



# Aircraft Cabin Noise Reduction

— A Primer

**January 2021**



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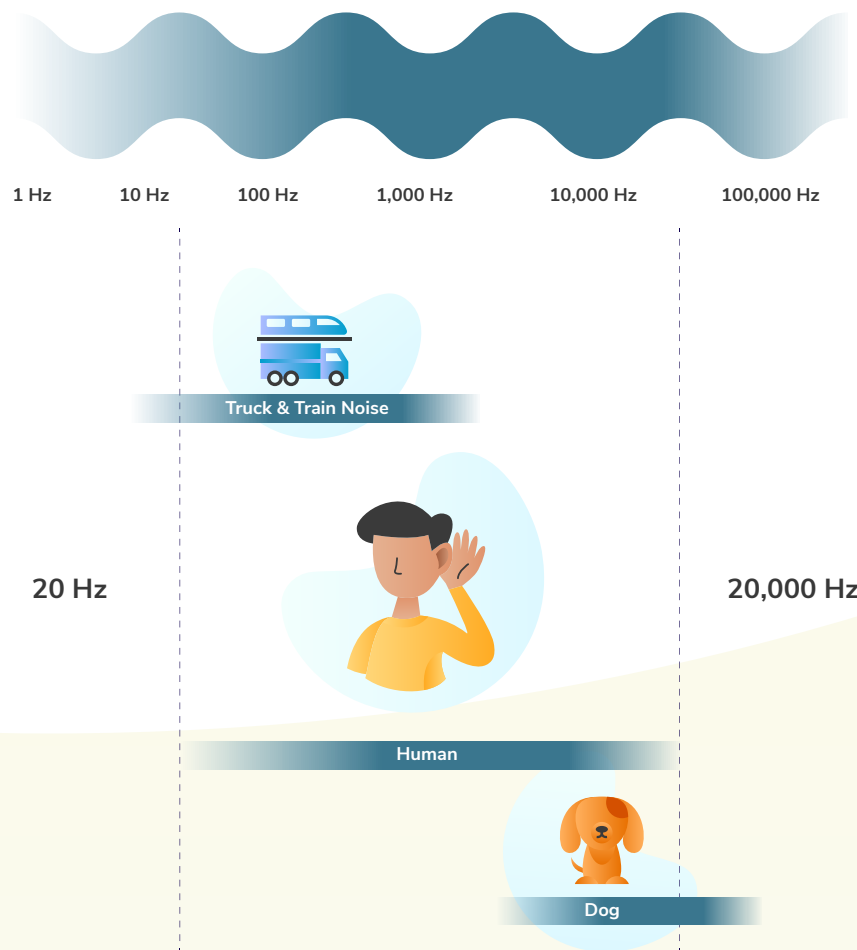
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# I. What is Noise?

Noise is unwanted sound that people can hear.

## 1. Human Hearing

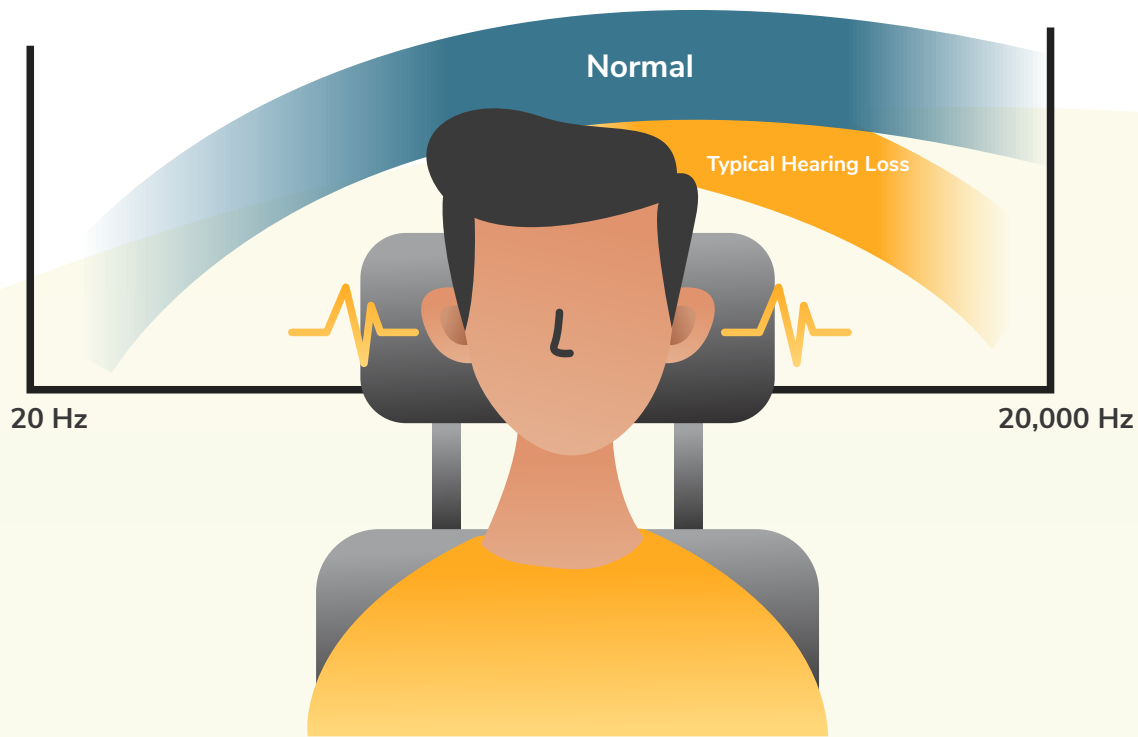
The human ear is sensitive to sounds whose frequencies lie between 20 and 20,000 cycles per second, or Hertz (Hz).



- The ear perceives the superposition of sounds at all frequencies.
- All of us are less sensitive to sound in the lower part of the hearing range below 500 Hz and in the higher part of the hearing range, above 6,000 Hz. The normal human is most sensitive in the 500 Hz to 6,000 Hz range. As we age, we lose hearing in the high frequency end of the normal hearing range.

