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Guidance on Mitigation Strategies Against Laser Illumination Effects

RATIONALE

The greatest single bright-light concern in aviation today is portable hand-held lasers misused by the general public. Bright laser light aimed at the aircraft during night and dim conditions can interfere with pilots' vision. There is also a small but finite possibility of laser light causing an injury to pilots' eyes.

This document provides information about (1) operational considerations, (2) education and training, and (3) whether and how to mitigate these effects using Laser Glare Protection (LGP). In addition, a brief description of devices to locate and report laser illuminations is given in Appendix D.

Stakeholders include: Pilots and aircrews, aircraft operators, public safety managers such as police and medical officials, and the U.S. Federal Aviation Administration (FAA).

FOREWORD

Laser illumination of aircraft has been a problem since the mid-1990s. The issue was originally with outdoor laser light shows that used large and expensive entertainment lasers. This problem was essentially solved around 2000 with new regulations and procedures. The U.S. Food and Drug Administration (FDA), which regulates laser shows, requires shows to be submitted for FAA review using the forms in FAA Advisory Circular 70-1. FAA reviews the submitted information and either objects (necessitating changes by the show producers) or does not object (allowing the shows to proceed). If FAA objects, FDA does not allow the laser show to be performed. The FAA review procedures were also recommended for scientific and other outdoor laser users; for example, guidestar lasers used by observatories.

However, in the mid-2000's hand-held laser powers increased and prices decreased to the point that ordinary consumers could purchase lasers with enough brightness and range to interfere with pilots' vision. In 2004, the first year FAA required pilots to report laser incidents, there were 46 reported incidents. Figure 1 shows how that number has risen to over 6700 reported incidents in 2017.

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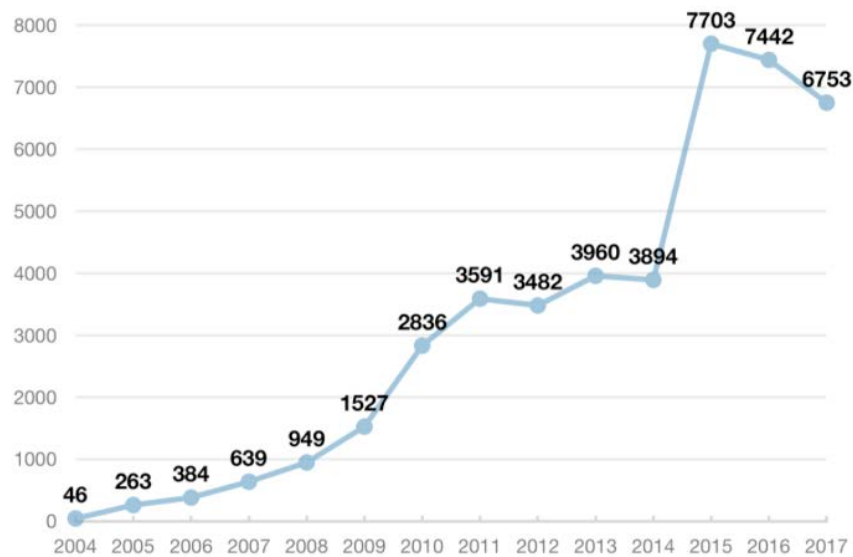


Figure 1 - Laser illuminations reported to FAA, annual total

From 2004 through 2017, pilots have reported to the FAA a total of over 43000 laser illumination incidents. During this time, the most serious consequences of laser illumination have been go-arounds, interrupted missions, and one interrupted commercial flight. (In February 2016, an Airbus A340 flight was illuminated shortly after takeoff from Heathrow Airport. The pilot declared a medical emergency over Ireland and turned back to land at Heathrow. This is the only known return by a commercial flight.) As of January 2018 there have been no accidents and no documented permanent eye injuries.

There have been calls by pilot groups and others to take action on the ground to reduce the number and effect of laser illumination incidents. These actions include finding and prosecuting laser perpetrators, restricting illegal laser pointer imports, and considering a ban or other restrictions on laser pointer ownership. Unfortunately, such actions have not yet been found to significantly reduce incidents, and they would not dissuade deliberate misuse of lasers against aircraft.

For this reason, pilots and other stakeholders should be aware of the steps that they can take, as the “last line of defense,” to understand and mitigate effects from the increasing numbers of laser illuminations.

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1. SCOPE

This document is intended to give guidance to users, regulators and persons in the aviation field who may be affected by the potential visual interference effects of lasers aimed at aircraft by the general public. The potential effects include startle (distraction, disruption, disorientation, and operational incapacitation), glare, and flashblindness. This document provides mitigation strategies against such effects, including operational procedures, pilot education, and the use of Laser Glare Protection.

Prevention of harm from laser eye injuries is discussed but is not a focus of this document, due to the extremely low likelihood of injurious levels of laser light in typical aircraft illumination scenarios.

Devices for detecting and reporting hazardous laser illuminations are briefly described in Appendix D, but are not a focus of this document.

Some information in this document may also be useful for non-aviation users, such as persons driving vehicles. Additional information can be found in ANSI Z136.6, "Safe Use of Lasers Outdoors".

1.1 Purpose

The goal of pilot education is a reduction in risk to operational efficiency of the pilot. This is achieved by developing mitigation strategies for various risk groups such as commercial and law enforcement pilots, and communicating these to pilots.

Because laser illuminations affect pilots, they need tools to successfully mitigate and handle an adverse event during a critical phase of flight. Due to the nature of laser illuminations – the pilot is only "hit" with light – with education and training a pilot can successfully overcome the effects and have a safe outcome.

