SPATIAL DISORIENTATION AND FATIGUE

Wondai, QLD, a healthy, instrument rated type experienced pilot flies a perfectly sound Beech King Air into the ground only seconds after taking off into a clear, resulting in his own death and that of four of his five passengers. Los Rodeos Airport, Canary Islands, and two Boeing 747 aircraft collide: five hundred and eighty three fatalities, the worst aircraft accident in aviation history.

Pilot education on phenomena such as spatial disorientation and fatigue is a cornerstone of air safety and is the first step in avoiding becoming a victim of ‘pilot error’. Fatality rates for pilots are significantly higher in crashes that occur between 6 p.m. and 5 a.m. and in instrument meteorological weather conditions (IMC).

This can be attributed partly to limitations imposed by the human sensory system in flight. The false climb illusion, also known, as the somatogravic illusion occurring in dark night take-off, is an example of how limited the human senses are in flight. Tragic consequences of such illusions can be minimised by understanding the mechanisms that bring them to the fore.

This article attempts to explain only a few of the illusions encountered by aviators.

Definitions

Spatial disorientation is a state characterized by an erroneous orientational perception, i.e., an erroneous sense of one's position and motion relative to the plane of the earth's surface.

Geographic disorientation, or "being lost," is a state characterized by an erroneous locational percept. These definitions together encompass all the possible positions and velocities, both translational and rotational, along and about three orthogonal earth-referenced axes.

Orientation information includes those parameters that an individual on or near the earth's surface with eyes open can reasonably be expected to process accurately on a sunny day. Lateral tilt, forward-backward tilt, angular position about a vertical axis, and their corresponding first derivatives with respect to time are the angular positions and motions included; height above ground, forward-backward velocity, sideways velocity, and up-down velocity are the linear position and motions included.

Absent from this collection of orientation information parameters are the location coordinates, the linear position dimensions in the horizontal plane. In flight, orientation information is described in terms of flight instrument-based parameters.
Angular position is bank, pitch, and heading; and the corresponding angular velocities are roll rate, pitch rate, and turn rate (or yaw rate). The linear position parameter is altitude, and the linear velocity parameters are airspeed (or groundspeed), slip/skid rate, and vertical velocity. In-flight navigation information is composed of linear position dimensions in the horizontal plane, such as latitude and longitude or bearing and distance from a navigation reference point.

**TYPES OF SPATIAL DISORIENTATION**

**TYPE I (UNRECOGNIZED)**

A disoriented aviator does not perceive any indication of spatial disorientation. In other words, he does not think anything is wrong. What he sees—or thinks he sees—is corroborated by his other senses. Type I disorientation is the **most dangerous** type of disorientation. The pilot—unaware of a problem—fails to recognize or correct the disorientation, usually resulting in a fatal aircraft mishap:

The pilot may see the instruments functioning properly. There is no suspicion of an instrument malfunction.

There may be no indication of aircraft-control malfunction. The aircraft is performing normally.

An example of this type of SD would be the height-/depth-perception illusion when the pilot descends into the ground or some obstacle above the ground because of a lack of situational awareness.

**TYPE II (RECOGNIZED)**

In Type II spatial disorientation, the pilot perceives a problem (resulting from spatial disorientation). The pilot, however, may fail to recognize it as spatial disorientation:

The pilot may feel that a control is malfunctioning.

The pilot may perceive an instrument failure as in the graveyard spiral, a classic example of Type II disorientation. The pilot does not correct the aircraft roll, as indicated by the attitude indicator, because his vestibular indications of straight-and-level flight are so strong.

**TYPE III (INCAPACITATING)**

In Type III spatial disorientation, the pilot experiences such an overwhelming sensation of movement that he or she cannot orient himself or herself by using visual cues or the aircraft instruments. Type III spatial disorientation is not fatal if the co-pilot can gain control of the aircraft.
THE INNER EAR

Most problems related to disorientation can be traced to the inner ear, a sensory organ. It's the key to our ability to balance when on the ground, or to remain oriented in space when we fly.

