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HUMAN PERFORMANCE AND LIMITATIONS

CHAPTER 10 – HEARING

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HEARING

10.1 The Hearing System

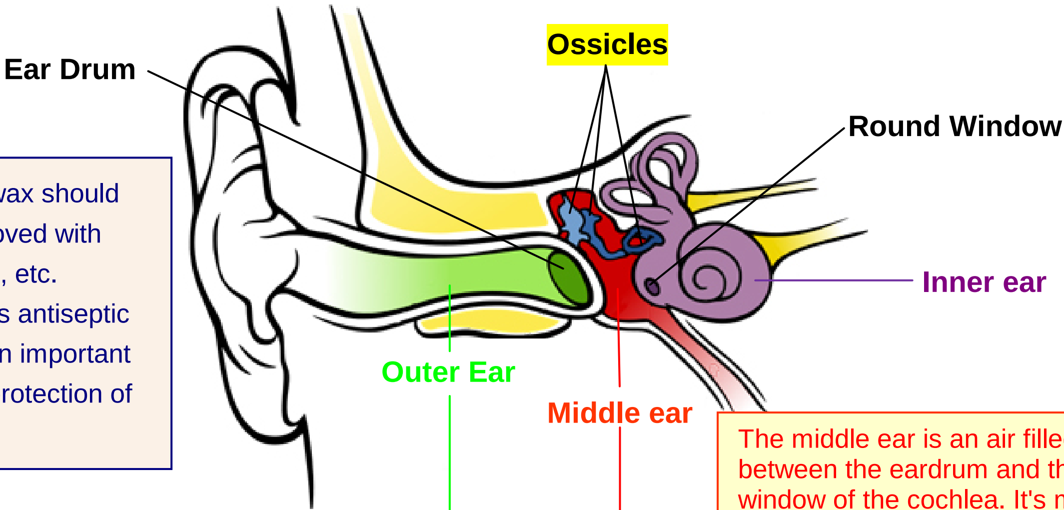
10.1.1 Introduction

When a pin drops, a voice box vibrates or a jet aircraft zooms across the sky, it sends out ripples of sounds, rather like a stone thrown into a pond. The ripples are called sound waves. You cannot see sound waves but your ears detect them and your brain translates them into sounds.

Hearing provides more information about the world around you than any other sense, apart from sight.

10.1.2 Anatomy

The ear is divided into three sections, the outer, middle and inner ear.



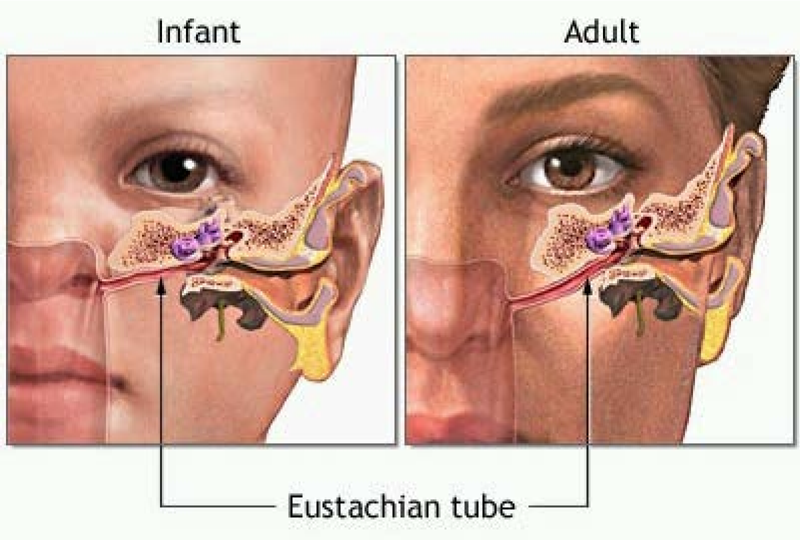
Note: Earwax should not be removed with cotton buds, etc. because it is antiseptic and plays an important role in the protection of the ear.

The outer ear consists of the earflap (pinna), the flap of skin and gristle at the side of your head, and the ear canal. In-built defences, earwax and filtering hairs, line the ear canal to keep out harmful substances like dust and small insects. The ear canal leads to the middle ear and ends up at the ear drum.