- The human ear is non-linear: as the noise level decreases, the ear's sensitivity increases. Noise is thus usually given in decibels (dB), which is a logarithmic scale. A 10 dB increase in the sound pressure level corresponds to the tripling of the pressure fluctuation. Still, humans may only perceive it as a doubling in loudness. To measure the quality of sound abatement, one must select the proper metrics, taking into account the specificity of human hearing.

## Human Hearing Sensitivity



*Humans are less sensitive at the low and high end of the hearing range*

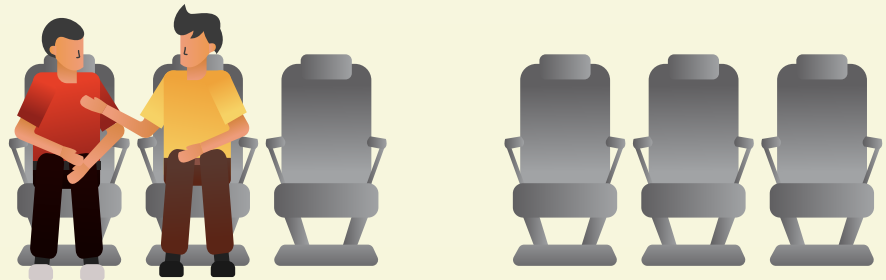
- Special decibel scales are used to reflect differences in hearing sensitivity. The A-weighted scale, in dB (A), accounts for the sensitivity reduction at the low and high frequency ends of the hearing spectrum.

## 2. Background Noise in Aircraft

- Background noise in aircraft affects both the comfort of passengers and the ability to carry a conversation.
- Normal conversation occurs at approximately 65 dB (A). Background noise that rivals that level interferes with normal conversation.

**100 dB(A)**

Older airline jet  
Aft Cabin  
Take-off/Climb



**90 dB(A)**

Modern airline jet  
Aft Cabin  
Take-off/Climb



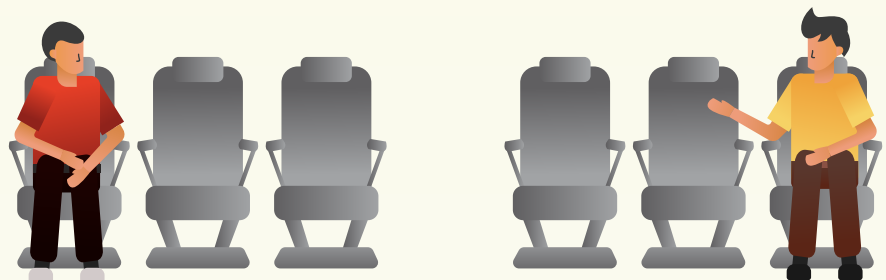
**80 dB(A)**

First Class  
High Altitude



**70 dB(A)**

Biz-jet  
salon  
High Altitude



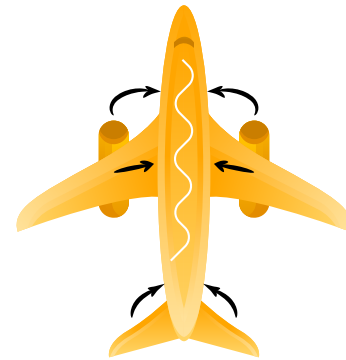
Background noise affects the distance at which conversation can occur

## II. Aircraft Cabin Noise

An aircraft cabin receives noise from many sources, external and internal.

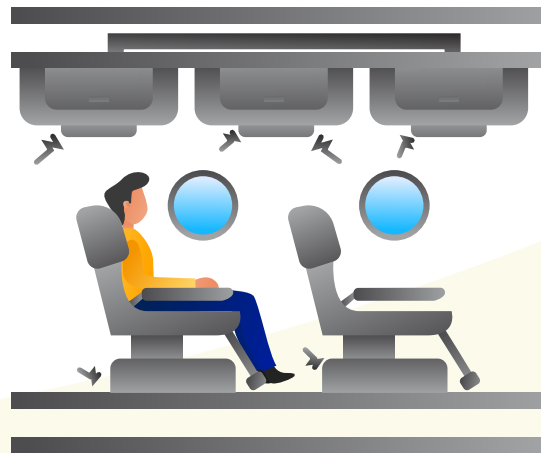
### External noise sources:

- Airborne engine noise
- Structure-borne engine noise, including fan and core imbalance
- Jet inlet and exhaust
- Turbulent boundary layer
- Antennae



### Internal noise sources:

- Air distribution and venting
- Hydraulics
- Electrical and lighting
- Auxiliaries
- Appliances, etc.



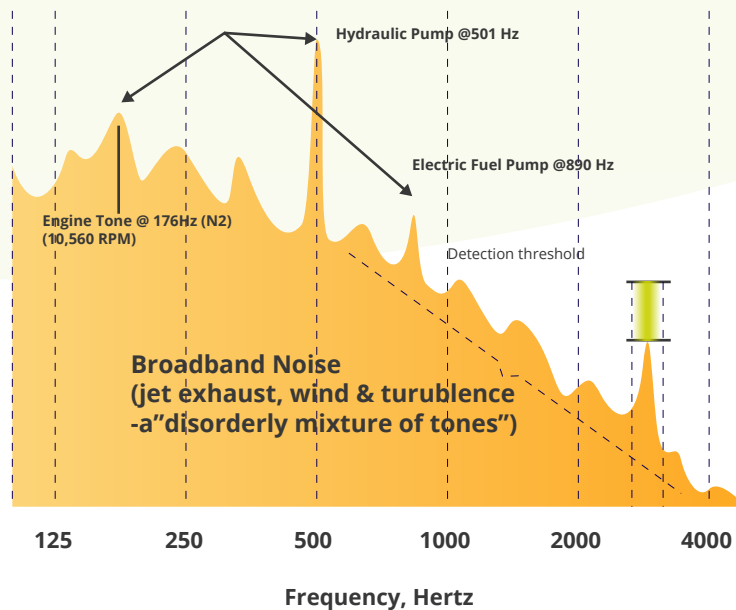
### III. Noise is a combination of Tones

Noise is a combination of tones occurring at various frequencies.

