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Aircraft Accidents and Incidents Associated With Visual Disturbances From Bright Lights During Nighttime Flight Operations

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16. Abstract INTRODUCTION. Preservation of optimal night vision is important for pilots operating an aircraft at night. When the eyes are adapted to low-light levels, exposure to bright light can result in temporary visual impairment due to glare, flashblindness, and afterimages. The purpose of this study was to investigate operational problems experienced by civilian airmen exposed to bright light sources while performing nighttime aviation activities. METHODS. The National Transportation Safety Board (NTSB) Aviation Accident and Incident Data System (January 1982 to February 2005) and the Federal Aviation Administration (FAA) Accident/Incident Data System (January 1978 to January 2005) were queried using terms associated with night vision problems. Accident and incident reports annotated with one or more of these terms were reviewed to determine whether vision difficulties resulting from exposure to bright lights contributed to the mishap. RESULTS. Vision problems resulting from exposure to bright lights at night were found to have contributed to 58 mishaps. Reports included 30 (NTSB) accidents and 28 (FAA/NTSB) incidents. The majority of accidents (57%) occurred during the approach and landing phase of flight. Incidents occurred most frequently while taxiing (54%) and during approach and landing (36%). CONCLUSIONS. Exposure to glare sources at night can affect an aviator's dark adaptation and has contributed to aviation accidents and incidents. The study of these events assists airport authorities in defining appropriate modification of existing airport lighting systems and eliminating hazardous lighting near flight paths and surface movement areas (e.g., ramps, taxiways, runways). Preventive measures for avoiding similar glare conditions that impair vision and compromise the safety of aviation operations at night will be discussed.					
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AIRCRAFT ACCIDENTS AND INCIDENTS ASSOCIATED WITH VISUAL DISTURBANCES FROM BRIGHT LIGHTS DURING NIGHTTIME FLIGHT OPERATIONS

BACKGROUND

Today's commercial and military aircraft have sophisticated avionics and computer-based systems to assist aviators with many common flight operations. Aviation safety, however, is still largely dependent on the pilot's ability to efficiently process the visual scene, both inside and outside the cockpit, while controlling the aircraft in the aviation environment. Even the most technologically advanced aircraft require pilots to make quick decisions in response to air traffic control (ATC) instructions, changing weather conditions, and during "see-and-avoid" traffic situations. General aviation (GA) aircraft usually have fewer automated systems to assist the pilot, making vigilance even more critical to flight safety. Pilots are normally well trained to effectively cope with difficulties they encounter in the aviation environment. Operation of an aircraft at night, however, presents its own unique problems. Darkness limits a pilot's visual range and reduces the time a pilot has to respond to a critical situation, which can seriously compromise aviation safety. When the eyes are adapted to low-light levels, exposure to bright light can result in temporary visual impairment due to glare, flashblindness, and afterimages, further limiting the pilot's response time (1).

The human eye captures and processes light energy (photons) of different intensities and wavelengths. Light passes through the cornea, the opening in the iris (pupil), crystalline lens, vitreous humor, and finally reaches the retina (Figure 1). The retina contains receptor cells called rods and cones that are stimulated by light and send signals through the optic nerve to the brain. The brain interprets these signals as a visual image. The rods are highly sensitive to light and are primarily responsible for vision in dimly lit environments (scotopic vision). Of poorer quality than daytime vision, scotopic vision transforms colors to shades of gray and black. In a darkened environment, peak resolution of central vision is equivalent to Snellen visual acuity of 20/200 or less after complete dark adaptation. As a result, an object viewed at night should be fixated on a few degrees off the visual axis (or adjacent to the fovea) in the peripheral retina, where the rods are more densely concentrated. In contrast, the cone receptors require much more light to react and function best at higher levels of illumination (photopic vision). Cones are densely concentrated in the macular region (fovea and parafoveal), which

corresponds to the central portion of the field of view, where they provide resolution of fine detail (i.e., Snellen 20/20 or better) and color discrimination (2).

The eye's dual-receptor system allows it to maintain sensitivity over a large range of ambient light levels. The intensity of light from the sun is approximately 30,000 times that of the moon, yet the eye can function in bright sunlight as well as in dim moonlight when adapted for each condition.

At intermediate levels of illumination, the rods and cones function simultaneously. The transition zone between photopic and scotopic vision, where the level of illumination is equivalent to twilight or dusk, is called mesopic vision (2). Neither the rods nor the cones operate at peak efficiency in this range, but both actively contribute to visual perception. Mesopic vision may be of primary importance to the pilot when operating an aircraft at night, since some level of ambient illumination is often present in the cockpit.

