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Awareness of Causes and Symptoms of Flicker Vertigo Can Limit Ill Effects

Pilots (and others exposed to some types of flickering lights) may have reactions ranging from mild discomfort to seizures and unconsciousness. Nevertheless, they often fail to recognize the problem as flicker vertigo.

Clarence E. Rash

Flicker vertigo is an imbalance in brain-cell activity caused by exposure to the low-frequency flickering (or flashing) of a relatively bright light (such as a rotating beacon; a strobe light; or sunlight seen through a windmilling propeller). Flicker vertigo can result in nausea, dizziness, headache, panic, confusion, and — in rare cases — seizures and loss of consciousness, which could result in a pilot's loss of control of an aircraft.

Flicker vertigo occurs most often among helicopter pilots but also affects pilots of fixed-wing, propeller-driven airplanes. Cabin crewmembers and passengers also experience its effects.

Although flicker vertigo sometimes results in a spinning sensation, it should not be confused with vertigo, a disorder of the inner ear in which an individual feels as if he or she — or the surroundings — is spinning.

Although not technically an illusion,[1] flicker vertigo often is cited as one of a group of visual illusions that can result in spatial disorientation, which in turn can lead a pilot to experience inaccurate perceptions of attitude, altitude and speed.[2]

Flicker vertigo is defined as a confusion of the vestibular system (the mechanisms in the inner ear responsible for the internal sensation of change in pitch, roll and yaw, as well as longitudinal, lateral and vertical changes) usually associated with a light-flashing sequence between approximately four hertz (cycles per second) and 20 hertz.[3]

Another definition is provided in the U.S. Air Force *Flight Surgeon's Guide*, which says that flicker vertigo can be a result of exposure to "sun or light passing through or reflecting off [a helicopter's] main rotor blade system [and] produc[ing] a moderate-frequency flicker in the cabin, similar to the flicker of a failing neon light tube."[4]

Flicker vertigo also can develop in someone viewing strobe lights or rotating beacons — or their reflections off clouds or water. In fixed-wing propeller-driven aircraft, the phenomenon is associated most often with taxiing situations in which propeller blades are rotating at a relatively low frequency; the movement of the blades can make a low-lying light source such as the sun, moon or runway lights appear as flickering light.

In most cases, symptoms of flicker vertigo are mild and sometimes vague — so vague that the pilot might not recognize the cause of his or her discomfort — and symptoms usually disappear when the flickering stops. In other cases, symptoms persist for hours after exposure to the flickering light has stopped.

Rarely, flicker vertigo may induce photosensitive epilepsy — a type of epilepsy that has been reported in about 0.02 percent of the general population.[5] Photosensitive epilepsy also can be induced by exposure to other sources of flickering light, such as television, video games or computer graphics, or looking at a moving escalator.

The terms "flicker" (and "flashing") describe modulated light. Modulation is a periodic variation in a light's intensity (brightness). This increase and decrease in intensity usually is expressed in hertz.

Perception of Flicker Depends on Interaction of Eyes, Brain

The eye and the brain act together to perceive flickering light. The activities in the retina (the light-sensitive tissue at the back of the eye where the final image is formed) and in the brain are synchronized, as part of the visual process.[6]

If the modulation (flicker frequency) is high enough, the visual system will perceive flickering light as continuous (steady), and flicker vertigo will not occur. The frequency at which this happens is the "critical flicker frequency" (CFF) and depends on multiple factors related to the light source, the individual viewing the light, and the environment.[7] The CFF, which is between 25 hertz and 55 hertz, varies from person to person.

Studies investigating gender differences in CFF have been inconsistent, but more studies have reported higher CFF values for men than for women.[8,9] Similarly, studies on the effect of age on CFF have reported generally inconsistent findings. Nevertheless, some specialists believe that CFF decreases with age. Regardless of definitive effects for age and gender, there is substantial individual variability.[10,11]

Specialists also believe that CFF may increase during the day and decrease at night.[12]

The factors affecting CFF are considered likely to affect the onset frequency for flicker vertigo. Although the actual effects of some of these factors are not fully understood, specialists have identified other factors, such as fatigue, anxiety and mild hypoxia, known to increase susceptibility to the onset of flicker vertigo.[13]

The effects of exposure to low frequency flickering light have been known at least since the 1940s.[14] A 1953 study of what was then referred to as "flicker sickness" examined the effects of intermittent light stimulation in 500 people (including 160 psychiatric patients). Frequencies from two hertz to 30 hertz were investigated. Eighty-seven of the nonpsychiatric individuals displayed symptoms of either a visceral nature (e.g., nausea or headache) or kinesthetic nature (e.g., a sensation of the body moving in space); 16 of the 87 experienced fainting or convulsions. Doctors and nurses conducting the study also reported experiencing symptoms.

