

Human Performance & Limitations · Module E — The Senses

The Ear & Balance

Chapter 13 — The organ that both hears and keeps you upright: the three sections of the ear, the Eustachian tube and barotrauma, noise and hearing loss, and the vestibular balance system that illusions will later fool.

BOOK

Human Performance & Limitations

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CHAPTER

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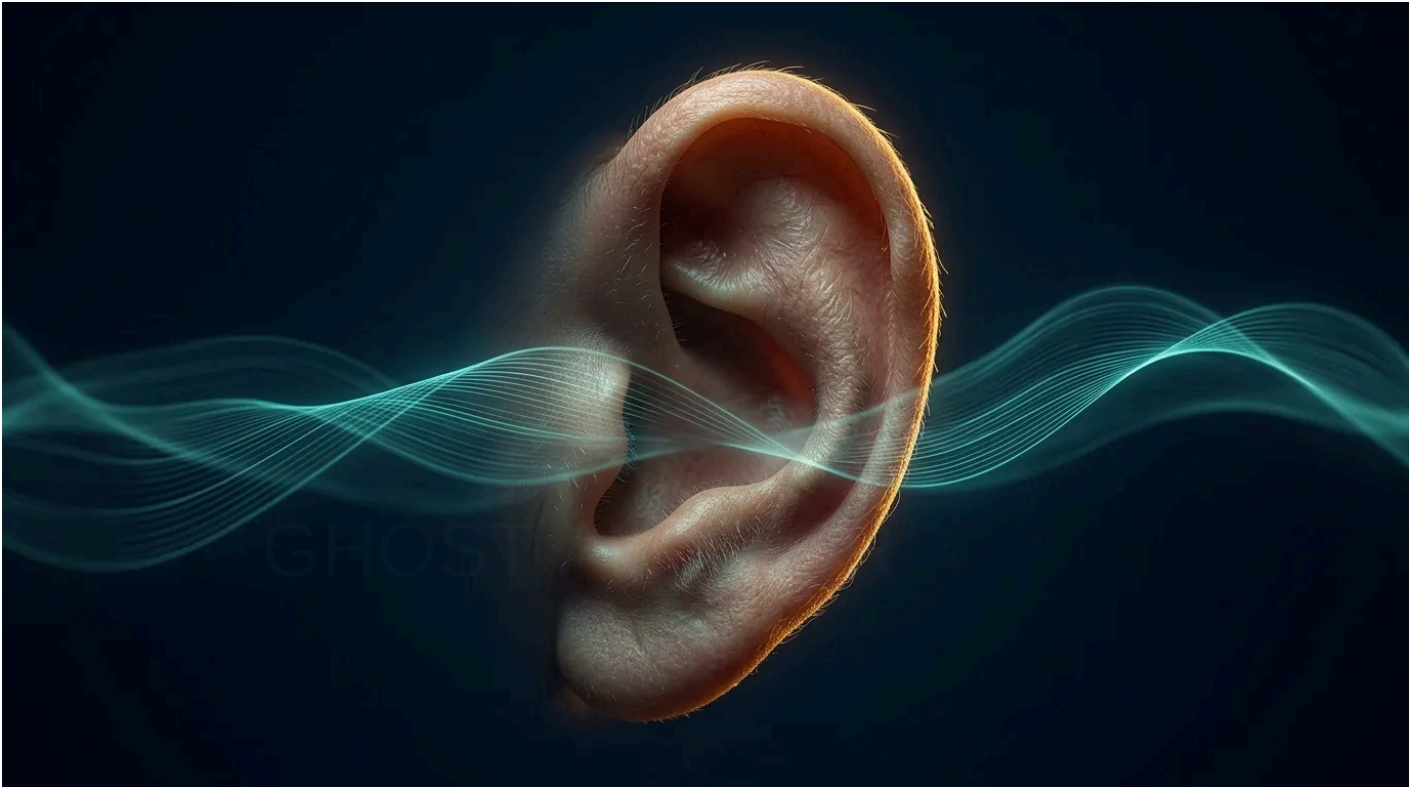


Plate 13.0 — Two instruments in one: the ear both hears the world and tells the brain which way is up.

§ 37

THE EAR — Two Functions, Three Sections

DGCA-QUOTED — THE TWO FUNCTIONS OF THE EAR

The ear performs two quite separate functions:

- To receive vibrations or sound waves in the air which it transmits to the brain.
- To act as a balance organ and acceleration director.

