



**International
Laser Display
Association**

Lasers and Aviation Safety

Patrick Murphy

Abstract

When laser beams intersect an aircraft's path, a hazard can result. There are four primary areas of concern: distraction, glare, and temporary flashblindness (for visible laser wavelengths only) and eye injuries (for all laser wavelengths). The threat level depends on factors including: type and power of the laser, how the laser is operated, day vs. night, aircraft motion and distance, flight phase, pilot workload and pilot awareness of laser hazards. There are two primary ways to minimize or eliminate these hazards: careful and responsible laser use on the ground to avoid aircraft, and pilot knowledge of procedures to follow in case of accidental or deliberate laser exposure.

Since the early 1990s, the industry group SAE G-10T Laser Safety Hazards Subcommittee has developed guidance for laser users and aviation regulators. Responsible laser users have followed governmental reporting procedures derived from SAE recommendations. These include U.S. FAA Order 7400.2 and U.K. CAA CAP 736. The threat to aviation is now primarily due to irresponsible users of low-cost, high-visibility, hard-to-regulate laser pointers. Helicopters especially may be at risk, although they also have the ability to track rogue pointer users. The number and nature of incidents has led to a ban, or proposed ban, on laser pointers in some jurisdictions. Also, those who misuse laser pointers are at risk from arrest and even jail time; a number of people have already been caught and prosecuted.

Note

Version 1 of this paper appears in the Proceedings of the International Laser Safety Conference, March 2009. Version 2.1 incorporates color photos, some additional material, and minor corrections. Version 2.2 has some minor corrections plus new information on aviation safety labels for laser pointers. The latest version will be available at the ILDA website; search the site for "Safety links & articles".

Introduction: Lasers in Airspace

There are many valid reasons that lasers and bright lights are aimed into airspace. Lasers are used in industry, research and science. Examples include atmospheric remote sensing, "guide stars" used in adaptive optics astronomy, and satellite communications and ranging. Lasers and searchlights are used in outdoor entertainment such as the nightly IllumiNations show at Walt Disney World's EPCOT Center. Laser pointers are used by the general public; sometimes they will be accidentally or deliberately aimed at or near aircraft. (Of course, it is never permissible for an unauthorized person to deliberately aim any type of laser at or near an aircraft.)

Lasers are even deliberately aimed towards aircraft for aviation-related purposes. For example, pilots straying into unauthorized airspace over Washington, D.C. can be warned to turn back by shining eye-safe, low-power red and green lasers at them.¹ At least one system has been tested that would use lasers on final approach to help line up the pilot on the proper guide slope. NASA has tested a Helicopter Airborne Laser Positioning System.²

Because of these varied uses, it is not practical to ban lasers from airspace. This would unduly restrict legitimate uses, it would not prevent accidental illumination incidents, and it would not stop someone who deliberately (whether out of malice or ignorance) targeted aircraft. For this reason, practical laser/aviation safety is based on informed laser users and pilots.

Lasers and Bright Lights

Although this paper concentrates on lasers, it should be noted that other bright directional lights such as searchlights and spotlights may have the same dazzling/distracting/flashblinding effects. Operators of searchlights and spotlights should take the same basic precautions as laser users.³ Similarly, pilots and safety officials should keep in mind that a reported "laser" incident may be caused by a non-laser bright light.

Primary Hazards of Lasers

There are some subjects which laser/aviation safety experts agree pose no real hazard. These include passenger exposure to laser light, pilot distraction during cruising or other non-critical phases of flight, and laser damage to the aircraft.

The main concerns of safety experts are almost exclusively focused on lasers that can temporarily distract or block pilots' vision when they are in a critical phase of flight: takeoff, approach, landing, and emergency maneuvers. A secondary concern is over potential eye injuries to those onboard an aircraft, especially the pilot(s).

Visual Effects of Lasers and Bright Lights

Potentially hazardous "visual effects" occur only with visible lasers and bright lights during nighttime. (Daytime use of visible lasers is rare; also, the eye is light adapted so the laser is much less dazzling against the daytime ambient light.) There are three types of visual effects: distraction, glare, and temporary flashblindness.

Distraction and Startle. An unexpected laser or bright light can distract the pilot during a nighttime landing or takeoff. He or she might not immediately realize what was happening. Also, the pilot may be worried that a brighter light or other threat would be coming.

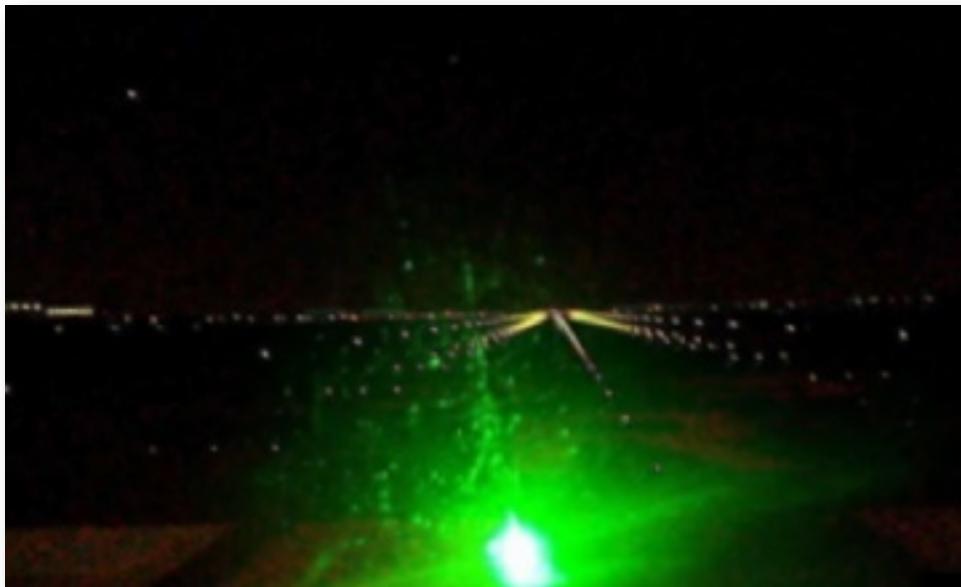


Figure 1, Distraction: FAA flight simulator showing that the light does not obscure runway lights in the background, but it is bright enough to distract the pilot. Irradiance in this photo is $0.5 \mu\text{W}/\text{cm}^2$; for example, a legal 5 mW laser pointer at 3,700 feet (1,130 m).

