CHAPTER 14 - AVIATION OTORHINOLARYNGOLOGY

1 INTRODUCTION

Oto-rhino-laryngology is an important medical specialty in aviation medicine. It concerns organs involved in verbal communication and physical orientation. Further, the middle ears and paranasal sinuses are semi-closed cavities sensitive to pressure variations. Verbal communication between air traffic controllers and pilots is essential for flight safety. Disorientation is one of the important causes of major accidents and barotraumas of the middle ears and sinuses can cause considerable discomfort and distraction during aircraft descent and approach.

2 KEY TO THE EAR-NOSE-THROAT EXAMINATION PROCEDURES

CLASS 1	**EXAMINATION**			**MANUAL REFERENCE**
	A	**B**	**C**	
[Pure tone audiometry (subsequently 5 yearly, after 40th birthday 2 yearly)**]**	☞	–	–-	
Impedance tympanometry **[**or equivalent**]** including valsalva manoeuvre	☞	–	–	3.5
Pure tone audiometry	☞	☞	–	4.3
Anterior rhinoscopy	☞	☞	☞	6.3
Spoken voice test	☞	☞	☞	4.6
On indication tests may include				
[Pneumatic otoscopy**]**				**[**3.3**]**
Speech audiometry				
Eog spontaneous & positional nystagmus				
Differential caloric test Or vestibular autorotation				
Posterior rhinoscopy				
Mirror or				
Fibre laryngoscopy				

A Comprehensive initial examination **[**at initial examination by AMC or**]** a specialist in aviation otorhinolaryngology acceptable to the AMS

B Comprehensive renewal examination **[**on clinical indication**]** by **[**AME or**]** a specialist in aviation otorhinolaryngology acceptable to the AMS

C Routine renewal examination (JAR–FCL 3.230 and 3.235 refer)

CLASS 2	EXAMINATION		MANUAL REFERENCE
	A	B	
Spoken voice test	☞	☞	4.6
Pure tone audiometry [(When an instrument rating is to be added, subsequently 5 yearly, after 40th birthday 2 yearly)]*	☞	☞	
On indication tests may include			
Pneumatic otoscopy			[3.3]
Impedance tympanometry Including valsalva manoeuvre			
Speech audiometry			
Barany chair test			

A At first issuance by an authorised medical examiner
B Subsequent renewal examinations

3 THE EAR

3.1 General

Anatomically, the ear is divided into three parts, the external ear, the middle ear and the inner ear (the inner ear will be discussed in the hearing and vestibular function sections).

3.2 The external ear

The external ear includes the pinna, the external ear canal and the tympanic membrane.

a *The [external] ear canal*

In the adult, the external ear canal is an approximately [3,5] cm long and 1 cm wide tube, usually slightly curved forwards-downwards. The inner [1,5] cm of the canal is surrounded by bone and extremely sensitive to touch. Ear wax, produced by modified salivary glands in the inner part of the canal, is extruded as a tube and tends to accumulate if this extrusion is impeded.

Usually, diseases of the external ear canal will not disqualify a pilot from his duties. Nevertheless, it is important that the ear canal permits the inspection of the tympanic membrane. If meatal exostotic growths or other abnormalities of the ear canal interfere with a thorough examination of the tympanic membrane during otoscopy (see below), the applicant can be considered [unfit during] a physical examination, even though he might be physically fit for duty. The decision to reject a pilot candidate for that reason must be made with caution and presupposes a careful examination including an oto-microscopy performed by a specialist. The physician should be able to inspect at least 2/3 of the surface of the tympanic membrane to be able to state that no gross pathology of the tympanic membrane is present. In cases of a history of recurrent middle ear infections, insertions of grommets into the ear drum, or the presence of even a slight conductive hearing loss indicating the risk of an atrophic degeneration or perforation of the tympanic membrane, a full examination of the tympanic membrane must be performed. The physician's possibility to assess, whether a pilot is fit for duty, should not under these conditions be limited by abnormalities of the canal.

b *The tympanic membrane*

The normal tympanic membrane is a cone-shaped, semi-transparent, pearly grey structure at the end of the ear canal. It is orientated like the cheek, not exactly in the sagittal plane, but facing slightly anteriorly and inferiorly. The handle of the *malleus* is embedded in the membrane with its lower end close to the centre of the membrane, indicating the deepest point of the membrane, the *umbo.* From the upper end of the handle, the short process of the malleus protrudes into the canal. The anterior and posterior hammer folds, projecting almost horizontally from the short process toward the border of the membrane, divide the tympanic membrane in its upper flaccid part (*pars flaccida*) and the much larger lower tense part (*pars tensa*). Under illumination during inspection, a cone of light appears in the antero-inferior quadrant where the light reflects from the part of the tympanic membrane perpendicular to the light beam.

The tympanic membrane separates the ear canal from the middle ear and is essential for a normal sound transmission.

Atrophic areas of the membrane will rupture when they are exposed to even small differential pressures. They are characterized by their lack of elasticity due to the disappearance of the normal *lamina propria* of the tympanic membrane, which results in a flaccid and thin appearance at normal middle ear pressures. At negative middle ear pressures, atrophic areas can adhere to the promontory of the medial wall of the tympanic cavity or can look like a thin tapestry over the long process of the incus and the stapes. In its uttermost consequence, an atrophy of the ear drum is associated with an *atelectasis* of the middle ear. In this case, the medial wall of the middle ear is entirely lined by the adherent atrophic tympanic membrane.

Owing to their fragility, atrophic areas, seen from an aviation medical point of view, should be treated as if they were true perforations. Historically, they may represent insufficiently healed perforations, even though more likely they represent parts of the membrane disintegrated by a sustained negative pressure.

Perforations of the *pars tensa* of the membrane are grouped as either *marginal* or *central.* Both marginal perforations and perforations of the *pars flaccida* indicate that a *cholesteatoma* may be present in the middle ear. The mechanism behind the development of cholesteatomas is still under debate. From a marginal perforation, keratinized epithelium is able to migrate into the tympanic cavity or the cholesteatoma may originate from a pocket of the tympanic membrane sucked into the middle ear by a negative pressure. During their growth, cholesteatomas destroy the surrounding bony tissue. They should be recognised as early as possible. Central perforations are less dangerous. Usually, they result in recurrent or chronical mucosal infections. In all types of perforations, conductive hearing impairments are to be expected.

Fibrosis of the tympanic membrane is usually associated with a history of tubo-tympanic dysfunction. It may indicate the presence of a similar pathology in the middle ear, *typanosclerosis* (see below). *Per se*, fibrotic plaques or scar tissue in the tympanic membrane are insignificant for the function of the tympanic membrane, nevertheless, their presence should sharpen the attention of the examiner toward the possible presence of atrophic areas or perforations.

3.3 Inspection of the ear = otoscopy

a *Screening otoscopy*

Otoscopy is usually performed by means of an otoscope. Modern otoscopes use a fibre light source and are equipped with a magnifying glass, providing excellent illumination and magnification of the visual field. The removal of small amounts of ear wax or small foreign bodies from the ear canal is very often impossible through the otoscope. For that purpose, an old-fashioned ear speculum, a suitable light source and a frontal mirror is much to be preferred.

Irrigation of the ear canal in order to remove ear wax should be performed only in examinees without any history of middle ear disease in order to avoid iatrogenic perforations of the tympanic membrane. The irrigation water must be held at body temperature in order to avoid caloric vestibular reactions. The water beam should not be directed toward the ear drum and the water must be allowed to wash the ear canal freely. An occlusion of the canal by the tip of the syringe will result in an iatrogenic traumatic perforation of the membrane.

Otoscopy should be performed by carefully inserting the tip of the otoscope into the ear canal with simultaneous inspection of the canal, following the canal lumen. In order to straighten the cartilaginous part of the canal, the pinna is pulled upwards-backwards by the free hand. It is essential to avoid touching the bony part of the canal with the tip of the speculum. The landmarks of the ear drum (i.e. *the handle of the malleus*, the *short process of the malleus* and the *cone of light)* are identified and the two parts of the membrane are carefully inspected.

With negative middle ear pressures, the tympanic membrane retracts into the tympanic cavity. Because of the oblique position of the tympanic membrane in relation to the view axis, the *umbo* appears to have moved upwards-backwards, and the handle of the malleus appears shortened and rotated in a more horizontal position.

In order to obtain a three-dimensional impression of the ear drum and in order to reveal atrophic and sclerotic areas, a *pneumatic otoscopy* may be indicated. For that purpose, the otoscope should be mounted with a balloon and a speculum capable of occluding the lumen of the cartilaginous part of the canal. The pressure of the air, trapped in this air-tight system, can be varied by gently squeezing the balloon. This results in discrete movements of the tympanic membrane, which can be observed through the otoscope. If the membrane does not move, it may be for one of the following five reasons:

i) the system is not air tight,

ii) there is a perforation,

iii) there is a negative pressure in the middle ear,

iv) the middle ear is fluid filled or

v) the middle ear is atelectatic.

