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Laser exposure incidents: Pilot ocular health and aviation safety issues

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Abstract
INTRODUCTION: A database of aviation reports involving laser illumination of flight crewmembers has been established and maintained at the Civil Aerospace Medical Institute. A review of recent laser illumination reports was initiated to investigate the significance of these events.
METHODS: Reports that involved laser exposures of civilian aircraft in the United States were analyzed for the 13-month period (January 1, 2004, through January 31, 2005).
RESULTS: There were 90 reported instances of laser illumination during the study period. A total of 53 reports involved laser exposure of commercial aircraft. Lasers illuminated the cockpit in 41 (46%) of the incidents. Of those, 13 (32%) incidents resulted in a visual impairment or distraction to a pilot, including 1 incident that reportedly resulted in an ocular injury. Nearly 96% of these reports occurred in the last 3 months of the study period. There were no aviation accidents in which laser light illumination was found to be a contributing factor.
CONCLUSION: Operational problems have resulted from laser illumination incidents in the national airspace system. Eye care practitioners, to provide effective consultations to their pilot patients, should be familiar with the problems that can occur with laser exposure.
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LASER is an acronym that stands for light amplification by stimulated emission of radiation. When a laser beam is incident on an object, energy may be partially absorbed, raising the temperature of the surface or the interior of the object, potentially causing an alteration or deformation of the material. In addition to thermal effects upon tissue, there also can be photochemical effects when the wavelength of the laser radiation, typically expressed in nanometers (nm, or 10^{-9} m), is in the ultraviolet or blue region of the spectrum and irradiance level is high.[1]

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The human eye is more vulnerable to injury from laser radiation than the skin. Unlike skin, the cornea does not have an external layer of dead cells for protection.[2] In the mid-ultraviolet (<300 nm) and far-infrared (>1,400 nm) regions of the electromagnetic spectrum, the cornea absorbs energy and may be damaged. At certain wavelengths in the near-ultraviolet region and in the near-infrared region, the crystalline lens of the eye is vulnerable to injury.[1,3] Of greatest concern, however, is exposure to excessive levels of radiation in the retinal hazard region of the spectrum, approximately 400 nm (violet) to 1,400 nm (near-infrared), which includes the entire visible portion of the spectrum (approximately, 400 to 700 nm). Within the retinal hazard region, the eye's optical system focuses radiation to a point (10 to 20 μm in diameter), exposing the retinal tissue to high levels of energy per unit area.[2]

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Laser exposure is most hazardous when a direct laser beam, or its specular (mirrorlike) reflection, enters the pupil along the axis of vision when the eye is focused on a distant object. The energy density of the laser beam can be intensified up to 100,000 times by the focusing action of the eye. If the irradiance entering the eye is 1 mW/cm^2, the irradiance at the retina will be 100 W/cm^2.[4] Direct viewing of a laser beam through binoculars or some other magnifying device tends to increase the hazard, depending on the optical power of the device and the incident laser's characteristics.

The U.S. Food and Drug Administration's (FDA's) Center for Devices and Radiological Health regulates the manufacture of commercial laser products. Manufacturers must classify their laser products as class I, II, IIIA, IIIB, or IV. This is certified by product labels and a report showing that requirements of compliance standards are met. Table 1 below identifies the various classes of lasers, their maximum output, and labeling requirements.[5]

Studies show that exposure to a green class IIIA laser will cause retina damage in as little as 60 seconds, whereas no damage resulted from equally long exposures to a red class IIIA laser pointer.[6,7] However, brief exposures to low-level laser radiation are more likely to result in a temporary visual impairment. The severity and duration of the impairment varies significantly, depending on the intensity and wavelength of the light, the individual's current state of light (or dark) adaptation, the use of photosensitizing medications, and even the person's skin pigmentation (eye color). When the human eye is fully dark adapted, it is more sensitive to light at 507 nm, whereas the light-adapted eye perceives yellow-green light (555 nm) more vividly.

A temporary visual impairment is associated with adverse visual effects that include glare, flashblindness, and afterimage. Although none of these visual effects causes permanent eye injury, the distraction, disorientation, or discomfort that often accompanies them can create a hazardous situation for pilots performing critical flight operations.[8]

In the 1990s, several incidents of illumination of flight-crew personnel were attributed to light from laser demonstrations designed to amuse or attract the public. Subsequently, to protect aircraft operations, in 1995 the Federal Aviation Administration (FAA) established flight-safe exposure limits for lasers projected into specific zones of navigable airspace around airports. Development of these exposure limits relied on existing scientific research, along with consultation with industry and governmental laser experts and aviation safety personnel. The resulting guidelines were published in FAA Order 7400.2, Procedures for Handling Airspace Matters, Chapter 29, Outdoor Laser Operations.[9] The order identifies 3 zones of protected airspace around airports and assigns specific exposure limits to these zones (*see* Figure 1). Within these zones, laser emissions above that which could cause vision impairment and interfere with normal flight operations are prohibited. These zones include the laser-free zone (50 nW/cm^2) (*see* Figure 2), critical flight zone (5 μW/cm^2), and sensitive flight zone (100 μW/cm^2). Incident reports collected by Civil Aerospace Medical Institute's (CAMI's) Vision Research Team indicate that implementation of these guidelines has resulted in a substantial reduction in accidental exposure of pilots to entertainment and demonstration laser light shows. However, these procedures are only useful when laser proponents comply with applicable guidelines and voluntarily notify the FAA of proposed outdoor laser operations.

A database of laser exposure incidents has been maintained at CAMI for nearly a decade. As a result of numerous incidents that occurred in the fall/winter of 2004, there was renewed interest in lasers and their impact on aviation activities. This report reviews recent incidents involving lasers to investigate the significance of these events. Issues that eye care practitioners should be aware of when consulting with pilot patients concerned about this threat to themselves and aviation safety are also discussed.

Methods

Reports of high-intensity light illumination of civilian aircraft were collected from various sources including FAA regional offices, Transportation Security Administration (TSA), Department of Homeland Security/Federal Bureau of Investigation Information Bulletin, the FAA's Office of Accident Investigation, newspaper articles, and personal interviews with reporting and investigating personnel. Details from these reports were entered in a computer database maintained by the Vision Research Team at CAMI. Those reports that involved laser exposure of civilian aircraft in the

Table 1 Laser product classification and labeling information

Class	Max power mW	Logotype	Warning label
I	≤0.0004	None Required	None required
II	≤1	CAUTION	Laser Radiation—Do Not Stare into Beam
IIIA	≤5	CAUTION (Irradiance <2.5 MW/cm^2)	Laser Radiation—Do Not Stare into Beam or View Directly with Optical Instruments
IIIB	≤500	DANGER	Laser Radiation—Avoid Direct Exposure to Beam
IV	≥500	DANGER (>500 mW or pulsed >10J/cm^2)	Laser Radiation—Avoid Direct Exposure to Beam