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DOCUMENT TITLE
HUMAN PERFORMANCE AND LIMITATIONS

CHAPTER 15 – VESTIBULAR ILLUSIONS

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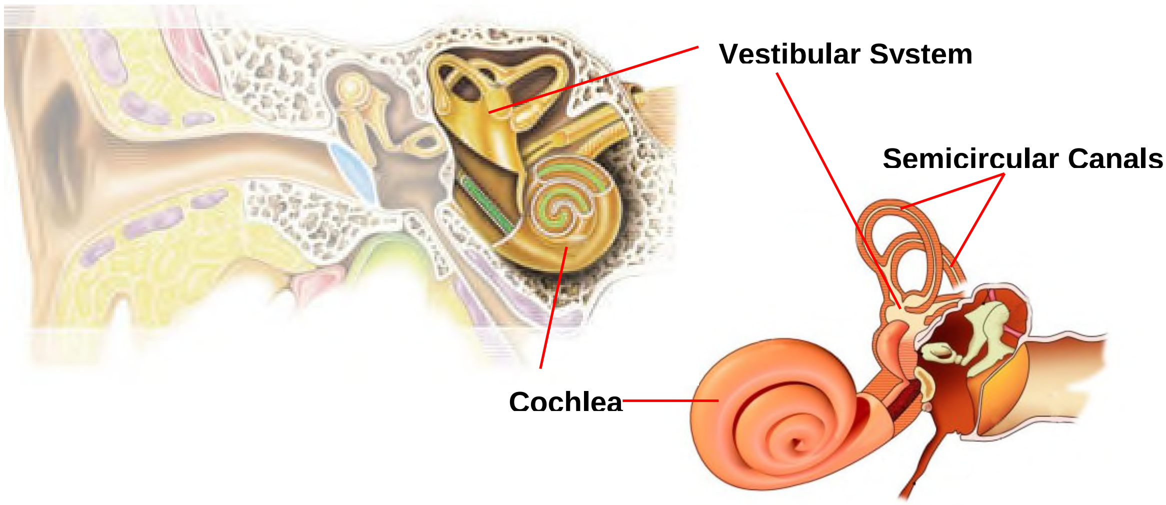
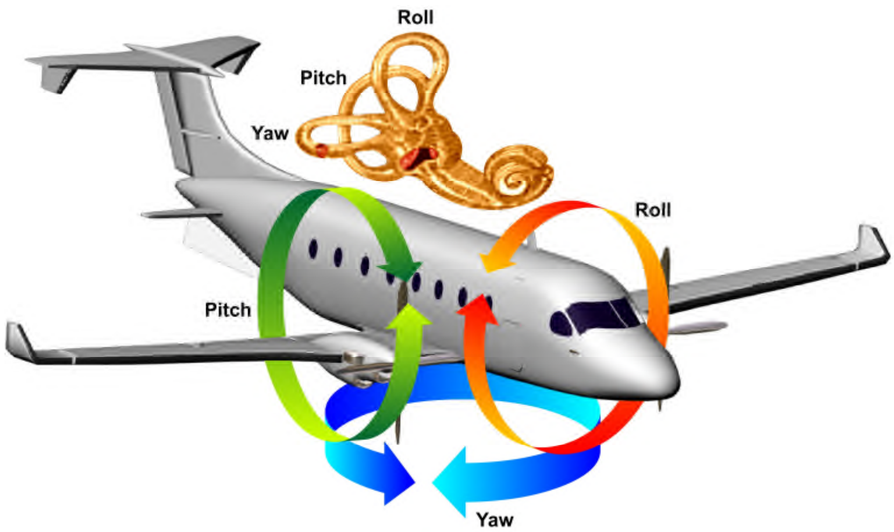
THE HUMAN BALANCE MECHANISM

The inner ear has two functions:

