Some Physical and Psychological Aspects of Noise Attenuation by Vegetation

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ABSTRACT.—The physical mechanisms governing sound attenuation by foliage, stems, and ground are reviewed. Reflection of sound energy is found to be the primary mechanism. In addition, new experimental results are discussed that help to quantify the psychological effect of a plant barrier on perceived noise level. Listeners judged the loudness of noise transmitted through hemlock trees and through a minimal fence barrier to differ by as much as 7 dB even though the sound level at the listener was the same.

CONSIDERABLE MEASUREMENTS OF NOISE muffling by plants have been made. To properly interpret these measurements, a firm understanding of the physical mechanisms of sound attenuation by plants is required. For example, many of the differences in sound attenuation by plants found by earlier workers (Eyring 1946, Wiener and Keast 1959, Embleton 1963) can now be reconciled by physics (Aylor 1972a).

Besides physical effects, there can be psychological effects of plant barriers on the perception of noise. The visual shielding of a source by plants may have a beneficial effect for reducing the annoyance of noise (Kurze 1974, Herrington 1974). So far, this potential psychological effect has not been quantified.

PHYSICAL EFFECTS

Plants can attenuate sound by reflecting energy, by absorbing energy in the viscous and thermal boundary layers near the plant surface, or by internal damping of sound-driven oscillations of branches or stems. Moreover, plants can modify the texture of the ground and thus alter sound attenuation by ground. Microclimate, which has profound effects on sound transmitted outdoors, will not be discussed here. For a review of meteorological effects on sound transmission see Ingard (1953).

Scattering by Foliage

Sound is attenuated by foliage primarily by reflection or scattering. This conclusion is supported by the following observations: the attenuation of sound transmitted through foliage is much larger and increases more rapidly with sound frequency than predicted for absorptive mechanisms (Aylor 1972a, Embleton 1963); attenuation does not increase in direct proportion to the amount of foliage, but rather less rapidly; attenuation of a given sound frequency increases with the width of the leaf (Aylor 1972a and 1972b). Still further evidence indicating that foliage attenuates sound mainly by scattering, rather than by absorption, was deduced from measurements of sound reverberation between buildings covered with ivy (Aylor et al. 1973).

Clearly, the energy transmitted through a canopy of leaves is scattered many times, and the mathematical solution of this multiple-scattering problem is evasive. Fortunately, however, the reduction of a direct beam of sound by foliage can be estimated in terms of the leaf area per unit volume of canopy, leaf width, breadth of the canopy, and wavelength of the sound (fig. 1). Because leaves diffuse concentrated sound effectively but absorb little, best results are obtained when a screen of vegetation is placed on a line of sight between a.
direct source of sound and a listener and closer to the source than the listener. Sound that is already diffuse is reduced relatively little.

Scattering by Trunks and Branches

Since trunks and stems are quite rigid, little energy is scattered when the wavelength of sound is large compared with their diameter. However, in the high frequency limit — when the wavelength is small compared to the stem diameter — the amount of scattered energy can be significant. For this limit, at the far edge of a dense forest, the attenuation $A$ varies (Aylor 1972a) according to:

$$A \sim Z + \frac{1}{2} \log Z$$  \[1\]

where $Z = 4 \, N \, a \, y$ is the dimensionless scattering pathlength. $N$ is the number of trees per unit land area, $a$ is the average trunk radius, and $y$ is the distance into the woods. This approximate expression is not valid for small $Z$.

The values of the parameter $Na$ for most wooded sites range from $1 \times 10^{-2} \, m^{-1}$ to $5 \times 10^{-2} \, m^{-1}$. The predicted attenuation due to stems for high sound frequencies at 100 m or so distance agrees fairly well with measurements (Aylor 1972a). Finally, the principles of scattering show why visibility is a poor estimate of sound attenuation by trees. Because of the much shorter wavelength of light compared to that of sound, visibility is greatly reduced by small stems and needles. However, because of their small size, they do not scatter much sound.
Attenuation by Ground

When the source and receiver of sound are both near the ground, sound attenuation exhibits a maximum at a specific frequency (Ingard 1953). This attenuation is due primarily to destructive interference between the direct and reflected sound at the receiver, and it depends on the source and receiver heights, source-to-receiver distance, and the acoustic impedance of the ground surface.

