FLIGHT SAFETY FOUNDATION
HUMAN FACTORS & AVIATION MEDICINE
Vol. 39 No. 1 *For Everyone Concerned with the Safety of Flight* January/February 1992

Inflight Spatial Disorientation

Pilots must learn to recognize the visual and sensory signs of approaching problems interpreting motion, position and attitude and to minimize their effects on the safety of flight.

by
Melchor J. Antuñano, M.D.
KRUG Life Sciences/U.S. Air Force School of Aerospace Medicine
and
Stanley R. Mohler, M.D.
Wright State University/Aerospace Medicine Program

Spatial orientation refers to a person's ability to perceive motion, position and attitude in relation to the surrounding environment. This capability depends upon the reception, integration and interpretation of sensory inputs from visual, vestibular (inner ear), muscular and skin receptors. The genetic design of the spatial orientation mechanism copes with usual human activities (sitting, standing, walking, running, and jumping, for example). However, this mechanism can encounter interpretation problems when outside visual references are lost and an illusory environment exists. These conditions include: accelerations (for example, spinning motions) and under certain other situations, including the influence of diseases and toxemias (e.g., alcohol). Under these conditions, spatial orientation may not be easily and accurately achieved.

The healthy, non-blind person in a lighted environment can incorporate two modalities of vision. The first is focal vision, which is involved in the recognition and identification of viewed objects (resulting from the stimulation of the central region of the retina, the fovea, and immediately adjacent areas). The second is peripheral vision, which provides spatial visual reference (resulting from the stimulation of the retina beyond the foveal area). Foveal vision provides the fine, detailed sense of the visual image. Peripheral vision is more sensitive to motion and also provides overall broad field of vision position cues. The great importance of peripheral vision in spatial orientation is demonstrated by the sensations of self-motion that can be experienced while watching wide-screen movies. The modern flight simulator takes advantage of this visual characteristic.

The role of the vestibular system in providing spatial orientation is extremely important when, for example, a person is standing on a dark path under an overcast night sky with no lighting (the worst-case scenario would be standing in the pitch-black darkness of a cave). The vestibular system responds to linear (translation) and angular (rotation) accelerative forces. Sensory elements of the inner ear vestibular system stabilize vision under lighted conditions during motion of the head, and, in dark areas, assist in position sensing. This system also provides orientational information that allows the automatic execution of skilled and reflexive motor activities.

In addition to the visual and vestibular system receptors, there are other sensory receptors located in the muscles, tendons, ligaments and joints (proprioceptive receptors), and skin (exteroceptive receptors) that assist in spatial orientation. These other receptors are known as mechanoreceptors because they respond to the mechanical displacement of tissue, and they are the sensors for touch, pressure, vibration and posture. These sensory inputs, concerning relationships and movements of one part of the body with respect to another, are necessary to maintain adequate orientation. In addition, the sensory information allows the determination of shape, size and texture of the structures with which the body is in direct contact.

On the ground, there is a degree of physiological compensation that allows spatial orientation in the natural gravity environment even if, for example, there is an absence of vision. In this case, the vestibular system can interact with proprioceptive and exteroceptive receptors to maintain spatial orientation and postural equilibrium. If there is an absence of a reliable vestibular function on land, the visual system can, under suitable lighting conditions, interact with proprioceptive and exteroceptive receptors to maintain orientation and posture. The compensatory capacity of the spatial orientation mechanism will be effective on land so long as there is a functional integrity of at least two sensory systems.

Maintaining spatial orientation during flight when the outside horizon visual reference is lost requires either orientation instrument displays or automatic stabilization systems. Pilot exposure to linear and angular accelerative forces during loss-of-outside-reference flight produces confusing vestibular and proprioceptor stimulations that result in motion illusions which impair spatial orientation. Inflight sensory spatial orientation cannot be maintained after loss of outside visual horizon references without flight instruments. For orientation in this situation, the pilot must utilize attitude information provided by the cockpit flight displays. The pilot must learn to not trust intrinsic orientational sensory perceptions during flight, but must obtain orientation from the flight instruments.