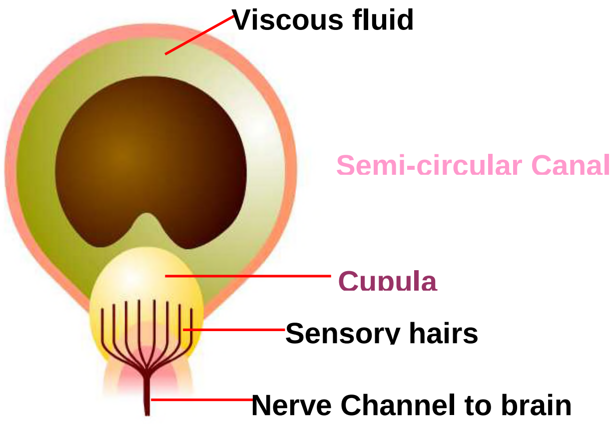
- The cochlea, dedicated to hearing
- The vestibular system, dedicated to balance



The vestibular system consists of three semicircular canals which contain fluid. The three semi-circular canals are at right angles to each other (they are orthogonal), like the pitch, roll and yaw planes of an aeroplane, and can detect angular accelerations (changes in motion) in pitch, roll and yaw.



The human body is designed to cope with a continuous acceleration in the form of Earth gravity. The semi-circular canals can only detect angular acceleration (pitch, roll and yaw) not linear acceleration (accelerating down the runway for example).



The cupula is a saddle-shaped chamber at the base of each canal. It has a cluster of fine hairs that protrudes into the fluid. Movement of the fluid is sensed by these hairs.

Nerve endings at their base send corresponding signals to the brain for interpretation.

In straight and level flight, the sensing hairs are upright, affected only by the force of gravity, no fluid movement.

Initiating a roll, for example to the left, the hesitant fluid in the canal bends the hairs, causing electrical signals to go to the brain “We are rolling to the left” (The head actually moves around the fluid)

The hairs only detect the entry to the roll, but not its continuing steady state. Once a steady roll rate is established, the fluid will catch up and the hairs will return to their normal position

As is the case with any stimulus or sensation, there is a threshold below which movement will not be detected. It will sense a moderate roll acceleration but not a very gentle one

Note:

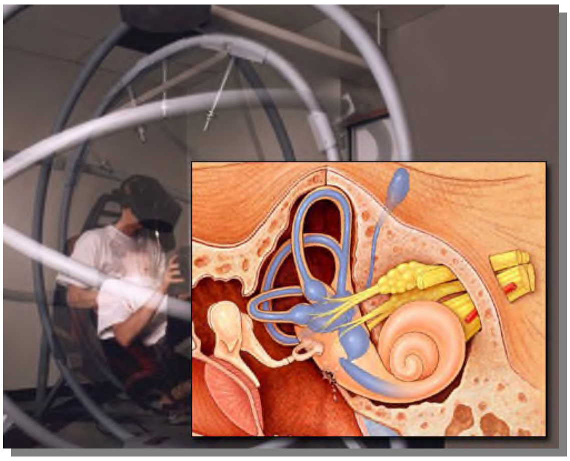
In flight, the sensory mechanisms are suppliers only of crude and potentially deceptive messages. In reality, when the angular acceleration that conmences the roll is detected, you will feel a rolling sensation. Similarly the roll acceleration that stops the roll at the selected bank angle is sensed. However, rolling signals from adjustments to the control input while adjusting either roll rate or angle of bank may be missed or mis - interpreted. The brain is trying to integrate the signals - a rolling acceleration to the right but not sustained, then a rolling sensation to the left - is that stopping the roll or starting a roll to the right? - and so on ... More importantly, in many flight regimes, control inputs will be so gentle that the canals will not detect any rolling sensation at all. The potential for confusion is serious.

It is therefore important to always trust your instruments, and not to follow your “gut feeling”

In a sustained turn, there is no rolling motion. The bank angle is constant. Further, the resultant of the force of gravity and centrifugal force aligns the otholithic organ to a false vertical.

With no visual reference, you will feel that you are still sitting upright with respect to the external forces. You cannot know if you are level or in a banked turn – hence the need for visual cues to confirm actual attitude.

