



# AEROSPACE STANDARD

**AS6029™****REV. B**Issued 2011-01  
Revised 2023-07

Superseding AS6029A

## (R) Criteria for Laser Control Measures for Aviation Safety

### RATIONALE

Proponents are responsible for implementing appropriate laser control measures to prevent hazardous aircraft illuminations and ensure aviation safety. The AS6029 standard was developed to establish criteria and guidance to aid proponents and aviation officials for developing and evaluating laser control measures to prevent hazardous exposure in navigable airspace. This standard also provides a framework for proponents pursuing a Letter of Non-Objection from the Federal Aviation Administration (FAA).

As laser control measures are being designed with increasing levels of automation, a need was identified to revise the AS6029 standard. Revision B provides updated criteria and guidance that considers laser control measures with varying levels of automation.

### INTRODUCTION

The SAE G-10T Laser Safety Hazards Subcommittee was requested to develop criteria for acceptable control measures for outdoor laser operations. This standard includes requirements for control measures. The audience for this standard includes the FAA and outdoor laser proponents. Clear and specific criteria will facilitate the research and development of improved control measures and their implementation. Without specific criteria for laser control measures, safety may be negatively affected by reducing the development of potentially more effective or reliable means of mitigating risk.

It should be noted that U.S. regulations prohibit interference with crewmembers of an aircraft; therefore, laser beams shall not be used to track aircraft in flight, except for systems specifically designed for this purpose or when sufficient control measures are used to ensure aviation safety.

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## 1. SCOPE

This document provides requirements and guidance for laser proponents and aviation authorities to determine the criteria that laser hazard control measures shall meet for the operation of an outdoor laser system in navigable airspace. This document has been developed to be used for a wide range of outdoor laser hazard control measures from completely manual systems to those with various levels of automation.

This document applies to laser propagation which may expose persons in navigable airspace to laser energy above the applicable maximum permissible exposure limit or which emits visible light in excess of the visual interference limits in the applicable Laser-Free, Critical, and Sensitive Hazard Zones.

The document does not cover systems intended to deliberately aim and or track lasers at aircraft, such as Federal Aviation Administration (FAA) approved purposes, including visual warning systems, search and rescue, etc. Additionally, laser-affected airspace above 60000 feet mean sea level (MSL) is outside the scope of the performance criteria contained herein.

### 1.1 Purpose

The purpose of this document is to specify criteria and guidance for control measures to ensure the safe incorporation of lasers propagated into the navigable airspace.

## 2. REFERENCES

### 2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), [www.sae.org](http://www.sae.org).

|         |                                                                                            |
|---------|--------------------------------------------------------------------------------------------|
| ARP5293 | Safety Considerations for Lasers Projected in the Navigable Airspace                       |
| ARP5535 | Observers for Laser Safety in the Navigable Airspace                                       |
| ARP5560 | Safety Considerations for High-Intensity Lights (HIL) Directed into the Navigable Airspace |
| ARP5572 | Control Measures for Laser Safety in the Navigable Airspace                                |
| ARP5674 | Safety Considerations for Aircraft-Mounted Lasers Projected into the Navigable Airspace    |
| AS4970  | Human Factor Considerations for Outdoor Laser Operations in the Navigable Airspace         |

#### 2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org>.

|             |                                                            |
|-------------|------------------------------------------------------------|
| ANSI Z136.1 | American National Standard for Safe Use of Lasers          |
| ANSI Z136.6 | American National Standard for Safe Use of Lasers Outdoors |

### 2.1.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, [www.faa.gov](http://www.faa.gov).

Title 14 CFR §91.11 Prohibition on interference with crewmembers

Advisory Circular (AC) 70-1 Outdoor Laser Operations

### 2.1.4 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-STD-882 Department of Defense Standard Practice: System Safety

### 2.1.5 National Fire Protection Agency Publications

Available from NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, [www.nfpa.org](http://www.nfpa.org).

NFPA 79 Electrical Standard for Industrial Machinery

## 2.2 Other Publications

Kosinski, R.J. (2012). *A literature review on reaction time*. Clemson University.