Glare and Disruption. As the light brightness increases, it starts to interfere with vision. Veiling glare makes it difficult to see out the windscreen. Night vision starts to deteriorate.

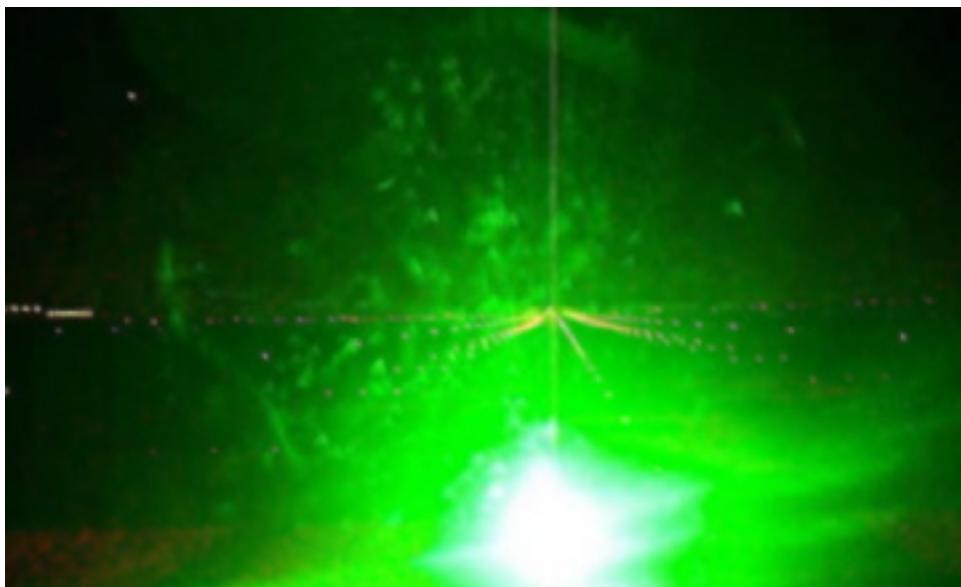


Figure 2, Glare: FAA flight simulator showing veiling glare where it is difficult to see through the light to the runway lights in the background. Irradiance in this photo is $5.0 \mu\text{W}/\text{cm}^2$; for example, a legal 5 mW laser pointer at 1,200 feet (365 m).

Temporary Flashblindness. This works exactly like a bright camera flash: there is no injury, but a portion of the visual field is temporarily knocked out. There may be afterimages -- again, exactly like a bright camera flash leaving temporary spots.

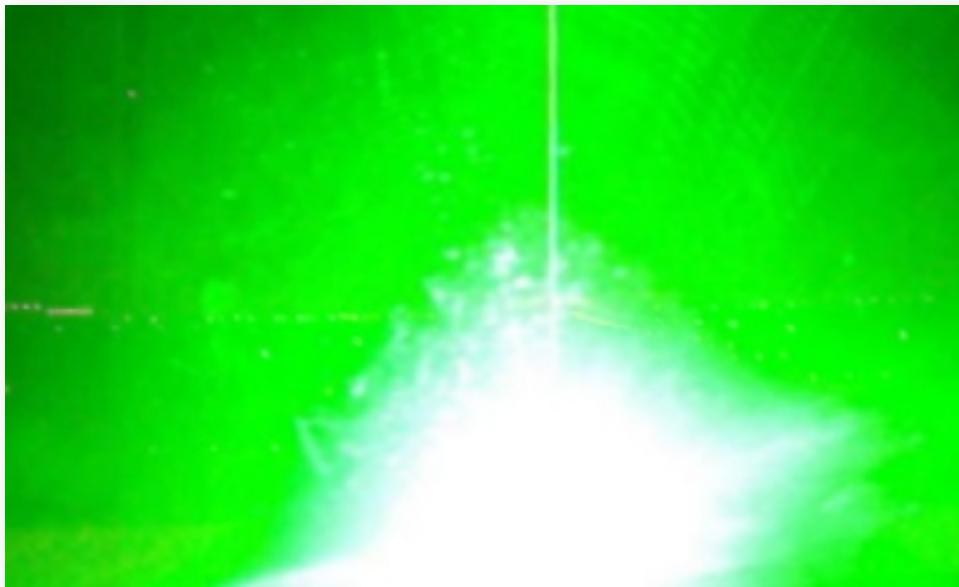


Figure 3, Flashblindness. FAA flight simulator showing flashblindness level. Not only is vision blocked as shown here, but the bright spot will take from a few seconds to a few minutes to fade away, depending on the exposure. Irradiance in this photo is $50 \mu\text{W}/\text{cm}^2$; for example, a legal 5 mW laser pointer at 350 feet (107 m).

A 2004 FAA study looked at the effect on pilots of the irradiance levels shown in Figures 1, 2 and 3. Pilots flew a “short-final” approach in the FAA’s Boeing 727 flight simulator. The glare ($5.0 \mu\text{W}/\text{cm}^2$) and flashblindness ($50 \mu\text{W}/\text{cm}^2$) levels were found to be significantly more troublesome than the distraction level ($0.5 \mu\text{W}/\text{cm}^2$).⁴ Pilots reported adverse effects for more than half of the approaches, with a 20-25% rate of aborted landings.⁵

Flashes vs. Continuous Illumination

Figures 1, 2 and 3 show the brightest part of a laser illumination. Most incidents are of flashes and not of steady illumination.

For accidental exposures, there may be just one or a few flashes. Even in deliberate illuminations, it is hard to hold a laser beam on a moving target, so there will be a series of longer flashes. (With helicopters at close range, it is possible to have a more-or-less continuous light.)

Potential Eye Injuries from Lasers

The three visual effects above are the primary concern for aviation experts. This is because they could happen with lower-powered visible lasers that are commonly available. The fourth concern, eye injuries, is much less likely. It would take specialized equipment not readily available to the general public.

Eye Injury. Though it is unlikely, high power visible or invisible (infrared, ultraviolet) laser light could cause permanent eye injury. The injury could be relatively minor, such as spots only detectable by medical exam or on the periphery of vision. At higher power levels, the spots may be in the central vision -- in the same area where the original light was viewed.

Most unlikely of all is injury causing a complete and permanent loss of vision. To do this requires very specialized equipment and a desire to deliberately target aircraft. Someone wanting to do this could find far less expensive and much easier ways to attain their goals.

It should be noted that claims of permanent injuries are not proof of injury. Some laser experts are skeptical of some reported pilot injuries, as the injuries would have required different types or powers of lasers than those reported.

