Federal Aviation Administration

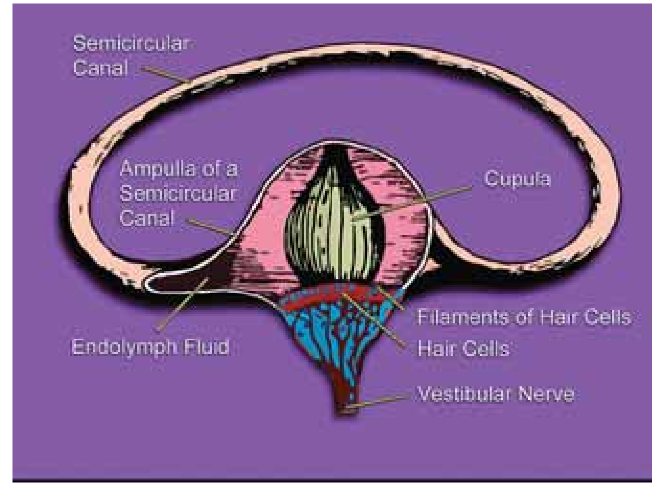

## Spatial Orientation

Defines our natural ability to maintain our body orientation and/or posture in relation to the surrounding environment (physical space) at rest and during motion. Genetically speaking, humans are designed to maintain spatial orientation on the ground. The three-dimensional environment of flight is unfamiliar to the human body, creating sensory conflicts and illusions that make spatial orientation difficult, and sometimes impossible to achieve. Statistics show that between 5 to 10% of all general aviation accidents can be attributed to spatial disorientation, 90% of which are fatal.

## Spatial Orientation in Flight

Spatial orientation in flight is difficult to achieve because numerous sensory stimuli (visual, vestibular, and proprioceptive) vary in magnitude, direction, and frequency. Any differences or discrepancies between visual, vestibular, and proprioceptive sensory inputs result in a sensory mismatch that can produce illusions and lead to spatial disorientation. Good spatial orientation relies on the effective perception, integration and interpretation of visual, vestibular (organs of equilibrium located in the inner ear) and proprioceptive (receptors located in the skin, muscles, tendons, and joints) sensory information.



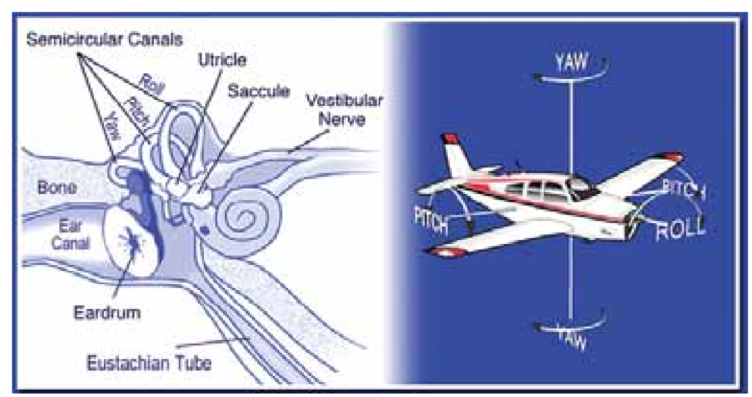



## Vestibular Aspects of Spatial Orientation

The inner ear contains the vestibular system, which is also known as the organ of equilibrium. About the size of an pencil eraser, the vestibular system contains two distinct structures: the semicircular canals, which detect changes in angular acceleration, and the otolith organs (the utricule and the saccule), which detect changes in linear acceleration and gravity. Both the semicircular canals and the otolith organs provide information to the brain regarding our body's position and movement. A connection between the vestibular system and the eyes helps to maintain balance and keep the eyes focused on an object while the head is moving or while the body is rotating.