Characteristically, an atrophic area of the membrane, owing to its lack of elasticity, is only capable of presenting itself in two positions by pneumatic otoscopy: intruded into the tympanic cavity or extruded into the canal, depending on the pressure applied to the ear canal. Intermediate positions are not seen.

In the case of a partially fluid filled middle ear space, the meniscus indicating the air-fluid transition, will simulate a small hair on the membrane. By pneumatic otoscopy or by rotation of the head, the meniscus will move.

b *Oto-microscopy*

At any suspicion of tympanic membrane pathology, most otologists will perform an examination with an operation microscope which allows description of pathology not revealed by otoscopy.(*Impedance tympanometry:* See below.)

3.4 The middle ear and the Eustachian tube

Functionally, the middle ear and the *Eustachian tube* are an entity. The sound transmission from the tympanic membrane to the inner ear depends on the normal movements of the membrane-ossicular system, which depends on an equivalence between the pressures of the middle ear and the ear canal.

The tympanic cavity communicates with the naso-pharynx by way of the Eustachian tube, which is an approximately 4 cm long tube lined with ciliary epithelium, capable of transporting mucus from the middle ear into the naso-pharyngeal space. The lateral third of the tube is rigid and surrounded by bone. The medial two thirds are surrounded by the V-shaped tubal cartilage. Normally, the medial part is collapsed. By swallowing, yawning or chewing, the *tensor veli palati* and *sapingopharyngea* muscles open the tube, allowing an equalisation of the middle ear pressure in relation to the naso-pharyngeal air pressure. The muscles are innervated by the *trigeminal* nerve. A voluntary activation of the trigeminal muscles can be achieved by a voluntary, isometric contraction of the masticatory muscles. Very often this act results in an audible click. This click does not indicate an opening of the tube, but is the result of an activation of the *tensor tympani* muscle, which is also trigeminally innervated.

The Eustachian tube behaves as a one-way-valve allowing air to escape from the middle ear if the middle ear pressure for some reason exceeds the nasopharyngeal pressure by more than approximately 40 hPa in a normal person. (Originally in tympanometry, the unit of mm H_20 was used. It has been replaced by the corresponding SI-unit of dekaPascal (daPa). 10 daPa = 1 hPa = 1 mbar). This phenomenon is responsible for the 'popping' sensation sometimes felt in the naso-pharynx during aircraft ascent.

If, for some reason, the middle ear pressure is not equalised with the external pressure for some time, a negative pressure will build up in the middle ear. This is caused partly by the resorption of the gasses from the middle ear space through the mucosa to the blood stream, but active pressure balancing processes are involved too. The procedure will result in a middle ear pressure at approximately –200 daPa. Under normal middle ear pressure conditions, a delicate balance seems to exist between the intracapillary blood pressure and the middle ear air space pressure. As soon as a negative pressure of this degree is established in the tympanic cavity, a swelling of the mucosa will appear followed by a transudation of plasma from the blood stream to the middle ear. When this condition has existed for more than a few days, the transudate will change into a more and more viscous fluid because of the formation of mucous glands in the middle ear mucosa. This condition, the *secretory otitis media*, is the simple consequence of tubal dysfunction.

Another result of the development of negative middle ear pressures is that the pressure equalisation between the naso-pharynx and the middle ear becomes more difficult at increasing differential pressures. At approximately 120 hPa differential pressure, the Eustachian tube *locks and blocks*. If a person suffers from a common cold, this critical value is lower due to the swelling of the naso-pharyngeal mucosa. If this '*locked-and-blocked' threshold* approaches zero, normal swallowing, yawning or chewing will not cause a pressure equalisation and the tubal dysfunction will, eventually, result in a secretory otitis media.

3.5 Examination of the tubal function

For screening purposes the tubal function can be judged by making the examinee perform a ***Valsalva's manoeuvre***. With his nostril closed by digital compression, the examinee performs a forceful expiration against his closed nostrils. Very often the examiner is able to see the tympanic membrane change its position during or after the manoeuvre. If this effect is not visible, it does not exclude that the manoeuvre has been successful.

Toynbee's manoeuvre is performed by letting the examinee swallow while he closes his nostrils and mouth. Very often, the ear drum will become displaced inwards due to the suction effect on the Eustachian tube. A negative result of this test does not always indicate a tubal dysfunction. If these two tests are implemented in the physical examination, one has to accept that a negative result is not interpretable. *A pragmatic solution of this problem is to accept all Class 1 applicants with no history of chronic or recurrent tubo-tympanic disease if they present themselves with a* *normal impedance tympanometry (see below).* Class 2 applicants do not require impedance tympanometry to be undertaken.

***Impedance tympanometry*:** During the last decades, this method has become an international standard in the routine specialist otologic examination. It is based on the fact that acoustic energy, not transmitted by the sound transmission system, is reflected from the tympanic membrane. By measuring of the relation between an acoustic energy presented in the ear canal and that reflected from the ear drum, the acoustic impedance of the sound transmission system can be estimated. If the pressures in the ear canal and the middle ear are identical, the acoustic impedance will be at a minimum. With a systematic variation of the ear canal pressure (e.g., from +200 to –300 daPa) accompanied by a simultaneous impedance measurement, a curve can be produced, indicating the actual middle ear pressure at the point of the impedance minimum. Furthermore, an estimate of the compliance of the sound transmission system can be made, based on the amplitude of the impedance variation caused by a standard ear canal pressure variation.

An objective Valsalva's test can be performed by means of impedance tympanometry. Applicants not controlling or understanding the Valsalva technique, when explained to them may still have a normal tubal function. The final judgement of the tubal function should not be based on the momentary performance by the Valsalva's test alone, but on evidence of chronic or recurrent tubal dysfunction obtained by a positive history. Impedance tympanometry or pneumatic otoscopy may be indicated.

High sound pressures (above 65–75 dB) result in reflex contractions of the *stapedial muscles*. This contraction raises the acoustic impedance, which can be measured by means of an impedance-meter. The impedance tympanometry should be accompanied by a stapedial reflex test to confirm the presence of a normal ossicular chain and a normal stapedial reflex pathway.

3.6 Guidance regarding assessment

a **[***Applicants***]** *at initial examination*

A history of recurrent acute otitis media in childhood should not entail disqualification unless the applicant still has a perforation or atrophic areas of the tympanic membrane. A history of a single grommet insertion or multiple insertions before the age of ten should be considered acceptable, unless the applicant has a chronic perforation of the tympanic membrane, atrophic areas or partial or total atelectasis of the middle ear. If the applicant has no history of chronic or acute middle ear disease after the age of ten, the risk of a recurrence at higher age is negligible.

A history of recent barotitis caused by flying or diving should result in a thorough evaluation of possible medical causes of the event (sino-nasal or naso-pharyngeal disorders) and be judged on this evaluation.

The presence of perforations (independent of their location or aetiology) and the presence of atrophic areas require a careful evaluation.

A history of middle ear surgery for infective middle ear disease should be **[**disqualifying**]**, except for a simple mastoidectomy in childhood and grommet insertions.

b **[***Applicants at revalidation / renewal examinations***]**

During a pilot's career, the risk of middle ear disorders is presumed higher than average owing to exposures to pressure alterations during flight. If a pilot suffers from frequent episodes of barotitis during training or in his early career without an obvious explanation, he will normally understand that he is not suited for this profession and should be advised to withdraw from his flying activities.

Cases of acute barotitis should be treated as soon as possible and **[**- after a period of temporary infitness -**]** the pilot **[**assessed as fit**]** as soon as he is able to demonstrate normal middle ear pressure and normal ability to clear his middle ears by Valsalva's manoeuvre. Acute suppurative middle ear disease should be cured and **[**- after a period of temporary infitness -**]** the pilot **[**assessed as fit**]** as soon as pneumatic otoscopy is normal and he is able to demonstrate normal middle ear pressure at impedance tympanometry and normal ability to clear his middle ears, provided that his hearing is still within the hearing requirement.

3.7 Other middle ear conditions

3.7.1 Petrosal fracture

Applicants **[ ]**with a history of petrosal fracture or with a proven or suspected *perilymphatic fistula* present a problem concerning aeromedical assessment. Owing to a unique structure and bone biology of the otic capsule, fistulae and fractures of the capsule do not heal with bone formation. A thin bony layer surrounding the perilymphatic space does not undergo the usual re-modelling processes of other bone, but remains unmodified from early foetal life. This secures the lifelong stability of the physical dimensions of the membraneous labyrinth (and hence the frequency characteristics of the sensory organs). The insufficient healing process is believed to be the result of this biologic inertness of the otic capsule. If an otic capsule fracture or a perilymphatic fistula is present, sudden deterioration of the hearing and vestibular function could result from sudden pressure gradients in the middle ear. Strictly speaking, the final proof of resistance against pressure gradients in these cases can be made only by exposing the applicant to this physical stress, jeopardising his hearing and vestibular function, which is unethical. This is further complicated by research results showing that a large percentage of patients suffering from post-concussion syndrome actually suffer from a perilymphatic fistula. The final assessment of these cases must be left to a specialist familiar with both the diagnostic problems and the treatment of perilymphatic fistulae and with aviation medicine.

