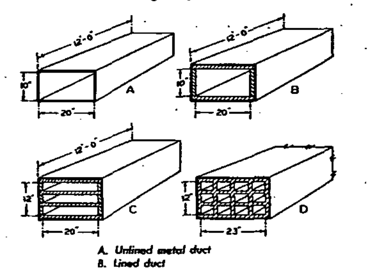
Table 7 .... Attenuation Data for Typical 1-in. and ½-in. Thick Duct Lining Board

Frequency Cycles Per Second	1-Inch Thickness: Absorption Coefficient α	1-Inch Thickness: $\alpha^{1.4}$	1-Inch Thickness: Attenuation db	½-Inch Thickness: Absorption Coefficient α	½-Inch Thickness: $\alpha^{1.4}$	½-Inch Thickness: Attenuation db
128	0.12	0.051	$0.64\, l \frac{P}{A}$	0.09	0.034	$0.43\, l \frac{P}{A}$
256	0.38	0.26	$3.2\, l \frac{P}{A}$	0.25	0.15	$1.9\, l \frac{P}{A}$
512	0.70	0.60	$7.6\, l \frac{P}{A}$	0.40	0.28	$3.5\, l \frac{P}{A}$
1024	0.80	0.73	$9.2\, l \frac{P}{A}$	0.72	0.63	$7.9\, l \frac{P}{A}$
2048	0.79	0.72	$9.1\, l \frac{P}{A}$	0.78	0.71	$8.9\, l \frac{P}{A}$

This formula was empirically developed for a set of duct sizes ranging from 9 x 9 in. to 18 x 18 in.; for cross-sectional dimension ratios of 1:1 to 2:1; for frequencies between 256 and 2048 cycles; and for absorption coefficients between 0.20 and 0.80. The duct lining material used was 1-in. rock wool sheet. The absorption coefficients of a material of this type in one-half and one-inch thickness are listed in Table 7.

It is also possible to calculate the absorption by a very complicated mathematical theory.[17, 18] Such calculations are in substantial agreement with Equation 22. This equation may be in error when applied to other types of duct lining and to duct sizes and shapes greater than those specified.

With every application, the use of sound absorptive material should be considered in the dual function of insulation and sound absorption. It has been shown theoretically that the reduction (in decibels per linear foot) of sound transmitted along a duct lined with sound absorbing material is related in a rather complicated manner to the size and shape of the duct, to the frequency of the sound, and to the sound absorbing characteristics of the lining. Experimental evidence likewise indicates that there is no simple formula involving the variables which will apply accurately to all cases. However, it may be stated generally that the attenuation in decibels at a given frequency is directly proportional to the length of lined duct. It decreases as the cross-sectional area increases, and increases as the aspect ratio is increased.



A. Unlined metal duct
B. Lined duct
C. Splitter plate type absorber
D. Cell-type absorber
The open area is the same for each case shown if 1 in. thick absorption material is assumed.

Fig. 12 .... Acoustic Treatment of Ducts

Rectangular Cells (Plate or Cell Absorbers)

If the available length of duct between the main duct (or the fan) to the grille is shorter than the length of lining indicated as necessary by Equation 22, the duct may be subdivided into smaller ducts as shown in Fig. 12, or it can also be even more subdivided by an egg-crate construction. In such a construction in which all the subdivided ducts are the same size, sound will be equally absorbed down each channel. It is, therefore, only necessary to calculate the sound attenuation of an individual channel. For this, Equation 22 is adequate, assuming that the thickness of the material is halved if it forms a common splitter between two cells.

When the number of splitter plates or cell partitions is large, the percentage free area of the gross duct size may be materially reduced. This leads to a further sound attenuation. Values of the attenuation possible, due to this cause, are given in Table 8.

Table 8 .... End Reflection of Plate or Cell Absorbers

Percentage Free Area of Absorber	50	40	30	25	20
Attenuation db	1	2	4	5	6

Plenum Absorption

In systems where individual ducts are directed to a number of rooms, and sound treatment is required in every duct, a sound absorption plenum on the fan discharge as shown in Fig. 13 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.[19]

$$\text{db (attenuation)} = 10 \log_{10} \frac{1}{\dfrac{S_e \cos\theta}{2\pi d^2} + \dfrac{1-\alpha}{\alpha S_w}} \qquad (23)$$

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.
θ = the angle of incidence at the exit, i.e., the angle which the direction d makes with the normal to the exit opening.

