How As a Passenger One Can Use HFE Countermeasures to Minimize Noise Pollution Aboard Consumer Aircrafts.

QAS 515 – Term Paper
Olivier W. Gill
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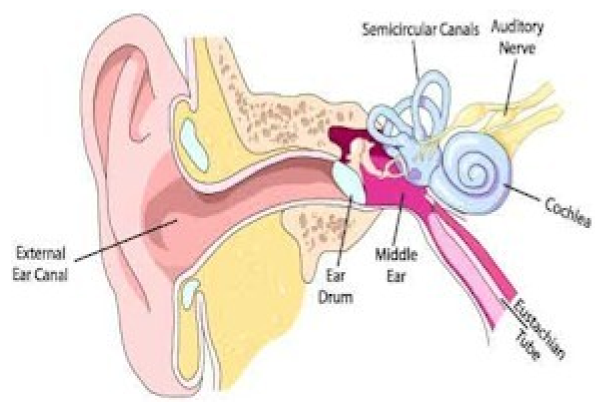
Some of us have been near an airstrip to watch airplanes taking off and landing. What a rush seeing and hearing these massive marvelously engineered objects of human creativity take off and land. Not only is it a visually stimulating experience but it is an auditory one as well, research shows that if one is placed within one hundred yards of an airplane taking off the average decibel level is around one hundred and twenty decibels. [Ref 1] These are very dangerous levels as studies have proven that a human can loose hearing when exposed to a noise level of one hundred and ten decibels for a period of one minute and twenty-nine seconds. [Ref 2]

Although there have been many advances in reducing aircraft cabin noise the technology still has not canceled out the noise completely in commercial aircraft or to acceptable levels where some hearing loss does not occur. Depending on the commercial airplane one travels on and where on the airplane a passenger is seated, aircraft cabin noise varies between ninety-five and one hundred and fifteen decibels at peak levels. [Ref 1] Taking a flight from New York JFK to Paris France CDG takes on the average of seven hours and sixteen minutes [Ref 3]; this is plenty of time for damage to be inflicted to our auditory system. Therefore, airplane travelers are being exposed to dangerous levels of noise pollution.

In order to understand the heath implications it is necessary to describe at a high level, how the ear works, how we are able to hear a sound and what is noise.

Our auditory system is comprised of the following: [REF 3]

- External ear
- Ear canal
- Eardrum
- Auditory Ossicles
- Cochlea
- Auditory nerve



Sound waves such as sinus and saw tooths enter external ear, pass through the ear canal, and cause the eardrum to vibrate. These vibrations are passed to the ossicles and create pressure waves in the cochlea's fluid which facilitates the movement of the thousands of receptors located on the walls of the cochlea. These sensors produce electrical signals that the auditory nerve transmits to the brain. At this point the brain then processes the signal and is identified by sound.

Sound is composed of the following three very distinct variables, frequency, intensity, and duration. [REF 4]

Frequency: The sound energy that passes through the external ear is a wave form or forms, which are physical entities and gives the sound pitch. This energy is measured by Hertz (Hz) or how many oscillations or cycles there are per second. We cannot hear sounds below 20 Hz or over 20,000 Hz however we are able to perceive sound between this range by feeling the sound's vibration. The frequency range of a normal conversation is between five hundred and three thousand

Intensity: The unit that is used to measure the loudness of a sound or its intensity is the decibel (dB). Humans are able to perceive sounds between -10 and 25 dB.

The **length** or duration of a sound is how long a sound lasts; this variable is necessary to calculate the risk of exposure to a sound and is measured in seconds. This risk can be qualified by the following scenario: a five second high intensity sound around one hundred and thirty dB can be just as bad as listening to a two hour less intense sound.