3.7.2 Otosclerosis

Otosclerosis gradually impedes the natural mobility of the stapes footplate resulting in a progressive conductive hearing loss caused by the increased stiffness of the sound transmission system. Usually, the disease is bilateral and develops slowly. If **[**an**]** applicant **[ ]**is suspected of this disease, he should be warned of the high risk of being [assessed] as unfit for duty because of the resulting hearing loss, or in case of surgery because of surgery itself (see below) or because of surgical complications. If surgery is performed in a pilot suffering from otosclerosis, a so-called 'closed-window-technique' must be employed. During surgery, a perilymphatic fistula is created in the stapes footplate; then, a small piston prosthesis replacing the supra-structure of the stapes is attached to the long process of the incus and inserted into the fistula. The closed-window-technique involves a sealing of this fistula by means of a vein or fascia graft. If the fistula is not sealed, the lateral displacement of the piston during a decompression could result in an opening of the fistula which would cause a severe attack of vestibular vertigo and a sudden loss of hearing. In order to ensure healing, pilots who have undergone stapes surgery should not fly for the next three months. Approval following surgery should be based on a non-complicated post-surgical course, the absence of dizziness, spontaneous or positional nystagmus and a satisfactory hearing result.

3.7.3 Post-surgical assessment in general

Except for applicants and certificate holders, who have undergone minor surgery such as simple mastoidectomies or grommet insertions during childhood (see above), the assessment of ear surgery as a cause for exclusion from flight duties must be based on an individual evaluation founded on particulars concerning the underlying pathology, surgical procedures and results and the post-surgical condition of the ear. Emphasis must be put on the risk of opening a potential perilymphatic fistula when the ear is subjected to sudden pressure variations. If the pilot is going to fly pressurised-cabin-airplanes, events resulting from a sudden decompression must be anticipated. If the decompression results in a sudden vigorous spell of vestibular vertigo and a sudden loss of hearing, the pilot instantaneously becomes incapacitated (in a situation where there is an urgent need for his pilot skills). Information concerning the individual case of ear surgery must be evaluated, primarily with this risk in mind. The risk of a fracture of the continuity of a reconstructed ossicular chain caused by sudden change of the middle ear pressure must be considered. Lastly, it is reasonable to evaluate the risk of a rupture of weak areas of the tympanic membrane. At least a three months healing period should be **[**required**]** before approval. In cases involving a potential, but not obvious risk of a perilymphatic leak (stapes surgery, including type III tympanoplasties, and intra-operative observations of an otic capsule weakness) **[**a multi-pilot (Class 1 'OML') or safety pilot (Class 2 'OSL') limitation may be required for two years**]**.

Note: *In all cases of ear canal, tympanic membrane or middle ear disease and in all post-surgical cases, the hearing and vestibular requirements must be fulfilled* **[***for a fit assessment***]***.*

4 HEARING REQUIREMENTS

Definition: *Hearing is the conscious, sub- or pre-conscious perception of any sound.*

4.1 General

A pilot must be able to decipher verbal messages from the ATC. Further, the pilot must be able to perceive sound warning signals from the aircraft. These warning signals can be either an integrated part of the aircraft safety system, such as a stall warning signal, or the result of a mechanical or electrical malfunction of the aircraft.

Physically, sound is defined as progressive longitudinal oscillations in a physical medium, in the present context, air. A sound is characterized by its pitch (or frequency) composition (expressed in Hz **[**Hertz = cycles per second**]**) and its amplitude, which determines the intensity (expressed in dB **[**decibel**]**). The normal ear is capable of perceiving a frequency band from 18 to 20 000 Hz and a 1 012-fold (120 dB) intensity variation. Physically, 0 dB refers to the established perception threshold of a normal human ear at a given frequency.

A pure tone has a sinusoidal waveform. Physically, noise is a random composition of a large spectrum of pure tones, psycho-physically noise can be defined as an unintended, ungraceful or unwanted sound, independent of its frequency composition. Physically, the acoustic environment in a motorised aircraft is characterised by a high noise level, caused mainly by the engines. A person exposed to high sound intensities, such as aircraft noise, will experience a temporary threshold shift (TTS). The duration and magnitude of this threshold shift will depend upon the sound intensity, the exposure duration and an individual sensitivity factor. Frequent exposures to high sound intensities will result in permanent threshold shifts (PTS) – still influenced by noise characteristics and individual factors. Very often, the pilot's exposure to high noise level during his career will result in a significant PTS. The ability of a pilot to perceive, decode and take advantage of an acoustic signal, verbal or non-verbal, depends not only on his hearing abilities, but just as well on his experience with the signal in question. A skilled and experienced pilot is able to screen an ATC-message and consciously only perceive the information he needs. A pilot student, in contrast, listens carefully to each word, considers the true meaning of each word, extracts what he believes he needs to know and tries to memorise the meaning of the message. The two procedures sketched, require different hearing abilities (and strategies).**[ ]**

4.2 Hearing tests

Before interpreting the results of a hearing test or prior to deciding which test should be used, it is important to consider the different dimensions of hearing as a psycho-sensory process involved in different test modalities.

a *Threshold determination tests*

The tests determine the limit between non-perceived and perceived sound signals. Stimuli are pure tones or standard speech signals. Only a very few real life hearing tasks are concerned with sound intensities at hearing threshold levels. Threshold tests provide no safe information about hearing dynamics or discrimination abilities. During the test, the examinee will pay all his attention to hearing and detecting possible sound signals and ignoring all other sensory signals in the environment. Tests are performed in sound proof rooms or using noise-protecting head-sets in order to optimise the signal-to-noise ratio. Circumstances are very far from practical flying hearing requirements. Originally, these methods were designed for diagnostic purposes only and not for the purpose of demonstrating that a person is fit for certain professions.

b *Discrimination tests*

The tests utilise the spoken word. The examinee must master the language used. In speech audiometry, words (or sentences) are standardised from a phonetic point of view and relate to semantically different, unexpected spheres. The tests can be performed in different noise environments; nevertheless, a ‘standardised flight noise environment’ cannot be defined. Audiometric speech discrimination tests are intensity standardised according to threshold estimates in normally hearing subjects. In the clinical tests (the whispered and spoken voice tests), intensity standardisation is crude and examiner dependent. Most conditions however are far from the real life pilot acoustic environment (e.g. ‘say again’ appeals are usually not responded to) and all the attention of the examinee is aimed at the acoustic part of the total sensory environment.

4.3 Pure tone audiometry

Properly calibrated audiometers must be used and the calibration must be checked at regular intervals. The results are recorded in a standard audiogram; the standards requiring that the horizontal octave (frequency doubling) interval measure is identical with the vertical 20 dB interval. The audiometry and the audiogram should cover at least the six octave bands from 250 to 8 000 Hz. In this frequency band, thresholds should be determined at the following frequencies: 250, 500, 1 000, 2 000, 3 000, 4 000 and 8 000 Hz. **[**For aeromedical assessment only the frequencies 500, 1000, 2000 and 3000 Hz are required.**]** The threshold is defined as the lowest intensity at which the tone is heard at least 50% of the times tested. Usually, a 5 dB intensity interval is used; higher intervals are not [acceptable]. It is important to prevent the examinee from observing the examiner operating the tone button. Screening audiometry at 20 or 30 dB(HL) might secure the fulfilment of the hearing requirements, but would jeopardise the diagnostic opportunities of series of audiometries at the required intervals.

If the pure tone threshold difference between the two ears exceeds 50 dB at a given frequency in an air-conduction test (using a head-set), the sound signal presented to the worst ear will be heard in the best ear. To avoid this effect (resulting in a ‘shadow-audiogram’), a 50 dB masking noise must be presented to the contra-lateral ear.

Bone-conduction tests are not required by the requirements. If performed, the examiner must be aware of the sharpened masking demands of this test. The trans-cranial attenuation of a bone-conducted tone is 5–10 dB, making masking (by means of air conducted noise) compulsory to be able to distinguish safely between bone-conduction thresholds of the two ears. The purpose of a bone-conduction test is to establish the nature of a hearing loss. A true conductive hearing loss will present with normal bone-conduction thresholds, whereas a sensory-neural hearing loss will show identical bone- and air-conduction thresholds.

In audiometry, the following notification rules must be regarded. Air-conduction: right ear: O; left ear: X. Masked air-conduction: right ear: • ; left ear: **_** . Bone-conduction without masking: right ear: **[**; left ear:**]**. Masked bone-conduction: right ear: <; left ear: >. If colours are used, **r**ed indicates the **r**ight ear, blue indicates the left ear.

