**Laser Hazards in Aviation**

*Quay Snyder, MD, MSPH*

*Virtual Flight Surgeons*

*Aviation Medicine Advisory Service*

**Introduction**

Laser light sources are characterized as single wavelength (color) emissions with minimal divergence of the beam over significant distances. For pilots, the dangers from exposure to lasers in the aviation environment are threefold. First, the visual effects of lasers may compromise aviation safety, particularly at critical phases of flight. Secondly, the laser may cause temporary or permanent physical damage to the eyes. Finally, laser exposures may result in psychological trauma with residual effects.

This paper describes the physiology of vision and the characteristics of lasers. It also discusses the high-risk factors for visual damage and hazards to aviation safety related to lasers. A self-assessment tool for pilots exposed to lasers is highlighted.

**The Problem**

Flight crew laser exposures incidents have been increasing worldwide over the last decade with the advent of readily available handheld lasers to the general public. From 2005 when 283 laser incidents were reported to the FAA until 2011 when thirteen times as many (3,591) events occurred, there was a steady yearly rise. In 2012, the FAA reported 3,482 events, the first decrease since collection of statistics.

Great Britain, Canada and Australia report similar rises in aircraft being accidentally struck or intentionally targeted by ground-based lasers, usually handheld. Per capita and aircraft flights, these countries have higher rates than the US.

The trend may be flattening out in the US due to increased awareness of the potentially severe risks posed by these events. The Federal government has recently increased the penalties for striking an aircraft with a laser. In 2012, President Obama signed a law subjecting those who knowingly aim a laser pointer at an aircraft to $11,000 fines and up to 5 years in prison for each event. The media has increased coverage of both aircraft struck by lasers and prosecutions of offenders, increasing public awareness of the problem. Other countries are also taking steps in increase the civil and criminal penalties for interfering with a flight crew by use of laser illumination.

**Physiology of Vision**

An individual perceives images by focusing visible light entering the eye on the retina, a nerve layer at the back of the eye and transmitting the nerve impulses to a portion of the brain termed the ocular cortex. Because of the eye’s ability to focus small amounts of energy of various wavelengths, high energy light may cause damage to the retina or other components of eye. Non-visible wavelengths of light, infrared and ultraviolet, may cause damage without a person being aware of the light energy.

The outer, clear layer of the eye is termed the cornea. It is responsible for protecting the eye and much of the focusing of light on to the retina. Because of its impact on focusing (refraction) and the easily assessable location, it is the site of refractive surgeries such as LASIK.

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Figure 1

As light passes through the cornea, it enters the eye through the pupil which controls the amount of light/energy entering the eye. The pupil dilates and constricts when the circular iris (colored portion of the eyes) adjusts in size. It then passes through the lens which further focuses the image further by adjusting its thickness to attempt to bring the image clearly to the retina. [Figure 1]

The retina is composed of several layers of specialized nerve cells that perceive light and then transmit the energy to the brain where an image is formed. The “rods” of the eyes are more concentrated in the periphery and serve to detect motion and provide vision in low light conditions. The rods do not perceive fine detail or colors very well and have limited visual acuity.

The “cones” are concentrated in the area the cornea and lens focus incoming light and have a rich blood supply. Cones perceive colors and give the best visual acuity, but require more light to function. The highest density of cones is found in the macula, viewed as a darker red spot in the back of the eye. Different cones perceive different wavelengths of light or colors, such as red, blue and green. A combination of cone stimulation perceives the full spectrum of visible colors.

The optic disk is the bundle of nerves travelling from the retina to the brain as well as the blood supply to the eye. Because it does not have rods or cones, it is frequently termed “the blind spot” and appears as a pale area on the back of the eye with blood vessels branching out from it. [Figure 2]

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Figure 2

The eye perceives equal intensity of various wavelengths with different sensitivities. Green light (530 nm) is perceived as 8–35 times brighter than an equal luminosity of red light (630–670 nm). This is why emergency vehicles and safety vests use have green colors as opposed to red. [Figure 3]