VESTIBULAR ILLUSIONS



Even when deprived of vision, we can still sense our orientation to the ground as well as movement occurring during activity. Part of this ability for orientation is due to the organ of equilibrium found in the inner ear, the vestibular apparatus. The vestibular system detects the position, motion and acceleration of the head in space. Although we are not usually aware of the vestibular system, as we are with sight, hearing, touch and smell, it is essential for motor-coordination, eye movements and posture.

The function of the vestibular system in spatial orientation is not so overt as that of vision but is extremely important for three major reasons: **Visual tracking**, **reflex information**, and **orientation in the absence of vision**.

Visual tracking is the most important function of the vestibular system. It provides input to the brain to trigger reflex mechanisms in the eyes so that when the head is turned, they can track an object accurately to prevent a blurred image on the retina.	**The vestibular apparatus provides reflex information by providing the brain with information on the body's activities. This is accomplished through what is called vestibular-spinal reflexes. They operate to ensure stability of the body.**	**The vestibular apparatus provides the brain the necessary orientation information when there is an absence of vision. If we did not have the vestibular mechanism providing additional orientation information, we would not be able to walk in complete darkness. We would always lose our balance and fall.**

Vestibular illusions of flight usually occur when the pilot is deprived of a visual horizon and is involved in accelerative and decelerative flight.

Somatogyral Illusions (Semicircular Canals)	Somatogravic Illusions (Otoliths)
These illusions are created when the body is turning or when it is subjected to angular acceleration for prolonged periods. It is caused by the inability of the semi-circular canals in the inner ear to accurately register a prolonged rotation.	These illusions are produced when the body is subjected to gravito-inertial (simulated gravity produced by acceleration) forces whereby the pilot falsely perceives a nose high or nose low attitude during changes in linear acceleration (up and down, fore and aft).
Examples: ▪ The leans; ▪ The graveyard spin ▪ The graveyard spiral; ▪ Coriolis illusion.	Examples: ▪ Oculoagravic illusion ▪ Elevator illusion ▪ False Climb ▪ Inversion illusion ▪ Climb sensation when entering a turn. ▪ Descent sensation when exiting a turn,

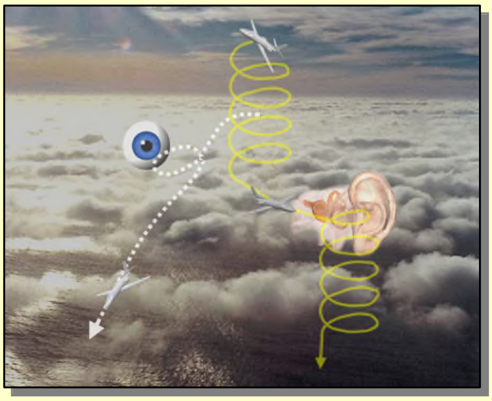
SOMATOGYRAL ILLUSIONS

THE LEANS

"**The leans**" is the most common form of spatial disorientation. It usually occurs when an aircrew member lacks visual cues for orientation and is characterised by a false sensation of bank when the aircraft is in level flight. The leans are caused when a pilot allows the aircraft to enter into an imperceptible turn for several seconds. The semi-circular canals in the inner ear will not detect the roll if the rate of roll is less than 2°/sec (sub-threshold manoeuvre). Some time afterward, the pilot may become aware of the wing-low attitude from reference to the instruments and initiate a recovery to level flight. This manoeuvre will stimulate the semi-circular canals such that, the pilot will perceive a banked attitude in the opposite direction of the initial turn. The vestibular system will tell the pilot they are now turning. The false sensation of bank can persist for several minutes. The failure to perceive the initial sub-threshold roll, and then the conflict between the correct visual perception of straight and level and the vestibular perception of a false turn causes the pilot to lean in the initial roll. The result is the pilot's subconscious attempt to reduce the conflict between the visual and vestibular system.

GRAVEYARD SPIN

Whilst the semi-circular canals are able to determine **angular accelerations**, they are unable to perceive **angular velocity**. This situation can be experienced during a spin, when the pilot has no external visual reference. When the pilot enters the spin, he experiences an initial angular acceleration and will perceive this correctly as entering the spin. However, as the spin stabilises, and within about 20 seconds, the endolymph velocity relative to the canal will gradually decrease to zero, resulting in the perception that motion has ceased. The pilot may remain in the spin.



