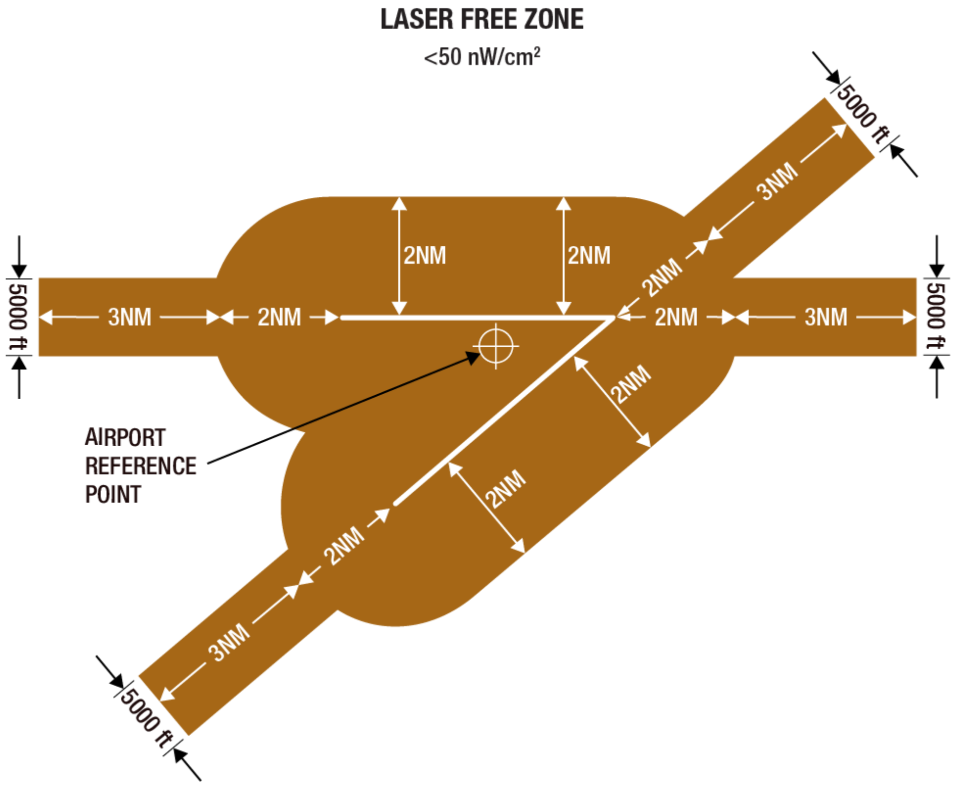
- In the MPE row of section 12b of the form, enter “2.6” (this can be done because all wavelengths in the example multiple-wavelength laser beam have the same MPE).

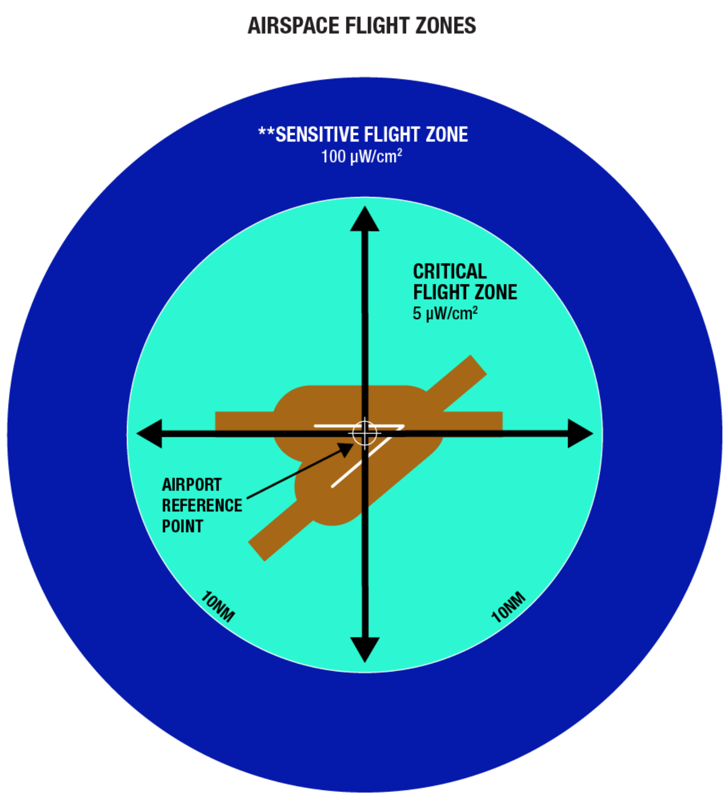
- In the slant range column of cell 14a, enter the $NOHD_{SRC}$ of 812 ft.