- The noise source may have a steady frequency: this is the case of noise initiated from machinery, which occurs at an integer multiple of the rotational speed (e.g. noise from fan imbalance at a frequency equal to the fan revolutions per second, noise from the hydraulic system at a frequency equal to the number of pistons times the number of revolutions per second). In such a case, we speak of tones.
- The source may be the superposition of small sources whose frequencies spread over the entire spectrum and whose relative phases are random: the noise is then broadband and random. Such noise is generated by wind turbulence and by jet exhaust.

#### Tonal noise - Typical airliner cruise:

Tone's 1Hz Amplitude must be 15dB-20dB above broadband noise in a band + 50Hz about ton's frequency to be detected by the human ear.



Aircraft noise spectra often show both tonal and broadband characteristics

- Tonal noise can be traced back to the equipment by identifying the frequency of the tone (APU, engine spools, gear mesh, fuel pumps, electrical system etc.)
- Broadband noise spectra (sound pressure density as a function of frequency) are characteristics of aircraft models. Appendages, like antennae, can also produce tell-tale spectral signatures in the cabin.

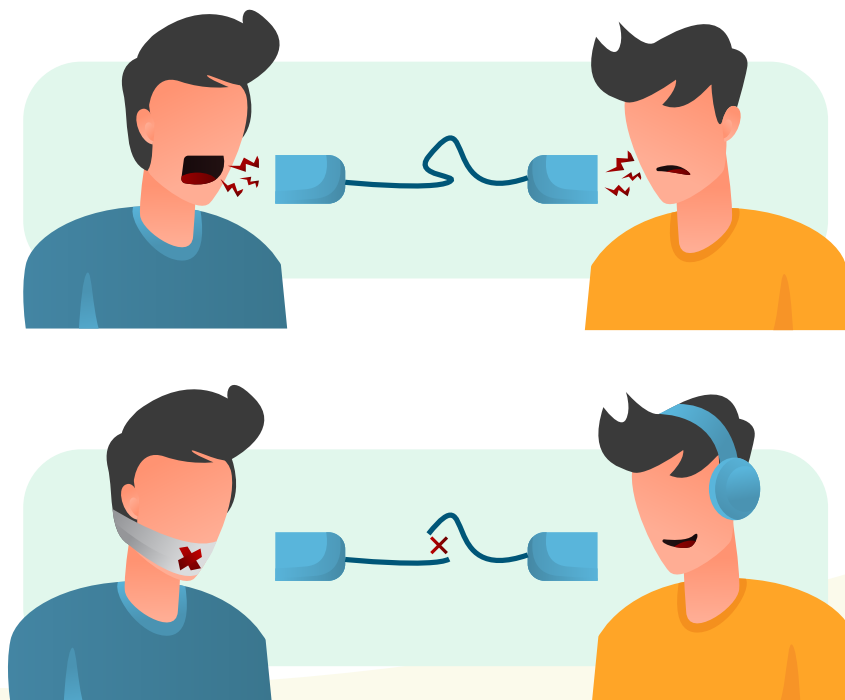
Noise analysis often uses a power spectrum to provide a measure of the sound energy generated in a specific frequency band:

- A standard analysis band is 1 Hz wide. Also commonly utilized are wider bands such as third-octave or octave bands. The power spectrum is calculated from noise measurement and recordings, and can be converted into decibel and weighted in various ways. One scale, for instance, weighs noise in frequencies below 1 kHz less heavily to "match" the human ear's sensitivity.
- Wind noise appears as a continuous line which is approximately flat (on the A-scale) below 1,000 Hz and rolls-off above 1,000 Hz. Tonal noise such as engine tones or pump noise appear as sharp peaks above the broadband noise level.
- Broadband noise tends to mask pure tone. Even if the 1Hz-band analysis of a microphone recording sharply detects a tonal peak, one must consider the ambient broadband noise level about 50 Hz above and below the tone's frequency to figure out the tone's audibility to the ear. At low frequency (500 Hz), and in an aircraft noise environment, the average human ear will notice the tone if it is 20dB above ambient; at high frequency, tones 15dB above ambient begin to be audible.

To understand masking, one should remember that broadband noise is the superposition of many random noise sources emitting in every frequency band of the spectrum. What these elementary sources lack in intensity, they make up in numbers. A tone which appears in a single frequency band must therefore be quite intense to be heard.



## IV. A Noise System Consists of: (1) a Source (2) a Path and (3) a Receiver



*The basic elements of a noise system  
Noise reduction can be attempted at any element*

- A noise source is the element that creates the initial disturbance. In general, the source is a vibrating body or surface.
- A noise path is a medium or set of media through which vibrating, or acoustical, energy propagates from one point to another – for example, through the skin, frame, and/or trim cavities and trim panels of an aircraft.
- The person or group who experience the quality or level of noise within the cabin are noise receivers.

## V. Noise Control Treats at Least One of the Basic Elements

Noise reduction can be addressed at the source, the transmission path, or the receiver. Each control point has advantages and disadvantages.

### 1. Treat the Receiver

Small aircraft operators often resort to headphones, reducing sound at the receiver. This is also typically done in cockpits. This method is usually not practical for passengers in larger aircraft.

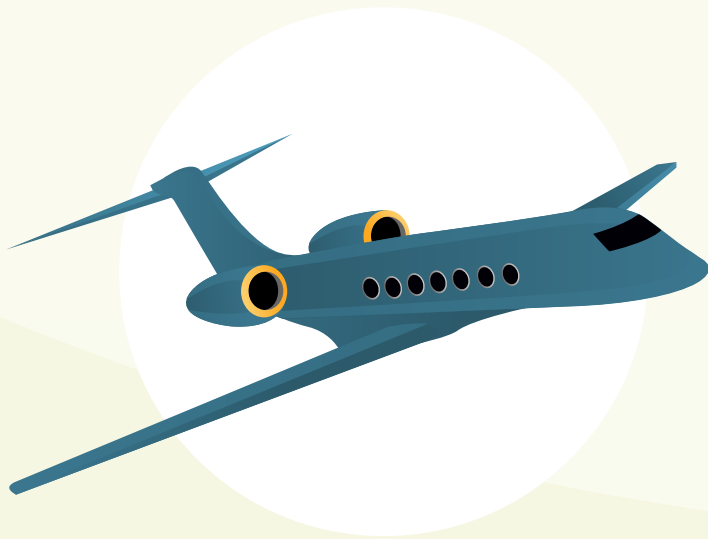


Reducing noise at the receiver is typical for small airplanes, but generally not practical in larger aircraft.