4.4 Speech audiometry

The degree of the development of speech audiometry tests in a certain language depends on both the extent of the language area involved and on the general development of the medical services in that particular area. Since English has become the official international ATC-language, one could **[**assume**]** that internationally all pilots should undergo a test conducted in English. Basically, speech audiometry is a speech intelligibility test, this implies that the examinee should master the language used. To do justice to non-Anglo-Saxon pilots, one would have to use ATC-communication-type speech material only. But then the speech audiometry would become an ATC-communication-skill-and-experience test which is not intended. Therefore, the recommendation is that, when examining a pilot according to the requirements, the following two-step test procedure should be used:

a Perform a speech audiometry test according to the national standards of the language preferred (or spoken daily) by the pilot. Make sure that both the threshold of speech intelligibility (TI) and discrimination loss (DL) are determined. Further, if a standard exists, a discrimination test in noise should be performed. Then compare the results of the tests with the documented normal limits of that particular test. Even though the test results are within the normal limits, the aetiology of the hearing loss should be further investigated. If the aetiology is non- or only slowly progressive, approve the hearing, but consider **[**shorter**]** audiometry intervals. If the results are abnormal or border-line normal, consider the aetiology and make sure that a safe diagnosis is established. In cases of border-line results and non-progressive aetiology, the following test should be executed:

b **[**Collect**]** authorised information about the noise spectrum and spectral intensities experienced on the flight deck of the particular aircraft flown by the applicant. If inaccessible as authorised figures or reliable manufacturer information, a measurement using a sound-level-metre is performed and, if convenient, recorded by means of a high-fidelity tape-recorder. Then, in a sound proof room, the flight deck noise level is reconstructed according to the frequency and intensity measurements and checked by means of a sound-level-metre. A tape-recording of selected ATC-communication is presented to the pilot with a realistic volume control. The pilot should be allowed to wear his own head-set or listen to a loudspeaker placed according to the flight deck design. Preferably, the noise source is placed behind the pilot, as in the aircraft. The pilot is given 25 ATC-messages, he is allowed to make notes and told to read back the essential cues of the ATC-communication. The result is considered satisfactory if all essential information is read back correctly. In this case acceptance of the pilot's hearing ability should be restricted to the aircraft from which the noise information was acquired.

[A medical flight test is an appropriate alternative**.]**

Speech audiometry must always be performed by an audiometrist familiar with aeromedical problems or by a specialist in oto-rhino-laryngology acceptable to the AMS.

4.5 Guidance regarding [aeromedical assessment]

The requirements (JAR–FCL 3.235 & 3.355) and the interpretation above describing additional speech audiometry tests offer sufficient guidance concerning **[ ]**the hearing requirements. It is essential to realise that any hearing loss caused by a disease **[ ]**should undergo a diagnostic evaluation. This means that all abnormal hearing results must be accompanied by a diagnosis. Too often it has been claimed that a pilot with a hearing loss, but fulfilling the hearing requirements should be allowed to fly without further ado. However, a deterioration of the hearing is always a sign of disease **[ ].**

4.6 Other hearing tests for diagnostic purposes

For diagnostic purposes two groups of simple audiometer independent tests can be used, the tuning fork tests and the whispered and spoken voice tests. More advanced diagnostic tests, the acoustic brain-stem response (ABR) and electro-cochleography (ECoG), should be used for advanced diagnostic purposes, but will achieve no further attention in this context as their use must be considered a specialist task. Objective information can be obtained by a determination of the stapedial reflex thresholds, but this information must be interpreted in context with clinical and audiometric information, which is outside the scope of this text.

a Tuning fork tests

Use an A1 (= 440 Hz) or a C2 (= 512 Hz) tuning fork. When you strike it, snap it between your thumb and index finger or tap it gently on your knuckle or knee.

Rinne's test: Compare air- and bone-conduction by pressing the hilt of the struck tuning fork against the mastoid process. When the examinee indicates that the tone is no longer heard, move it so the vibrating tines are held 1–2 cm from the ear canal. Ask the examinee if he hears the tone now. If the answer is positive, the test result is indicated *positive.* If it is not audible by air-conduction, the test is repeated in the reverse order. If the tone is heard by bone-conduction after having faded out by air-conduction, the test result is said to be *negative.* A shorter version of the test is to let the examinee compare air- and bone-conduction by alternately placing the tuning fork on the mastoid process and 1–2 cm from the ear canal and making him indicate where the tone seems loudest. *A negative Rinne's test indicates a conductive hearing loss of more than 20 dB.*

Weber's test: When a sounded tuning fork is placed in the mid-line of the forehead, it is normally heard equally in both ears. In the case of a simple unilateral sensory-neural hearing loss, the sound will lateralise to the normal (or better) ear. If a unilateral conductive hearing loss is present, the tone will refer to that ear. This phenomenon is difficult to explain, but easy to produce in a normal person, creating a temporary unilateral conductive hearing loss by occluding the ear canal with a finger. For good reasons, the phenomenon surprises the patient. In order to avoid confusion it is wise to ask a patient with a known unilateral hearing loss if the tone 'is heard in the better or the worse ear'. Lateralisation is produced at a hearing loss of just 5 dB. The outcome of the test can be capricious if central hearing mechanisms have compensated for the directional hearing impairment caused by a chronic hearing loss.

Gellé's test: If the footplate of the stapes is bone fixed, as in otosclerosis, no intensity variation can be produced when the ear canal is occluded. The test result is indicated positive in the case of an intensity variation by occlusion of the ear canal.

b The spoken voice tests

It is difficult to standardise these tests because of large variations between examiners and different national traditions. The following may serve as a guideline:

i *Prevent lip-reading* by having the examinee turn his back to the examiner.

ii *The whispered voice test* should be performed by a whispering produced using the expiratory reserve (after completing a normal expiration). A unilateral test can be performed, when occluding the contra-lateral ear.

iii *The spoken voice test.* Use an average conversational voice. Both ears are tested simultaneously unless a sufficient masking noise is presented to the contra-lateral ear.

iv Use *numerals* between 21 and 99. Let the examinee repeat, what he has heard.

v Use the *threshold distance* between the examinee and the examiner to indicate the outcome of the test.

vi The tests should be performed in a *relatively silent room.*

4.7 Comments

a *Noise induced hearing losses*

Permanent threshold shifts are characterised by the so-called 'noise-dip' maximal, at 4 000 or 6 000 Hz. If present **[**in initial applicants**]**, the prognosis of the hearing loss should be considered. A noise induced hearing loss is the result of noise exposures influenced by a hereditary predisposition. The physical examination should, if possible, prevent selection of very noise sensitive individuals for the pilot profession – or at least such individuals should be warned that the noisy flying environment could harm their hearing to a degree that would cause a loss of licence at a later stage of their career. At any sign of a noise induced hearing loss, the applicant should be questioned carefully about his past noise exposures. If this exposure is negligible, the applicant should be considered very noise sensitive. If the hearing loss is pronounced, but the hearing (because of the high frequency configuration of noise induced hearing losses) is still within the required limits (JAR–FCL 3.235 (a), (c) & (d) and JAR–FCL 3.335 (a) & (b)), rejection or a waiver should be considered based on JAR–FCL 3.230. It is important to realise, that sensory-neural hearing losses have been proven super-additive – the pre-existence of a sensory-neural hearing loss of any origin makes that particular ear much more sensitive to a noise induced hearing deterioration. In all cases of noise induced hearing loss in young people, instructions and guidance should be given concerning the use of hearing protectors when exposed to noise of any origin, privately and professionally.

Most professional pilots exposed to aircraft noise for decades present themselves with a more or less pronounced high frequency hearing loss. **[**They have proven themselves sensitive to noise and the almost inevitable progression of their hearing loss can only be delayed by a proper protection.**]** These pilots should be instructed to wear external hearing protectors of the *ear-muff type* whenever moving outside the aircraft on the apron or close to other aircraft. **[**Active noise reduction headsets should be used in the cockpit environment (sound levels of more than 85 dB have been measured in certain aircraft types, resulting in sensory-neural hearing-loss upon long-lasting exposure).**] [ ]**Further, they should be aware of the noise exposures in their private life and protect themselves under these conditions as well.

b *Presbyacusis*

In all civilised societies, most individuals will develop a high frequency sensory-neural hearing loss with increasing age. The degree of this hearing loss is determined by hereditary factors. As mentioned above, sensory-neural hearing losses are super-additive. That increases the need for proper noise protection with increasing age.

c *Unilateral hearing loss and unilateral deafness*

In normal life, unilateral deafness is a minor handicap, usually only affecting the directional hearing, once the patient has become accustomed to the condition. Directional hearing is a rather unimportant function during flight. If the aetiology of the existing hearing loss does not indicate a higher than normal risk of a hearing deterioration in the normal ear, **[**a fit assessment may be considered, a multi-pilot (CLASS 1 'OML') limitation may be required**]**, provided that an ATC-communication test in aircraft-noise (as described above) is flawless.

d *Hearing aids*

The development of small, technically advanced, functionally reliable hearing aids has more or less been disregarded by the aviation medical community. Compared to correcting lenses, hearing aids are much more complex and the risk of functional disturbances is considerably higher, but still relatively low. Whenever a pilot's hearing performance can be improved significantly by the use of a hearing aid, it should be considered a benefit for flight safety. If the hearing aid is fitted with a non-air-tight ear-mould and acoustically adjusted to the pilot's hearing loss and the speech intelligibility benefit tested and proven in noise comparable to aircraft noise, such hearing aid should be allowed for flying duty. The conditions should be analogous to those applied in pilots with correcting lenses. The aid must be approved by a specialist acceptable to the AMS and an extra aid and battery should be carried by the pilot on duty.