The middle ear is an air filled section between the eardrum and the oval window of the cochlea. It's made up of the eardrum, a thin, taut layer of skin and muscle, three small bones called the ossicles and another layer of skin, the oval window.

Note: The smallest bones in the human body are the three ossicles of the middle ear. They are named for their shape: the hammer (malleus), anvil (incus) and stirrup (stapes). If noise is exceptionally loud, two tiny muscles attached to the bones automatically damp down vibrations to prevent them from damaging hearing receptors. The ossicles are the only bones to be fully formed when you are born.

The **Eustachian tube** links the middle ear with the nose. It equalizes air pressure on both sides of the eardrum; at high altitudes you can feel this when your ears 'pop', so it can vibrate freely.



Read once

Note: A blocked Eustachian tube could result in barotrauma during flight. The Eustachian tube regulates the pressure in the middle ear by releasing air from the middle ear during ascent, and by allowing air into the middle ear during descent.

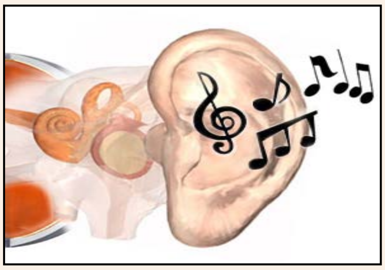
When the Eustachian tube becomes blocked, fluid and phlegm building up inside the middle ear can cause middle ear infection. The pressure differential between the external and middle ear cannot be regulated by the Eustachian tube when it is blocked, causing pain and barotrauma.

Barotrauma is defined as the tissue damage, in aircrew normally the eardrum that tears or bursts, resulting from expansion or contraction of enclosed gas spaces (for instance in the middle ear if the Eustachian tube is blocked) that occurs during a level change with a subsequent change in the outside air pressure.

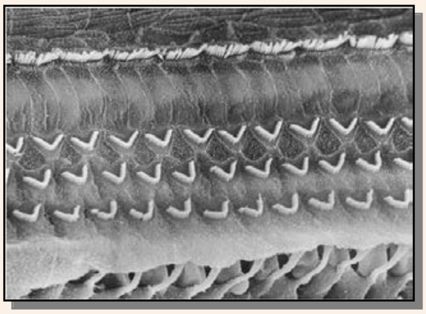
The inner ear contains three important components for pilots:

- The **cochlea**, which converts the mechanical vibrations arriving via the ossicles into nerve signals that are transferred to the brain to be interpreted as sounds.
- The **vestibular apparatus** consists of (a) **the semicircular canals** and (b) **the otolith organ.**
- **Semicircular canals,** comprised of three fluid-filled canals, are arranged in very much the same axes as the roll, pitch and yaw axes of an aircraft and measure **angular acceleration/deceleration** (or the initial change) in these axes. (It is important to note that the **canals do NOT measure angular velocity, only angular acceleration/deceleration.** This is an important element in the understanding of the information provided to the pilot's brain from this part of the body.)
- Each of the three canals has a group of small, fine hairs at its base, standing upright in the fluid. This chamber is knows as the **cupula.** As our body moves in any of the three axes, the inertia in the movement of the fluid within the canal is sensed by the fine hairs. The resulting nerve signals are transferred to the brain to be interpreted as movement. (See more in Section 8)
- Eventually, the fluid in the canals will 'catch up' with the movement of the body and the hairs will no longer sense any movement, even though our aircraft is in, say, a constant turn.
- **Otoliths.** This organ works in a similar manner to the semi-circular canals; it also contains sensitive hairs and fluid. There are two components: the **utricle** which lies horizontally and the **saccule** which is oriented vertically. Horizontal and vertical **acceleration** (not velocity) are sensed respectively by these organs, with information being passed to the brain for interpretation as **linear accelerations**.