## The Semicircular Canals

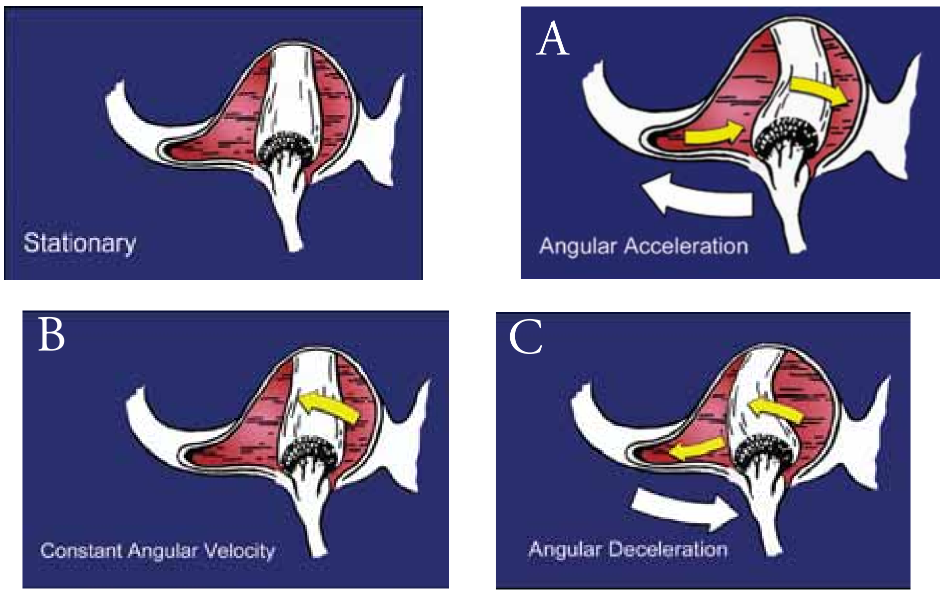
The semicircular canals are three half-circular, interconnected tubes located inside each ear that are the equivalent of three gyroscopes located in three planes perpendicular (at right angles) to each other. Each plane corresponds to the rolling, pitching, or yawing motions of an aircraft.



Each canal is filled with a fluid called endolymph and contains a motion sensor with little hairs whose ends are embedded in a gelatinous structure called the cupula. The cupula and the hairs move as the fluid moves inside the canal in response to an angular acceleration.

The movement of the hairs is similar to the movement of seaweed caused by ocean currents or that of wheat fields moved by wind gusts. When the head is still and the airplane is straight and level, the fluid in the canals does not move and the hairs stand straight up, indicating to the brain that there is no rotational acceleration (a turn).

If you turn either your aircraft or your head, the canal moves with your head, but the fluid inside does not move because of its inertia. As the canal moves, the hairs inside also move with it and are bent in the opposite direction of the acceleration by the stationary fluid (A). This hair movement sends a signal to the brain to indicate that the head has turned. The problem starts when you continue turning your aircraft at a constant rate (as in a coordinated turn) for more than 20 seconds.




In this kind of turn, the fluid inside the canal starts moving initially, then friction causes it to catch up with the walls of the rotating canal (B). When this happens, the hairs inside the canal will return to their straight up position, sending an erroneous signal to the brain that the turn has stopped–when, in fact, the turn continues.

If you then start rolling out of the turn to go back to level flight, the fluid inside the canal will continue to move (because of its inertia), and the hairs will now move in the opposite direction (C), sending an erroneous signal to the brain indicating that you are turning in the opposite direction, when in fact, you are actually slowing down from the original turn.



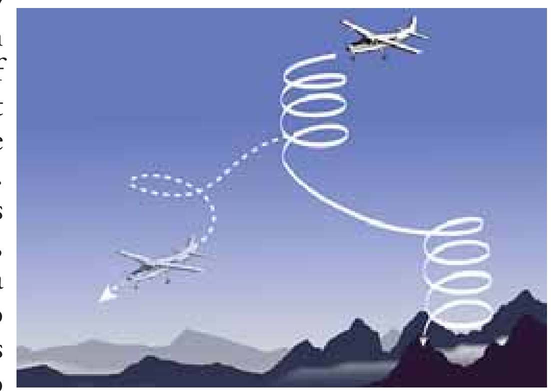
## Vestibular Illusions (Somatogyral - Semicircular Canals)

Illusions involving the semicircular canals of the vestibular system occur primarily under conditions of unreliable or unavailable external visual references and result in false sensations of rotation. These include the Leans, the Graveyard Spin and Spiral, and the Coriolis Illusion.