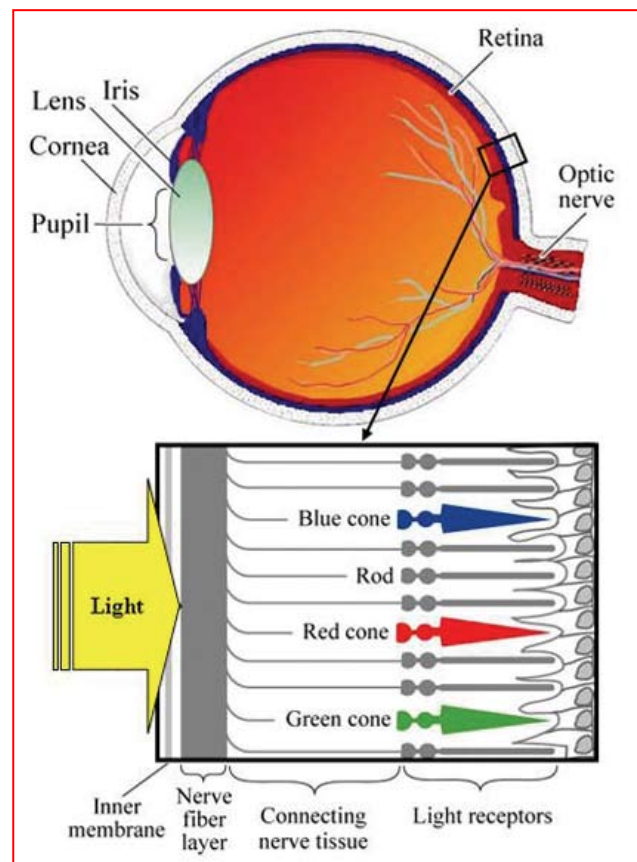


Figure 1: Diagram of the human eye.

Dark adaptation is an independent process during which each eye adjusts from a state of high luminance to one of low luminance. This adjustment to lower levels of illumination involves biochemical, physical, and neuronal aspects. Both rods and cones contain light-sensitive chemicals called photopigments. The photopigment in the rods is called rhodopsin, or “visual purple.” There are three different types of cone photopigments (red-, blue-, and green-sensitive). Upon exposure to light, photopigments undergo a chemical reaction that converts light energy to electrical activity, initiating visual impulses in the retina that are transmitted through nerve fibers from the eyes to the brain. The initial chemical reaction is called light adaptation and, in this process, the photopigments are decomposed. Intense light decomposes the photoreceptor pigments rapidly and completely, thus reducing retinal sensitivity to dim light (3). Regeneration of the photopigments occurs during dark adaptation.

The fully dark-adapted eye, in which photopigment regeneration is complete, restores retinal sensitivity to its maximal level. Depending upon the eye’s state of preadaptation to light, dark adaptation is about 80% complete within 30 minutes, but it may take several hours to achieve total dark adaptation (3). Retinal adaptation can be affected by physical changes in the size of the pupil. The amount of light entering the eye is proportional to the area of the pupil (i.e., the square root of the pupillary radius). In a healthy adult 18 - 50 years of age, the diameter of the pupil can constrict to 1.5 mm and dilate to 8 mm, which equates to a 30-fold range in the quantity of light entering the eye (3). This range in pupil size often diminishes with age, as the iris becomes less reactive to light, resulting in smaller pupils under low-light conditions, longer adaptation periods, and poorer scotopic vision. There are other factors, however, that can compromise an individual’s ability to achieve dark adaptation or, once exposed, recover it in a timely manner, including preexisting physical conditions (4), altitude hypoxia (5), and the effects of diet (6), alcohol (7), smoking (8), and medication (9).

The common visual effects from bright light that may compromise night vision are:

- Flashblindness – A visual interference effect that persists after the source of illumination has been removed (10).
- Afterimage – A transient image left in the visual field after an exposure to a bright light (10).
- Glare – Obstruction of an object in a person’s field of vision due to a bright light source located near the same line-of-sight (10).

The Federal Aviation Administration’s (FAA’s) Vision Research Team has an ongoing research program that

investigates the effects of lasers and other high-intensity light sources on pilot vision and performance. This study reviewed aircraft accident and incident reports to determine whether visual difficulties from bright light sources encountered by civilian airmen performing nighttime aviation activities were contributing factors in these mishaps.

METHODS

Reports from the National Transportation Safety Board (NTSB) Aviation Accident and Incident Data System and the FAA Accident/Incident Data System were reviewed for this study (11). Computer searches of the databases were conducted using the word “night,” together with each of the following terms: glare, bright light, flash, flashblindness, blind, reflection, and vision. The search periods varied due to differences in the dates when these databases were established and last updated (i.e., NTSB: Jan 1982 – Feb 2005, and FAA Accident/Incident Data System: Jan 1978 – Jan 2005).

