

A particularly severe cross transmission problem exists in prisons, where ducts could be used for communication between cells. In this case, no credit should be taken for the ratio S_p/S_e , as the inmates will move close to the outlets to talk and to listen.

STEP 4—DESIGN OF ACOUSTIC TREATMENT FOR DUCT SYSTEMS

Selection of the Absorptive Material

When a sound wave impinges on the surface of a porous material, the air within the small pores of the material is set into a vibrating motion. The flow resistance within the pores of the material converts a portion of the sound energy to heat. The decimal fraction representing the absorbed portion of the incident sound wave is called the absorption coefficient. Considerable absorption may also result, particularly in the low-frequency range, from the flexural vibrations of duct walls. In the selection and application of the absorptive material, the following points should be considered:

1. For the absorption of the low-frequencies below 500 cps the material should be 2 to 12 in. thick. Thin materials, particularly when mounted on hard solid surfaces, will absorb only the high frequencies.

2. It has been shown⁵⁷ that increased attenuation at frequencies below 700 cps may be realized by using a perforated facing in which the area of the perforations is from 3 to 10 percent of the surface area. Such facings, however, decrease the sound absorption at higher frequencies.

3. Any air space behind the material has considerable effect (see Fig. 16). Absorption coefficients should be based on the particular mounting method intended.

Sound absorbing materials suitable for use in air ducts are available in the form of blankets, semi-rigid boards, and loose fill. Specifications and absorption coefficients for most materials can be obtained from the Acoustical Materials Association.⁵⁸

The following additional properties should be evaluated in the selection of acoustical materials: (1) adequate strength to avoid breakage and crumbling, (2) fire resistance and compliance with national and local code requirements, (3) particles should not fray off at the higher air velocities, and (4) freedom from odor when either dry or wet.

There are several ways in which sound absorbing material can be arranged in a duct system:

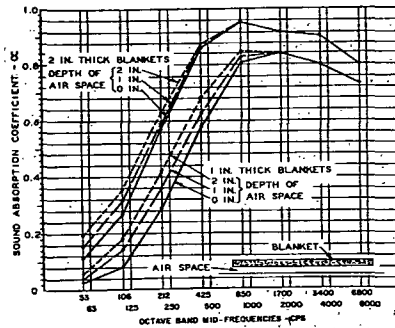


Fig. 16 Approximate Sound Absorbing Coefficients⁵⁷

1. Line all fan suction and discharge plenums. This is a very economical way to get considerable sound absorption in systems containing such elements.
2. Line ducts with sound absorbing material which also serves as thermal insulation. Note: Duct dimensions must be increased to compensate for area lost due to lining.
3. Locate lined duct sections close to elbows to take advantage of the interaction of sound absorption and sound reflection.
4. Introduce large amounts of sound absorbing materials into a limited length of duct as special purpose duct silencers.
5. Install prefabricated attenuators which contain specially shaped perforated baffles filled with sound absorbing material.

Usually, several arrangements are combined, in order to achieve the required amount of sound attenuation calculated in Step 3.

Attenuation of Lined Plenums

A sound absorption plenum on the fan discharge, as shown in Fig. 17, will often prove the most economical arrangement. Based on both experiment and ray acoustics theory, the following approximate expression has been derived for acoustic plenum attenuation:⁵⁹

$$\text{Attenuation (db)} = 10 \log_{10} \left[\frac{1}{S_e \left(\frac{\cos \theta}{2\pi d^2} + \frac{1 - \alpha}{\alpha S_w} \right)} \right] \quad (16)$$

where

- α = absorption coefficient of the lining, dimensionless.
- S_e = plenum exit area, square feet.
- S_w = plenum wall area, square feet.
- d = distance between entrance and exit, feet. (See Fig. 17.)
- θ = the angle of incidence at the exit, i.e., the angle which the direction d makes with the normal to the exit opening, degrees.

The ratio represented by the bracketed term in Equation 16 is evaluated by substituting values for the symbols. From this ratio in lower scale of Fig. 1, proceed vertically to the intersection with the diagonal and then read the attenuation of the plenum in the left vertical scale.

For frequencies sufficiently high so that the wave length is less than the plenum dimensions, Equation 16 is accurate within a few decibels. At lower frequencies, Equation 16 is conservative, and the actual attenuation exceeds the calculated value by 5 to 10 db, due to sound reflection by the plenum.⁵⁹

Attenuation of Lined Ducts

Duct linings may be designed for the dual function of providing sound absorption and thermal insulation. Thicknesses between $\frac{1}{4}$ and 2 in. are usually adequate for thermal insulation. The sound absorption of such relatively thin linings, however, is limited, especially at low frequencies (see Fig. 16).

The exact mathematics of sound attenuation in lined ducts⁶⁰ is very complicated. Empirical formulas, such as Equation 17,⁶¹ can be used for design calculations within certain limits.