As a last option, pilots may further mitigate the effects of a laser illumination event using appropriate Laser Glare Protection (LGP). This document gives guidance as to when LGP is appropriate, the advantages and disadvantages of various types of LGP, and how to select and evaluate LGP for use in a specific cockpit prior to deployment.

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, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Telephone: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), <http://www.sae.org>.

AIR5995	Evaluation of Human Factor Considerations for Outdoor Laser Operations in the Navigable Airspace
ARP5293	Safety Considerations for Lasers Projected in the Navigable Airspace
ARP5598	Unauthorized Laser Illuminations: Pilot Operational Procedures (Note: This document, ARP6378, may supercede the pilot operational procedures listed in ARP5598. In case of any conflict use the procedures in ARP6378.)
AS4970	Human Factors Considerations for Outdoor Laser Operations in the Navigable Airspace

2.1.2 Other Publications

FAA AC 70-2A Reporting of Laser Illumination of Aircraft

ANSI Z136.6 Safe Use of Lasers Outdoors

2.2 Definitions

AFTERIMAGE: A transient image that persists in one's vision after a bright source of illumination has been removed.

CRITICAL PHASE OF FLIGHT: Flight during takeoff or landing; at low altitude or when hovering, or during an emergency. Pilots are most at risk from illumination effects during a critical phase of flight. During non-critical phases such as cruise, there is sufficient time to recover from visual interference.

DAZZLE: The temporary loss of clear vision from looking at a bright light source.

DISTRACTION: Momentary attention shift from primary tasks due to sudden exposure to a bright light source.

DISRUPTION: Interference or interruption of critical tasks or task sequences that extend the shift of attention from primary tasks requiring selective attention.

DISORIENTATION: Losing perspective in the relationship between the direction of travel and surroundings. Loss of spatial orientation (SO) and loss of situational awareness (SA). Disorientation can include both distraction and disruption. Transfer of aircraft control may be delayed as a result of disorientation.

FLASHBLINDNESS: A visual interference effect that persists as an afterimage after an intense source of illumination has been removed.

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

HAND-HELD LASER: A laser intended primarily to be held in the hand while in use. Generally these are self-contained with a battery, driver/electronics and laser source (usually a diode or diode-pumped crystal). Contrast with a laser module, which separates the diode, driver and power source and is usually intended for original equipment manufacturers or for experimental use. Throughout this document, the term "hand-held laser" will include laser pointers.

IRRADIANCE: The laser beam's power density: radiant power incident per unit area upon a surface, expressed in watts per centimeter squared (W/cm^2). A laser can be made less hazardous to the eye by enlarging the beam with a lens or other technique, to reduce the beam's irradiance at the pupil.

LASER: Light Amplification by Stimulated Emission of Radiation. Laser energy is coherent, monochromatic and collimated. This means that visible laser light is focused to a smaller area on the retina than incoherent light, that the light is one very specific color such as green light at 520 nm, and that the beam gets wider (diverges) more slowly than incoherent light. (Some lasers emit light of different wavelengths simultaneously, such as an argon gas laser. However, each color is a very specific wavelength such as 514 nm green and 488 nm blue.)

LASER EYE PROTECTION (LEP): Glasses, goggles, visors, windows or similar products which transmit some wavelengths of light but which block other specified wavelengths of laser radiation, used for protection against an eye injury due to accidental exposure to laser radiation.

LASER GLARE PROTECTION (LGP): In this document, LGP includes personal eyewear, windscreen film, visors and other techniques designed to attenuate (by absorbing and/or reflecting) laser radiation of one or more visible wavelengths. LGP is used to reduce the potential hazard of visual interference effects. Laser Glare Protection is distinguished from Laser Eye Protection which is designed to protect against possible injury to the eye (e.g., levels above the Maximum Permissible Exposure).

LASER LIGHT: Electromagnetic radiation in the visible portion of the spectrum, produced or amplified primarily by the process of controlled stimulated emission. Laser *light* (visible) is contrasted with laser *radiation*, which can be in the infrared or ultraviolet portion of the electromagnetic spectrum. See also *Nanometer* and *Visible Radiation (light)*.

LASER POINTER (general definition): Laser pointers are hand-held lasers that are promoted for pointing out objects or locations. The “dot” at the end of the beam can be used as the indicator, or the beam itself – if visible in mid-air – may be the indicator. A pointer usually has a momentary press-to-activate switch, although some pointers may have a press-on/press-off switch instead.

LASER POINTER (FDA/CDRH definition): The U.S. Food and Drug Administration’s Center for Devices and Radiological Health states that “Laser pointers are hand-held lasers that are promoted for pointing out objects or locations.... Laser products promoted for pointing and demonstration purposes are limited to hazard Class IIIa by FDA regulation. 21 CFR 1040.11(b) and 1040.11(c), limit surveying, leveling, and alignment, and demonstration laser products to Class IIIa. This means that pointers are limited to 5 milliwatts output power in the visible wavelength range from 400 to 710 nanometers. There are also limits for any invisible wavelengths and for short pulses. Pointers may not exceed the accessible emission limits of CDRH Class IIIa or IEC Class 3R.” Source: “Important Information for Laser Pointer Manufacturers, FDA/CDRH.”

LASER POINTER (FDA/CDRH definition proposed October 2016 for a possible future regulation): “Handheld laser products designed for battery-powered operation that are manufactured, designed, intended or promoted to provide illumination, designation of a target or point of origin, or sighting, with no associated technological or scientific purpose for the laser’s emission. Laser products are not excluded as laser pointers when used for visual entertainment, vision disruption, to startle, or novelty purposes.” Source: “FDA Background Materials Prepared for the October 25-26 2016 TEPRSSC Meeting, page 29.”