## 2. Quiet the Source

Treatment of the noise at its source is usually the most effective for localized noise problems, particularly for tonal vibrations. The vibration is eliminated before it spreads to the cabin of the aircraft.

Engine fan balancing is an obvious procedure to keep fan tones down. A poorly balanced engine generates low frequency noise and vibration felt through the floor and which can significantly increase cabin noise.



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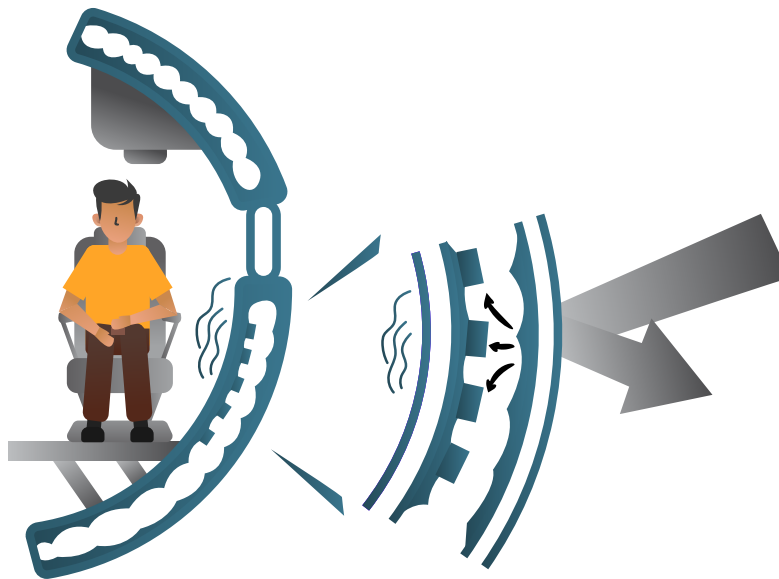
**Treatment of the noise source can be effective for localized, tonal sources. For example, actively tuned vibration absorbers are used to eliminate noise originating from engine imbalance, which is otherwise transmitted to the aft cabin in older generation airliners**

Successful examples of the elimination of noise at the source includes the elimination of hydraulic pump noise and the elimination of engine tone noise in aircraft with aft-mounted engines.

In some cases, however, source treatments are difficult to accomplish and can affect proper operation of the equipment generating the noise. In those cases, reductions may have to be realized elsewhere.

### 3. The Noise Path

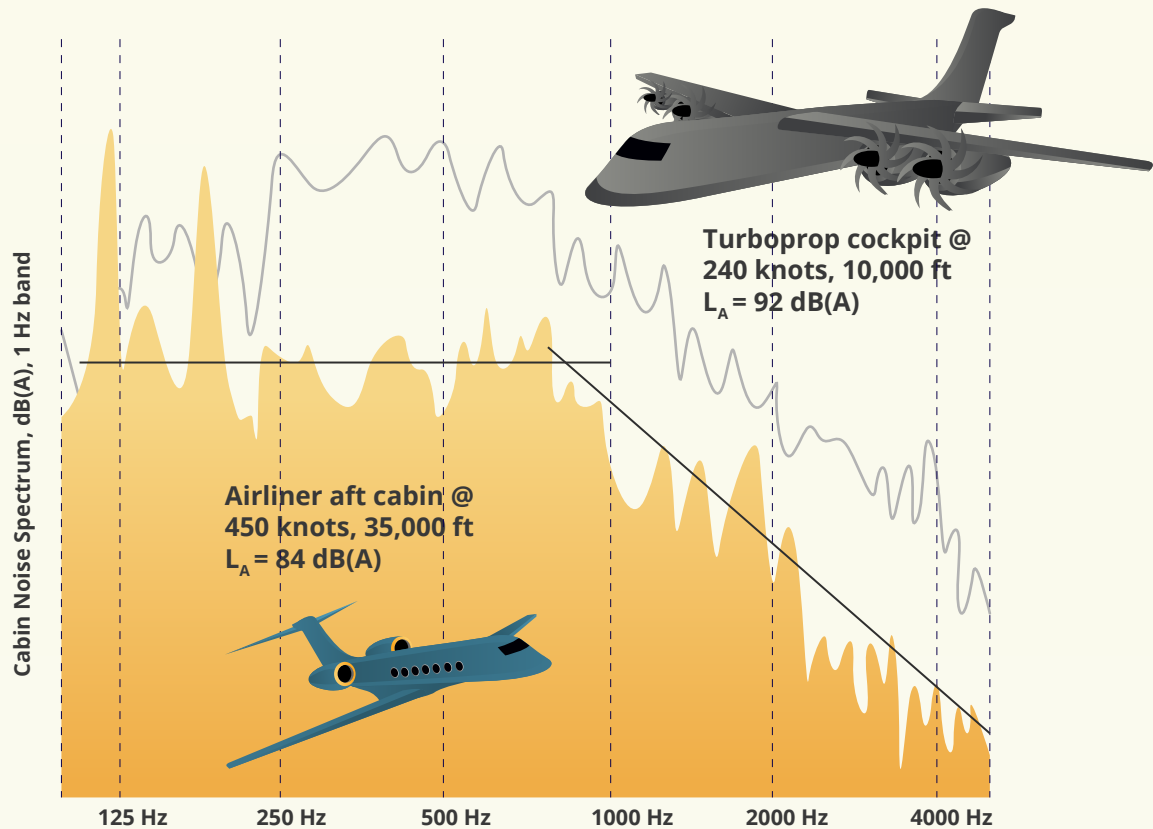
The noise path is the most common element at which to control noise. In its simplest form, a treatment in the noise path consists of material placed between the noise source and the receiver so that propagation of noise producing energy is reduced. A somewhat more complicated approach is to use absorber devices or even active systems to modify the sound transmission, so as to reduce noise at particular frequencies.



