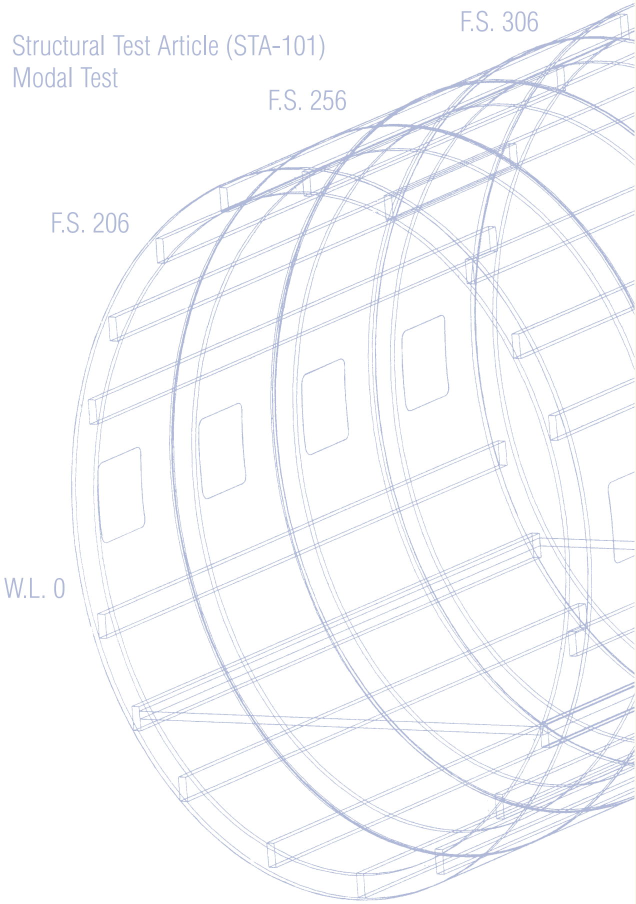
Aircraft Interior Acoustics

THE BASICS

By Jennifer Renninger
Applications Engineer



Introduction

Controlling the interior noise level within an aircraft requires a system-level treatment technique that is designed to address both the airborne acoustic energy and the structureborne vibration energy. In order to achieve the greatest performance both per dollar and per pound, the treatment requires not only the correct choice of materials, but also an understanding of how they work, and how and where to install them. All noise control systems use at least one of the following control types:

Barriers...APU enclosures, overframe blankets, interior trim.

Absorption materials...polyimide foams, fibrous batts or blankets, acoustical tiles.

Vibration isolators...trim panel isolators, engine mounts.

Damping materials...elastomeric composites, adhesive films.

The first two categories deal with *airborne* noise, noise already present in the environment. The last two items deal with *structureborne* noise, or vibration, which will appear as airborne noise after being radiated by a structure, unless it is either isolated or damped. In general, effective noise control incorporates the use of *both* absorption and barriers for airborne noise and *both* isolation and damping for structureborne noise. It is important to remember that sound is mechanical energy, and that it will always find paths to travel from the noise source to the interior of the aircraft. The process of noise control involves blocking these paths and eliminating the energy wherever possible.

Barriers and Enclosures

A sound barrier is usually a solid material which, by virtue of its mass, acts as an acoustical reflector, interrupting the path of a sound wave. A barrier may be a rigid structure, such as a trim panel, or a limp sheet material, such as an overframe blanket/barrier. For most installations, it is not the stiffness of the barrier that produces the noise reduction, but the mass. More specifically, the weight per unit area—usually stated in pounds per square foot—provides the best single indicator of the attenuation characteristic of a barrier. A common myth purports that lead sheet is the best choice for barrier applications. In truth, however, it does not matter what sort of material is used to produce the weight, as long as the surface density (psf) is the same everywhere over the barrier's surface.

Obeying the laws of physics, a barrier will produce increasing attenuation at higher frequencies. This attenuation—*transmission loss (TL)*—is measured according to ASTM Standard E-90. *Figure 1* shows a graph of TL for a simple limp barrier material (Curve A). The upward sloping curve indicates the increase in TL with increasing frequency. Experience shows that a simple limp barrier may be very useful in reducing noise in the range of 250 Hz and above, depending, of course, on the surface mass utilized. Very low frequency noise, however, can be attenuated only by using very massive constructions, such as multiple layers of gypsum board or masonry, which would not be possible in an aircraft application.