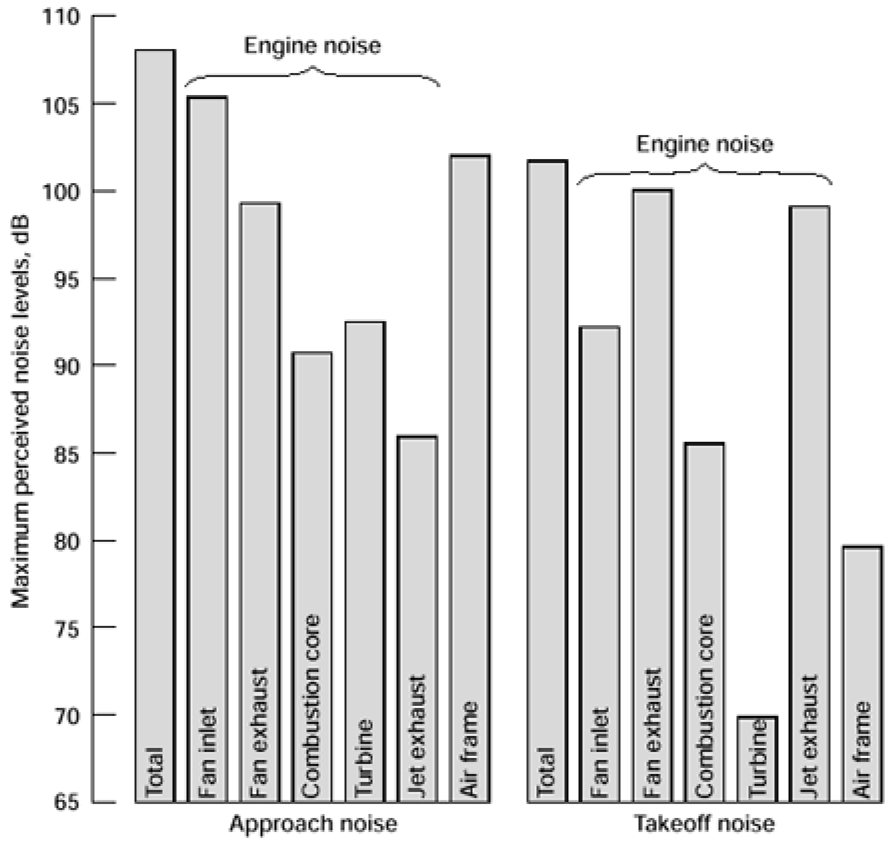
Scientists and medical practitioners quantify the potential of hearing damage by measuring the duration of the intensity and frequency of sound that a human is being subjected to or has been subjected to.

Noise is very personal in nature. Some people can be offended by rock music; others have no problem listening to classical music for hours. There is even a genre or type of music called Noise. Noise is to the person being subjected to it any unwanted, unpleasant or un-comfortable sound of varying duration, intensity and frequency. [REF 4]

Looking at the following table [REF 5] demonstrates that there is some intense power emanating from an airplane.

Noise Source	**Decibel Level**	**Comment**
Jet take-off (at 25 meters)	150	Eardrum rupture
Aircraft carrier deck	140	
Military jet aircraft take-off from aircraft carrier with afterburner at 50 ft (130 dB).	130	
Jet take-off (at 305 meters. Boeing 707 or DC-8 aircraft at one nautical mile (6080 ft) before landing (106 dB); jet flyover at 1000 feet (103 dB); Bell J-2A helicopter at 100 ft (100 dB).	100	8 times as loud as 70 dB. Serious damage possible in 8 hr exposure

Before focusing on how to try to quell this sound or noise (as it is hard to imagine that someone could enjoy these sounds) it would be important to analyze from where on an aircraft sound is being generated.[Graph from REF 6]