*Treatment of the noise path is the most common means to reduce noise in aircraft cabins.  
Noise path treatments are applied to the cabin walls and partitions*

Materials in the noise path must be carefully chosen and applied in order to be effective and efficient in achieving noise reductions. For example, not only air paths but also structural paths must be addressed. Assembly and/ or attachment of the materials must always be skillfully completed. Grounding of any internal panel to the aircraft will negate the benefits of much of the treatments intended to reduce cabin noises (More details in Section 8.)

## VI. Noise Varies Greatly According to Aircraft & Operating Conditions

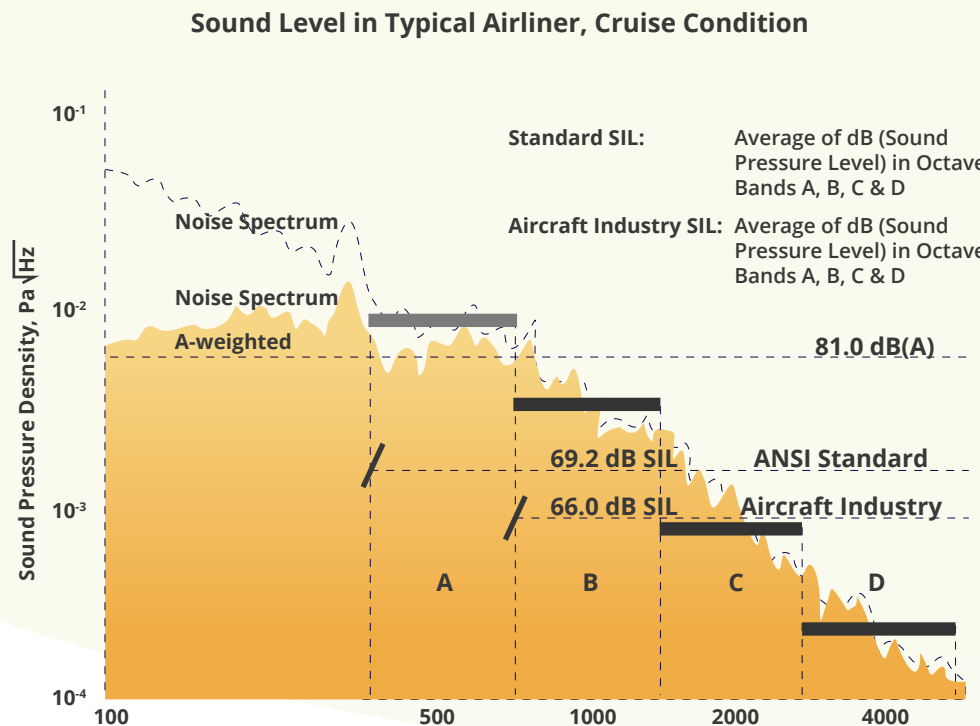


*Different aircraft and conditions create widely different noise patterns*

- Cabin noise spectra in jetliners are usually flat below 1,000 Hz on the A-scale, then roll off as an inverse power of frequency (a straight line on a dB vs. log Frequency plot of the noise spectral density).
- The slope of the roll-off depends on the diameter of the cabin, the sound-proofing treatment and the amount of absorbing surfaces within the cabin.
- Cabin noise increases with speed and decreases with altitude.

## VII. Methods for Expressing Noise

Several measures of noise are used in the airline industry. Two commonly used figures of merit include the measure of "Speech Interference Level" (SIL) and the measure of the A-weighted sound level  $L_A$ , stated in dB(A).



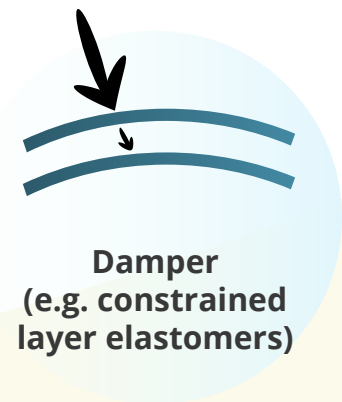
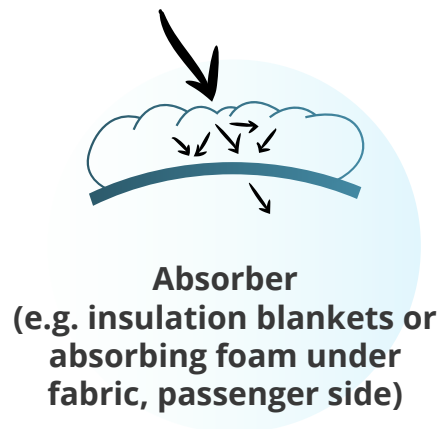
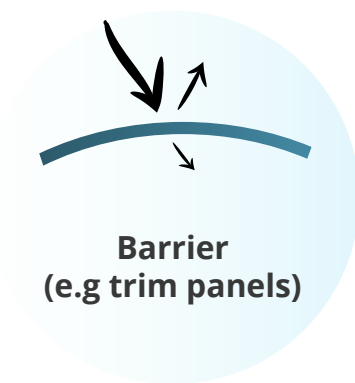
*Aircraft noise spectra often show both tonal and broadband characteristics*

- The Speech Interference Level commonly used in the aircraft industry uses three octave bands only, centered at 1,000 Hz, 2,000 Hz and 4,000 Hz. High frequency noise makes speech recognition more difficult. The SIL helps quantify the difficulty to comprehend speech. The aircraft industry SIL does not use the 500 Hz octave band (the ANSI standard). SIL can be helpful to compare acoustic trim panels or acoustic blankets. SIL fails, however, to capture the change in noise obtained by changing engine mounts, by balancing the engines or changing appendages such as roof-antennae.

- The A-weighted Sound Pressure Level approximates the response of human hearing. The most heavily weighted frequencies are in the 1,000 Hz to 5,000 Hz region. Above approximately 1,000 Hz, cabin noise decays as the inverse of frequency. After A-weighting, and as a rule of thumb, cabin spectra should flat on the A-scale from 100 Hz to 1000 Hz.
- The use of dB SIL is one of several methods to define contracted noise in an aircraft. SIL (Aircraft industry formula) does not, however, cover the discomfort associated with low frequency noise (engine, wind rumble) which does not enter into the SIL formula, nor does it cover the discomfort caused by narrow-band tones.
- Tones (fan, hydraulic and fuel pumps, etc.) must be considered separately since they may not measure on any of the aforementioned scales and may yet be very disturbing. Tones 10dB to 15dB above ambient (normalized 1Hz spectrum) should be looked at and their source identified as these tones could become troublesome, especially if sound proofing reduces the ambient level.