5 THE VESTIBULAR FUNCTION

5.1 Definition

The vestibular function is an integrated part of the balance system. The balance system can be defined as an integrated neural system which by means of several sensory functions serves the postural and oculomotor reflexes and provides the individual with pre-conscious or conscious orientational information.

5.2 The sensory input

Vision and vestibular function are far the most important sensory inputs to the balance system. The division of labour between the two sensory functions is defined by the frequency of the movements stimulating the balance system.

Below 1–2 Hz, vision provides sufficient information about movements, above this limit the visual picture of the object or surrounding visual world becomes blurred because of a disappearance of the eye movements stabilising the visual field in relation to the movement. Compensatory eye movements caused by low frequency vestibular stimuli, generated by active or passive head movements without supporting visual stimuli, are insufficient. Above 1–2 Hz, compensatory eye movements elicited by vestibular stimuli are sufficient to stabilise the visual field during subjective movements. Normal active motion covers a broad spectrum of frequencies including both low and high frequency stimuli.

Spatial orientation has been described as a pre-conscious/conscious sensory percept. Visual and vestibular stimuli have different priorities in spatial orientation. The frequency limit of visual orientation is identical with that of visual compensatory eye movements. Visual information has a broader access to consciousness than vestibular information – the phenomenon is described by the term *visual dominance*. If for some reason deprived of unambiguous visual information, the balance system turns to the vestibular system in order to utilise that information. The phenomenon is described as *vestibular opportunism*. If the vestibular information originates from a low frequency stimulus, it is insufficient and at the worst misleading, resulting in a state of *spatial disorientation* which can be disastrous in aviation.

In aviation, vision is the most important sensory input to the balance system because of the low frequency spectrum of most aircraft movements.

5.3 Visual reflexes

Seen from a balance system point of view, vision is clearly divided into two separate functions; firstly, *peripheral* or *ambient vision* and secondly, *central* or *foveal vision.*

a *Ambient vision*

Contrasting linear structures are interpreted as either horizontal or vertical. In the presence of unambiguous ambient visual information about the true or apparently true direction of the horizon or large objects with obvious vertical cues, vision provides information about the true or apparent direction of the horizon or the gravitational vertical. A moving ambient visual field is interpreted as the result of a subjective motion, resulting in compensatory *optokinetic eye movements.* The optokinetic reflex is an open loop reflex, not sufficiently controlled by feed-back information. Optokinectic nystagmus is maintained after the disappearance of the stimulus by central mechanisms (cerebellar velocity storage). In humans, optokinetic movements are vestigial and inaccurate.

If a sufficiently contrasting object is localised by the ambient vision, it stimulates a fast *saccadic eye movement*, placing the object in the foveal region.

b *Foveal vision*

The vision identifies objects by their shape, colour and apparent size and contributes to identification by a distance estimate. In humans, the smooth pursuit reflex more or less has replaced the function of the optokinetic reflex. By means of this foveal reflex, small objects can be tracked very exactly. It is a closed loop reflex. The true stimulus is minor movements of the object (retinal slippage) fed back from the foveal sensory cells and zero-adjusted by small second-order compensatory eye movements. At optimal stimulus conditions, this reflex is extremely precise. The reflex is able to utilise pre-programmed eye motion patterns; preferably ballistic trajectories making it possible to perform eye movements which, under certain predictable circumstances, are ahead of the object and for instance makes it possible to predict the impact of a thrown ball.

5.4 The vestibular input

The three *semi-circular canals* placed about three orthogonal axes and the two otolith organs, *utriculus* and *sacculus* of each labyrinth comprise the vestibular end-organs. The physical dimension of the stimuli acting on these organs is *acceleration; angular* accelerations in the case of the semi-circular canals, *linear* accelerations in the case of the otolith organs.

Certain anatomical and physiological aspects are important for the understanding of the function and malfunction of these organs. The sensory cells of both types of organs are *hair-cells*. When stimulated mechanically, a hair cell reacts according to the direction of the mechanical force with respect to the polarisation of the hairs of the cell. The position of one of the hairs, the *kinocilium,* determines the directional properties of the cell. If the hairs are bent in the direction of the kinocilium, the firing rate of its efferent neuron increases; forces acting in the opposite direction result in a decrease of the firing rate. If the hairs are in their resting position or influenced by forces perpendicular to the axis of the cell, a certain resting firing rate is maintained.

In the ***ampullae of the semicircular canals***, the sensory cells are organised in a homogenous pattern. The determination of the direction of the axis of rotation of a certain stimulus is a central procedure based on the vector contribution of each of the semi-circular canals. Because of the mirror-symmetry of the two labyrinths, a stimulus resulting in an increased firing in one group of sensory cells will cause a comparative decrease of the firing rate in its antipodal cell group of the opposite ear. In that way, the signal arriving in the central nervous system will always possess the characteristics of a *differential signal*. If the connection between one labyrinth and the CNS is interrupted or if the end-organs of one ear are destroyed, the normal peripheral resting potential information will not arrive centrally and this will be interpreted centrally as the result of an anti-kinocilium-directed stimulation of the organs involved. That explains why end-organ vestibular disease simulates a stimulation and results in rotatory sensations (= *vertigo*) and compensatory eye movements corresponding to a continuous rotatory movement (= *nystagmus*).

In the ***maculae of each otolith organ***, the sensory cells are organised in a more refined pattern, covering all possible stimulus directions. Directional information is already present at the sensory organ level. Destruction of the sensory organ or first sensory neuron will not signal any specific directional cues to the CNS. Consequently, failure of the otolith organ function will not result in any illusions of motion, nor in any meaningless ‘compensatory’ eye movements, but cause a feeling of a less specific unsteadiness, not accompanied by a nystagmus.

The otolith organs are stimulated by linear accelerations. The effect of gravity is identical with the effect of a sustained [9,81] m/s^2 (= 1 G) upward acceleration. The vestibular perception of simple linear accelerations depends on the ability of the balance system to dissolve into its components the resultant of the gravitational and motional vector. This depends on the presence of other, non-vestibular, directional cues. In a flight simulator, a backward tilt ('G-tilt') combined with a visually stable horizon gives a perfect illusion of a forward acceleration. Contrary to this, the forceful acceleration of an aircraft under poor visual conditions with no clear horizon seen is felt like an increasing climb rate. These two erroneous orientational percepts are called *somatogravic illusions*.

When an aircraft performs a co-ordinated turn, the resultant of the gravitational and centripetal force vectors is aligned with the vertical axis of the aircraft. The bank of the aircraft is felt only when the horizon is seen – if not, a somatogravic illusion of being in level flight will be perceived. The somatogravic illusion is one of several causes of spatial disorientation during flight – one of the most powerful and important.

5.5 The vestibular reflexes

Usually, vestibular stimulation elicits compensatory eye movements. Since eye movements are rotatory, their amplitudes and timing are related to a central estimate of the rotatory amplitude and timing of the eliciting head movement. These two parameters are analytically expressed by the *gain* and *phase deviation* of the eye movement compared to the head movement. Usually, the evaluation is made by a frequency analysis, comparing the two signals. This is meaningful because, as mentioned above, the frequency responses are important characteristics of the balance system function. The low frequency domain (< 2 Hz) is the visual domain – even though the vestibular organs may contribute to the responses – the accuracy of the gain and phase in this domain is determined by the visual information. At high frequencies, the vestibular system has its monopoly, and high frequency vestibular stimuli result in accurate gain and phase responses.

Continuous rotatory stimuli (extremely low frequency) is compensated by a continuous rotatory eye movement in the same plane as the stimulus. Since the eyes cannot continue their rotation for more than a limited angular distance, the compensation becomes bi-phasic, i.e. composed of a compensatory phase based on a rotatory velocity estimate and a fast anti-compensatory, saccadic movement in the direction of the stimulus. This eye movement pattern is called *nystagmus.* At high frequency, low amplitude head movements, there is no need for the anti-compensatory phase and the compensatory movements simply mirror the stimulus.

5.6 Non-eye-movement efferent phenomena

The most dominant of these is the *spatial orientation*. It is based on the integrated sensory product, a spatial image created by the sum of sensory inputs arriving at the balance system centres of the CNS. Since it is possible to distinguish between active and passive movements, information about central motor commands are believed to be integrated with the sensory information.