## 2.3 Definitions

The definitions of the terms listed below are specific to this standard and are in no way intended to constitute a general dictionary of terms.

**AIRCRAFT LASER PROTECTION SYSTEM (ALPS):** A system of control measures, outside of those inherent to a laser product, to prevent hazardous laser exposure to aircraft and aircrew.

**ATTENUATION:** The decrease in the radiant power as a laser beam passes through a medium, such as an optical filter or air, typically through absorption or scattering.

**AUTOMATION:** Independent accomplishment of a function by a device or system reducing the need for human information acquisition, decision-making, or action.

**BUFFER ZONE:** The airspace around a laser beam intended to provide a margin of safety. The buffer zone extends from the edge of the beam to a distance equal to twice the reaction time of the protection system times the maximum aircraft speed reasonably expected. In this document, this term is used to help describe the size of the protected airspace.

**EFFECTIVE IRRADIANCE:** The actual radiometric irradiance from a light source multiplied by a factor equal to the normalized, wavelength-based, photopic visual response for a standard observer (refer to FAA AC 70-1). Invisible laser radiation has no effective irradiance. For exposure durations less than 0.25 second, the effective irradiance may be averaged over 0.25 second.

**EFFECTIVE RADIANT EXPOSURE:** The effective irradiance from a light source multiplied by the expected duration of the exposure, but not to exceed 0.25 second.

**FAIL-SAFE:** A design feature that either ensures that the system remains safe or, in the event of a failure, causes the system to revert to a state which is not expected to cause a hazardous exposure condition.

**FAILURE:** Deviation in operational characteristics from required performance of equipment, subsystem, or component, which would require repair, recovery, or replacement to return to a normal operational state.

**FAULT:** An abnormal condition or defect at equipment, subsystem, or component level which may lead to a failure in an unknown state.

**FLIGHT HAZARD ZONES:** Locations defined by the FAA within the navigable airspace based on the performance of various critical tasks. Other than for the Normal Flight Zone, corresponding levels of effective irradiance and/or effective radiant exposure have been defined that are often less than the maximum permissible exposure (MPE), but could adversely affect performance of those critical tasks due to the possibility of visual interference. In addition to the Normal Flight Zone, these zones are the Laser-Free, Critical, and Sensitive Flight Zones.

**LASER-FREE ZONE (LFZ):** The zone extends 2 NM in all directions from usable runway surfaces. Additionally, it includes a 3 NM extension at each end of the runway with a width of 5000 feet (2500 feet from the projected centerline of the runway). The zone includes all altitudes between 0 to 2000 feet above ground level (AGL). With airports with multiple runways, the region is defined as the superposition of each runway zone. Exposure to aircrews within this zone is limited to an effective irradiance not to exceed 50 nW/cm<sup>2</sup> to prevent any visual disruption.

**CRITICAL FLIGHT ZONE (CFZ):** Covers 10 NM around the airport reference point, and extends vertically to 10000 feet AGL. Exposure to aircrews within this zone is limited to an effective irradiance not to exceed 5 µW/cm<sup>2</sup> to eliminate disability glare effects, flash blindness, and afterimages.

**SENSITIVE FLIGHT ZONE (SFZ):** An optional zone, identified by FAA, military, or other authorities that needs to be protected from the potential visual effects of laser radiation. An example would be designation of an SFZ around a busy flight path or where military operations are taking place. Exposure to aircrews within this zone is limited to an effective irradiance not to exceed 100 µW/cm<sup>2</sup> to preclude effects of flash blindness and afterimages.

**NORMAL FLIGHT ZONE (NFZ):** This zone includes all navigable airspace outside the Laser-Free, Critical, and Sensitive Flight Zones. Laser exposure within this zone is not based on visual interference, but exposure in any zone is limited to the MPE (e.g., 2.6 mW/cm<sup>2</sup> for continuous-wave visible lasers).

