

Instrument Flying Handbook



U.S. Department
of Transportation
**FEDERAL AVIATION
ADMINISTRATION**



Semicircular canals

Tubular ducts containing endolymph

Utricle

Sacculle

Cochlea

Ampullae

Chapter 3

Human Factors

Introduction

Human factors is a broad field that examines the interaction between people, machines, and the environment for the purpose of improving performance and reducing errors. As aircraft became more reliable and less prone to mechanical failure, the percentage of accidents related to human factors increased. Some aspect of human factors now accounts for over 80 percent of all accidents. Pilots, who have a good understanding of human factors, are better equipped to plan and execute a safe and uneventful flight.

Flying in instrument meteorological conditions (IMC) can result in sensations that are misleading to the body's sensory system. A safe pilot needs to understand these sensations and effectively counteract them. Instrument flying requires a pilot to make decisions using all available resources.

The elements of human factors covered in this chapter include sensory systems used for orientation and illusions in flight. For more information about physiological and psychological factors, medical factors, aeronautical decision-making (ADM), and crew resource management (CRM), refer to the Pilot's Handbook of Aeronautical Knowledge.

Margin of Safety

Effort

Preflight

Takeoff

Time

Cruise

Task requirements

Approach & Landing

Sensory Systems for Orientation

Orientation is the awareness of the position of the aircraft and of oneself in relation to a specific reference point. Disorientation is the lack of orientation, and spatial disorientation specifically refers to the lack of orientation with regard to position in space and to other objects.

Orientation is maintained through the body's sensory organs in three areas: visual, vestibular, and postural. The eyes maintain visual orientation. The motion sensing system in the inner ear maintains vestibular orientation. The nerves in the skin, joints, and muscles of the body maintain postural orientation. When healthy human beings are in their natural environment, these three systems work well. When the human body is subjected to the forces of flight, these senses can provide misleading information. It is this misleading information that causes pilots to become disoriented.

Eyes

Of all the senses, vision is most important in providing information to maintain safe flight. Even though the human eye is optimized for day vision, it is also capable of vision in very low light environments. During the day, the eye uses receptors called cones, while at night, vision is facilitated by the use of rods. Both of these provide a level of vision optimized for the lighting conditions that they were intended. That is, cones are ineffective at night and rods are ineffective during the day.

Rods, which contain rhodopsin (called visual purple), are especially sensitive to light and increased light washes out the rhodopsin compromising the night vision. Hence, when strong light is momentarily introduced at night, vision may be totally ineffective as the rods take time to become effective again in darkness. Smoking, alcohol, oxygen deprivation, and age affect vision, especially at night. It should be noted that at night, oxygen deprivation, such as one caused from a climb to a high altitude, causes a significant reduction in vision. A return back to the lower

altitude does not restore a pilot's vision in the same transitory period used at the climb altitude.

The eye also has two blind spots. The day blind spot is the location on the light sensitive retina where the optic nerve fiber bundle (which carries messages from the eye to the brain) passes through. This location has no light receptors, and a message cannot be created there to be sent to the brain. The night blind spot is due to a concentration of cones in an area surrounding the fovea on the retina. Because there are no rods in this area, direct vision on an object at night will disappear. As a result, off-center viewing and scanning at night is best for both obstacle avoidance and to maximize situational awareness (SA). (See the Pilot's Handbook of Aeronautical Knowledge and the Aeronautical Information Manual (AIM) for detailed reading.)

The brain also processes visual information based upon color, relationship of colors, and vision from objects around us. *Figure 3-1* demonstrates the visual processing of information. The brain assigns color based on many items, to include an object's surroundings. In the figure below, the orange square on the shaded side of the cube is actually the same color as the brown square in the center of the cube's top face.

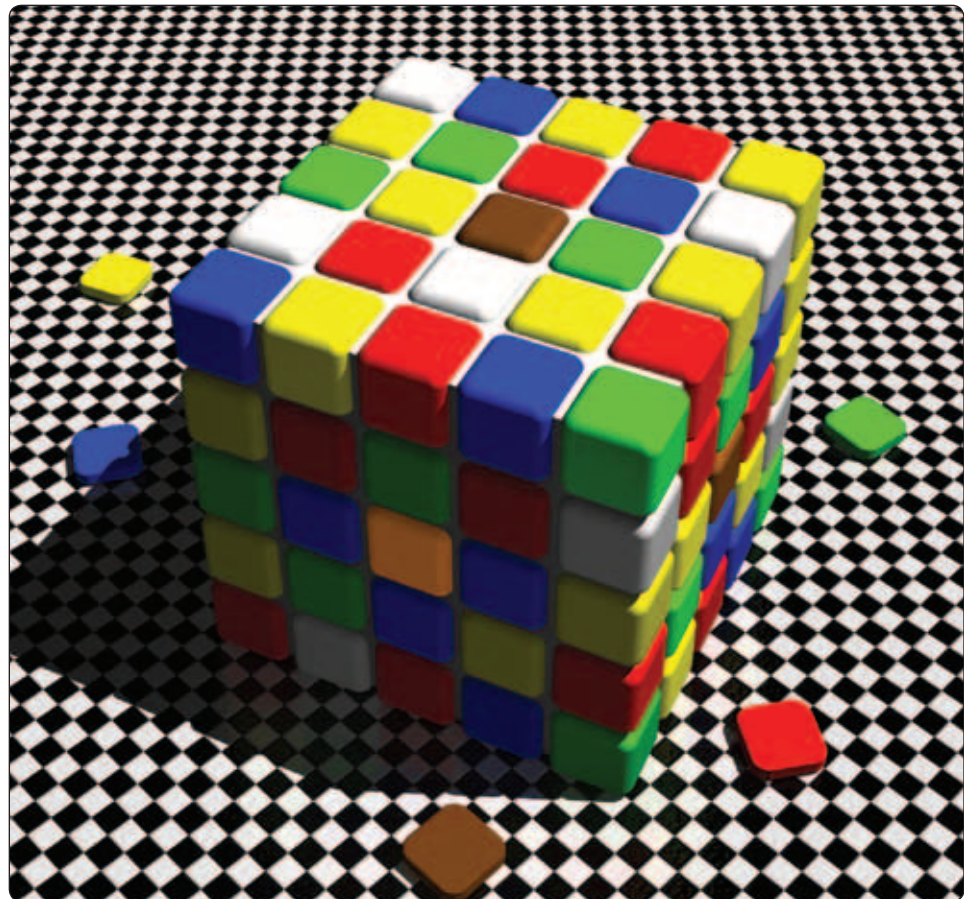


Figure 3-1. Rubik's cube graphic depicting the visual processing of information.