MAXIMUM PERMISSIBLE EXPOSURE (MPE): The level of laser radiation to which a person may be exposed without adverse biological changes to eye or skin. The criteria for MPE is detailed in the ANSI Z136.1 standard. Factors involved in calculating the MPE are laser wavelength and time of exposure. For visual interference with aircraft, the MPE for a 0.25 second exposure is used if no other exposure duration is known, since this relies on the human aversion response (blinking, turning away) to avoid a longer, more deliberate exposure.

NANOMETER (nm): A unit of measure commonly used when discussing the wavelength of visible and non-visible laser radiation. For visible light, different wavelengths are perceived by the human eye as different colors. For example, light between roughly 450 and 495 nm is perceived as blue, light between roughly 495 to 570 nm is perceived as green, and light between roughly 620 to 730 nm is perceived as red. This document considers the visible range to be 380 to 780 nm. Other sources may define different ranges; for example, the U.S. FDA CDRH uses 400 to 710 nm.

NIGHT: For convenience, this document uses “night” to include dark and dim conditions including evening and morning twilight, and dim light due to weather conditions such as dense clouds. For reference, the FAA definition of “night” in FAR Section 1.1 is “the time between the end of evening civil twilight and the beginning of morning civil twilight, as published in the Air Almanac, converted to local time.” (Evening civil twilight begins at sunset and ends when the sun reaches 6 degrees below the horizon. Morning civil twilight begins when the sun is 6 degrees below the horizon and ends at sunrise.)

NOMINAL OCULAR HAZARD DISTANCE (NOHD): The distance along the beam path beyond which a beam’s irradiance does not exceed the MPE. Beyond the NOHD, the beam is considered safe to be directly viewed (intraocular exposure).

OPERATIONAL INCAPACITATION: In the context of this document, operational incapacitation is the loss of spatial orientation and loss of situational awareness in reference to the outside world. Operationally incapacitated flight crew members should immediately transfer control of the aircraft because they can no longer reliably discern or control the attitude, altitude, or direction of the aircraft.

OPTICAL DENSITY (OD): A unitless number which defines the amount of “light stopping power” in a LEP or LGP. OD is the Log of the ratio of the power before it passes through the protection to the power after it passes through the protection. An OD is usually between the numbers of 1 and 10. Higher number ODs provide increased protection.

PHOTOPIC VISIBLE LIGHT TRANSMITTANCE (VLT): VLT is the percentage of visible light transmitted through a filter, calculated against the spectral sensitivity of the eye to daylight. For example, eyewear with a VLT of 90% would allow 90% of visible light to be transmitted. VLTs below 30% should not be used in aircraft working environments. Throughout this document, “visible light transmittance” or similar refers to photopic (light-adapted) visible light transmittance. This is more relevant to reading backlit cockpit displays and indicator lights in aircraft, than scotopic (completely dark-adapted) VLT.

STARTLE EFFECT: The involuntary reaction to an unexpected event that alters mental, physical, and visual activities and diverts selected attention away from the normal primary tasks of the flight crew. The startle response can be broken into four specific categories: Distraction, Disruption, Disorientation and Operational Incapacitation.

VISIBLE RADIATION (LIGHT): For purposes of this document, the visible range is considered to be 380 to 780 nm. Light within this range can produce visual response that can interfere with the safe performance of sensitive or critical tasks.

VISUAL INTERFERENCE EFFECTS: A visible wavelength laser beam directed into a person's eye can interfere with the safe performance of sensitive or critical tasks by air crews or other personnel. This can happen even when the laser exposure is below the MPE. Visual interference effects include temporary flashblindness, afterimages, and glare. For purposes of this document, "visual interference effects" also includes effects which may not directly degrade vision but which may affect performance, such as startle, distraction, and disruption.

3. LASER EFFECTS ON VISION AND TASK PERFORMANCE

It should first be noted that not all laser light in airspace poses a risk to flight operations. For example, in May 2005, NORAD began using a laser Visual Warning System in the Washington, D.C. Air Defense Identification Zone (ADIZ). A low-power laser beam that flashes red-green-red is aimed directly at aircraft in the ADIZ when the pilot cannot be reached by radio. The beam is visible at a distance of up to 25 miles.

3.1 Visual Interference Examples

The primary concern of laser/aviation experts is visible laser beams that can interfere with pilots' vision or otherwise adversely affects their ability to safely operate the aircraft. The photos below were taken in an FAA simulator, with an airport runway being displayed. The photos show examples of the three main visual interference effects.



Figure 2 - Startle/distraction example

Startle/Distraction: The light is brighter than background lights. ARP5293 and FAA have set 50 nW/cm² (0.05 μW/cm²) as the irradiance where laser light begins to be distracting. (Note: While this is technically not a vision impairment, distraction has traditionally been listed as "visual interference" along with dazzle/glare and flashblindness.)

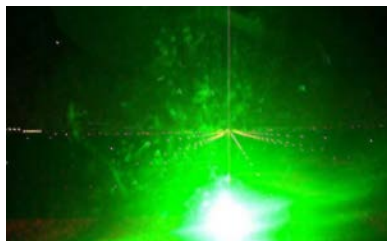


Figure 3 - Dazzle/glare example

Dazzle/Glare: It is difficult to see past the light, as long as it remains aimed towards the eye and remains on. ARP5293 and FAA have set 5 μW/cm² as the irradiance where laser light begins to cause this visual interference effect.