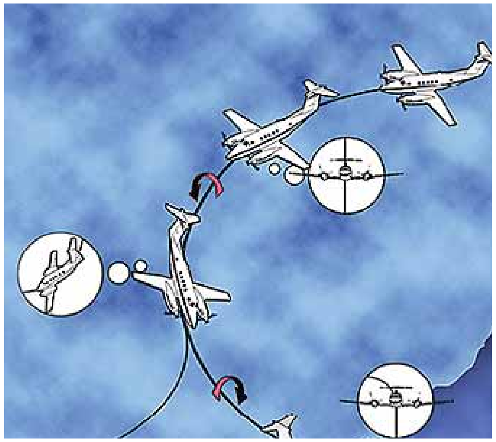
**The Leans.** This is the most common illusion during flight and is caused by a sudden return to level flight following a gradual and prolonged turn that went unnoticed by the pilot.

The reason a pilot can be unaware of such a gradual turn is that human exposure to a rotational acceleration of 2 degrees per second or lower is below the detection threshold of the semicircular canals. Leveling the wings after such a turn may cause an illusion that the aircraft is banking in the opposite direction. In response to such an illusion, a pilot may lean in the direction of the original turn in a corrective attempt to regain the perception of a correct vertical posture.

**The Graveyard Spin** is an illusion that can occur to a pilot who intentionally or unintentionally enters a spin. For example, a pilot who enters a spin to the left will initially have a sensation of spinning in the same direction. However, if the left spin continues the pilot will have the sensation that the spin is progressively decreasing. At this point, if the pilot applies right rudder to stop the left spin, the pilot will suddenly sense a spin in the opposite direction (to the right). If the pilot believes that the airplane is spinning to the right, the response will be to apply left rudder to counteract the sensation of a right spin. However, by applying left rudder the pilot will unknowingly re-enter the original left spin. If the pilot cross checks the turn indicator, he/she would see the turn needle indicating a left turn while he/she senses a right turn. This creates a sensory conflict between what the pilot sees on the instruments and what the pilot feels. If the pilot believes the body sensations instead of trusting the instruments, the left spin will continue. If enough



altitude is lost before this illusion is recognized and corrective action is taken, impact with terrain is inevitable.

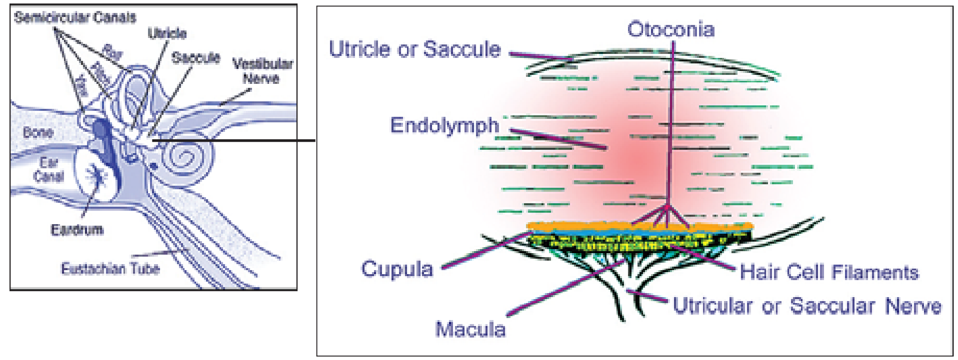


**The Graveyard Spiral** is more common than the Graveyard Spin, and it is associated with a return to level flight following an intentional or unintentional prolonged bank turn. For example, a pilot who enters a banking turn to the left will initially have a sensation of a turn in the same direction. If the left turn continues (~20 seconds or more), the pilot will experience the sensation that the airplane is no longer turning to the left. At this point, if the pilot attempts to level the wings this action will produce a sensation that the airplane is turning and banking in the opposite direction (to the right). If the pilot believes the illusion of a right turn (which can be very compelling), he/she will reenter the original left turn in an attempt to counteract the sensation of a right turn. Unfortunately, while this is happening, the airplane is still turning to the left and losing altitude. Pulling the control yoke/stick and applying power while turning would not be a good idea–because it would only make the left turn tighter. If the pilot fails to recognize the illusion and does not level the wings, the airplane will continue turning left and losing altitude until it impacts the ground.