## VIII. Acoustic Materials Reduce Sound in the Noise Path

Acoustic materials may: (1) form sound barriers, (2) absorb sound, or (3) damp out vibration. Though these three methods of reducing noise are often confused, they are quite distinct methods and require different materials and strategies.

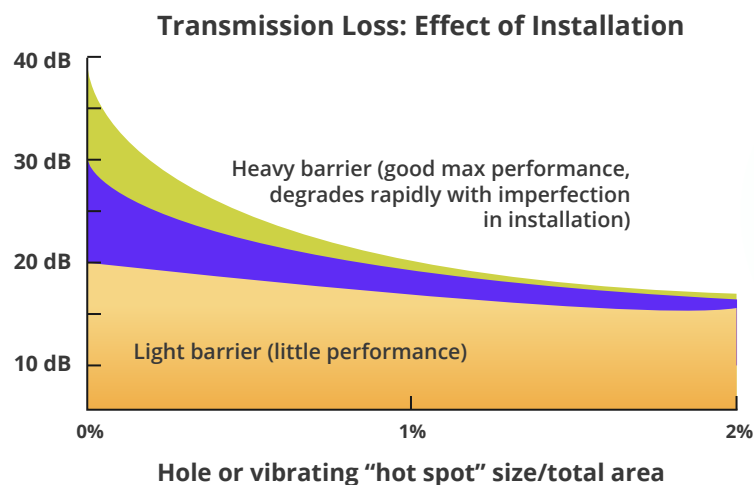
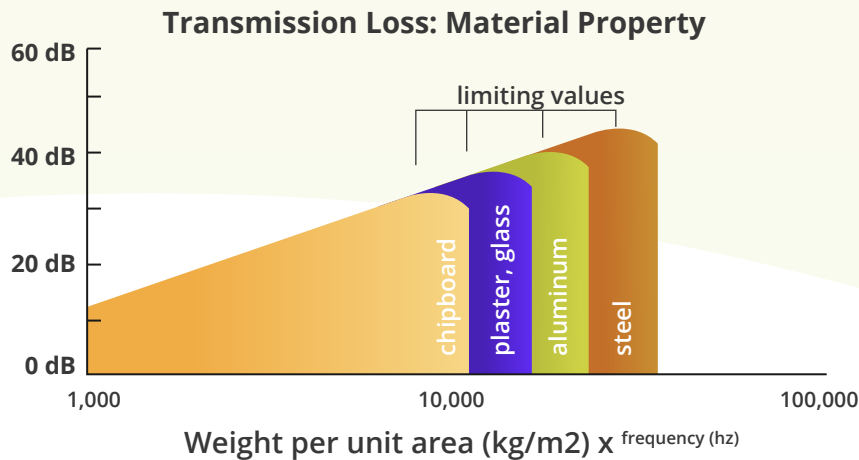


Aircraft noise spectra often show both tonal and broadband characteristics



## 1. Barrier Materials Reduce the Amplitude of Transmitted Sound Waves

- Barrier materials reduce transmitted noise by reflecting sound. Transmission loss, stated in decibels, describes the effectiveness of the barrier. Transmission loss is principally determined by the mass of the barrier. Doubling the mass increases transmission loss by six decibels (6 dB) at most frequencies.
- A good barrier, in order to interfere effectively with sound waves, should be continuous and without openings or gaps between panels.
- Typical sound barriers in airplanes include the skin, windows, bulkheads, and floor and wall structures.



Good noise barriers should be heavy, non-porous, and have neither gaps, holes, nor vibrating "hot spots"

## 2. Sound Absorbing Materials Reduce Acoustic Energy as Sound Waves Pass Through

Sound absorbing materials reduce the acoustic energy of the sound waves by promoting interactions between the air molecules and the sound absorbing medium.

- A good sound absorbing medium must be porous to let air through and tortuous, meaning that the air is not offered a straight path but is channeled through a long tortuous path with many changes in direction.
- Mounted to a reflective surface, absorptive materials work better as sound passes through the medium twice.
- Absorption inside of passenger occupied compartments can reduce noise from 2 to 4 dB.

## 3. Damping Materials Reduce Resonant Vibration

Damping is usually used to "fix" sound barriers when the sound barrier ceases to be effective due to a structural resonance. At resonance, the structure can be easily excited and will radiate and possibly amplify noise. Damping reduces noise transmission / amplification by converting vibration energy to heat.

Tapping a crystal glass produces a loud ring.



Damping eliminates the ring.