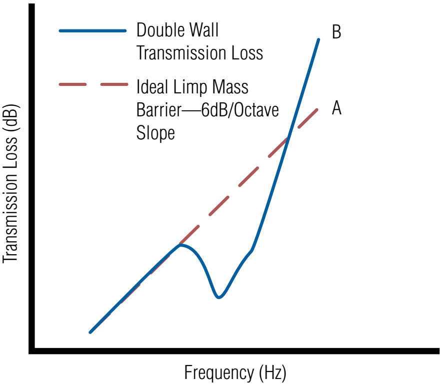


Figure 1: Transmission Loss Behavior of Single and Double Wall Systems

Curve B depicts the performance of a *double-wall* barrier. An example of a double-wall barrier in an aircraft would be the combination of the aircraft skin and the interior trim panels. In between these two walls is an air gap filled with fiberglass. Performance at higher frequencies is enhanced using these systems, or equivalent performance can be attained at lower weight. Therefore, the interior trim components are an integral part of the overall noise control system.

The key to effective utilization of a barrier material lies in reducing the number and size of holes, gaps and other penetrations in the assembly to an absolute minimum, consistent with accessibility and ventilation. An overframe barrier/blanket can be used to eliminate "direct" line of sight acoustic gaps in the interior trim of an aircraft. Generally, the percentage of open area relative to the total enclosed area should never exceed 10 percent. Under ideal conditions, a 10 dB(A) reduction may be achieved with this amount of open area. If the open area can be decreased to 1 percent, the potential noise reduction improves to 20 dB(A) (See *Figure 2*).

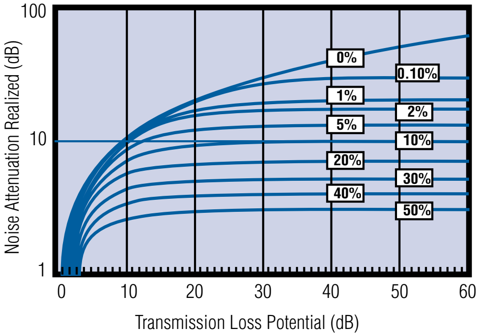


Figure 2: Performance of an Enclosure Based upon Percentage of Open Surface Area

Absorption Materials

Absorption materials are almost always used in conjunction with a barrier of some type, since their porous construction permits noise to pass through relatively unaffected. An absorber, when backed by a barrier, reduces the energy in a sound wave by converting the mechanical motion of the air particles into low-grade heat. This action prevents a build-up of sound in enclosed spaces and reduces the strength of reflected noise.

Typical absorption materials for an aircraft are bagged fiberglass or polyimide foam. While these products provide some degree of absorption at nearly all frequencies, performance at low frequencies typically increases with increasing material thickness. Thin materials show the general characteristic of higher absorption at higher frequencies. In *Figure 3*, the curves show the *absorption coefficient* values, alpha (α), of a 1-inch-thick foam. An alpha (α) of 0.5 indicates that the material under test reduces the strength of reflected sound waves by 50 percent. The absorption characteristics change when the foam is faced with a thin material (i.e., bagging for the fiberglass bags).

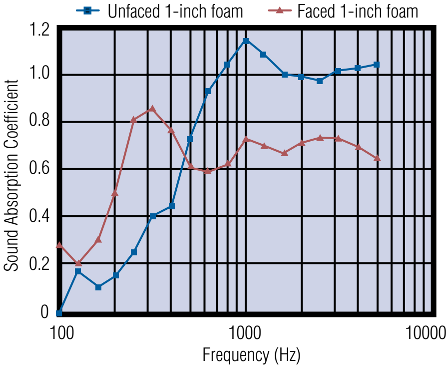


Figure 3: Performance of 1-inch Acoustical Foams (Polyimide) with and without Thin Film Facing

The thin-film bagging used for the fiberglass and polyimide thermal/acoustic insulation is designed to prevent contamination and moisture retention, and to improve the *acoustic* performance of the materials.

Combining these absorptive materials with damping materials increases performance by providing increased structural noise control, additional mass and the acoustical absorption of the fiberglass/polyimide.

In addition to the sidewall and overhead thermal/acoustical insulation, the type of decorative materials used within the cabin interior have an effect on the overall noise level. The plushness of the carpet and the type of material used in the seat covers can reduce or increase the cabin noise level depending upon their specific absorption properties. Generally, the softer decorative materials will possess greater absorption characteristics.

Figure 4 suggests the importance of using absorption. This graph shows the *insertion loss,* or noise reduction in dB, for an "ideal" (0 percent opening) enclosure system. If a uniform noise pressure spectrum initially exists, an enclosure without added absorption has an amplifying effect at low frequencies and limited performance at high frequencies (Curve A). The same enclosure *with* added absorption (Curve B) shows considerably better attenuation in the higher frequency range and at lower frequencies as well. This illustrates the acoustic impact of "soft" surfaces within the cabin. Fabric seat covers will absorb more acoustic energy than leather seat covers, thus reducing the interior noise.