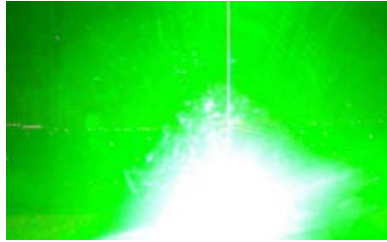


Figure 4 - Flashblindness example

Flashblindness: The light is so bright that it causes afterimages that last even after the light is no longer aimed towards the eye. ARP5293 and FAA have set $100 \mu\text{W}/\text{cm}^2$ as the irradiance where laser light begins to cause this visual interference effect.

3.2 Visual Interference Effects on Pilot Tasks in a Critical Phase of Flight

During non-critical phases of flight such as cruise, there is time to recognize and recover from a laser illumination.

It is when pilots are in a critical phase of flight – takeoff, landing, low-altitude flight or during an emergency – that visual interference becomes a task performance issue.

Laser light can distract, disrupt, disorient and operationally incapacitate the flight crew. If the laser light is unexpected – there is no prior knowledge of laser beams in the surrounding airspace – this creates a startle effect.

3.2.1 Startle Effect

Startle effect is the involuntary reaction to an unexpected event that alters mental, physical, and visual activities and diverts selected attention away from the normal primary tasks of the flight crew. The startle response can be broken into four specific categories:

- **Distraction:** Momentary attention shift from primary tasks.
- **Disruption:** Interference or interruption of critical tasks or task sequences that extend the shift of attention from primary tasks requiring selective attention.
- **Disorientation:** Losing perspective in the relationship between the direction of travel and surroundings. Loss of spatial orientation and loss of situational awareness. Disorientation can include both distraction and disruption startle. Transfer of aircraft control may be delayed as a result of disorientation.
- **Operational incapacitation:** Loss of spatial orientation and loss of situational awareness in reference to the outside world. Incapacitated flight crew members should immediately transfer control of the aircraft because they can no longer reliably discern or control the attitude, altitude, or direction of the aircraft.

With startle, as with any operational environment, flight crews utilize normal, abnormal, and emergency procedures to operate in navigable airspace. During any abnormal or emergency event, the flight crew must recognize the event, and then respond with the appropriate checklist procedure to neutralize and restabilize the aircraft profile. Appendix A has suggested procedures and checklists for dealing with laser illuminations.

3.2.2 Dazzle and Glare

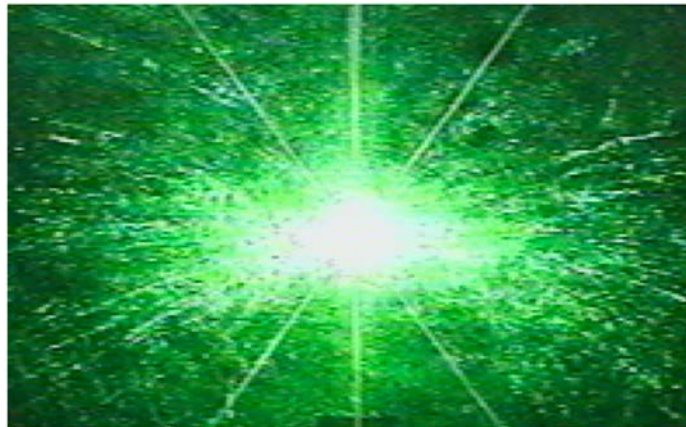


Figure 4 - Photo of dazzle and glare

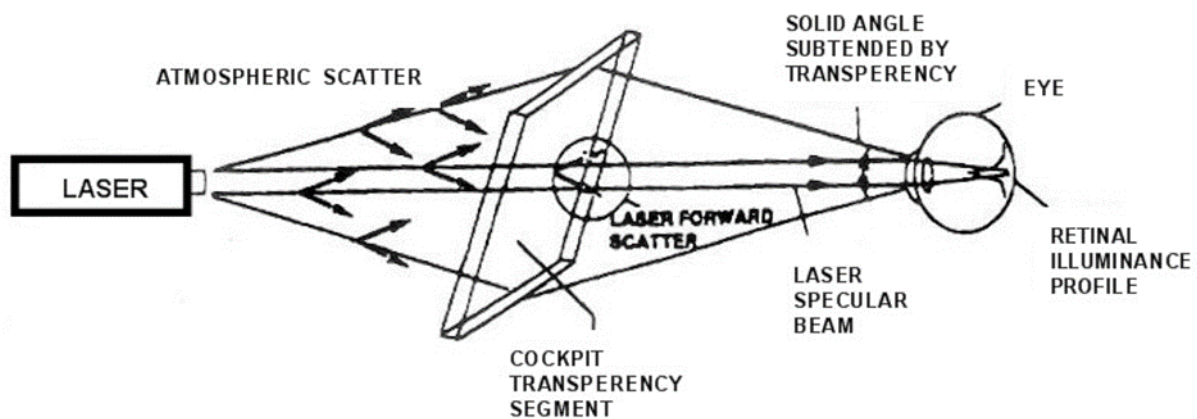


Figure 5 - Sources of scatter

Figure 4 shows the dazzle/glare effect. Figure 5 shows sources of scatter for the laser light. The atmosphere, windscreen, and intraocular scatter all contribute to obscuration of vision by laser light.

