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A Review of Recent Laser Illumination Events in the Aviation Environment

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16. Abstract

INTRODUCTION: Flight crewmember exposure to laser light, while operating an aircraft at night, has resulted in glare, flashblindness, and afterimage. Temporary visual impairment and the distraction, disorientation, and discomfort that can accompany it often result in hazardous situations. 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 of high-intensity light illumination of aircraft were collected from Federal Aviation Administration (FAA) regional offices, Transportation Security Administration, Department of Homeland Security/Federal Bureau of Investigation Information Bulletins, the FAA's Office of Accident Investigation, newspaper articles, and interviews with pilots submitted by the airline industry. Reports that involved laser exposures of civilian aircraft in the United States were analyzed for the 13-month period (January 1, 2004 – 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 visual impairment or distraction to a pilot, including 1 incident that reportedly resulted in 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:** The study of laser illumination incidents in the national airspace system can identify the operational problems that result from such events. Improved reporting and analysis of laser events enhances aviation safety by providing the FAA with data necessary to assist in the development of methods for mitigating the effects of laser exposure.

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A Review of Recent Laser Illumination Events in the Aviation Environment

INTRODUCTION

LASER is an acronym that stands for Light Amplification by Stimulated Emission of Radiation. The electrons of the atoms within the lasing medium are excited or "pumped" above their ground state. Energy contained in these electrons is amplified until it is released in the form of photons (particles of light), a process called stimulated emission. This process results in the laser emitting photons of a specific wavelength that are coherent (photons in phase with each other) and a directional (very strong and concentrated) beam of light. If this beam is incident on an object, laser energy may be partially absorbed, raising the temperature of the surface and/or the interior of the object, potentially causing an alteration or deformation of the material. These properties have been put to use in many ways, including laser surgery and material processing. In addition to thermal effects upon tissue, there can also 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).

Generally, in humans the eye is more vulnerable to injury from laser radiation than the skin. The cornea (the clear, outer most surface of the eye), unlike the skin, does not have an external layer of dead cells for protection (2). In the far-ultraviolet (< 300 nm) and far-infrared (> 1400 nm) regions of the electromagnetic spectrum, the cornea absorbs this 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 may be vulnerable to injury (Figure 1) (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 1400 nm (near-infrared), which includes the entire visible portion of the spectrum (approximately 400 – 700 nm). Within the retinal hazard region, the eye's optical system focuses radiation to a point (10-20 microns in diameter), exposing the retinal tissue to high levels of energy per unit area (2).

Laser exposure is most hazardous when the direct laser beam, or its specular (mirror-like) 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.

Two studies show that exposure to a green Class 3A laser will cause retina damage in as little as 60 seconds, while no damage resulted from equally long exposures to a red Class 3A laser pointer (5,6). However, brief exposures to low-level laser radiation are more likely to result in 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 dark-adapted (scotopic vision) it is more sensitive to light at 507 nm, while the light-adapted (photopic vision) eye perceives yellow-green light (555 nm) more vividly.

Temporary visual impairment is associated with adverse visual effects that include: glare (a temporary disruption in vision caused by the presence of a bright light within an individual's field of vision); flashblindness (the inability to see, caused by bright light entering the eye that persists after the illumination has ceased); and afterimage (an image that remains in the visual field after an exposure to a bright light). While none of these visual effects cause permanent eye injury, the distraction, disorientation, or discomfort that often accompanies them can create a

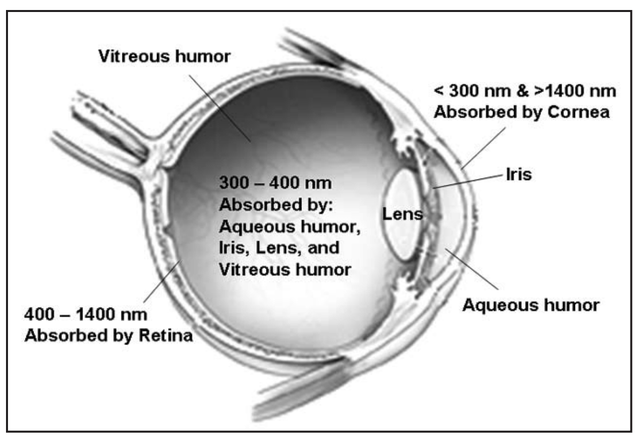

Figure 1: Light absorption characteristics of the human eye

hazardous situation for pilots performing critical flight operations (7).