While it is unlikely that laser exposure – either visual effects or eye injuries – would cause loss of an aircraft (especially if the pilots react properly), certainly all prudent steps should be taken to avoid exposing pilots to lasers or bright lights.

Type of Laser

The primary concern at this time is over misuse of laser pointers by the general public. While other types of lasers may be much more powerful (observatory “guide stars”, laser light shows), these also are generally well-controlled.

In the past ten years, the power and apparent brightness of laser pointers has greatly increased, while costs have greatly decreased. This has led to widespread use – and misuse – of pointers against aircraft.⁶ Some incidents are caused by individuals who do not realize the potential hazard. Others are caused by persons not caring about or believing that the hazard is real.

Analyzing the Hazard

The exact hazard in a specific situation depends on a number of factors.

Laser/Bright Light Source Factors

Power of the Laser or Bright Light. The more light emitted, the brighter and more hazardous it will be.

Beam Divergence. A low-divergence "tight" beam will be a hazard at greater distances than one which spreads out rapidly.

Visibility (Wavelength) of the Beam. An infrared or ultraviolet laser beam does not present any visual effect risk to pilots, as they cannot see it. However, at high powers it can present an eye damage risk. In some cases, this hazard may be greater since a pilot would not know they were being illuminated.

Color of the Beam (for Visible Wavelengths). In general, the eyes of pilots in an illuminated nighttime cockpit are most sensitive to greenish-yellow light (of wavelength around 500–600 nanometers, peaking at 555 nm).⁷ A blue or red laser will appear much dimmer -- and thus less distracting -- than a green or yellow laser of equal power (wattage).

Pulsed vs. Continuous Nature of the Beam. Some laser beams emit their energy in pulses. A pulsed laser presents a greater eye damage risk than a continuous laser of equal (average) power. This is because the power is concentrated into shorter pulses.

Operational Factors

Beam Movement. If the beam is moving around, such as in a laser show, it covers a greater area of the sky and thus has a greater chance to illuminate an aircraft. However, if it did scan across a cockpit, in general the exposure duration would be shorter. (A more precise analysis would look at the relative motion of the beam and aircraft.)

Location of the Beam Relative to Airports. The beam must avoid airspace around airports and busy air routes. The FAA has established safety zones around airports, which are described in the "Regulation and Control" section below. It is possible to use beams within the zones, if the beam power is below the FAA limit for the zone.

Projector and Laser Stability. To avoid accidents, the laser projector must be secured with relation to termination points, any bounce mirrors, and beam blocks. If a projector or a mirror slips, or safety software fails, the beam could enter unsafe areas of airspace.

Situational factors

Day vs. Night. Almost all concern is over nighttime illumination. The three visual effects listed above (distraction, glare and flashblindness) are minimized during the day since the eye is light adapted and since visible lasers are infrequently used outdoors in daytime.

Motion and Speed of the Aircraft. A slow aircraft is at greater risk than a fast one (relative to travel across the viewer's line of sight). Helicopters are at greatest risk because they can hover, presenting a relatively stationary target.

Distance to the Aircraft. A low-flying aircraft is at greater risk. Again, helicopters are vulnerable due to their close ground proximity.

Pilot/Aircrew Factors

Flight Phase. The risk is greatest when the exposure occurs during a time of high workload: takeoffs, critical or emergency maneuvers, and landings.

Pilot Awareness and Response. Ideally, pilots will be aware of laser and bright light hazards, and will know how to recover in case of an incident. Conversely, a pilot can make the situation worse if he or she overreacts, stares at the light to try to locate its source, or takes unnecessary evasive maneuvers.