WHY THIS DISTINCTION IS CRITICAL

Most students think of the ear as the "hearing organ" only. The second function — **balance** — is arguably more important for pilots, because **spatial disorientation kills pilots, hearing loss usually doesn't**. The vestibular apparatus inside the inner ear (covered in §42–43) is what tells you which way is up — when it lies to you, you crash.

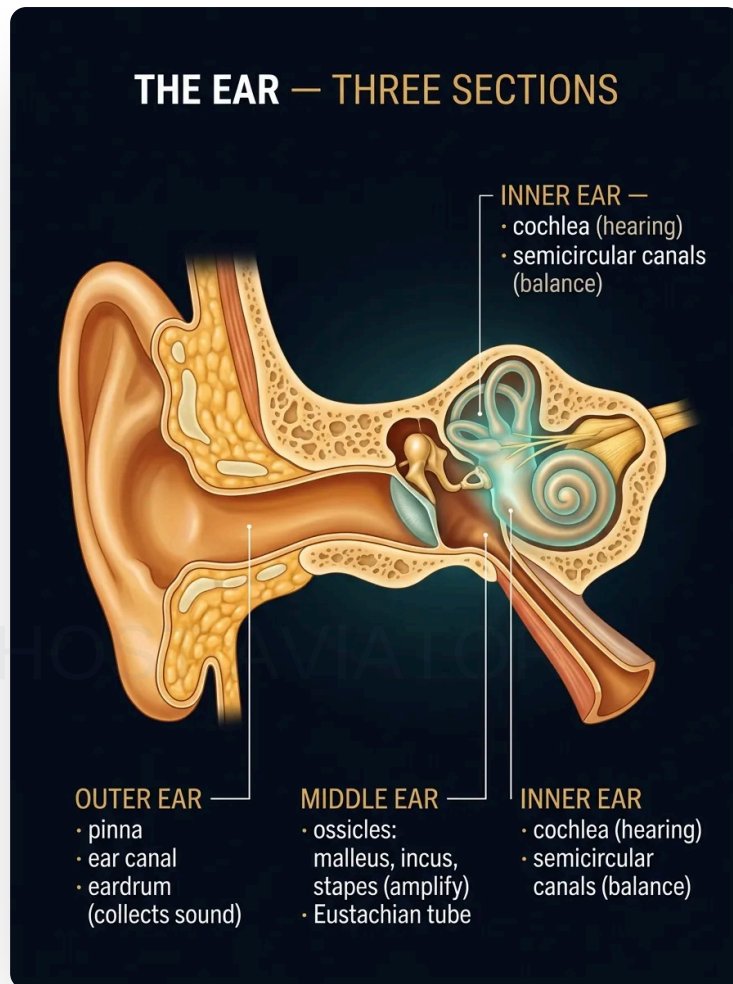


Figure 13.1 — The ear's three sections: outer (collects sound), middle (ossicles amplify), inner (cochlea hears, semicircular canals sense balance).

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The Middle and Inner Ear • The Eustachian Tube

DGCA-QUOTED

The Tympanum and the Ossicles transmit sound waves to the inner ear.

The **Tympanum** is the eardrum. The **Ossicles** are the three smallest bones in the body — **Malleus, Incus, Stapes** (Hammer, Anvil, Stirrup). They form a tiny amplifying lever system that converts air pressure waves at the eardrum into mechanical motion at the oval window of the cochlea.

38.1 The Eustachian Tube — pressure equalisation

DGCA-QUOTED

The **Eustachian tube** allows pressure in the middle ear to equalize across the ear drum with outside or ambient pressure when climbing or descending.

DGCA-QUOTED — THE NO-FLY RULE

No one should fly if their Eustachian tube is blocked, and they cannot "clear" their ears.

Join live classes for guided practice and doubt clearing.

38.2 Effects of Altitude Change — Clearing the Ears

DGCA-QUOTED — DESCENT IS THE DANGEROUS PHASE

It is during DESCENT when difficulty in clearing the ears is most likely to be experienced.