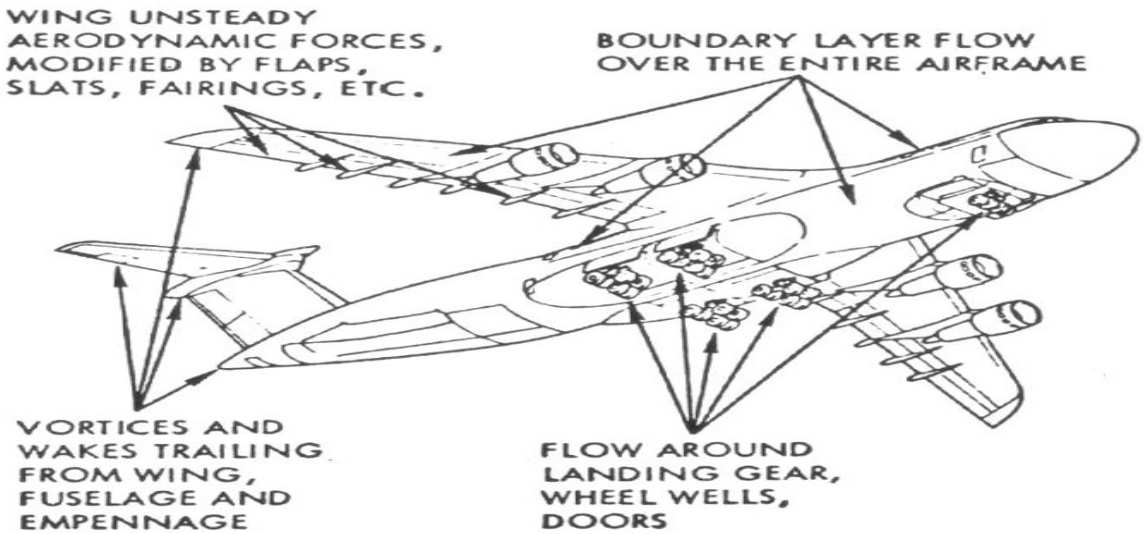


An aircraft will produce noise when the engines are turned on, while the aircraft is waiting for and or on the way to taking off, takes off, and en route to a destination at any altitude and finally landing. [REF 7]

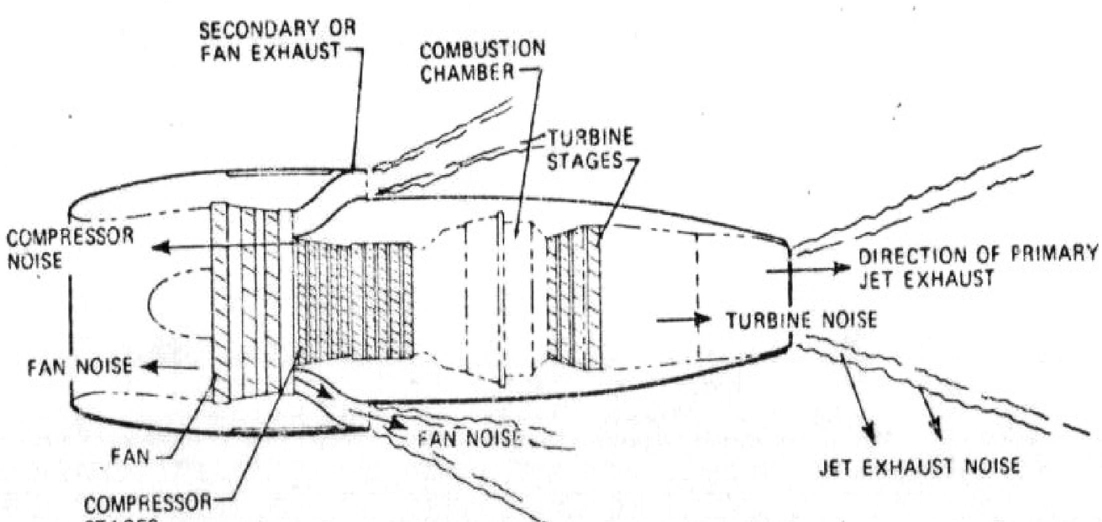
Following are the areas from where noise comes from an aircraft: [REF 7]

- **Aerodynamic noise** is caused by airflow around the aircraft fuselage and control surfaces. The noise will increase as the airplane goes faster and also at low altitudes due to the density of the air.

