6 Spatial Disorientation and Sensory Illusions

6.1 Introduction to Spatial Disorientation

The brain processes information from the eyes, the vestibular system, the ears and the proprioceptors (sensory receptors in the muscles, tendons and joints) to determine the direction of gravity ('the vertical') and the position of the body in space. That is what we call spatial orientation.

The most important information for orientation must come from well-defined external visual cues or visual references. If these are not or not sufficiently present we have a problem: we can become spatially disorientated.

While on earth we may use our hands or ears to compensate for the loss of visual cues, the pilot can't. In addition, the vestibular and somatosensory senses have become fully unreliable. Many fatal accidents have resulted and still result from spatial disorientation in the air under bad visual conditions.

An analysis of the USA's National Transportation Safety Board's (NTSB) aviation accident database indicates that between 1990 and 1997, 2.5% of more than 14 000 general aviation (GA) accidents were classified as involving visual flight rules (VFR) flights into instrument meteorological conditions (IMC). These "VFR flight into IMC" accidents accounted for approximately 11% of the fatalities in that 8-year period. 75% of all VFR flight into IMC accidents in that time period were fatal (Goh & Wiegmann, 2000).

The aviation accident records of other countries (e.g., United Kingdom and New Zealand) also show similar trends, indicating that VFR flight into IMC is a major hazard in general aviation.

Tests have proved that without adequate visual clues, directional control of an aircraft can be lost within 60 seconds during straight and level flight and even quicker during a turn.

The lessons learned from these accidents and tests may already be clear:

- VFR-pilots who have little or no experience in IFR-flying should never decide to go into adverse meteorological conditions because they stand a fair chance of becoming spatially disorientated
- Pilots flying under IMC must RELY SOLELY ON THEIR INSTRUMENTS instead of any perception resulting from their vestibular cues.

Why are cues from our vestibular apparatus so unreliable under conditions of few visual reference? Because in 3-dimensional space our vestibular apparatus generates illusions, which are false perceptions of reality that we can't avoid. We can, however, become aware of them and that is the theme of section 6.2 Vestibular Illusions.

When flying, even our eyes and visual perceptions can deceive us by illusions. But the same is true here; we can learn to be alert and aware of visual illusions. These Visual Illusions are the theme of section 6.3.

6.2 Vestibular Illusions

An illusion is a false interpretation of sensory information by the brain.

Vestibular illusions are illusions created in general by a conflict of information received by external visual clues and by the vestibular system.

Also the proprioreceptors, which are receptors in the muscles and tendons of the body and which gives us information about our posture, may play a role in the creation of spatial disorientation.

The following are examples of vestibular illusions, which may be encountered in flight.

6.2.1 The Illusion of Straight-and-Level Flight While Banking and Turning

When in straight and level flight there is no movement of fluid in the semi-circular canals, resulting in the correct perception of being straight and level.

However, any movement of the head as a result of aircraft roll, pitch or yaw will cause the hairs in the fluid of the appropriate semi-circular canal(s) to move. Continued motion at a steady rate of turn will, after 10-15 seconds, allow the fluid to 'catch up' with the canal causing the hairs to revert to their upright position. This lack of vestibular input leads to a false perception that the aircraft is straight and level, when in fact it is not. ***See fig. HP 6.1*** left and middle.

6.2.2 The Illusion of Banking (Rotating) While Flying Straight-and-Level (Somatogyral Illusion)

A somatogyral illusion is a false sense of rotation that results from misperceiving the magnitude or direction of actual rotation. It may, for example, result from the situation described in section 6.2.1. when from a prolonged turn we roll the aircraft back to straight and level flight.

In *fig. HP 6.1,* middle, the aircraft has a constant rate of turn and the sensory hairs are erect because the fluid in the roll canal has come to a rest. The pilot perceives a straight and level position.

When the wings are levelled, the fluid in the semi-circular canals moves in the opposite direction, but when the wings are level and the canal itself has come to rest the fluid continues to move due to inertia. This leads to a sensation of turning in the opposite direction and the pilot will tend to bank the aircraft away from the falsely perceived turn.