Isolating the orange square from surrounding influences will reveal that it is actually brown. The application to a real environment is evident when processing visual information that is influenced by surroundings. The ability to pick out an airport in varied terrain or another aircraft in a light haze are examples of problems with interpretation that make vigilance all the more necessary.

Figure 3-2 illustrates problems with perception. Both tables are the same lengths. Objects are easily misinterpreted in size to include both length and width. Being accustomed to a 75-foot-wide runway on flat terrain is most likely going to influence a pilot's perception of a wider runway on uneven terrain simply because of the inherent processing experience.

Vision Under Dim and Bright Illumination

Under conditions of dim illumination, aeronautical charts and aircraft instruments can become unreadable unless adequate flight deck lighting is available. In darkness, vision becomes more sensitive to light. This process is called dark adaptation. Although exposure to total darkness for at least 30 minutes is required for complete dark adaptation, a pilot can achieve a moderate degree of dark adaptation within 20 minutes under dim red flight deck lighting.

Red light distorts colors (filters the red spectrum), especially on aeronautical charts, and makes it very difficult for the eyes to focus on objects inside the aircraft. Pilots should use it only where optimum outside night vision capability is

necessary. White flight deck lighting (dim lighting) should be available when needed for map and instrument reading, especially under IMC conditions.

Since any degree of dark adaptation is lost within a few seconds of viewing a bright light, pilots should close one eye when using a light to preserve some degree of night vision. During night flights in the vicinity of lightning, flight deck lights should be turned up to help prevent loss of night vision due to the bright flashes. Dark adaptation is also impaired by exposure to cabin pressure altitudes above 5,000 feet, carbon monoxide inhaled through smoking, deficiency of Vitamin A in the diet, and prolonged exposure to bright sunlight.

During flight in visual meteorological conditions (VMC), the eyes are the major orientation source and usually provide accurate and reliable information. Visual cues usually prevail over false sensations from other sensory systems. When these visual cues are taken away, as they are in IMC, false sensations can cause the pilot to quickly become disoriented.

An effective way to counter these false sensations is to recognize the problem, disregard the false sensations, rely on the flight instruments, and use the eyes to determine the aircraft attitude. The pilot must have an understanding of the problem and the skill to control the aircraft using only instrument indications.

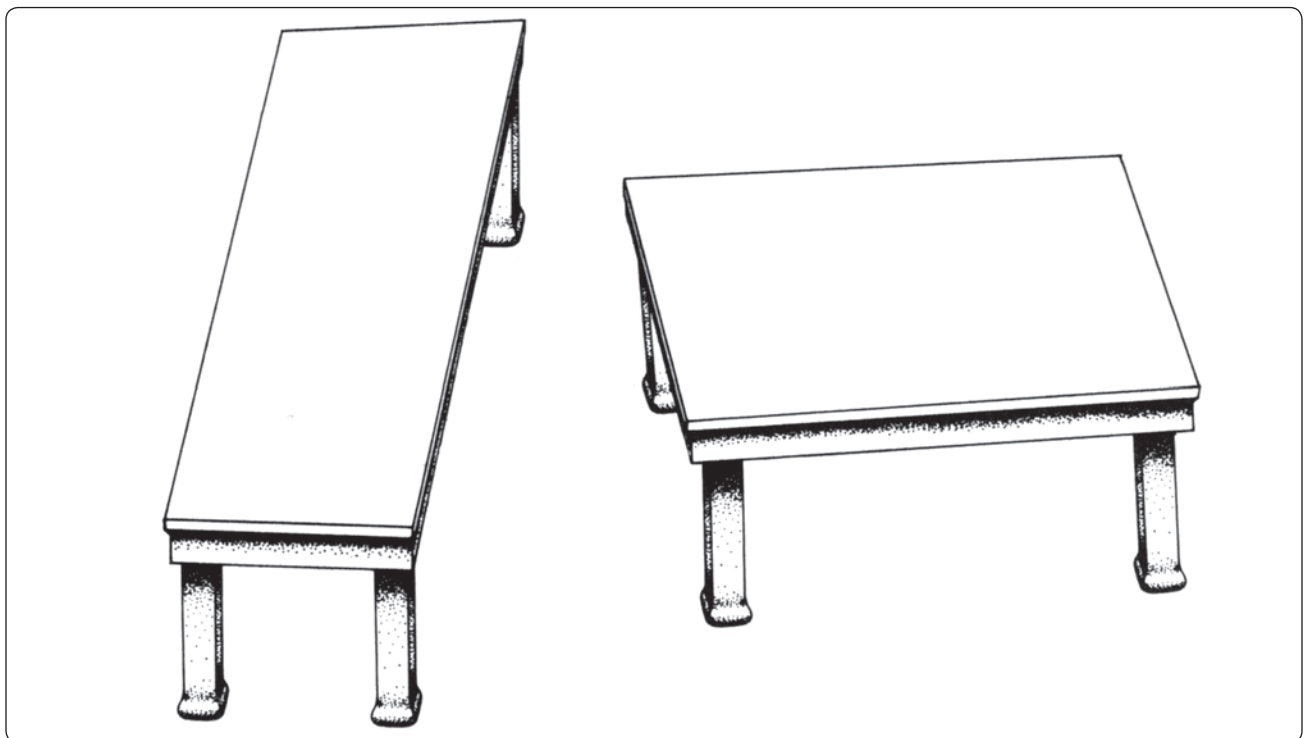


Figure 3-2. *Shepard's tables illustrating problems with perception as both tables are the same length.*

