FLIGHT SAFETY FOUNDATION
HUMAN FACTORS & AVIATION MEDICINE

Vol. 48 No. 6 *For Everyone Concerned With the Safety of Flight* November–December 2001

Laser-light Displays, Laser Pointers Disrupt Crewmember Vision

Exposure to intense beams of laser light has caused occurrences of short-term visual disruption. Crewmembers can minimize their risks by being aware of situations in which laser lights are most likely to be in use and by appropriate reactions if they are exposed to laser light.

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Lasers are devices that emit intense, narrow beams of light, which can cause eye damage, visual disruption and distraction. In recent years, laser-light beams have been used to create laser-light displays for entertainment, and laser pointers have been used as aids to public speakers to draw attention to items on projected charts or graphs, as alignment tools in construction and as aiming devices for firearms, among other uses.[1]

Reports are rare of pilots who have experienced long-term eye damage because of laser-light exposure; nevertheless, reports of temporary visual disruptions and distractions associated with exposure on the flight deck are numerous (see "Guidelines for Preventing Laser-light Exposure," page 2).[2]

More than 600 incidents have been reported worldwide in which aircraft flight decks were illuminated by laser-light beams.[3] In some of those incidents, pilots experienced sudden impairment of vision because of an unexpected encounter with laser light. Many of these incidents have been associated with laser-light displays or with individuals who use lasers as a hobby.

In a report to the U.S. National Aeronautics and Space Administration Aviation Safety Reporting System (ASRS),[4] the captain of an Embraer EMB-120 Brasilia described his encounter with a laser-light beam in November 1996:

> While on vectors for a visual approach to … [Los Angeles (California, U.S.) International Airport], we were over a college campus. I looked out the right side window to check for traffic. Approximately one second later, the aircraft was struck by a very bright laser beam coming from the vicinity of that campus. I recovered from the initial flash [of light] but within two minutes was experiencing blurred vision in my right eye. The first officer continued the approach, and we landed … without further incident. An eye examination later in the evening revealed that the cornea [the transparent tissue over the front of the eyeball that covers the iris and the pupil] of my right eye suffered multiple flash burns.[5]

The ASRS report said that the laser operation was not approved but included no other details about what the laser operation involved.

Laser Light Differs From Light Generated by Other Sources

Light acquires different characteristics depending upon its source. Therefore, laser light differs from light generated by fire, light bulbs and other sources. Light from fires is produced by chemical combustion. Light from a household light bulb is produced by the flow of electrons (current) through a thin tungsten wire that is heated to incandescence. Light from these types of sources can be thought of as randomly generated light.

Laser light differs from randomly generated light primarily because laser light is synchronized in its production, replacing the randomness of the other sources. (The word "laser" is an acronym for the process that produces laser light — light amplification by stimulated emission of radiation.) Because of the unique process that produces laser light, the light has three characteristics:

- Laser light is monochromatic — that is, it is virtually at a single wavelength (i.e., single color);
- Laser light has a high level of coherence, which is a measure of the phase difference between each light wave produced within the laser. Because of the high level of coherence, laser light can travel long distances without spreading significantly and can be focused more precisely than randomly generated light; and,
- Laser light has a low level of divergence — the characteristic that has the greatest effect on the risk of laser-light exposure. Laser-light waves are confined to a narrow cone, nearly parallel; laser-light beams are very directional (straight; Figure 1, page 3). In comparison, light from most other sources spreads out almost equally in all directions. When the eye encounters a laser-light beam, the lens of the eye focuses the beam into a small point on the retina (the eye's light-sensitive innermost lining), concentrating the laser's energy onto a very small area, which can result in burns on the retina.