Daytime light adapted (photopic) vision of the cones is more sensitive to red light whereas dark adapted night (scotopic) vision is not affected by red light. Thus red lighting is frequently used in the cockpit to preserve night vision as the rods lose effectiveness when exposed to light wavelengths they can perceive. [Figure 4]

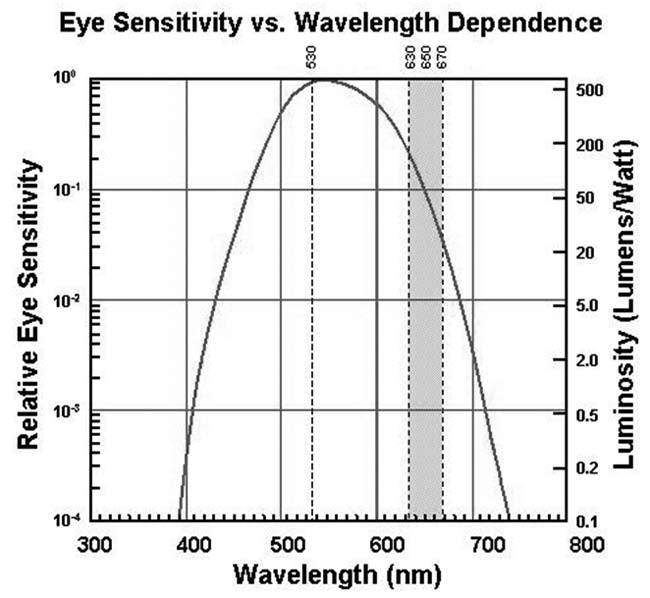


Figure 3



Figure 4

**Laser Damage to the Eye**

Energy entering the eye may cause damage in various parts depending on the intensity and wavelength. Ultraviolet (UV) in the frequency of 280–400 nm is absorbed by the iris, lens, cornea and fluid in the front of the eye. High exposures to UV light may cause cataracts in the lens.

Visible light with wavelengths of (400–760 nm) is absorbed most strongly by the retina. These wavelengths provide the images we see, but may also be over-stimulated to cause glare-induced *distraction*. With more intense sudden light, a persistent image may linger as the retinal cells are still stimulated after the light exposure ends. This is the phenomenon of an *after-image*following a flash picture. With even higher intensities of visible light, temporary flash blindness may occur. With *flash blindness*, individuals cannot see any image clearly until the nerve cells of the retina recover from the extremely strong stimulus. When vision does return, it does so gradually over minutes. Night vision is severely degraded for a prolonged period of time with each of these events.

The near-infrared wavelengths (760–1400 nm) are not visible to humans, but may cause damage due to heating and interrupting the blood supply of the retina. If the energy is high enough, this damage is permanent and vision is lost for the affected section of the retina. If the light strikes both eyes, a small blind spot may form. However, if the light only strikes one eye, the overlapping visual fields of the eyes may prevent a blind spot from being perceived when using both eyes.

Medical professionals use this ability to “burn” the eye with laser energy of various wavelengths for beneficial medical purposes. Examples include halting leaking blood vessels in the eye of diabetics, vaporizing layers of the cornea during LASIK procedures and in treating glaucoma patients.

Lasers may be used for intentionally harmful purposes in certain military applications with higher power emitters. In addition to targeting, lasers may temporarily or permanently blind a combatant. Much higher powered lasers may be used to destroy aircraft or incoming missiles.

**Risk Factors**

Many factors affect the likelihood of visual damage. These factors include features of the laser, environmental conditions, distance from the laser source, phase of flight and a pilot’s reaction to the laser.

**Laser Characteristics**

Lasers are classified by the *maximum power* they can emit. Class 1 lasers emit less than 0.5 milliwatts (mW) of power. They are used in devices such as CD and DVD players to read the digitally encoded data. Class 2 lasers emit 0.5–1.0 mW and are found in retail store barcode scanners. For practical purposes, these categories of lasers will not cause eye damage if used as intended.

Class 3 lasers are divided into Class 3a having powers of 1.0–5.0 mW and Class 3b having 5–500 mW. The class 3a laser is the most powerful allowed to be sold in the US and be termed a “laser pointer.” The UK limits the maximum power of laser pointers to 1.0 mW. Lasers with this power are unlikely to cause physical damage to the eye, although glare and distraction hazards exist at close range.

