PAYLOAD ACOUSTIC ATTENUATION VIA BLANKETS
Revision E

By Tom Irvine
Email: tomirvine@aol.com

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Introduction

A fairing is the shroud that surrounds the payload in a launch vehicle. The fairing protects the payload from the atmosphere. The fairing is jettisoned when the launch vehicle leaves the atmosphere.

Typically, fairings are constructed with a solid metal wall or a layered wall including a standard hexagonal cell aluminum honeycomb core with composite cover sheets.

The acoustic energy generated during liftoff and the transonic regime can damage the payload and its electronic components. Solar panels, antennas, and other appendages are also at risk.

Acoustic blankets are mounted on the inside walls of the fairing to reduce the fairing's interior acoustics, as well as the resulting vibration response of the payload.

The main function of a blanket is to serve as a barrier to attenuate external noise from propagating to the inside of the fairing. A secondary function is to absorb noise that has already penetrated the fairing inner volume, thus reducing reverberation.

The blankets are not effective in the lower frequency range, say, below 100 Hz. The wavelengths are relatively long at low frequencies, and there is not a sufficient depth of material in blankets to absorb a significant portion of the energy.

The blanket thickness is limited by mass and volume constraints.

Blanket Design

Industrial blankets are usually made of fiberglass batting or a combination of fiberglass sheets and batting which are of different thicknesses and are layered together. The batting may be covered by aluminum-vinyl, vinyl-coated polyester, or polymer cover sheets.

Launch vehicle blankets are commonly made from open-cell melamine foam, which is a thermoset polymer. The foam is covered by polymer cover sheets. The total thickness is typically 1 to 4 inches. The mass density is 0.6 to 2.0 lbm/ft^3. Additional information is given in Appendix E.

Attenuation & Damping Mechanisms

The blankets convert the acoustic energy to heat. The two primary mechanisms are:

1. Viscous losses in air channels
2. Material friction caused by fibers rubbing together

The blanket attenuation can also be characterized in terms of its impedance for transmission loss calculations.