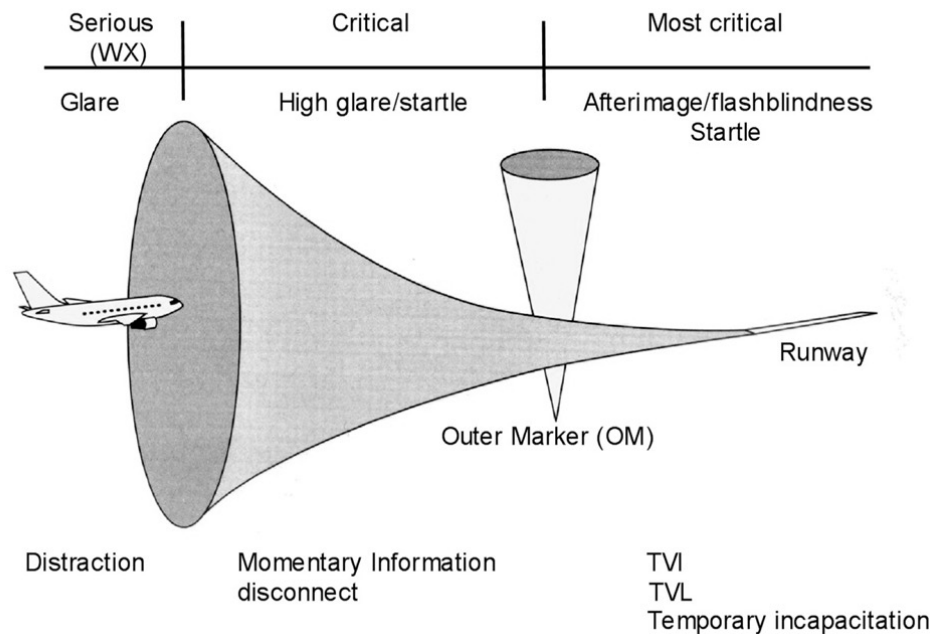


Figure 6 - Decrease in tolerance due to visual disruption

In Figure 6, the cone represents the decrease in tolerance to visual disruption during the final phases of aircraft flight. Note that visual function becomes most critical to flight safety in the final moments before landing—a period that overlaps the period of greatest vulnerability to unauthorized laser illuminations due to the aircraft's low altitude (not to scale). TVI is temporary visual impairment and TVL is temporary visual loss.

3.3 Visible Light Eye Injury Potential

In addition to the visual interference effects described above, pilots may also be concerned that a laser exposure during flight could cause an eye injury. While this document does not cover eye injuries, we will briefly discuss the topic and why it is not considered a significant hazard for pilots.

3.3.1 Retina

This document is concerned with visible light lasers. Visible light goes through the eye's cornea and lens, which are clear, and is absorbed by the retina. Thus, the structure of the eye most vulnerable to visible light is the retina.

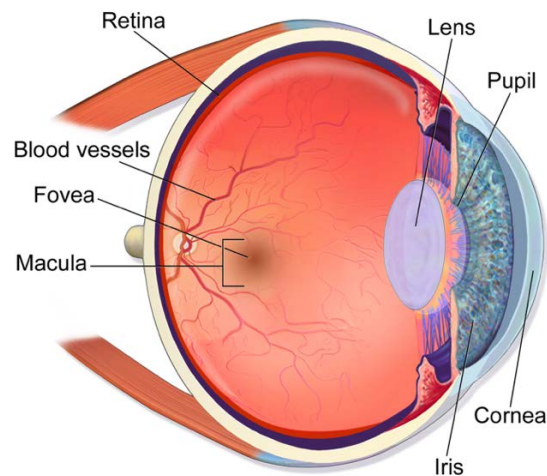


Figure 7 – Structure of the eye (Attribution: BruceBlaus via Wikimedia; CC 3.0)

If the heat of absorption is too great, the retina can suffer heat damage (i.e., a burn). Whether the damage affects sight depends on the size and location of the burn.

A retinal burn can disrupt vision and with time the retina can recover/heal, just as skin can. A small burn outside the central vision (fovea) may cause little or no lasting effect, while a more severe burn can cause permanent vision loss. Visual loss can often be compensated by the brain, which “fills in” the spot so it is less noticeable.

Loss in the fovea is more serious since this can cause a hole in the central visual field. For this reason, persons exposed to laser light are cautioned not to look directly at the light. If exposure is necessary (such as a police pilot searching for a laser perpetrator), look off-axis.

3.3.2 Cornea

Visible light passes through the surface of the eye, the cornea, and thus does not damage the cornea. Some pilots have reported corneal injuries after a laser illumination. Such injuries are from post-illumination causes such as rubbing the eye too hard.

3.3.3 Light Level That Can Cause Injury

For eye exposure to lasers with wavelength between 380 and 780 nm and an exposure duration of 0.25 seconds (e.g., a person can detect the laser light and can blink and/or turn away within 0.25 seconds), the Maximum Permissible Exposure is an irradiance of 2.6 mW/cm².

Once an exposure begins to exceed the MPE, injury to the retina becomes increasingly possible. The more the MPE is exceeded, the greater the chance of injury, and the more severe the injury.

Generally, retinal injuries are not seen from hand-held lasers until the MPE is exceeded by a factor of 10 or more. Such injuries generally occur at close range to the laser (within feet or yards).

3.3.4 Pilot Retinal Injuries are a Remote Possibility

Many lasers involved in aircraft illuminations have been found to be relatively low-powered Class 2 (<1 mW) or Class 3R (1 to 5 mW) lasers. They have short Nominal Ocular Hazard Distances. For example, the NOHD of a 5 mW laser pointer with a 1 mrad divergence is about 50 feet. (This assumes a person blinks and/or moves away within 0.25 seconds, so the exposure is accidental or unwanted.)

While these Class 2 and 3R lasers are bright enough to cause visual interference, even at close range they are highly unlikely to cause eye injury unless a person deliberately stares into the direct or reflected beam.

Higher powered Class 3B (5 to 500 mW) and 4 (≥ 500 mW) hand-held lasers have been involved in aircraft illuminations as well. These have longer NOHD's. A 1000 mW (1 W) laser with a 1.5 mrad divergence has a NOHD of 490 feet. A 3000 mW (3 W), 2 mrad laser has a NOHD of 640 feet.