Lasers can be classified in several ways, including:

- The region of the electromagnetic spectrum in which the laser light is emitted — X-ray, ultraviolet (UV), visible or infrared (IR). These references are defined by the laser's wavelength. Lasers that emit light at wavelengths of less than about 380 nanometers (nm; a nanometer is one-billionth of a meter) are called UV lasers. Lasers that emit light between about 380 nm and 730 nm are called visible lasers because this wavelength range is the visible part of the electromagnetic spectrum (i.e., wavelengths

Guidelines for Preventing Laser-light Exposure

The following are guidelines for avoiding or limiting exposure to laser light while on the flight deck:

- Look away immediately from the source. If possible, shield the eyes;
- Alert other flight crewmembers to the presence of the laser operation and determine whether they also have been exposed;
- If another flight crewmember has not been exposed, turn over control of the aircraft. If all crewmembers have been exposed, engage the autopilot;
- Turn on additional exterior lights to aid observers on the ground in locating the aircraft and turn on thunderstorm lights (which provide high-intensity lighting for basic instruments) to minimize the effects on crewmembers' eyes of the illumination of the flight deck by laser light;[1]
- Be aware of the possibility of vision impairment and disorientation. Rely on instruments to monitor flight status;
- Resist the urge to rub the eyes after exposure; and,
- Contact air traffic control (ATC) and report a "laser-illumination incident."[2] After you have landed the aircraft, you should file a complete incident report with ATC.[3]

If, as a result of your exposure, you experience pain or visual abnormalities, you should seek prompt medical attention, preferably from an ophthalmologist. A thorough examination typically will include: an inspection of the retina to detect burn spots, a visual acuity test to detect a loss in central vision, an external examination of skin around the eyes to detect thermal burns, and a color vision test. Treatment, if required, might include topical steroids or oral steroids. Cloudy vision caused by floaters (bits of material that float in the back of the eye and that are seen as dark spots) and retinal bleeding typically improve without treatment.♦

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Notes

1. Connor, C.W.; McLin, Leon. "That Laser Zapped My Eyes!" *Air Line Pilot* Volume 67 (October 1998): 6.
2. Connor et al.
3. European Organisation for the Safety of Air Navigation (EUROCONTROL). Safety Regulation Commission Document SRC DOC 7, "Outdoor Laser Operations in the Navigable Airspace." Feb. 14, 2001.

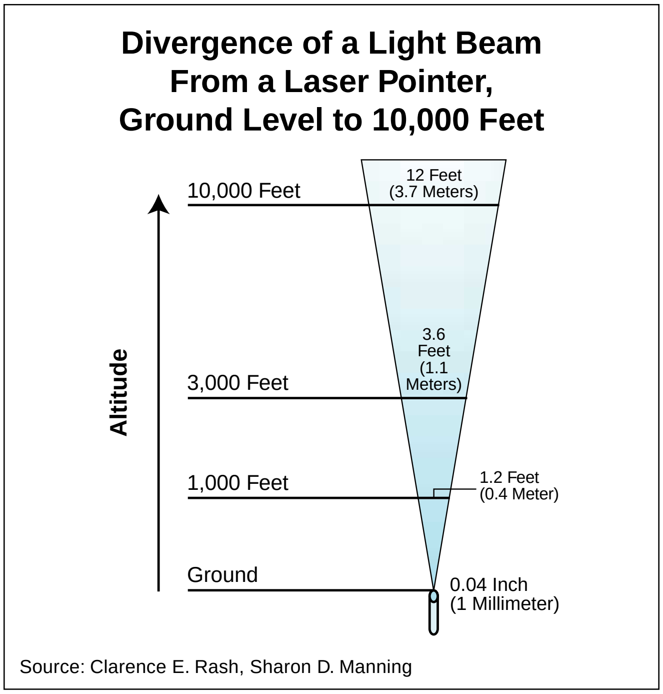

Figure 1

that can be seen by the human eye). Lasers used in outdoor laser-light displays and in laser pointers are visible lasers. Lasers that emit light at wavelengths typically greater than 730 nm are called IR lasers. Often, because the IR part of the spectrum is so large, IR lasers are further classified as near-IR, mid-IR and far-IR;

- The temporal (time) characteristics of the laser. Lasers can emit energy either in a continuous beam or in a beam that consists of a series of pulses. Lasers that emit light continuously until turned off are called continuous wave (CW). Lasers that emit light as a series of pulses are called pulsed lasers; and,

- The optical medium used within the laser to produce the light. Standard laser mediums include gases, solid-state materials and dyes.