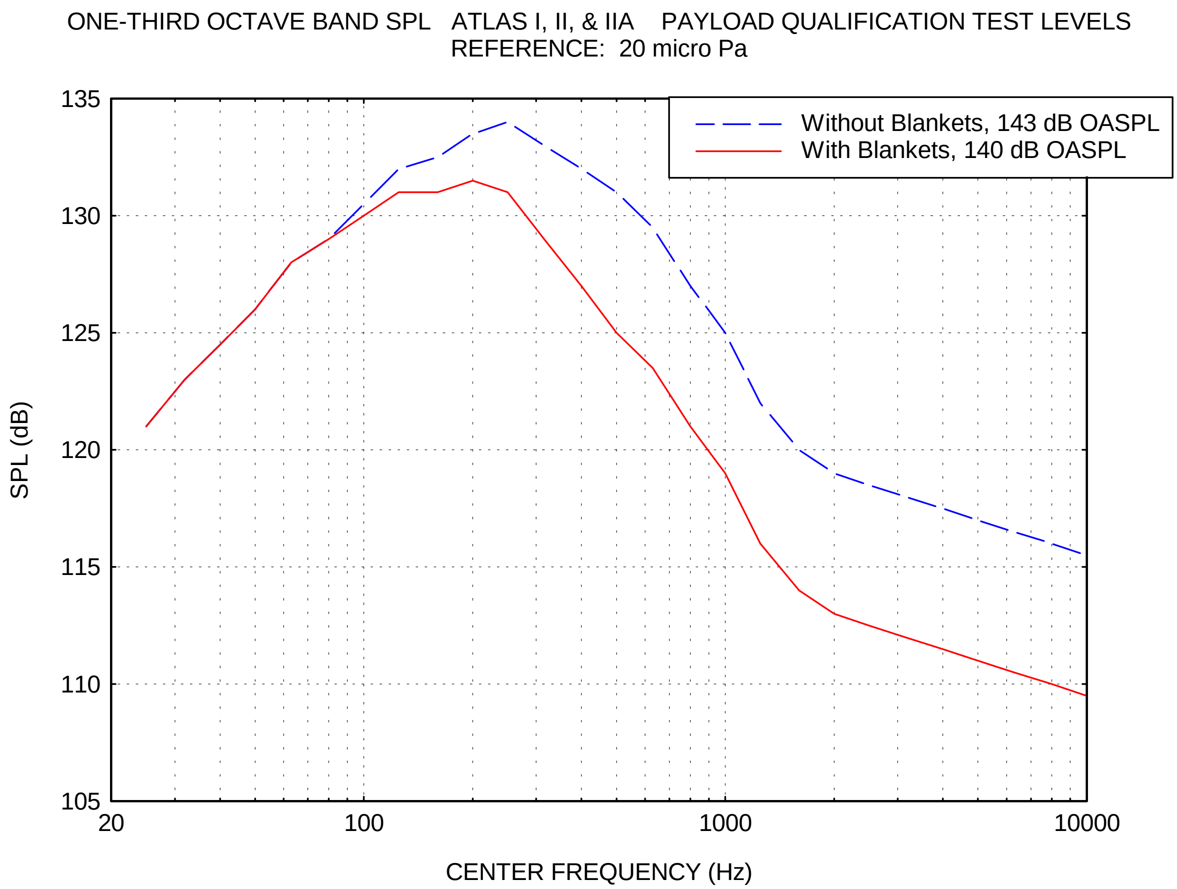


Figure 1.

ATLAS Data

The effect of the acoustic blankets in the Atlas fairing is shown in Figures 1 and 2. The blanket material and thickness data is not immediately available.

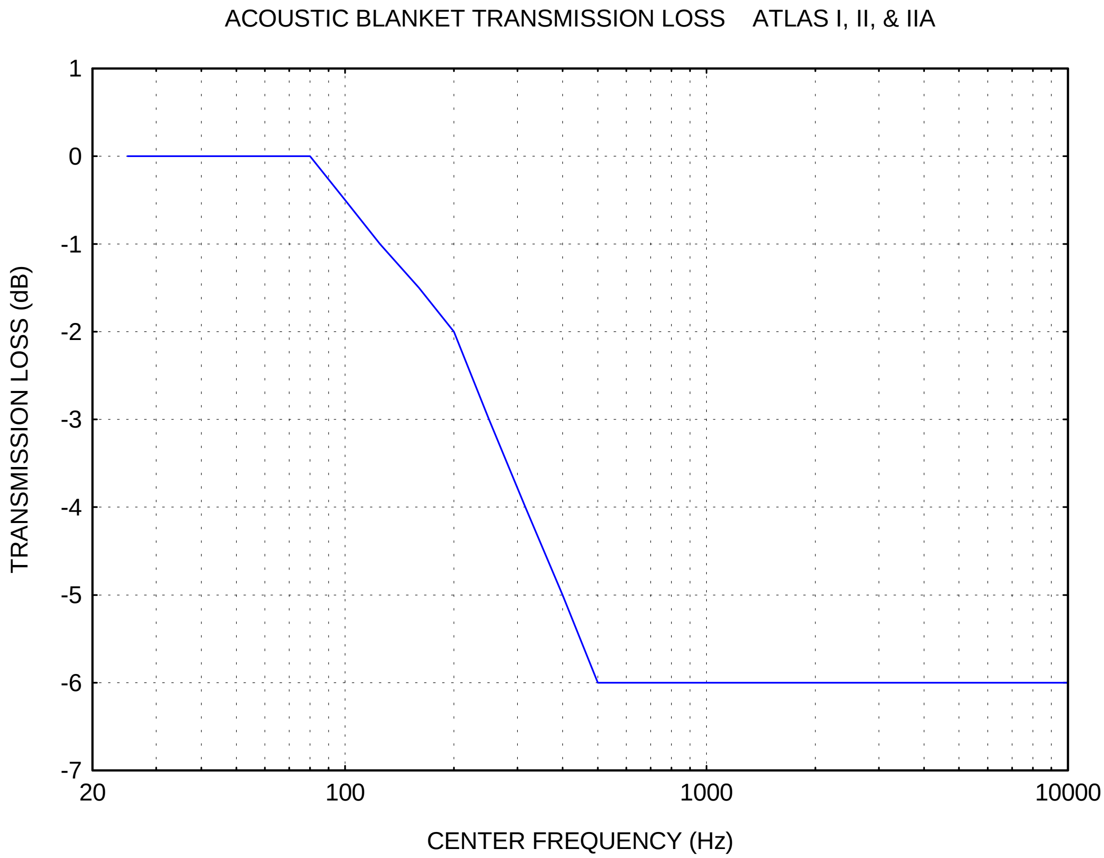


Figure 2.