At first glance it might seem as if such lasers could cause injury at 490 or 640 feet. But the Nominal Ocular Hazard Distance is just that – *nominal*. For a variety of reasons, there is only a remote possibility that pilots will sustain a retinal injury from the type of hand-held lasers that have been involved in FAA-reported illumination incidents.

- It is difficult for a person to keep a hand-held laser focused on a target (such as an aircraft) that is hundreds or thousands of feet away. The laser will sweep across the eye instead of being steady. This reduces the exposure time and does not allow heat to build up.
- The target (aircraft) is usually in motion relative to the laser; again, this makes it difficult to keep the beam on the target.
- Laser beams diverge (spread out) so that what is a tiny dot close to the laser is many inches or feet in diameter at the aircraft. This divergence spreads out the light so that only a small portion directly enters a pilot's pupils. For example, at 500 feet from a typical low-powered laser pointer with 1 milliradian divergence, the beam will be 6 inches in diameter. After being spread so much, less than 1% of the pointer's original light output will enter a dark-adapted pupil 0.28 inch (7 mm) in diameter.

This is why it is not valid to compare the adverse effects of a given laser at close range – a few feet or yards – to those of the same laser at aviation distances – hundreds or thousands of feet away.

- Microscratches on the windscreen, and refraction from the windscreen material, further spread out the laser light.
- For consumer-grade hand-held lasers, in general the higher the power output, the larger the beam divergence. (This principle was applied to the earlier NOHD example distances.) So while the power is going up, the beam is also spreading out more. This partially counteracts the power increase in terms of irradiance (power density) at the eye.
- As laser power increases, the NOHD increases more slowly. Specifically, the NOHD increases as the square root of the power increase.

Here is an example comparing two lasers, one that is 5 mW and one that is 20 mW – four times more powerful. The NOHD only increases two times (square root of four); from about 50 to about 100 feet. This, combined with the divergence increase discussed above, is beneficial for laser safety.

A laser that is, say, 10 times more powerful than another laser is not 10 times more hazardous to pilots. The hazard to the pilot depends on the irradiance at the pilot's eye. The NOHD would be only 3.14 times longer (square root of 10), and if the more powerful laser has an increased divergence then the NOHD would be less than 3 times longer.

- The concept of Maximum Permissible Exposure includes what can be considered a "safety factor." So laser light at the MPE level is unlikely to cause a significant or permanent retinal lesion. Said another way, a person directly exposed to laser light at the NOHD, or even well within the NOHD, is unlikely to have a significant or permanent retinal lesion.

This is why, out of the over 56000 laser illumination incidents reported to the U.S. FAA and the U.K. Civil Aviation Authority between 2004 and 2017, there have been no proven or documented cases of permanent eye injury to pilots, according to FAA, CAA and independent laser/aviation safety experts.

A January 2018 U.K. government report, responding to comments from pilots, the public, laser safety experts, and others, concluded "[t]here have been no recorded cases of damage to vision of pilots from laser attacks (laser pointers directed from the ground at planes in flight). Due to the broadening and weakening of the laser beam light with distance, there is no risk of permanent vision damage. Rather, the danger comes from the distraction that laser pointers can cause to pilots." (Source: "Call for evidence: laser pointers - government response," published by the U.K. Department for Business, Energy & Industrial Strategy.)

3.3.5 Post-Exposure Eye Injury Concerns

Pilots exposed to laser illuminations should “fly the plane” and follow the procedures in Appendix A. They should concentrate on flying and not be unduly worried about permanent harm to their vision. If it is necessary to rub the eye, they should be cautious not to rub too hard which can cause painful corneal abrasions.

If exposure effects (such as headache, blurred vision, eye pain, afterimages lasting more than a few minutes, etc.) persist and/or are worrisome, pilots should seek qualified medical assistance from an ophthalmologist, retinal specialist or optician, in that order of preference.

3.3.6 Consult Other Sources for Mitigation of Eye Injuries

This document is primarily concerned with mitigating aviation-related laser visual interference effects. There are numerous other resources which can be consulted regarding mitigation of laser eye injury hazards.

4. PILOT EDUCATION AND TRAINING

This section addresses the recommended aircrew operational procedures in response to the startle reaction from laser illuminations. These procedures utilize recognition and response (R&R) techniques that train flight crew's reaction away from startle and surprise by exposure reinforcement. These visual event rehearsals establish training behavioral objectives (TBO) for strategic memory that identifies event patterns with the appropriate procedure to return the flight crew and aircraft to a normal operating status.

4.1 Information to be Presented to and Learned by Pilots

4.1.1 Background Material

Pilots should be made aware that the primary concern from laser illumination is visual interference effects and the resulting impact on task performance. They should understand why eye injury is much less of a concern.

4.1.2 Laser Illumination Procedures and Checklists

During critical phases of flight, disruptive laser illuminations should be treated as any other abnormal or emergency situation. Appendix A has suggested procedures for dealing with laser illuminations. It is recommended that airlines should add procedures such as these to their company checklists.

4.1.3 Human Factors Issues

Any time a flight crewmember experiences visual impairment with loss of spatial orientation and loss of situational awareness, the safety of the flight becomes a priority. The flight crewmembers should immediately communicate their visual status and transfer control to the pilot that has not been affected by the laser illumination. If the pilot flying (PF) is executing a steady state departure turn, the human balance system will revert to inner ear (vestibular sensing). This information is highly unreliable due to the visual/inner ear conflict known as sensory cross coupling. This cross coupling can influence the crewmember to make inappropriate decisions with respect to aircraft control.