**HARM:** An unwanted consequence to people, material, or the environment. Harm can be transient, temporary, or permanent. This includes laser exposures above the maximum permissible exposure (MPE) limit and visual interference limits in the applicable flight hazard zones.

**HAZARD:** Potential source of harm.

**LASER-AFFECTED AIRSPACE:** All airspace through which the laser beam may be propagated and where aircraft may also be present. This airspace is equivalent to that described in FAA Form 7140-1, Notice of Proposed Outdoor Laser Operation(s) that a proponent submits to the FAA (e.g., Geographic Location and/or Beam Direction sections). Laser-affected airspace above 60000 feet MSL is outside the scope of the performance criteria contained herein.

**MAXIMUM PERMISSIBLE EXPOSURE (MPE):** The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin. The MPE depends on the duration of the expected laser exposure and on the laser characteristics.

**NAVIGABLE AIRSPACE:** Airspace at and above the minimum flight altitudes prescribed by or under 14 CFR Chapter 1.1, including airspace needed for safe takeoff and landing.

**NOMINAL HAZARD ZONE:** Airspace surrounding the laser beam where the MPE may be exceeded.

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

**OUTDOOR LASER SYSTEM:** A system that projects laser energy into the navigable airspace.

**PROPAGATE:** Emission of laser energy into or through the navigable airspace.

**PROPONENT:** An entity who owns, designs, operates or is otherwise responsible for laser operations propagating laser energy through the navigable airspace.

**PROTECTED AIRSPACE:** Protected airspace is the volume of airspace in the immediate vicinity of a laser beam (plus a protective buffer zone) where aircraft or aircrew could experience an adverse effect if the laser continued to propagate. For this airspace, one or more control measures are necessary to prevent unwanted exposure to aircraft. The protected airspace

extends along the laser beam to the end of the NOHD and, for visible laser beams which penetrate flight hazard zones (Laser-Free, Critical, and Sensitive zones), extends to the end of the appropriate visual protection distance.

**REACTION TIME:** When implementing a laser hazard protection system, the reaction time is the maximum time from when a protected event occurs (e.g., an aircraft entering a protected zone, emergency stop) until the hazard mitigation (e.g., beam shuttered or laser deactivated) becomes fully effective. The reaction time for the overall aircraft protection includes all time needed to detect the aircraft, process the information, decide on mitigation, and fully implement any needed response.

**SAFETY-CRITICAL FUNCTION:** A function whose loss would reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions. For an aircraft protection system, safety-critical functions consist of those required to prevent laser illumination of aircraft.

**SAFETY OBSERVER:** A person tasked with observing airspace into which a laser beam is being propagated so as to ensure that the beam does not illuminate unintended objects; thus avoiding adverse effects. The observer is trained according to applicable standards such as ARP5535 or ANSI Z136.6. The observer has the ability to immediately attenuate the laser beam.

**SHUTTER:** The action of stopping a laser beam from propagating beyond a specific point by blocking or covering the beam at that location. In the context of this document, shuttering stops the laser beam from entering airspace. As a noun, it is a device used to block a laser beam to prevent propagation.

**VALIDATION:** The assurance that a product, service, or system meets the needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers. Contrast with *verification*.

**VERIFICATION:** The evaluation of whether or not a product, service, or system complies with a regulation, requirement, specification, or imposed condition. It is often an internal process. Contrast with *validation*.

**VISIBLE LASER:** A laser operating in the wavelength range of 390 to 780 NM. Such wavelengths can be seen by human beings.

**VISUAL INTERFERENCE LIMIT:** The minimum effective irradiance or radiant exposure which can produce a visual response that interferes with the safe performance of sensitive or critical tasks by aircrew or other personnel. Visual interference limit is a generic term for laser-free, critical, or sensitive limit. The visual interference limit is generally less than the MPE.

**VISUAL PROTECTION DISTANCE:** The distance from the laser source, beyond which the irradiance of the laser beam does not exceed the applicable visual interference limit.