Ears

The inner ear has two major parts concerned with orientation: the semicircular canals and the otolith organs. [Figure 3-3] The semicircular canals detect angular acceleration of the body, while the otolith organs detect linear acceleration and gravity. The semicircular canals consist of three tubes at approximate right angles to each other, each located on one of three axes: pitch, roll, or yaw as illustrated in Figure 3-4. Each canal is filled with a fluid called endolymph fluid. In the center of the canal is the cupola, a gelatinous structure that rests upon sensory hairs located at the end of the vestibular nerves. It is the movement of these hairs within the fluid that causes sensations of motion.

Because of the friction between the fluid and the canal, it may take about 15–20 seconds for the fluid in the ear canal to reach the same speed as the canal’s motion.

To illustrate what happens during a turn, visualize the aircraft in straight-and-level flight. With no acceleration of the aircraft, the hair cells are upright, and the body senses that no turn has occurred. Therefore, the position of the hair cells and the actual sensation correspond.

Placing the aircraft into a turn puts the semicircular canal and its fluid into motion, with the fluid within the semicircular canal lagging behind the accelerated canal walls. [Figure 3-5] This lag creates a relative movement of the fluid within the canal. The canal wall and the cupola move in the opposite direction from the motion of the fluid.

The brain interprets the movement of the hairs to be a turn in the same direction as the canal wall. The body correctly senses that a turn is being made. If the turn continues at a constant rate for several seconds or longer, the motion of the fluid in

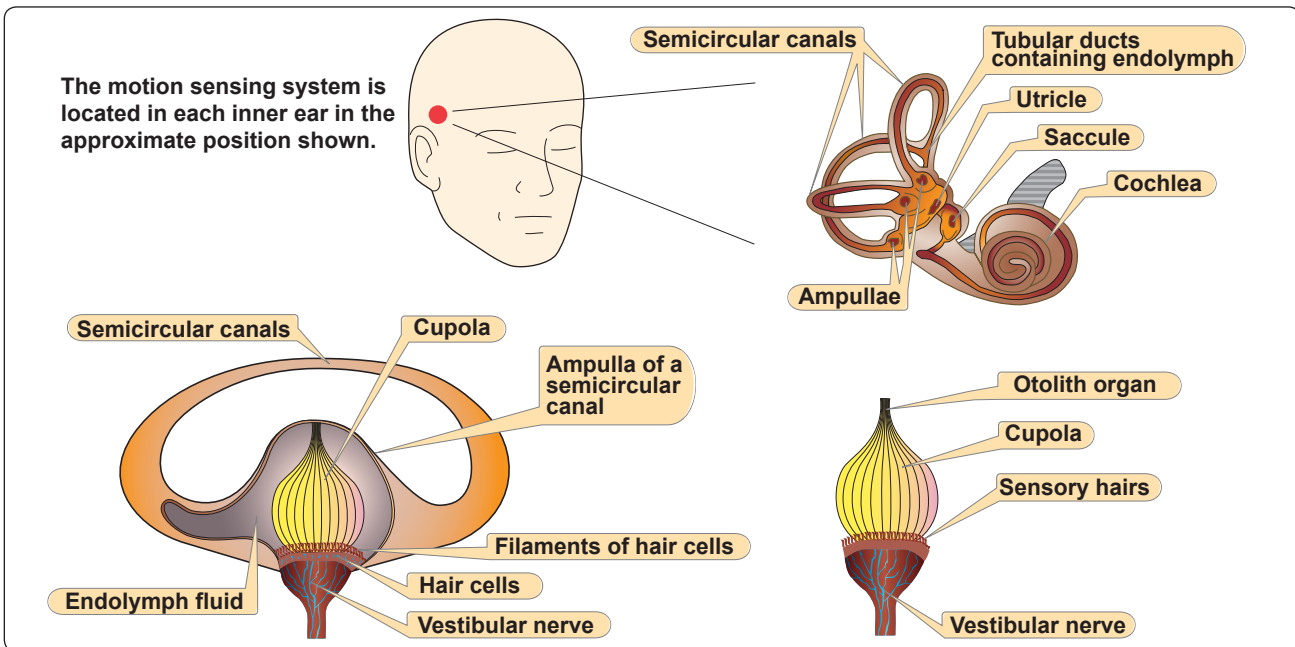


Figure 3-3. Inner ear orientation.

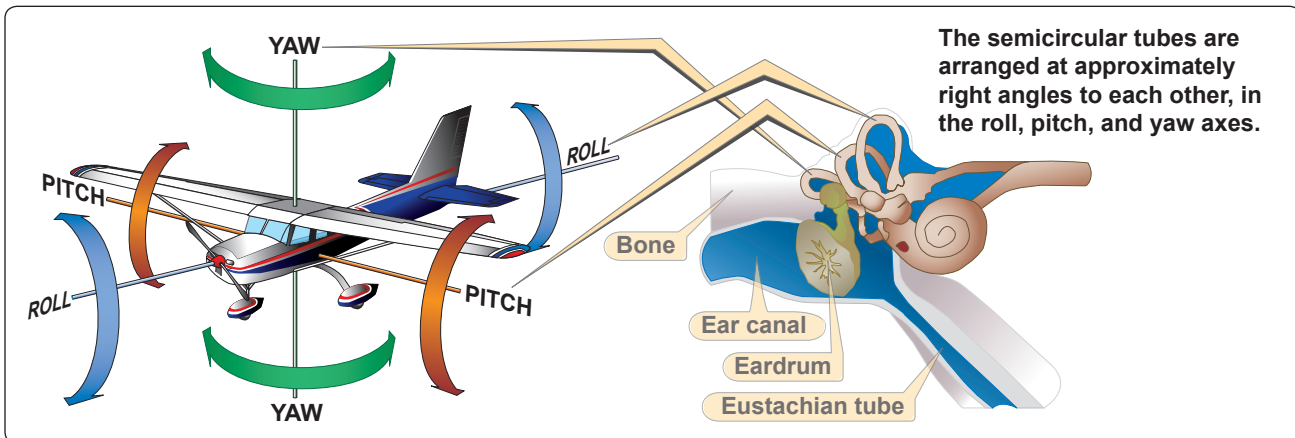


Figure 3-4. Angular acceleration and the semicircular tubes.