In the 1990s, several incidents of illumination of flight-crew personnel were attributed to light from laser demonstrations designed for public amusement or attractions. Subsequently, in 1995 the FAA established flight-safe exposure limits for lasers projected into specific zones of navigable airspace to protect aircraft operations 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 (8). The order identifies three zones of protected airspace around airports and assigns specific exposure limits to these zones (Figure 2). 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) (Figure 3), critical flight zone (5 µW/cm^2), and sensitive flight zone (100 µW/cm^2). Incident reports collected by the 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. No order or regulation can prevent thoughtless individuals, criminals, or terrorists from using lasers to interfere with the operation of law enforcement and emergency medical evacuation helicopters or private and commercial aircraft.

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 outdoor laser operations and their impact on aviation activities. This paper reviews recent incidents involving lasers to investigate the significance of these events. It also discusses issues that Aviation Medical Examiners (AMEs) and eyecare practitioners should be aware of when consulting with pilots concerned about this new threat to themselves and aviation safety.

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 Investigation Information Bulletin, the FAA's Office of Accident Investigation, newspaper articles, and personal

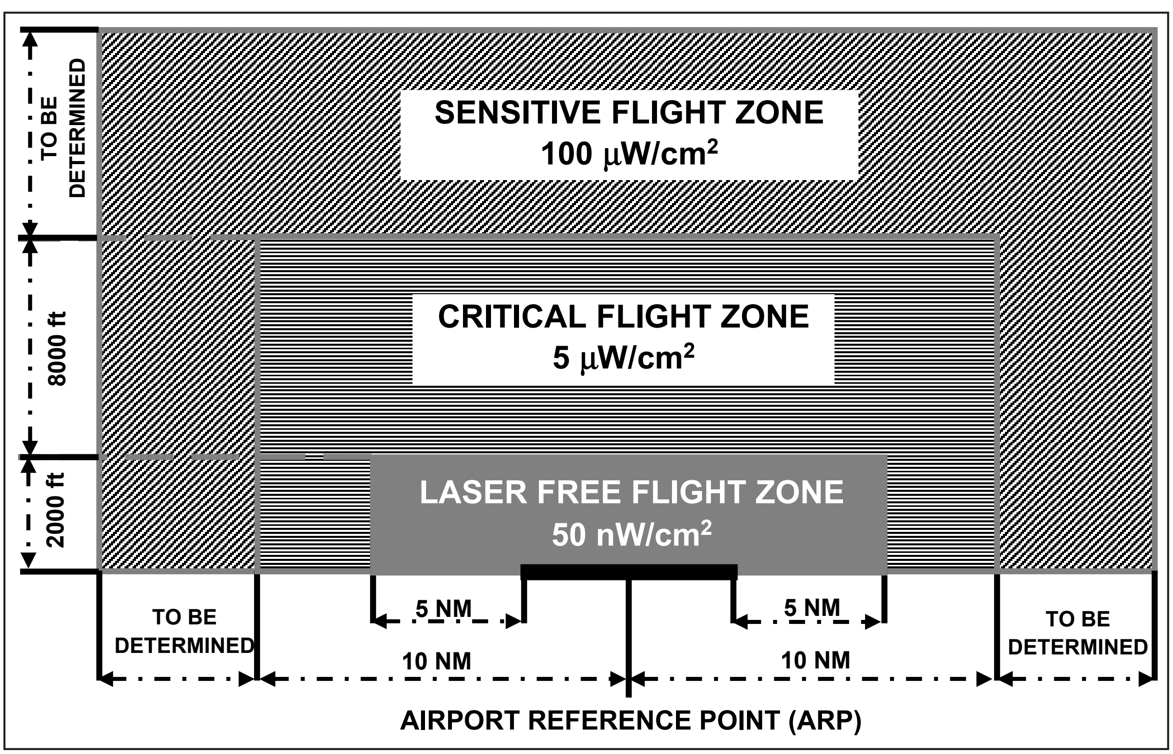

Figure 2: Zones of protected airspace around a single-runway airport

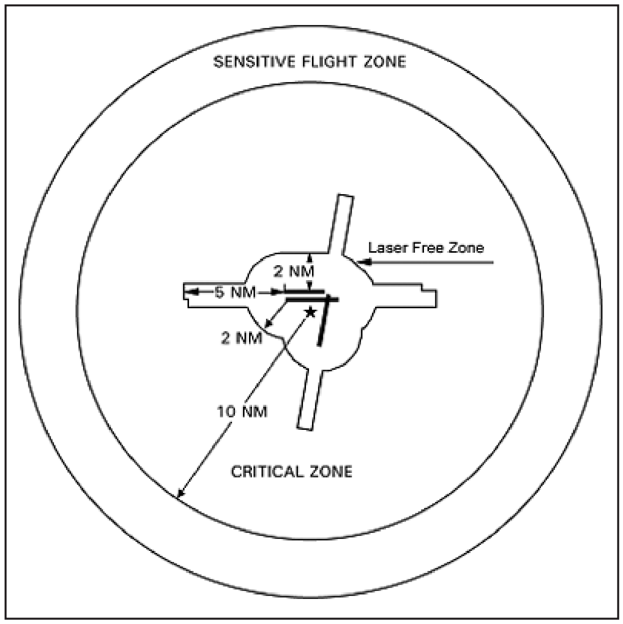

Figure 3: Protected zones of airspace around an airport

Table 1. 1/1/2004-1/31/2005 Laser Strikes by Month and Type of Flying

Month	**Type of Flying**				