## 2.4 Abbreviations and Acronyms

|        |                                                         |
|--------|---------------------------------------------------------|
| ASDI   | Aircraft Situation Display to Industry                  |
| AGL    | Above ground level                                      |
| ANSI   | American National Standards Institute                   |
| CCD    | Charge-coupled device                                   |
| FAA    | Federal Aviation Administration                         |
| FOV    | Field of view                                           |
| IRB    | Infrared boresight camera                               |
| IR     | Infrared                                                |
| LASER  | Light amplification by stimulated emission of radiation |
| LGS-AO | Laser Guide Star – adaptive optics                      |

|       |                                      |
|-------|--------------------------------------|
| LGSO  | Laser Guide Star Observatory         |
| MPE   | Maximum permissible exposure         |
| MSL   | Mean sea level                       |
| NOHD  | Nominal ocular hazard distance       |
| NOTAM | Notice to air missions               |
| WVW   | Wide field visible wavelength camera |

### 3. BACKGROUND

Historically, safety observers have been used as the primary control measure. They provide safety by detecting the presence of aircraft that may be adversely affected by an outdoor laser operation. The safety observers cause the hazard to be mitigated until the aircraft leaves the protected airspace. Information related to the attributes and training of a safety observer and procedures that shall be followed are detailed in ARP5535.

Although safety observers have a proven record of effectiveness, some factors may decrease their efficacy; for example working at high altitudes, working for long durations, working in cold locations, or the difficulty in detecting aircraft at long distances. In such cases, other control measures are needed to ensure aviation safety. These measures may include optical aids (binoculars) or automated aircraft detection/safety systems utilizing bore-sighted radar, scanning radars, infrared cameras, CCD camera, etc., or some combination of these control measures.

Technological advances and complications of environmental conditions have resulted in the development of systems with increased use of automation. The level of automation for laser hazard control for outdoor laser systems can vary from completely manual, to partial automation, to completely automated requiring no human interaction. The complexity resulting from automation may introduce additional failure modes that must be considered.

In the application of safety control measures, engineering controls (design features that minimize or mitigate hazards) are preferred over those that depend on administrative controls (e.g., policies, procedures, practices, and training). Appropriate controls must be selected based on the severity and likelihood of a hazard leading to potential injuries or incidents. Therefore, a need exists for validating the efficacy of these control measures. Also, control measures need to be designed, selected, and evaluated based on site and laser use characteristics since outdoor laser applications can vary widely. To give one example, operations conducted in daytime may require different types of control measures than operations conducted at night. See Appendix A for a table showing the uniquely different characteristics of typical outdoor laser uses.

NOTE: For descriptions of control measures and information on typical applications, pros, cons, and limitations refer to ARP5535 and ARP5572. Additional information on related laser safety issues can be found within ARP5293 and AS4970.

### 4. PERFORMANCE/FUNCTIONAL REQUIREMENTS

An aircraft laser protection system (ALPS) is required when it is reasonably foreseeable that aircraft can be illuminated by laser energy in excess of the MPE or applicable visual interference limits. Protective means shall be employed to ensure that aircraft occupants are not exposed to laser limits above the MPE; this protects occupants from eye and skin damage. The MPE will be determined from a worst case assessment based on the expected duration of the exposure. In addition, for visible lasers, protective means shall be employed to ensure that pilots are not exposed above any applicable visual interference limits. (Visual interference limits were established by the FAA to protect pilots from bright light effects such as temporary flash blindness, afterimage, glare, and distraction/startle.) For unintended exposure to aircraft from visible or infrared laser beams from ground based or airborne platforms, a maximum exposure duration of 0.25 second is used in the computation of the MPE or visual effects, due to natural relative motion between the beam and aircraft related to wind and other stabilization issues. The actual duration of exposure is used to compute the MPE when the exposure of aircraft is intentional. For persons exposed to the laser beam for less than 0.25 second, determination of the presence of visual interference will be based on the laser beam irradiance averaged over 0.25 second. The laser proponent's ALPS, which can include one or more control measures, shall meet the following criteria. The Appendices illustrate how systems can be implemented to meet the following criteria.