However, if he initiates a recovery from the spin, he will undergo a deceleration that may be interpreted by the semi-circular canals as a spin or turn in the opposite direction. Reluctance to believe and obey the aircraft's instruments and deprived of external reference, the pilot is tempted to make a correction in the opposite direction to the perceived new spin thereby returning the aircraft into the original spin direction. This is known as the graveyard spin, for obvious reasons.

GRAVEYARD SPIRAL

A "**graveyard spiral**" usually occurs in a fixed-wing aircraft but can occur in rotary-wing aircraft. The pilot unknowingly enters a coordinated steep descending spiral, which falsely stimulates the semicircular canals. If a pilot unknowingly enters a turn of less than 2°/sec, the pilot will have the false perception of straight and level flight. However, the aircraft will be descending in a turn. Upon recovery from the prolonged spiral to straight and level flight, the pilot will experience a sensation of turning in the opposite direction, because the fluid in the inner ear remains in motion. This makes him/her feel as though he/she were turning in the opposite direction. If the pilot is inexperienced, the pilot may correct for the false impression by entering back into the original spiral direction. The rates of descent in a spiral are extremely high; therefore quick action is necessary to overcome this type of illusion.

CORIOLOS ILLUSION

The "**Coriolis illusion**" is the most dangerous vestibular illusion because of its overwhelming and incapacitating effects. The Coriolis illusion may occur when a prolonged turn is initiated and the pilot makes a head motion in a different geometric plane. When a pilot enters a turn and then remains in the turn, the semi-circular canal corresponding to the yaw axis is equalised. If the pilot initiates a head movement in another geometric plane other than that of the turn, the yaw axis semi-circular canal is moved from the plane of rotation to a new plane of non-rotation. The fluid then slows down in that canal, resulting in a sensation of a turn opposing that of the original turn. The combined effect of the fluid in all three canals creates the perception of motion in three different planes of rotation: yaw, pitch, and roll. The pilot will experience a very strong tumbling sensation.

SOMATOGRAVIC ILLUSIONS

OCULOAGRAVIC ILLUSION

"**Oculoagravic illusion**" is the movement of the eyes during weightlessness. The oculoagravic illusion results from a rapid downward motion of the aircraft. Usually occurring during a down draft condition. The vertical stimulation of the otolith organ produces an upward shift of gaze in the eyes. The eyes then sense a movement of the aircraft instrument panel in a downward motion. This results in a sensation that the aircraft is in a nose-low attitude (diving). The pilot will then erroneously correct for the perceived condition by pulling back on the controls.

ELEVATOR ILLUSION

The "**elevator illusion**" occurs during upward acceleration. The upward vertical stimulation of the otolith organ produces a downward shift of gaze in the eyes. The eyes then detect movement of the aircraft instrument panel in an upward motion. Normal pilot response is to push forward on the controls to reduce perceived nose up attitude.

FALSE CLIMB

"**False Climb**" is the visual perception altered as a result of unfamiliar exposure to accelerative and decelerative gravito-inertial forces. When an aircraft accelerates forward, as in a takeoff or added power condition, a gravito-inertial force is applied to the head in a rearward motion. The otolith organ (utricle) is shifted to the rear just as if the head were tilted backward. This movement of the membrane is the same movement that would occur if the head were tilted backward. The otolith organ sends erroneous signals to the brain that the head is tilting backwards. This signal results in the pilot sensing a nose high attitude. The normal reaction is to push forward on the controls and dive the aircraft to overcome the sensation of an excessive climb. The decelerative version of the oculogravic illusion is an illusion of pitch nose down on sudden deceleration and is more frequent in rotary wing flight than the accelerative version. It can occur when an aircraft decelerates, such as a landing or reduced power condition, the gravito-inertial motion is applied to the head in a forward motion. The normal reaction is to pull back on the controls.