	Commercial	**General Aviation**	**Law Enforcement**	**Unknown**	**Total**
May		1			1
Sept	2				2
Oct	1				1
Nov	4	1*		8	13
Dec	20	1	2	4	27
Total 2004	**27**	**3**	**2**	**12**	**44**
Jan 2005	**26**	**6**	**2**	**12**	**46**
TOTAL	**53**	**9**	**4**	**24**	**90**

**Blimp*

Table 2. Laser Incident Report Summary

Laser		Reported Visual Effects					
Event No.	Color	Momentary Distraction	Temporary Impairment	Glare	Afterimage	Flashblinded	Injury
1	Green	X					
2	Unknown	X	X				
3	Green	X	X				
4	Green	X	X	X	X	X	Retinal Burn
5	Green	X					
6	Green	X*	X				
7	Green	X	X‡			X	
8	Green	X	X‡				
9	Green	X	X			X	
10	Green	X*	X		X		
11	Green	X*	X				
12	Green	X	X	X	X		
13	Red	X	X			X	

* Annoyance
‡ Loss of Visual Acuity

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 United States were analyzed for the 13-month period (January 1, 2004 – January 31, 2005).

RESULTS

The laser illumination incidents of civilian aircraft are summarized by month and type of aviation operations in Table 1.

Ninety incidents of laser illumination of aircraft were reported during the study period. Of these, 53 involved commercial aircraft, 9 general aviation, 4 law enforcement aircraft, and 24 reports did not identify type of aircraft operation. Eighty-six (96%) of all the laser events were reported in the last 3 months of the study.

The laser illumination incidents of civilian aircraft are summarized in Table 2 by the color of laser and the type of visual effects experienced by flight crewmembers.

Lasers illuminated the aircraft cockpit in 41 (46%) of the incidents, but only 13 (32%) of these resulted in visual impairment or distraction of the pilot, which includes 1 incident that reportedly resulted in an eye injury. Of the 90 incidents reviewed for the study period, green laser light was reported in 62 (69%) incidents. Of the 13 incidents that resulted in visual impairment or distraction, 11 (85%) involved green lasers.