[iv] Notes for Equation 70-1.14:

- Accounts for the wavelengths and divergences of each beam in a multiple-wavelength laser beam.
- Accounts for multiple-wavelength laser beams where some wavelengths are CW and some are pulsed (single or repetitively).
- Equation is valid as long as each squared slant range NOHD – $(NOHD_{SR})^2$ – represents the NOHD of one or more wavelengths with the same MPE, the same divergence, the same output mode (single pulse, repetitively pulsed, or continuous wave), and the wavelengths are within the same hazard range (either retinal or corneal).
- Examples:
    - Equation valid: Mixed beams where one wavelength may be pulsed and another is continuous wave, or where one wavelength may have a different divergence than another within either the retinal or corneal hazard range.
    - Equation invalid: NOHDs include wavelengths from different (retinal or corneal) hazard ranges.
- One must use Equation 70-1.14 to first determine the $NOHD_{SRC}$ of all wavelengths that are retinal hazards (400 nm to 1320 nm), then to separately determine the $NOHD_{SRC}$ of all wavelengths that are corneal hazards (<400 nm or >1320 nm). FAA will use the longer of the two, combined wavelength NOHDs ($NOHD_{SRC}$) as the eye protection distance for aeronautical review.

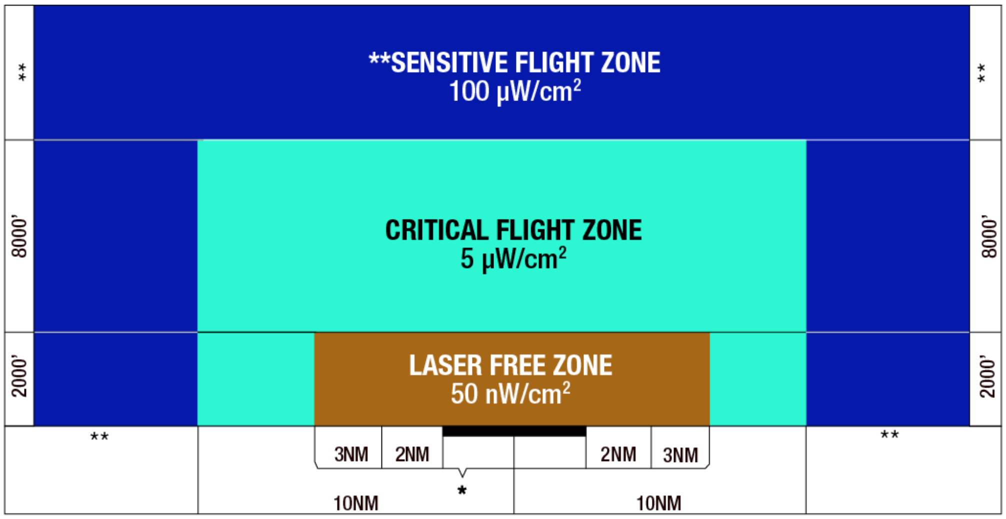
Appendix D. Depictions of Airspace Flight Zones and Graphic Examples