The air shearing caused by the landing gear, landing gear doors, flap edge flows also contribute a significant part of noise especially on larger aircrafts. [REF 6]



- **Engine and other mechanical noise** are caused by high rotational speed and fast movement of the moving parts. We can see from the graph on page 4 that the majority of the noise comes from the engine. [picture from REF 6]



The aircraft propulsion system could also include the noise coming from propellers. [REF 8]

- Noise can also originate form the **aircraft systems** such as the Auxiliary Power Unit which is an on-board generator used in aircraft to start the main engines and to provide electrical power while the aircraft is on the ground. Also cabin pressurization and conditioning systems also are the culprits.

- **Vibrations of aircraft parts** also cause noise. Also loose articles in the galley, loose luggage in the cargo hold will contribute to noise. [REF 9]

"The aviation agency regards a noise level of anything less than 65 decibels as acceptable from an environmental standpoint, but several studies have shown that noise levels of 60 to 65 decibels are annoying to 9 percent of the people sampled" [REF 10]

Some aerodynamic, engine and system noise is somewhat dampened when inside of the cabin of the aircraft thanks to some insulation, however noise still gets into the cabin and as we will see most of it does.

It is important to note that depending on where a passenger sits he or she will be exposed to more noise than others. The back of the plane is noisier than the front [REF 9]. Also, if a passenger sits near the food preparation area or near the lavatories there will noise as a consequence of the activity being performed in that particular area. For example sitting near the lavatories, lavatory doors can be heard opening, locking, un-locking and closing, the noise of the flush. These can be quite disturbing. Also sitting next to a crying child could be problematic. [REF - Group discussion board – Assignment Chapter 7 – Feb 27, 2008 Thread – Question Gill – Noise Canceling]

There are a few standards that guide airline manufacturing firms design airplanes with acceptable noise levels inside and out:

5129:2001 (Measurement of sound pressure levels in the interior of aircraft during flight) from the International Standards Organization provides a guideline that shows acoustic professionals how to measure sound inside of an aircrafts cabin during flight.
Annex 16 – Environmental protection, Volume 1 – Aircraft Noise to the Convention on International Civil Aviation [REF 11 & 12]

There have been many advances made in reducing noise from the actual airplane's components:

- "Reducing jet exhaust velocities and increasing mass airflow to achieve thrust could reduce the noise by 3 – 5 dB." [REF 13]

- "Nozzle lip treatment is being studied to ameliorate the speed of mixing jet exhaust, and minimize turbulence/vibration in the mixing process. This technique could reduce noise by 2 – 4 dB." [REF 13]

- "By matching the fan tip speed to the engine bypass ratio and a reduction of the fan tip speed to minimize aerodynamic shocks ahead of fan rotor blades would optimize rotor speed thereby decreasing noise by 2 – 4 dB." [REF 13]

- "By minimizing aerodynamic shocks ahead of fan rotor blades engineers would be able to optimize rotor sweep thereby decreasing fan tone intake noise by 1 – 3 dB." [REF 13]

- "By reducing unsteady loading on stators and reducing efficiency of radiation of stator noise and optimization of Stator Sweep and Lean would be reached lowering the noise by as much as 5 dB." [REF 13]

- "By minimizing the flow separations around landing gear engineers could lower the noise by 3- 4 dB." [REF 13]

A four step process is required to develop these noise reduction or abatement technologies: [REF 14]

Phase 1 – Computational modeling
Phase 2 – Scale model wind tunnel test
Phase 3 – Isolated engine static noise test
Phase 4 – Flight test validation

A new trend in the airline industry is to focus on cabin redesign. "The cabin design can have a big impact on the noise levels during flight" [REF 15]. Boeing has recently partnered with LMS in Belgium to work on predicting acoustic properties of new cabin configurations via software and acoustic modeling even before physical testing, this is a huge cost savings.