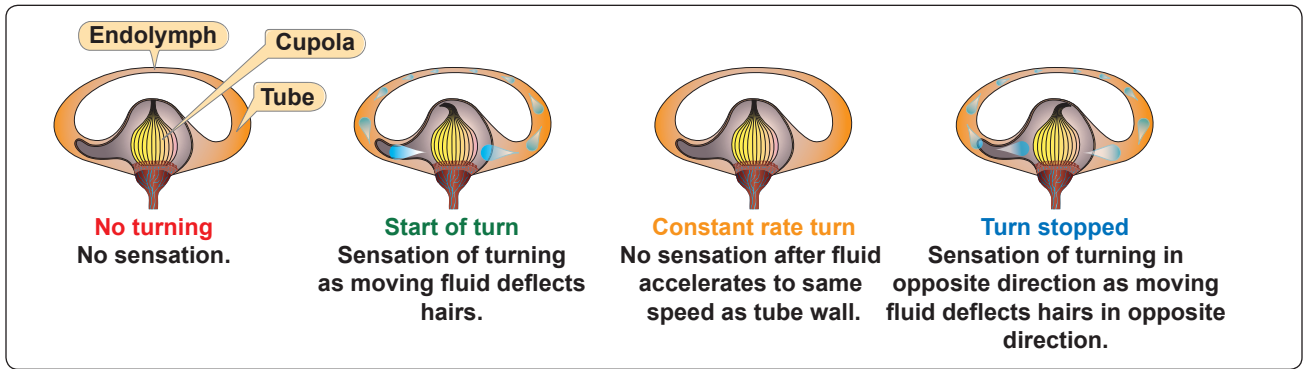


Figure 3-5. Angular acceleration.

the canals catches up with the canal walls. The hairs are no longer bent, and the brain receives the false impression that turning has stopped. Thus, the position of the hair cells and the resulting sensation during a prolonged, constant turn in either direction results in the false sensation of no turn.

When the aircraft returns to straight-and-level flight, the fluid in the canal moves briefly in the opposite direction. This sends a signal to the brain that is falsely interpreted as movement in the opposite direction. In an attempt to correct the falsely perceived turn, the pilot may reenter the turn placing the aircraft in an out-of-control situation.

The otolith organs detect linear acceleration and gravity in a similar way. Instead of being filled with a fluid, a gelatinous membrane containing chalk-like crystals covers the sensory hairs. When the pilot tilts his or her head, the weight of these crystals causes this membrane to shift due to gravity, and the sensory hairs detect this shift. The brain orients this new position to what it perceives as vertical. Acceleration and deceleration also cause the membrane to shift in a similar manner. Forward acceleration gives the illusion of the head tilting backward. [Figure 3-6] As a result, during takeoff and while accelerating, the pilot may sense a steeper than normal climb resulting in a tendency to nose-down.

Nerves

Nerves in the body's skin, muscles, and joints constantly send signals to the brain, which signals the body's relation to gravity. These signals tell the pilot his or her current position. Acceleration is felt as the pilot is pushed back into the seat. Forces, created in turns, can lead to false sensations of the true direction of gravity and may give the pilot a false sense of which way is up.

Uncoordinated turns, especially climbing turns, can cause misleading signals to be sent to the brain. Skids and slips give the sensation of banking or tilting. Turbulence can create motions that confuse the brain as well. Pilots need to be aware that fatigue or illness can exacerbate these sensations and ultimately lead to subtle incapacitation.

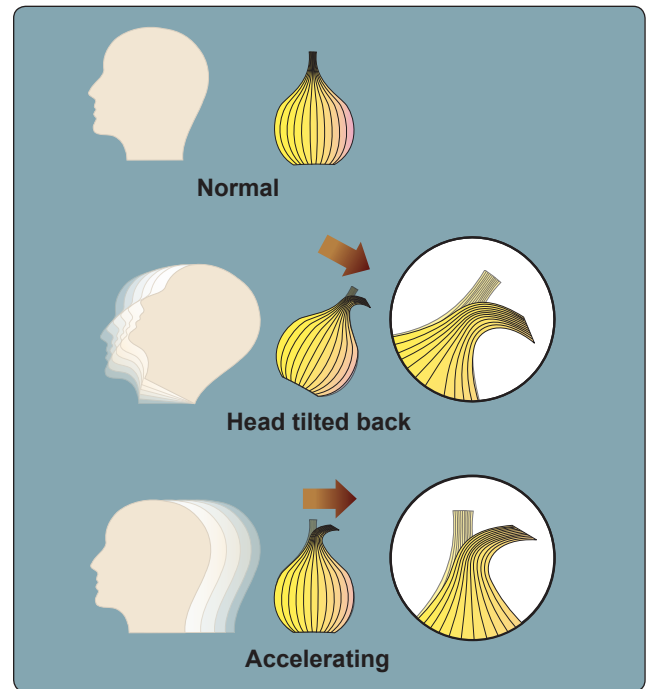


Figure 3-6. Linear acceleration.

Illusions Leading to Spatial Disorientation

The sensory system responsible for most of the illusions leading to spatial disorientation is the vestibular system. Visual illusions can also cause spatial disorientation.