Incidents of illumination that resulted in visual impairment or distraction are summarized below:

» May 14, 2004

At 9:30 PM PST, a general aviation aircraft was descending for approach from 9,000 feet to 7,000 feet above mean sea level (MSL) near Carlsbad Airport, CA, when the pilot was hit with a green laser light. There was an apparent deliberate intent to track the aircraft for 10 miles to the 2-mile final approach to Runway 25. The pilot reported distraction but no visual impairment.

» September 21, 2004

At 8:25 PM CST, an American Airlines aircraft (AAL 576) was on a 4-mile final to Chicago (IL) O'Hare International Airport at an altitude of 2,400 feet when the pilot experienced a laser light illumination of the cockpit. The pilot reported only distraction but no visual impairment.

» September 22, 2004

At 9:30 PM MST, a Delta Airlines B-737 aircraft (DAL 1025) was on final approach to Runway 35 at Salt Lake City (UT) International Airport at approximately 1,300 above ground level (AGL; 5,500 ft MSL), when a green laser light hit the Flight Deck. The First Officer (FO) was flying the aircraft at the time of the incident. Both Captain and FO saw the bright green light coming from the ground at the one to two o'clock position for a period of about 5 seconds. The Captain recognized the light as a laser and turned his eyes away while the FO did not. The FO landed the aircraft safely, but reported some loss of depth perception, causing him to flare too high. After the flight, the

FO noticed blurring in his eyes. The next day his vision was more blurred. An ophthalmologist's examination found retinal edema. The FO was unable to fly for about 3 weeks and remained sensitive to bright lights for some time.

» December 25, 2004

A Sky West Airlines aircraft (SKW 6166) was illuminated by a laser light approximately 8 miles from Rogue Valley International Airport, Medford, OR. The light initially started as a pulsating white light and changed to a steady green light. The pilot in command (PIC) reported some eye discomfort but was able to land the plane safely.

» December 29, 2004

At 5:35 PM EST a Cessna Citation, flying at approximately 2,500 AGL, was illuminated with a green laser near Rockaway, NJ, causing a temporary loss of vision for both the pilot and co-pilot, but they were able to safely land the plane. Two days later, one of the Cessna pilots joined federal agents in a police helicopter that was investigating the incident. The cockpit of the helicopter was illuminated with a laser light while flying in the vicinity of the previous illumination. The authorities were able to identify the location of the laser light, and an individual was arrested for both incidents. The suspect later plead guilty in court to interfering with the pilots of a passenger aircraft.

» December 30, 2004

At 5:35 PM EST, a Northwest Airlink/Pinnacle Airlines aircraft was on final to Runway 4 at the Cleveland-Hopkins (OH) International Airport at an altitude of about 4,000 feet when a green laser hit the aircraft and tracked it for about 3-4 seconds. The pilot reported annoyance from the light, but no visual impairment.

» December 31, 2004

The pilot of a general aviation aircraft departing from Wiley Post Airport in Oklahoma City, OK, reported that he was hit in the face by a green laser three times. Although the light temporarily blinded him, he was able to continue the flight.

» December 31, 2004

An Anne Arundel County, MD, police helicopter was "lazed by a high-intensity green laser" that interfered with cockpit visibility. The pilots determined that the laser came from a group of people standing near the scene of an accident. A 38-year old man was arrested and charged with reckless endangerment.

» December 31, 2004

At 7:26 PM PST, an American Airlines B-757 aircraft (AAL 2083) was illuminated by a green laser light while at an altitude of 4,000 feet on final approach to Runway 25L at Los Angles (CA) International Airport. The laser light tracked the aircraft for about 3 miles, and the FO reported vision problems similar to a camera flash and mild distraction.

» January 8, 2005

At 10:52 PM EST, an America West Airlines aircraft (AWE 744) was illuminated by a green laser light while at 8,000 feet on approach to Washington Dulles International Airport (VA). The cockpit was illuminated for about 5 seconds, after which the pilot experienced annoyance and a very short afterimage.