Example Laser Safety Considerations

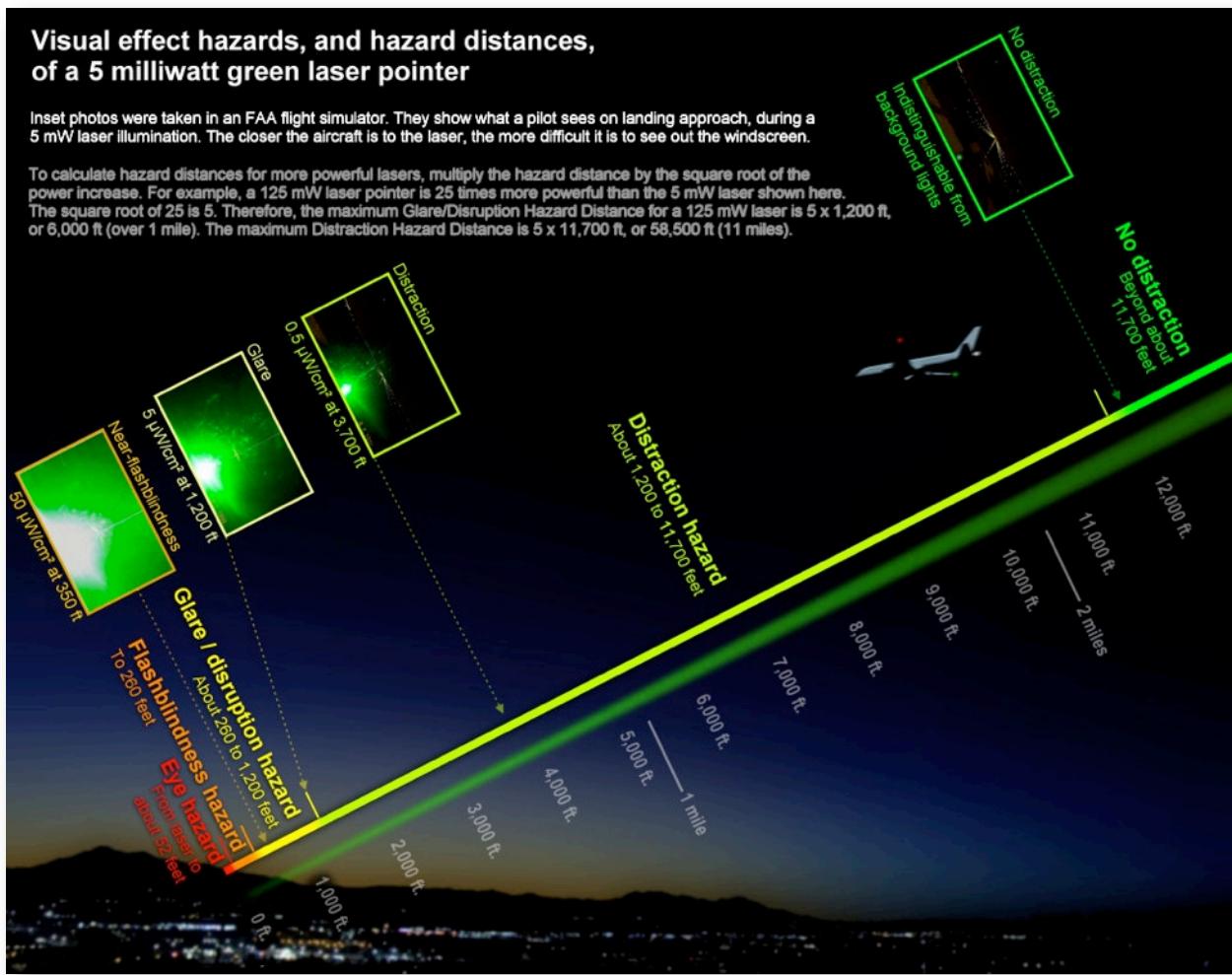


Figure 4: Visual effect hazards, and hazard distances, of a 5 milliwatt green laser pointer

Figure 4 demonstrates many important laser/aviation safety concepts. For example, it shows that the areas of most concern -- eye injury, flashblindness and glare -- occur relatively close to the aircraft. For the 5mW laser pointer depicted, these primary hazards occur within about 1,000 feet of the laser source. The distraction hazard covers about ten times this distance, but fortunately also presents less concern.

The inset photos in Figure 4 give an idea of what the visual effect looks like to the pilot, at various distances.

Note: While the distances given are exact ("52 feet", "260 feet"), the laser's brightness is in fact falling off slowly. It is not as if at 51 feet the laser is an eye hazard and at 53 feet it is eye safe. Effects diminish continuously with increasing distance. It should also be noted that for visible lasers, the weaker visual effects are part of any stronger effect. A visible laser capable of causing eye damage at 25 feet is also causing flashblindness and glare, and is a distraction.

Hazard distances shown in Figure 4 are valid only for a 532 nm (green) 5mW laser pointer. For other laser powers, colors and types, the distances shown here will change. For example, a 125mW laser pointer (25 times more powerful) will have hazard distances that increase by the square root of the increase (multiply the hazard distances by 5). The table below gives distances for various laser powers:

Eye and visual hazard distances for 532 nm (green) lasers of various powers							
Laser power	Power increase, compared to 5 mW	Square root of power increase	Maximum eye hazard distance, feet / meters	Maximum flashblindness hazard distance, feet / meters	Max. glare/disruption hazard distance, feet / meters	Maximum distraction hazard distance, feet / meters	"Safe" distance (laser is not considered a distraction)
5 mW	1	1	52 / 16	260 / 80	1200 / 366 1/4 mile	11700 / 3560 2.2 miles	Beyond 2.2 miles
50 mW	10x	3.162	164 / 50	822 / 250	3794 / 1156 7/10 mile	36995 / 11276 7 miles	Beyond 7 miles
125 mW	25x	5	260 / 79	1300 / 396	6000 / 1829 1.1 miles	58500 / 17830 11 miles	Beyond 11 miles
250 mW	50x	7.071	368 / 112	1838 / 560	8485 / 2586 1.6 miles	82730 / 25216 15.7 miles	Beyond 15.7 miles
500 mW (1/2 watt)	100x	10	520 / 160	2600 / 800	12000 / 3660 2.3 miles	117000 / 35600 22.2 miles	Beyond 22.2 miles

Figure 5: Eye and visual hazard distances for 532 nm (green) lasers of various powers

To give another example, calculations of a more powerful laser -- the type that might be used in an outdoor laser show -- are provided: A 6-watt green (532 nm) laser with a 1.1 milliradian beam divergence is an eye hazard to about 1,600 feet (488 meters), can cause flashblindness to about 8,200 feet (1.5 mi/2.5 km), causes veiling glare to about 36,800 feet (7 mi/11.2 km), and is a distraction to about 368,000 feet (70 mi/112 km).

Non-visible lasers (e.g., infrared, ultraviolet) will not cause visual effects. For these lasers, at aircraft ranges, the only distance of concern is the NOHD (nominal ocular hazard distance).

Reducing the Hazard

Successful laser/aviation safety requires effort both on the ground, from laser and bright light sources, and in the air, from pilots. While ground-based laser hazards should be reduced as much as possible, there is always the chance of accidental (or deliberate) exposure. In such a case, the pilot should not panic, should avoid looking at or near the beam, and should continue to "fly the plane".

Laser/Bright Light Hazard Reduction

Keep Light from Airspace. Use termination and beam stops to prevent laser light from being directed into protected airspace. Terminated beams are those stopped by buildings, dense trees and other impenetrable surfaces. Targets such as bounce mirrors used in laser shows should have beam stop barriers around them so that if the laser misses the mirror, it does not go off into the airspace. Care must be taken that the laser projector cannot be misaligned without an operator and/or visual spotter noticing and stopping the show.

Avoid Busy Airspace. Aim beams away from areas with many aircraft, such as airports and flight paths.

Use Airspace Observers (visual spotters), who can shut down the beam if they detect an aircraft. This topic is a complex one, which depends on the observer abilities, distance to planes, aircraft visibility, communications to ensure shutdown occurs, etc. At Walt Disney World, EPCOT's nightly IllumiNations laser show relies partially on laser spotters to keep the show safe and legal.

Use Automated Detection/Avoidance Systems. These shut down the laser or move the beam in case a plane is detected. Such systems are complex, must be proven to work, and must be reviewed and approved ("non-objection") by the FAA. As of this writing (Feb. 2009), the SAE G-10T Laser Safety Hazards Subcommittee is drafting guidelines for laser avoidance systems which use techniques such as radar, all-sky cameras and other non-spotter methods.⁸

Increase Beam Divergence. Adjust beam divergence and/or output power to meet the appropriate irradiance distance. In other words, make the beam wider and/or less powerful, so it does not exceed the laser power for a particular FAA flight safety zone (described in the "Regulation" section below). For light shows, increasing the divergence is preferable to reducing the beam power, as this has less of an adverse effect on beam visibility.

Regulatory and Other Hazard Reductions

Restrict the Sale or Use of Laser Devices. The Congressional Research Service notes that this was done in the United Kingdom with certain laser pointers, but in the U.S. this could "pose significant challenges because these devices are widely available at low cost and are used in a variety of applications such as laser pointers, laser levels and laser gun sights."⁹

Amend Existing Laws or Enact New Ones, to try to discourage irresponsible laser use. One U.S. federal effort in this direction is the "Securing Airplane Cockpits Against Lasers Act of 2005", discussed in the "History" section below.