Insulation material is also being installed in aircrafts. These are improved lightweight sound absorbing blankets that have been invented. [REF 16] Some are in use today such as the Aero Sound Shield. [REF 17]

All the above solutions and research is centered on passive noise reduction techniques, which require structural modifications.

Active noise control techniques can provide significant reductions in aircraft interior noise levels without these structural modifications. Following are a few examples:

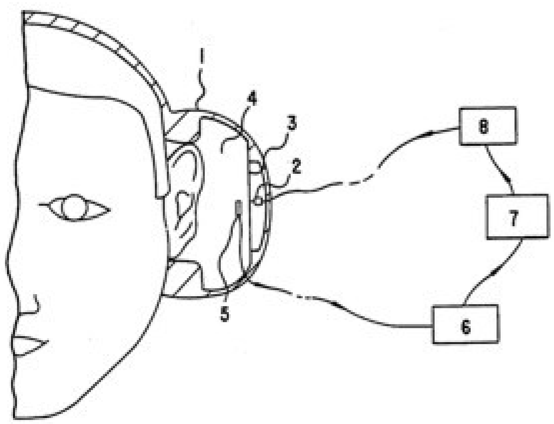
A few companies have invented an active noise control technology which is able to analyze sound and vibration and send out the reverse waveform through powered speakers that are located in the cabin, thereby canceling the noise. [REF 17, 18, 19]. These are not yet available on commercial aircraft. We will see in a subsequent section that this is the same concept that certain noise reduction headphones use.

As passengers on commercial airlines we have a long way to go towards traveling within silent cabins. However, in the mean time passengers that are not willing to wait for this silence to occur are presented with a few valid options in the form of active or passive headphones and passive ear plugs.

As with redesigning aircrafts to ameliorate noise reduction, headphones also use active and passive technology.

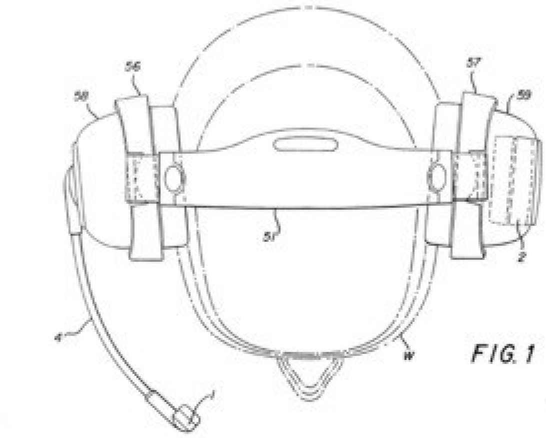
We will first describe active noise canceling technology and put this technology in historical perspective.

“A wave 180 degree out of phase and with the proper amplitude added to the first wave, will cancel the first wave” is the basic principle of Active Noise and Vibration Cancellation (ANVC). This principle originated by non other than Leonardo da Vinci in the 15 century. [REF 20] He described how water in two canals can "cancel each other" when they meet, given that the timing (phase) is correct. Thus was born the concept. It was not until 1954 that Olsen and May presented a solution to accomplish active noise control in a headset using the same principle da Vinci thought of many centuries earlier using water as an example. [REF 20]



In 1956 an ANVC analogue transformer was built. This technology is still being used today in ANVC devices except it is in the digital domain, thus a microprocessor is used. [REF 20]

On a 1978 flight to Europe, Amar Bose, the founder of Bose Corporation tried a pair of airline supplied headphones and he could not enjoy the music due to tremendous noise produced by the aircraft. Right then and there he drew up calculations and sketches of the modern day active noise canceling headphones, a decade later they were in production. [REF 21]. Many people think that Bose was actually the creator of today’s technology; however, it is now known that Chaplin and Englishman first put out a patent in 1986 for the first noise canceling headphones. [REF 20]