WHY DESCENT — THE ONE-WAY-VALVE EFFECT

On **climb**, ambient pressure falls; the higher-pressure middle-ear air *pushes outward* through the Eustachian tube — this happens easily and automatically. On **descent**, ambient pressure rises; the now-relatively-lower-pressure middle-ear air must *draw in* through the Eustachian tube against gravity and tissue swelling. The tube tends to act like a one-way flap valve. If congested (cold, flu, sinusitis), it fails to open and the eardrum is pushed inward by external pressure — **Otis Barotrauma**.

38.3 Otis Barotrauma

DGCA-QUOTED DEFINITION

Otis Barotrauma — Stretching of the ear drum caused by the expansion and contraction of gases trapped in the inner ear by a blocked Eustachian tube.

DGCA-QUOTED CLEARING TECHNIQUES + "STEP DESCENT"

If you experience problems with pressure equalization during descent:

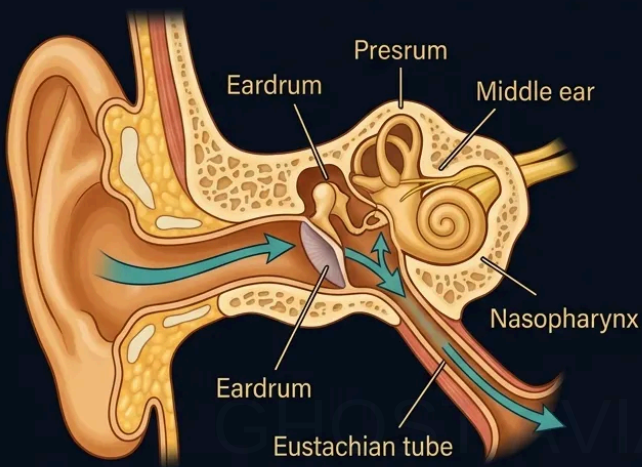
1. **Swallow deliberately** with the nostrils pinched closed,
2. **Yawn**,
3. **or BLOW DOWN THE NOSE**, again with the nostrils pinched closed. *(This is the Valsalva manoeuvre.)*

If the problem is not resolved, **the rate of descent should be decreased or stopped at intervals to allow more time for pressure to equalize. This is also known as STEP DESCENT.**

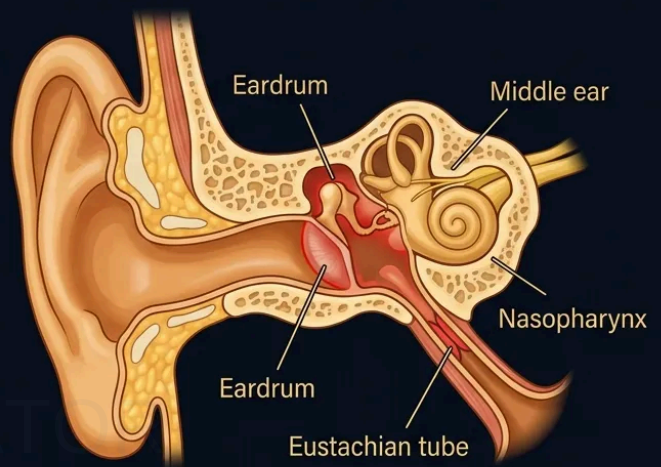
Pilot may resort to even CLIMB if pressure persists. Re-climbing reduces external pressure and helps un-block the tube.

Remember, never fly if your Eustachian tube becomes swollen or blocked and you cannot clear your ears.

THE EUSTACHIAN TUBE



OPEN — equalises middle-ear pressure with the cabin (a normal 'ear pop')



BLOCKED ON DESCENT — pressure difference bulges the eardrum = **OTIC BAROTRAUMA** · pain

Figure 13.2 — The Eustachian tube equalises middle-ear pressure with the cabin; a blocked tube on descent causes otic barotrauma.

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Audible Range of the Human Ear

DGCA-QUOTED — SOUND HAS THREE MAIN QUALITIES

- **Pitch** — which depends on the **frequency** of the vibration.
- **Loudness or Intensity** — which depends on the **amplitude** of the vibrations.
- **Quality** — which can be either **harmonious or just plain noisy**.

DGCA-QUOTED — FREQUENCY RANGE

The range of **pitch or frequency of sounds** that a fit young person can hear lies between **16 and 20,000 Hertz**, or cycles per second. **Detectable sound range** also depends on loudness.