VISION AND THE INNER EAR

The problem occurs when the outside visual input is obscured, and the seat-of-the-pants input is ambiguous. Then, you're down to just the output from the inner ear—and that's when trouble can start. The inner ear is similar to a three-axis gyro. It detects movement in the roll, pitch, and yaw axes that pilots know so well. When the sensory outputs of the inner ear are integrated with appropriate visual references and spatial orientation cues from our bodies, there is little chance to experience disorientation.

Fluid in the inner ear reacts only to rate of change, not a sustained change. For example, when you initiate a banking left turn, your inner ear will detect the roll into the turn, but if you hold the turn constant, your inner ear will compensate and rather quickly, although inaccurately, sense that it has returned to level flight.

SENSORY ILLUSIONS

As a result, when you finally level the wings, that new change will cause your inner ear to produce signals that make you believe you're banking to the right. This is the crux of the problem you have when flying without instruments in low visibility weather. Even the best pilots will quickly become disoriented if they attempt to fly without instruments when there are no outside visual references. That's because vision provides the predominant and coordinating sense we rely upon for stability.

Perhaps the most treacherous thing under such conditions is that the signals the inner ear produces—incorrect though they may be—feel right!

INSTRUMENT FLYING

The obvious method to prevent disorientation is the instrument rating. But, that rating alone is no automatic guarantee, because there is no such thing as "knowing how to fly on instruments." You must continue to practice your skills. You are either formally trained and current—or you are unqualified.

So, don't try to fly through a cloudbank or "scud-run" in low visibility conditions if you aren't a current, instrument-rated pilot. For the unqualified pilot, the sudden loss of visual reference is similar to a sudden loss of eyesight. All pilots should check the weather conditions and use good judgment in flight planning. The VFR pilot should avoid low visibility conditions, such as night flying, fog, clouds, and haze. And, if you're instrument-rated and current, you should always trust your instruments. Those gyros are much more reliable than the ones inside your head.
GRAVEYARD SPIN

- This illusion usually occurs in fixed-wing aircraft.
- For example, a pilot enters a spin and remains in it for several seconds.
- The pilot’s semicircular canals reach equilibrium; no motion is perceived.
- Upon recovering from the spin, the pilot undergoes deceleration, which is sensed by the semicircular canals.
- The pilot has a strong sensation of being in a spin in the opposite direction even if the flight instruments contradict that perception.
- If deprived of external visual references, the pilot may disregard the instrumentation and make control corrections against the falsely perceived spin. The aircraft will then re-enter a spin in the original direction.

A MISJUDGED APPROACH

In flight, the visual and vestibular systems play a dominant role in perceiving orientation. Visual processing involves focal and ambient modes of processing. Focal vision uses the central 30 degrees of the visual fields and is important for resolution of fine detail of the visual image. This mode of vision is adopted when reading flight instruments. Ambient vision determines orientation to the environment using the peripheral visual field. This process occurs without being consciously aware of the employed visual cues.

When flying in instrument meteorological weather conditions, a pilot is more likely to misjudge his or her approach. This occurs because flight instruments (focal vision) have to be used in orientating the aircraft. On land ambient vision is adopted for orientation. As a result, greater brain processing when using the focal mode of vision for orientation is required. This skill has to be learnt.

Illusions involving focal vision include shape constancy: runway slope illusions; size constancy: runway width illusions and the effect of the slope of the terrain under the approach on the approach slope. Illusions involving ambient vision include the black hole approach and solitary lights in the dark appearing to move although stationary.

THE "false climb" ILLUSION

The vestibular apparatus is a sensory receptor located in the ears, and is involved in maintaining balance. This organ of balance is about the size of a pea, but can be stimulated by angular accelerations of 0.9 mrad/s^2 and linear accelerations of 0.1m/s^2.

This organ can be divided into two:

- The semicircular canals responsible for angular acceleration and the otolith organs responsible for linear acceleration.
- Otolith organs provide the brain with information about the position of the head by sensing the direction of gravity acting on them. The brain interprets the information from the otoliths in conjunction with visual cues. When visual
cues are insufficient, the false climb illusion, also known as the *somatogravic illusion*, occurs.