#### 4.1 Detection

The ALPS shall detect all types of aircraft that may be reasonably expected (fixed wing, rotorcraft, lighter than air aircraft, balloons, gliders, etc.) in its operating area. The ALPS shall have the capability to detect these aircraft at all locations where (1) aircraft can be reasonably expected and (2) laser exposure at that location would be expected to exceed the MPE or an applicable visual interference limit.

#### 4.2 Beam Attenuation

The ALPS shall shutter, or attenuate, the beam to safe levels (e.g., below MPE and any applicable visual interference limit) before an aircraft enters the protected airspace. The protected airspace shall include the laser beam and a buffer zone extending from the edge of the beam to a distance equal to twice the reaction time of the ALPS times the maximum aircraft speed that is reasonably expected. This provides a 2X safety factor. Note that this means that the system must be able to detect aircraft and shutter or attenuate the beam to safe levels before an aircraft reaches the buffer zone. Information on and examples of how to calculate the reaction time for an ALPS can be found in Appendix B.

#### 4.3 Multiple Control Measures

If an ALPS making use of a single control measure cannot adequately protect aircraft throughout the laser-affected airspace, including aircraft at both near distance/low altitude and at far distance/high altitude, or in any reasonably expected site-specific scenario, then multiple control measures would be required.

Figure 1 illustrates protected airspace that extends from the laser to beyond 60000 feet. Figure 2 illustrates the protected airspace that extends from a laser beam that is being scanned across the sky, which will result in a much larger zone of airspace to be protected. Many laser beams may not require protection to 60000 feet MSL, and the protection of airspace above this altitude is outside the scope of the performance criteria contained herein.