The laser classification methods above are based on the physics of lasers. Other methods developed by the American National Standards Institute,[6] the International Electrotechnical Commission (IEC)[7] and the U.S. Center for Devices and Radiological Health (CDRH)[8] classify lasers according to their ability to damage the eyes or skin. The three classification methods are similar; the following are those developed by CDRH:

- Class I lasers have power levels of less than 0.39 microwatt (a microwatt is one-millionth of a watt)[9] continuous output — below the level at which damage can be caused to the eyes or skin;

- Class II lasers are visible lasers that are too bright to be viewed for extended periods. They emit less than one milliwatt continuous output and are considered safe for momentary exposures. (Any accidental exposure to a laser pointer would be interrupted by the natural blink reflex, which causes people to blink about every 0.25 second. The blink response, along with the normal human aversion response to uncomfortably bright lights, typically prevents injury to the eye, if the power of the laser pointer is less than five milliwatts. Intentional exposure that results in viewing of the laser-pointer beam for more than 10 seconds may result in eye injury.)[10] Class II lasers do not cause skin damage;

- Class III lasers are subdivided into Class IIIa and Class IIIb. Class IIIa lasers may have a maximum power output of no more than five milliwatts. They are considered safe for momentary viewing, but not safe for extended viewing or for viewing with binoculars or other magnifying lenses. Most laser pointers use Class IIIa lasers. Class IIIb lasers may have maximum power output of 500 milliwatts — a level that can cause eye damage. Viewing the beam of a Class IIIb laser is hazardous. Class IIIb lasers do not cause skin damage; and,

- Class IV lasers have a maximum power output of more than 500 milliwatts. They can cause severe eye injury and skin injury, even from reflected laser-light beams. They may cause skin damage. If their power is sufficient, some Class IV lasers can cause fires. Most lasers used in outdoor light displays are Class IV lasers.

Regulations Restrict Some Light-display Operations

In recent years, outdoor laser-light displays have become common in some parts of the world for entertainment and for advertising purposes. These lasers produce high-energy, highly coherent and highly directional beams of light of various colors. In 1996, more than 200 operators in the United States were estimated to have licenses to conduct laser-light displays.[11]

The simplest outdoor laser-light displays use static lasers, which project laser-light beams straight up into the atmosphere, either directly or by reflecting the beams from a mirror. Most laser-light displays are more complex, using computer-controlled, moving mirrors to draw complicated images with laser-light beams. To achieve the desired dramatic effects, operators of laser-light displays introduce artificial smoke, mist or fog into the air. The laser light becomes visible when it is reflected by the tiny smoke particles or fog water droplets.

Such scattered laser light presents no hazard to pilots, but direct laser-light beams do present risks. Direct laser-light beams can contain substantial energy, even at altitudes of 30,000 feet or higher.

Pilots who fly aircraft near laser-light displays may be exposed to laser-light beams, which can result in disruptions in vision such as flash blindness (a temporary vision impairment that follows a brief exposure to bright light and interferes with the ability to detect or to identify a target) and dazzle (also called glare, a reduction of vision or total loss of vision within the central field of vision that lasts only as long as the light source is present).

The first officer on an air carrier aircraft filed an ASRS report describing an August 1994 laser-light exposure:

> The captain and I were flying from Phoenix (Arizona, U.S.) to [Burbank-Glendale-Pasadena (California, U.S.)] at 31,000 feet. … [The] captain was looking at the lights of Las Vegas. He saw a bright flash and said, 'Look at the laser show in Las Vegas.' I looked at Las Vegas, and we both got hit in the eyes with a green laser. After we turned our eyes back forward, we both noticed a green glow around the periphery of our vision. This was a momentary condition, lasting no more than 10 minutes."[12]

