The Research on the hearing damage and methods of hearing protection against aircraft noise

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ABSTRACT

Nowadays aviation noise significantly affects a number of people over the world. This paper is mainly focused on the effect of temporary and permanent hearing loss of cockpit crew, flight attendants, passengers, persons in communities exposed to aircraft overflight. Also this paper describes the human hearing mechanism and the processes of temporary and permanent hearing loss. The results of research are presented and the potential for hearing loss in aviation noise environments evaluated. The Occupational Safety and Health Administration (OSHA) hearing protection criteria are also addressed.

Ⅰ. INTRODUCTION

Before 1960, there was little concern about aircraft noise. Since the introduction of commercial jet aircraft in 1959, there have been dramatic changes in the nature and magnitude of aircraft noise problems over the airport. So this paper is to study effects of aircraft noise on hearing loss and protection, being based on the fact that it is well established that continuous exposure to high levels of noise will damage human hearing. The content of this paper begins with a description of the hearing mechanism, followed by discussion of the effects of noise on hearing, along with criteria for hearing protection established by the Environmental Protection Agency (EPA), the Occupational Safety and Health Administration (OSHA) and the U.S. Air Force. Finally, methods for protection of hearing are discussed.

II. THEORETICAL REVIEW

2.1 HEARING MECHANISM

The ear is an external sense organ designed to receive and respond to air-borne acoustic vibratory energy. Figure 2.1 provides a schematic cross section showing the outer, middle and inner ears. The external ear, made up of the auricle and the ear canal, transmits sounds to the eardrum. The eardrum, which is a very thin membrane that moves very slightly in response to sound pressure levels, separates the ear canal from the middle ear.

The middle ear is an air-filled cavity that lies between the outer and the inner ear , see Figure 2.2 . It acts as a mechanical amplifier of the air pressure vibrations from the eardrum and through a series of bones called the ossicles. Air pressure vibrations displaces the ossicles, a link of three small bones which reach across the middle ear cavity to the delicate, fluid-filled membranes of the inner ear. The ossicles, made up of the malleus, the incus and the stapes, rest against the opening to the inner ear, the oval window ; when the ossicles are displaced, the stapes pushes through the oval window, displacing the fluid in the inner ear.

The middle ear allows pressure variations in air to be transmitted into pressure variations in fluid with very little loss of energy. This is due in part to the relative size difference between the eardrum and the oval window the eardrum has an area 20 times that of the oval window. Thus, the force exerted on the inner ear fluid by the stapes is about the same as the force exerted on the eardrum by the sound wave in the air, but the resulting pressure is much greater as much as a ratio of 22 to 1.

The inner ear contains the final section of the organ of hearing, the cochlea, which rests, coiled like snail, against the oval window. As the stapes forces the oval window in and out, the fluid of the cochlea is also moved. About thirty thousand hair cells called "cilia" located in the cochlea react to the fluid motions, translating them to nerve impulses i.e. converting them from mechanical to electrical energy, then transmitting the impulse to the brain for interpretation.

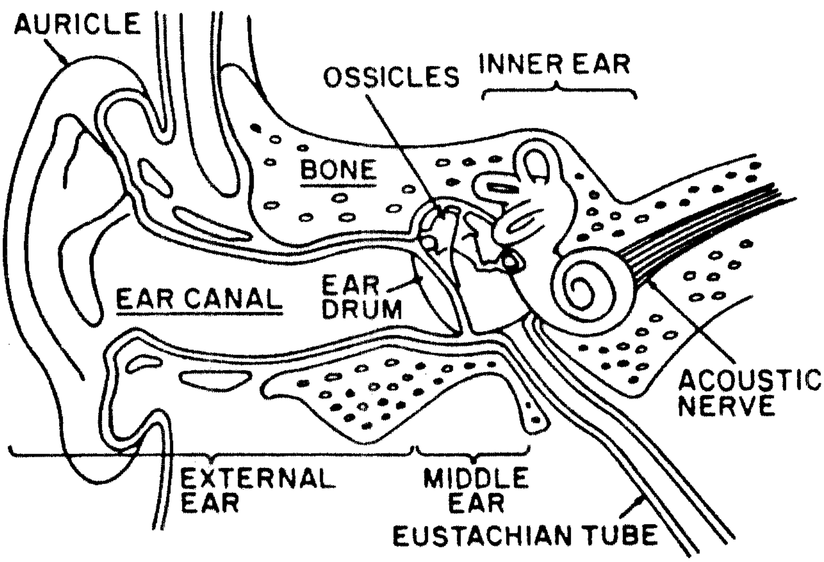

Figure 2.1 Schematic Cross-section of the Ear [1)]