Low altitude terminal operations below 10000 feet are a critical phase of flight, during which time the crew's visual, mental, and physical workloads are at their highest. At night, there are limited visual cues. The effects of a laser illumination could elevate the visual workload and reduce the flight crew's ability to recognize and respond. The recovery time for vision impairment varies with the intensity of the laser at the pilot's eye position, how well the pilot is dark-adapted, ambient flight deck illumination, and other physiological factors such as age of the pilot. However, for low intensity single exposures, a majority of the visual function will be restored in a reasonable time. The aftereffects may still affect the flight crewmembers' ability to restore color and symbology contrast recognition.

The startle effects of distraction, disruption, disorientation, and operational incapacitation are major factors that determine the level of impairment to spatial orientation and situational awareness.

In summary: During critical phases of flight, any visual impairment due to laser illumination can pose a possible disruption to verification of the aircraft's configuration or its flight guidance status. Laser illumination may induce an unwanted visual effect known as a startle effect. The four distinct types of startle effects are distraction, disruption, disorientation, and operational incapacitation. How these startle effects will affect the crewmember will depend upon the phase of flight, airport arrival and departure procedures, aircraft configuration, and altitude (AGL – Above Ground Level).

4.1.4 Communication

Communication procedures for the flight deck should be developed to determine transfer of control protocol. In addition, Air Traffic Control (ATC) procedures should be followed to report laser activity, laser illuminations, and ATC aircraft handling in the air or on the ground.

4.1.5 Use of Laser Glare Protection

Pilots should be made aware of the various types of Laser Glare Protection, including sun visors, eyewear, and windscreen film, as discussed later in this document. They should understand when LGP is appropriate, the advantages and disadvantages of various types of LGP, and how to select and evaluate LGP for use in a specific cockpit prior to deployment.

4.2 Training Considerations

The concepts in the prior sections can and should be presented in various ways, such as printed study material, videos, and classroom presentation and discussion. Training should culminate in experiencing the startle effects of bright light exposure in as realistic a form as time and budget allows. Pilots should experience, ideally in a simulator, the startle effects of laser light: Distraction, disruption, disorientation, and operational incapacitation. They should recognize the event, and then respond with the appropriate checklist procedure to reduce the laser effects and restabilize the aircraft profile.

Test and evaluate to ensure students have adequately mastered the concepts.

The objective of training is to condition the person to respond rapidly and safely if a laser illumination event occurs.

It should be sufficient to present these concepts one time for each method; e.g., once in printed material, once through videos, once in a classroom, and once in a simulator.

If laser illumination incidents significantly change, then updates or new training would be necessary; for example, if the power or brightness of lasers involved in incidents significantly increases, if new wavelengths become common, or if a rising number of incidents greatly increases the likelihood of experiencing an illumination.

4.2.1 Training Videos

In 2009 the FAA and Air Force jointly produced a video to help educate pilots and others. This is available on YouTube; search for the keywords "FAA Air Force Aircraft Laser Illumination." There is a full 21-minute version which is also available on the FAA website, <https://www.faa.gov/tv/?mediaId=526>. However, it may be better for pilots to view the 13-minute "extended version" on YouTube which condenses the material that is most important to pilots.

In April 2013, the L.A. Sheriff's Department released a video entitled "Laser Strike". The video was produced in association with the LASD Aero Bureau, the U.S. Department of Homeland Security, and the FBI. They use this for training, and it may be useful to other law enforcement aviators. To find this on YouTube, search for the keywords "Laser Strike LA County Sheriff's Dept."

Those presenting these or similar videos should review them in advance. There may be material which is outdated, which overstates the possibility of injury, or which is overly dramatic or sensationalized. Any such material can be updated or clarified so pilots do not receive an incorrect impression of laser illumination effects.

4.2.2 Use Colored Light in Presentations

For in-person presentations, the use of colored flashlights is suggested; for example, to allow pilots to experience the difference between glare and flashblinding levels. Providing simulated laser exposure in a classroom or similar presentation gives pilots an understanding of the issues involved.

However, it is vital that pilots also experience what a laser illumination is like under realistic conditions. This helps “inoculate” pilots so they are instantly aware of what to do, and also so they understand the limits of a laser illumination – “It does not get worse than this.”

Ideally, this means use of a simulator. A full motion simulator is preferred, so pilots can experience the loss of vestibular information due to startle from a bright light. However, if only fixed base simulators are available or within budget, these still can give a good idea of what a bright light exposure is like, and how to recover from it.

4.2.3 Suggested Procedures for Flight Simulation

The pilot should be given a somewhat difficult task, during a critical phase of flight such as a short final approach or an emergency situation. Without warning, use a colored light from a flashlight at a moderate glare level to illuminate the windscreen, shining directly into the pilot's eyes, similar to Figure E3 in Appendix E.

For training purposes, setting an exact brightness level is not necessary. The glare should be such that a person cannot see past the light while it is on, but it is not so bright as to leave an afterimage.

After completion of the simulation run, the instructor should go over the pilot's response, noting any deviations from the procedures listed in this document. Stress to the pilot that this could have been a real laser on a real flight. Address any concerns or questions raised by the pilot; for example, “Should I seek medical attention?”

Repeat the run once or twice, with some differences such as using different flight characteristics, or having the light come on at different times.

A 2003 FAA study described in Appendix B followed procedures similar to the above. A key result of the study was:

“Once they realized that the duration of the laser exposures were brief, several pilots commented that they were less concerned about the laser's influence on their performance. Consequently, they became increasingly comfortable flying, even while visually impaired, during and immediately after exposure.... Acquainting pilots with low-level laser exposure could minimize its effects and reduce the chance of an extreme reaction.”