INVERSION ILLUSION

This illusion is similar to the “False climb” illusion explained above. After a steep rapid climb when the aircraft levels off and accelerate, the otolith organ (utricle) is shifted to the rear just as if the head were tilted backward. The brain can interpret the otolith signals as the body tumbling backwards. The natural reaction will be to lower the nose of the aircraft, resulting in a further acceleration which could intensify the backward tumbling sensation. The aircraft can end in a steep decent as a result of this illusion.

CLIMB SENSATION ENTERING A TURN

As an aircraft enters a turn, the g-forces on the pilot’s body could give him the impression that he actually pulled back on the controls and that the aircraft is in a climb. The natural reaction could be to push on the controls to stop the climb.

DESCENT SENSATION EXITING A TURN

When an aircraft exits a turn the pilot can sense some negative g-force, leaving him with the impression that a descent has be initiated. The natural reaction would be to pull back on the controls to prevent this from happening.

IDENTIFYING THE TYPES OF SPATIAL DISORIENTATION (SD)

TYPE I - UNRECOGNISED

The pilot does not perceive any indications of spatial disorientation. In other words, he/she has no apparent orientation problems. Type I disorientation is the most dangerous type of disorientation, because the pilot is unaware of a problem and fails to correct the disorienting situation. This type of disorientation usually results in aircraft mishaps.

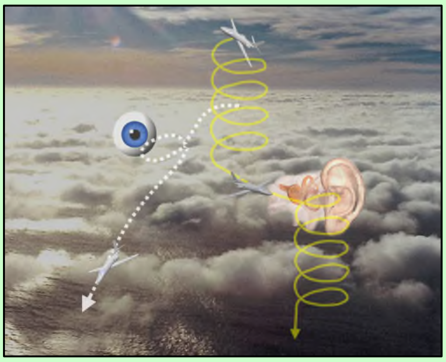
- The pilot may see the instruments as functioning properly.
- There may be no indications of aircraft control malfunction.
- An example of this type of SD would be the height/depth perception illusion (Black Hole Approach) where the pilot inadvertently flies the aircraft into the ground due to lack of visual cues.

TYPE II - RECOGNISED

The pilot perceives a problem (resulting from spatial disorientation) but may not recognise it as spatial disorientation.

- The pilot may feel that a control malfunction is occurring.
- 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 on the attitude indicator because his/her false vestibular indications of straight and level are so strong.

TYPE III - INCAPACITATING



The pilot experiences an overwhelming sensation of movement, such that he/she cannot properly orient himself/ herself by using the aircraft instruments.

MEASURES TO PREVENT AND CORRECT SPATIAL DISORIENTATION

PREVENTION

Although spatial disorientation cannot be totally prevented, the use of the following measures may reduce the possible occurrence thereof:

- <u>Aviation Training</u>

  Training is the most important measure to reduce the possibility of spatial disorientation. Through training, an aircrew member learns the "how's" and "why's" of spatial disorientation. An aircrew member must understand the limitations of the sensory mechanisms, the particular flight manoeuvres that can lead to spatial disorientation, and the conditions where errors in perception are most likely to occur.

  Instrument training must be performed on a regular basis in order to maintain proficiency. It also reinforces the skills necessary for a good instrument cross check.

- <u>Fly the Aircraft</u>

  Never try to fly both VMC and IMC at the same time. If you lose sight of the ground or significant objects, transition to the instruments and perform the emergency IMC procedures.

  Never fly without visual reference points (either an actual horizon or an artificial horizon).

  Utilize continuous scanning techniques during the day and during night operations. Never stare (either at lights or objects).

- <u>Instrumentation</u>

  Trust your instruments.

  Cockpit design: Position new equipment within the cockpit in areas that reduce the necessity for head movements. Ideally, instruments should be as easy to interpret as external cues.

- Stressors

Avoid self-imposed stressors. They make one more susceptible to sensory illusions.

CORRECTIVE ACTIONS

- Transfer control of the aircraft if there are two pilots (seldom will both pilots experience disorientation at the same time).
- Delay intuitive reactions.
- Refer to the instruments immediately upon losing the horizon as reference.
- Develop and maintain instrument crosschecks.
- Trust your instruments.