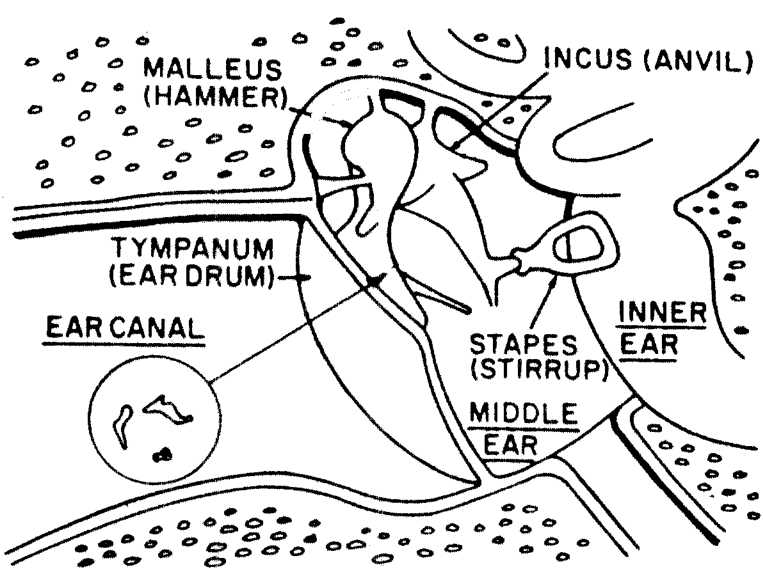

Figure 2.2 Schematic Cross-section of the Middle Ear [2)]
Inset shows actual size of ossicles.

1), 2) Michael, P.L., W.T. Anchor, G.R. Bienvenue et al. Community Noise Funadamentals : A Training Manual and study Guide. Pennsylvania State University College of Education, June 1980.

Acoustical energy may also be conducted to the inner ear through vibration of bone. An example is the sound of one's own voice. Bone-conducted vibrations set up similar patterns of vibration of the cochlea partition as does air-conducted sound.

2.2 AUDITORY RANGE

The ear is capable of hearing a frequency range of about 9 octaves and a dynamic range of more than 120 dB. The least pressure needed to make a tone audible or the "threshold pressure" depends on the frequency of the tone. The lower frequency limit of hearing is a vague boundary because hearing merges into the sensation of vibration ; the upper intensity limit of hearing is sometimes taken as the threshold of discomfort, which is a sound pressure level of about 120 dB independent of frequency. At 120 dB, there may be a sensation of tickling in the middle ear. However, the threshold of pain appears to be 140 dB, with sound continuing to sound louder, with increasing pressure, until auditory fatigue or acoustical injury is reached.

2.3 EFFECTS OF NOISE ON HEARING

The sensitivity of the ear is not constant with frequency. Both the threshold at which a tone can be heard and how loud it sounds may vary considerably as a result of previous exposure to sounds of the same or of different frequencies. Even sounds below 90 - 100 dB may bring about short-term changes in hearing ; these changes, however, are simply adjustments of the balance within the ear, much like the process of light or dark adaptation in the eye.

Other sounds may produce longer-lasting changes in the threshold of hearing ; the chances of these changes occurring increase with continuing exposure to loud noise. The three principle effects are :

1. temporary reduction in hearing acuity, which is referred to as "Temporary Threshold Shift" or TTS

2. permanent hearing loss referred to as a "Noise Induced Permanent Threshold Shift" or NIPTS

3. ringing in the ears, or tinnitus

TTS is a common effect of noise on hearing in noisy industrial and entertainment situations. When an individual is tested for hearing acuity, an audiometer is used to establish the lowest levels of sound that person can perceive at different frequency bands. After exposure to high noise levels for a short time, or moderate noise levels over a long time, the minimum level the the person can perceive may shift to a higher level. Temporary shifts of 20 to 30 dB are usual in healthy ears in noisy situations with a typical eight-hour exposure. This shift is only temporary, however , a 100% recovery of the pre-noise exposure hearing acuity usually occurs within several hours. TTS is also known as "auditory fatigue."