** To be determined by FAA evaluation and/or local airport operations.

AIRSPACE FLIGHT ZONES

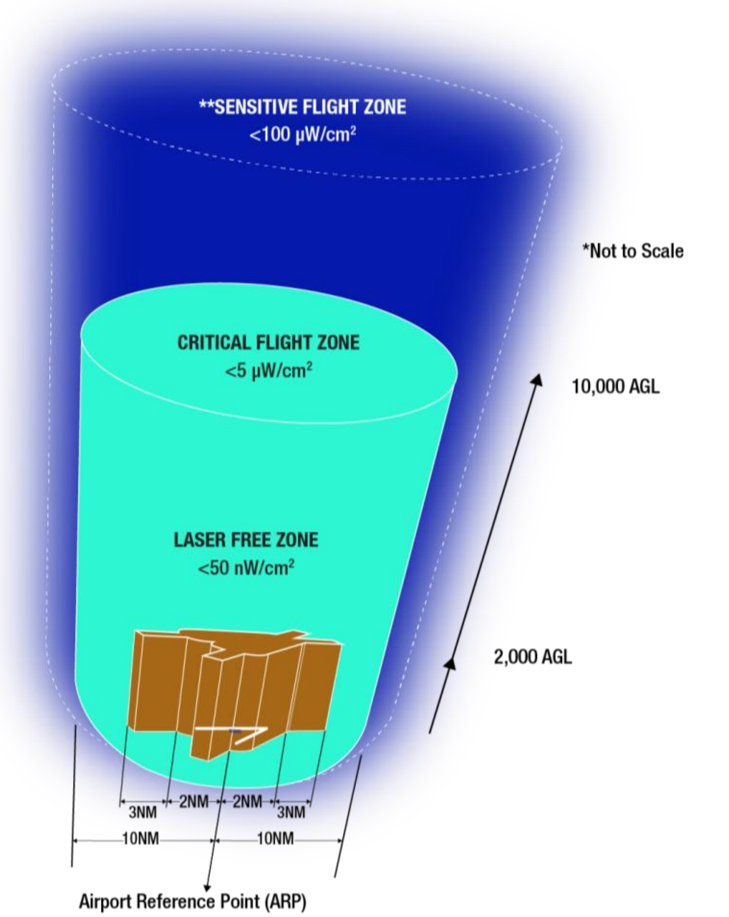


AIRPORT REFERENCE POINT (ARP)

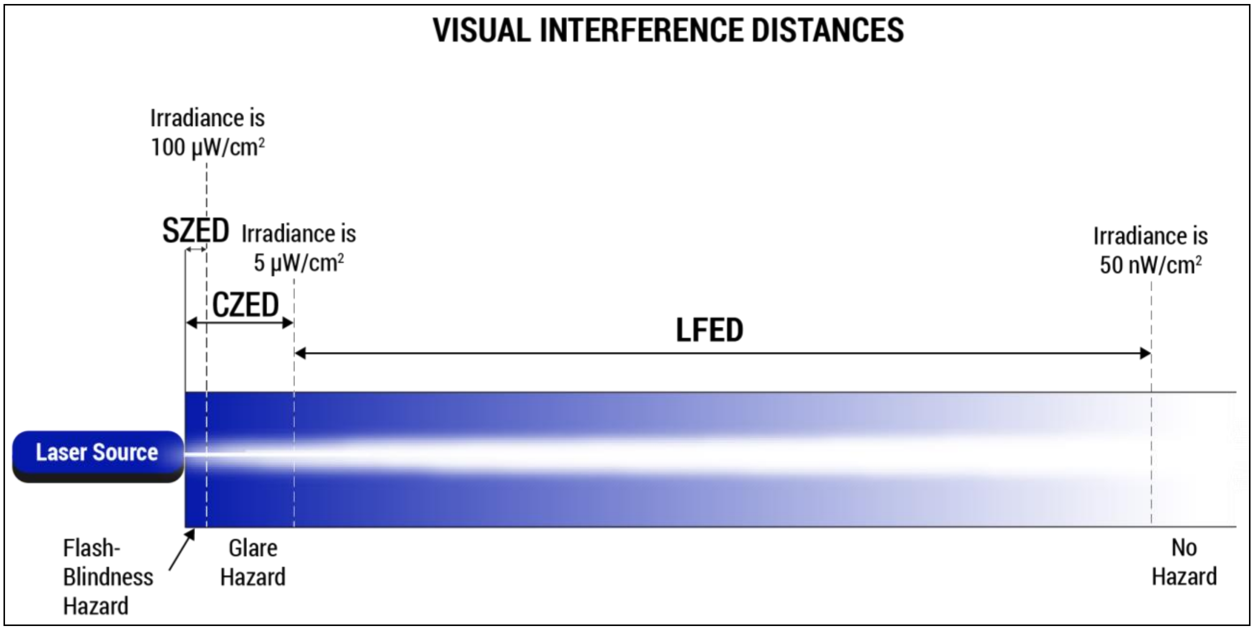
*Runway length varies by airport. Altitudes in AGL based on established airport elevation.