For more information, review Appendix B which summarizes the study and has a link to the full report.

4.2.4 Alternatives to Full Flight Simulation

Since time in a flight simulator is limited and expensive, there may be other ways to allow pilots to experience a laser or bright-light flash under a realistic cognitive workload.

For example, one company has developed a virtual reality (VR) simulator based around the Oculus Rift. This interfaces with a low-cost flight simulator yoke. A pilot dons the VR headset and begins to “fly”. At some point, the VR headset viewscreen fills with a simulated laser strike, blocking the pilot's view briefly, like a real-world laser illumination. Pilots report that this gives a good simulation of the challenges involved in flying after a laser illumination.

4.2.5 Summary of Training Experience

The most important training outcome for a pilot is being able to mitigate adverse reactions from being startled. The pilot needs to know the “recognize and recover” techniques to turn what could be a major disruption into a minor distraction. The ideal way to prepare a pilot is to do this under a realistic cognitive workload, e.g., during flight simulation.

4.3 Considerations for Use of Incoherent Light and Lasers

4.3.1 Use of Conventional Incoherent Light for Training or Demonstrations

For training or demonstration purposes, where light will be aimed directly at a subject (e.g., a pilot in a classroom or simulator), it is sufficient to use a non-laser light source such as a green LED flashlight, or a white-light flashlight with a green filter, that can be focused to different spot sizes. (Because over 90% of FAA-reported laser incidents involve green light, green is the preferred color for training.)

Figure 8 shows two representative focusable green LED flashlights. The LED chip itself emits green light, so no external green filter is needed.



Figure 8 - Examples of flashlights using a green LED as the light source, with a focusable beam

NOTE: These are shown as examples; no specific endorsement of these models/manufacturers is intended.

In committee testing with pilots in a cockpit mockup, use of a green LED flashlight was found to effectively emulate the brightness and general color of a laser strike. (See Appendix E for details.) Advantages of this technique include:

- **Pilot acceptance and safety:** No laser light is being aimed at a person's eyes – only conventional incoherent light.
- **Low cost:** A focusable green LED flashlight costs less than \$20.
- **Ease of setup:** There is no need for expensive, complicated meters to confirm that a laser exposure is safe.

It should be noted that there are a few disadvantages:

- **No laser speckle:** Laser light has a distinctive shimmering, granular speckle that cannot be duplicated with incoherent light.
- **Not a precise color match:** It is difficult to match the exact color of a laser. A filtered (colored) incoherent light source may be “off” a bit in color compared side-by-side with a laser. For training purposes the color differences are not significant.
- **Not for use with LGP:** Most importantly, laser glare protective eyewear and film may let through significantly more of the incoherent light, which emits over a much wider range of wavelengths than laser light. Someone trying on LGP, when looking at the colored light may falsely believe that the LGP is ineffective. For this reason, use of a colored incoherent light is NOT recommended when demonstrating the use or effectiveness of LGP. This is discussed in more detail below.

In the view of pilots who were exposed to both laser and LED sources during committee testing, the advantages of using a colored incoherent light for training or demonstration purposes outweigh the disadvantages.

The primary exposure should be done with a green LED or green color filter. If time permits, it may be interesting to also demonstrate other colors such as blue or red; however, this is not necessary.

For training or demonstration purposes, the exposure level can be set “by eye”. This is done by adjusting the focus to its widest setting, and then tightening the beam width (thus increasing the brightness) until the desired effect – glare or the onset of flashblindness – is seen. Usually simple glare, where it is impossible to see past the light until it is turned off or moved away, is sufficient to demonstrate a typical laser strike.

4.3.2 Selecting a Laser for Demonstrations

The use of actual laser light is also suggested to demonstrate speckle, and to demonstrate how Laser Glare Protection attenuates laser light.

Such demonstrations should be done only indirectly, by aiming the laser light onto a wall or similar surface. (Laser light should not be aimed at pilots’ eyes unless extensive measurements and checks are done by knowledgeable, trained laser safety personnel using the correct equipment and techniques to ensure that accurate, safe irradiance levels are used.)

As discussed above, it is NOT recommended to use colored incoherent light from a standard flashlight to try to demonstrate the effectiveness of Laser Glare Protection eyewear. This is because LGP eyewear is designed to block one or a few particular wavelengths from common lasers. However, colored incoherent light sources emit over a much wider range of wavelengths. The undesired result is that the LGP will let through much more of the incoherent light and thus may incorrectly appear to not provide glare protection.

Because green lasers with a wavelength of 532 nm are the most common, this color should be the first choice. If LGP eyewear attenuating multiple wavelengths is in use, lasers with those wavelengths will also be useful in demonstrations.

4.3.2.1 Laser Pointers

The most readily available laser source is a laser pointer. These should be purchased from reliable sources. The laser should be Class 3R (power <5 mW). This is considered safe if handled carefully, with no deliberate direct eye exposure to the beam. Some pointers mislabeled as Class 3R may actually be much more powerful, so treat the beam with caution.

4.3.2.2 Laser Illuminators

An especially effective laser source for demonstrations is a laser illuminator. This is a flashlight-type device with a focusing lens that can be rotated to change the size of the laser spot. The laser source must be continuous wave (CW); pulsed lasers cannot be used for this application.



Figure 9 - Laser illuminator

NOTE: This is shown as an example; no specific endorsement of this model/manufacturer is intended.

At its narrowest (tightest) setting, the beam is still much wider than a standard laser – perhaps a few inches across at a distance of 2 m. At its widest setting, the beam is like a laser floodlight, with a wide “disk” of light. At any setting, the laser spot is roughly uniform in intensity across the spot.