A negative value indicates attenuation.

<u>Proposed Blanket Transmission Loss</u>

The proposed transmission loss (TL) for an acoustic blanket is

$$TL = 20 \log W + 20 \log f - 28.5 \quad dB \tag{1}$$

where

W is the surface weight density in pounds per square foot

f is the forcing frequency in Hertz

Furthermore, the TL value is limited such that: $-6\ dB \leq TL \leq 0\ dB$

The TL value in equation (1) is loosely based on the Atlas function in Figure 1 and on the method in Appendix A. Further effort is needed to verify this equation. The equation is only intended for preliminary estimates, prior to actual testing.

The fill factor, flanking noise, and vent openings are additional concerns. These effects may be partially accounted for by applying the -6 dB limit. Again, further work is needed.

Examples

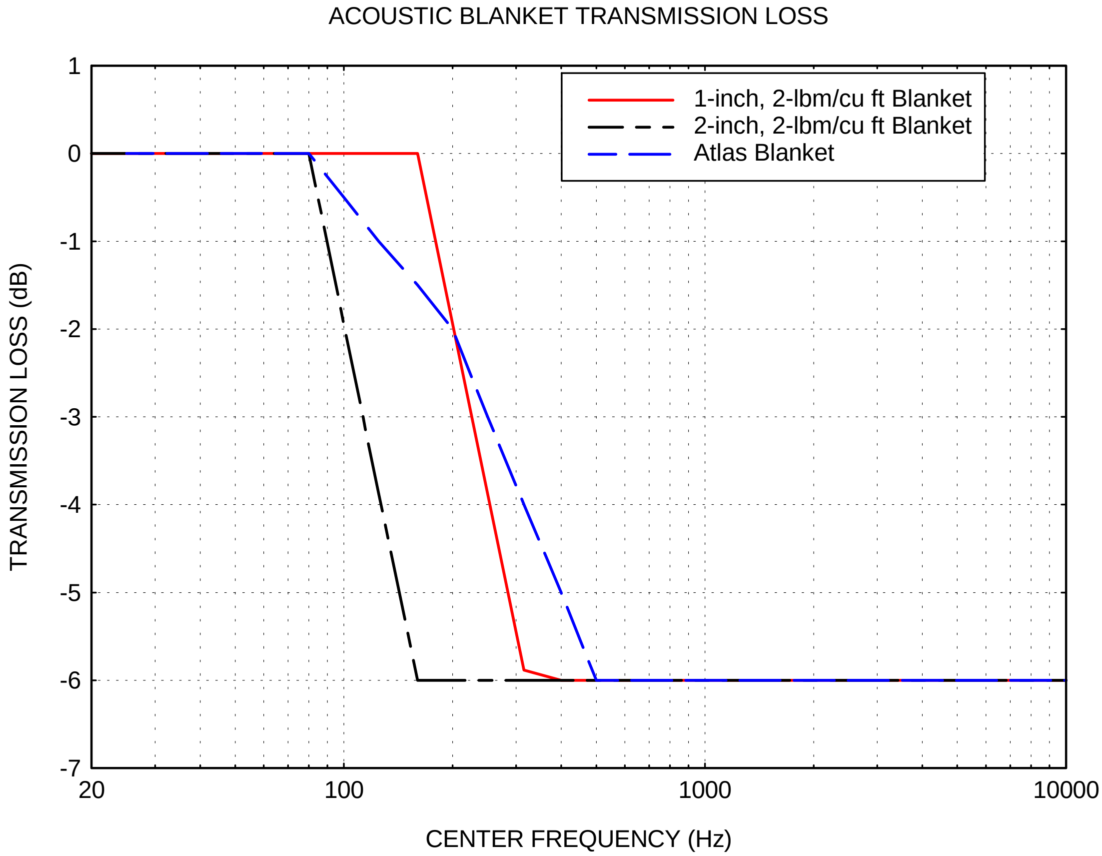


Figure 2.

A negative value indicates attenuation.

The transmission loss functions for two blanket designs are shown in Figure 2, along with the Atlas curve.

Acoustic Experimental Results

Reference 4 gives experimental results for a “grid-stiffened, composite fairing.” The tests were performed in “large, semi-reverberant laboratories.”

