

AVIATION MEDICINE, ILLNESS AND LIMITATIONS FOR FLYING

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Introduction

The world has celebrated over 100 years of powered flight. In December 1903, on a very windy beach in North Carolina, USA, Wilbur and Orville Wright successfully designed, built, and flew the first powered aircraft. In the air for only seconds, it marked the beginning of modern aviation. In just a short time span, aviation has progressed to high-altitude flight, flight at supersonic speeds, and flight to space and back. Aviation is integrated into

our modern world and has blurred the boundaries of countries, enhanced business and communication across the world, and become an integral part of military operations. Much has been learned in a century of flight, including the importance of aeromedical factors on the safety of flight.

While the medical regulations will differ between countries, there are some general guidelines that prevail over most aviation governing agencies. The most comprehensive source for international medical requirements is updated regularly and can be found on the International Civil Aviation Organization (ICAO) website or in its information sources. The ICAO compiles the medical regulations from over 180 contracting states, each with slightly different medical requirements. For specific medical requirements

for a particular area, the chief medical officer, or, in the USA, a local flight surgeon or the Federal Aviation Regulations can provide current medical standards. Those requirements and factors that do not change are discussed in this article.

Fitness for Flight and Medical Certification

Pilots must have an overall fitness for flight. The ultimate safety and success of the flight depend on the pilot in command. An important component of any successful and safe flight is a healthy pilot who is “fit for flight.” Fitness is a combination of physical and mental well-being, good preflight planning, and currency of training and, of course, an aircraft that is well maintained.

Most regulatory or licensing agencies will have their own specific medical and physical requirements for those who wish to obtain and maintain a pilot’s license. Depending on the type of license (private versus commercial), the medical certification will differ in standards and is renewed at various time intervals. For example, in the USA, a commercial pilot must have a first-class medical certificate, which must be renewed twice yearly, while a private pilot who is less than 40 years of age must renew his/her medical certificate every 3 years. Most countries have

similar medical requirements to those in the USA. Using organ system class, some general requirements of US medical certification are listed in [Table 1](#). [Table 2](#) provides a concise summary of two US general aviation accidents in which underlying pathologies and/or drug use were factors in the outcome.

Medication Use and Flight Performance

[Table 1](#) describes conditions that pose a risk for the safety of flight because poor control or exacerbation of these disease states could adversely affect the pilot’s performance of duties. For example, one of the well-known adverse effects of drugs used for the treatment of diabetes is hypoglycemia. Hypoglycemia may result in altered mental status, which can adversely impact a pilot’s performance. In addition to the disease states listed in [Table 1](#), other factors should be considered during preflight planning. Acute illness may also reduce pilot performance to an unsafe level. Infection, anemia, peptic ulcer, acute injury, or pain are examples of such conditions. Note that, even when some conditions are treated, the medications used may impair flight performance and cause undue risk. Use of certain medications may be precluded in pilots because they may alter memory, concentration, alertness, and coordination, or otherwise

Table 1 Summary of some of the requirements for medical certification for an airman certificate – US standards^a

<i>Organ/system</i>	<i>Standards</i>
Eye	Distance visual acuity of 20/20, corrected or uncorrected Near vision of 20/40 or better, or Snellen equivalent at 16 in each eye separately with or without corrective lenses Ability to perceive those colors that are necessary for safe performance of airman duties Normal visual fields No underlying pathology that interferes with proper vision, or a condition that would progress to such, or one that is aggravated by flying Normal convergence
Ear, nose, throat, and equilibrium	Normal hearing by specific standards, no disease of the ear, nose, or throat that would interfere with duties as a pilot, absence of any disease or impairment that would interfere with speech communication No underlying condition that would cause vertigo or a disturbance in equilibrium
Mental	No history or diagnosis of a personality disorder severe enough to cause overt acts, psychosis, delusions, hallucinations, grossly bizarre or disorganized behavior. No history of substance abuse ^b
Neurologic	No medical history or clinical diagnosis of epilepsy, unexplained loss of consciousness, unexplained transient loss of control of nervous system functions, no other disorder that would render the pilot unable to perform the duties of an airman in a safe manner
Cardiovascular	No history or diagnosis of myocardial infarction, angina, coronary artery disease (requiring treatment or symptomatic), cardiac valve replacement, pacemaker implantation, heart transplant
Other	No history or diagnosis of diabetes mellitus requiring insulin or other hypoglycemic treatment, or other underlying disease, that at the medical judgment of the flight surgeon makes the safe performance of airman duties questionable

^aThe Federal Aviation Administration designates flight surgeons of the Armed Forces on specified military posts or designated aviation medical examiners on nonmilitary sites as those authorized to issue medical certification for flight.