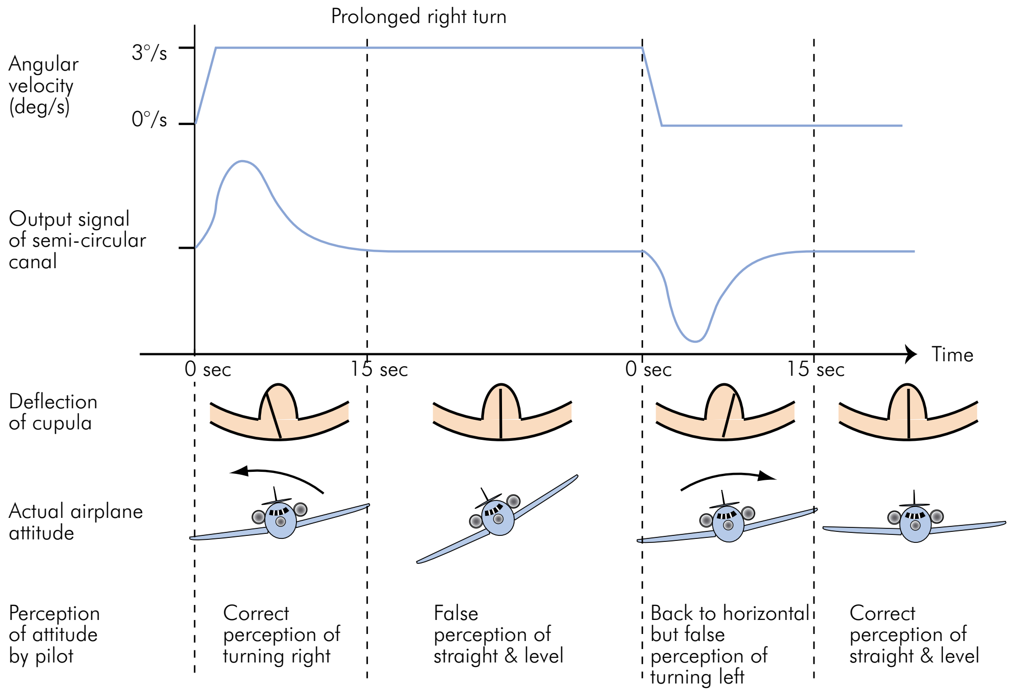


Fig. HP 6.1 Correct and false perceptions when rolling

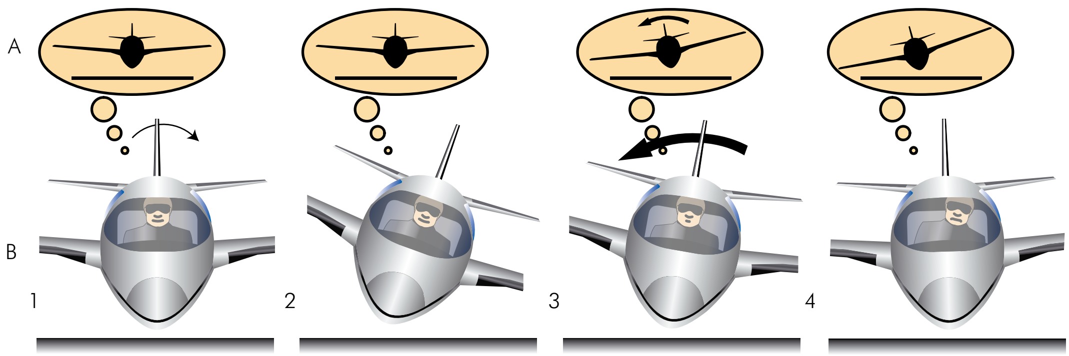
6.2.3 The Leans

The false sense of rolling when levelling the wings described in 6.2.2 may lead to a phenomenon we call the "Leans". It means that the pilot perceives the conflict between the rolling sensation and the level wings and tries to "solve" this conflict by leaning to one side of the cockpit (the side of the original turn). The process is depicted in *fig. HP 6.2.*

The leans could happen when the pilot inadvertently enters a turn gradually and smoothly without exceeding the angular detection threshold of the semicircular canals ("sub-threshold movement"). While softly banking he keeps the illusion of being straight and level. When he becomes suddenly aware of the inaccurate roll attitude and abruptly rolls the aircraft back to wings level he applies a "supra-threshold" roll movement sufficient to make him aware of a rolling sensation. As a result of the false perception of a roll to the opposite side he will "lean" his body to a "false vertical".