The NTSB database is the official repository of aviation accident data, causal factors, and selected incident data, while the FAA Accident/Incident Data System contains accident and incident data records for all categories of civil aviation (12).¹ The records collected from the database searches were categorized by type of event. The narratives of each record were individually reviewed to determine whether visual impairment during nighttime aviation operations was a contributing factor and to ensure that reports from the two databases were not duplicated.

RESULTS

Total aircraft accidents and incidents by the phase of flight are summarized in Table 1. There were 58 reported mishaps that identified vision problems at night resulting from exposure to sources of bright light as a contributing factor in the accident (n=30) or incident (n=28). The majority of accidents (n=17) occurred during the approach and landing phase of flight. Incidents occurred most frequently while taxiing (n=15) and during approach and landing (n=10).

¹ The terms *aviation accident* and *incident* refer to events that are defined, in part, as follows:

Accident. An occurrence associated with the operation of an aircraft, which takes place between the time any person boards the aircraft with the intention of flight until such time as all such persons have disembarked, in which:

- a) a person is fatally or seriously injured,
- b) the aircraft sustains major damage or structural failure,
- c) or, the aircraft is missing or completely inaccessible.

Incident. An occurrence, other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operation.

Table 1: Aircraft accidents and incidents categorized by phase of flight.

PHASE OF FLIGHT	ACCIDENT	INCIDENT	TOTAL
Taxiing	6	15	21
Takeoff/Departure	3	2	5
Enroute	4	1	5
Approach/Landing	17	10	27
TOTAL	30	28	58

DISCUSSION

Flight crewmembers were more susceptible to night vision problems during the approach and landing phases of flight, possibly due to prolonged exposure to low-light levels prior to being illuminated by airport lighting systems or other bright light sources. The greatest percentage (47%) of aviation accidents (n=17) and incidents (n=10) found in this study occurred during these maneuvers. In the text of these reports, pilots commented that they lost the ability to judge distances (depth perception) after experiencing glare or from being flashblinded by approach or runway lights (5 accidents, 5 incidents). One of these accidents occurred when the pilot asked the control tower to turn up the intensity of the approach lights so she could visually acquire the runway on approach. The pilot reported that she experienced “excessive glare in her contact lenses” on short-final approach, which distracted her and caused her to collide with the approach-light structure. Other pilots complained of similar visual difficulties when their landing lights were reflected back into the cockpit by dust, fog, rain, snow, or ice just prior to landing (5 accidents, 2 incidents). There were 3 incidents where the pilot-in-command reported being flashblinded and seeing “spots” or other afterimages when laser light illuminated the cockpit during approach maneuvers. Three accident reports described vision problems resulting from inappropriate interior lighting or instrument lights. After being distracted by bright light sources, several reports suggest that pilots lost their ability to properly judge height and distance, resulting in short (or long) landings and collisions with terrain (and/or obstacles) at either end of the runway. In other instances, pilots damaged their landing gear during hard landings caused by flaring too early (or too late), which resulted in the loss of control of the aircraft (2 accidents). Finally, 2 reports described accidents involving emergency medical evacuation helicopters. One occurred when the pilot crashed after hitting power lines while attempting to land, and the other damaged the aircraft

during a hard landing near the scene of a traffic accident. Both reports suggested that the pilots were flashblinded by the lights of emergency vehicles on the ground at the accident scenes.

Taxiing aircraft accounted for the second largest percentage (36%) of night vision mishaps (6 accidents, 15 incidents). Ineffective lighting configurations in the airport environment appear to be a root cause of these visual difficulties while taxing. The majority of these involved pilots who strayed off ramps, taxiways, and runways (2 accidents, 5 incidents), hitting obstacles (3 incidents) or other aircraft (4 accidents, 5 incidents) due to the effects of glare and/or flashblindness. In several of these mishaps, the pilots reported that inappropriate or poorly positioned ramp or apron lighting hampered their ability to distinguish runway markings or determine exactly where the taxi surface began and ended. One incident occurred when a pilot stopped too abruptly, causing his aircraft to nose over and damage the propeller. According to the report, reflections and shadows from the airport lighting produced an illusion that someone had run in front of the aircraft. Another incident occurred when glare interfered with a pilot’s ability to see a hold short line (i.e., a line indicating the boundary between the taxiway and an active runway). This resulted in a collision with a second aircraft that was cleared to taxi on the runway. At many of the airports where these mishaps occurred, pilots described the runway and taxiway markings as inadequate, in need of repair, or totally obscured (due to poor meteorological conditions). It appears, when mechanical and/or meteorological problems combine with a pilot’s loss of dark adaptation, the risk of runway incursions, collisions between aircraft, and excursions off of aircraft movement areas (onto terrain that is either too rough or too soft to support the weight of the aircraft) increases.