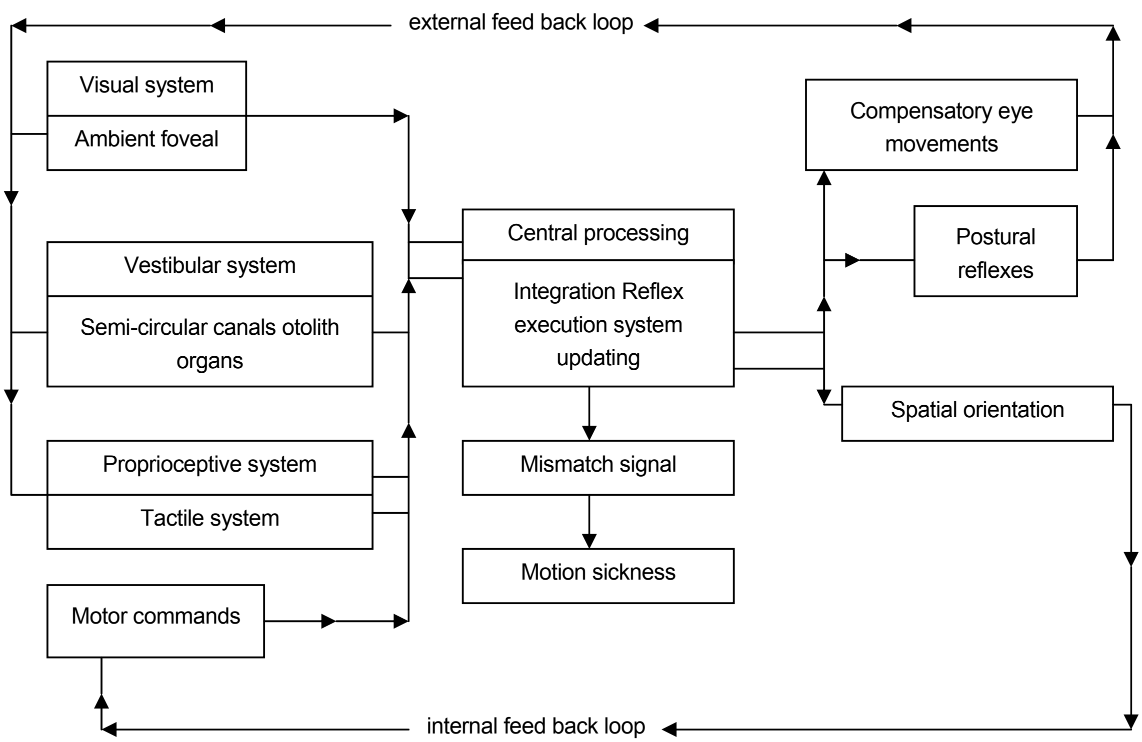
5.6.1 Spatial disorientation

(see below)

5.6.2 Postural reflexes

Postural reflexes are simple and primitive when they serve simple static purposes. In humans, locomotion by walking, running and jumping are physically complex tasks. These tasks serve as characteristic examples of learned, pre-programmed, complex behaviour. Running is an excellent example. It is based on the ability to predict the point of projection of the centre of gravity resulting from the next movement – this prediction can not be the result of sensory organ information alone.

The sensory organ function in this context is to establish a feed-back from the motor activity making it



possible to check a proper development of the current pre-programmed project.

5.6.3 Motion sickness

Motion sickness is an inexpedient, seemingly meaningless reaction to a balance system stimulation. The currently most widely accepted theory of the aetiology of motion sickness has been suggested by *Reason.* Semantically, it is contradictory that motion sickness under certain circumstances can be caused by the absence of motion. If a person has been adapted to a motion environment (like a ship) and returns to a normal non-moving environment, he may become sick (*mal de débarquement*). An experienced pilot flying a simulator easily feels sick due to the lack of the customary vestibular stimuli in the simulator and may feel embarrassed, when he realises that a much less experienced pilot, not habituated to the intimate correlation between certain visual and
inertial stimuli of flying, does not experience any simulator sickness symptoms at all.

A simple theory explaining motion sickness as the result of vestibular over-stimulation is insufficient to explain these phenomena. Reason claims a '*neural mismatch*' *theory,* postulating that unusual or unknown combinations of simultaneous sensory stimuli will result in a mismatch signal evoking the symptoms of motion sickness. In fact, this theory contains most of our present knowledge of motion sickness provoking environments. It explains the coherence between the capability of a moving visual environment without inertial stimuli to cause disease, and the symptom-provocative effect of the removal of relevant visual information in an unusual inertial environment. In order to explain that an experienced fighter pilot flying as a back-seat passenger in a fighter aircraft may be sick if the pilot in control of the aircraft makes manoeuvres which would be non-provocative if he made them himself, it is necessary to include motor commands as a part of the balance system integration product. The mismatch theory firmly connects the motion sickness aetiology with the adaptational and learning processes of the balance system.

Motion sickness *symptomatology* can be described as an avalanche of symptoms, developing at various speeds, culminating in nausea and vomiting. The important initial symptoms are *drowsiness* (the first to yawn is the first to throw up) and *headache.* Then *hyper-salivation, bodily warmth, cold sweat, paleness* and various degrees of *mental depression* or *apathy* develop. This is accompanied by the development of an *awareness of the stomach* into *epigastrial discomfort* and *retching.* At the same time, a feeling of *nausea* (located to the throat) develops culminating in *vomiting* followed by a return to an earlier step of the symptomatology – very often just to realise that a new development of symptoms is on its way.

Motion sickness research, the comprehension of other kinds of interaction between different sensory functions in the balance system and the experience with spatial disorientation during flight, have emphasised the need of a holistic view of the balance system physiology. The flow chart above is an attempt to give a simple survey of the cue points of the balance system physiology described above. It is based on a system concept which involves a high degree of integration and feed-back processes.

5.7 Spatial disorientation phenomena in flight

[Spatial disorientation can be defined as a false orientational perception. Since both, eye movements and orientation, are based on the integrated sensory product, there is an intimate correlation between inexpedient eye movement responses and spatial disorientation.**]**

Spatial disorientation can be defined as any incident occurring during flight where the pilot fails to sense correctly the position, motion or attitude of his aircraft or of himself in relation to the system of co-ordinates provided by the surface of the earth and the gravitational vertical. This does not include errors of navigation which can be defined as geographical disorientation. It is important to realise that the absence of a relevant orientational sensation is just as much a disorientation event as the experience of a false sensation.

Spatial disorientation is very often disregarded as a cause of aircraft accidents. The pilot's orientational experience can only occasionally be reconstructed after a major accident. Very seldom sensory physiology experts are involved in accident investigations. Very often pilots 'forget' to report spatial disorientation as a cause of minor incidents – possibly because they fear to be **[**assessed as unfit**]** due to a CNS- or vestibular system disease. They may not realise that the vast majority of cases of spatial disorientation are considered signs of a normally functioning sensory system in an abnormal environment, rather than the opposite.

Spatial disorientation can be divided into *peripheral* and *central errors*. Peripheral errors can be caused by both visual and vestibular insufficiencies, vestibular errors by both canal and otolith stimuli.

Very often, central errors are caused by an *error of expectancy* – a more or less clear visual picture of the surrounding world (or instrument reading) is misinterpreted. Below, some of the more pronounced or characteristic illusions will be expounded.

[5.7.1] ***Somatogravic illusions*** are mentioned and exemplified above. They depend on an insufficient ability to dissolve the resultant linear acceleration vector into its constituent vectors. Primarily, the resultant vector is experienced as the true gravitational vertical unless clear (ambient) visual information provides a stronger cue. The illusions can appear during turns, accelerations or decelerations or when an aircraft levels out from a climb. Under the former circumstances, where the horizon may be below the pilot's visual field, the size and direction of the centrifugal forces interfere with the gravitational force vector resulting in a feeling of a nose-up pitch rotation of the aircraft. This can lure the pilot to exaggerate the manoeuvre, directing the aircraft into an unintended dive.

[5.7.2] If, for some reason, the pilot is able to visually fixate a light source outside the aircraft when experiencing a somatogravic illusion it will appear to move according to the illusion; this phenomenon is called an ***oculogravic illusion***.

[5.7.3] The semi-circular canals are stimulated by accelerations only. At constant angular velocities the stimulus fades out after 15–30 seconds, depending on the stimulus characteristics. A pilot experiencing an aircraft spin will soon lose the spinning sensation if he has no outside visual reference. The lack of the spinning sensation is in this case a ***somatogyral illusion***. When he recovers from the spin, his semi-circular canals are decelerated causing an erroneous feeling of spinning in the opposite direction, his second somatogyral illusion, which can be responded to by an attempt to recover from his illusory spin, leading him back into his original spiral (the so-called graveyard spiral). When affected by this stimulus, the oculomotor system will produce a nystagmus smearing the pilot's vision and making him unable to read the instruments and realise what is happening.

[5.7.4] If the pilot for some reason moves his head up or down during the steady rotation phase of an unnoticed spin, he will perceive a tumbling sensation. During a spin, the horizontal semi-circular canals are in the plane of the rotation. When they are moved out of this plane, they will react as during a deceleration. With a nose-down pitch head movement during a clock-wise spin, he will feel he is tumbling counterclockwise in the actual plane of the horizontal semi-circular canals. When he moves his head back to the normal position, he will feel he is tumbling in the opposite direction. This illusion is caused by a cross-coupled stimulation of the canals and is called a ***Coriolis illusion***. This type of stimulus has been exploited for standardised tests of motion sickness sensitivity.