^bThose who have a history of substance abuse who have been abstinent for the preceding 2 years may be eligible at the discretion of the flight surgeon.

Table 2 Concise summary of National Transportation Safety Board investigations where underlying disease states or drug use were determined to be factors in the outcome

Case 1

In July 2003, a Piper PA28 was destroyed in daylight hours operating in visual flight conditions and without a flight plan. A witness described the airplane as flying over the airport at an altitude of 180–240 m (600–800 ft) above the ground. The witness reported that the aircraft suddenly turned to the left and flew straight into the ground. The pilot was fatally injured and the aircraft was destroyed. The pilot held a private certificate for single-engine aircraft and was instrument-rated. He had a valid third-class medical certificate and had a total flight time of 657 h, 442.5 of which were in that airplane. He reported on his application for a medical certificate that he did not take medication and he did not have a history of any illness.

Review of the pilot's medical records revealed that he had a 12-year history of depression. Two days before the accident he was admitted to an inpatient psychiatric facility for a suicide attempt in which he had ingested 8 Ambien tablets. He had been treated intermittently since 1991 with antidepressants. Because there were no inpatient beds available, the pilot was discharged home after several hours on citalopram (Celexa).

Postmortem toxicological analysis showed brain ethanol concentrations of 23 mg dl⁻¹, muscle ethanol 14 mg dl⁻¹, and trace amounts of diphenhydramine, citalopram, fluoxetine, and norfluoxetine in the liver and kidney.

Case 2

In August 2003, an experimental amateur-built Young Pietenpol Air Camper piloted by a recreational pilot was destroyed on impact with trees and terrain during a landing at a local airport. Visual flight conditions prevailed at the time of the accident and there was no flight plan on file. The pilot survived the accident only to die from his injuries during the following 24 h. The pilot had a recreational pilot certificate with a single-engine land airplane rating and a valid third-class medical certificate. He had 70 h total flight time, 15 of which were flown in the 6 months before the medical certificate was issued.

There were no witnesses to the accident, but it appeared from the wreckage that the aircraft may have impacted trees with its left wing. Postmortem toxicological analysis (more than 24 h after the accident) revealed that the pilot had ingested diphenhydramine around the time of his last flight.

Table 3 Drugs that may alter flight performance

<i>Agent</i>	<i>Effect</i>	<i>Example</i>
Sedating antihistamines	Sedation, dry mouth, mydriasis, cycloplegia	Diphenhydramine
Muscle relaxants	Sedation, impaired coordination	Cyclobenzaprene
Ethanol	Impaired judgment, increased reaction time, impaired coordination, visual disturbances, exacerbates the central nervous system depressant effect of other drugs, increased susceptibility to hypoxia, amnesia	
Sedatives	Sedation, impaired coordination, impaired judgment, amnesia, increased reaction time	Alprazolam
Antiemetics	Sedation, dry mouth, mydriasis, impaired judgment, increased reaction time	Promethazine
Antihypertensives	Risk of orthostatic hypotension, sedation	
Antidepressants	Sedation, impaired coordination, increased susceptibility to depressant effect of other central nervous system depressants	
Analgesics	Sedation, impaired coordination, increased reaction time	Hydrocodone, tramadol
Hypoglycemics	Hypoglycemia, change in mental status, loss of consciousness	Insulin, glipizide
Drugs of abuse	Impaired coordination, memory, judgment, and reaction time	Marijuana, phencyclidine, cocaine, ecstasy

compromise flight performance. Examples of these are listed in [Table 3](#). Note that, in addition to affecting coordination, memory, judgment, and reaction time, central nervous system depressants predispose the pilot to the effects of hypoxia. Despite widespread knowledge of the effects of certain medications, postmortem toxicological analysis of samples from fatal accidents still indicates that these drugs are commonly used by pilots. A short review of National Transportation Safety Board (NTSB) cases shows that the drugs most commonly used by pilots involved in fatal accidents are diphenhydramine and ethanol. Use continues despite the well-known impairment of

driving performance by diphenhydramine. In a study published in 2000 in the *Annals of Internal Medicine*, 25 mg diphenhydramine was noted to cause more impairment in driving performance than a blood alcohol concentration of 0.10 mg dl⁻¹.