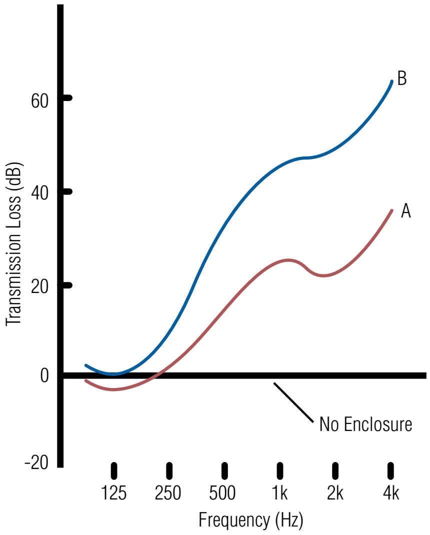


Figure 4: Insertion Loss of Sealed Enclosure without Absorption (A) and with Added Absorption (B)

Vibration Isolation

Vibration, like sound, travels in all directions away from a source to surfaces from which it can be radiated as noise. For example, it often is not the motor in a device that produces the most noise, but the panel or structure to which the motor is attached. Use of vibration isolators can stop the flow of vibration from one point to another and reduce noise.

While isolators are available in a very broad variety of designs, all have one characteristic in common: they provide a means of connecting two structures so as to control relative motion between them under dynamic loads. The amount of motion required depends on many variables, the chief one being the range of frequencies over which the isolator must be effective. Isolation of noise in the A-weight frequency range—above 250 Hz—requires a relatively stiff, low-deflection mount. Isolation of very low vibration frequencies, such as the fundamental rotation speed of a jet engine (125 Hz), requires considerably greater deflection capability from the mount. For example, an isolator designed to isolate vibration above 10 Hz requires 25 times more deflection under load than one operating at 50 Hz and above.

Transmissibility, TR, provides a common measure of isolator performance. Transmissibility can be expressed in linear units or logarithmically, for example, in decibels (dB). Briefly, transmissibility is a measure of the vibration response of a system divided by the magnitude of the vibration input to the system. Without exception, the lower the transmissibility, the better the isolation performance.

Figure 5 plots the transmissibility characteristics of several types of isolation materials. The shaded bands on the right-hand side of the figure indicate that transmissibility of less than about 6 dB of resonance can be considered well-controlled; between 7 and 15 dB is conditional and may cause equipment to malfunction; and above 15 dB the level can be damaging, depending on the force levels involved. For reference, 6 dB is a magnification factor (X) of 2X; 10 dB is 3X and 20 dB is 10X. So, for example, if an isolated system has an amplitude at resonance of 10 dB, the vibration output forces are 3 times the input forces.

The frequency of the resonance point of an isolated system can be controlled by pairing the correct type of isolator with the total weight of the machine to be isolated. The corresponding transmissibility curve shows that

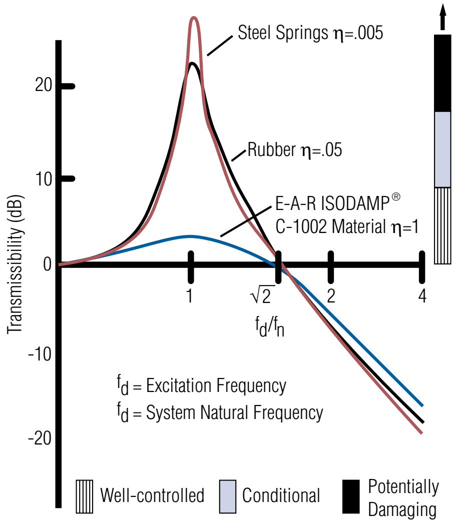


Figure 5: Transmissibility of Isolation Materials with Different Loss Factors. Loss Factor (η) is a Measure of Damping

vibration isolation begins to the *right* of the point where TR crosses the reference (0 dB) line. More specifically, the frequency at which isolation begins is about 1.4 times the natural frequency of the system. Isolation or attenuation of vibration is provided only above this frequency.

Resonance is the point of maximum response amplitude in an isolated system and can be a disruptive, as well as destructive, phenomenon. Damping, in the form of an isolation material, provides the only means to control resonance. Presently, damped materials specifically formulated to minimize resonance problems are available and should be used whenever machinery will be operated at or near the system's natural frequency. Highly damped materials also excel at controlling or preventing rebound, thus making damped isolation mounts ideal for controlling shock problems.

Structural Damping

Structural damping is to structural vibration what absorption is to airborne sound. That is, it provides a means for eliminating mechanical energy by converting it to heat. The "ringing" of the aircraft skin or trim is reduced or eliminated by the optimal application of a structural damping treatment. *Figure 6* illustrates the reduction in vibration of an aircraft skin panel when a structural damping treatment is applied.

The applied damping material produces a three-fold reduction in the skin panel vibration level.