Various tests were performed with and without melamine acoustic foam blankets. The foam had a density of 8.9 kg/m^3 (0.56 lbm/ft^3). The foam thickness and surface area coverage were both varied. Furthermore, tests were performed with ports both open and closed to account for alternate transmission paths. Tests were also performed with and without thermal protection system (TPS).

Here are some particular findings from Reference 4:

1. A 20 Hz internal resonant peak was measured during a bare fairing test with 1.2% holes/openings. This was not a standing wave within the fairing volume, but rather a “breathing mode” or “Helmholtz mode” that resulted from openings in the fairing. The sum of the air mass at the openings acted as a lumped mass oscillating on an air spring provided by the fairing volume, like a large Helmholtz resonator (page 1136).

2. The fairing was tested with a 5-cm (2-inch) thick blanket but with no TPS for a particular case. The blanket coverage was 50%. Below 200 Hz, the interior responses were similar to the bare case, indicating that the acoustic foam had little effect on the band averages at lower frequencies. Furthermore, the blanket provided about 5 dB of attenuation, in a somewhat uniform manner above 400 Hz (page 1136). Increasing the coverage to 93% increased the attenuation to about 9 dB above 400 Hz.

3. The bare faring noise reduction was between 6.0 and 7.5 dB (page 1137).

4. The fairing with TPS but with no blankets has a noise reduction of 11 to 14 dB (page 1137). The TPS added approximately 7 dB to the noise reduction, which is attributable to mass loading, structural damping, and acoustic absorption (page 1138).

5. Thicker foam treatment is better able to couple and damp the low frequency acoustic modes (page 1137).

Appendix Index

Table 1. Appendix Index

Appendix	Title
A	Single Panel, Mass Law
B	Transmission Loss Equations
C	Historical Blanket Reference
D	Acoustic Leakage
E	Melamine Foam Properites

References

1. General Environmental Verification Specification for STS & ELV Payloads, Subsystems, and Components Rev A, NASA Goddard Space Flight Center, June 1996. See Appendix C.

2. T. Irvine, Acoustic Transmission Loss, Rev C, Vibrationdata, 2008.

3. http://www.qwyatt.com/blankets.html

4. Lane, Kennedy, & Richard, Noise Transmission Studies of an Advanced Grid-Stiffened Composite Fairing, Journal of Spacecraft and Rockets, Vol. 44, No. 5, September-October 2007.

5. P. Franken, WADC Technical Report 58-343, Vol II, Methods of Space Vehicle Noise Prediction, Wright-Patterson AFB, Ohio, 1960.

6. T. Irvine, Payload Acoustic Attenuation via Blankets, Rev B, Vibrationdata, 2008.

7. NASA-HDBK-7005, Dynamic Environmental Criteria, 2001.

8. Malcolm J. Crocker, Handbook of Noise and Vibration Control, Wiley, 2007.

9. Jaouen, Renault, Deverge; Elastic and Damping Characterizations of Acoustical Materials: Available Experimental Methods and Applications of a Melamine Foam, 2009.

APPENDIX A

Single Panel, Mass Law

This section is given for *Reference Only.*

Consider a single, homogenous, nonporous panel. The transmission loss TL is calculated by

$$TL = 20 \log W + 20 \log f - 33 \quad \text{dB} \tag{A-1}$$

where

W is the surface weight density in pounds per square foot

f is the forcing frequency in Hertz

Equation (A-1) is taken from Reference 2.

The transmission loss TL should be taken as zero dB, however, if either W or f is so small that equation (A-1) yields a positive value.

The transmission loss per equation (A-1) increases by 6 dB each time either the weight or the frequency is doubled. Equation (A-1) thus represents the "mass law."

The transmission loss is less than 6 dB in practice, however. The discrepancy between the mass law and actual measurements may be due to:

1. The neglect of stiffness and damping in the mass law equation
2. Cracks and porosity
3. Alternate sound transmission paths such as vents

APPENDIX B

Transmission Loss Equations

The transmission loss TL in decibels for a panel is defined as

$$TL = 10 \log \left(\frac{\Pi_S}{\Pi_t} \right) \tag{B-1}$$

where

Π_S is the total power incident on the source of the panel
Π_t is the total power transmitted through the panel

The transmission loss may also be expressed as

$$TL = 10 \log \left(\frac{1}{\tau} \right) \tag{B-2}$$

where τ is the transmission coefficient.

Note that transmission loss is function of frequency.