Inflight sensory spatial orientation cannot be maintained after loss of outside visual horizon references without flight instruments.

Inflight spatial disorientation describes the undesirable condition of an individual who does not know the true attitude of the aircraft in relation to the surface of the earth. This condition involves visual and vestibular illusions and results from the physiological characteristics and limitations of sensory mechanisms that were designed for maintaining spatial orientation while moving about on the earth's surface.

There are several examples of sensory illusions that lead to inflight spatial disorientation. These include both visual and vestibular illusions.

Visual Illusions Vary

Visual Illusions

Illusions of altitude, distance, attitude and motion relative to the ground occur when the available visual cues are absent, unfamiliar, degraded or do not correspond with the pilot's expectations. Among visual illusions there are aerial perspective illusions, peripheral cues, autokinesis, vection illusion and false visual cues.

Aerial Perspective Illusions

Under normal flying conditions, pilots learn to automatically associate a typical approach path for landing (for example, a three-degree slope in relation to a horizontal runway) with a corresponding visual perspective of the runway ahead. If the runway appears shorter than usual, the corresponding approach path is perceived as too low (less than a three-degree slope), whereas, if the runway looks longer than usual, the corresponding approach path is perceived as too high (more than a three-degree slope). In addition, a visual approach to a sloping runway can be disorienting. When the runway is sloping down toward the approach end, the pilot may perceive the approach as too high (because the runway appears longer than usual). The opposite illusion can occur with a runway that slopes down away from the approach end, giving the appearance of an approach that is too low.

Differences in runway width also can create visual illusions. When the runway is wider than usual, it will appear closer and shorter, and consequently, the aircraft may be perceived as lower, and vice versa. These illusions occur because the visual perspective of the runway being approached does not conform to the pilot's established mental image of a runway during typical circumstances. In other words, the pilot is not seeing what he anticipated. Accidents have occurred where unsuspecting pilots have flown a visual illusion rather than reality. These illusions are often more pronounced at night.

Visual approaches over smooth water surfaces, snow-covered terrain, or flat desert terrain often are characterized by few peripheral visual cues. These can result in a misperception of height above the surface. Daytime visual approaches with reduced visibility due to fog, rain, smoke, haze or snow can make a runway appear farther away as a result of restricted focal vision. Nighttime visual approaches under reduced visibility conditions can make runway approach lights appear dimmer than they are in clear air. Dimness gives the illusion that the runway is farther away.

Peripheral Cues

During flight, any condition that impairs the perception of peripheral visual cues (also known as ambient vision) forces the individual to rely on focal vision. This may cause visual illusions with resulting spatial disorientation. Another aircraft that appears to be at a higher altitude under hazy conditions may actually pass below the inflight observer. Also, a pilot can experience difficulty in establishing the relative position and velocity of nearby aircraft. Visual approaches made during a pitch-black night over a large body of water or over unlighted terrain, beyond which the horizon is not distinguishable, are likely to produce a visual illusion of high altitude that the pilot could mistakenly attempt to correct. This type of illusion was cited as a factor in a fatal Boeing 707 accident that occurred in Pago Pago, Samoa, in 1974. Similarly, visual approaches under "whiteout" conditions often created by blowing snow, that are characterized by the absence of an outside horizon and absence of other peripheral visual cues, can cause misperceptions of altitude and attitude.

There are several illusions resulting from the perception of false visual cues.

Autokinesis

The visual illusion called autokinesis occurs when a fixed light (star, individual ground light, wingtip light) seen against a featureless dark background appears to move about in the pilot's field of vision. This illusion is the result of the normal small oscillations of the eyeball. The "moving" point of light can be falsely perceived as another aircraft.

Vection Illusion

Misinterpretation of ambient visual cues can result in visually induced perception of self-motion (linear or angular) and is called a vection illusion. Most people have experienced this type of illusion while sitting in a stopped car as another car moves slowly by. The illusion of motion of the subject's car moving opposite to the other occurs. This linear vection illusion is often very compelling, especially in trains. During takeoff or landing, a snowstorm or sandstorm in a given direction can create the illusion of the subject's movement in the opposite direction and impair the normal directional control of the aircraft. A pilot can experience an angular vection illusion if the anti-collision light on the aircraft is on during flight through clouds or fog. The pulsating light can produce a strong ambient visual stimulus indicating rotation in the yaw or other axis. Linear and angular vection illusions are exploited by advanced flight simulators in order to create a more realistic sensation of flight.