The phase of the reflected wave is retarded with respect to the direct wave by two effects. First, there is a delay due to the increased distance traveled by the reflected energy. In addition, for porous surfaces there is a phase lag due to interaction of sound with the surface. Because the ground is porous, it reflects sound only after a slight delay, while the air in the pores is being compressed. This delay, combined with the longer distance traveled, causes acoustic interference at the receiver. In general, the more porous the soil, the longer the delay in compressing air in its voids. The result is that the peak attenuation occurs at lower frequencies over more porous soils (Aylor 1972a) and is less dependent on source-receiver separation. Moreover, far from the source with both source and receiver near the ground, i.e. grazing incidence, ground attenuation is very nearly 6 dB per doubling of distance (Ingard 1953, Aylor 1972a).

Psychological Effects

Although a narrow barrier of plants may give measurable attenuation of sound energy, some people believe that the visual shielding of the sound source may nevertheless have a positive or beneficial, psychological effect for reducing noise (Kurze 1974 and Herrington 1974). To help define the interaction of sight and sound on perceived noise levels, Lawrence E. Marks of the John B. Pierce Foundation Laboratory in New Haven, Connecticut, and I asked human observers to scale numerically, by the method of magnitude estimation (Marks 1974), the relative loudness of a narrow band of noise transmitted outdoors through barriers of different solidity.

Thirty subjects were asked to compare the relative loudness of a third-octave of noise at 1000 Hz transmitted to them through each of three barriers of contrasting physical characteristics or without an intervening barrier. The subjects were instructed to assign any number they wished to the first stimulus but to thereafter assign numbers in proportion to loudness. Sound levels, between 40 and 100 dB lasting 3 seconds, were presented at random from each of the four conditions. For each stimulus the subject faced the source of sound. In all, more than 1,400 separate loudness judgments were made when the barrier could be seen and the sound could be heard. As a control for our experiment, an additional 400 loudness judgments were made by 12 of these subjects while blindfolded.

The three barriers, constructed of acoustic tile, snow fence, or hemlock trees, with an identical sound source directly behind each one, as well as a source without any barrier, were arranged around a 15-foot radius circle. The barriers were about 3.7 m long and 1.5 m high. For the tile and hemlock barriers, sight of the source was completely obscured. The snow fence had a porosity of about 50 percent, so the source was only partially obscured, and, of course, for the no-barrier situation, the source was totally visible. Subjects were seated at the center in a swivel chair. The sound pressure level (SPL) was measured by a microphone centered about 15 cm above and facing towards the subject’s head.

Geometric averages of the magnitude estimates of loudness and arithmetic averages of SPL (dB) were made for all subjects for each of the conditions. The blindfolded subjects, on the average, judged all conditions equally loud at the
same SPL. However, when the barriers could be seen, sizable differences in perceived loudness emerged (fig. 2). Although a given noise transmitted through hemlock (H) and tile (T) seemed equally loud, this same noise, surprisingly, seemed less loud when transmitted across an open unobstructed space (O) and even less loud when transmitted through the minimal snow-fence barrier (F). That is, to maintain a given loudness for the listener, more sound energy was required at the listener for the F and O than for the H and T conditions. At the mid-range of stimulus levels, this difference was as much as 3.5 dB for the open and 7 dB for the fence.

These results were evaluated statistically by fitting a separate psychophysical function (Marks 1974) for each subject and taking the difference of their magnitude estimates for each condition at 70 dB SPL. All differences except T - H were significantly different from zero.

Visual shielding of the sound source dramatically affects the perception of
sound transmitted through a barrier, but this effect is not related simply to shielding. As long as the source can be seen, reduced visibility is accompanied by a reduction in apparent loudness. However, when sight is completely obscured, this effect reverses, and the apparent loudness increases. This last result may (of course, many alternative explanations exist) hinge on people's expectation of a solid barrier's effectiveness. In that regard, it might be analogous to the well-known size-weight illusion, in which the weight feels heavier when it is compressed into a small volume (Stevens and Rubin 1970). Based on experience, people generally expect that weight will increase with increasing volume, and thus the weight of massive object in a small container is often overestimated.

Perhaps this same kind of logic applies when a sound source is visually occluded by a barrier. Again, based on experience, people expect a solid barrier to reduce transmitted sound. Therefore, a given sound coming from behind a barrier seems surprisingly loud compared to one of the same level coming from a visible source and may, therefore, be overestimated. These results demonstrate a psychological effect of barriers on perceived loudness of as much as 7 dB. Unfortunately, the direction of this effect is not related simply to the visibility of the source. This certainly exemplifies the complex nature of the perception of environmental noise.

LITERATURE CITED