Takeoff and departure maneuvers appear less influenced by the effects of night vision problems. Less than 9% of the events (3 accidents, 2 incidents) identified in this study occurred during this phase of flight. In these mishaps,

the aircraft either hit an obstruction (2 accidents) or the terrain (1 accident, 1 incident) during or shortly after takeoff. In the other incident, which occurred during the takeoff and departure of a Boeing 737 air carrier, the first officer (FO) was visually incapacitated when exposed to an unidentified ground-based laser (13). The FO was flashblinded in his right eye and had afterimages in the left after being illuminated by a green laser light. He also reported that he experienced brief spatial disorientation and temporarily lost his ability to focus. Fortunately, the captain took over control of the aircraft and the FO suffered no permanent eye damage. If both the captain and FO had been exposed and equally affected, this event could have ended tragically.

Approximately 9% of these mishaps occurred during enroute flight operations (4 accidents, 1 incident). Exposure to abruptly changing lighting conditions during low-level flight operations can increase the chance of aviation mishaps. Three pilots reported being affected by glare and/or flashblindness from exposure to various bright light sources that resulted in collisions with obstacles (2 accidents) and the terrain (1 incident). One accident involved a monocular pilot who was flying without a current FAA airman's certificate just after sunset. The aircraft collided with trees and crashed, killing the pilot and his two daughters. The accident occurred immediately after the aircraft made a low pass over a valley where a group of campers were gathered including the pilot's oldest daughter. The contributing factors in this tragedy included the pilot's pre-existing visual deficit, incomplete dark adaptation, and an ill-advised low pass over a valley made darker by the shadows from the surrounding hilly terrain. The fifth mishap involved a United States Coast Guard pilot on an authorized night tactical flight. The report indicated that the aircraft flew at a high rate of speed from daylight into night conditions. Dark adaptation was impeded by flight through a range of light conditions created by the terrain and ambient light levels. Without proper dark adaptation, the pilot was unable to make out changes in the elevation of the terrain, which rose abruptly by 300 feet at the point of impact.

In addition to the NTSB and FAA database searches, a similar search was conducted of the Aviation Safety Reporting System (ASRS). The ASRS was established in 1988 under a Memorandum of Agreement between the FAA and the National Aeronautics and Space Administration (NASA) to lessen the likelihood of aviation accidents (11). It is a voluntary and confidential incident reporting system where pilots, ATC personnel, flight attendants, mechanics, ground personnel, and others involved in aviation operations can file reports concerning instances

where aviation safety is compromised. The ASRS includes reports submitted from 1988 through November 2004. While ASRS reports may be criticized for allowing the submission of anonymously obtained, subjective accounts that cannot be properly investigated, the information they provide may be important in identifying potentially hazardous situations.

The ASRS database contained 153 reports where night vision problems resulted in unsafe conditions. Fifty-nine percent (n=90) of these events occurred during taxiing operations, while 27% (n=41) involved approach and landing maneuvers. Enroute flight and takeoff/departure operations accounted for 7.2% (n=11) and 5.2% (n=8) of these incidents, respectively. Flight crewmembers and ATC personnel submitted the three remaining reports identifying visual problems caused by airport lighting. Under some circumstances, poorly positioned airport lighting and temporary construction lights obstructed the tower controller's view of aircraft or hindered the flight crew's view of other aircraft and terrain as they navigated airport ramps, taxiways, and runways.

One example of ATC personnel hampered by glare from airport lighting involved a runway collision between USAir flight 1493 and Skywest flight 5569 at Los Angeles International Airport on February 1, 1991, that resulted in 34 fatalities (14). The accident occurred when the USAir Boeing 737 that was cleared to land collided with the Skywest Fairchild Metroliner that was holding on the same runway awaiting clearance to takeoff. Although not determined to be the primary cause of the accident, the NTSB's findings included the following statement: "The ability of the Los Angeles Air Traffic Control tower personnel to distinguish aircraft on the runways and other airport traffic movement areas, including the accident site, was complicated by some of the terminal II apron lights which produced glare." This unsafe lighting situation was rectified after this accident.