Damping materials are typically applied directly to the aircraft skin to reduce the effects of boundary layer excitation, engine exhaust impingement and engine vibration. They are applied to the surfaces of the interior trim structure to reduce the effects of airborne-induced vibration and engine vibration. Unlike barrier materials, coverage need not be total in order to be effective, with 50 to 75 percent coverage as typical.

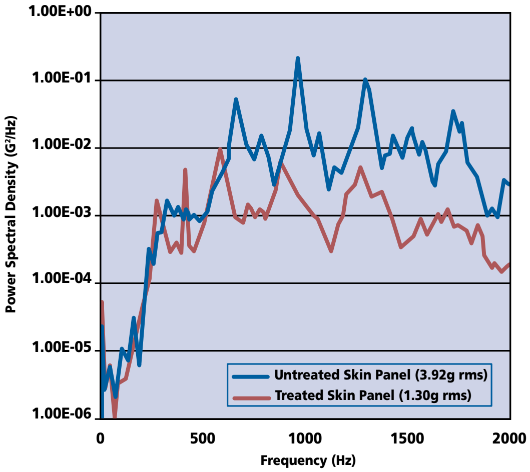


Figure 6: Vibration Spectrum of MD-80 Skin Panel

Several environmental and performance parameters are important when determining the correct application of structural damping treatments:

1. Structural substrate material stiffness
2. Damping material performance properties
3. Environmental conditions (e.g., temperature, humidity, etc.)
4. Vibration levels and frequencies
5. Ratio of damping material thickness to substrate material thickness.
6. Percentage of surface area covered.

There are two principal types of damping treatments, extensional and constrained, and either treatment can be employed depending upon the parameters listed above (See *Figure 7* and *8*).

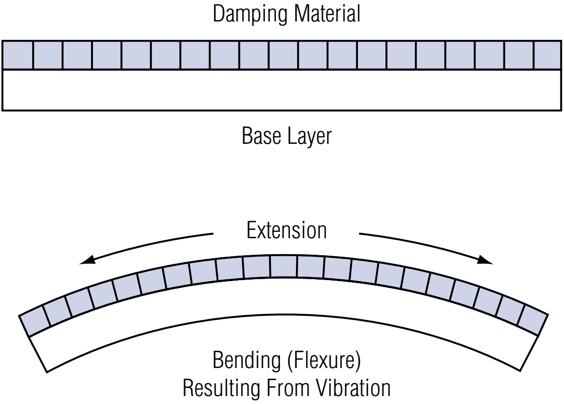


Figure 7: Extensional Damping

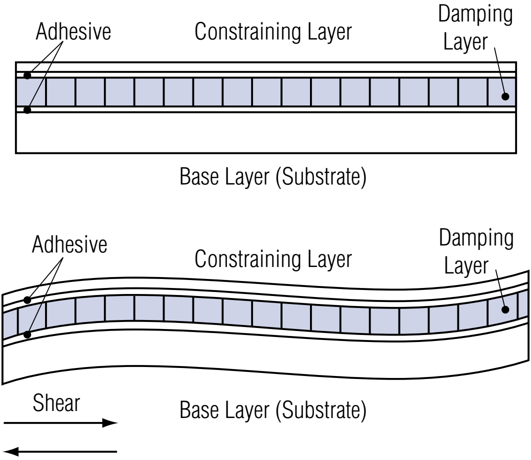


Figure 8: Constrained Layer Damping

The performance of damping systems is measured in terms of system loss factor (η_S). The higher the system loss factor the greater the reduction in vibration.

Conclusion

The best, and often least expensive, noise control is achieved by working as closely to the source of the noise or vibration as possible. This means extensive use of vibration damping treatments for the skin, trim panels and floor along with isolation mounts for engines and trim panels. For airborne noise within the interior of the aircraft, fiberglass, polyimide and other absorptive materials can be used to reduce reverberant build-up of noise within the aircraft cavity. Care should be used in selecting materials that will not degrade over time. This is particularly true for materials that are porous, such as foams or fiberglass, and materials that require a high performance adhesive to function properly, such as damping sheet.

Choosing the right materials for an aircraft does not require magic, but can be sometimes tricky. Knowing the areas to be treated, weight constraints, and the desired results will help in choosing the proper combination of materials for the quietest aircraft possible.

For nearly 20 years, E-A-R Specialty Composites has employed systems engineering techniques to address the complex requirements of aircraft interior noise control. Our applications engineers understand aircraft weight metrics, aircraft environments, FAA regulations, airborne and structureborne acoustics and material behavior. They use that breadth of knowledge to meet the unique requirements of each customer.

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7911 Zionsville Road
Indianapolis, IN 46268

Toll-free (877) EAR-IDEA
(327-4332)
Fax (317) 692-3111
Website: www.earaircraft.com
E-mail: solutions@earsc.com

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