» January 25, 2005

At 7:30 PM PST, a Delta Airlines aircraft (DAL 446) was on approach to Runway 27 at the San Diego (CA) International Airport, when a green laser light flashed the pilots about 4 times. The pilot reported annoyance, but no visual impairment.

» January 28, 2005

At 7:48 PM PST, a United Postal Services aircraft (UPS 905) was illuminated by a green laser light while enroute at 15,000 feet MSL after departing from John Wayne Airport, San Ana, CA. The exposure lasted 1-2 seconds, and the pilot reported experiencing glare and afterimages lasting 1-2 minutes.

» January 29, 2005

At 6:59 PM EST, a Mesaba Airlines aircraft (MES 3253) was illuminated by a red laser light while at an altitude of 2,100 feet on 5-mile final approach to Runway 21L at the Detroit (MI) Metropolitan Wayne County Airport. The pilot reported slight flashblindness and annoyance from the 2-3 second exposure.

DISCUSSION

Prior to 1995, the FAA did not object to laser demonstrations directed into the navigable airspace as along as these beams did not exceed the applicable Maximum Permissible Exposure (MPE) level beyond which biological damage may occur (7). In 1995, the FAA adopted "Recommended Interim Guidelines" for lasers in navigable airspace that was developed by the Society of Automotive Engineers' Laser Safety Hazards Subcommittee. The guidelines were subsequently incorporated into FAA Order 7400.2, Procedures for Handling Airspace Matters, Chapter 29, Outdoor Laser Operations (8), establishing lower laser exposure limits for protecting flight crewmembers from adverse visual effects in specific zones of airspace over and around airports. Laser illumination reports collated by CAMI's Vision Research Team indicate there was a substantial decrease in the number of inadvertent illuminations by demonstration lasers in the years following this action. Unfortunately, during the study period there was a marked increase in reported laser incidents. These incidents, according to our study, were not from outdoor laser shows. The majority appears to be random acts by individuals using portable, hand-held laser devices. In response to the rapid increase in laser incidents, on January 12, 2005, the Secretary of Transportation, Mr. Norman Mineta, held a press conference at the FAA's Civil Aerospace Medical Institute in Oklahoma City to announce the publication of an Advisory Circular, entitled "Reporting of Laser Illumination of Aircraft" (AC No: 70-2) (9). The document provides information on aircrew mitigation procedures and how to report laser illumination incidents. It is an initial step in improving coordination with local and federal law enforcement agencies in apprehending and prosecuting violators. In December 2005, the House and Senate voted to amend Chapter 2, Title 18 of the United States Code by approving a bill (H.R. 1400), which would impose fines and/or imprisonment for violators that shine a laser pointer or similar device at an aircraft. (10). The bill does make exceptions for research conducted by aircraft manufacturers, the FAA, the Department of Defense, or an emergency distress signal.

The data collected as a result of Advisory Circular 70-2 can provide information that may be used to measure the effectiveness of current policies and procedures used to protect pilots from hazardous exposure to laser lights in navigable airspace and help to identify new laser sources and their availability. These reports can be used to document the frequency and severity of such events and help determine whether a pattern of criminal and/or malicious behavior exists. Comprehensive reporting is expected to result in better communication between the FAA and the aviation personnel who first learn of or experience a laser incident. Timely reporting should also provide local and federal authorities with a better opportunity to investigate and apprehend perpetrators.