Noise Reduction

The noise reduction NR can be calculated by either of the following formulas.

$$NR = 10 \log \left(\frac{I_1}{I_2} \right) \tag{B-3}$$

$$NR = L_1 - L_2 \tag{B-4}$$

where I_1 and I_2 are the intensities and L_1 and L_2 are the sound pressure levels in the source and receiver rooms, respectively.

The transmission loss and noise reduction are related by the following formula

$$\mathrm{TL} \quad = \quad \mathrm{NR} + 10 \log \left(\frac{\mathrm{S}}{\mathrm{A}} \right) \tag{B-5}$$

where

S is the surface area

A is the sound absorption of the receiver room

Equation (B-5) is taken from Reference 2.

The average Sabine absorptivity $\bar{a}$ is

$$\bar{a} = \mathrm{A} / \mathrm{S} \tag{B-6}$$

By substitution,

$$\mathrm{TL} \quad = \quad \mathrm{NR} + 10 \log \left(\frac{1}{\bar{a}} \right) \tag{B-7}$$

APPENDIX C

Historical Blanket Reference

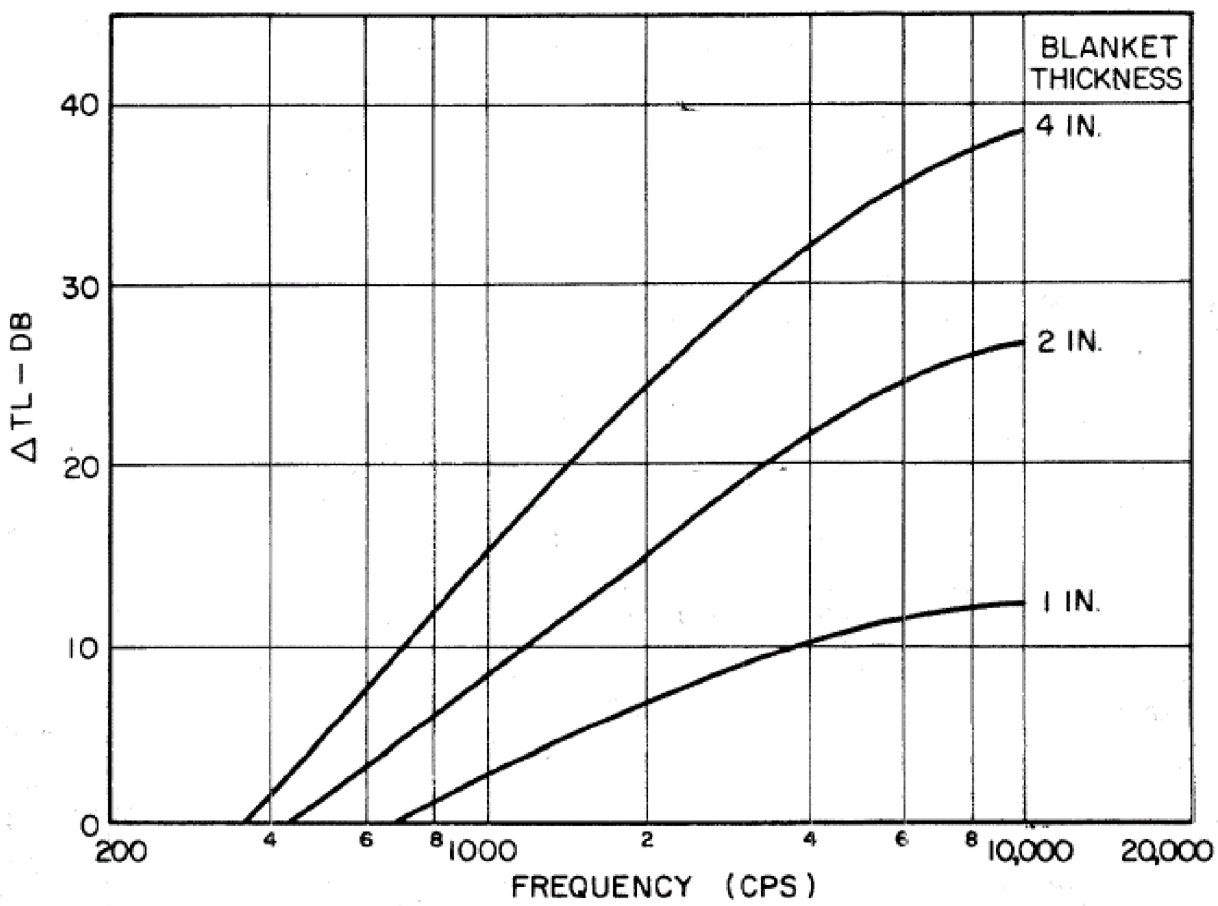
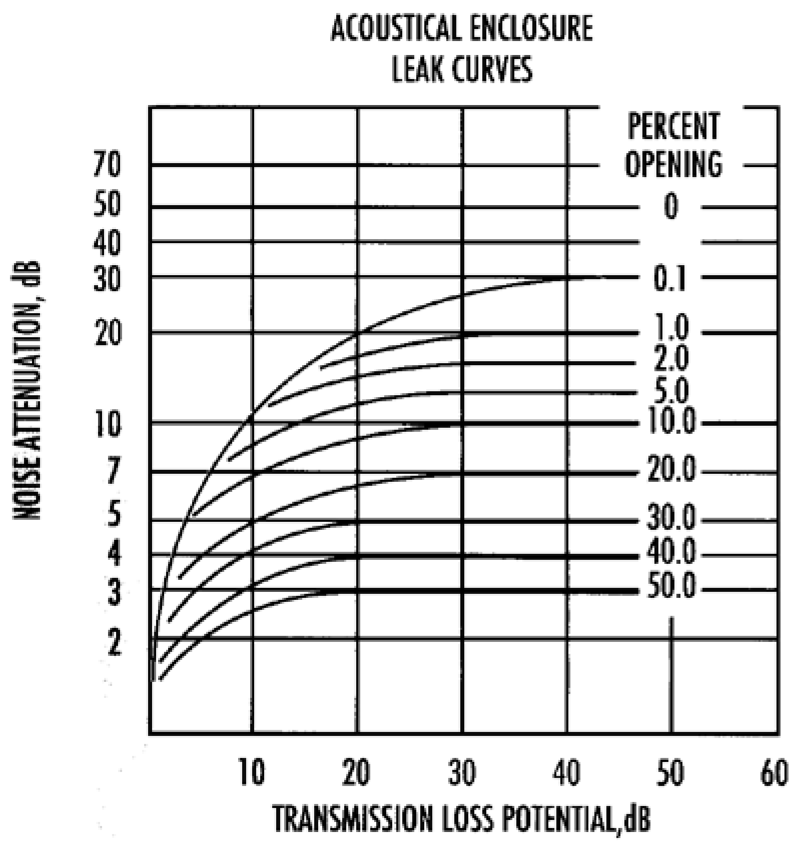