16_{Hz} Lower limit of audible frequency

20,000_{Hz} Upper limit (fit young person)

3^{qualities} Pitch · Loudness · Quality

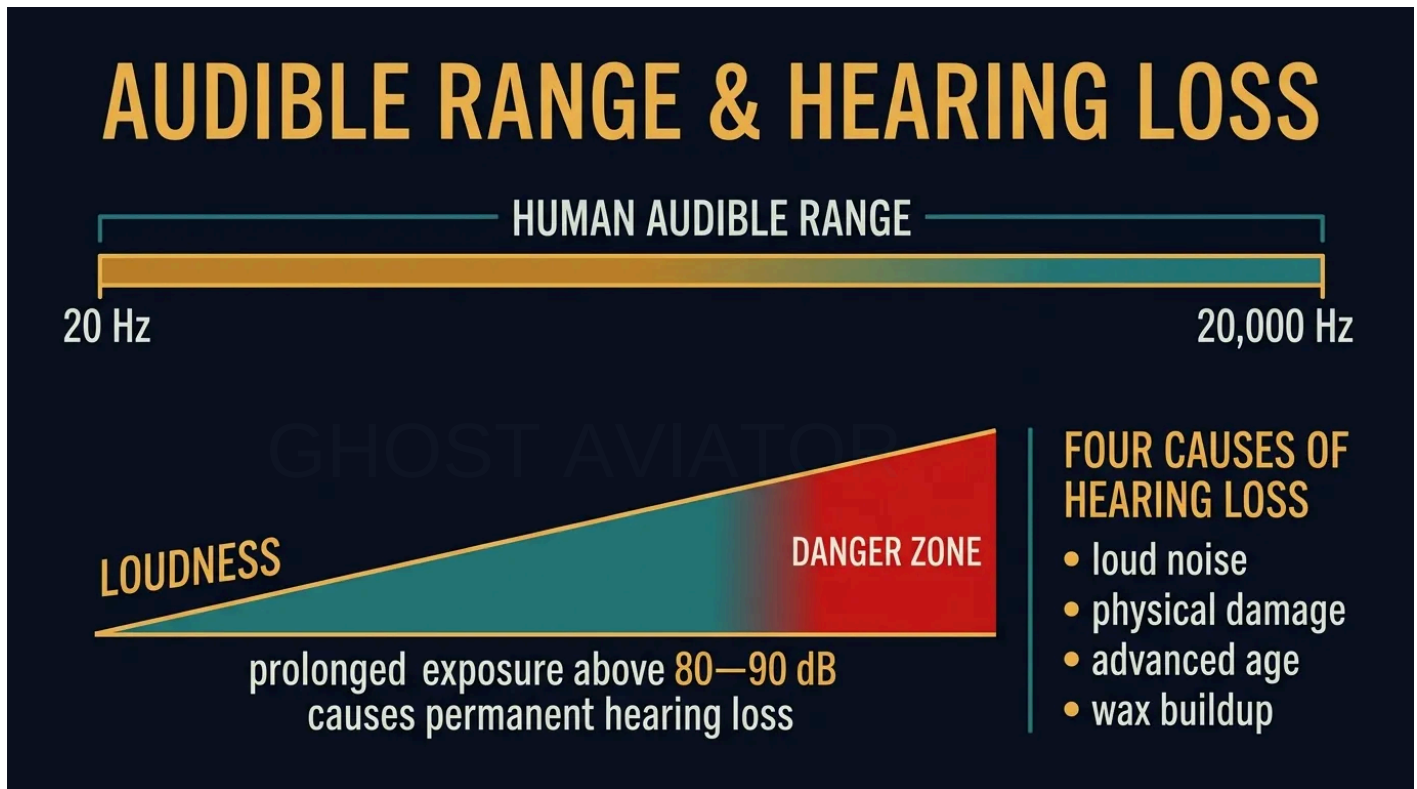


Figure 13.4 — The audible range (20 Hz–20,000 Hz) and the noise thresholds: prolonged exposure above 80–90 dB causes permanent hearing loss.

DGCA-QUOTED — FOUR CAUSES OF HEARING IMPAIRMENT

Hearing impairment can arise because of:

1. Exposure to loud noise.
2. Physical damage to the hearing mechanism.
3. Advanced age.
4. A buildup of wax.

40.1 Conductive Deafness

DGCA-QUOTED

Conductive Deafness — is caused by damage to the ossicles or the ear drum.