** To be determined by FAA evaluation and/or local airport operations.

AIRSPACE FLIGHT ZONES



** To be determined by FAA evaluation and/or local airport operations.



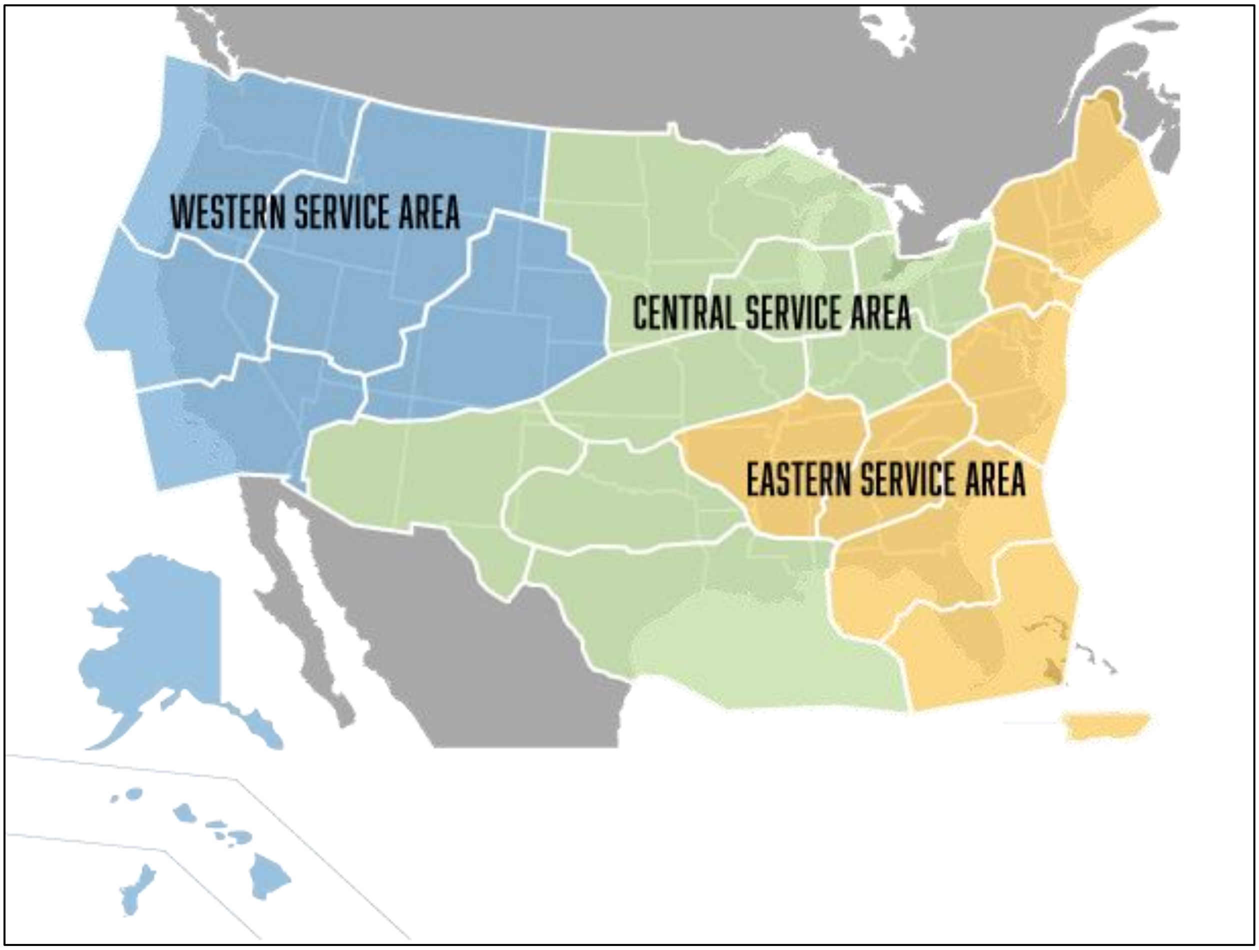
NOTE: *Visual distraction may occur at any distance*

Appendix E. FAA Service Center Information

FAA Service Center and Corresponding Service Area boundaries align with Air Route Traffic Control Center airspace boundaries. FAA encourages proponents to contact the service centers with any question relating to submitting FAA Form 7140-1.

If emailing the submission to an FAA service center, please include the name, location, and date of the proposed operation in the subject line to assist service center personnel with their review and timely response.