A U.S. National Transportation Safety Board (NTSB) report on an Oct. 30, 1995, incident said that a laser-light beam from a laser-light display swept over the flight deck of a Southwest Airlines Boeing 737 during departure from McCarran International Airport in Las Vegas, Nevada, U.S.:

> The first officer, who was the flying pilot … said he immediately experienced eye pain and was completely blinded in the right eye. Afterimage effects also included a blind condition in his left eye. He said the total inability to see lasted 30 seconds, and for an additional two minutes, he could not focus on or interpret any instrument indications and was completely disoriented in his spatial relationship to the vertical. The captain was not irradiated by the beam and assumed control of the aircraft and continued the climb.[13]

The report said that because many large hotels in Las Vegas operate outdoor laser-light displays, the location of the laser light that affected the B-737 first officer could not be determined. In the two years preceding the incident, 51 incidents of laser irradiations to pilots were recorded in the Las Vegas area. The year after the incident, in 1996, U.S. officials began developing more stringent standards for laser operations and flight safety.

U.S. standards, which took effect in 2000, are based on those established by the Society of Automotive Engineers (SAE). They designate "laser-free zones," in which the level of laser irradiation must not exceed 50 nanowatts per square centimeter (a nanowatt is one-billionth of a watt), in the areas immediately surrounding airports. The laser-free zones are surrounded by "critical flight zones" and "sensitive flight zones" in which higher levels of irradiation are permitted. Outside the three circles, the laser irradiation level must not exceed 2.6 milliwatts per square centimeter, the maximum permissible exposure (MPE) for visible CW lasers.[15] (The MPE also is known as the "eyesafe" level, the level of laser radiation to which an individual may be exposed without experiencing adverse effects on the eyes or the skin. Laser-light exposures that exceed the MPE can result in hemorrhaging [bleeding] within the eye; the creation of small lesions (burn spots) on the retina, which can cause blind spots within the field of vision; or, rarely, total loss of vision.)

Canadian authorities were developing standards and procedures similar to those implemented by FAA. Proposed amendments to Canadian Aviation Regulations — expected to take effect in 2002 — would prohibit lasers from being projected at any aircraft "in such a manner as to create a hazard to aviation safety, damage to the aircraft or injury to crew or passengers"; would require individuals planning to operate outdoor laser-light displays to notify authorities in writing; and would prohibit pilots from operating aircraft in areas where laser beams were in use, except under specific circumstances.[16]

A panel established in 1996 by the International Civil Aviation Organization (ICAO) determined that 18 countries had imposed flight safety requirements involving the use of laser lights, including 12 countries that had agencies to regulate laser use to prevent laser-related hazards to flight safety.[17]

The panel has proposed recommendations that resemble U.S. and Canadian standards. The recommendations were expected to be adopted in 2003 as amendments to ICAO *Annex 14, Aerodromes.* The panel also was developing the *Manual on Laser Emitters in Flight Safety*, which includes guidelines for writing regulations to prevent laser light from presenting flight safety hazards. The manual was expected to be published in late 2001 or 2002.

In the United Kingdom, guidelines for laser-light displays say that the lights never should be directed toward aircraft or airports. Aeronautical Information Circular (AIC) 103/2000, *Safeguarding Coordination — Guidelines for Outdoor Use of Lasers, Searchlights and Fireworks*, says that if laser lights are used in light displays within 500 meters (1,641 feet) of an extended runway center line and within 10 statute miles (16 kilometers) of an airport, they should have a maximum peak radiant power of 20 watts and that the beams "should be below the horizontal, or a physical barrier such as a building or a land feature should be in place to prevent light escaping along the [runway] centerline." If the laser-light beams cannot be prevented from escaping along the centerline, organizers of the laser-light display "should arrange a telephone [contact] or radio contact through which the light display can be extinguished immediately" at the request of a flight crew or an airport, the AIC says.[18]

"If this is not possible, then the light display may represent a threat to flight safety and should not proceed," the AIC says.