FIG. 110 APPROXIMATE TRANSMISSION-LOSS INCREASE (ΔTL) DUE TO ACOUSTICAL BLANKETS.

The figure is taken from Reference 5. The corresponding mass density was not given in the reference.

APPENDIX D

Acoustic Leakage



TRANSMISSION LOSS POTENTIAL, dB

Explanation: The above table indicates theoretical noise attenuation actually realized as a function of any openings or gaps in an acoustical enclosure. For example, if a typical metal panel type enclosure has a transmission loss potential (STC) of 40 decibel (dB) (as listed across the bottom of the chart) and there was a 1% opening in that enclosure (the right hand side of chart), they intersect at a point showing an actual noise attenuation of 20dB (on the left hand side of the chart).

In comparison, an Acoustical Curtain Enclosure of QABAC-25 with an STC of 29 (Transmission Loss Potential) incorporating the same 1% opening intersects at a point showing an actual noise attention of 19 dB. Therefore, when there is as little as a 1% opening in any acoustical enclosure, the significant cost savings and ease of access provided by Barrier Absorber Blankets, versus a metal panel enclosure, should be strongly considered.

Reference: http://www.qwyatt.com/blankets.html

APPENDIX E

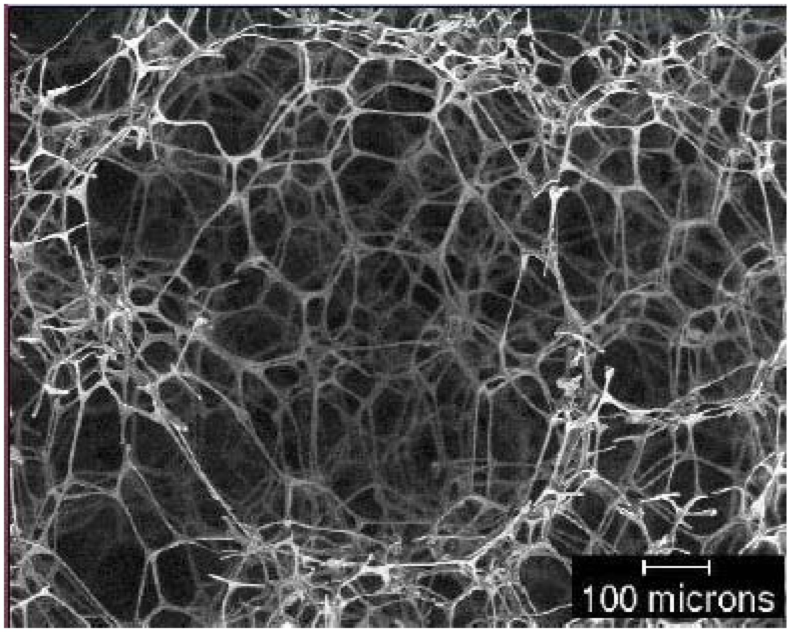


Figure E-1.

Electron microscope picture of the tested melamine foam in Reference 9. The solid phase, or skeleton, of the foam appears in white.

Melamine Foam Properties

Again, the main function of a blanket is to serve as a barrier to attenuate external noise from propagating to the inside of the fairing. A secondary function is to absorb noise that has already penetrated the fairing inner volume, thus reducing reverberation.

Melamine foam by itself has a high acoustic absorption coefficient. This is desirable for absorbing reflected sound inside the fairing volume. On the other hand, the high absorption coefficient is somewhat counterproductive for the barrier objective.

The cover sheets may have the effect of lowering the absorption coefficient.

Transmission Loss

The transmission loss can be calculated using textbook formulas if the following parameters are known for each medium:

1. Mass density
2. Thickness
3. Acoustic Impedance
4. Speed of Sound

Variables

E	=	Elastic Modulus
p	=	Surface sound pressure
r_n	=	Normal specific acoustic resistance
x_n	=	Normal specific acoustic reactance
u	=	Surface particle velocity
Z_o	=	Specific acoustic impedance, relative to air
α	=	Absorption coefficient
ρ	=	Mass density
ρc	=	Characteristic impedance of air (415 rayls)
θ	=	Angle of incidence

Acoustic Impedance

The specific acoustic impedance is

$$Z_o = \frac{p}{u} = \rho c \left(r_n + j x_n \right) \quad \text{(E-1)}$$

Assume for a porous material that

$$r_n >> 1 \quad \text{(E-2)}$$

and

$$r_n >> x_n \tag{E-3}$$

Thus

$$Z_o \approx \rho c r_n \tag{E-4}$$

Reference 7, Chapter 57, Equation (8) page 699, gives the following formula for relating the absorption coefficient to the resistance.

$$\alpha_\theta = \frac{4 r_n \cos\theta}{(1 + r_n \cos\theta)^2} \tag{E-5}$$

Assume that the sound wave strikes perpendicular to the surface.

$$\alpha = \frac{4 r_n}{(1 + r_n)^2} \qquad \text{for } \theta = 90° \tag{E-6}$$

$$\alpha \approx \frac{4 Z_o}{(1 + Z_o)^2} \tag{E-7}$$

$$\alpha(1 + Z_o)^2 - 4 Z_o = 0 \tag{E-8}$$

$$\alpha(Z_o{}^2 + 2Z_o + 1) - 4 Z_o = 0 \tag{E-9}$$

$$Z_o{}^2 + 2Z_o + 1 - \frac{4}{\alpha} Z_o = 0 \tag{E-10}$$

$$Z_o{}^2 + \left[2 - \frac{4}{\alpha}\right] Z_o + Z_o = 0 \tag{E-11}$$

The acoustic impedance can thus be calculated from the absorption coefficient using the quadratic formula.

The acoustic impedance of melamine blankets is not readily available.

The overall absorption coefficient of the foam batting is approximately 0.8 to 0.9 per typical vendor specification.

The cover sheets should reduce the absorption coefficient by some margin. Assume a coefficient of 0.6 for the complete blanket. This value would vary according to the blankets mass density, thickness, and other properties. It would also vary with frequency, even though a single value is chosen for convenience.

The resulting melamine blanket impedance is:

$$Z_o = 1840 \text{ rayls} \tag{E-12}$$

This impedance value is 4.44 times greater than that of air.