On land, gravity and visual cues act on the otoliths to provide the correct information on head position. When taking off on dark night, visual cues from the runway give correct information to the brain thus no illusions occur. Once the aircraft is rotated and starts to climb, gravity and straight-line acceleration combine to give a resultant force. The otolith organs sense this resultant force.

The resultant force makes the pilot feel that he is in a higher nose attitude than he is. Because on a dark night or in bad weather there is inadequate outside reference, the illusion causes the pilot to ‘correct’ the apparent nose-up attitude.

The ‘corrections’ cause more acceleration and a worsening of the illusion, with dire consequences. Tragic consequences of the false climb illusion can be avoided by an **effective instrument scan, maintaining Vx**, and being especially **careful** when flying from, or into, unfamiliar runways on dark nights.

**THE LEANS**

The most commonly reported manifestation of spatial disorientation is the leans. Almost all pilots have experienced this form of disorientation. It occurs frequently with recovery from a co-ordinated turn to level flight when flying by instruments. It is a false sense of roll attitude.

The illusion occurs when a pilot drops one wing at a rate that is below the threshold for detection of a change in angular velocity. The linear acceleration occurs smoothly enough for the otoliths to not be stimulated, thus the brain still believes the aircraft to be level. The error is noticed on instruments and the aircraft quickly rolled back to wings level.

The information transmitted to the brain gives the illusion of roll attitude. Information on the instruments and what the brain thinks then conflict. The pilot then leans in the direction of the original sub-threshold roll in order that he/she aligns his/her body with
the perceived vertical. The brain eventually recognises what attitude it is actually in but until that time, attention must be paid to the attitude indicator. Minimising head movements, maintaining a high proficiency in instrument flying and transition onto instruments early are ways of avoiding this illusion.

**FALSE HORIZON ILLUSION**

The false horizon illusion occurs when the aviator confuses cloud formations with the horizon or the ground. This illusion occurs when an aviator subconsciously chooses the only reference point available for orientation. A sloping cloud deck may be difficult to perceive as anything but horizontal if it extends for any great distance in the pilot’s peripheral vision. An aviator may perceive the cloudbank below to be horizontal although it may not be horizontal to the ground; thus, the pilot may fly the aircraft in a banked attitude. This condition is often insidious and goes undetected until the aviator recognizes it and makes the transition to the instruments and corrects it. This illusion can also occur if an aviator looks outside after having given prolonged attention to a task inside the cockpit. The confusion may result in the aviator placing the aircraft parallel to the cloudbank.

**HEIGHT-DEPTH PERCEPTION ILLUSION**

The height-depth perception illusion is due to a lack of sufficient visual cues and causes an aircrew member to lose depth perception. Flying over an area devoid of visual references—such as desert, snow, or water—will deprive the aircrew member of his perception of height. The aviator, misjudging the aircraft’s true altitude, may fly the aircraft dangerously low in reference to the ground or other obstacles above the ground. Flight in an area where visibility is restricted by fog, smoke, or haze can produce the same illusion.

**RECOMMENDATIONS**

Spatial disorientation can’t be totally eliminated. However, aircrew members need to remember that misleading sensations from sensory systems are predictable. These sensations can happen to anyone because they are due to the normal functions and limitations of the senses. Training, instrument proficiency, good health, and aircraft design minimize spatial disorientation. Spatial disorientation becomes dangerous when pilots become incapable of making their instruments read right. **All pilots, regardless of experience level, can experience spatial disorientation**

- Never fly without visual reference points (either the actual horizon or the artificial horizon provided by the instruments).
- Trust the instruments.
- Avoid fatigue, smoking, hypoglycaemia, hypoxia, and anxiety, which all heighten illusions.
- Never try to fly VMC and IMC at the same time
- Refer to the instruments and develop a good crosscheck.
- Delay intuitive actions long enough to check both visual references and instruments.
• Transfer control to the other pilot if two pilots are in the aircraft. Rarely will both experience disorientation at the same time.
• Don't try to fly through a cloudbank or "scud-run" in low visibility conditions if you aren't a current, instrument-rated pilot.