Class 3b and Class 4 (> 500 mW = ½ Watt) lasers have definite potential for permanent damage to the eye and must be sold with an interlock key to turn them on. These lasers are used for industrial purposes, for targeting of weapons by the military and for light shows by entertainment groups, to name a few examples. *Flash blindness, afterimages, glare and distraction* may occur at distances of several miles with these lasers. Lasers having 1 W (1000 mW) of power are available for purchase on the internet for $300 powered by lithium batteries.

The *wavelength* of the laser used is also important. As noted above, the eye perceives green light (~532 nm) about 35 times brighter than red light (~760 nm) and up to 30 times as bright as blue (445 nm) lasers. Therefore the distance that incapacitating effects can occur at is nearly five times farther with green lasers than with other colors.

*Divergence* is the measure of the spread of the laser beam over distance measured in milliradians or degrees. The divergence is proportional to the wavelength meaning short wavelengths (blues) will diverge or spread out less than a longer wavelength source (red). Because a laser has a *coherent beam* of a single wavelength versus the *incoherent beam* of an incandescent flashlight or search light, it has much less divergence and focuses more energy on a smaller point.

Pulsed lasers emit more energy in short bursts than a continuous laser of similar power.

**Environmental Factors**

Daytime exposure to lasers is less hazardous than nighttime exposure because the pupil is constricted, allowing less light into the eye than the fully dilated pupil in darkness. Moisture, haze or other types of atmospheric obscuration can reduce light energy from a laser or cause the beam to be diffracted and diverge. Some temperature changes layers in the atmosphere may reduce a laser’s ability to penetrate from the user’s perspective, but still may penetrate to objects beyond, such as aircraft.

Other environmental factors depend on whether exposure to the laser is direct or indirect, such as entering the eye from an angle or being reflected off a surface. Eyeglasses may increase or decrease damage to the eye by concentrating the beam in those correcting for nearsightedness or blocking beams of specific wavelengths. This is the principle behind laser protective eyewear.

**Distance**

The most significant factor in danger caused by lasers is the distance from the source. Light intensity decreases with the square of the distance. Thus, doubling the distance from the source reduces the luminosity by a factor of four. Likewise, the distance from which a laser can cause damage is reduced by the square root of the power increase. For example, a 500 mW laser will cause damage at 10 (not 100) times the distance of a 5 mW laser. [Table 1]



Table 1

**Aviation Safety Compromise**

The compromise to aviation safety is highly dependent on the *type of operations* and the *phase of flight*. As noted above, distance is a big factor in the ability of a laser to cause damage, but more importantly, distraction, glare, afterimages and flash blindness. An airline flight crew cruising at FL370 may be able see a ground based laser, but not have any significant hazard presented by the laser. The lower portion of the cockpit and recessed location of the crew seats from the wind screen also makes significant exposures unlikely.

In contrast, a helicopter with a large bubble canopy extending down to the rudder pedals presents a large area of potential laser illumination. Once the laser hits the canopy, the light can be refracted within, causing the entire canopy to glow with a dazzling green light and totally obscuring vision. Helicopters generally operate in lower and slower conditions than airplanes making them more vulnerable to both unintentional exposure and intentional targeting of aircraft.

Aircraft in critical phases of flight put the aircrew at particular risk. Taxiing, takeoff, approach and landing put an aircraft close to the ground near to laser sources. Flash blindness and other hazards are more likely to occur and have severe consequences during these phases of flight when the aircraft is slow, close to the ground, the aircrew is task saturated and vision both inside and outside the aircraft is critical. *A laser exposure that does not cause permanent damage to the eye can still be disastrous because of the interfering effects on the ability to safely complete all duties.*

Other risk factors include VFR type operations with the eyes outside of the cockpit and predictable flight paths which increased the vulnerability to intentional targeting.

**Types of Injuries and Effects**

Laser effects include the distraction, glare, afterimages and flash blindness discussed above. Although these are not injuries per se, these effects certainly can interfere with safe flight operations.