6.2.4. Coriolis Illusion

This illusion is caused by the interaction of angular motion in more than one plane. For example, if you are in a turn, drop your pencil and bend over to pick it up, the motion of the head you make adds to the



A - Perceived attitude
B - True attitude

1. Pilot allows wing to drop with a rate under the perceptual threshold
2. Pilot still thinks "wings level"
3. Pilot notices bank and corrects above perceptual threshold
4. Pilot perceives banking to other side, experiences perceptual conflict, and tries to solve this by leaning in the direction of the original bank

Fig. HP 6.2 The leans, the most common form of spatial disorientation

motion of turning. While the fluid in the canals had come to a rest, there is suddenly movement in another canal and in the utricule and saccule. This results in a strong sensation of tumbling backwards or forward. The body feels a new "subjective (but false) vertical", giving you a strong sensation of climbing or diving. You may tend to correct this illusion by control inputs, but these will certainly be wrong because you were only in a level turn. It is considered that when the head is turned at a rate of 3° per second or more, while in a turn, the coriolis effect may be encountered.

The coriolis illusion may provoke nausea and is used in air sickness desensitisation therapy to test the susceptibility for motion sickness.

6.2.5 Vertigo

Vertigo is a false sense of turning usually in one plane in which the individual or his/her surroundings appear to whirl dizzily about. It may be accompanied by nausea or vomiting and can be caused by disease. Vertigo occurring in flight is usually temporary, lasting for a few seconds.

6.2.6 Graveyard Spin

When pulling out of a dive following a spin, the endolymph fluid in the semicircular canals will still be moving under its own inertia and the pilot may feel that the spinning manoeuvre has not yet been recovered. He may respond to this illusion of still being in a spin by putting the aircraft into a spin in the opposite direction.

6.2.7 Somatogravic Illusion

The somatogravic illusion is a dangerous illusion that is believed to have caused a large number of mishaps in civilian and military aviation over the years. When accelerating in straight and level flight, you may falsely perceive that the aircraft is climbing. Similarly, when decelerating, a sensation of pitching down may be perceived. The forward acceleration creates a backward inertial force that combines with gravity to produce a resultant gravito inertial vector rotated backward from the pilot; hence, the pilot perceives a pitching up of the aircraft. The false climb illusion demonstrates the limitations of the otolith organs in providing accurate information to the brain, when there is insufficient visual information to correct the misinformation. *See fig. HP 6.3.*

In the early days of launching Navy aircraft from aircraft carriers at sea, the somatogravic illusion – which is quite intensely felt by the pilots during the launch - has led to many accidents. The pilots reacted to the illusion by pushing the control stick forward and pitching down, while the aircraft was actually horizontal or climbing. As a consequence many dived into the sea in front of the moving ship.

The somatogravic illusion also played an important role in the accident of an Airbus