More examples of drug use and accident factors can be found on the NTSB database (www.nts.gov).

Flight performance is a combination of coordination, focus of attention, clarity of thought, judgment, training, and proficiency. Note that being “current” according to flight regulations does not necessarily ensure that a pilot is “proficient” to execute the flight safely. Fatigue, illness, stress, and emotional liability

can degrade and detract from a pilot's ability to conduct a flight safely.

Summaries of aviation accidents and incidents from multiple sources consistently show that aviation accidents are rarely the result of one catastrophic event or cause. This is not to say that a single overwhelming cause does not exist; certainly, catastrophic events do occur. Data trending and analysis of aviation accidents show that the majority of accidents have multiple factors that contribute to unsafe flights. Surprisingly, many of these factors are easy to identify and to prevent by simply delaying or changing other aspects of the flight. In 1999, there were 1933 aircraft involved in 1906 accidents, 340 of which were fatal accidents. These numbers can be translated to 2.41 accidents per 100 000 h flown. Personal flights for recreational or business had a higher rate of fatal accidents, effectively double that of any other type of flying, such as commercial carriers and military flights. Seventy-four percent of personal/business flight accidents resulted in a fatality. Other notable factors associated with fatal aviation accidents include the failure to file a flight plan, flying in low-visibility conditions (either instrument meteorological conditions or at night), drug use, pilots with low flight time, and pilots flying in weather that exceeds their ability or training.

Other Factors and Flight Performance

Fatigue

Fatigue is one of the most indolent and difficult-to-recognize factors. The NTSB reviews general aviation accident data and summarizes the characteristics of each accident that degrade flight performance. Acute fatigue, flying after a long day of work, or lack of sleep can impair judgment, impair coordination, increase the work associated with flying, and negatively affect alertness. Lack of adequate rest can result in chronic fatigue. Commercial airlines have regulations on the number of hours a pilot is on duty per month, and the number of consecutive hours a pilot would be on duty without rest.

Stress

Stress can detract from alertness, concentration, and judgment, and can degrade the safety of any flight. Pressure to adhere to a time schedule, sometimes known as "get-thereitis," often promotes poor judgment and flights into weather conditions that are beyond the capability of either the aircraft and/or the pilot. Pressure from passengers or employers can often push pilots into making poor decisions that

compromise the safety of the flight. Although pilots are trained and educated to dissociate from stressful factors, it is often impossible to identify and remove the causes of stress.

Emotional

Anger, depression, or other emotional trauma, like stress, can negatively impact the safety of flight by distracting the pilot, so that he/she executes poor judgment, and has decreased reaction time, and poor attention to detail. Case 1 in [Table 2](#) illustrates an extreme of this example.

A common acronym used in preflight planning includes not only an evaluation of the weather, the aircraft, and the route of flight, but also of the pilot. This personal checklist is taught to student pilots from their earliest lessons as part of the preflight checklist. "I am not impaired by" (I'M SAFE), where I is illness, M is medication, S is stress, A is alcohol, F is fatigue, and E is emotion.

Physiological Aspects of Flight

Effects of Altitude, Pressurization, and Depressurization

Hypoxia or relative lack of oxygen can occur in unpressurized aircraft or in aircraft that lose their pressurization systems. As altitude increases, the relative amount of oxygen decreases. Those organ systems that are particularly sensitive to hypoxia are the central nervous system, the heart, and the visual system. Because of the relative dependence of rhodopsin formation on the presence of oxygen, night vision begins to deteriorate at a mean sea level (MSL) altitude of 1500 m (5000 ft). This deterioration is more noticeable at night. If supplemental oxygen is not used, the effects of hypoxia progress as altitude increases. The danger in hypoxia is in its indolence. Judgment, memory, alertness, coordination, and ability to make calculations become progressively impaired. The pilot may feel drowsy or dizzy or euphoric and belligerent. These effects can also be produced by the presence of carbon monoxide in the cabin – also a cause of hypoxia in aviation. As hypoxia increases, peripheral vision decreases and tunnel vision can result. Extremities may become cyanotic and have a bluish hue. Lack of judgment and clarity of thought impairs the pilot from correcting the situation. Loss of consciousness can occur in as little as 20 min at an altitude of 5400 m (18 000 ft) MSL without oxygen supplementation, and in as little as 5 min without supplemental oxygen at an altitude of 6000 m (20 000 ft) MSL. At higher altitudes,