There were 90 incidents reported during the 13-month study period, with the majority occurring during December 2004 (n = 27) and January 2005 (n = 46). Of the 90 incidents, 41 (46%) illuminated the cockpit and, of these, only 13 (14%) resulted in visual impairment or distraction to pilots, suggesting that the perpetrators did not intend to illuminate the flight crew or that targeting an aircraft's windscreen with these devices over such distances is not an easy task. Interestingly, review of the reported laser incidents prior to 2004 indicates the majority of exposures involved the use of red lasers. However, during the 13 months reviewed in this study, when the color of the beam was identified, only 7 of the 90 incidents involved red laser light, while the majority (62) reported the use of green lasers. This is likely because, until recently, commercially available green laser devices that the average person could readily afford were difficult, if not impossible, to find. At the present time, relatively affordable green laser pointers with output power up to 95 mW (Class 3B) and reported ranges of up to 45 miles are available through several online retailers. The affordability and availability of these and similar laser devices are expected to increase in the future and may increase the likelihood of a serious laser-related incident or accident. Fortunately, to date, no aviation accident report has cited laser light illumination as a contributing factor. However, most of the incidents reviewed in this study have gone unprosecuted, with only 3 arrests being made during the 13-month period.

The human eye is inherently sensitive to certain wavelengths more than others (Figure 4). Most green laser pointers emit a 532-nm beam of light that is near the eye's peak sensitivity, resulting in exceptional visibility and brilliance. The human eye perceives a 532-nm beam to be about 30 times brighter than an equivalently powered 670-nm laser beam (11). Therefore, it is not surprising that, given their increased visibility and availability, green lasers were involved in 29 of the 41 incidents (71%) that resulted in actual cockpit illuminations.

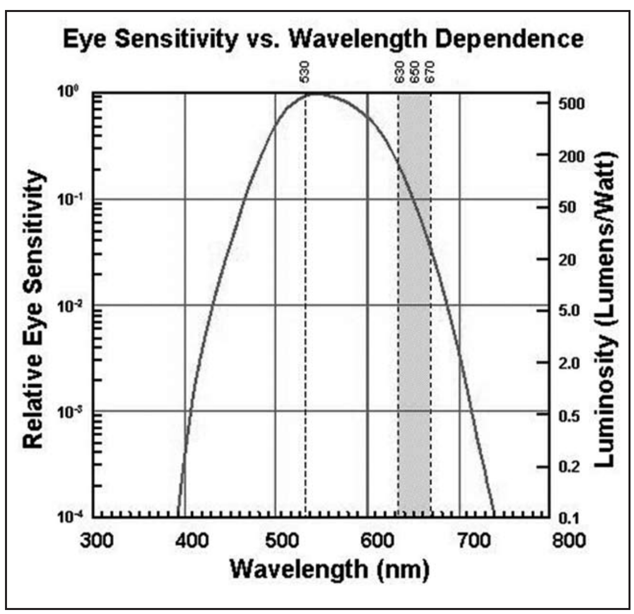

Figure 4: The human eye's relative sensitivity as a function of wavelengths

Recommendations for eliminating or reducing the problem of malicious laser illumination of aircraft include:

1. Educate the public regarding the risks of lasers to aviation safety, particularly near airports, and provide a means to report malicious behavior.
2. Restrict the sale or use of certain laser devices. This may include lasers produced by manufacturers that do not provide proof that their product can be classified as Class 3A or less.
3. Amend criminal statutes to strengthen law enforcement ability to prosecute those who interfere with flight operations. Currently, law enforcement may use Title 14 CFR §91.11 (Prohibition on interference with crewmembers) to prosecute individuals that illuminate aircraft with lasers (12).
4. Perform human factors studies to investigate whether providing pilots with Laser Eye Protection (LEP) is a practical means to mitigate certain potential laser hazards. These studies should also address the effects of LEP on color vision, visual acuity, and operational performance.
5. Expand and enforce laser free zones around airports. For example, increase the laser free zone from 2,000 feet AGL to 4,000 feet AGL.