For frequencies sufficiently high so that the dimensions of the plenum exceed about one wavelength, Equation 23 will predict the sound attenuation within a few decibels. At low frequencies, somewhat more attenuation is realized than will be computed by Equation 23, due to the existence of a resonant muffler action in the duct-plenum system.

Outlet Sound Absorbers

Outlet sound absorbers are rectangular or plate cells installed directly behind an outlet or they may be the lining of a pan or plaque outlet. They are particularly effective in the elimination of high frequency whistles which are generated by air flow in the ducts. They are also employed in large systems with long runs where only a few outlets near the fan require treatment. Frequently outlet cells are the only means of correcting existing noisy installations, as the duct sections directly behind the outlets may be the only sections accessible for treatment. (See Fig. 14.)

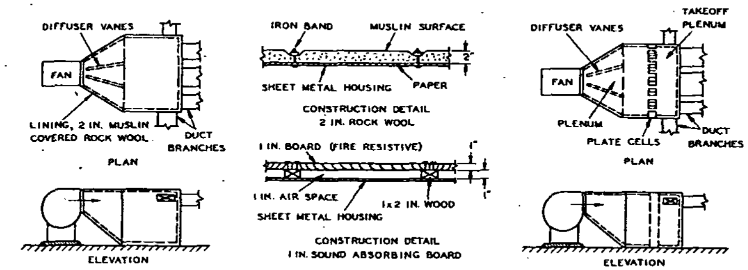


Fig. 13 .... Absorption Plenums With and Without Sound Cells

Package Units

Package units for attenuating sound in ducts are coming more and more into common use. These units have the advantage of providing, in a short length, a known amount of noise reduction with a minimum opportunity for errors in installation and for erosion of materials. The cost of inspection of the completed job is eliminated and the outside dimensions of the duct can be reduced as compared to a lined duct.

These units are available in sizes to fit 6 x 12 in. ducts up to 80 x 84 in. ducts. Charts are supplied by the manufacturers giving the attenuations and pressure drops for different types of units.

In Figs. 15 and 16, the noise reductions and static pressure drops for several types of package units are shown. Manufacturers' literature should be consulted for exact values.

Selection of the Absorptive Material

When a sound wave impinges on the surface of a porous material, a vibrating motion is set up within the small pores of the material by the alternating sound waves. As the ratio of the cross-sectional area of the pores to their interior surface is small, the resistance to the movement of air in the pores is large. This viscous resistance within the pores of the material converts a portion of the sound energy into 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 the duct. 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. In order to provide as much low-frequency noise absorption as possible by means of flexural vibration, it is desirable to fasten the absorptive panels discontinuously. This result may be attained to some extent by spot cementing, but better results are obtained when it is possible to fasten the absorptive panels to furring strips, leaving an air space behind. However, the exact resonance characteristics of the panels, and thus their absorption, are so unpredictable that flexural vibration cannot be relied upon for a specific value of attenuation.

Requirements for a good sound absorption material are: (1) high absorption at low frequencies;[16] (2) adequate strength to avoid breakage; (3) fire resistance and compliance with national and local code requirements; (4) low moisture absorption; (5) freedom from attack by bacteria and algae; (6) low surface coefficient of friction; (7) particles should not fray off at the higher design velocities; and (8) freedom from odor when either dry or wet.

DETERMINATION OF ROOM LEVELS

In the previous sections on fan and grille noise, sound power levels were given in dbe referred to 10^{-13} watt. These quantities as they appear at the duct termination (grille) must be

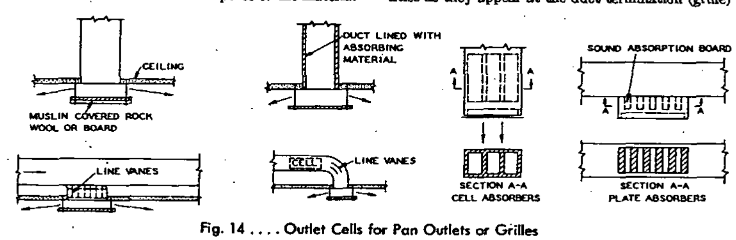


Fig. 14 .... Outlet Cells for Pan Outlets or Grilles