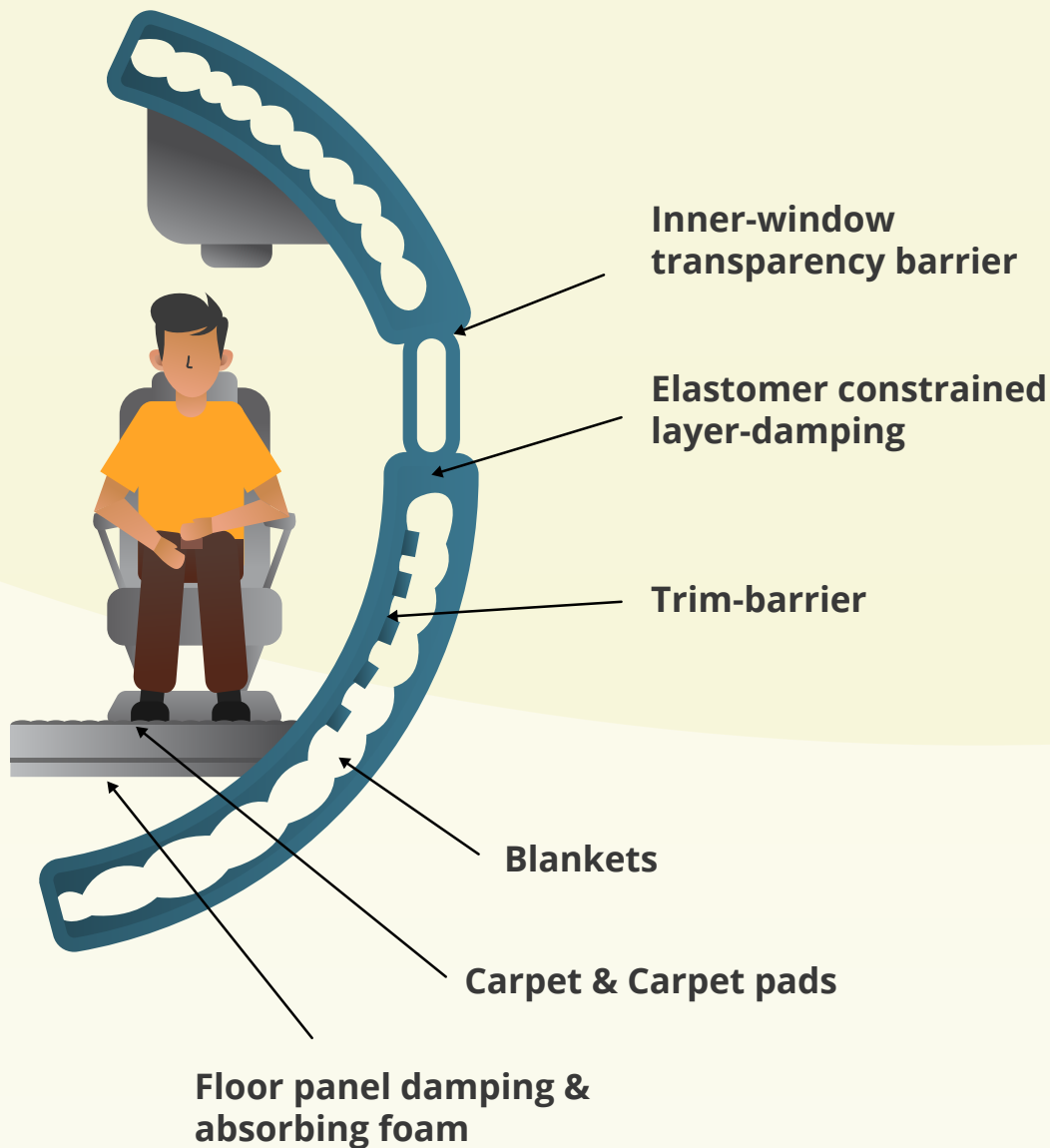


*Damping converts vibration into heat*

Damping is often accomplished by using visco-elastic materials that generate heat as they are deformed. Cleverly designed mechanical devices can also provide excellent damping. The methods of attaching or connecting damping materials to vibrating areas can greatly determine their effectiveness. Care must be taken to assure that damping materials and devices work as intended.

## IX. Acoustic Materials are Widely Used in Aircraft

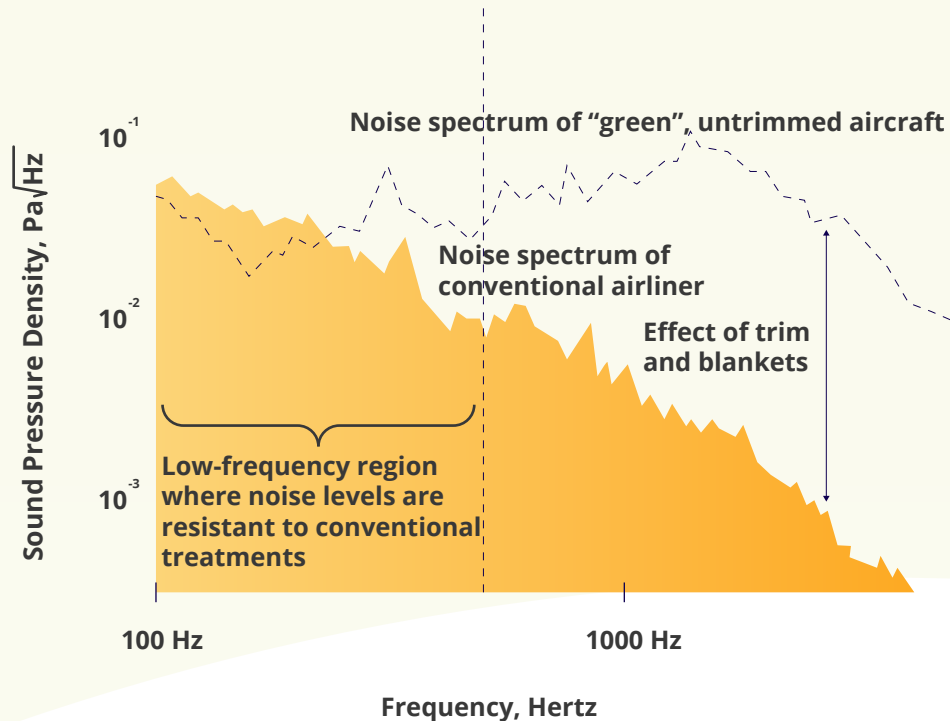
All three types of acoustic materials - (1) barrier, (2) absorption, and (3) damping - are commonly used throughout aircraft.



*Acoustic materials are used throughout airplanes*

## X. Low Frequency Noise

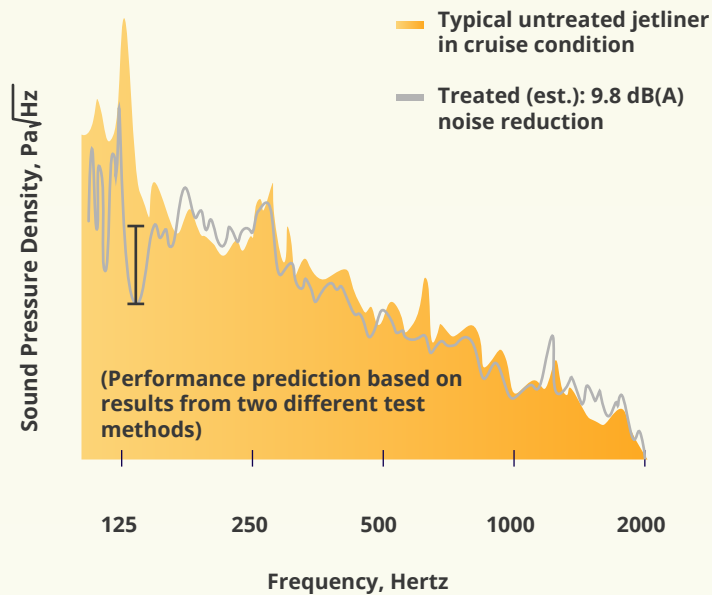
Noise in even a well-finished cabin can remain loud at low frequencies. The reason is that wavelength increases as frequency decreases and barriers must become heavier, sound absorbing layers thicker to obtain good low frequency sound performance.