Subsequent military studies were conducted to investigate and quantify the potential problem of exposure to flickering lights. A 1959 study of U.S. Army helicopter pilot candidates found that 6 percent experienced abnormal brain waves during an electroencephalogram (EEG) when exposed to a flashing light.[15] A 1960 report discussed two incidents in which U.S. Air Force helicopter pilots reportedly experienced seizures that were attributed to exposure to light intermittently viewed between rotating blades.[16]

In a study of 102 U.S. Navy helicopter pilots under actual flight conditions and in the laboratory, 25 percent of the pilots said that flicker during flight was annoying or distracting, and one pilot reported a near-accident that was attributed to flicker. None of the EEG laboratory measurements was considered abnormal. Nevertheless, EEG measurements correlated with pilots' reports of general feelings of discomfort because of the flashing light used in the laboratory measurements. The study also found that about 20 percent of the pilots were drowsy and less alert after exposure.[17]

In a survey of U.S. Navy helicopter pilots, 35 percent said that they had experienced visual disturbances caused by rotor flicker, and 70 percent reported similar disturbances from reflections of anti-collision lights.[18]

Light Patterns, Fog Cited as Sources of Disorientation

A 1971 study found that, from 1956 through 1971, in 26 percent of disorientation incidents involving helicopter pilots and 13 percent of disorientation incidents involving the pilots of transport airplanes, training airplanes and high-altitude airplanes, the pilots said that the pattern created by sunlight and propellers or rotor blades caused flicker and the associated symptoms.[19] Twenty-two percent of helicopter pilots and 30 percent of airplane pilots said that flight through fog with a rotating beacon had caused flickering light in the cockpit.

Flicker vertigo has been cited in several accidents, including a Dec. 22, 1988, accident in which a Bell 206L-1 Long Ranger II emergency medical services (EMS) helicopter struck a power line in Cape Girardeau, Missouri, U.S., during a night flight. Two medical crewmembers and the patient were killed; the pilot received serious injuries. The pilot told investigators that he "had left the strobe light on and experienced flicker vertigo."

The U.S. National Transportation Safety Board (NTSB) final report on the accident said that the probable cause was "proper altitude not maintained, … spatial disorientation … and VFR [visual flight rules] flight into IMC [instrument meteorological conditions]."[20]

Two reports filed with the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS)[21] discussed the effects of flicker vertigo.

In one report, the captain of a Boeing 767 described his observations of a flashing light during a preflight inspection of his airplane:

> While doing [a] a preflight walk around, I had to shade my eyes from a very bright yellow strobe. This strobe was on top of the fuel truck, about head level high. All the fuel trucks have them, and they cannot be turned off. The ramp agents were also blinded by the brilliant flash and had to walk with their heads turned away to avoid being blinded/disoriented by the flash. This could cause flicker vertigo, nausea or temporary blindness. The ramp area around aircraft is the most dangerous on the airport, and this [is] potentially a very bad addition to the danger.[22]

The second report, filed by an air taxi helicopter pilot, described his encounter with flickering light:

> While in a hover over a pool at the base of a waterfall, I experienced some light turbulence and was also subjected to flicker vertigo caused by the sunlight through [the] rotor blades. I misjudged the distance on the right side of the helicopter and the main rotor tips struck the side of the mountain. A vibration was immediately experienced. I ascertained I could control the aircraft, and I flew to a suitable landing area and shut down.[23]

Another helicopter pilot wrote the following description for a trade publication of an incident that he believed involved flicker vertigo:

> It was a beautiful night. Clear sky and excellent visibility. A bright full moon and lots of stars. I looked up through the rotor disk to look at the stars and the moon. Almost immediately, a weird feeling came over me. A feeling that is hard to describe. It wasn't exactly fear, but it seemed to have something like that in it. I felt tentative, unsure. Nausea was not quite an apt description; but I did feel unwell. This feeling was strong enough to make me consider making a precautionary landing. … [I] decided to go on instruments, even though it was VFR. I did, and in a little while, that weird feeling went away. I don't know for sure what it was. Perhaps it was a touch of flicker vertigo caused by looking at the moon through the rotors.[24]