Educate the Public in the safe use of laser pointers. To help this effort, the website www.laserpointersafety.com was sponsored by the International Laser Display Association (ILDA) and Dr. Charles Maricle of AixiZ Lasers. The website is intended to be a "one-stop" resource on laser pointer safety, especially with respect to aviation. To try to reach those who might aim lasers at aircraft, the site stresses three potentially adverse effects: it is unsafe for pilots and passengers, it is unsafe for the laser user (possibility of arrest, fines and jail) and causing incidents could lead to a ban on laser pointers. Efforts are being made to link to this website from online laser pointer sellers and from laser hobbyist forums.

Permanent Warning Labels. ILDA has called for laser pointers – especially those above 5mW -- to have a permanent label or engraving with text such as “NEVER point at or near any aircraft”. In addition, an education sheet discussing safe laser pointer user should be included with each order or shipment.¹⁰ In September 2009, a major Internet seller of laser pointers began voluntarily including an aviation warning on their labels (see below). Their text reads: “WARNING: DO NOT SHINE YOUR LASER AT AN AIRCRAFT. Shooting a laser at an aircraft is considered a felony in the U.S.”



Participation in the Regulatory Process. Laser pointer manufacturers, distributors and sellers should become more involved in the regulatory process; for example, by participating in SAE G-10T meetings. Such participation worked well in the late 1990s for the laser show industry, which implemented appropriate control measures and helped develop regulations and reporting requirements.

Pilot/Aircrew Hazard Reduction

Read NOTAMs. Pilots should read the “Notice to Airmen” for points along their planned flight path. NOTAMs should list all laser or bright light uses which have been reported to the FAA.

Learn About Laser Hazards and Defensive Measures. Ideally, pilots would receive formal training in how to "recognize and recover" from an illumination incident. If not, individual pilots can search out information about the potential hazards in online and other resources. One excellent resource is a 22-minute video developed by the U.S. Air Force and the FAA. As of February 2009, this is being reviewed for final release. The intent is for this to be distributed to pilots and the general public.

Goggles and Glare Shields

Goggles and glare shields may have applications in special situations such as military operations.^{11 12} However, they may not be practical or recommended for widespread use by civil aviation aircrews.

Laser Safety Goggles. For aviation use, this is a complex subject due to the wide variety of laser wavelengths/colors needed to guard against. If all wavelengths are protected, the goggles

are essentially opaque. There are other issues as well, such as the discomfort of continually wearing goggles, and their potential interference with nighttime vision and cockpit indicators. It may be a benefit to have goggles available that can be donned by at least one pilot (in a multi-pilot aircraft) if a persistent, deliberate illumination occurs.

Active "Smart" Goggles have been developed that can detect laser light and then activate a blocking/dimming process.¹³ Again, the need to constantly wear goggles makes this impractical for civil aviation use.

Glare Shields can be pulled down over a windscreen to reduce all incoming light.¹⁴

Regulation and Control

In the United States, laser airspace guidelines can be found in Federal Aviation Administration Order JO 7400.2 (Revision "G" as of April 2008), Part 6, Chapter 29, "Outdoor Laser Operations".¹⁵ Bright light airspace guidelines are in Chapter 30, "High Intensity Light Operations".¹⁶

In the United Kingdom, CAP 736 is the "Guide for the Operation of Lasers, Searchlights and Fireworks in United Kingdom Airspace".¹⁷

For all laser users, ANSI Z136.6 gives guidance for the safe use of lasers outdoors.¹⁸ NASA has a public "Use Policy for Outdoor Lasers" which may be helpful.¹⁹

Airspace Zones

The FAA has established airspace zones around airports. Laser irradiance must be below the limit for each zone, unless alternative control measures such as spotters are used, to give equivalent safety.

The **Laser Free Zone** extends immediately around and above runways, as depicted in Figure 6. Laser irradiance within the zone must be less than 50 nanowatts per square centimeter (nW/cm²). This is the same as 0.05 microwatts per square centimeter (μ W/cm²)