FAA Service Center	States and Territories
Eastern Service Center 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	Alabama (portions), Arkansas (portions), Connecticut, Delaware, District of Columbia, Florida, Georgia, Illinois (portions), Kentucky (portions), Louisiana (portions), Maine, Maryland, Massachusetts, Mississippi (portions), Missouri (portions), New Hampshire, New Jersey, New York (portions), North Carolina, Oklahoma (portions), Pennsylvania (portions), Puerto Rico, Rhode Island, South Carolina, Tennessee (portions), Vermont, Virginia (portions), West Virginia (portions)
Central Service Center Attn: Manager, Operations Support Group Central Service Center, AJV-C2 10101 Hillwood Parkway Fort Worth, TX 76177 9-ASW-Operations-Support-Lasers@faa.gov	Alabama (portions), Arizona (portions), Arkansas (portions), Colorado (portions), Illinois (portions), Indiana, Iowa, Kansas (portions), Kentucky (portions), Louisiana (portions), Michigan, Minnesota, Mississippi (portions), Missouri (portions), Nebraska (portions), New Mexico (portions), New York (portions), North Dakota (portions), Ohio, Oklahoma (portions), Pennsylvania (portions), South Dakota (portions), Tennessee (portions), Texas, Virginia (portions),West Virginia (portions), Wisconsin
Western Service Center Attn: Manager, Operations Support Group Western Service Center, AJV-W2 2200 S 216 Street Des Moines, WA 98198 9-ATO-WSA-OSG-Lasers@faa.gov	Alaska, Arizona (portions), California, Colorado (portions), Hawaii, Idaho, Kansas (portions), Montana, Nevada, New Mexico (portions), North Dakota (portions), Northern Mariana Islands, Oregon, South Dakota (portions), Utah, Washington, Wyoming


WESTERN SERVICE AREA
CENTRAL SERVICE AREA
EASTERN SERVICE AREA

Appendix F. Glossary

Afterimage – A reverse contrast shadow image left in the visual field after an exposure to a bright light (e.g., flashblindness from a camera flash) that may be distracting and disruptive, and may persist from several seconds to several minutes.

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.

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

Distraction – The redirection of attention from primary tasks due to a sudden exposure to a bright light source. While distraction technically does not interfere with vision, redirection of attention is a visually triggered hazard. For this reason, distraction is classified as one of the three primary visual interference hazards (along with glare and flashblindness/afterimage).

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% (1/e) of the peak irradiance.

Flashblindness – A temporary visual interference effect that persists as an afterimage after the source of illumination has ceased. Flashblindness is not associated with biological damage.

Flight zones – Airspace areas where laser light levels may be restricted to avoid visual interference effects (LFZ, CFZ, SFZ) or are unrestricted when aircraft are not present (NFZ). A given flight zone may not be continuous or concentric with other flight zones. There are four types of flight zones, ordered here from most to least restrictive.

> **Laser Free Zone (LFZ)** – Airspace zone where the level of laser light is restricted to 50nW/cm^2 or less, a level that should not cause any visual distractions or disruptions.
>
> **Critical Flight Zone (CFZ)** – Airspace zone where the level of laser light is restricted to 5 μW/cm^2 or less, a level that should not cause veiling (obscuring) glare.
>
> **Sensitive Flight Zone (SFZ)** – Airspace zone where the level of laser light is restricted to 100 μW/cm^2 or less, a level that should not cause flashblindness or afterimage effects. This is a locally defined area beyond the Critical Flight Zones that authorities (e.g., FAA, local departments of aviation, or military) have identified as requiring protection from visual interference effects.
>
> **Normal Flight Zones (NFZ)** – All airspace not defined by the aforementioned zones where any laser light (visible or non-visible) is restricted to less than the MPE. In the NFZ, any visible laser light that may cause visual interference is not expected to be hazardous.

Glare – A temporary disruption in vision caused by the presence of a bright light (for example, an oncoming car's headlights) within an individual's field of vision. Glare is not associated with biological damage. Its effect only lasts as long as the light source is present within the individual's field of vision.

Horizontal Distance – The maximum distance along the ground where an angled (elevated) laser beam may be an eye hazard or a visual interference hazard.