False Visual Cues

There are several illusions resulting from the perception of false visual cues. Flying above a sloped cloud deck creates the illusion of a false horizon that a pilot can mistakenly use for orientation. Upsloping terrain can cause an illusion of a false horizon. A distant rain shower can obscure the real horizon and create the illusion of a horizon at the base of the rainfall. During night flight, isolated ground lights can be perceived as stars and create the illusion of a nose-high attitude. Unlighted areas of terrain or water can blend with a dark overcast sky and create the illusion that the unlighted terrain or water is part of the sky. Takeoffs over a large body of water that cannot be visually distinguished from the night sky can create the illusion that a shoreline receding beneath the aircraft is the horizon, leading the pilot to make a wrong corrective action. This type of illusion was suggested as a factor in a Boeing 747 accident that occurred in Bombay, India, in 1978 where the aircraft was flown into the ocean.

Vestibular Illusions Can Be Fatal

Illusions produced from within the inner ear manifest themselves in various ways, each of which can lead the pilot into trouble. A familiarity with the following six types of vestibular illusions can help prevent being misled by them.

Somatogyral Illusion

The somatogyral illusion is due to the inability of the semicircular canal receptors of the vestibular system to continuously perceive a sustained angular velocity. During the execution of a sustained coordinated turn, a sustained roll or a sustained rotation, the vestibular system will correctly perceive the rotational input only during the first few seconds of the maneuver. After approximately 15-30 seconds of constant angular acceleration such as what occurs during a steady turn, the vestibular system stabilizes to the angular velocity and the pilot may have the illusion that rotation has ceased. Subsequently, when the pilot initiates the recovery to level flight (angular deceleration) the illusion occurs that the aircraft is turning in the opposite direction although it is stopped or proceeding in the original direction more slowly. After the rotational maneuver ceases, the illusion of rotation in the opposite direction may persist for 15 seconds or more. A pilot can make a potentially fatal mistake by attempting to correct the attitude of the aircraft based upon the wrong orientational inputs caused by any of these vestibular illusions.

Oculogyral Illusion

An oculogyral illusion is the visual correlation of somatogyral illusion. A pilot who is experiencing a somatogyral illusion will simultaneously experience an oculogyral illusion in which the peripheral visual references (the horizon, the ground) in front of the aircraft appear to be turning in the opposite direction (which corresponds to the direction of the actual rotational maneuver). However, under conditions of restricted ambient visibility, the pilot can only see the instrument panel ahead. Consequently, the oculogyral illusion of rotation will be in the same direction as the somatogyral illusion (which is opposite to the direction of the actual rotational maneuvers). This is a case where the pilot should rely on the gyroscopic instruments, assuming they are functioning properly as shown by the approved indications.

Coriolis Illusion

This is another well-documented vestibular illusion affecting pilots. A classic example of the Coriolis illusion is one in which a pilot, during a descending turn while flying on instruments (with no external visual cues), must bend his head down to see and to operate a switch. If the sustained descending turn is to the right, the pilot looking ahead will initially perceive rotation in the same direction, and 15-20 seconds later this sensation will disappear, as mentioned earlier. At this point, if the head is pitched down (to look for the switch in the example), the resulting Coriolis illusion produces the sensation of aircraft rolling and yawing to the right.

Samatogravic Illusion

The samatogravic illusion may occur during takeoff under instrument meteorological conditions or under conditions of white-out or a pitch black environment. Due to the linear acceleration, the pilot may have the illusion that the aircraft has pitched up. In this case, the pilot's intuitive reaction is to pitch the aircraft down, possibly causing it to strike the ground. The opposite sensation of pitch accompanies deceleration. This illusion is based on the gravireceptors in the inner ear that normally sense the downward pull of gravity as well as other linear accelerations.