seconds are available before hypoxia ensues, with rapid loss of pressurization of the aircraft. In the USA, the Federal Aviation Administration mandates that, at altitudes above 3750 m (12 500 ft) MSL, the flight crew must wear oxygen after 30 min. At altitudes of 4200 m (14 000 ft) MSL and above, all crew must wear supplemental oxygen, and at 4500 m (15 000 ft) MSL all passengers must be provided with supplemental oxygen. For pressurized aircraft, regulations stipulate that, at altitudes above 7500 m (25 000 ft) MSL, a minimum of 10 min of supplemental oxygen must be available for each occupant in the event of rapid decompression. At flights above 10 500 m (35 000 ft) MSL, a quick-donning type of oxygen masks must be worn.

Sinuses and Ears

As altitude increases, equalization of the pressure between each side of the tympanic membrane becomes unequal and can produce intense pain. This unequal pressure can be compounded by the presence of allergic inflammation or an upper respiratory infection can make equalization difficult. This results in ear pain and loss of hearing that can last for several hours after flight. Pain can be minimized by executing the Valsalva maneuver (pinching the nose and attempting to blow through it), by yawning, swallowing, or opening and closing the mouth. For very young passengers, often sucking on a pacifier, nursing, or swallowing can minimize ear discomfort. Tympanic membrane rupture can occur if the pressure difference is excessive. There are no data to indicate that topical nasal decongestants can reduce congestion around the eustachian tubes, but they may provide some palliative comfort.

Vision in Flight

US Federal Aviation regulations require that a pilot have or be corrected to 20/20 distance vision and no less than 20/40 near vision. It is understood that good visual cues and rapid interpretation are important for safe flight. Drugs that cause dry eye, mydriasis or cycloplegia, such as anticholinergics can impair vision. Changes in refractive error caused by underlying diseases such as diabetes can degrade a pilot's vision and have a negative impact on safe flight. The effects of hypoxia cause a loss of peripheral vision.

Illusions occurring in flight are well known. Orientation is maintained by a combination of systems; by the input of the visual system, the inner ear, or vestibular system, and sensory input from skin, muscles, and joints. With a decrease or lack of vision such as occurs in night flight or during instrument meteorological conditions (IMC), sensory input from the

inner ear and motion and position from gravitational (G) forces become more acute. The sensations of motion and position during various flight maneuvers are often misleading and may compel pilots to believe they are in straight and level flight when they are indeed in a bank or ascending or descending. In flight conditions where visibility is decreased, pilots are trained to ignore sensory input and focus on the information provided by the instruments of the airplane. During training, an instructor trains a student pilot by demonstrating the various forms of disorientation and methods used to prevent these illusions. In low-visibility conditions, failure to fly the airplane by the instruments and follow sensory input leads to disorientation and is one of the main causes of pilot error and accidents during low-visibility flight conditions. Illusions during flight are created when visual scenes and sensory input confuse the pilot. When this happens, pilots are spatially disoriented; they are unable to determine the attitude or motion of the aircraft accurately in relation to the earth's surface. Despite this widely known phenomenon of spatial disorientation, the Federal Aviation Administration Advisory Circular indicates that spatial disorientation as a result of continued visual flight into adverse weather conditions is a common cause or a factor in annual statistics on fatal aircraft accidents. It is not unusual for visibility to be above visual-flight-rule (VFR) minimums and a visible horizon to be absent. This is particularly common in night flight, flight in haze, flights over water, or over sparsely populated areas.