40.2 Noise-Induced Hearing Loss — the 80 / 90 dB thresholds

DGCA-QUOTED — EXACT DB THRESHOLDS

Noise Induced Hearing Loss:

- > **80 dB** — task performance may be impaired.
- > **90 dB** — measurable impairment of task performance.

DGCA-QUOTED — THE COUNTERINTUITIVE "AROUSAL" EFFECT

However, it has been shown that in some situations performance of VIGILANCE tasks can actually be BETTER in high noise levels than in low noise levels. This is because noise increases AROUSAL and can move the individual into the optimum performance area.

Any prolonged exposure to noise in excess of **90 dB** can end up in **noise-induced hearing loss**. This can **damage the very sensitive membrane in the cochlea**.

40.3 Presbycusis — Hearing loss with age

DGCA-QUOTED

Presbycusis — is the name given to the deterioration of hearing with advanced age. **HIGH TONES** are cut off **FIRST**.

AUDIBLE RANGE YOUNG

16 - 20,000 Hz

PERFORMANCE IMPAIRED ABOVE

80 dB

MEASURABLE IMPAIRMENT ABOVE

90 dB

CONDUCTIVE DEAFNESS — SITE

Ossicles / eardrum

AGE-RELATED HEARING LOSS TERM

Presbycusis

PRESBYCUSIS — FIRST TO GO

High tones

NOISE DAMAGE SITE

Cochlear membrane

"OPTIMUM" ZONE OF NOISE-
AROUSAL

~ 70 - 80 dB (implied)

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Protection of Hearing

DGCA-QUOTED

Noise induced hearing loss can be avoided or reduced to a minimum by wearing suitable **EAR PROTECTORS**.

Always protect your ears if you know you are going to be exposed to excessive noise. In the cockpit, use the best quality HEADSET you can afford in order to reduce background noise.

PRACTICAL COCKPIT APPLICATION

- **Active Noise Reduction (ANR) headsets** — provide both passive (foam seal) and active (anti-phase electronic cancellation) noise attenuation. Reduce cockpit noise by 15–25 dB.
- **Maintenance crews on ramp** — must use over-the-ear muffs near running engines (105–130 dB at engine intakes).
- **Earplugs alone** — useful for passengers; usually inadequate for sustained cockpit duty.
- **Cumulative exposure** — even short bursts of 130+ dB (gunfire, jet blast) can cause permanent damage. Each pilot's hearing is a non-renewable career asset.

§ 42

The Ear and Balance • Orientation

DGCA-QUOTED DEFINITION

"Orientation" refers to a human being's ability to maintain equilibrium and to interpret the body's position in space. The ear also provides us with our sense of balance.

DGCA-QUOTED — VISION IS PRIMARY

The primary and most reliable sense of spatial orientation is EYESIGHT.

The balance sensors situated in the ear provide us with a **SECONDARY** system.

WHY THIS HIERARCHY MATTERS

This is the single most important fact in spatial-disorientation training. The eyes are primary; the ear's balance organ is secondary. When the two disagree — as happens in IMC (Instrument Meteorological Conditions) where the eyes lose external reference — **the pilot must trust the instruments (which calibrate to true vertical), not the inner ear (which lies)**. This is the foundational principle of IFR (Instrument Flight Rules).

§ 43

THE BALANCE MECHANISM

43.1 Proprioception

DGCA-QUOTED DEFINITION

Proprioception: is the **awareness of the body in space**. It is the use of **joint position sense and joint motion sense** to respond to stresses placed upon the body by alteration of posture and movement.

43.2 The Vestibular Apparatus — Otoliths & Semi-Circular Canals

DGCA-QUOTED — MEMORISE THE COMPONENTS & FUNCTIONS

The **Vestibular apparatus (Otoliths + Semi-circular canals)** helps maintain spatial orientation.

- The **Otoliths** detect **LINEAR ACCELERATION**.
- The **Semi-Circular Canals** detect **ANGULAR ACCELERATION**.

OTOLITHS — linear acceleration

The otoliths are tiny **calcium-carbonate crystals embedded in a gelatinous membrane** sitting on top of hair cells in the utricle and saccule.