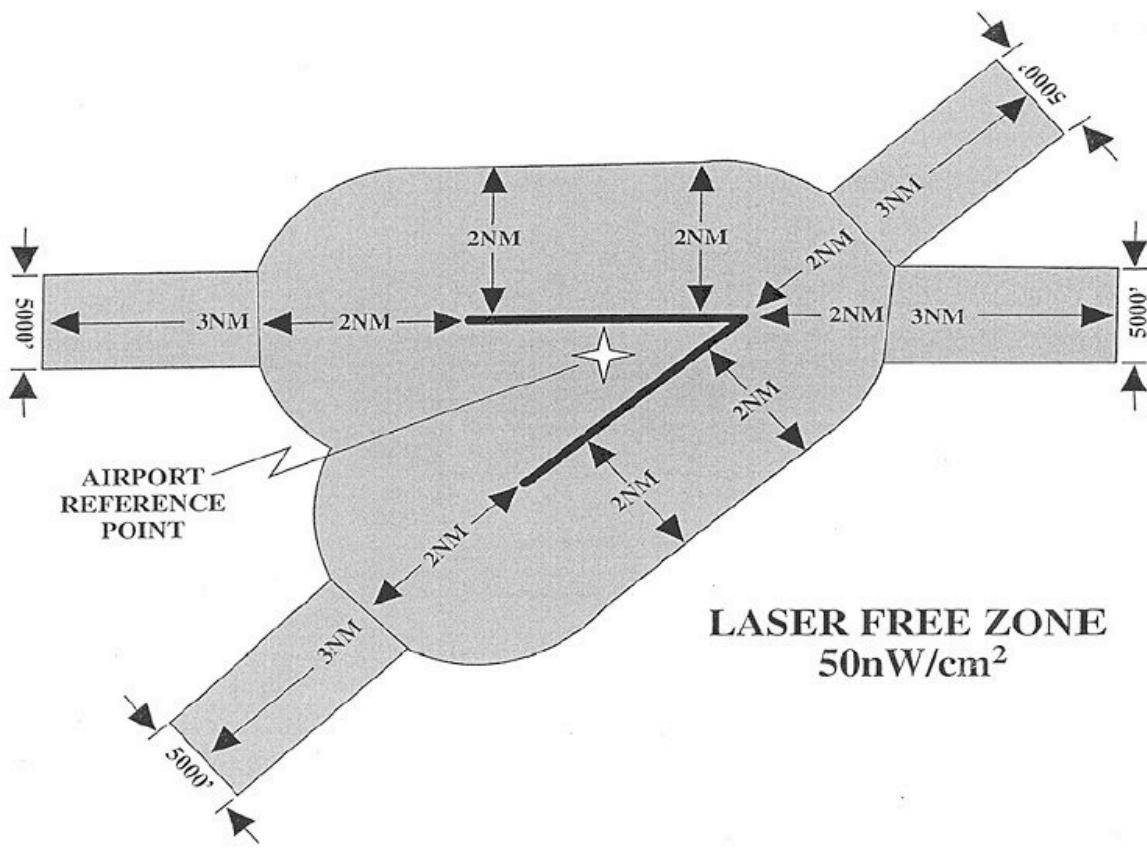


Figure 6: The FAA Laser Free Zone extends horizontally 2 nautical miles (3,700 m) from the centerline of all runways (two dark lines in this diagram) with additional 3 nautical mile (5,560 m) extensions at each end of a runway. Vertically, the LFZ extends to 2,000 feet (610 m) above ground level.

AIRSPACE FLIGHT ZONES

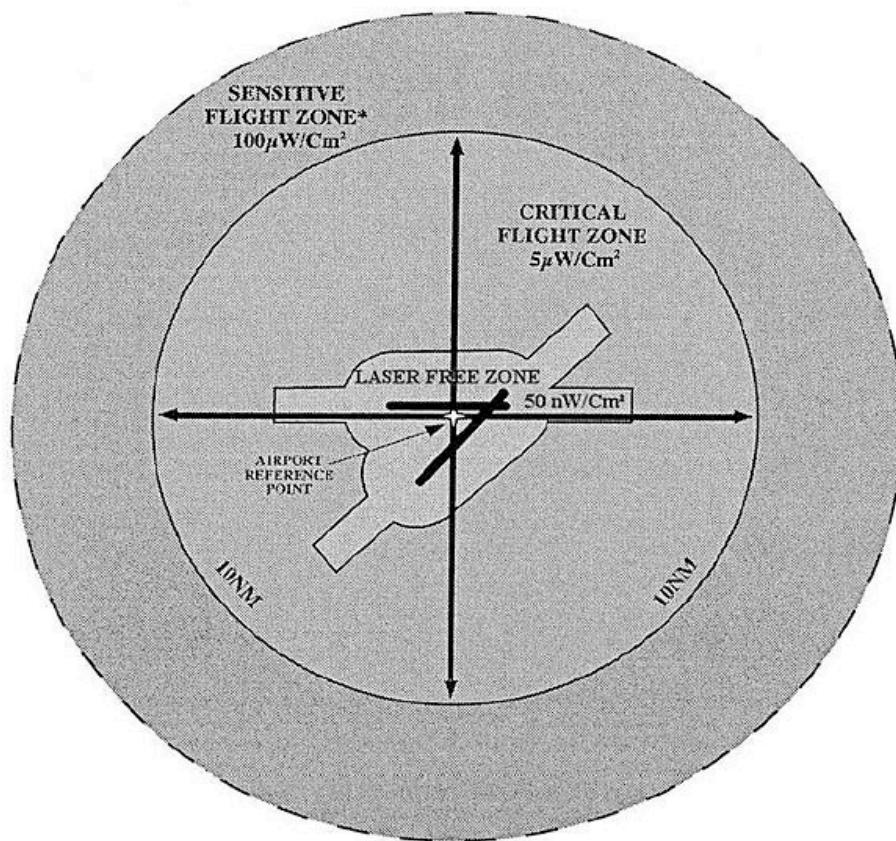


Figure 7, FAA Airspace Flight Zones. The Critical Flight Zone extends horizontally 10 nautical miles (18.5 km) around the airport, and extends vertically to 10,000 feet (3,050 m) above ground level. The optional Sensitive Flight Zone is designated around special airspace needing bright-light protection.

The **Critical Flight Zone** covers 10 nautical miles (NM) around the airport; the irradiance limit is 5 microwatts per square centimeter ($\mu\text{W}/\text{cm}^2$).

The **Sensitive Flight Zone** is an optional zone designated by the FAA where irradiance must be less than $100 \mu\text{W}/\text{cm}^2$. This might be done for example around a busy flight path or where military operations are taking place.

In the UK, restrictions are in place in a zone that includes a circle 3 NM (5.5 km) in radius around an aerodrome (airport) plus extensions off each end of each runway. The runway zones are rectangles 20 NM (37 km) in total length and 1000 meters (3280 feet) wide, centered about each runway.

Airspace Needing to be Controlled

Almost all U.S. outdoor lasers are subject to FAA regulation, even if the beam is below the FAA's minimum altitudes of flight (example: between two buildings on a city street). The FAA's rationale is that a police or emergency helicopter may need to fly through the beam. In the FAA's view, it is not up to the helicopter pilot to avoid the beam; the laser operator must detect the helicopter and terminate the beam.

FAA-controlled navigable airspace tops out at "Flight level 600" or approximately 60,000 feet. Because military flights and spacecraft above this level may be affected by powerful lasers, coordination of such laser usage may need to be made with the Air Force and with Air Force Space Command.

For practical reasons, the FAA does not currently require detection of stealth aircraft, unmanned aerial vehicles, supersonic planes and other hard-to-spot aircraft. Again, if such aircraft are common near the laser location, coordination with the military may be advantageous.

U.S. Reporting Requirements

In the U.S., persons operating outdoor lasers are requested to file reports at least 30 days in advance. They must reference their operation location with respect to local airports and describe the laser power emitted within the Sensitive, Critical and Laser Free zones.

It is possible to use lasers whose output exceeds the limits of these zones, if appropriate and approved control measures are in place. For example, visual spotters can be used to watch for aircraft, and turn off the laser if a potential conflict is sighted.

FAA Advisory Circular 70-1²⁰ "Outdoor Laser Operations" contains two forms with instructions. One form is a "Notice of Proposed Laser Operations", the other is a "Laser Configuration Worksheet" which is filled out for each laser or each different laser configuration. The FAA will review the report, and will either send a letter of objection or will send a letter of non-objection. Note: The FAA does not "approve" or "disapprove" as this is not part of their regulatory authority (they do not have direct authority over outdoor laser usage).