Vestibular Illusions

The Leans

A condition called "the leans" can result when a banked attitude, to the left for example, may be entered too slowly to set in motion the fluid in the "roll" semicircular tubes. [Figure 3-5] An abrupt correction of this attitude sets the fluid in motion, creating the illusion of a banked attitude to the right. The disoriented pilot may make the error of rolling the aircraft into the original left banked attitude, or if level flight is maintained, feel compelled to lean in the perceived vertical plane until this illusion subsides.

Coriolis Illusion

The coriolis illusion occurs when a pilot has been in a turn long enough for the fluid in the ear canal to move at the same speed as the canal. A movement of the head in a different plane, such as looking at something in a different part of the flight deck, may set the fluid moving and create the illusion of turning or accelerating on an entirely different axis. This action causes the pilot to think the aircraft is doing a maneuver that it is not. The disoriented pilot may maneuver the aircraft into a dangerous attitude in an attempt to correct the aircraft's perceived attitude.

For this reason, it is important that pilots develop an instrument cross-check or scan that involves minimal head movement. Take care when retrieving charts and other objects in the flight deck—if something is dropped, retrieve it with minimal head movement and be alert for the coriolis illusion.

Graveyard Spiral

As in other illusions, a pilot in a prolonged coordinated, constant-rate turn, will have the illusion of not turning. During the recovery to level flight, the pilot experiences the sensation of turning in the opposite direction. The disoriented pilot may return the aircraft to its original turn. Because an aircraft tends to lose altitude in turns unless the pilot compensates for the loss in lift, the pilot may notice a loss of altitude. The absence of any sensation of turning creates the illusion of being in a level descent. The pilot may pull back on the controls in an

attempt to climb or stop the descent. This action tightens the spiral and increases the loss of altitude; hence, this illusion is referred to as a graveyard spiral. [Figure 3-7] At some point, this could lead to a loss of control by the pilot.

Somatogravic Illusion

A rapid acceleration, such as experienced during takeoff, stimulates the otolith organs in the same way as tilting the head backwards. This action creates the somatogravic illusion of being in a nose-up attitude, especially in situations without good visual references. The disoriented pilot may push the aircraft into a nose-low or dive attitude. A rapid deceleration by quick reduction of the throttle(s) can have the opposite effect with the disoriented pilot pulling the aircraft into a nose-up or stall attitude.

Inversion Illusion

An abrupt change from climb to straight-and-level flight can stimulate the otolith organs enough to create the illusion of tumbling backwards or inversion illusion. The disoriented pilot may push the aircraft abruptly into a nose-low attitude, possibly intensifying this illusion.

Elevator Illusion

An abrupt upward vertical acceleration, as can occur in an updraft, can stimulate the otolith organs to create the illusion of being in a climb. This is called elevator illusion. The disoriented pilot may push the aircraft into a nose-low

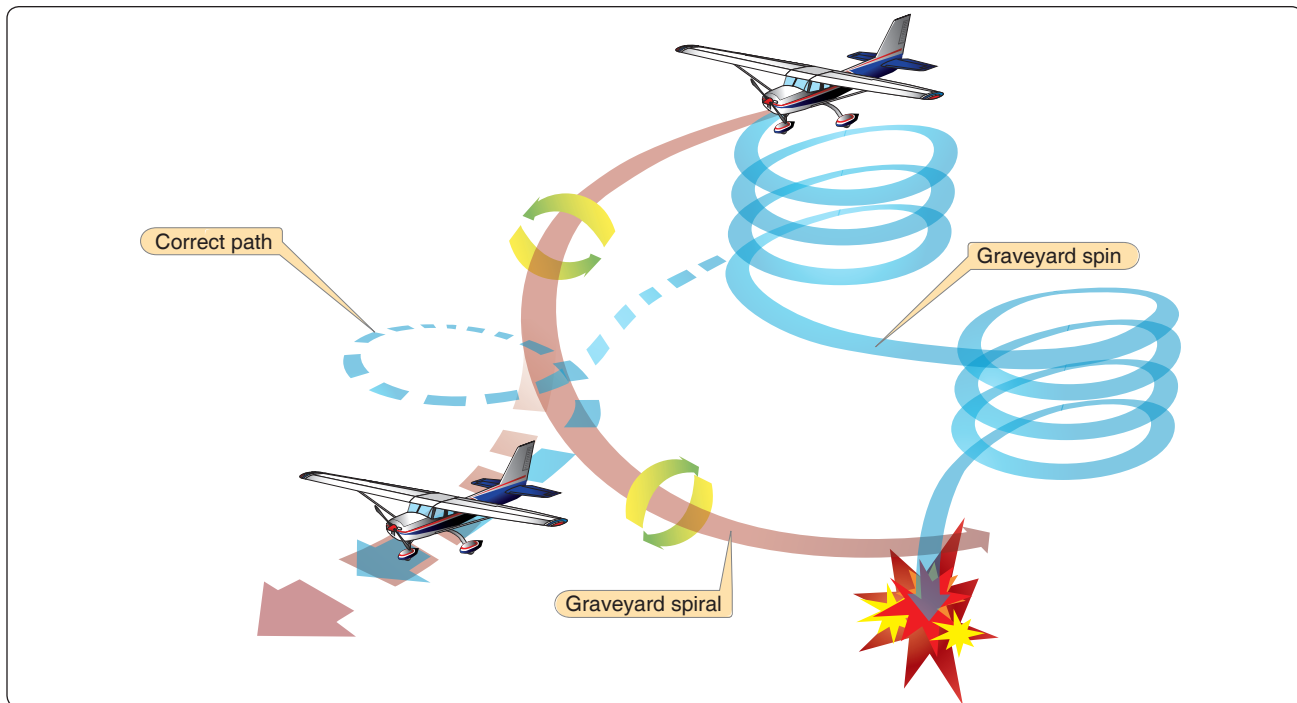


Figure 3-7. *Graveyard spiral.*

attitude. An abrupt downward vertical acceleration, usually in a downdraft, has the opposite effect with the disoriented pilot pulling the aircraft into a nose-up attitude.