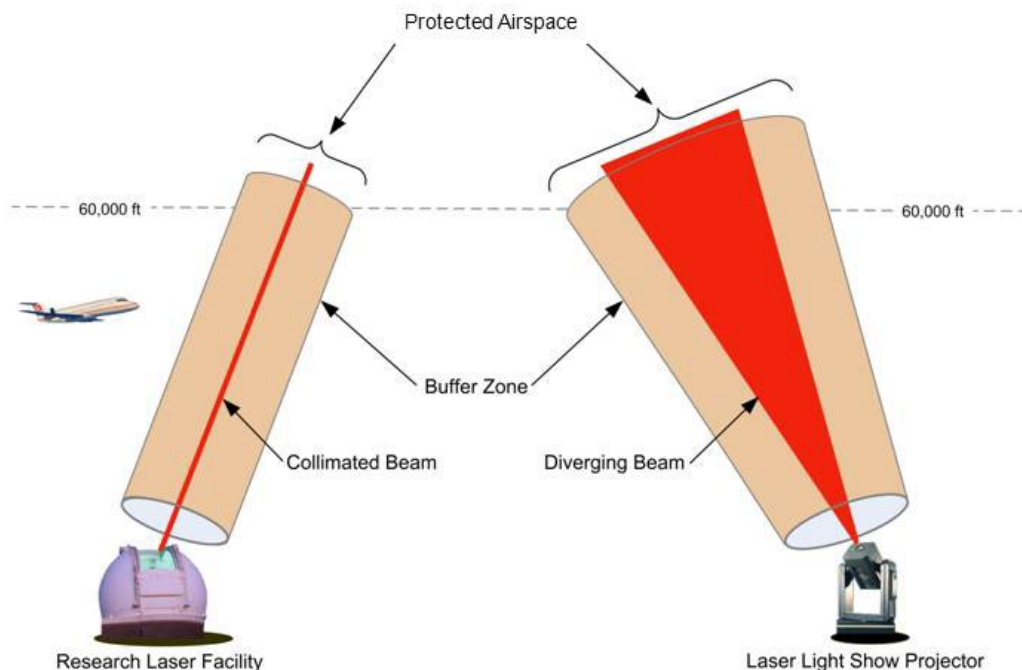


**Figure 1 - Illustrates the protected airspace that extends from the laser beam**

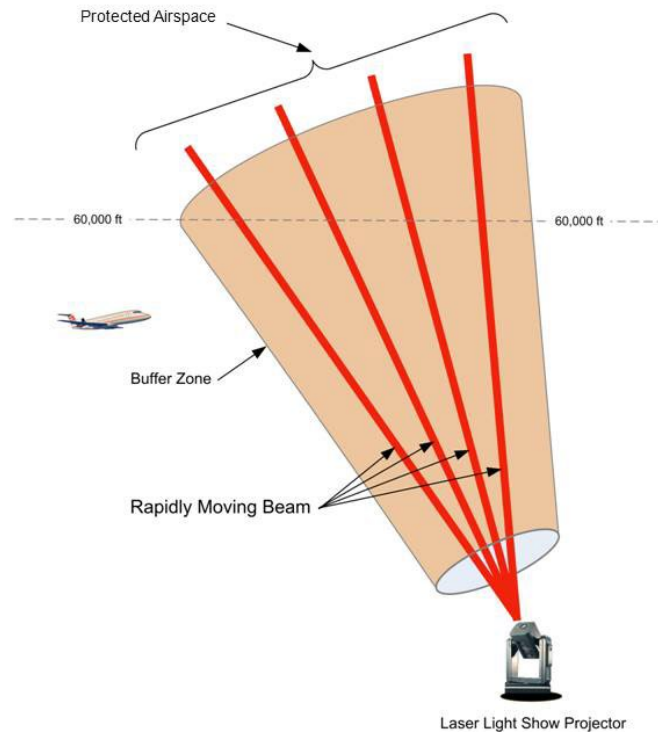


**Figure 2 - The protected airspace around a rapidly moving laser beam**

#### 4.4 Aircraft Altitude and Speed

The proponent shall determine what aircraft altitudes and speeds are to be reasonably expected in the operating environment of the laser facility. This information is available from sources such as Aircraft Situation Display to Industry (ASDI), the local (geographically responsible) FAA air traffic facility, or qualified consultants. The following information may be useful in developing the analysis:

- Maximum aircraft altitude: 60000 feet MSL. The ceiling of 60000 feet MSL is based on FAA having control of air traffic up to flight level 600.
- Minimum aircraft distance from laser source: 200 feet (it is reasonable to expect aircraft not to operate within 200 feet from the laser source).
- Minimum aircraft speed: This value will vary depending on the type of aircraft reasonably expected in the area. For fixed wing aircraft, it is based on the stall speed.
- Maximum civilian aircraft speed: 250 knots (288 mph) below 10000 feet MSL. The civilian aircraft airspeed of 250 knots is based on 14 CFR §91.117(a).
- Typical maximum civilian aircraft speed above 10000 feet can be assumed to be 540 knots (621 mph).
- Typical military aircraft speed: 540 knots (621 mph) below 10000 feet MSL, unless otherwise determined. The military aircraft airspeed of 540 knots is based on 0.9 Mach, which is typical for low-level training routes.
- Because military aircraft may have different flight characteristics, it is necessary to coordinate with local military facilities to establish what altitudes and speeds are reasonably expected at the laser location.

For aircraft at any speed and distance that can be reasonably expected in the area, the proponent shall show either that (1) the laser can be terminated before the aircraft enters the protected airspace, or (2) the aircraft's speed and distance reduce any possible human exposure to below the MPE and any applicable visual interference limit.

In summary, the ALPS shall detect all types of aircraft flying at all speeds and altitudes that may be reasonably expected to operate within the laser-affected airspace and shutter or attenuate the beam before the aircraft enters protected airspace. The ALPS shall safeguard protected airspace to the NOHD. For visible laser beams that penetrate the corresponding flight hazard zones at night (Laser-Free, Critical, and Sensitive Zones), the ALPS shall safeguard all protected airspace to the appropriate visual protection distances.

## 5. SYSTEM DESIGN REQUIREMENTS

The following list describes design elements for ALPS that support the functional requirements.