One of the most widely publicized aviation accidents in history that ended with three deaths was the last flight piloted by John F. Kennedy Jr in July 1999. Flying a Piper Saratoga, a high-performance aircraft, on a night flight in marginal night VFR conditions, this accident was like many others. It was not caused by one catastrophic mistake, but by a series of smaller, less severe errors, all leading to spatial disorientation and what is known as the "graveyard spiral" with impact into the Atlantic Ocean. The pilot, John F. Kennedy Jr, was a relatively low-time private pilot who was not instrument-rated. He had a total of 310 flight hours, 55 of which were at night; 3 h were solo in the aircraft he was flying at the time of the accident. The flight departed late, at night in marginal visual flight conditions after the pilot had worked a full day. There was no flight plan filed, and no contact with air traffic control. Review of radar tracings of his aircraft indicated that the aircraft entered a descent, then a right turn, then a left turn, followed by a descent that ended in the aircraft impacting the water at a descent rate of over 1410 m min^{-1} (4700 ft min^{-1}). Over water, where

there were no lights or other horizon for visual reference, the pilot apparently became spatially disoriented and entered into a spiral downward attitude that ended with the aircraft impacting the water. Factors in this accident were determined to be haze, a dark night, and the pilot's failure to maintain control of the airplane.

Common illusions during low-visibility flight occur. One common illusion, known as "the leans," occurs when the airplane banks too slowly. When this happens, the fluid in the vestibular system does not move. Any abrupt correction of the bank angle can set the fluid in movement, and the pilot may sense a bank to the opposite side. The pilot may lean to the originally banked side until the fluid in the vestibular system is in concert with the bank.

The Coriolis illusion occurs when an aircraft is in a prolonged constant rate of a turn. If the pilot has an abrupt head movement the fluid in the vestibular system can create an illusion of turning or accelerating in an entirely different axis. The disoriented pilot may maneuver into a dangerous flight attitude in an attempt to correct this illusion.

The "graveyard spiral" occurs when the fluid in the vestibular system ceases movement while the aircraft is in a prolonged, constant-rate turn. The illusion created is an aircraft descent with the wings level. The disoriented pilot, in an effort to correct the perceived descent, may increase the pitch of the aircraft, tightening the spiral and increasing the loss of altitude.

A false horizon may occur when the pilot uses a sloping cloud formation for visual reference. An obscured horizon, a dark scene with ground lights, and stars can disorient pilots and cause the aircraft to be misaligned with the false horizon.

Autokinesis occurs when a pilot fixates his/her vision in the dark on a stationary light. When the pilot stares at a stationary light, it will appear to move, and the disoriented pilot may try to align the aircraft with the light.

During a rapid acceleration, like that occurring in the takeoff roll, spatial disorientation, also referred to as a somatogravic illusion, can create the illusion of the aircraft being in a nose-high attitude. The disoriented pilot may correct the aircraft into a nose-low or dive attitude.

The best mechanism for coping with spatial disorientation is thorough preflight planning, proficiency in instrument conditions, using visual references that are reliable fixed points, avoiding sudden head movements during critical flight times and ensuring that illness and medication use do not impair flight performance. If disorientation occurs, attention and focus should be on the flight instruments.

Other Considerations in Aviation

Night Flight

Under low light conditions, pilots should give themselves 20–30 min to adapt to night vision. Red lighting in the cockpit can maintain dark adaptation, but renders the colors on an aeronautical chart and small print difficult or impossible to read. Low lighting can exacerbate the effects of presbyopia, requiring some pilots to wear reading glasses for night flight. Dark adaptation can be impaired by some drugs such as Accutane (isotretinoin), exposure to carbon monoxide through compromised engine exhaust, or smoking. Cabin pressures at greater than 1500 m (5000 ft) can also render the pilot less adaptive to low light conditions.

Motion Sickness

Motion sickness is intense nausea and/or vomiting. Symptoms of motion sickness are gradual and include salivation, anorexia, hyperhidrosis, dizziness, and disorientation. Nausea followed by vomiting can occur and it is possible that the pilot may become incapacitated. Classic antiemetic agents such as promethazine, although effective in preventing nausea and vomiting, have unacceptable side-effects for the pilot, including drowsiness, sluggish thought, mydriasis, and impaired visual accommodation. For acute motion sickness, minimal head movement, focusing vision on a point outside the airplane, and cool air directed at the face can provide some abatement. Termination of the flight should occur as soon as practicable if the symptoms do not improve or become severe.