One issue frequently raised is whether or not pilots should wear some form of LEP to protect their vision from the effects of laser exposure during landing and departure maneuvers. LEP currently used by the military incorporates cutting-edge technologies (principally advanced dyes and dielectric coatings) to provide protection from lasers at a variety of wavelengths in the infrared and visible portions of the electromagnetic spectrum (13). Such devices do not protect against all wavelengths. Recent advances in holography and other interference optical technologies have provided a closer balance between eye protection and visibility, but much more remains to be done. The aviation and medical industries are developing the tools, methods, and guidance for assessing this reflective LEP. Unfortunately, at present, regardless of the type of LEP used, problems persist with regard to the integration of these devices into civil aviation environment. LEP may mask colors used in aviation charts and maps and can be incompatible when used in combination with equipment, such as oxygen masks, communication headsets, and sophisticated avionics (heads-up displays, glass cockpit displays, and night vision goggles). Additionally, current methods of providing LEP with vision correction, while usable, can exacerbate the equipment integration problems. For these reasons it is questionable if pilots would actually wear LEP if it were provided. Any LEP device should provide high luminance transmission (>70%) over the visible spectrum while delivering protection of an appropriate optical density for the specific wavelength(s) of concern to minimize any adverse effect on color vision. Finally, in terms of optical quality, negative factors associated with LEP (haze, distortion, aberration, prism, and artifacts) must be eliminated or minimized so as to not degrade visual performance with technology meant to protect vision.

Other efforts to develop technologies to mitigate the effects of laser illumination that may have applications for civil aviation are ongoing. One possible solution is a Laser Event Recorder (LER) such as the LER made by OPTRA (13). The LER is a device that mounts to the aircraft than can detect laser illumination (both visible and invisible), photograph the source, measure the intensity and bandwidth, and warn the pilot of the relative threat level (13). Another (less expensive) effort to mitigate the hazardous effect of laser illumination is a U.S. Air Force research project to train pilots in utilizing countermeasures that can minimize the adverse effects of laser illumination (13).

The development of effective countermeasures is important, given that several foreign countries have produced military-grade laser blinding systems that are designed to blind optics, such as night vision goggles and the human eye (14). For example, the Chinese introduced the ZM-87 at defense exhibitions in March 1995, but there is no indication that these systems have been obtained by terrorist groups or are currently available on the black market. The Japanese terrorist cult Aum Shinrikyo (14), which is primarily known for its 1995 gas attack on the Tokyo subway, also experimented with the use of lasers as weapons. Japanese press reports indicated that the cult obtained laser design information from Russian institutes they visited and built a laser weapon mounted on a truck. They had planned to use the laser against Tokyo policemen, but the plan failed when the laser malfunctioned during testing (14).

A recent memo, sent by the FBI and the Department of Homeland Security in December 2004, stated there was evidence that terrorists have explored using lasers as weapons (15). Our study found no evidence that any military-grade laser system was utilized in the laser illumination incidents in this report or any other incidents reviewed over the past decade. However, international concerns over the possibility of laser-induced eye injuries resulted in the 1998 Vienna Protocol, which called for a ban on the use of lasers in conventional weapons for blinding individuals (16).

In conclusion, this study suggests that the recent spike in reported laser exposure incidents of civilian aircraft is most likely the result of the increased availability of relatively high-powered, hand-held laser devices. Fortunately, these incidents appear to be the careless acts of thoughtless individuals, rather than purposeful acts of terrorism. Only 14.4% (13/90) of the reported incidents resulted in distraction or some type of visual impairment, and only one incident resulted in ocular injury. None of these incidents were determined to be deliberate attempts to debilitate civilian pilots. Even so, these incidents do pose a serious threat to aviation safety and should be reported immediately to the proper authorities, as directed by Advisory Circular No. 70-2. The Advisory Circular also includes a "Suspected Laser Beam Exposure Questionnaire" to be filled out by the exposed pilot(s) to provide additional data to better identify the nature of the threat and its affect on civil aviation operations. Aviators should educate themselves on the effects of laser illumination and try to avoid direct exposure and seek the immediate attention of an eyecare professional in the event a laser exposure is suspected. Aviation Medical Examiners and eyecare practitioners should also be familiar with the physiological effects of laser radiation on ocular tissues, the treatment options, and potential for visual performance loss. Finally, improved reporting is necessary to monitor the scope of this problem, and continuing research may assist in the development of new methods and technologies to reduce the possibility of laser exposures or mitigate their effects.

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