Irradiance – The intensity of the laser beam over a given area, expressed as power per unit area, e.g., milliwatts per square centimeter (mW/cm^2) or watts per square meter (W/m^2). Irradiance is used for power (watts) while radiant exposure is the same concept for energy (joules).

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.

Laser – An acronym for Light Amplification by Stimulated Emission of Radiation. A laser is a device that produces an intense, directional, coherent beam of visible or invisible light.

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.

Laser operator – A person in control of the operation of a laser system. A laser operator should be a knowledgeable person, present during laser operation, and given authority to operate the laser system in compliance with applicable safety standards, subject to direction or recommendations of the Laser Safety Officer.

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

Local Laser Working Group (LLWG) – A group convened as necessary to assist the regional air traffic division in evaluating the potential effect of laser emissions on aircraft operators near the proposed laser activity.

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. The MPE value varies based on the beam's characteristics (e.g., wavelength, irradiance, or radiant exposure level, or continuous wave or pulsed), exposure duration, and body part exposed to the light (eye or skin). Since the eye is the most sensitive to laser injury, this document uses eye MPE values. In general, MPE is expressed in watts or joules per square centimeter.

Milliradian (mrad) – A measure of angle used for beam divergence. A milliradian is 1/1000 of a radian, or approximately 1/17th of a degree. There are 6283.185 milliradians in a circle.

Protection distances – Distances along the laser beam to a point where the laser is no longer considered an eye injury hazard (NOHD), or to where it is no longer considered a hazard for flashblindness/afterimage (SZED), glare (CZED), or to where it is no longer expected to cause distraction (LFED). FAA is concerned with the NOHD for any laser in navigable airspace, whether it emits a visible or non-visible beam. FAA is only concerned with the other three distances when lasers with visible wavelengths (between 400 nm and 700 nm) are emitted in navigable airspace. There are four protection distances (NOHD, SZED, CZED, and LFED), defined as follows.

Nominal Ocular Hazard Distance (NOHD) – The protection distance from the laser source to where the beam irradiance or radiant exposure falls below the MPE for human eyes. Within the NOHD, potential eye injury may occur. Beyond the NOHD, the beam irradiance or radiant exposure would be less than the eye MPE and is not expected to cause eye injury.

Sensitive Zone Exposure Distance (SZED) – The visual interference distance from the laser source to where the beam irradiance is less than 100 $\mu W/cm^2$. Within the SZED, potential eye injury and temporary flashblindness with resulting afterimages may occur. Beyond the SZED (beam irradiance less than 100 $\mu W/cm^2$), flashblindness or afterimages are not expected to occur.

Critical Zone Exposure Distance (CZED) – The visual interference distance from the laser source to where the beam irradiance is less than 5 $\mu W/cm^2$. Within the CZED, potential eye injury, flashblindness/afterimages, and veiling (obscuring) glare may occur. Beyond the CZED (beam irradiance less than 5 $\mu W/cm^2$), glare which obscures objects is not expected to occur.

Laser-free Exposure Distance (LFED) – The visual interference distance from the laser source to where the beam irradiance is less than 50 nW/cm^2. Along the beam from the laser source to the LFED, potential eye injury, flashblindness/afterimages, veiling glare, and distraction may occur. Beyond the LFED (beam irradiance less than 50 nW/cm^2), the laser light is similar in brightness to most other bright city and airport lights seen at night and is not expected to cause additional distraction.

Radiant exposure – The intensity of the beam over a given area expressed as energy per unit area, generally joules per square centimeter (J/cm^2). Radiant exposure is used for energy (joules) while irradiance is the same concept for power (watts).

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 near a laser beam to identify any potentially unsafe condition.

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

Terminated beam – A laser beam that ends on a surface and is blocked from continuing into navigable airspace.

Unterminated beam – A laser beam that is directed or reflected into navigable airspace. The proponent should provide sufficient evidence to FAA that users of the National Airspace System are not adversely affected by the beam.

Variance – FDA approval for a laser manufacturer or operator to vary from compliance with 21 CFR § 1040.11 by providing an equivalent level of safety via alternate means.

Vertical Distance – The maximum altitude above the ground where an angled (elevated) laser beam may be an eye hazard or a visual interference hazard.

Watts – A unit of measurement associated with power output. The wattage of a laser system or limit of laser power in a flight zone is often expressed as a milliwatt (mW), microwatt (µW), or nanowatt (nW). One watt is one joule per second.