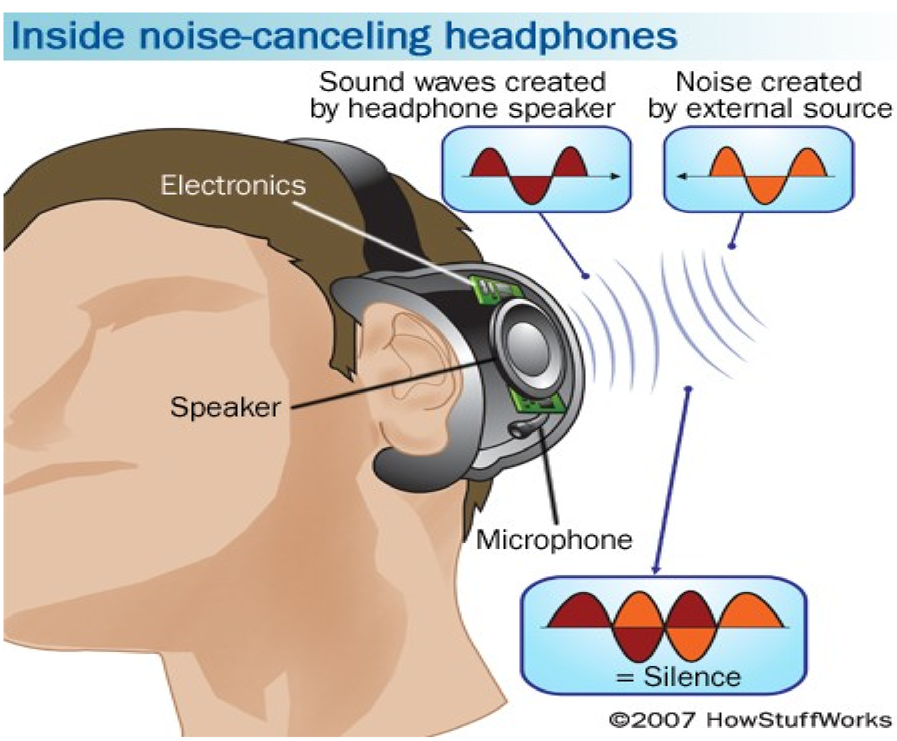
However Amar Bose was the first to successfully commercialize headphones specifically for airline passengers. In 2000 the BOSE QuietComfort® could be purchased. [REF 20]

Sony corporation invented an in ear canal headphone or earplug that works the same way as out ear headphones.[REF 22]

Passive headphones do not have any active circuitry, they are any headphone that are built with material that prevents sound waves from entering the ear canal consequently most types of headphones can provide some passive noise reduction. That's because the materials of the headphones themselves block out some sound waves, especially those at higher frequencies. Some of the best headphones are engineered with high-density foam or other sound-absorbing material. Research demonstrated that passive headphones reduce noise by 15 to 20 decibels (dB). We can see that this reduction is not appropriate for airline travel even if an airline emits 75 dB of noise wearing passive headphones will still keep the user in the 55 – 60 dB range which is not optimal. [REF 21]

The most effective solution or HFE countermeasure for today's airline traveler is the active headphone or earplug. Let's take a look at how active headphones or earplugs are able to remove an additional 20dB of ambient noise compared to passive headphones.

Inside of the active headphones there is a microphone that is placed near the ear. This microphone listens only to frequencies that are not being blocked passively. Connected to the microphone is a microchip that analyses the incoming frequency and intensity of the sound wave and automatically generates a sound wave that is 180 degrees out of phase with the original wave. In other words this anti sound wave along with the noise coming in is summed up to silence. Both of these waveforms are then passed on to a speaker and mixed with any other audio. The headphones need power in order to power the circuitry and the speaker, consequently a battery is used, and this is why active is used to describe these types of headphones as they need power to operate them. [REF 21]



The headphones that are on the consumer market today which do use ANVC technology are only able to drone out low frequency waveforms and not high frequency ones thus relying on the passive or structural nature of the earphones to aid in eliminating high frequency. There are a few reasons for this first is that it simplifies the electronic circuitry, and second active cancellation is not as effective at higher frequencies since higher frequency waveforms have a shorter wavelength.