### 5.1 Failure Modes

There shall be no reasonably expected failure modes that prevent aircraft detection or laser shutoff and for which no redundancy or alternative operational procedure exists. It is preferred that safety-critical equipment failures are detected via automatic means (i.e., continuous monitoring function) with automatic system transition to a safe state. Non-safety-critical equipment failures may be detected via regular operational checkout procedures. The frequency of checkout shall be specified to achieve equipment effectiveness goals (e.g., shift, day, month).

#### 5.1.1 Failure Modes Analysis

The proponents shall perform a failure-modes analysis to identify possible modes of failure, including malfunctions, adverse effects from the operational environment, human errors, and defects in systems and subsystems where laser hazards to personnel or aircraft in navigable airspace may be left uncontrolled. The analysis shall consider failures, multiple failures, and reasonable other factors that may be present which could compromise the laser safety controls. Examples could include failure of a component such as an interlock, software errors, and impacts from weather or natural disasters. The proponent shall identify appropriate mitigation based on the laser hazard and risk to address identified failures and determine failure recovery strategies to ensure safe use prior to returning to operation. ARP5572 provides additional information on hazard mitigation and selecting appropriate control measures.

Methodologies for failure and hazard analysis are beyond the scope of this document. Several options for best practices exist, which proponents may wish to consult or adopt. Some examples include MIL-STD-882 or the FAA System Safety Handbook.

#### 5.1.2 Fail-Safe

For any identified failure conditions that could otherwise allow laser illumination of aircraft, the ALPS shall incorporate fail-safe provisions that cause the system to revert to a safe state. The goal of a fail-safe design is to prevent inadvertent aircraft illumination exceeding the MPE or applicable visual interference limit. The fail-safe design concept may include provisions for failure warning or indication to provide detection and allow appropriate response (e.g., to address the condition or implement alternative measures).

NOTE: Proponents wishing to develop an ALPS that will meet the criteria contained in this document may benefit from the description of the protection system development procedures contained in Appendix C.

#### 5.1.3 Redundancy Considerations

Redundancy may be considered as part of the fault tolerance design to achieve laser hazards mitigation goals.

### 5.2 Redundant Control Measures Systems

Some proponents may wish to have redundant, independent detection systems such that even if one system fails, the other is capable of detecting aircraft in the laser-affected airspace. Redundant systems are not required if the single detection system meets the Performance/Functional and System Design Requirements.

### 5.3 Initialization and Mode/State Change

The ALPS shall not allow hazardous laser propagation into the navigable airspace during initialization.

The ALPS shall not allow hazardous laser propagation into navigable airspace during a change in mode/state (e.g., training to tactical, low power to high power) unless safe to do so in both modes/states.

When hazardous laser propagation has been disabled by the ALPS, it shall not be re-enabled until safe to do so.

#### 5.4 Human Factors

If used, controls, status indicators, etc., should be intuitive to whomever is using it, easily accessible, and viewable under the operational conditions intended.

#### 5.5 Security

The proponent shall identify and address potential security threats, including physical and information technology (IT), where unauthorized access could result in laser hazards in the navigable airspace. Security considerations shall be included in the proponent's failure modes analysis.

##### 5.5.1 Physical Security

Unauthorized physical access could result in misuse, modification, or harm which may result in laser hazards. Proponents shall implement physical controls necessary to protect laser operations from unauthorized physical access. Examples of physical controls include protective barriers, access controls, lighting, intrusion detection systems, and security guards.

##### 5.5.2 IT Security

Unauthorized access of computer systems, including networks, internet access points, hardware, software, and other data, can result in intentional or unintentional changes, disruption, or misdirection of laser systems and equipment. The proponent shall identify and evaluate IT security vulnerabilities and determine appropriate controls to prevent or reduce the risk of access that may impact laser systems and present hazards in the navigable airspace or to other personnel.

#### 5.6 System Design Requirements

The proponent can use a hazard analysis to address requirements and design considerations for the ALPS. Fault tolerance, environmental conditions, storage, and limitations in the design or the materials used have to be considered in the requirements, design, and implementation processes.