U.S. laser light show users have a slightly different regulatory process. The agency with direct authority over laser light shows and displays is the Food and Drug Administration's Center for Devices and Radiological Health. Any use of lasers in a show or display (whether indoors or outdoors) requires pre-approval from CDRH. This is required both for the laser equipment, and separately for the show itself (site, audience configuration, beam effects, etc.). As part of the CDRH's show approval ("variance") process, the CDRH will require a letter of non-objection from the FAA for outdoor shows.²¹ Without this, an outdoor laser show cannot legally proceed.

In the U.S., laser activity in a given area is communicated to pilots before their flight via a Notice to Airmen (NOTAM). Pilots exposed to a laser or bright light during flight should report the incident using Advisory Circular 70-2 "Reporting of Laser Illumination of Aircraft".²²

Regulatory and Standards Development

A key group working on laser/aviation safety is the SAE G-10T Laser Safety Hazards Subcommittee. It consists of laser safety experts and researchers, pilots and other interested parties representing military, commercial aviation, and laser users. Their recommendations have formed the basis of the FAA laser and bright light regulations and reporting forms, as well as standards adopted in other countries and by the ICAO.

The ANSI Z136.6 standard is the "American National Standard for Safe Use of Lasers Outdoors". The Z136.6 committee has worked closely with SAE G-10T and others, to develop recommended safety procedures for outdoor laser use.

A Brief History

Until the early 1990s, laser and bright light aviation incidents were sporadic. In the U.S., NASA's Aviation Safety Reporting System (ASRS)²³ showed only one or two incidents per year. The SAE G-10T began meeting around 1993 as the number of incidents grew. Almost all of the incidents were known or suspected to be due to outdoor laser displays. The primary concern was over potential eye damage. At the time visual effects were felt to be a minor consequence.

In 1995, a number of illumination incidents occurred in Las Vegas due to new outdoor laser displays. Although the displays had been approved by the CDRH as eye-safe for their airport proximity, no one had realized that the glare/distraction hazard would adversely affect pilots. In December 1995, the CDRH issued an emergency order shutting down the Las Vegas laser shows.²⁴

Within the SAE G-10T, there was some consideration about severely restricting or simply banning laser shows. However, it became apparent that there were a large number of non-entertainment laser users as well. The focus shifted to control of known laser users, whether shows or scientific research. New policies and procedures were developed, such as the FAA Order JO 7200.2, and Advisory Circular 70-1. Although incidents continued to occur (from January 1996 to July 1999, the FAA's Western-Pacific Region identified more than 150 incidents in which low-flying aircraft were illuminated by lasers) [5], the situation seemed under control.

Then in late 2004 and early 2005, came a significant increase in reported incidents linked to laser pointers. The wave of incidents may have been triggered in part by "copycats" who read press accounts of laser pointer incidents. In one case, David Banach of New Jersey was charged under federal Patriot Act anti-terrorism laws, after he aimed a laser pointer at aircraft.²⁵ Because there was no federal law specifically banning deliberate laser illumination of aircraft, Congressman Ric Keller introduced H.R. 1400, the "Securing Airplane Cockpits Against Lasers Act of 2005." The bill was passed by the U.S. House and Senate, but did not go to conference and thus did not become law.²⁶ In 2007, Keller re-introduced the bill as H.R. 1615. It passed the House in May 2007 but was not voted on in the Senate and thus it died for the legislative year.²⁷

On March 28, 2008, a "coordinated attack" took place using four green laser pointers aimed at six aircraft landing at the Sydney (New South Wales) Australia airport.^{28 29} As a result of this attack plus others, a law was proposed in mid-April 2008 in NSW to ban possession of handheld lasers, even "harmless classroom pointers."^{30 31} The Australian state of Victoria has reportedly had a similar ban since 1998, but press reports state that it is easy to buy lasers without a

permit. Laser pointers ban spread, Herald Sun of Melbourne, Australia (dated April 22, 2008). Available at <http://www.news.com.au/heraldsun/story/0,21985,23577920-662,00.html>.

For a selected list of laser/aviation incidents, including news stories and videos about arrests, fines and jail sentences, see the “News” section at www.laserpointersafety.com. NASA’s ASRS has a more complete list going back to the early 1990s. The FAA also maintains an up-to-date list which is available to those with a demonstrated need.³²

About the Author

Patrick Murphy is executive director of the International Laser Display Association. ILDA has 150 members in 38 countries that are involved with laser shows and displays. Murphy has participated in the SAE G-10T subcommittee since the mid-1990s. He has written extensively on laser/aviation safety, including creating in September 2006 a Wikipedia page on the topic.

This paper incorporates material which Murphy originally wrote for Pangolin Laser Systems and for Wikipedia. A draft of this paper was submitted to SAE G-10T and received comments which were incorporated. However, the present version of this information expresses the author’s viewpoint and not that of ILDA, SAE G-10T, Pangolin, Wikipedia or any other person or group.

Murphy wishes to express his gratitude to Greg Makhov, ILDA Safety Committee chair; William R. Benner Jr. of Pangolin Laser Systems Inc.; and to the members of the SAE G-10T Laser Safety Hazards Subcommittee, especially chair Van Nakagawara and Wesley Marshall.

Endnotes

¹ Pilot Laser Warning System. Video, fact sheet and Q&A available from the Eastern Region FAA Safety Team. Available at http://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afs/divisions/eastern_region/avsafety_program/vws/ (retrieved Feb. 11, 2009).

² Eppel, J.C., Christiansen, H., Cross, J. & Totah, J. (1990) Helicopter Airborne Laser Positioning System (HALPS), NASA Technical Memorandum 102814.

³ Safety Considerations for High-Intensity Lights (HIL) Directed into the Navigable Airspace (2008), SAE document ARP5560. “This document applies to regulatory/approving authorities involved with decisions regarding the use of HIL directed into the navigable airspace. For the purpose of this document, lights greater than 0.25 million candlepower meet the minimum threshold of an HIL.”

⁴ The words “glare”, “flashblindness” and “distraction” are used to describe the general effect of these levels. It is important to note that the levels tested in this study are NOT the same as the levels used in FAA’s laser zones. To wit: FAA Laser-Free Zone, laser irradiance must be below 0.05 $\mu\text{W}/\text{cm}^2$ (50 nanowatts/cm²) so it is not a distraction. In the FAA Critical Zone, laser irradiance must be below 0.5 $\mu\text{W}/\text{cm}^2$ so it does not cause glare. In the FAA Sensitive Zone, laser irradiance must be below 100 $\mu\text{W}/\text{cm}^2$ so it does not cause flashblindness and afterimages.