During this search, only 3 reported incidents were found as the result of laser illumination. Although there are only a handful of aviation incidents documented by the Department of Transportation regarding pilots being visually impaired by laser light, there are more than 500 reports of laser incidents from other FAA sources, newspaper accounts, safety documents, etc. As a result, the FAA established Flight Safe Exposure Levels with corresponding Laser-Free, Critical, and Sensitive Zones over and around airports when it adopted "Recommended Interim Guidelines" drafted by the Society of Automotive Engineers' Laser Safety Hazards Subcommittee in 1995. These new procedures were later incorporated into FAA Order 7400.2, Procedures of Handling Airspace Matters, Chapter 29, Outdoor Laser Operations. More recently,

the FAA's System Operations Security published on January 11, 2005, an Advisory Circular entitled "Reporting of Laser Illumination of Aircraft" (AC No: 70-2). This document provides guidance on reporting of laser illumination of aircraft and aircrew mitigation procedures if illuminated by a laser light. Further research on laser light in outdoor environments and their affects on aviation is needed as this technology continues to mature and new laser and high-intensity light applications emerge.

Exposure to light that is several orders of magnitude brighter than that to which the eyes are adapted can reduce or eliminate a pilot's ability to correctly perceive depth or clearly see obstacles and the terrain (Figure 2). The period of time and extent to which these effects may last varies considerably among individuals.



Figure 2: Cockpit glare induced by a 532 nm laser exposure ($50 \mu\text{W}/\text{cm}^2$).

As these events illustrate, aviation personnel performing flight operations at night are presented with a serious challenge. The darkness of night and the human eye's reliance on light requires that a balance be maintained between dark and light adaptation to optimize visual performance for the task at hand. During critical nighttime operations, direct exposure to very bright light sources can result in the loss of dark adaptation, while adaptation to total darkness can result in night myopia (i.e., diminished visual acuity due to the inactivity of the eye's cone receptors). The following are recommendations to optimize visual performance and enhance aviation safety during nighttime activity.

- Clean the windshield thoroughly during the preflight check. It should also be inspected regularly for damage or excessive wear that may result in glare from increased light scatter, and worn windshields should be replaced when transparency becomes degraded.
- Allow eyes to become properly dark-adapted by wearing sunglasses during the day, and avoid brightly illuminated environments (e.g., beach or snow skiing) before flying at night.

- Avoid medications that could affect eyes' sensitivity to light or prolong recovery from exposure to a bright light source whenever possible. These include some over-the-counter nonsteroidal anti-inflammatory drugs and prescriptive medications, such as antibiotics, oral contraceptives, and acne medication.
- Keep one eye shut should you look in the direction of a bright light source to maintain dark adaptation in at least one eye.
- Use the glare shield (sun visor), bill of a cap, or other opaque objects to shield your eyes from harsh ramp lighting.
- Be aware that some forms of ophthalmic correction or refractive surgical procedures can increase sensitivity to glare.
- Report to the appropriate airport authorities all damaged, ineffective, or inappropriate airport navigation aids and lighting problems both on and off airport property.
- To avoid flash blinding other pilots, dim aircraft landing lights as soon as safety concerns allow.
- Once the runway is identified, have the approach lights dimmed whenever possible to avoid excessive glare and to preserve dark adaptation during roll-out and taxiing operations.
- Be prepared for external lighting to reflect back into the cockpit when flying in marginal weather conditions, such as fog, mist, rain, or snow.
- Use off-axis vision and peripheral visual clues to assist in judging altitude and distances when glare is present.
- Maintain a marginal lighting condition in the cockpit to retain some cone photopigment function and to avoid night myopia.
- Be aware that physiological conditions (e.g., monocular vision and advanced age) or smoking can adversely affect your ability to adapt to a darkened environment and/or accurately judge distances at night.

In conclusion, this study found that pilots and other aviation personnel have been distracted and/or disoriented from the effects of bright lights during nighttime aviation activities. The effects are primarily seen in loss of visual skills, depth perception, and temporary visual impairment due to glare, flashblindness, and afterimages. The flight operations most affected by glare, flashblindness, and loss of proper dark adaptation were taxiing and approach/landing. Pilots were unable to effectively judge altitude and/or distances while landing and taxiing their aircraft. Glare from bright lights made it difficult for pilots to see the edges of taxiways and runways and created problems for controllers when viewing aircraft activities from the tower. Heightened situational awareness

and the elimination of avoidable exposure to bright light sources are important steps in preventing the debilitating effects on vision at night. The study of such mishaps can assist airport authorities in defining appropriate modification of existing airport lighting systems and eliminating hazardous lighting near air traffic corridors. In addition, a good understanding of what can trigger vision difficulties at night could avert similar mishaps and improve aviation safety.

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