This report prompted the publication's request that readers provide their accounts of other experiences of flicker vertigo. A subsequent issue of the publication included the following reports:

- "On a night flight over Montauk, Long Island (New York, U.S.), as I was performing a turn, I felt funny. My flight instructor advised that I immediately utilize the instruments. The feeling of dizziness and nausea soon subsided. Quite a feeling. I believe it [was] caused by [the presence of] low lights and turning";

- "Just after takeoff in the predawn light, I was just beside myself. My head was just spinning, and I completely lost my faculties. The moonlight reflected off the ocean and back through the rotor system. This strobe effect put me on my knees";

- "I was returning from Fort Smith, Northwest Territory [Canada] from a fire in the East. …The sun was about 15 degrees to the right of [the] nose of my Bell 47G-5 and about a foot [0.3 meter] above the blade tips. … About 30 minutes into the flight … , it started to get uncomfortably warm in the cockpit. I was perspiring freely and began to feel bloated and nauseous. I started to look for a suitable place to land when my vision began to narrow. … My vision closed in to zero about two feet [0.6 meter] off the ground, and the landing was a bit abrupt. … I didn't connect the incident to flicker vertigo until much later. I've had the onset of it a couple of times in the intervening years, but have managed to avoid the effects by turning away from the sun for a few minutes, or having my copilot take control while I covered my eyes with my hands to eliminate the flicker effect."[25]

Pilots Report Queasiness, Confusion

Of more than one dozen U.S. Army helicopter pilots interviewed by the author, one-third reported incidents in which they experienced vague symptoms of queasiness, confusion and general discomfort that they later attributed to an environment that included flickering lights.

Another published report described an incident involving the military pilot of a high-performance propeller-driven aircraft, who landed his airplane after a training mission. The airplane rolled to a stop on the runway, and after the pilot made no attempt to taxi the airplane off the runway, ground personnel were sent to investigate. The pilot was found unconscious, bent over the controls, with the engine idling. An investigation revealed that light from the sun, which was low on the horizon, was shining through the slowly turning propeller blades, producing flicker at a frequency of approximately 12 hertz. The resultant flashes of light hitting the pilot's eyes had caused him to lose consciousness.[26]

A helicopter's main-rotor hub typically rotates at a frequency of 120 revolutions per minute (rpm) to 500 rpm — the equivalent of two hertz to 8.3 hertz. The resulting flicker frequency (blade-passing frequency) depends on the hub-rotating frequency and the number of rotor blades. The flicker frequency can be found by multiplying the hub-rotating frequency by the number of blades (Table 1, page 4). For example, the Eurocopter Colibri

Table 1
Main-rotor Specifications and Predicted Flicker Frequencies

Helicopter Model	Utility	Number of Blades	Hub Rate (revolutions per minute/hertz)	Flicker Frequency (hertz)
AgustaWestland EH101	Passenger service	5	214/3.6	18.0
Bell 206B-3 JetRanger III	Corporate, law enforcement, military training (modified)	2	442/7.4	14.8
Bell 407	Corporate, law enforcement, emergency medical services (EMS)	4	413/6.9	27.6
Eurocopter Colibri EC 120B	Passenger service, corporate, law enforcement	3	413/6.9	20.7
McDonell Douglas MD 500E	Law enforcement, utility	4	485/8.1	32.4
Sikorsky S-76B	Search and rescue, EMS, utility	4	314/5.2	20.8

Source: Clarence E. Rash

EC 120B has three main-rotor blades with a hub-rotating frequency of 413 rpm (6.9 hertz). This would produce a flicker frequency of 20.7 — at the upper limit of the generally cited frequency range for flicker vertigo.

The U.S. Army's McDonnell Douglas AH-64 Apache helicopter has four main-rotor blades and a hub-rotating frequency of approximately 292 rpm or 4.9 hertz, making the flicker frequency about 19.6 hertz — also within the generally cited range for flicker vertigo.