NIPTS is just that the minimum level at which a person can perceive sound permanently shifts to a higher level. In layman's terms, a person incurs a permanent hearing loss of some degree. It is hypothesized that years of incurring a daily TTS may eventually lead to an NIPTS of similar magnitude.

III. ASSESSMENT OF DAMAGE RISK CRITERIA

In order to determine at what levels and under what conditions an NIPTS may occur, damage risk criteria, or noise limits which should not be exceeded for specified time periods, were developed. Damage risk criteria are generally set out in a table or curve such as that shown in Figure 3.1 specifying the allowable relationship between noise level and time of exposure. The guiding hypothesis in most of the criteria is the maintenance of "equal energy" in acoustical dose, which is defined by the level and duration of the noise exposure. In each case, there is a level of risk associated with the specified criteria. It is also worth pointing out that damage risk criteria exist for several different classes of hearing protection : (1) no protection, (2) protected by ear plugs, and (3) protected by ear plugs and headphones. One also encounters damage risk criteria established for specific classes of "unusual" noises, such as impulsive noise, very loud sounds, and sounds dominated by narrow bands of acoustical energy or tones.

The basic damage risk criteria in use today were set forth by the Committee on Hearing Bioacoustics and Biomechanics (CHBAB) in 1965, after comparison of studies related to the effects of noise on hearing. The committee concluded that a sound environment would be acceptable if people, after ten years of almost daily exposure to the environment, had permanent hearing loss of no more than 10 dB at 1000Hz or below, 15 dB at 2000Hz or 20 dB at 3000Hz or above.[3] Thus, 50% of the people would have losses greater than these amounts, and 50% of the people would have less. The development of this criterion was based on three points :

1. Temporary Threshold Shift is a constant measure of the effects of a single day's exposure to noise

2. All exposure that produce a given TTS2 (TTS measured two minutes after cessation of noise exposure) will be equally hazardous.

3. TTS2 is approximately equal to the noise induced permanent threshold shift (NIPTS) after ten years.

Final limits for both broad-band noise are given as damage risk contours in Figure 3.1. These contours provide the maximum octave or one-third octave band levels for specified daily amounts of time, or conversely, the maximum amount of time an individual may be exposed at a speified sound level. Octave or one-third octave band data may be plotted on this figure to determine which particular one-third octave band controls or limits the noise exposure for a specific environment. Similar damage risk criteria for pure tones show the ear to be slightly more susceptible to damage from pure tones.

3) Pearson, Karl S. and John F, Wilby. "Possibility of Hearing Loss from Exposure to Interior Aircraft Noise," Ref. No. FAA-AEE-81-15, November 1981.