Popularity of Laser Pointers Presents Increasing Risks

In recent years, advances in laser technology have reduced the power requirements, size and cost of low-energy lasers, which previously were used only by the military and large commercial organizations. These relatively new devices, known as laser pointers, typically consist of a metal shell or plastic shell, batteries, a laser diode and a simple lens to collimate (to adjust the direction of or to make parallel) the laser-light beam.

U.S. regulations require that laser pointers sold in the United States have a maximum power output of five milliwatts.[19] Nevertheless, inspections have revealed that some of the millions of laser pointers imported into the United States are mislabeled as having the acceptable five-milliwatt power output, although their power output was measured at 10 milliwatts or more.[20] Many imported laser pointers are not inspected.

In the years since laser pointers first became readily available, a number of incidents of misuse have occurred, involving intentional episodes and unintentional episodes of dazzle and flash blindness. A study conducted in the FAA Western-Pacific Region (including Arizona, California, Hawaii, Nevada and Pacific island territories) from January 1996 through July 1999 found reports of more than 150 incidents of low-flying aircraft that were illuminated by lasers — primarily by laser pointers.[21]

The incidents included the April 16, 1997, illumination of a United Airlines Boeing 737 at 13,000 feet on descent to Ontario, California.

In its report on the incident, NTSB said, "The captain was on the controls when he noticed a green light illuminating the aircraft. It appeared to him that the light was tracking the aircraft, but as he was pointing out that fact to the first officer, the light disappeared. He reported that, although his exposure to the light caused a minimal yet persistent loss of night vision, he was able to maintain control of the aircraft."[22]

Because the widespread use of laser pointers is a relatively recent phenomenon, few scientific studies have been conducted to assess their effects on the eye. A small study — with three subjects — conducted at the Mayo Clinic in Rochester, Minnesota, U.S., tested the effects of laser pointers of one milliwatt, two milliwatts and five milliwatts on the participants, who were exposed to the laser lights for up to 15 minutes.[23] While their retinas showed slight abnormalities after exposure, there were no signs of significant damage to the retina, the cornea or the lens of the eye. Writing in the December 2000 issue of the *Journal, Archives of Ophthalmology*, the authors of the study said that the risk from this exposure "seems negligible."

A 1999 study conducted at the Bristol (United Kingdom) Eye Hospital included 14 participants — the largest clinical review of laser exposure to date.[24] In 11 (78 percent) of the 14 cases, the exposed individuals sought medical treatment within 24 hours of exposure. Their most common complaint was eye discomfort (79 percent), followed by "blurred vision" or "dazzle" (64 percent) and "headaches" (14 percent). The most common physical result of the exposures was corneal abrasion, which occurred in five (36 percent) of the 14 cases. Thirty-six percent of the participants also exhibited reduced visual acuity, although in one case, previous visual acuity was in question. None of the 14 cases involved retinal damage, and the report on the study said that the corneal abrasions probably resulted from "significant" eye-rubbing following the exposure. The report said that there was no evidence of consistent, long-term damage to the eye resulting from these transient exposures to laser-light beams from laser pointers.

U.K. Reports Include Eye Pain, Visual Impairment

The U.K. Civil Aviation Authority Mandatory Occurrence Reporting system recorded 31 incidents from 1976 through Nov. 20, 2001, involving reports of flight crewmembers exposed to laser light. Many of the reports do not include details of the incidents, such as whether a pilot's vision was affected. Nevertheless, eight of the 31 reports said that flight crewmembers had reported pain in their eyes or temporary impairment of vision; in another report, a Boeing 757 captain said that the event had been a distraction.[25]

A search of the NTSB Aviation Accident/Incident Database, which contains reports of civil aviation accidents and selected incidents since 1983, showed that four incidents involved laser-light exposure; all four incidents occurred from 1995 through 1997. Two incidents occurred during approach, one incident occurred during descent and one incident occurred during climb while the aircraft was at 4,500 feet above ground level. In three incidents, flight crewmembers said that they had experienced eye pain or temporary loss of vision or both.[26]