Visual Illusions

Visual illusions are especially hazardous because pilots rely on their eyes for correct information. Two illusions that lead to spatial disorientation, false horizon and autokinesis, are concerned with only the visual system.

False Horizon

A sloping cloud formation, an obscured horizon, an aurora borealis, a dark scene spread with ground lights and stars, and certain geometric patterns of ground lights can provide inaccurate visual information, or false horizon, for aligning the aircraft correctly with the actual horizon. The disoriented pilot may place the aircraft in a dangerous attitude.

Autokinesis

In the dark, a stationary light will appear to move about when stared at for many seconds. The disoriented pilot could lose control of the aircraft in attempting to align it with the false movements of this light called autokinesis.

Postural Considerations

The postural system sends signals from the skin, joints, and muscles to the brain that are interpreted in relation to the Earth's gravitational pull. These signals determine posture. Inputs from each movement update the body's position to

the brain on a constant basis. "Seat of the pants" flying is largely dependent upon these signals. Used in conjunction with visual and vestibular clues, these sensations can be fairly reliable. However, because of the forces acting upon the body in certain flight situations, many false sensations can occur due to acceleration forces overpowering gravity. [Figure 3-8] These situations include uncoordinated turns, climbing turns, and turbulence.

Demonstration of Spatial Disorientation

There are a number of controlled aircraft maneuvers a pilot can perform to experiment with spatial disorientation. While each maneuver normally creates a specific illusion, any false sensation is an effective demonstration of disorientation. Thus, even if there is no sensation during any of these maneuvers, the absence of sensation is still an effective demonstration in that it shows the inability to detect bank or roll. There are several objectives in demonstrating these various maneuvers.

1. They teach pilots to understand the susceptibility of the human system to spatial disorientation.
2. They demonstrate that judgments of aircraft attitude based on bodily sensations are frequently false.
3. They help lessen the occurrence and degree of disorientation through a better understanding of the relationship between aircraft motion, head movements, and resulting disorientation.
4. They help instill a greater confidence in relying on flight instruments for assessing true aircraft attitude.

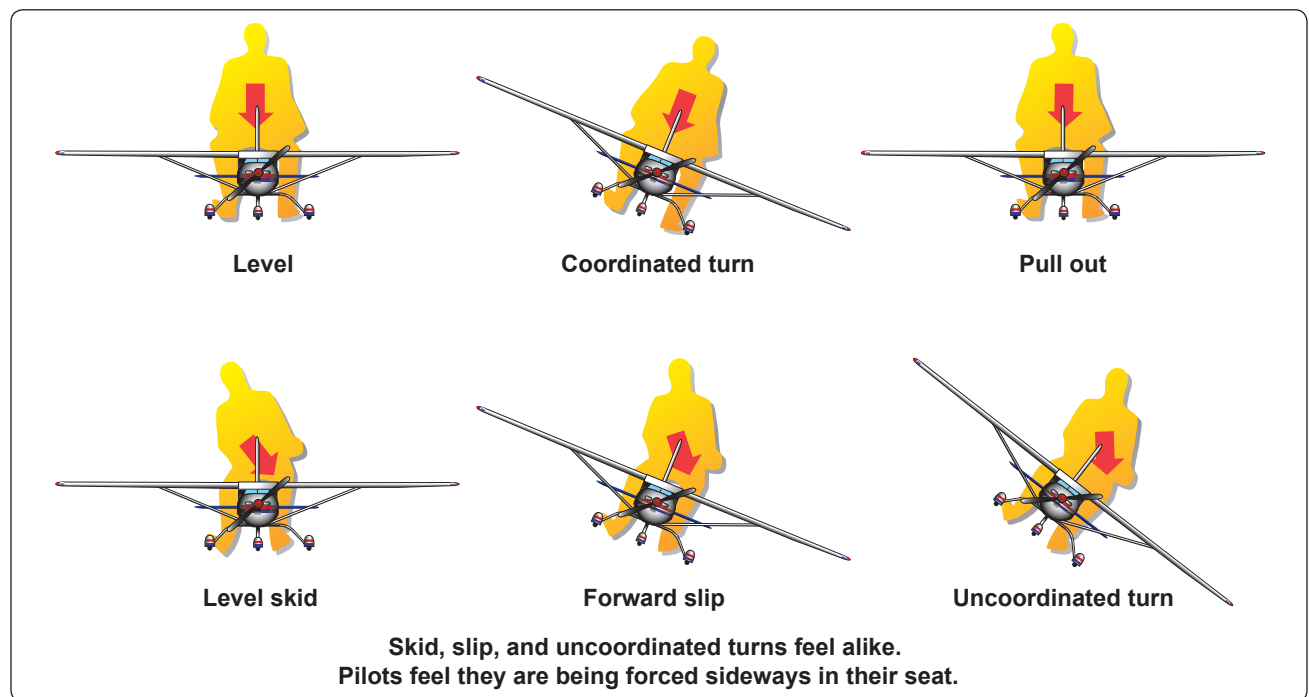


Figure 3-8. Sensations from centrifugal force.

A pilot should not attempt any of these maneuvers at low altitudes or in the absence of an instructor pilot or an appropriate safety pilot.

Climbing While Accelerating

With the pilot's eyes closed, the instructor pilot maintains approach airspeed in a straight-and-level attitude for several seconds, and then accelerates while maintaining straight-and-level attitude. The usual illusion during this maneuver, without visual references, is that the aircraft is climbing.