10.1.3 Hearing



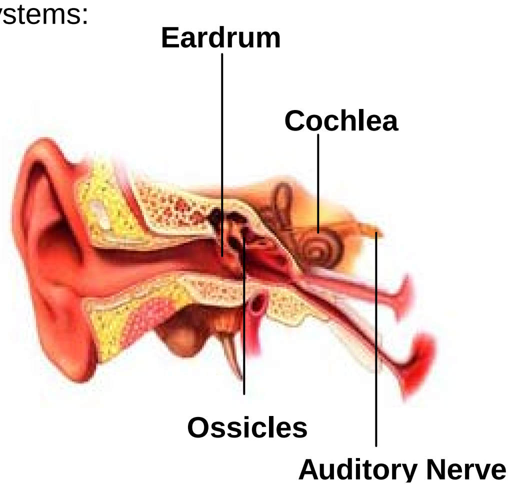
Your earflaps are shaped like the flared end of a trumpet to collect sound waves travelling through the air. These waves flow through the ear canal and vibrate your eardrum, which makes the ossicles vibrate. The ossicles increase the force of the vibrations and send them through the oval window.



When the vibrations reach the inner ear, they move fluid and tiny hairs (stereocilia) in the cochlea. The hairs turn the vibrations into the sound signals that are carried along nerves to the brain. Your brain decodes the signals and tells you what you are hearing. It also tells you whether the sound is high or low (pitch) and soft or loud (volume). Pitch depends on the frequency of the sound waves and volume depends on their strength.

10.1.4 Hearing Loss

From the anatomical description of the ear we can deduct that hearing largely depends on the correct functioning of two systems:



- Firstly an intact conductive system, consisting of the eardrum, and the three small bones called the ossicles, to transmit the vibrations.
- Secondly the transducer system, consisting of the cochlea and the auditory nerve that converts these vibrations into sounds.

It is thus obvious that deafness will result from interference with either of these two systems. Any interference with the conductive hearing mechanism will lead to a form of deafness known as "conductive deafness".

10.1.4.1 Conductive Loss

The conductive system concerns the outer and middle ear, the components of which are the outer canal, ear drum and the ossicles. Anything that prevents sound from freely reaching the eardrum, or vibrations being freely conducted via the ossicles to the cochlea will result in some hearing loss. Reasons for conductive loss in these areas may include the following:

- Congenital abnormalities, e.g. deformation of the ear canal
- Wax that can build up and partially or completely block the canal
- Infections in the canal can cause swelling, which may partially or completely block the canal
- Bony outgrowths from the skull can protrude into and obstruct the ear canal
- Infection of the middle ear, perhaps from a head cold
- Perforation of the ear drum may occur as a result of very loud sounds or chronic infections of the middle ear. The size and position of the perforation determines the extent of the hearing loss.
- Allergies can cause swelling and inflammation of the eardrum
- Disorders, i.e. thickening and fusion of the ossicles, will cause poor transmission of sound. This can occur through aninherited disorder and with age.

Grommets inserted in the inner ear

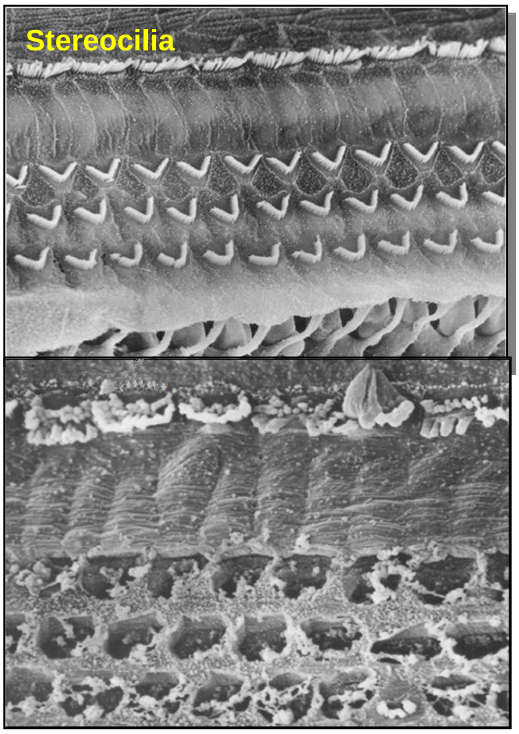
This is to help keep the pressure in the middle ear equal to atmospheric pressure in order to prevent the eardrum from tearing or deforming.

In many cases, conductive loss is reversible; colds and flu pass; allergies can be controlled; surgery can repair a perforated eardrum, remove growths etc. The important aspect for pilots is to be aware of the problem, to treat it and not aggravate it, as the problem may become permanent.