For a typical small-sized to medium-sized civil aircraft, propeller hub-rotating frequencies for taxiing are about 1,000 rpm (16.7 hertz). During flight, typical rpm values are much higher, most exceeding 1,700 rpm (28.3 hertz). At 1,000 rpm, propeller-blade passing frequencies (flicker frequencies) for airplanes are about 57 hertz for two-blade propellers, 85 hertz for three-blade propellers and 113 hertz for four-blade propellers. All of these values are outside the range of susceptibility. For example, a Cessna 172 has an in-flight propeller hub-rotating frequency of approximately 2,400 rpm (40 hertz), which with two blades produces a flicker frequency of 80 hertz, well above the flicker vertigo range. During taxiing, the propeller hub-rotating frequency ranges from 750 rpm to 1,000 rpm (12.5 hertz to 16.7 hertz), which produces flicker frequencies between 25 hertz and 33.4 hertz, just above the flicker vertigo range.

Some accident reports have attributed the onset of flicker vertigo to flashes of light from strobe (anti-collision) lights reflecting off clouds or rain.

For civil aviation, U.S. Federal Aviation Regulations Part 23.1401 (fixed-wing) and Part 27.1401 (rotary-wing), "Anticollision Light System," limit the flash frequency to between 40 flashes per minute and 180 flashes per minute, which is 0.67 hertz to three hertz. A typical flash rate for many strobes sold by aircraft parts suppliers is 50 flashes per minute, plus or minus five flashes (less than one hertz). Military aircraft also comply with this regulation. These frequencies are just below the range of susceptibility for flicker vertigo.

Flicker vertigo also could occur during night flights in which night-imaging devices (night-vision goggles) are used and during simulator flight.

Most military helicopter night operations and many commercial EMS flights are conducted using night-vision goggles. During such flights, the primary visual input is obtained by viewing the image produced by these devices rather than direct viewing of the external scene. A 1994 study evaluated flicker detection through these night-vision devices and found that, while flicker sensitivity decreased at frequencies greater than 10 hertz (the middle of the flicker vertigo range), under optimal stimulus conditions, the maximum rate of flicker that could be detected through the night-vision devices was only slightly less than those frequencies that could be detected with unaided vision.[27] Thus, the study found that the use of night-vision devices did not significantly limit the pilot's ability to detect flicker rates. Therefore, a likely extrapolation is that the use of such devices does not have a significant effect on the onset of flicker vertigo.

In flight simulators, the following design factors may influence the occurrence and duration of simulator sickness, and — more specifically — flicker vertigo:[28]

- The refresh rate, which is the frequency at which the simulated imagery is updated. A slow refresh rate can lead to a visual lag, which may result in symptoms of simulator sickness;

- Simulator luminance, which is the intensity of the light on the simulator display. To prevent flicker, the refresh rate must increase as luminance increases. Conversely, night simulation (i.e., low luminance) can operate at lower refresh rates without inducing flicker; and,

- Field of view, which is the area that is visible. There are two reasons to increase the field of view: A larger field of view increases the likelihood that flicker will be detected,[29] and the human eye has a greater sensitivity to flicker in its periphery than in the central part of the retina.[30]

Countermeasures to prevent the onset of flicker vertigo and to minimize adverse reactions can be taken by pilots, airport administrators and the aviation community.

Pilots can take the following actions:

- Where appropriate, look away or turn away from the light source. If a copilot is present, eyes can be closed or covered, after transferring aircraft control to the other pilot;

- When entering IMC and solid cloud cover, turning off strobe lights prevents reflections off clouds and rain. When taking this action, air traffic control should be notified; and,

- In airplanes (especially single-engine airplanes), pilots should try — if possible — to avoid conducting a landing into the sun or bright lights, and engine (propeller) rpm should be changed during descent and taxiing if symptoms of flicker vertigo occur.

In EMS helicopter flights, medical personnel should take precautions to protect the patients' eyes from main-rotor flicker. This is especially important for patients with a history of motion sickness or epilepsy.

At airports, floodlights should be designed to be high-mounted and directed downward.[31]

Industry publications should continue to educate pilots about conditions that can lead to flicker vertigo.[32]

Flicker vertigo can cause physiological symptoms ranging from mild discomfort to unconsciousness. Although a number of factors are known to influence susceptibility to and the onset of flicker vertigo, their effects are not fully understood. Nevertheless, an awareness of the causes of flicker vertigo and recommended precautions for avoiding exposure can help limit the symptoms.♦

Notes

1. When visual input is erroneous or contradicts other sensory inputs, illusions can occur. The major spatial-disorientation illusions are classified as visual illusions, vestibular illusions and somatosensory ("seat of the pants") illusions.
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21. 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 identity, 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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