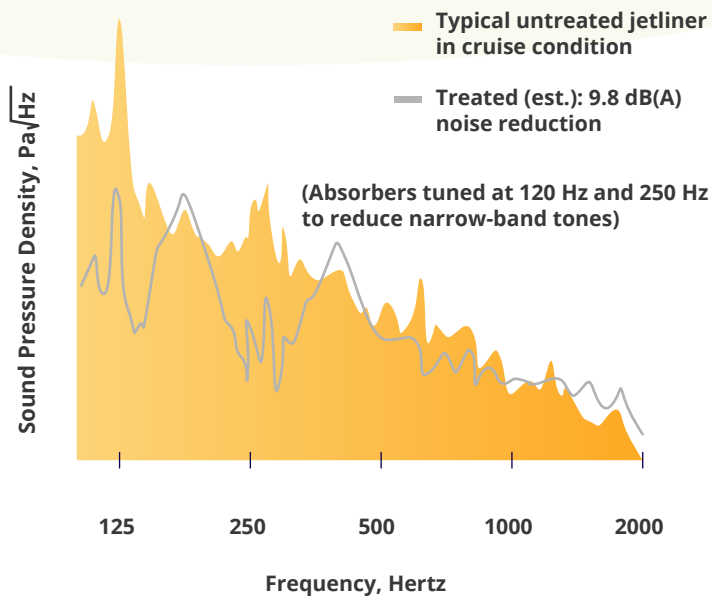
*Additional noise reduction may be needed at low frequencies*

Trim and blankets are very effective above 500 Hz to 1,000 Hz against wind and jet exhaust noise. Wind noise is however important at low frequency and cabin sound quality will not improve until low-frequency noise is abated. Qualitatively, the low frequency noise might be termed a "rumble" or a "roar".

# XI. Clever Devices Can Supplement Acoustic Materials



Frequency-targeted noise control: cabin noise in an aircraft with a single set of trim-mounted devices tuned to address the 130 Hz noise.



Frequency-targeted noise control: two sets of trim-mounted devices tuned to control the 130 Hz and 250 Hz noise (Results extrapolated to flight data from test in narrow body acoustic trim test cell)

## **XII. Practical Tips for Making Airplane Cabins Quiet**

### **1. Reduce noise levels at the source**

1. Engine rotating components: balance engines.
2. Hydraulic systems: isolate pumps and hoses; install a fluid ripple damping system or hydraulic muffler
3. Main door and escape hatches: ensure good seals, well faired.
4. Air conditioning, vent and cooling systems: use quiet air outlets and large ducts, reduce air flow velocities, and avoid flow turbulence.

### **2. Reduce noise levels in the noise path**

1. Isolate mechanical vibration transmitted through:
  - Interior panels and furniture
  - Fluid lines and attachments
  - Floor panels
2. Damp floor, interior and skin panels if resonant and where appropriate.
3. Block or reduce noise to the occupied areas using:
  - Interior panels, bulkheads, door materials
  - Active or tuned devices where appropriate
  - Door seals
  - Cabin interior windows
  - Window reveal and shade assemblies
  - Supplemental weighted layers
4. Absorb noise in occupied areas
  - Interior panel treatment
  - Noise-absorbing sub-layers under fabric-covered surfaces
  - Noise-absorbing bulkhead panels
  - Finishing materials
  - Carpet pad
  - Carpet

5. Absorb noise outside occupied areas

- Interior panels and furniture
- Fluid lines and attachments
- Floor panels

6. Reduce radiated and reflected noise

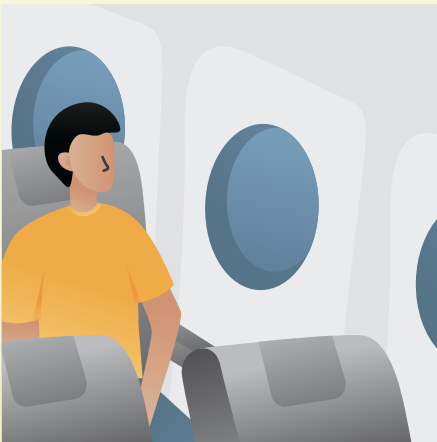
- Avoid hard finishing surfaces
- Avoid hard surfaces opposite one another
- Use room dividers



## About Luminary Air Group

Luminary Air Group, LLC (“Luminary”) is a leader in the design, manufacturing, and certification of acoustic and thermal insulation systems for VIP and Corporate Aircraft. The company is also a manufacturer of VIP and military aircraft interiors, whose capabilities included cabinet fabrication, panel upholstery and seat refurbishment. In addition, Luminary offers engineering and program management services.

## Aircraft Insulation



Luminary Air Group is an established leader in the design, manufacturing, and certification of aircraft acoustic insulation systems. The company’s noise reduction kits have been installed on hundreds of aircraft worldwide, including Boeing 737s, 747s, 777, Airbus 340, and multiple other aircraft types.

Aircraft cabins are noisy by necessity. Engines, vibration, and air flow are sources of noise that come with traveling through the air at high speeds. This environment makes conversations more difficult, renders sleep less effective, and amplifies the effects of jet lag. Reducing sound levels in the cabin not only makes a flight more enjoyable, it also allows for easier recovery after the trip.

Luminary Air Group strives to create the most comfortable cabin environment possible.

*Notable achievements in aircraft cabin noise reduction include:*

- The world record for quietest Boeing Business Jet cabin at 46.7 dB SIL
- Deliveries to over 50 VIP customers, including heads of state, corporate executives and artists
- Conference room acoustical treatment for the U.S. presidential fleet of 747s (E4-B).