Climbing While Turning

With the pilot's eyes still closed and the aircraft in a straight-and-level attitude, the instructor pilot now executes, with a relatively slow entry, a well-coordinated turn of about 1.5 positive G (approximately 50° bank) for 90°. While in the turn, without outside visual references and under the effect of the slight positive G, the usual illusion produced is that of a climb. Upon sensing the climb, the pilot should immediately open the eyes and see that a slowly established, coordinated turn produces the same feeling as a climb.

Diving While Turning

Repeating the previous procedure, with the exception that the pilot's eyes should be kept closed until recovery from the turn is approximately one-half completed can create this sensation. With the eyes closed, the usual illusion is that the aircraft is diving.

Tilting to Right or Left

While in a straight-and-level attitude, with the pilot's eyes closed, the instructor pilot executes a moderate or slight skid to the left with wings level. This creates the illusion of the body being tilted to the right. The same illusion can be sensed with a skid to the right with wings level, except the body feels it is being tilted to the left.

Reversal of Motion

This illusion can be demonstrated in any of the three planes of motion. While straight and level, with the pilot's eyes closed, the instructor pilot smoothly and positively rolls the aircraft to approximately a 45° bank attitude. This creates the illusion of a strong sense of rotation in the opposite direction. After this illusion is noted, the pilot should open his or her eyes and observe that the aircraft is in a banked attitude.

Diving or Rolling Beyond the Vertical Plane

This maneuver may produce extreme disorientation. While in straight-and-level flight, the pilot should sit normally, either with eyes closed or gaze lowered to the floor. The instructor pilot starts a positive, coordinated roll toward a 30° or 40° angle of bank. As this is in progress, the pilot tilts his or her head forward, looks to the right or left, then

immediately returns his or her head to an upright position. The instructor pilot should time the maneuver so the roll is stopped as the pilot returns his or her head upright. An intense disorientation is usually produced by this maneuver, and the pilot experiences the sensation of falling downward into the direction of the roll.

In the descriptions of these maneuvers, the instructor pilot is doing the flying, but having the pilot do the flying can also be a very effective demonstration. The pilot should close his or her eyes and tilt their head to one side. The instructor pilot tells the pilot what control inputs to perform. The pilot then attempts to establish the correct attitude or control input with eyes closed and head tilted. While it is clear the pilot has no idea of the actual attitude, he or she will react to what the senses are saying. After a short time, the pilot will become disoriented, and the instructor pilot then tells the pilot to look up and recover. The benefit of this exercise is the pilot experiences the disorientation while flying the aircraft.

Coping with Spatial Disorientation

To prevent illusions and their potentially disastrous consequences, pilots can:

1. Understand the causes of these illusions and remain constantly alert for them. Take the opportunity to understand and then experience spatial disorientation illusions in a device, such as a Barany chair, a Vertigon, or a Virtual Reality Spatial Disorientation Demonstrator.
2. Always obtain and understand preflight weather briefings.
3. Before flying in marginal visibility (less than 3 miles) or where a visible horizon is not evident such as flight over open water during the night, obtain training and maintain proficiency in airplane control by reference to instruments.
4. Do not continue flight into adverse weather conditions or into dusk or darkness unless proficient in the use of flight instruments. If intending to fly at night, maintain night-flight currency and proficiency. Include cross-country and local operations at various airfields.
5. Ensure that when outside visual references are used, they are reliable, fixed points on the Earth's surface.
6. Avoid sudden head movement, particularly during takeoffs, turns, and approaches to landing.
7. Be physically tuned for flight into reduced visibility. Ensure proper rest, adequate diet, and, if flying at night, allow for night adaptation. Remember that illness, medication, alcohol, fatigue, sleep loss, and

mild hypoxia are likely to increase susceptibility to spatial disorientation.

8. Most importantly, become proficient in the use of flight instruments and rely upon them. Trust the instruments and disregard your sensory perceptions.

The sensations that lead to illusions during instrument flight conditions are normal perceptions experienced by pilots. These undesirable sensations cannot be completely prevented, but through training and awareness, pilots can ignore or suppress them by developing absolute reliance on the flight instruments. As pilots gain proficiency in instrument flying, they become less susceptible to these illusions and their effects.

Optical Illusions

Of the senses, vision is the most important for safe flight. However, various terrain features and atmospheric conditions can create optical illusions. These illusions are primarily associated with landing. Since pilots must transition from reliance on instruments to visual cues outside the flight deck for landing at the end of an instrument approach, it is imperative they be aware of the potential problems associated with these illusions and take appropriate corrective action. The major illusions leading to landing errors are described below.

Runway Width Illusion

A narrower-than-usual runway can create an illusion the aircraft is at a higher altitude than it actually is, especially when runway length-to-width relationships are comparable. *[Figure 3-9A]* The pilot who does not recognize this illusion will fly a lower approach with the risk of striking objects along the approach path or landing short. A wider-than-usual runway can have the opposite effect with the risk of leveling out high and landing hard or overshooting the runway.

Runway and Terrain Slopes Illusion

An upsloping runway, upsloping terrain, or both can create an illusion the aircraft is at a higher altitude than it actually is. *[Figure 3-9B]* The pilot who does not recognize this illusion will fly a lower approach. Downsloping runways and downsloping approach terrain can have the opposite effect.

Featureless Terrain Illusion

An absence of surrounding ground features, as in an overwater approach, over darkened areas, or terrain made featureless by snow, can create an illusion the aircraft is at a higher altitude than it actually is. This illusion, sometimes referred to as the “black hole approach,” causes pilots to fly a lower approach than is desired.

Water Refraction

Rain on the windscreen can create an illusion of being at a higher altitude due to the horizon appearing lower than it is. This can result in the pilot flying a lower approach.

Haze

Atmospheric haze can create an illusion of being at a greater distance and height from the runway. As a result, the pilot has a tendency to be low on the approach. Conversely, extremely clear air (clear bright conditions of a high altitude airport) can give the pilot the illusion of being closer than he or she actually is, resulting in a high approach that may cause an overshoot or go around. The diffusion of light due to water particles on the windshield can adversely affect depth perception. The lights and terrain features normally used to gauge height during landing become less effective for the pilot.