- **Sense linear acceleration:** forward/back (takeoff, braking), up/down (turbulence, climb/dive)
- Also sense **gravity at rest** (which way is "down")
- Can be tricked by sustained acceleration → "**somatogravic illusion**" (Part 9)

SEMI-CIRCULAR CANALS — angular acceleration

Three fluid-filled loops at right angles to each other (one per axis: roll, pitch, yaw). Each ends in an **ampulla** containing a cupula with hair cells.

- **Sense angular acceleration:** turning, pitching, rolling
- Only respond to **change** in rotation, not steady rotation
- Can be tricked by sustained turns → "**the leans**" / spiral dive illusion (Part 9)

43.3 The Three Orientation Factors — DGCA's "Big Three"

DGCA-QUOTED — THE THREE FACTORS

Human beings maintain spatial orientation using a combination of three factors:

1. **The sense of vision.**
2. **The Vestibular Apparatus.**
3. **The Somatosensory system** ("seat of the pants" feeling) / **G-Force.**

DGCA-QUOTED — RELIABILITY RANKING (MEMORISE VERBATIM)

- The most reliable sense is the **SENSE OF VISION**.
- Our **vestibular apparatus** can detect accelerations but cannot determine what position we are in if no acceleration is present.
- The **somatosensory system** is **NOT RELIABLE AT ALL**.
- Neither is the ear's balancing mechanism sufficiently reliable for a pilot to maintain spatial orientation using this sense alone.

THE VESTIBULAR SYSTEM

THREE SEMICIRCULAR CANALS — sense rotation (pitch, roll, yaw)

OTOLITH ORGANS
— utricle & saccule
— sense linear acceleration & gravity

COCHLEA
— hearing

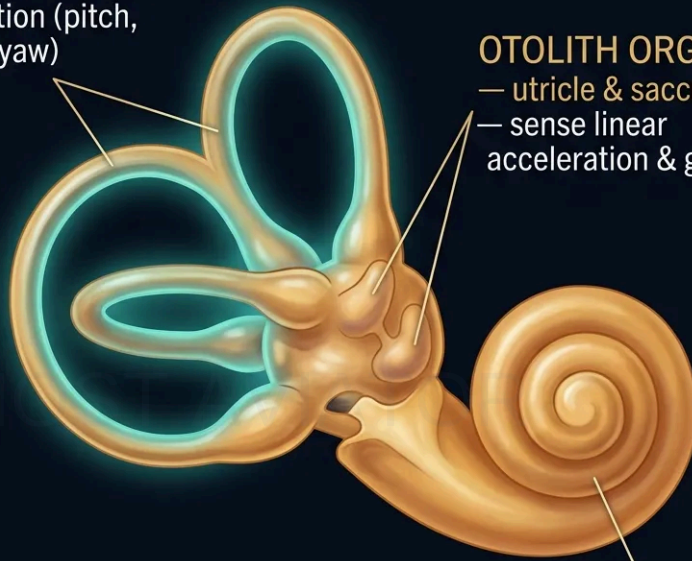


Figure 13.3 — The balance mechanism: the three semicircular canals and otolith organs sense rotation and acceleration.

43.4 How Angular Acceleration is Sensed — DGCA-quoted

THE FLUID-FLOW MECHANISM

- Both the Otoliths Organs and the Semi-Circular Canals send signals to our brain by means of impulses arising from the body being subjected to accelerations.
- Fluid flow occurs when the body is subject to angular acceleration.
- The flow takes place in the **OPPOSITE** direction to the acceleration, moving **sensory hairs** which send signals to the brain that the body is in motion.

THE CRUCIAL FAILURE MODE — DGCA-QUOTED

There is **NO FLUID FLOW** when the body is at rest or if linear or turning movement is taking place at a **STEADY SPEED**. In these situations, the vestibular apparatus alone **CANNOT DETECT MOTION**.

Only the eyes and instruments tell a pilot that he is in a steady turn.

WHY THIS IS THE FOUNDATION OF "THE LEANS"

In a steady-rate turn, the canal fluid catches up with the canal walls and stops flowing. The sensory hairs return to centre — the brain thinks **"no turn is taking place"**. If the pilot then rolls out, the fluid *now* flows (in the opposite sense to the roll-out) → the brain interprets this as *a turn in the opposite direction*. The pilot, feeling that "wing-low" sensation, tends to re-roll back into the original turn = **graveyard spiral**. The cure: trust the attitude indicator, not the inner ear. (Detailed Part 9 — illusions.)

✦ END OF CHAPTER 13 ✦

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