**The Coriolis Illusion** involves the simultaneous stimulation of two semicircular canals and is associated with a sudden tilting (forward or backwards) of the pilot's head while the aircraft is turning. This can occur when you tilt you head down (to look at an approach chart or to write a note on your knee pad), or tilt it up (to look at an overhead instrument or switch) or tilt it sideways. This produces an almost unbearable sensation that the aircraft is rolling, pitching, and yawing all at the same time, which can be compared with the sensation of rolling down on a hillside. This illusion can make the pilot quickly become disoriented and lose control of the aircraft.



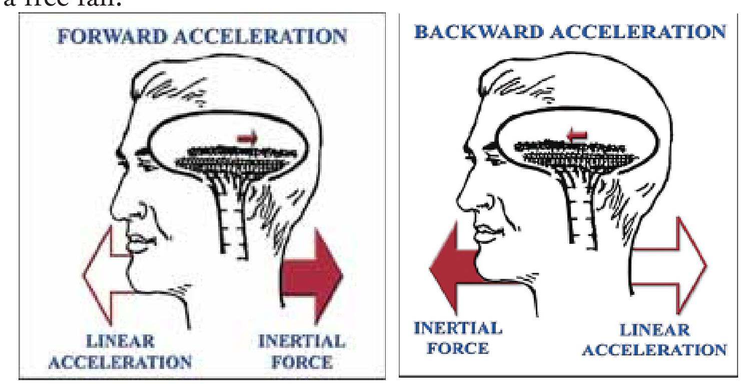
## The Otolith Organs




Two otolith organs, the saccule and utricle, are located in each ear and are set at right angles to each other. The utricle detects changes in linear acceleration in the horizontal plane, while the saccule detects gravity changes in the vertical plane. However, the inertial forces resulting from linear accelerations cannot be distinguished from the force of gravity; therefore, gravity can also produce stimulation of the utricle and saccule. These organs are located at the base (vestibule) of the semicircular canals, and their structure consists of small sacs (maculas) covered by hair cell filaments that project into an overlying gelatinous membrane (cupula) tipped by tiny, chalk-like calcium stones called otoconia.

## Change in Gravity

When the head is tilted, the weight of the otoconia of the saccule pulls the cupula, which in turn bends the hairs that send a signal to the brain indicating that the head has changed position. A similar response will occur during a vertical take-off in a helicopter or following the sudden opening of a parachute after a free fall.

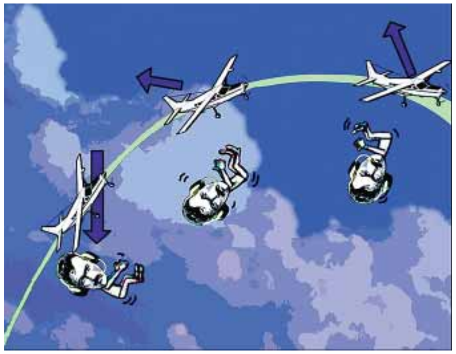



## Change in Linear Acceleration

The inertial forces resulting from a forward linear acceleration (take-off, increased acceleration during level flight, vertical climb) produce a backward displacement of the otoconia of the utricle that pulls the cupula, which in turn bends the haircell filaments that send a signal to the brain, indicating that the head and body have suddenly been moved forward. Exposure to a backward linear acceleration, or to a forward linear decceleration has the opposite effect.

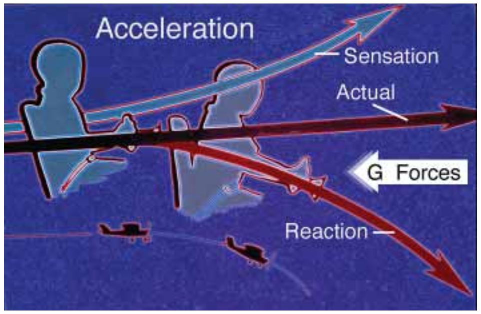
## Vestibular Illusions

(**Somatogravic - Utricle and Saccule**) Illusions involving the utricle and the saccule of the vestibular system are most likely under conditions with unreliable or unavailable external visual references. These illusions include: the Inversion Illusion, Head-Up Illusion, and Head-Down Illusion.