A search of the FAA Incident Data System, which contains civil aviation incidents that have occurred since 1978, revealed one additional incident of laser-light exposure.[27] The incident occurred April 15, 1980, when the captain of a Continental Airlines Boeing 727 was flying the airplane on approach to Albuquerque, New Mexico, and was "struck by a laser-type light." The source of the laser light was not found, and the report did not include details of the incident.[28]

The ASRS database, which contains reports of occurrences since 1988, includes 14 occurrences involving exposure to laser-light beams. One occurrence involved a passenger who exposed another passenger with a laser pointer. The remaining occurrences involved exposures from laser lights or unknown high-intensity lights from the ground. One occurrence involved a diagnosis of retinal burns. All other occurrences were described as producing episodes of flash blindness, glare, afterimages and/or blurred vision.

The Rockwell Laser Industries (RLI) database, which contains data on people injured in laser-light accidents from 1964 to 1994, includes reports on 272 occurrences. Only 3.3 percent of the injuries reported involved pilots or military personnel.[29]

Another RLI report quoted a pilot for an unnamed airline as saying that a red laser-light beam illuminated the flight deck when his airplane — carrying 180 passengers — was at 600 feet on approach to Manchester, England in autumn of 1997. The pilot said that the "blinding red beam" had forced him to look away.[30]

"This could have caused dangerous problems," the pilot said.

The flight crew completed the landing, and the report included no other details of the occurrence.

The U.S. Army Medical Research Detachment at Brooks Air Force Base, Texas, maintains the Laser Accident and Incident Registry (LAIR), which contains reports on 101 occurrences from 1964 to 2000. Four occurrences (involving seven people) were associated with aviation — each of the four involved a law-enforcement helicopter.[31]

The earliest occurrence, in October 1991, involved a police helicopter being flown at 120 knots to 140 knots at 500 feet over Los Angeles. A laser-light beam irradiated the cockpit for one second to two seconds, then for two seconds to three seconds. The beam was described as being narrow, bright and deep blue. The pilot said that his vision went "white" for several seconds, then changed to a "blackout effect," then returned. The incident was recorded as an episode of flash blindness caused by exposure to a 514-nm laser.

The most recent LAIR report involved a sheriff's helicopter being flown over West Seattle, Washington, U.S., in June 2000. The pilot and the copilot reported seeing a bright flash of light from the ground and being blinded briefly. Both pilots reported headaches and "scratchy" eyes, but a medical examination detected no vision abnormalities.

Safety Devices, Education Help Prevent Injury

Typically, when lasers are in use, laser injuries can be prevented through engineering controls designed to make laser operations safer; education of users and others within the operational vicinity of lasers about potential risks; and personal safety devices, such as protective goggles and glasses. Military aviators have for many years worn laser-protective visors that are designed to prevent eye injuries and are manufactured to fit military helmets.

For civil aviation pilots, protective eyewear is unlikely to be useful, partly because the most likely laser-light hazard is not eye injury but vision disruption, such as flash blindness and dazzle. Nevertheless, sunglasses worn during daytime flights could reduce the effects of vision disruptions from exposure to laser-light beams from laser pointers at low altitudes. Laser-protection eyewear typically would not be practical on the flight deck at night.

The best defense against sudden visual disruptions caused by laser light is knowing how to avoid exposure.[32] In the United States, the locations of outdoor laser-light displays, dates, durations and eyesafe distances are published in each regional FAA *Airport/Facility Directory*. If pilots become aware of a laser-light display while flying, they should avoid looking in that direction, assume that they might experience flash blindness and know what to do if flash blindness occurs.

The effects of flash blindness can persist from seconds to minutes, depending on the brightness (energy) of the light source, the length of exposure and the surrounding lighting condition. For example, flash blindness impairs night vision. After the bright light is removed, a persistent image of the source, called an afterimage, remains and may persist for several minutes, along with a perception of spots. An example of flash blindness (and the accompanying afterimage) is exposure to the flash of a camera.