FATIGUE

A review of the Aviation Safety Reporting System reported that fatigue was cited as a factor in 20% of reported incidents. Fatigue causes decreased concentration. The combination of fatigue, positive G-forces and oxygen deficiency is known to negatively influence vision. Thus, the addition of this negative influence to spatial disorientation could have disastrous consequences.

Disruptions in wake-sleep rhythms, particularly induced by sleep deprivation, are limiting factors for aviators. Diurnal biochemical reactions occurring at set times during the day and night is affected by sleep deprivation and fatigue. Long-haul flights across time zones result in desynchronisation of the sleep/wake cycle, leading to compromised cognitive ability. As a rule of thumb, it takes one day per time zone crossed to recover from jet lag. The role of sleep and naps in the recovery of performance is generally accepted. The combination of naps and certain pharmacological aids has been investigated and found improve cognitive performance during sleep deprivation.

Below are extracts from a South African aircraft accident report, in which the pilot was fatally injured, and of which the probable cause was attributed to that of "disorientation".

ZS-TOM accident number 7331

The aircraft took-off from Springbok Aerodrome to Springs Aerodrome early in the morning under typical night conditions when the Eastern sky just started lighting up.

The aircraft entered a tight left-hand turn after take-off and impacted the mountain initially with its right-hand wing and rolled over to impact the top surface of the mountain in an inverted attitude. The pilot was fatally injured during the impact.
No defects were detected with the aircraft or it's systems.

Although the pilot was night rated he had not flown in night conditions in the last 23 months.

**Additional Information**

1. A quote from “Human Factors for Aviation” relates to the effect of disorientation as follows: We start with a cautionary note. Disorientation can happen to anyone, even instrument-rated pilots. However, non-instrument-rated pilots are much more prone to it. Disorientation is also one of the most common reasons why pilots have accidents. It is not only very unsettling, but also extremely dangerous to lose orientation when flying. It is also very easy. In fact, it is impossible to maintain orientation when flying using the body's sensory organs alone, unless you can see the horizon.

2. In the book “The Pilot’s Night Flying Handbook” the writer describes: The inner ear is an extremely sensitive indicator. Walk across a room with eyes closed and your progress should be as nearly true as when your eyes are open. As you move, three semicircular canals in each ear sense any position error and signal the brain to make corrections through the muscles. As seen in Figure 57, the canals function in any dimension because they lie at right angles to each other. They generate signals through moving fluids, which
stimulate nerve endings within each canal.

3 The semicircular canals are sensitive to changes in the body's angular motion; a companion structure responds to linear motion, or acceleration and deceleration. It's done by a sac of tiny granules, which presses against nerve endings in the static organ (Fig 58) as the body moves. Scientists believe this elegant sensory equipment evolved eons ago to accommodate one of the most fundamental human characteristics: the ability to walk upright.

4 But the delicate sensory equipment is linked to earth walking, not airplane flying. The forces of flight easily fool the inner ear into sending the wrong directional signals. Because of inertia, inner-ear fluids cannot detect very slight changes of an airplane's attitude and fail to sense a gentle turn. Too, they are unable to perceive attitude changes if they occur at a constant rate. Even if a pilot suddenly realizes his airplane's attitude is wrong, his problem isn't over. If he tries to recover without seeing the horizon, inner-ear fluids spill beyond their rest position and tell the pilot he is now entering a similar maneuver, but in the opposite direction!

5 Vertigo is a killer but for the wrong reasons. Its confusion can be cured in moments by simple procedures. Catastrophe happens when a pilot believes his body's false signals and attempts to fly the airplane solely by feeling. Uncertainty develops into panic if the eyes catches sight of outside lights and tries to form a coherent picture. During this sensory struggle the plane escapes control and chances of recovery rapidly fade.
Sources

- RICHARD M HARDING, FJ MILLS - AVIATION MEDICINE THIRD EDITION PAGE 87 TO 100

- RECHARD O, REINHARD, FIT FOR FLIGHT SECOND EDITION PAGE: 57 TO 78


- ZS-TOM, SA-CAA ACCIDENT NUMBER 7331