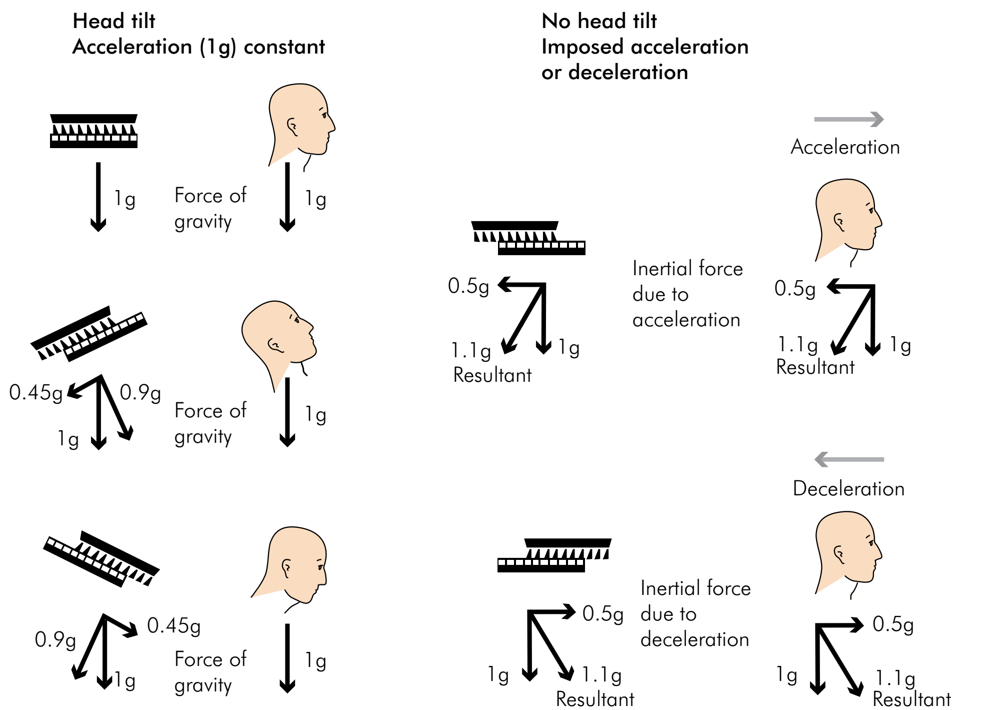


Fig. HP 6.3 Somatogravic illusion

A320 of Gulf Air that crashed into the Gulf of Bahrain. The captain, acting as pilot flying, initiated the go-around (strong linear acceleration!) flying in the direction of the gulf. It was night and in the dark he had no visual cues. However, neither did he monitor his instruments for the correct go-around pitch (nor did the co-pilot). He experienced a strong illusion of pitching up, causing him to push the control stick forward for a certain time, instead of keeping it fully aft, as was the prescribed procedure. While the captain still had a false nose high perception the airplane was already descending to the water. It crashed, leaving no survivors.

6.2.8 Inversion Illusion

An abrupt change from a fast climb to levelling-out may lead to over-stimulation of the otoliths and may cause a sensation of turning upside down.

6.3 Visual Illusions

The following are examples of visual illusions that may be encountered in flight.

6.3.1 Oculogravic Illusion

This illusion is the visual component of the somatogravic illusion previously mentioned. When an aircraft accelerates, the pilot experiences an illusion of pitching up, which can cause the apparent upward movement of objects, such as a line of lights, within the visual field.

6.3.2 Autokinesis

At night in the dark a static light may appear to move if it is allowed to become the prime focus of attention. To prevent this happening it is not advisable to stare for any length of time at a single dim light source.

6.3.3 False Horizons and Surface Planes

Often the horizon perceived through ambient vision is not really horizontal. A sloping cloud layer is very difficult to perceive as anything but horizontal if it extends for any great distance into the pilot's peripheral vision. The tendency to "Lean on the clouds" is very well known to many pilots, even airline crews in automatic flight.

Uniformly up-sloping terrain can create an illusion of horizontality with disastrous consequences for the low-flying pilot thus deceived.

6.3.4 Light-star Confusion

Pilots can confuse stars for lights on the ground and vice versa, again with dire consequences.

6.3.5 Approach and Landing Errors

Shape Constancy

This is illustrated in *fig. HP 6.4* where the runway is seen during final approach.

In "a" where it is flat, a normal approach is achieved.

In "b" where the runway is up sloping, the pilot will perceive the illusion of "being high" and, if he still tries to achieve the normal aspect, will fly a low approach with the possibility of landing short of the runway.

In "c" where the runway is down sloping and the pilot still tries to achieve the same