These are not audiophile headphones since as mentioned earlier it mixes in another audio signal which the original one and this distorts the original signal. However, lower audio quality is the price consumers have to pay for noise reduction.

There are many companies that have excellent quality Noise Canceling headphones or plugs: JVC, Panasonic, Bose, Audio Technica, JBL, Logitech, Able Planet, Sennheiser, AKG, Sony, Etymotic Research. The prices can range from 100 – 600 USD. As with any responsible purchase the consumer would have to research reviews. There are great review sites like Cnet, ZDnet, The Travel Insider, and Amazon. At some point trying them on at a retail outlet would give an added advantage. The lucky consumer would be able to do a real A,B,C,D comparison on a real flight. The New York Times wrote an article where one of their reporters did just that. [REF 23]

Just as the interpretation of noise is very subjective so is the comfort factor and fell of headphones and plugs. Brand alliances, quality of construction, the weight are some of the characteristics that a consumer might be looking for choosing the right model. Consequently, different characteristics are important for different consumers.

OSHA has published permissible noise exposure limits for the workplace these can also be assess noise in the cabin of the aircraft [REF 24]

Noise Exposure Level Limits	
Noise Intensity (dB)	**Exposure Limit(hrs. per day)**
90	8
92	6
95	4
97	3
100	2
102	1.5
105	1
110	.5
115	.25

If a passenger is aboard an aircraft without noise canceling headphones or plugs there is a certain risk of noise overexposure. As mentioned earlier the noise of a cabin can range from best case scenario 95 – 100 dB. The OHSA table demonstrates that depending on the duration there is potential risk to overexposure which is detrimental to the health. Since wearing active noise canceling headphones reduces the noise by 40dB (20 dB from the insulation material and 20 dB from the 180 degree phase circuitry) passengers, who are wearing these they are well within the limits and are protected from overexposure.

There are physical consequences that occur if a human is exposed to high noise intensity for a particular duration.

In the next section we will explore some of these factors and prove that passengers should protect their ears when traveling aboard consumer airlines.

Although passengers are never exposed to very high levels of noise for example 130 – 140 dB it is worth noting that at 130 dB ear pain may occur and at 140 dB a human's eardrum may rupture.

It has been proven that exposure to noise over 90 dB that is constant for several hours contribute to hearing impairment. [REF 24]

Exposure to noise over 90 dB for 8 hours a day for several years causes permanent hearing damage.

In addition to adverse physical consequences there are also adverse psychological factors that tie into physical factors of being overexposed to noise. For example a passenger could experience the following conditions:

Distraction	Loss of appetite
Fatigue	Headache
Irritability	Vertigo
Startle responses	Nausea
Sudden awakening	Impairment of concentration and memory.
Poor sleep quality	

Some people with a sensitive inner ear have had adverse reactions by wearing noise canceling headphones. There is a possibility that not all the frequencies of a wave get canceled, consequently there are some low frequency vibrations that stimulate the balance receptors inside of our ear. The brain interprets these vibrations to mean that the head is moving but the eyes report otherwise. In essence there seems to be a short circuit in the brain causing the person that is afflicted by this phenomenon to feeling dizzy, out of balance or sea sick. [REF 25]

This paper has been passenger centric, let us think about the people who work aboard aircrafts, pilots, air cabin personnel, and marshals. They are subjected to high noise levels whenever they work. As a passenger and thinking of these employees hopefully the airline industry will eventually invest in equipping their aircraft with active technology that will eliminate the noise.

In the interim wearing noise canceling headphones or plugs is the only valid, HFE Countermeasure or solution to the un-silent aircraft cabin.

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