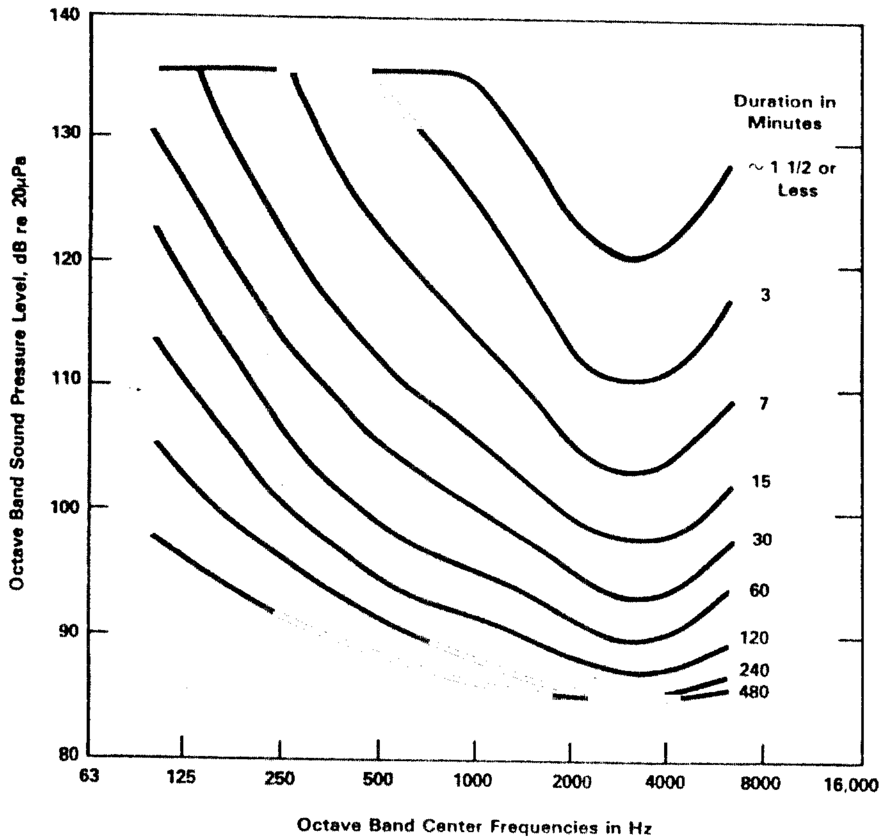

Figure 3.1 Damage Risk Contours for One Exposure Per Day to Octave Bands of Noise

Ⅳ. ANALYSIS OF EXISTING STUDIES

A number of studies have been determined the effect of aircraft noise on hearing ; the studies tend to focus either on the effect of noise on crew and passengers inside an aircraft or on the effects of noise on individuals regularly exposed to aviation noise, such as people who reside around airports.

4.1 INTERIOR AIRCRAFT NOISE.

The 1981 FAA research investigated the potential impact of interior aircraft noise on the crew and passengers of an aircraft.[4] The researchers concluded that the damage risk criteria of CHBAB, is adequate for evaluation of potential hearing damage in both commercial and business jet-powered aircraft. Interior noise levels in both types of aircraft were tested, and none of the average levels in commercial or business jets exceeded the CHBAB recommended levels. The study reports that less than 0.1% of the commercial and less than 1% of business jets are expected to exceed damage risk contours. Given these small percentages, the researchers drew the following conclusions :

1. For the crew of an aircraft, long exposures to noise of as many as sixteen hours flight time should not present any problems as long as the average daily exposure is four hours. Four hours is currently the maximum average daily amount flown in commercial jet aircraft..

2. For the passengers of an aircraft, the report concluded that "A passenger would need to fly at least 400,000 miles per year over 10 years to attain exposures equivalent to the exposure of airline crews." Since the crews are at so little risk themselves, an aircraft passenger is at virtually no risk of hearing damage from inteiror noise.

4.2 COMMUNITY HEARING LOSS.

These are three studies known to have apecifically addressed the question of community hearing loss around airports. The first, a 1972 study, compared the hearing acuity of two groups of residents, one group near Los Angeles International Airport and the second group from a relatively quiet area away from the airport. There was no significant difference in the hearing acuity of the two groups of people, and there was no correlation between hearing acuity and length of residency near the airport.[5]

The second, a 1974 laboratory study conducted near Los Angeles International Airport, exposed two small groups of young men to recorded aircraft flyover noise consisting of forty events per hour, each event with a

4) : Pearson, Karl S. and John F, Wilby, "Possibility of Hearing Loss from Exposure to Interior Aircraft Noise," Ref. No. FAA-AEE-81-15, November 1981.

5) : Parnell, Nagel, and Cohen, "Evaluation of Hearing Levels of Residents Living Near a Major Airport," Report FAA-RD-72-72, June 1972.

maximum level of 111 db(A), over six hour periods.[6] The recorded flyovers were repeated every three minutes for one group, and every 90 seconds for the second group. The measured temporary threshold shifts for these subjects were negligible. Since temporary threshold shift is considered to represnt a precursor to permanent hearing loss, the finding of no temporary threshold shift in this study is interpreted to indicate that there is no danger of permanent hearing loss from high levels of aircraft noise.