[5.7.5] ***Flicker vertigo*** is a visual illusion associated with the presence of flickering visual stimuli. A rotating anti-collision beacon or the down blast of a helicopter rotor making waves in the grass of the ground or on a water surface, easily induces a sensation of rotation in the opposite direction.

[5.7.6] A spell of transitory vertigo usually lasting 10–15 seconds may be experienced if the middle ears are exposed to different pressures due to the appearance of a sudden pressure transient in one middle ear. This condition is called ***alternobaric vertigo***. It may be the response to a Valsalva manoeuvre performed during descent. The risk of experiencing alternobaric vertigo is increased considerably with the presence of a unilateral tympanic membrane perforation. The attack is accompanied by blurring of the vision because of the accompanying nystagmus and rotatory motion illusions. It is usually short lived (but may last for minutes); typically it is very intense and causes a state of disorientation which may be dangerous when appearing during the pressure variation caused by descent during approach and landing.

[5.7.7] A large number of visual illusions can be classified as ***errors of expectancy***. Strong horizontal or near-horizontal ambient visual cues are interpreted as a true horizon. This may be dangerous during approach, if the street lights from a nearby highway are interpreted as the horizon. The pilot will perceive an erroneous nose-high attitude and if the visual cue is not horizontal, an unintended lean.

Pilots have certain expectancies concerning the dimension of a runway. If the runway has unusual dimensions or slopes, the pilot might misjudge his altitude and the distance to the runway threshold. A pilot flying over an oblique cloud top easily gets a 'lean', an illusion of flying wings level when his aircraft banks parallel to the cloud top.

Most pilot students have problems interpreting the artificial horizon. When looking at the instrument, he spontaneously interprets the inclination of the artificial horizon as an expression of the inclination of the aircraft. If he, in his mind, extends the plane of the artificial horizon into his ambient vision and so-to-say translates a foveal visual cue into an ambient visual cue, he will realise that he is wrong. This procedure is time consuming. A skilled and experienced pilot may become the victim of the same illusion if his flying abilities deteriorate due to panic.

5.8 Vestibular requirements

a *Vertigo and dizziness*

A pilot shall not suffer from spells of vertigo, dizziness or unsteadiness of any origin. Even the most thorough vestibular examination might not reveal any signs of vestibular disturbances in a patient suffering from an early stage Ménière's disease. A pilot's Ménière attack of vertigo during flight would be a disaster. An applicant not informing his examiner about symptoms of this type **[**jeopardises**]** flight safety. This imaginary, dishonest applicant might suffer from a minor sensory-neural hearing loss, safely within the hearing requirements. This is an example of, when judging vestibular function, even minor disturbances of hearing must be considered. Audiologic tests are much more sensitive to minor inner ear function deficiencies than vestibular tests.

b *Other vestibular conditions*

The presence of a *spontaneous or positional nystagmus* should be interpreted as evidence of a spontaneous drift of the balance system showing that a signal is generated somewhere in the system indicating a constant rotation in the plane of the nystagmus and in the direction of the fast anti-compensatory nystagmus phase. If generated in the vestibular part of the system, nystagmus is always associated with rotational sensations; if generated in the CNS, it may or may not be accompanied by sensations; if originating from an ocular disease, it is never associated with sensations. Nystagmus is judged by its slow phase rotatory velocity. If a 6°/s slow phase velocity horizontal spontaneous nystagmus is recorded, it compares to an error signal indicating that the aircraft is performing a horizontal turn at 6°/s = 1 rpm. The slow phase velocity of nystagmus can be manipulated by closing or opening the eyes and by visual fixation and even by having the patient imagine a fixation point in darkness. If the nystagmus is vestibular of origin and its maximal slow phase velocity is recorded with the eyes closed – it decreases slightly when the eyes are opened in darkness and decreases further if a fixation point at a far distance is imagined and can be abolished in the presence of a real fixation point. If a nearby point is fixated or imagined, the slow phase nystagmus velocity will increase.

If this information is applied to the pilot's working conditions, instrument meteorological conditions (IFR) can be compared with the open eyes in darkness and the instrument reading task can be compared with the fixation of a real nearby point.

Vestibular asymmetrical threshold conditions involve a risk of not detecting and reacting to motions in one direction while detecting and reacting to comparative motions in the opposite direction. An aircraft exposed to even slight turbulence during flight will perform small, oscillating movements about any axis. The pilot's ability to maintain a stable aircraft attitude during turbulence depends on his symmetrical responses to these relatively high frequency motions.

The ratio of more or less conscious reactions to instrument reading versus reactions to vestibular information, depends on the pilot's skill and experience with instrument flight. A very low ratio is expected in IFR-trainees and VFR-pilots when unintentionally flying into IFR-conditions. An experienced pilot exposed to an unusual physical or mental stress during flight will mentally be moved to a point on a scale ranging from a condition of acute awareness at one end to panic at the other. This scale of increasing mental arousal is intimately associated with a progressive loss of recently acquired skills (= regression). This means that a pilot's skills should not be judged as a constant based on his number of flying hours, but should also be seen in the light of the risk of putting him into a state of reduced cerebral competence due to physical and mental stress. This means that a pilot's *instrument vestibular reaction ratio* is situation dependent and that signs or symptoms of vestibular insufficiency should not be accepted neither at the first issue of a licence nor at renewal, although skill and experience should be considered.

5.9 Accepted routine screening methods

[5.9.1 Electro-oculography (EOG) method]

The evaluation of the vestibular function is a specialist task and should be performed using methods ensuring objectivity, reproducibility and aviation relevance. Eye movements should be recorded by means of the electro-oculography (EOG) method. This method is based on the presence of a small electrical potential between the cornea and the fundus of the eye. When a person performs an eye movement in the direction of an electrode attached to the skin in the orbital region, this electrode will pick-up a positive electrical signal. Clinical EOG is performed by placing superficial electrodes in the temporal regions close to the outer canthi of both eyes for a horizontal lead and just above and below the orbital margins in the pupillary plane for vertical leads. The signals are amplified by means of a differential amplifier capable of giving a 25 μV input signal the deflection of the tracing of at least 1 cm. In order to reduce the disturbing influence of electrical noise, a body-worn pre-amplifier should be used. With an AC-amplification, a time constant of at least 5 s must be used. The corneo-fundal potential will vary depending on the light intensity. Its stability is highest when the subject is adapted to darkness. Calibration must be performed just prior to each recording by means of two small sharp light sources (LEDs) placed at least 2 m in front of the subject at a known horizontal angular distance, not more than 20°. If vertical recordings are done, the calibration should be performed in the vertical plane also.

Spontaneous nystagmus is defined as nystagmus present when a persons torso and head are in the anatomical normal position. If the nystagmus is provoked by a certain position, it is characterized as a *positional nystagmus*. Positional nystagmus is looked for in the supine position and with the examinee lying on his left and right sides. It is important to move the examinee slowly to the different positions; nystagmus provoked by the movement itself and not by the position is characterised as positioning nystagmus. EOG is recorded for at least 30 seconds in each position.

The EOG-recording is evaluated by a calculation of the slow phase eye velocity. The slopes of the slow phases of characteristic nystagmus beats are computed and evaluated in the unit of °/s by considering the calibration signal and time axis information. It can also be measured by the so-called *Ohm's energy*-method. By adding the amplitudes of each nystagmus beat in a 10 seconds period and then dividing the result by ten, a figure close to the average slow phase velocity of that particular period is obtained. Computerised programmes for slow phase velocity determinations are commercially available. If the recording is performed with the subject's eyes closed, spontaneous and positional nystagmus velocities below 6°/s are considered clinically insignificant – for aviation medical purposes, a 4–5°/s-limit seems more reasonable.

In order to detect vestibular threshold asymmetries at the [initial examination], vestibular reactions should be induced by either rotatory or caloric stimuli. Technically, *the caloric test* is the only clinical means of unilaterally testing responses from the vestibular end-organs. Seen from an aviation physiology point of view, the caloric stimulus is a rude, non-physiological stimulus. For clinical and diagnostic purposes, side or directional differences of as much as 25% are accepted as normal. The balance system reaction to the stimulus reflects fully the non-physiological properties of the stimulus, demonstrated by the induction of signs and symptoms of motion sickness in many normal persons exposed to a caloric stimulus. On the face of its clinical indispensability, the caloric test can be accepted as a means of excluding vestibular pathology in aviation medicine. Ideally, a much more physiological stimulus with a more intimate relation to aviation physiology should be applied. When implemented in the examination, a full differential caloric test should be performed, using 30° and 44°C water stimulation. The responses should be recorded by the means of EOG and evaluated as the maximum eye velocity response of each irrigation. The examination should be performed with the examinee in the supine position with his head elevated approximately 30° in order to place his lateral semi-circular canals in their optimal vertical position. The examinee should be told either to keep his eyes closed or keep them open in darkness, to keep his gaze in a straight forward direction and to maintain his level of arousal by means of *mental arithmetics* during the whole EOG-recording which should last for at least 100 seconds from the initiation of the ear canal irrigation. An interval of at least 5 minutes should be observed between each irrigation and calibration should be performed just prior to each EOG-recording. The maximum eye velocity results should be evaluated according to the Jongkees's formulae:

$$Isd = \frac{(L44+L30)-(R44+R30)}{L44+L30+R44+R30}$$

Isd is the index of side difference, L44, L30, R44 and R30 are maximal eye velocity responses from the left and right ears with 44° and 30° water stimuli, respectively.

$$Idp = \frac{(L30+R44)-(L44+R30)}{L44+L30+R44+R30}$$

Idp is the index of directional preponderance.