Carbon Monoxide

Carbon monoxide is a colorless, odorless gas with an affinity to the oxygen-binding sites on hemoglobin that is 220 times that of oxygen. By binding to these sites, oxygen binding is prevented and hypoxia occurs. Sources of carbon monoxide in aircraft are limited to those with piston engines, and occur most commonly when airflow over the engine to the heating system becomes contaminated with exhaust fumes from manifold cracks and faulty engine seals. Signs of carbon monoxide exposure include headache, drowsiness, or dizziness, temporally related to the use of the aircraft heating system. A pilot who detects exhaust fumes in the cabin of the aircraft should shut any heating vents, open all vents to provide outside air into the cabin, and have the system examined with due haste. Cockpit carbon monoxide detectors are relatively inexpensive and can help detect faulty engine systems before they present a

problem. If carbon monoxide exposure is suspected, it can be confirmed by measuring blood carboxyhemoglobin. Carboxyhemoglobin concentrations above 20% indicate exposure and are generally considered to be symptomatic. Treatment of carbon monoxide exposure includes removal from the source, oxygen administration, and, in severe cases, hyperbaric oxygen therapy that hastens the elimination of carbon monoxide.

Flying after Scuba Diving

During diving, there is an absorption of nitrogen into the blood. Flying too soon after diving, without allowing for the elimination of nitrogen, can result in decompression sickness, or the bends. The recommended wait time before flying above 2400 m (8000 ft) MSL is 24 h after the last dive that had a controlled ascent.

G-force

Gravitational force is the measure of the force of gravity. Normal gravitational force is 1, or 1 g. When an aircraft changes speed or direction, the magnitude of acceleration is measured by the G-force. With increasing positive G-forces, blood is forced downward and away from vital areas such as the brain and heart. Pooling blood in the legs and splanchnic circulation can result in loss of vision, and loss of consciousness. This is obviously more of a problem with high-powered aircraft or aerobatic flight than with a slower, less-powerful aircraft. The onset of G-induced hypoxia or loss of consciousness can occur gradually or can be nearly instantaneous, depending on the rate of change in G-force. Much has been published on the syndrome known to military pilots as “acceleration-induced near-loss of consciousness” or ALOC. The ALOC syndrome seems to be more common with rapid and short-lived changes in G-force. Short-term memory loss, degradation of vision characterized by light loss, loss of peripheral vision, sensory abnormalities, confusion, euphoria, dysphasia, and reduced auditory acuity are commonly encountered with short rapid changes in G-force. To combat G-force hypoxia and prevent loss of consciousness, early pilots were trained and taught to tense their legs and abdomen and to grunt, yell, or practice the Valsalva maneuver to keep blood in the brain. More sophisticated equipment was developed in the form of pressure suits, or clothing with air bladders that inflate automatically and help maintain blood flow to the brain during high-G-force maneuvers.

With vibration and rapid changes in acceleration, vertebral and cervical problems have been documented in pilots who fly both jet fighter and helicopter aircraft. With the development and implementation of helmet-mounted displays comes increased weight of head and neck musculoskeletal load. Helicopter pilots who wear heavy headgear are more likely to experience compression fractures – a complication that increases with age or with pilots who have osteoarthritic changes. Pilots with increased age and taller stature tend to be more at risk for vertebral problems.

Medical Risks Encountered with Commercial Flight

In patients with underlying risk factors for venous thromboembolism or pulmonary embolism, extended commercial flights increase the incidence of developing thrombus after air travel. One of the most significant modifiable risk factors is movement during flight. Complete immobility or limited movement is associated with a higher incidence of thrombus than in those patients with risk factors who have some type of activity during flight.

Communicable Infections and Commercial Flight

With the abolition of international boundaries by commercial aviation, and the relatively enclosed environment and air supply, there is a risk for person-to-person transmission of respiratory infections, including tuberculosis, influenza, and severe acute respiratory syndrome (SARS). Common-sense practices of hand-washing and the use of personal protective equipment can decrease the spread to illness.

See Also

Aviation Accidents, Role of Pathologist; Injury, Transportation: Air Disasters

Further Reading

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