The third study repeated the above experiment in a Japanese laboratory, with the same conclusions found.[7]

V. ANAYSIS OF CURRENT STANDARDS ON HEARING PROTECTION IN U.S.A.

The Occupational Safety and Health Administration (OSHA), the Environmental Protection Agency (EPA) and the U.S. Air Force have issued various statues and regulations for hearing protection. In 1971, OSHA issued regulations for the protection of the hearing of industrial workers.[8] These standsrds prescribe permissible noise exposure limits for an eight hour work day, which is a continuous A-weighted sound level of 90 dB. The OSHA standrds also incorporate the time-level tradeoff approach (5 dB incerase in level per halving of time) as seen in Table 5.1 . A maximum level of 140 dB is also specified for any impact or impulsive noise exposure. The EPA has recommended an average equivalent noise level of 70 dB(A) for continuous 24-hour exposure as the maximum exposure level required to protect hearing with an adequate margin of safety.[9] The EPA criterion is extremely conservative, however, and is based on the probability of negligible hearing loss (less than five decibels in 100% of the exposed population) at the

6) : Ward, Cushing and Burns, "TTS From Neighborhood Aircraft Noise," Journal of Acoustical Society of America, Vol. 60, No. 1, July 1976.

7) : Kabuto and Suzuki, "Temporary Threshold Shift from Transportation Noise," Journal of Acoustical Society of America, Vol. 66, No. 1, July 1979.

8) : Occupational Safety and Health Administration, Code of Federal Regulations, Title 29, Chapter 27, Part 1910.

9) : U.S. Environmental protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, "EPA 550/9-74-004, March 1974.

human ear's most damage-sensitive frequency (4,000 Hz) after a 40-year exposure.

Table 5.2 shows 1982 Air Force Regulations on noise levels that are acceptable without hearing protection when the noise exposure occurs only once a day, for a given time of exposure.10)

able 5.1 Permissible Noise Exposure*

Duration Per Day (Hours)	Sound Level (dBA)
8	90
6	92
4	95
3	97
2	100
1 1/2	102
1	105
1/2	110
1/4 or less	115

*When the daily exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered rather than the individual effect of each.11)

Table 5.2 Limiting Values for Total Daily Exposure12)

Duration of Total daily Exposure Time (T)
*As A Function of A-weighted Sound Level (dB(A))***

Sound Level,dB(A)	T* (Minutes)	Sound Level,dB(A)	T* (Minutes)
Above 115	Ear Protection Required		
115	2.2	96	60
114	2.7	95	71
113	3.2	94	85
112	3.8	93	101
111	4.5	92	120
110	5	91	143
109	6	90	170
108	8	89	202
107	9	88	240
106	11	87	285
105	13	86	339
104	15	85	404
103	18	84	480
102	21	83	571
101	25	82	679
100	30	81	807
99	36	80	960***
98	42	79	1142
97	50	78	1358
		Below 78	No limit

10), 11) : U.S. Air Force Regulation 161-35, April 1982.

12) : U.S. Air Force Design Note 3F1, January 1974.

* Rounded to nearst 0.1 below 5 minutes and nearst integer above 5 minutes.

** The A-weighted sound level is used to assess hearing damage risk due to exposure to noise ; for engineering noise control, other measures are reqired. These limiting values apply to the estimated noise level in the ear canal. These limiting duration of daily exposure at any noise level can be determined from the equation :

$LDD(Hours) = 16 \div \exp[\ (L-80) \div 4\ ] = \exp[\ (96-L) \div 4]$, *where* L is the A-weighted sound level, measured with slow time constant.

*** If exposures longer than 16 hours at levels above 80 dB(A) do occur, allowexposed personnel to recover in a relatively quiet environment (less than 70 dB(A)) from the noise for a period at least as long as the exposure duration.

VI. EFFECT ANALYSIS OF HEARING PROTECTION

Since work must often be carried out in high noise level environments, much attention has been given to met

hods of hearing protection. Earplugs, when they are the correct size and are inserted to form a good acoustical seal, provide good attennuation below 500Hz. They are also comfortable to wear. Figure 6.1 shows the attenuation rate of typical earplugs. Earmuffs, whether liquid or foam filled, provide attenuation as great as that of earplugs, but they are not comfortable to wear for very long. The solution that provides the most protection is a combination of earplugs and earmuffs. Although the total attenuation provided by the two is not as great as the sum of the attenuation provided by the devices individually, Figure 6.2 clearly illustrates that the two working in tandem provide greater attenuation and more protection for the listener.[13)]

13) : U.S. Air Force Design Note 3F1, January 1974.