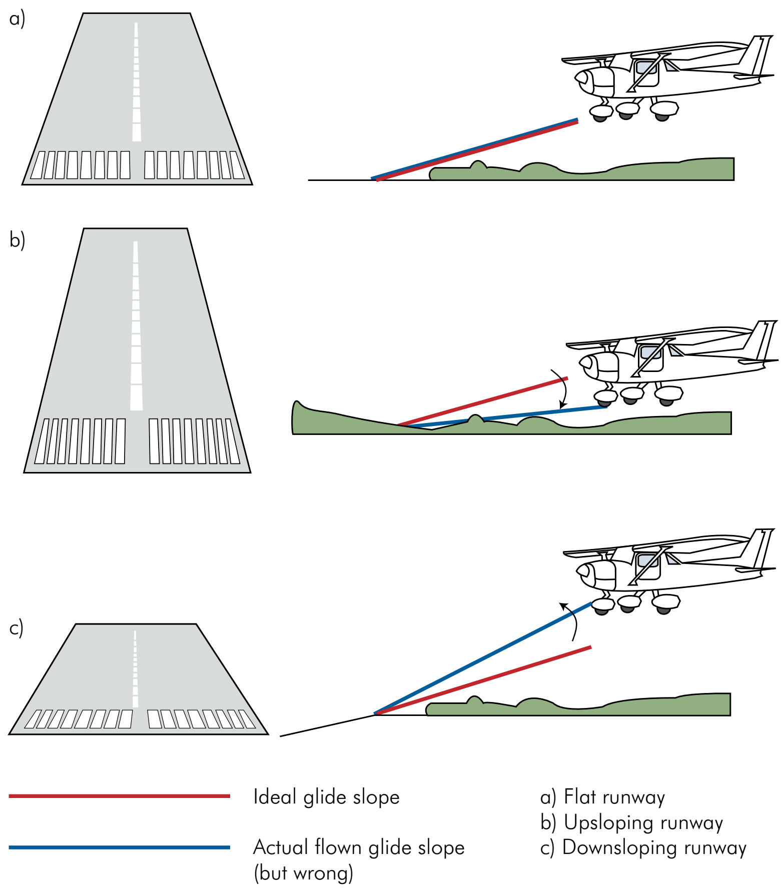


Fig. HP 6.4 Shape constancy

aspect as a flat runway, he flies a higher than normal approach with the possibility of a long landing and going off the end of the runway.

Size Constancy

This is illustrated in *fig. HP 6.5.*
In "a" the width of the runway is the one with which the pilot is familiar and a normal approach is flown.

In "b" the runway is narrower than expected giving him the illusion of making a high approach. So the pilot tends to fly a lower than normal approach to try and achieve the same aspect as for the normal runway width. This could lead to landing short of the runway.

In "c" the width of the runway is wider than normal so the pilot tends to fly a higher than normal approach to achieve the same aspect as for the normal runway width. This could lead to a long landing or going off the end of the landing distance available.