*Temporary injuries* due to lasers include pain in the eye, a burning sensation or feeling of grittiness to the lid and a watering of the eyes. There can be photophobia (light sensitivity), a slowed pupillary response and spasm of the lens, making focusing on objects at different distances difficult.

*Permanent eye injuries* due to aviation laser exposures are very rare. Retinal damage in the form of burns, hemorrhage and holes causing permanent blind spots are possible with a powerful enough laser at a close enough distance.

Many injuries are *prevented or minimized* by a person’s natural “blink and turn” reflex when exposed to a bright light source. This minimizes time of exposure as well as avoiding having the laser beam remain on one part of the retina for any significant time. Calculations of injury potential make conservative assumptions with a widely dilated pupil, slow blink reflex and continuous exposure to a laser light source. The Nominal Ocular Hazard Distance is the maximum possible distance for permanent eye injury and is noted in the left column of the chart above.

The *most common injury from laser exposure is not physical, but psychological*. The trauma of safety compromised at critical flight phases may cause immediate distress about safely completing the flight. Longer term concerns may recur when flying in a similar situation, to include the possibility of PTSD. Because of uncertainty about eye health and risk to aviation careers, further anxiety may develop until resolved by medical personnel or the employer. Many eye specialists are not familiar with laser exposure evaluations, creating more anxiety.

**Risk Mitigation Strategies**

What should a pilot do when exposed to a laser beam? There are excellent references giving guidance to pilots. Both the Air Line Pilots Association, International and the British Air Line Pilots Association have published documents to fit into a flight manual. The FAA, CAA and Transport Canada have technical manuals and guidance on how to respond to laser illumination as well as documents to report such incidents to appropriate authorities. The guidance below is adopted from ALPA International:

**Recommended Crew Actions**

1. When struck by a laser on approach, do not continue to look into the beam. Shield your eyes and *go heads-down immediately.* This action will protect your eyes while the laser light is illuminating the cockpit.
2. Consider executing a missed approach. As with any event that is the catalyst for a go-around (e.g., low weather, birds, aircraft on the runway), a go-around may be your most prudent course of action in responding to a laser illumination.
3. Do *not* rub your eyes.
4. Consistent with flight manual restrictions, use cockpit automation to the fullest extent.
5. Maintain control of aircraft, monitoring configuration, altitude, and airspeed to maintain or re-establish desired flight profile.
6. Turn instrumentation and panel background lighting *up*.
7. Communicate with other flight deck crewmembers and assess condition. In the event of an injury, declare an emergency and request priority handling, if necessary.
8. Transfer control of aircraft to the other pilot, if necessary.
9. Expeditiously advise ATC of the laser event. Provide the most accurate description possible of the location of the laser source, beam direction, and color and length of exposure (flash or intentional tracking).
10. While in the arrival area, if you are notified that a laser event has been reported and remains unresolved, request a different runway or ask for holding until the area has been secured and the threat has ceased.
11. Consider need for diverting if laser threat continues.
12. Follow all company protocols relating to reporting laser illuminations in a safe and timely fashion.
13. Cooperate with law enforcement officials conducting follow-up investigation of the event.
14. Download, print and use the ALESA form, and see an eye specialist if your responses to the ALESA form suggest doing so.
15. Consult an Aerospace Medicine specialist if eye damage is suspected/confirmed.

The ALESA (Aviation Laser Exposure Self Assessment by Stephanie Waggel, MS for UK CAA) is a downloadable form for pilots to determine if they need to consult an eye professional to evaluate for possible permanent damage to the eye or if it can be self treated. Most cases do not require professional medical attention, which should reassure pilots and minimize psychological damage from exposures. <http://www.caa.co.uk/docs/49/Alesa%20card%20web.pdf> [reproduced below]

**Conclusion**

Handheld lasers do present a threat to aviation safety, but permanent eye damage is unlikely. Risks can be mitigated if flight crews and the public understand the characteristics of lasers, the injuries they can cause to the eye, and how exposure to lasers during critical phases of flight can be dangerous. Flight crews are encouraged to follow the guidance offered by the various aviation agencies in order to respond to a laser exposure safely.