The first officer on an air carrier aircraft described an experience with flash blindness that occurred during a June 1990 approach to Miami, Florida, U.S.:

> At 10,000 feet, approximately eight miles from downtown … a green laser was being used … for a laser-light show. The laser [beam] flashed directly into my eyes. I was blinded for about two seconds. I had trouble with near focus for about 15 seconds. My eyes "hurt" for about two minutes. All normal post-incident.[33]

In comparison, dazzle persists only while the light source is present. For example, a person experiences dazzle when he or she encounters an oncoming car with high-beam headlights. After the car has passed, the ability to see returns immediately.

People who have been exposed to laser light tend to rub their eyes afterward. Such rubbing — especially if done overzealously or while wearing gloves — can result in corneal irritation or corneal abrasions.

Although civil aviation authorities in many countries have used regulatory enforcement to reduce the number of incidents involving exposure to laser lights from outdoor laser-light displays, the risk has increased for pilot exposure to laser-light beams from low-cost laser pointers. Nevertheless, serious eye injuries are unlikely to result from exposure to lights from laser pointers. Flight crews are more likely to suffer temporary vision disruptions and distractions from flight duties. To minimize vision disruptions, flight crews should comply with safety guidelines, know what to expect in the event of a sudden laser-related disruption in vision and know how to react appropriately, considering known risks.♦

Notes

1. Laser Institute of America, *Safety Bulletin: Laser Pointer Safety.* www.laserinstitute.org. June 14, 2001.

2. Connor, C.W.; McLin, Leon. "That Laser Zapped My Eyes!" *Air Line Pilot* Volume 67 (October 1998): 6.

3. McCormick, C. "Laser-safe skies." *Air Traffic Management* Volume 9 (November–December 2000): 14–16.

4. The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised. … ASRS de-identifies reports before entering them into the incident database. All personal and organizational names are removed. Dates, times, and related information, which could be used to infer an identify, are either generalized or eliminated."

   ASRS acknowledges that its data have certain limitations. ASRS *Directline* (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation-safety incidents of that type."

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7. International Electrotechnical Commission (IEC). *Safety and Use of Laser Products,* IEC publication 60825-1, Part 1, "Equipment Classification, Requirements and Users' Guide." Geneva, Switzerland. 1993.

8. U.S. Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Devices and Radiological Health (CDRH). *Laser Light Show Safety: Who's Responsible?* HHS Publication FDA 86-8262. Rockville, Maryland, U.S. 1986.

9. Although the term "watt" is used to describe the output of lasers and conventional electric devices, the meanings are not the same. The U.S. Center for Devices and Radiological Health (in its publication *Laser Light Show Safety: Who's Responsible?)* explains the difference by saying, "When you have a 100-watt light bulb, the wattage refers to the power input or the electricity required to make the bulb work. The output from a 100-watt light bulb is about 15 watts. … When you have a one-watt laser, the wattage refers to the optical output of the laser. … At a distance of 100 feet [31 meters], the light from the one-watt laser can be about 1 million times more concentrated than from the light bulb."

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11. McCormick.

12. NASA ASRS report 285090. August 1994.

13. U.S. National Transportation Safety Board (NTSB). Aviation Accident/Incident Database (AID) report LAX96IA032. Oct. 30, 1995.

14. Society of Automotive Engineers. Aerospace Standards Document AS4970, "Human factors considerations for outdoor laser operations in the navigable airspace." December 1999.

15. U.S. Federal Aviation Administration (FAA). Order 7400.2E, Part 6, Chapter 28, "Outdoor Laser Operations." 2000.

16. Transport Canada. *Notice of Proposed Amendment* (NPA) 1999-145. www.tc.gc.ca/aviation. July 6, 2001.

17. McCormick.

18. U.K. Civil Aviation Authority. Aeronautical Information Circular (AIC) 103/2000 *Safeguarding Coordination — Guidelines for Outdoor Use of Lasers, Searchlights and Fireworks,* Nov. 16, 2000.

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*This electronic version includes author's changes.

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