⁵ Nakagawara, V.B., Dillard, A.E., McLin, L.N. & Connor, C.W. (2004) The Effects of Laser Illumination on Operational and Visual Performance of Pilots During Final Approach, U.S Department of Transportation report DOT/FAA/AM-04/9. Available at <http://www.faa.gov/library/reports/medical/oamtechreports/2000s/media/0409.pdf>.

⁶ Nakagawara, V.B. & Montgomery, R.W. (2001) Laser Pointers: Their Potential Affects [sic] on Vision and Aviation Safety. U.S. Department of Transportation report DOT/FAA/AM-01/7. Available at <http://www.hf.faa.gov/docs/508/docs/cami/0107.pdf>.

⁷ Laser experts on the SAE G-10T laser hazards subcommittee considered whether pilots at night have primarily scotopic (night) vision or photopic (color) vision. One difference is that scotopic vision shifts towards the blue-green (roughly 450-550 nm, with a peak at 507 nm) compared with photopic vision which is more green-yellow (roughly 500-600 nm, with a peak at 555 nm). The subcommittee decided that because most nighttime cockpits have color displays and lights, the pilots' color vision is activated, which means their vision is more photopic than scotopic. Source: Verbal communication from Greg Makhov of Lighting Systems Design Inc. in Orlando, an SAE G-10T member who participated on this debate. This is confirmed since the FAA uses photopic data for its laser-aviation safety calculations. FAA Advisory Circular 70-1, Table 5, which lists visual color correction factors, uses data from the CIE normalized efficiency photopic visual function curve for a standard observer. <http://forms.faa.gov/forms/faa7140-1%20appendix.pdf>

⁸ Laser Safety Control Measure Performance Criteria (draft as of Feb. 2009), SAE G-10T Laser Safety Hazards Subcommittee. When finalized and approved, this will be released as an SAE Aerospace Recommended Practice (ARP) document.

⁹ Elias, B. (2005) CRS Report for Congress - Lasers Aimed at Aircraft Cockpits: Background and Possible Options to Address the Threat to Aviation Safety and Security. CRS Order Code RS22033.

¹⁰"For laser pointer sellers" page at www.laserpointersafety.com., retrieved Feb. 11, 2009.

¹¹ Stewart, C.E. (2006) Weapons of Mass Casualties and Terrorism Response Handbook, Jones & Bartlett Publishers, p. 220.

¹² Harasaki, A. & Kamiya, N. (2005) Aircrew laser eye protection visors. Opt. Eng. Vol 44, 084303.

¹³ Harvie, M.R. (2007) Active laser protection system, U.S. Patent 7202852.

¹⁴ Derenski, P.A. (2008) Stowable laser eye protection, U.S. Patent 7344260.

¹⁵ U.S. Department of Transportation, FAA Order JO 7400.2G (Effective date: April 10, 2008). Subject: Procedures for Handling Airspace Matters. Part 6. Miscellaneous Procedures. Chapter 29. Outdoor Laser Operations.

¹⁶ U.S. Department of Transportation, FAA Order JO 7400.2G (Effective date: April 10, 2008). Subject: Procedures for Handling Airspace Matters. Part 6. Miscellaneous Procedures. Chapter 30. High Intensity Light Operations.

¹⁷ CAP736: Guide for the Operation of Lasers, Searchlights and Fireworks in the United Kingdom Airspace (dated Nov. 17, 2008). Available from <http://www.caa.co.uk/docs/33/CAP736.PDF>.

¹⁸ ANSI Z136.6 American National Standard for Safe Use of Lasers Outdoors, American National Standards Institute.

¹⁹ Use Policy for Outdoor Lasers, NASA. From http://ohp.nasa.gov/policies/pdf/Outdoor_Laser_Policy.pdf.

²⁰ FAA Advisory Circular 70-1 Subject: Outdoor Laser Operations (dated Dec. 30, 2004).

²¹ Application for a Variance from 21 CFR 1040.11(c) for a Laser Light Show, Display, or Device. Form FDA 3147 (dated May 2007). Note 13.I requires advance notification to the FAA "for any projections into open airspace at any time (i.e., including set up, alignment, rehearsals, performances, etc.) If the FAA objects to any laser effects, the objections will be resolved and any conditions requested by FAA will be adhered to. If these conditions cannot be met, the objectionable effects will be deleted from the show."

²² FAA Advisory Circular 70-2 Subject: Reporting of Laser Illumination of Aircraft (dated January 11, 2005)

²³ Aviation Safety Reporting System, NASA. Available at <http://asrs.arc.nasa.gov/>.

²⁴ Laser Notice 46, "To: All holders of approved variances for laser light shows and displays". (Dated Dec. 11, 1995) Available from <http://www.fda.gov/cdrh/radhlth/pdf/laser-notice-46.pdf>

²⁵ Levin, A. N.J. man charged with aiming laser at aircraft. USA Today.com (Posted Jan. 4, 2005). Available at http://www.usatoday.com/travel/news/2005-01-04-laser-aircraft_x.htm.

²⁶ H.R. 1400: Securing Aircraft Cockpits Against Lasers Act of 2005. Status page of this bill is at <http://www.govtrack.us/congress/bill.xpd?bill=h109-1400>.

²⁷ H.R. 1615: Securing Aircraft Cockpits Against Lasers Act of 2007. Status page of this bill is at <http://www.govtrack.us/congress/bill.xpd?bill=h110-1615>.

²⁸ Walker, F. City's worst laser attacks on aircraft. Sydney Morning Herald (dated March 30, 2008). Available at <http://www.smh.com.au/news/national/citys-worst-laser-attacks-on-aircraft/2008/03/29/1206207485440.html>.

²⁹ Laser 'cluster' attacks Sydney planes , Herald Sun of Melbourne, Australia (dated March 29, 2008). Available at <http://www.smh.com.au/news/national/citys-worst-laser-attacks-on-aircraft/2008/03/29/1206207485440.html>.

³⁰ Baker, J. Backlash over ban on laser pointers, Sydney Morning Herald (dated April 22, 2008). Available at <http://www.smh.com.au/news/national/backlash-over-ban-on-laser-pointers/2008/04/21/1208742851975.html>.

³¹ Nizza, M. Australia Takes On Laser Lunatics, The Lede, New York Times blog (dated April 21, 2008). Available at <http://thelede.blogs.nytimes.com/2008/04/21/australia-takes-on-laser-lunatics/?hp>.

³² Contact the FAA Airspace and Rules Group, Office of System Operations Airspace and AIM.