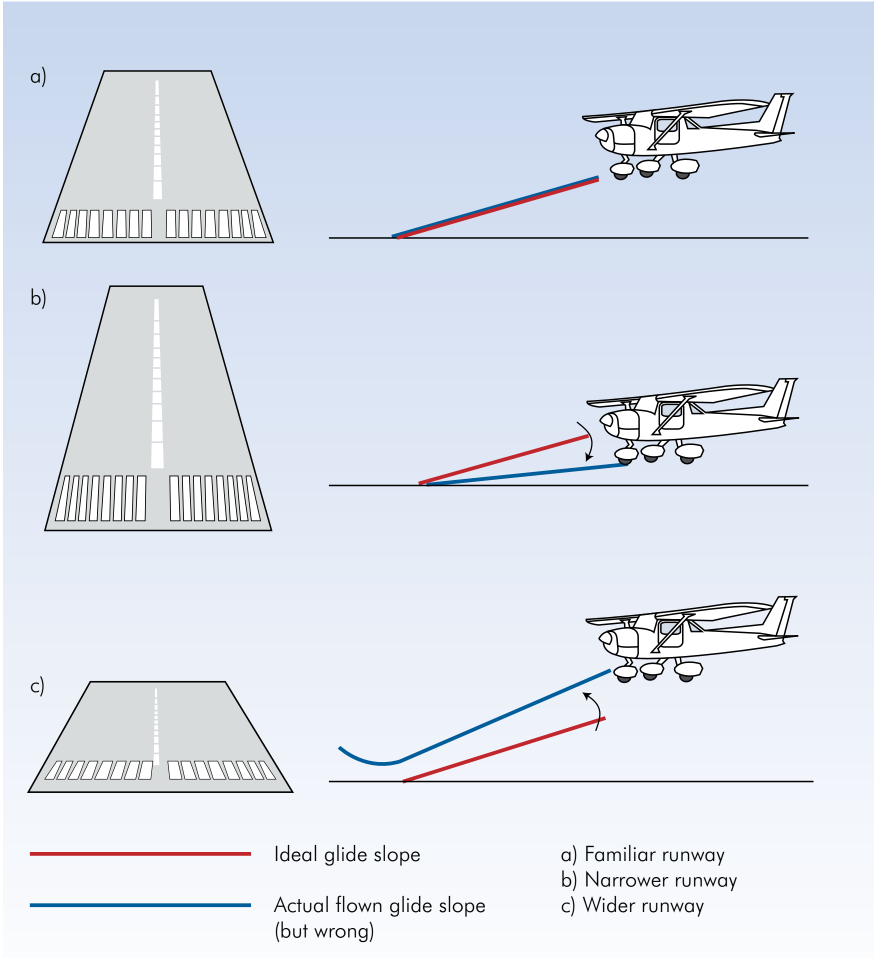


Fig. HP 6.5 Size constancy

6.3.6 Ground Lighting

Straight road lighting can be confused with runway lighting, especially in poor weather conditions where visibility is reduced and workload increased.

If the runway and approach landing systems are bright and there are few lights in the surrounding terrain, the runway threshold may appear to be closer than it actually is, leading to a lower than normal approach being made. Low approaches may lead to landing short of the runway or hitting unlit obstacles in the flight path.

6.3.7 Featureless Terrain and the Black Hole Effect

When approaching a runway from the sea or a featureless terrain such as desert or land covered by snow, the absence of visible ground features can lead to the illusion that the aircraft is too high, leading to a low approach being carried out.

At night time, with no visual clues apart from the runway lighting, there is nothing to provide scale and a false perception of distance and angle may occur leading to an excessively low approach being flown. As previously mentioned, low approaches lead to landing short of the runway or hitting obstacles in the flight path.

6.3.8 Atmospherics

Haze, mist, fog or rain on the windscreen may lead to the refraction of light, creating the illusion that you are higher than you should be, leading to a lower approach resulting in being too low, *see fig. HP 6.6.*

A rainstorm between the aircraft and the runway can lead to a too high approach, as the rain appears to push the runway further into the distance, making the pilot believe that he has got further to go than he actually has. This results in being too high over the threshold.

6.3.9 Blowing Snow

Snow blowing across the runway during landing and take off, gives you an illusion of the aircraft moving in the opposite direction of the blowing snow. This will make it difficult to align the aircraft with the runway. It is of utmost importance to the pilot to align the aircraft with the centreline lights or the runway lights in order to keep the correct direction.

6.4 How to Prevent Disorientation

The following is a list of rules that should be adhered to in order to prevent spatial disorientation:

- All visual clues should be reliable fix points on the earth's surface
- Never continue flying into bad weather unless qualified to do so

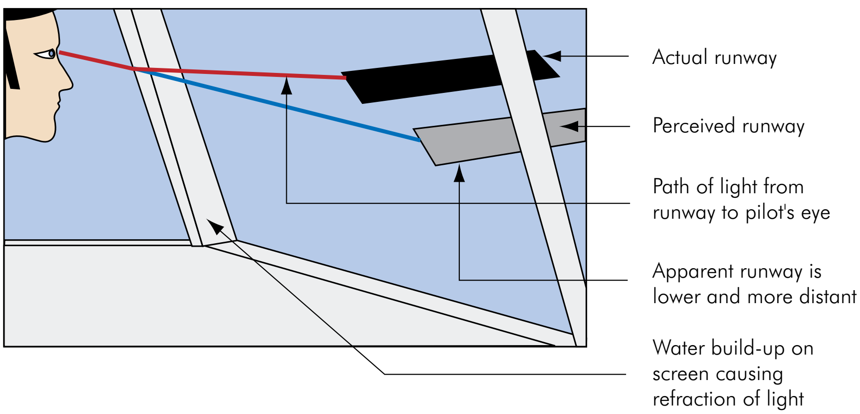


Fig. HP 6.6 Water build-up on the windscreen

- Never continue flying into dusk or darkness unless qualified to do so
- In poor visibility change over to instrument flying and solely RELY ON YOUR FLIGHT INSTRUMENTS
- In poor visibility do not mix visual and instrument flying
- Avoid sudden head movements particularly when manoeuvring
- Do not fly with a cold or any other illness
- Do not fly when tired
- Maintain practice and proficiency in instrument flying.