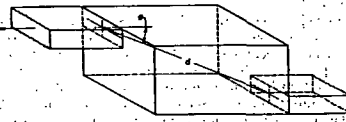


Fig. 17 Diagram of Sound-Absorbing Plenum

Table 19 Values of $(\alpha)^{1/4}$ for Equation 17

Absorption Coefficient α	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.5	0.6	0.7	0.8	0.9	1.0
$(\alpha)^{1/4}$	0.04	0.07	0.11	0.14	0.19	0.23	0.28	0.33	0.38	0.49	0.61	0.73	0.86	1.0

This equation gives the attenuation due to the lining which should then be added to the attenuation of the unlined duct (Table 13).

$$\text{Attenuation (db)} = 12.6 \frac{P}{S_e} \alpha^{1/4} \quad (17)$$

where

- l = length of lined duct, feet.
- P = perimeter of duct inside the lining, inches.
- S_e = cross-sectional area of duct, inside the lining, square inches.
- α = absorption coefficient of lining (a function of frequency).

The value of $\alpha^{1/4}$ can be found from Table 19 for various values of α .

The limitations of Equation 17 are:

1. Smallest duct dimension should not exceed 18 in., and not be less than 6 in.
2. Ratio of duct width to height should not exceed 2/1.
3. The absorption coefficient α should be representative for the entire octave band. A coefficient at 500 cps, for instance, is usually too high for the lower part of the 300-600 cps band. The average of the coefficients at 250 and 500 cps should be used for conservative results; if coefficients on an octave band basis are not available.
4. Air flow velocities should not exceed 4000 fpm.⁶²
5. Equation 17 does not allow for line-of-sight propagation of sound which limits high frequency attenuation. In a straight 12 in. duct, for instance, the attenuation above 4800 cps will be only about 10 db for any lining length over 3 ft.⁶³ The attenuation in the next lower octave band (2400-4800 cps), will be about midway between 10 db and the value calculated from Equation 17. The frequency above which the 10 db limit applies is inversely proportional to the shortest dimension of the duct.

Flanking Transmission

Some recent test data for 12 x 12 in. ducts⁶⁴ are shown in Fig. 18. In the first 5 ft of the lining, the sound level in any band in the 850-2400 cycle range was found to drop much faster than calculated from Equation 17. These tests confirm Morse's prediction⁶⁵ that lined ducts should have a rather steep attenuation peak when the duct width is between one and two times the wave length of the sound. Fig. 18 also shows that, after the first five feet, attenuation rates were much lower than those calculated from Equation 17. This is due to the flanking transmission of sound telegraphed along the vibrating walls of the sheet metal duct. This flanking was the limiting factor in any frequency band in which the lining attenuation exceeded 2 db per foot.

Practical formulas for calculating these two opposing effects do not exist at this time. It is therefore recommended, that Equation 17 be used to estimate the available lining attenuation and that flexible vibration breaks be installed for every 25 db of lining attenuation required in any frequency band.

Interaction of Duct Lining and Duct Elbows

If there is an elbow in a lined duct, the line-of-sight propagation of sound rays is interrupted. This results in a considerably improved sound attenuation⁶⁶ at frequencies for which the wave length of the sound is shorter than the duct width, D , (see Fig. 14 and Table 15). It should be noted that:

1. Only the lining on the sides of the duct is involved in this interaction.

2. This attenuation is the effect of this elbow and should be added to the attenuation which would be calculated for the length of lined duct which are involved. (Equation 17)

3. For best results, the sides of the duct should be lined, both before and after the elbow, for a length of at least two duct widths. This length is based on a lining thickness of at least 10 percent of the duct width.

4. If the duct is lined only before or after the elbow, there is still some gain in attenuation, as shown in Rows B and C of Table 15.

5. The attenuation which can be credited to the duct lining is the difference between the total attenuation in Rows B, C, or D of Table 15, and the attenuation of the unlined elbow (Row A).

6. The listed increases in elbow attenuation are obtained only with duct linings, not with sound traps or lined plenums.

Example 6: Calculate the sound attenuation obtained by lining the branch duct shown in Fig. 15, for a length of 10 ft, with 1 in. sound absorbing blanket insulation. Assume that the duct size can be increased to 14 x 20 in. to permit the same inside dimensions of 12 x 18 in.

Solution: The perimeter of the duct (inside the lining) is 12 + 12 + 18 + 18 = 60 in. The duct area (inside the lining) is 12 x 18 = 216 sq in.

Values of α for the octave frequency bands are found from Fig. 16 and entered in Line 1 of Table 20. Values of $\alpha^{1/4}$ are found from Table 19 and entered in Line 2.

From Equation 17, with $P = 60$ in., $S_e = 216$ sq in., $l = 10$ ft, and using the values of $\alpha^{1/4}$ from Line 2 of Table 20, the attenuation due to the lining is found and entered in Line 3.

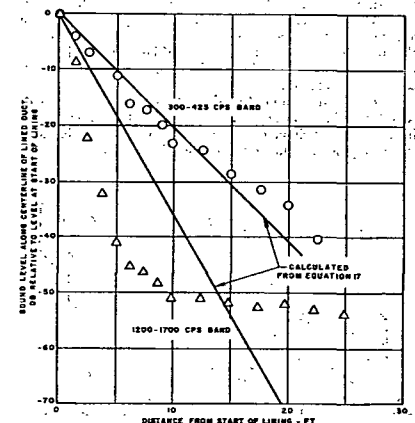


Fig. 18 Comparison of Measured and Calculated Attenuation in 12 in. x 12 in. Duct Lined with 1 in. Thick, 1 lb Density Blanket