10.1.4.2 Non-conductive Hearing Loss

This type of hearing loss is usually associated with the inner ear and is mostly non-reversible. It can be summarised as follows:

- A malformation due to infection, use of harmful drugs or vitamin deficiency, especially during pregnancy of the patient's mother.
- Noise induced hearing loss.



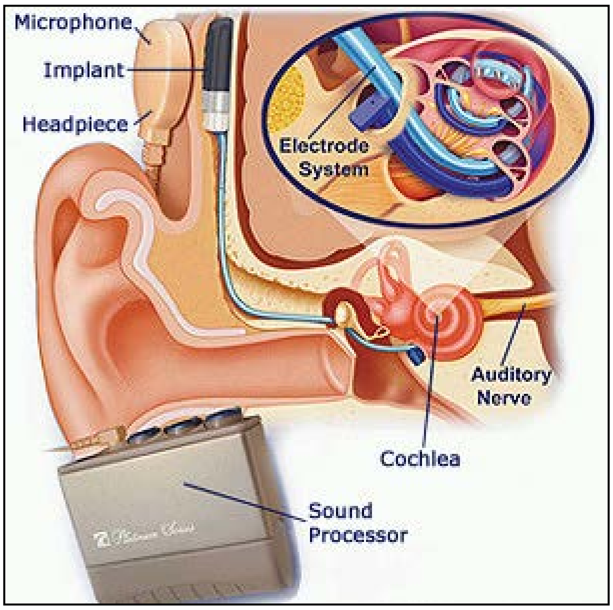
Example of damaged **stereocilia** due to noise

The result of this is **Noise Induced Hearing Loss** (NIHL) and, although this may be temporary at first, excessive exposure will lead to permanent damage and hearing loss.

- Jaundice or anoxia (lack of oxygen) during or just after birth.
- Untreated middle ear infection.
- **Age:** After the mid-twenties there is a gradual hearing loss, **affecting firstly the higher frequencies** (by about 5% by age 60 and 10% by age 70) and later, the lower frequencies. This can be further aggravated by smoking, alcohol, chronic infections and vascular problems. This is called **Presbycusis.**

As with noise exposure, the results of ageing are loss of the high tones first. Add to this a level of deafness already caused by noise exposure and this may be serious for a pilot who, as he/she reaches middle age, has to undergo regular hearing tests.

Cochlear implants may assist with a defective sound-receiving system in the inner ear.



Much more serious to pilots, is a defect in the sound-receiving system, the cochlea, as this is usually irreversible.

10.1.4.3 Noise Induced Hearing Loss (NIHL)

Exposure to noise of sufficiently high intensity may result in temporary or permanent damage to the cochlea and result in loss of hearing. The sound intensity threshold below which an individual cannot hear will be shifted upwards (called **Permanent Threshold Shift). Higher frequencies are lost first**. The hearing loss may occur in two different ways:

- **From a Constant Exposure to a Hazardous Noise Environment**

  Depending on the duration and intensity of the noise, damage may be either temporary or permanent. Temporary damage may occur from a short-term exposure to noise and the loss may be for a few hours or days. Initially, temporary hearing loss may be accompanied by a high pitched ringing sound, a feeling of fullness within the ear and muffled hearing.

  Prolonged exposure to sufficiently high levels of noise will result in permanent hearing loss.

- **A Sudden Explosive Noise**

  Again, damage may be temporary or permanent, depending on the intensity of the noise. Temporary damage may be accompanied by similar symptoms to those mentioned above. Permanent damage may also result, with possibly a ruptured ear drum, damage to the delicate ossicles and ultimately irreversible damage to the very sensitive membrane in the cochlea.

10.1.5 Noise Levels

The volume of sound is measured in decibels (dB). Sounds below 0dB cannot be heard. Frequent or prolonged noise above 85dB can damage your ears; initially temporary, lasting a few hours or days but eventually it may become permanent if the noise insult is prolonged.

The damage risk is also not simply related to the length of the exposure but it is also affected by the noise energy that is encountered, e.g. 90 dB for 8 hours will be as damaging as 103 dB for 30 minutes or 116 dB for a minute!