In both indices a positive sign is interpreted 'right' and a negative sign 'left' (Idp = +0·15 means a 15% directional preponderance to the right; Isd = -0·08 is a left side 8% unilateral weakness).

A unilateral weakness of less than 20% is considered normal; a directional preponderance of less than 25% is within accepted normal limits.

5.9.2 [Natural head motions]

A much more attractive way of inducing vestibular responses is by the means of natural head motions. If these are performed in the low frequency domain (< 2 Hz) an interference with visual oculomotor reflexes is expected, making it important to control visual fixation, which is difficult because a visual target fixation cannot be allowed. If performed in the high frequency domain, active head motion vestibular tests are easier to handle and interpret and are independent of the visual fixation state. A new standard termed the *Vestibular Autorotation Tes*t® (VAT) has been developed (by professor Dennis O'Leary of U.S.C., Los Angeles) and is recommended as an attractive, safe, easy-to-perform and aviation relevant replacement of the differential caloric test.

5.9.3 [Bárány rotating chair test]

A less sophisticated vestibular test method, the *Bárány rotating chair test*, may be used in Class 2 certificate applicants. A simple office swivel chair is used. The applicant is placed in the chair and mounted with Frenzel's glasses. With his eyes closed, the applicant is manually, but smoothly turned five rounds in twenty seconds. After a brisk stop, the applicant is told to open his eyes behind the glasses and the examiner notes the duration of resulting postrotational nystagmus. After a two to three-minute break, the procedure is repeated in the opposite direction. Following a clockwise rotation, the postrotational nystagmus is leftward and following a counter-clockwise rotation it is rightward. If the duration of the postrotational nystagmus in one direction is more than twice the duration of the nystagmus in the opposite direction, a *directional preponderance* is said to be present and the applicant should be submitted to a more sensitive and specific evaluation.

5.10 Other vestibular test for diagnostic purposes

[5.10.1 Romberg's test]

The *Romberg's test* is easy to perform and valuable for diagnostic purposes. The test can be sharpened by letting the examinee stand with his feet in a heel-to-toe position. The ability to walk a straight line can be tested using the *tandem-gait test*, making the examinee walk heel-to-toe with his eyes closed or blindfolded.

[5.10.2 Finger-to-nose test]

The *finger-to-nose test* is performed by letting the examinee place his finger on his own nose with his eyes closed.

[5.10.1 Bárány pointing test]

The *Bárány pointing test* is performed by having the examinee pointing at the examiner's finger and rapidly move his finger back and forth between his own nose and the examiner's finger with his eyes closed. Past-pointing will appear in acute vestibular disease and make any latent ataxia apparent.

[5.11 Guidance regarding aeromedical assessment]

As emphasised initially, evaluation of the hearing function is an important supplementary aspect of the evaluation of inner-ear balance function. Even small sensory-neural hearing losses must sharpen the examiners's attention to the vestibular function test results.

The presence of spontaneous or positional nystagmus at eye velocities above 5°/s demonstrated by an EOG-recording cannot be accepted. At revalidation / renewal, the appearance of spontaneous or positional nystagmus should entail a thorough vestibular examination including an audiologic evaluation. Following episodes of signs or symptoms of vestibular disease, the pilot should be allowed to recover until pathological nystagmus and all symptoms have disappeared.

[For initial applicants**]**, no abnormal caloric or rotational responses can be accepted. At later issues, the diagnostic evaluations must be completed and the reactions adjusted to the diagnosis.

6 THE NOSE AND SINUSES

6.1 General

The nose is the most important part of the air-conditioning system of the upper airways. Passing through the nose, the inspired air is heated and saturated with water vapour and cleaned from larger particles by the mucosa; when expired, the air returns some of the heat and humidity to the mucosa.

The in-door climate of an airliner is characterised by a very dry air. This is a challenge to the entire airway mucosa. If the air passage of the nose is obstructed, mouth-respiration will result in dryness of the mucosa of the throat making it sensitive to irritants and infections.

The paranasal sinuses are open cavities, which may behave as semi-closed cavities (as the middle ear) if their ostia are narrowed by a swelling of their mucosa. If the free exchange of air between sinuses and the nose through the ostia and canals is impeded, a ***sinus barotrauma*** will develop due to the same mechanisms as in the middle ear. From a clinical point of view, the maxillary sinuses are the most frequent location of sinus disease. This often causes mistakes as pain caused by maxillary sinus disorders is frequently referred to the frontal region. The same is valid for any sinus barotrauma.

A mucosa exposed to non-physiological challenges, **[**altered by allergic reactions**]** or infections will swell. A swelling of the nasal mucosa is regularly associated with a swelling of naso-pharyngeal mucosa and a reduction of blocked-and-locked threshold of the tubal ostia resulting in ***tubal dysfunction****.* Obstruction of the nasal passage or sinus cavities results in an abnormal nasal voice twang, *rhinolalia clausa* making the voice weak, difficult to modulate and less intelligible.

6.2 Standard requirements for nasal and sinus function

According to the requirements, nasal obstruction and sinus dysfunction are not **[**acceptable**]**. Septal deviation caused by either a nasal fracture or of congenital origin is the most common cause of a chronic nasal obstruction. In the case of a septal deviation, both nasal cavities should be capable of serving the air passage more or less equally.

Most people suffer from a ***common cold*** now and then. Many pilots are frequently exposed to fast and dramatic climatic variations. No clear limits of an acceptable common cold frequency can be assessed and a pilot’s tendency to frequent common colds must be seen from a tubal or sinus function point of view. The same counts for ***allergic nasal disease*** and ***nasal polypi***. If the nasal allergy is caused by a hypersensitivity to grass pollen, the examiner’s attention should be sharpened because, during the season, airfields are very productive of grass pollen.

It should be required that a pilot not suffers from recurrent barotrauma of his sinuses or middle ears due to a nasal dysfunction. A sinus barotrauma is very painful and might considerably distract the pilots attention from his duties during the critical phase of aircraft descent, approach and landing.

6.3 Methods of examination

The nasal air passage is checked by listening to the sound produced by the air passage through each nostril separately. This is done by blocking the contra-lateral nostril with the pulp of the examiner’s thumb during both in- and exhalation. The expiratory function can be examined further by making the examinee exhale on a mirror or metal surface held just below his nose and observing the symmetry of the dew spots.

When in doubt or if any suspicion of sinus disorders, an X-ray [or ultrasound] examination of the nose and sinuses should be performed.

At the specialist examination, an anterior and posterior rhinoscopy should be performed.

If a nasal allergy is suspected of interfering with normal flight duties, the applicant should be referred to a specialist for a thorough allergologic evaluation.

6.4 Guidance regarding [aeromedical assessment]

If an applicant at the first issue of a licence presents a total or subtotal obstruction of a nasal cavity or a history of recurrent barotrauma due to a nasal disease, he should not be accepted. Applicants needing chronic medication because of a nasal allergy or any other nasal disease should not be accepted either. Periodic systemic corticoid medication or antihistamine medication is unacceptable because of the side-effects.

7 ORAL CAVITY AND UPPER RESPIRATORY TRACT

7.1 General

A normal function of the oral cavity and upper respiratory tract is essential for respiration and speech and voice function. In aviation medicine, most problems in this region are attributed to disturbances in the speech and voice function which is an essential part of the ATC-communication. An applicant who constantly or temporarily is unable to communicate verbally in a comprehensible way or who suffers from a voice disorder making his voice less intelligible should not be accepted.

Stuttering is an inadequate co-ordination between the phonation, articulation and respiration. Usually, stuttering deteriorates with fatigue, anxiety or aggression. The examiner must be aware of any stuttering at the first licence application. If it results in an interruption of the normal rhythm of speech of such frequency and abnormality as to attract attention, interfere with communication or cause distress to the applicant or his audience, the applicant should not be accepted. When in doubt, the case can be conferred with a flight instructor listening to a tape-recording of the applicant's speech.

Phonastenia is a weakness of the voice which may develop both based on a laryngeal disorder and on a psychologic background. It may develop into *aphonia* making the pilot unable to communicate. This is inconsistent with pilot duties.

Laryngeal disorders should be evaluated and diagnosed by an accredited specialist. Approval should be based on a certainty that the disorder will not interfere with the ATC-communication.

7.2 **Methods of examination**

At all physical examinations, the examiner should listen carefully to the applicant's voice in order to detect any possible sign of malfunction of the speech or the voice. At the specialist examination, a mirror- or fibre-laryngoscopy must be performed in order to reveal signs of laryngeal disorders with possible effect on verbal communication.

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