**The Inversion Illusion** involves a steep ascent (forward linear acceleration) in a high-performance aircraft, followed by a sudden return to level flight. When the pilot levels off, the aircraft's speed is relatively higher. This combination of accelerations produces an illusion that the aircraft is in inverted flight. The pilot's response to this illusion is to lower the nose of the aircraft.

**The Head-Up Illusion** involves a sudden forward linear acceleration during level flight where the pilot perceives the illusion that the nose of the aircraft is pitching up. The pilot's response to this illusion would be to push the yolk or the stick forward to pitch the nose of the aircraft down. A night take-off from a well-lit airport into a totally dark sky (black hole) or a catapult take-off from an aircraft carrier can also lead to this illusion, and could result in a crash.

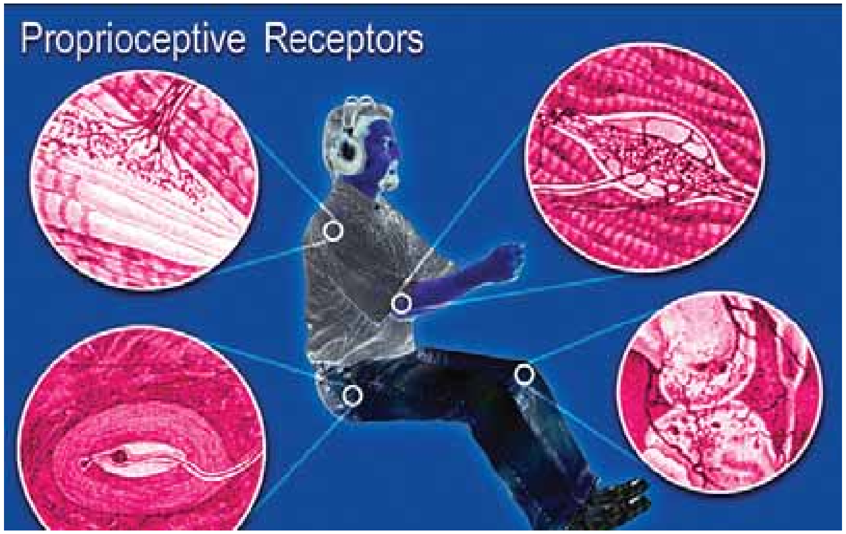



**The Head-Down Illusion** involves a sudden linear deceleration (air braking, lowering flaps, decreasing engine power) during level flight where the pilot perceives the illusion that the nose of the aircraft is pitching down. The pilot's response to this illusion would be to pitch the nose of the aircraft up. If this illusion occurs during a low-speed final approach, the pilot could stall the aircraft.

## The Proprioceptive Receptors

The proprioceptive receptors (proprioceptors) are special sensors located in the skin, muscles, tendons, and joints that play a very small role in maintaining spatial orientation in normal individuals. Proprioceptors do give some






indication of posture by sensing the relative position of our body parts in relation to each other, and by sensing points of physical contact between body parts and the surrounding environment (floor, wall, seat, arm rest, etc.). For example, proprioceptors make it possible for you to know that you are seated while flying; however, they alone will not let you differentiate between flying straight and level and performing a coordinated turn.

## How to Prevent Spatial Disorientation

The following are basic steps that should help prevent spatial disorientation:

- Take the opportunity to experience spatial disorientation illusions in a Barany chair, a Vertigon, a GYRO, or a Virtual Reality Spatial Disorientation Demonstrator.
- Before flying with less than 3 miles visibility, obtain training and maintain proficiency in airplane control by reference to instruments.
- When flying at night or in reduced visibility, use the flight instruments.
- If intending to fly at night, maintain night-flight currency. Include cross-country and local operations at different airports.
- If only Visual Flight Rules-qualified, do not attempt visual flight when there is a possibility of getting trapped in deteriorating weather.
- If you experience a vestibular illusion during flight, trust your instruments and disregard your sensory perceptions.