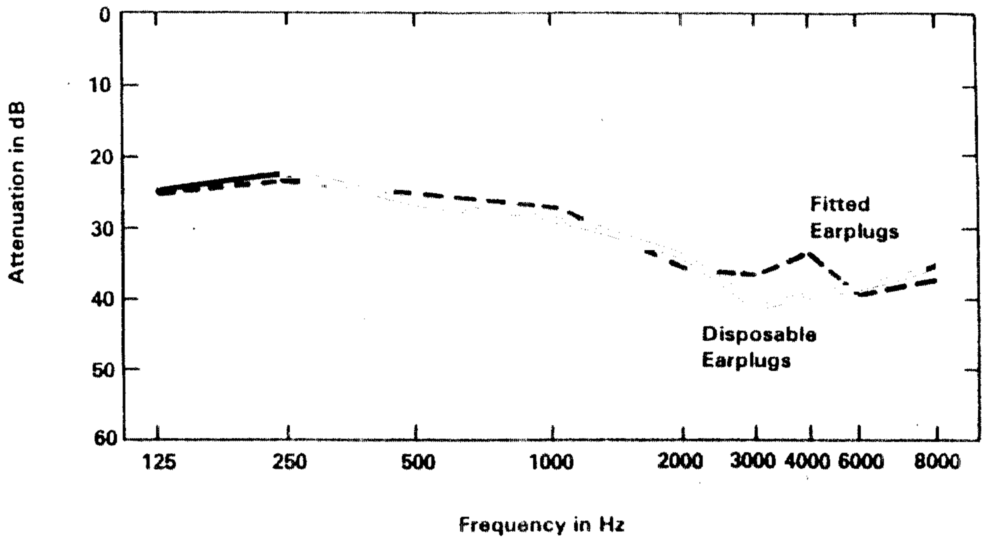

Figure 6.1 Attenuation by Earplugs [14]

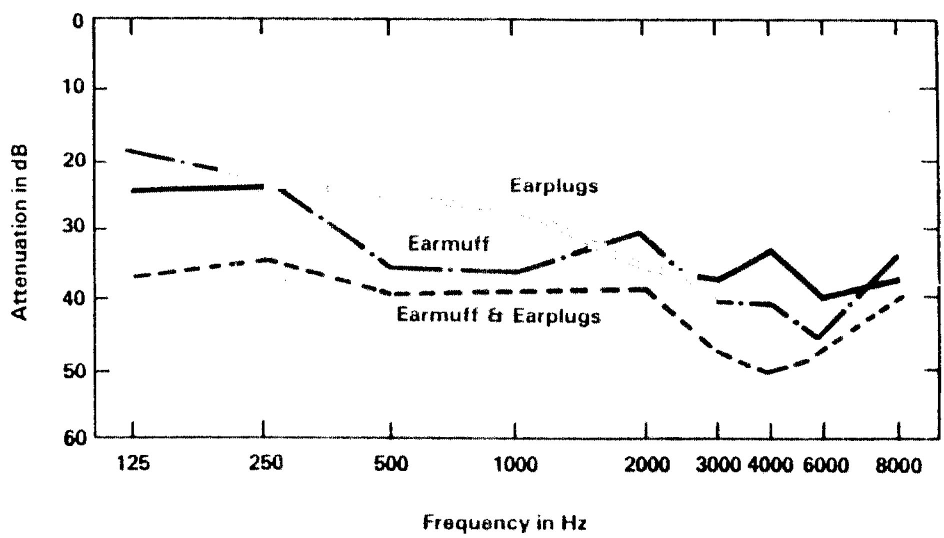

Figure 6.2 Attenuation by Earmuffs Combined With Earplugs [15]

14), 15) : U.S. Air Force. Design Note 3F1, January 1974.

Ⅶ. CONCLUSION

Research continues in the area of hearing damage as a result of aircraft noise, but the conclusions from the studies discussed above may be summarized as follows :

1. The flight crew of an aircraft will incur virtually no hearing damage, if the crew follows the proper procedures of wearing earplugs and earmuffs and of regulating flight time.

2. The aircraft passengers is at virtually no risk of hearing damage from interior noise. The passengers in an aircraft would have to fly an extraordinary number of miles over a long period of time before they would be in danger of any hearing loss.

3. The people in a community surrounding an airport are in no danger of hearing damage due to aircraft noise under normal circumstances. Persons on the ground exposed to aircraft overflights would typically not experience any temporary hearing loss due to the relatively short duration of the noise exposure.

4. A greater degree of temporary and possible permanent hearing loss can result in the case of long exposure times in certain small propeller driven aircraft.

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