Oculogravic Illusion

The oculogravic illusion is a visual misperception that accompanies the somatogravic illusion. For example, a pilot who is subjected to the deceleration resulting from the inflight application of speed brakes can experience an aircraft nose-down somatogravic illusion. Simultaneously, he has the illusion that the instrument panel is moving downward.

The "Leans"

The leans is a common type of vestibular illusion during flight. It is an illusion of angular displacement about the roll axis, and is commonly associated with an abrupt recovery from a coordinated turn to level flight while flying on instruments. When the aircraft is quickly returned to level flight, the pilot has the strong sensation of banking in the opposite direction. Once the aircraft is level, the pilot still feels that the aircraft is banked in the opposite direction. Therefore, the pilot aligns his head and trunk by leaning to the misperceived vertical even though the aircraft is in a level flight attitude. This illusion may persist for 30 minutes or more, but will disappear when the pilot can see the ground again. A quick shake of the head has helped some pilots make this illusion disappear.

Pilots can prevent being misled by the many causes of spatial disorientation.

Spatial Disorientation Can Be Managed

Pilots can prevent being misled by the many causes of spatial disorientation. Preventive measures include:

- Learn that sensory illusions (visual and vestibular) are common inflight occurrences that represent normal human responses to unusual sensor stimulations. Pilots should also learn to not trust their sensory perceptions under various circumstances that promote illusions, and to avoid sudden intuitive control manipulations based on these inaccurate orientational perceptions.

- Understand the nature of various illusions and their contributing factors to be aware of inflight conditions that are likely to promote the occurrence of such illusions.

- Learn to utilize and rely on orientational information available from non-sensory sources such as attitude instrument displays, radar, radar altimeter, navigation instrumentation, visual glideslope aids and other instruments.

- Develop instrument cross-check skills and maintain these to a high level of proficiency.

- Avoid unnecessary aircraft maneuvers and unnecessary head movements during circumstances that are likely to promote sensory illusions.

- Avoid mixing flight by instrument reference with contact flight when visibility is poor. Pilots should anticipate and make a timely transition to instruments when about to enter instrument conditions.

- Acquire a degree of visual adaptation to low levels of light prior to takeoff on a night flight.

- Avoid fatigue, sleep deprivation, tobacco, hypoglycemia and alcohol consumption prior to flight (at least 12 to 24 hours of abstinence) and avoid exceeding three alcoholic drinks per week on average.

- Avoid excessive caffeine consumption, self-medication or any other self-imposed stress, because these may contribute to or aggravate various illusions. Individuals who suffer from anxiety and who are fatigued or depressed may be more likely to experience perceptual illusions.

- Avoid flying if suffering acute medical problems that affect the sensory systems. A common cold can cause middle ear or sinus pressure vertigo which can result in inflight spatial disorientation.

- Learn that any induced accommodation to inflight motion conditions is transitory. Susceptibility to spatial disorientation increases after several weeks of no flying.

- Remember that a high level of flight experience does not produce immunity to spatial disorientation. A pilot can become adapted to inflight motion conditions, but can still experience sensory illusions that can result in spatial disorientation.

Manufacturers and operators also can contribute to the prevention of pilots' spatial disorientation. They should:

- Promote further standardization of flight instrumentation in an organized, readily interpreted fashion and incorporate modern human factors knowledge in the design of instruments.

- Provide adequate aircrew external and internal visibility with adjustable lighting.

- Provide for easy cleaning of cockpit windows.

Spatial Disorientation Occurrences Require Action

If preventive measures fail and the pilot recognizes himself as the victim of spatial disorientation, concerted effort can regain control of the situation. The following actions are suggested:

- When spatial disorientation is perceived, the pilot in command should concentrate on the flight instruments and postpone non-essential cockpit duties. The aircraft should be controlled so that the instruments are consistent with the desired flight attitude. *(Caution: Be alert for possible malfunctioning or mistakenly adjusted instruments.)* Crew coordination in regard to establishing and maintaining spatial orientation is a significant safety practice.