## Spatial Disorientation and Airsickness

It is important to know the difference between spatial disorientation and airsickness. Airsickness is a normal response of healthy individuals when exposed to a flight environment characterized by unfamiliar motion and orientation clues. Common signs and symptoms of airsickness include: vertigo, loss of appetite, increased salivation and swallowing, burping, stomach awareness, nausea, retching, vomiting, increased need for bowel movements, cold sweating, skin pallor, sensation of fullness of the head, difficulty concentrating, mental confusion, apathy, drowsiness, difficulty focusing, visual flashbacks, eye strain, blurred vision, increased yawning, headache, dizziness, postural instability, and increased fatigue.

The symptoms are usually progressive. First, the desire for food is lost. Then, as saliva collects in the mouth, the person begins to perspire freely, the head aches, and the airsick person may eventually become nauseated and vomit. Severe airsickness may cause a pilot to become completely incapacitated.

Although airsickness is uncommon among experienced pilots, it does occur occasionally (especially among student pilots). Some people are more susceptible to airsickness than others. Fatigue, alcohol, drugs, medications, stress, illnesses, anxiety, fear, and insecurity are some factors that can increase individual susceptibility to motion sickness of any type. Women have been shown to be more susceptible to motion sickness than men of any age. In addition, reduced mental activity (low mental workload) during exposure to an unfamiliar motion has been implicated as a predisposing factor for airsickness.

A pilot who concentrates on the mental tasks required to fly an aircraft will be less likely to become airsick because his/ her attention is occupied. This explains why sometimes a student pilot who is at the controls of an aircraft does not get airsick, but the experienced instructor who is only monitoring the student unexpectedly becomes airsick.

A pilot who has been the victim of airsickness knows how uncomfortable and impairing it can be. Most importantly, it jeopardizes the pilot's flying proficiency and safety, particularly under conditions that require peak piloting skills and performance (equipment malfunctions, instrument flight conditions, bad weather, final approach, and landing).

Pilots who are susceptible to airsickness should not take anti-motion sickness medications (prescription or overthe- counter). These medications can make one drowsy or affect brain functions in other ways. Research has shown that most anti-motion sickness medications cause a temporary deterioration of navigational skills or other tasks demanding keen judgment.



An effective method to increase pilot resistance to airsickness consists of repetitive exposure to the flying conditions that initially resulted in airsickness. In other words, repeated exposure to the flight environment decreases an individual's susceptibility to subsequent airsickness.

If you become airsick while piloting an aircraft, open the air vents, loosen your clothing, use supplemental oxygen, keep your eyes on a point outside the aircraft, place your head against the seat's headrest, and avoid unnecessary head movements. Then, cancel the flight, and land as soon as possible.

## FAA Aeromedical Training Programs for Civil Aviation Pilots

**Physiological Training Course.** The Civil Aerospace Medical Institute offers a 1-day training course to familiarize civil aviation pilots and flight crews with the physiological and psychological stressors of flight. Classroom training subjects include spatial disorientation, oxygen equipment, hypoxia, trapped gas, and decompression sickness.

**Demonstrations.** Spatial disorientation demonstrators provide pilots the experience of vestibular and visual illusions in a safe, ground-based environment–and they teach ways to avoid spatial disorientation while flying. Also, a ground-based altitude chamber flight offers a practical demonstration of rapid decompression and hypoxia. For information and scheduling, call (405) 954-4837, or check the FAA Web site:

www.faa.gov/pilots/training/airman_education/aerospace_physiology/index.cfm

# Medical Facts for Pilots

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To view these pilot and passenger safety brochures, visit the Federal Aviation Administration's Web Site

www.faa.gov/pilots/safety/pilotsafetybrochures/

## Physiological Training Classes for Pilots

If you are interested in taking a one-day aviation physiological training course with altitude chamber and vertigo demonstrations or a one-day survival course, learn about how to sign up for these courses that are offered at 14 locations across the U.S. by visiting this FAA Web site:

www.faa.gov/pilots/training/airman_education/aerospace_physiology/index.cfm