Fog

Flying into fog can create an illusion of pitching up. Pilots who do not recognize this illusion often steepen the approach quite abruptly.

Ground Lighting Illusions

Lights along a straight path, such as a road or lights on moving trains, can be mistaken for runway and approach lights. Bright runway and approach lighting systems, especially where few lights illuminate the surrounding terrain, may create the illusion of less distance to the runway. The pilot who does not recognize this illusion will often fly a higher approach.

How To Prevent Landing Errors Due to Optical Illusions

To prevent these illusions and their potentially hazardous consequences, pilots can:

1. Anticipate the possibility of visual illusions during approaches to unfamiliar airports, particularly at night or in adverse weather conditions. Consult airport diagrams and the Airport/Facility Directory (A/FD) for information on runway slope, terrain, and lighting.
2. Make frequent reference to the altimeter, especially during all approaches, day and night.
3. If possible, conduct aerial visual inspection of unfamiliar airports before landing.
4. Use Visual Approach Slope Indicator (VASI) or Precision Approach Path Indicator (PAPI) systems for a visual reference or an electronic glideslope, whenever they are available.

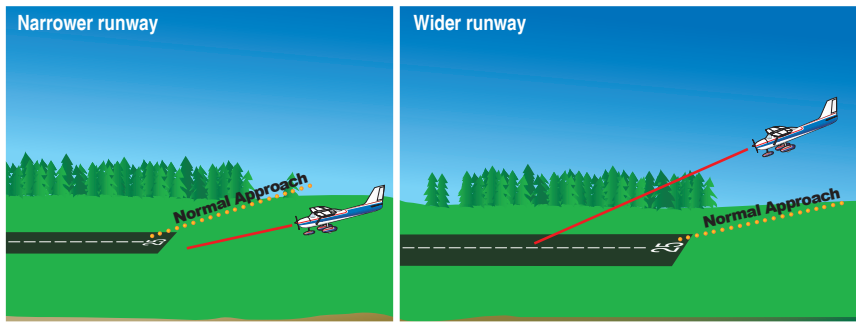


Figure 3-9A
Runway width illusion

- A narrower-than-usual runway can create an illusion that the aircraft is higher than it actually is, leading to a lower approach.
- A wider-than-usual runway can create an illusion that the aircraft is lower than it actually is, leading to a higher approach.

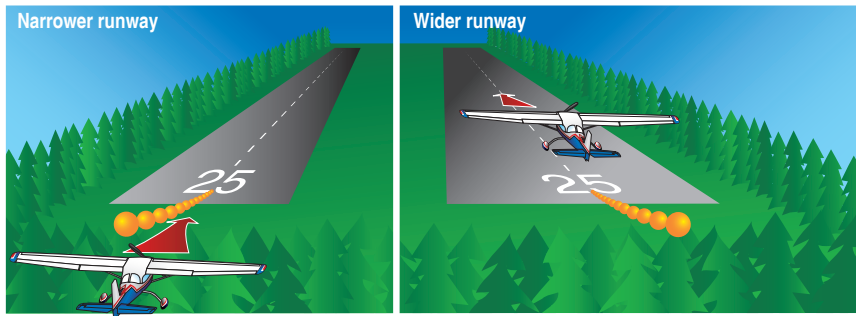
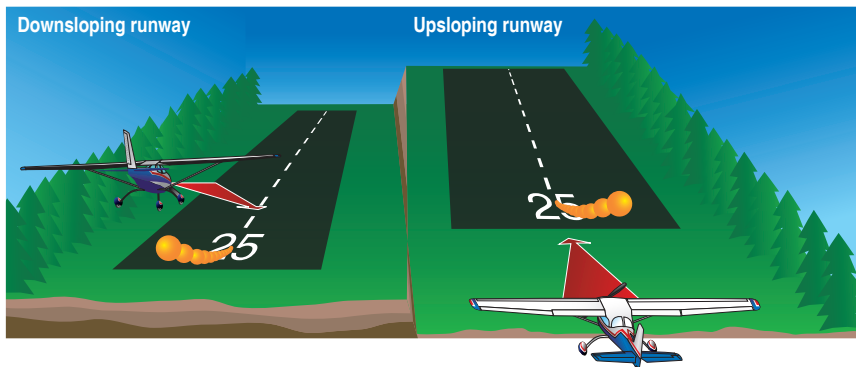
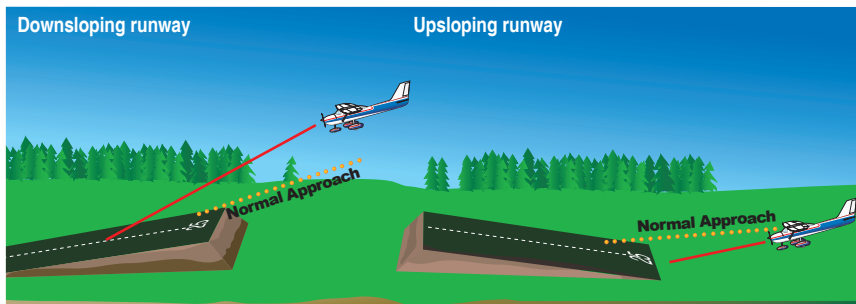


Figure 3-9B
Runway slope illusion

- A downsloping runway can create the illusion that the aircraft is lower than it actually is, leading to a higher approach.
- An upsloping runway can create the illusion that the aircraft is higher than it actually is, leading to a lower approach.



••• Normal approach
◀ Approach due to illusion

Figure 3-9. Runway width and slope illusions.

5. Utilize the visual descent point (VDP) found on many nonprecision instrument approach procedure charts.
6. Recognize that the chances of being involved in an approach accident increase when some emergency or other activity distracts from usual procedures.
7. Maintain optimum proficiency in landing procedures.