##### 5.6.1 Hardware and Software Development

A system can initiate, control, or monitor safety significant functions or operations. Proponents developing safety-significant hardware and software for ALPS shall implement a development process that mitigates the risk of hardware and software contributing to laser hazards. The rigor of hardware and software development increases with hazard severity.

Hardware and software system safety development activities typically include requirements, design, assurance, test, verification and validation, operation and maintenance, and change control/configuration management. Methodologies for hardware and software development are beyond the scope of this document.

##### 5.6.2 Emergency Shutoff

There shall be at least one human-activated emergency shutoff system capable of mitigating the hazard of laser emission by putting the laser system into a safe state. The emergency shutoff is not intended to be used in normal operation of the system. It should be used only for unexpected or unintended situations with the potential for hazardous laser emissions.

For systems where operators are located in close proximity to the laser system controls, the emergency shutoff may be a mushroom button where an electrical connection is broken to make the system safe, similar to an emergency stop (e-stop), as defined in NFPA 79.

For systems with remote operation, the emergency shutoff may include a remote control with a "heartbeat" signal and an operator-controlled software or hardware override button. If the heartbeat signal is not received within a specified interval, the ALPS attenuates or terminates the laser or otherwise makes the airspace safe. An operator may also trigger the ALPS by activating a button which commands the laser to a safe state.

The reaction time for use of an emergency shutoff is independent from the reaction time for the ALPS. However, it shall be considered when analyzing the efficacy of the emergency shutoff.

If the emergency shutoff is triggered, the system shall go into a safe state. Resetting the emergency shutoff (such as pulling out a mushroom switch or pressing a software “Restart” button) may return the system to either an armed state or a safe state depending on the operational requirements. The proponent shall define and document the process for using and resetting the emergency shutoff.

### 5.6.3 Operator Interface

An operator interface provides feedback and control to users about the status of the system (faulted/on/off, etc.) so that they can take appropriate action. An ALPS may require an operator interface to achieve the functional requirements of this standard. If an operator interface is used, it should be designed for the intended user. All controls associated with monitoring and warning means shall be easily accessible and viewable under the operational conditions intended and designed to minimize operator errors that could create additional hazards. Controls should be labeled so that the operator understands the intended use.

#### 5.6.3.1 Operator Interface/Console Software Design Considerations

- Software user interface should be as simple as practicable.
- Implementation of software must consider failure modes associated with software (monitor failure, computer crash, touch-screen failure, etc.).
- Safety-significant controls and indicators shall be visible, available, and controllable when using the software interface at all times.
- Indicators shall be separate from controls.
- The software user interface elements should be intuitive, clear, and unambiguous. The operator shall be trained to use the software interface and its indicators and controls.
- If implemented in software, a virtual e-stop should have a virtual protected cover to avoid accidental activation.
- User shall see appropriate cautionary labels—either actual or virtual—commensurate with the requirement for a system that does not rely on software.
- Color should not be the sole means of indication status. For example, some persons may be color-vision deficient or may have limited vision, or indicators may not be visible through laser safety eyewear. Refer to guides for user interface accessibility.
- The differentiation between armed and lasing state indicators shall be clear and understandable. For example, including a label to describe the difference in meaning between a flashing and steady state indicator light.

### 5.6.4 Communication Equipment

Communication systems/schemes/equipment such as telephones, internet, Ethernet, etc., used as an integral part of an ALPS or shutoff system shall conform to the criteria set forth in this document. Communications failure, consistent/inconsistent communications delays, etc., shall be considered and the appropriate system response developed to ensure aircraft and personnel safety are not compromised.

## 5.7 Compliance with Regulations

Laser safety systems are required to be designed, installed, operated, and maintained in compliance with regulations applicable to the location where outdoor laser operations will be occurring as appropriate to protect personnel and navigable airspace. In the United States this includes federal, state, and local regulations such as the Occupational Safety and Health Administration (OSHA) or state specific OSHA programs and the Food and Drug Administration (FDA). Internationally, many countries have specific regulations that apply to occupational safety or laser safety that must be followed in those jurisdictions. Failure to follow regulations can result in disapproval of laser operations, fines, and/or imprisonment.