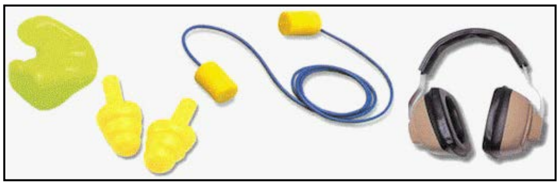
10.1.5.1 Decibel Chart

140dB	A gun shot or fire cracker **CAUSES SEVERE PAIN**	
130dB	Jet aircraft taking off	
120dB	Piston Engine a few feet away. This level causes discomfort	
110 dB	Rock band	
90 dB	Noisy motorbike	

85 dB	Busy city\traffic **CAUSES DAMAGE EVENTUALLY**	
80 dB	Train This is also the level at which protection is recommended	
70 dB	Telephone ringing	
60 dB	Crowded Street	
45 dB	Conversation in a busy office	
30 db	Conversation at home	
20 dB	Whispering	
10 dB	Leaves rustling	
0 dB	Hearing threshold	

Typical cockpit noise levels (in dB) in light aircraft:			
Aircraft Type	Take-Off	Cruise	Landing
Aerocommander 680	102	92	83
Beechcraft A36	97	86	75
Tobago TB10	94	89	75
Cessna 188 Agtruck	N/A	106	N/A
Piper PA25 Pawnee	103	102	N/A
Bell 206	91	92	89

The effects of gunfire, whether shotgun or a rifle, motor racing, music in clubs, as well as a personal hi-fi system at high volume, can all be damaging and proper hearing protection should be used if you want to retain good hearing.



It is common for pilots in light aircraft to wear noise-attenuating headphones. As well as allowing a clear reception of radio transmissions, the headsets provide a protection against engine noise. All pilots will have mandatory regular audiograms (hearing tests) as part of their medical examination requirements.

If you have to shout to be heard over a distance of 0.5 of a metre, then you should be wearing hearing protection!

10.2 Maintaining Healthy Hearing

10.2.1 Introduction

There are many diseases and health related issues, which affect all of us at some point in our lives. Many health issues have a specific effect on aviation personnel retaining their medical certification.

Many health problems are self-inflicted and therefore aviation personnel are encouraged to adopt a lifestyle and other behavioural patterns that minimise health risks.

Maintaining a healthy body is essential to a long flying career, with one of the most important aspects being healthy hearing.

10.2.2 Causes of Loss of Hearing

The causes of hearing loss usually fall under one of the following:

<u>Acute</u>

This includes physical damage such as is caused by blasts or penetrating injuries. Acute causes cannot usually be prevented, as they occur suddenly in most cases.

<u>Chronic</u>

This includes ear diseases, noise damage and ageing. The most common cause for hearing loss, namely noise induced hearing loss, is preventable and as such deserves the most attention.

10.2.3 Threshold Shift

10.2.3.1 Temporary Threshold Shift

Temporary Threshold Shift (TTS) is the temporary (i.e. less than 48 hours) decrease in hearing following exposure to loud noise, e.g. clubs, standing close to an aircraft engine, etc.

The ear has certain "defence mechanisms" to protect it against noise, including contraction of two muscles which damp the movement of the eardrum. Following short-term exposure to loud noise, the defence mechanisms are largely responsible for TTS and provided the intensity is below the level, which produces permanent damage, TTS resolves completely within 48 hours (provided there is no re-exposure).

> **Note:** Noise can be described as any unwanted or annoying sound. Categorising a sound as noise can be very subjective (e.g. loud rock music to a teenager is enjoyable, while to

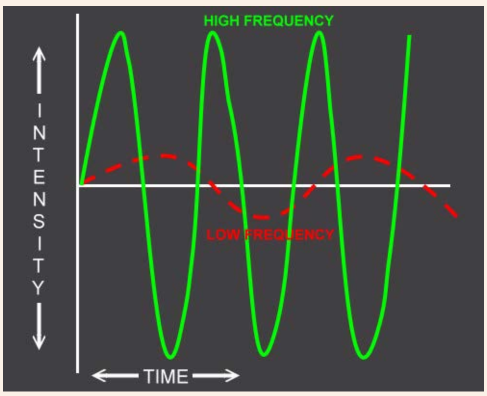
10.2.3.2 Permanent Threshold Shift

Permanent threshold shift is the term used to describe noise damage, which persists for more than 48 hours after noise exposure.