This value will later be shown to give rough agreement with the transmission loss curves in the main text. Verification of the impedance value by some independent means is still needed, however. Furthermore, the impedance value would likewise vary with frequency, mass density, thickness, and other properties.

Speed of Sound

The speed of sound in melamine foam is not readily available.

Assume that the melamine blanket mass density is 1 lbm/ft^3.

The estimated elastic modulus is E = 29 lbf/in^2 from Reference 9, Figure 10. Note that the stress-strain curve is non-linear, however. Furthermore, the modulus varies with direction and frequency.

The speed of sound is calculated from

$$c = \sqrt{\frac{E}{\rho}} \tag{E-13}$$

The resulting speed of sound for 0.6 lbm/ft^3 melamine blanket is

$$c = 367 \text{ ft/sec} \tag{E-14}$$

Again, this value needs independent verification.

Transmission Loss, Plane Waves, Normal Incidence, Melamine Blanket

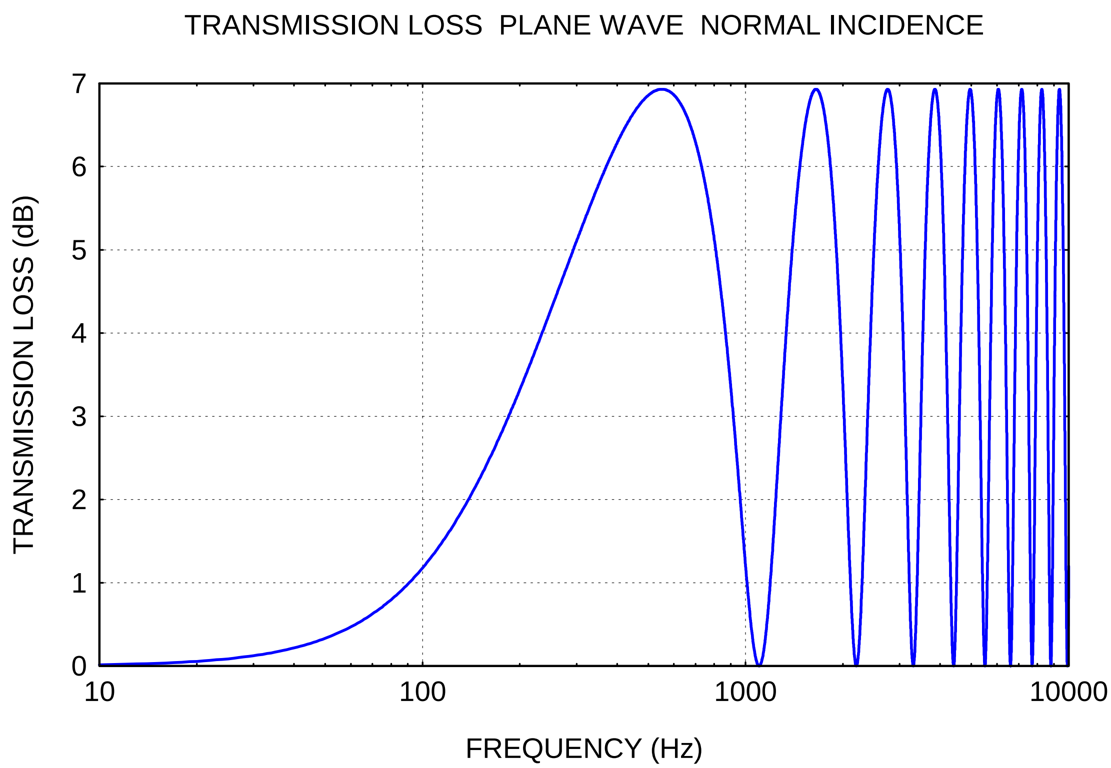


Figure E-2.

A positive value indicates attenuation.

The curve was calculated using the method in Reference 2, Appendix C, as implemented in Matlab script: single_partition_plane_wave.m, ver 1.3.

The parameters were

Density	=	1 lbm/ft^3
Thickness	=	2 inch
Speed of Sound	=	367 ft/sec
Absorption Coefficient	=	0.6
Impedance	=	1840 Rayls

Air was the medium on either side of the melamine blanket.

Note that the thickness is equal to a "one-half wavelength" at 1100 Hz. The transmissibility loss is zero at this frequency and integer harmonics thereof.