- Spatial disorientation during a flight can progressively worsen, even to the point where a pilot is unable to clearly see, interpret or process information from the flight instruments. If this should occur during a multi-crew flight, the pilot flying should turn over control of the aircraft to the other pilot.

- The autopilot can be used to help control the aircraft should spatial disorientation occur, especially during the various phases of flight such as climb, en route, descent or approaches. Automatic takeoff and landing equipment also can assist in maintaining aircraft flight profiles. However, should the equipment be disengaged during flight under circumstances of diminished visual cues, the possibility of illusions and spatial disorientation must be kept in mind. ♦

Crew coordination in regard to establishing and maintaining spatial orientation is … a significant safety practice.

References

1. Benson, A.J. "Spatial Disorientation-General Aspects." John Ernsting and Peter King, ed. *Aviation Medicine*. 2nd Ed. London: Butterworths, 1988, pp. 277-296.

2. Benson A.J. "Spatial Disorientation-Common Illusions." John Ernsting and Peter King, ed. *Aviation Medicine*. 2nd Ed. London: Butterworths, 1988, pp. 297-317.

3. Gillingham, K.K., and J.W. Wolfe. "Spatial Orientation in Flight." Roy L. DeHart, ed. *Fundamentals of Aerospace Medicine*. 1st Ed. Philadelphia: Lea & Febiger, 1985, pp. 299-381.

4. Hawkins, F.H. "Vision and Visual Illusions." Frank H. Hawkins, ed. *Human Factors in Flight*. 1st Ed. England: Gower Technical Press Ltd., 1987, pp. 100-123.

5. Leibowitz, H.W. "The Human Senses in Flight." Earl L. Wiener and David C. Nagel, ed. *Human Factors in Aviation*. 1st Ed. San Diego: Academic Press, 1988, pp. 83-110.

About the Authors

Dr. Melchor J. Antuñano is a physician specializing in aerospace medicine. He is a research scientist for Krug Life Sciences at the U.S. Air Force School of Aerospace Medicine, and studies the physiological and psychological effects of human exposure to environmental and operational stress.

Antuñano is chief editor of the Bulletin of the Iberoamerican Association of Aerospace Medicine, *and associate editor of the* Bulletin of the Aerospace Human Factors Association.

Stanley R. Mohler, M.D., is a professor and vice chairman at Wright State University School of Medicine in Dayton, Ohio, U.S. He is director of Aerospace Medicine at the university.

Mohler, who is an air transport pilot and certificated flight instructor, spent five years as director of the U.S. Federal Aviation Administration's Civil Aviation Medicine Research Institute, (CAMI) and an additional 13 years as FAA's chief of Aeromedical Applications Division.

What's Your Input?

Flight Safety Foundation welcomes articles and papers for publication. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Human Factors and Aviation Medicine* please contact the editor. Submitted materials are evaluated for suitability and a cash stipend is paid upon publication. Request a copy of "Editorial Guidelines for Flight Safety Foundation Writers."

HUMAN FACTORS AND AVIATION MEDICINE
Copyright © 1992 FLIGHT SAFETY FOUNDATION INC. ISSN 1057-5545
Please send two copies of reprinted material to the editor. Suggestions and opinions expressed in this publication belong to the author(s) and are not necessarily endorsed by Flight Safety Foundation. Content is not intended to take the place of information in company policy handbooks and equipment manuals, or to supersede government regulations. The editors reserve the right to edit all submissions. • Manuscripts must be accompanied by stamped and addressed return envelopes if authors want material returned. Reasonable care will be taken in handling manuscripts, but Flight Safety Foundation assumes no responsibility for material submitted. • Subscriptions : $55 U.S. (U.S. - Canada - Mexico), $60 Air Mail (all other countries), six issues yearly. • Staff: Roger Rozelle, director of publications; Arthur H. Sanfelici, senior editor; Ashton Alvis, production coordinator; Sandra Mitchell, editorial assistant • Request address changes by mail and include old and new addresses. • Flight Safety Foundation, 2200 Wilson Boulevard, Suite 500, Arlington, Virginia 22201-3306 U.S. • telephone: (703) 522-8300 • telex: 901176 FSF INC AGTN • fax: (703) 525-6047