Permanent hearing loss occurs with frequent or chronic noise exposure. Factors, which influence the extent of the hearing loss, are:

Frequency of the Sound

The frequency spectrum of the noise (pitch) is measured in Hertz (Hz). While some frequencies of noise are more damaging than others, the frequency responsible for most hearing loss is around the 4000 Hz range, due to the anatomy of the ear, and the way the sound waves are conducted in the inner ear. Normal conversation takes place around 3000 Hz.



Frequencies

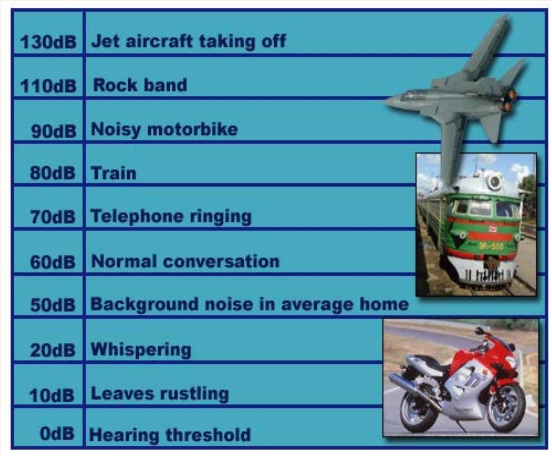
Sounds audible to the human ear (20 - 20 000Hz)

Highest Sensitivity (500 - 4000Hz)

Normal Conversation (500 - 3000Hz)

Intensity of the Sound

The intensity (loudness) represents the correlation between the sound pressure level, and the loudness of the sound. The intensity of sound pressure levels is measured in decibels (dB). The range of the normal human ear is between -10 dB and +25 dB. A pilot who cannot hear a sound until it is higher than +25 dB, may already be experiencing hearing loss. The human ear generally does not hear sounds below -10 dB.



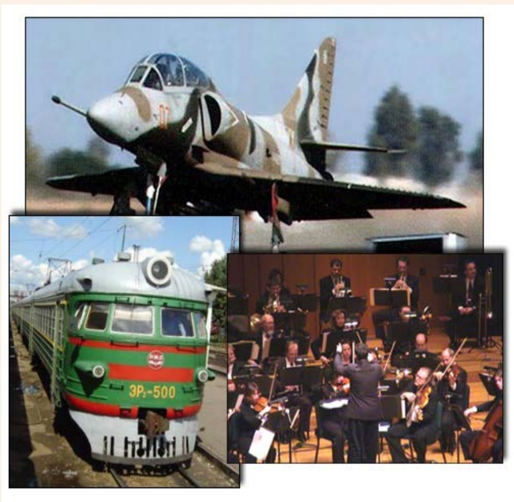
Hearing Loss Limits

At 500 Hz: No more than 25dB in both ears
At 1 000 Hz: No more than 25dB in both ears
At 2 000 Hz: No more than 25dB in both ears
At 3 000 Hz: No more than 40dB in both ears.

Duration of Exposure to the Sound

The level of the sound is not the only determinant of hearing damage; the duration of the exposure to the sound is also a critical factor. This means that short term exposure to high level (high intensity) sounds can have the same consequences as longer exposure times to lower intensity sounds.

American Occupational Safety and Health Administration
Guidelines to Sound Exposure Limits



Noise Level	Exposure limit (hours per day)
90dB	8
92dB	6
95dB	4
97dB	3
100dB	2
102dB	1.5
105dB	1
110dB	0.5
115dB	0.25

10.2.4 Methods of Ear Protection

10.2.4.1 Earmuffs

Earmuffs provide good noise reduction and dampen the conductivity of the mastoid. They are good for ground crew, but preclude radio communications for pilots.

10.2.4.2 Earplugs

Earplugs reduce noise level by about 25dB on average, but do nothing to reduce the noise conducted to the ear by the mastoid and other skull bones. It can best be regarded as an adjunctive measure. Each brand name has its own protection capability that is printed on the packaging.

10.2.4.3 Headsets

Headsets are essentially earmuffs, with built in communication facilities. Some designs give very little noise reduction, while others have active noise attenuation. Active noise attenuation is a device in the headset, which analyses incoming noise, and to a large degree neutralises it by means of sound wave negative interference. Headsets reduce noise level by about 40dB on average