Sound Absorption Characteristics of Tree Bark and Forest Floor

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ABSTRACT.—Results of basic research on absorption of sound by tree bark and forest floors are presented. Amount of sound absorption by tree bark was determined by laboratory experiments with bark samples in a standing-wave tube. A modified portable standing-wave tube was used to measure absorption of sound by forest floors with different moisture contents, with and without leaf litter, and with and without moss growth. The implications of the results are discussed in terms of the amount and mechanisms of sound absorption by entire forests.

PLANTINGS OF TREES and shrubs of sufficient density and depth are well known to reduce some highway and industrial noise. The pioneering work of Eyring *(1946)* and subsequent work by Wiener and Keast *(1959)*, Embleton *(1963)*, Aylor *(1972)*, Cook and Van Haverbeke *(1971)*, and Reethof *(1972)* generally showed that attenuation of noise by forests depends on four factors:

1. Forest density.
2. Forest depth.
3. Frequency of noise radiated by the source.
4. Micrometeorological factors such as temperature gradients and to some extent wind velocity and vertical wind profile (wind is significant only if large distances between source and receiver exist).

The attenuation of noise by forests is usually expressed by the terrain loss coefficient, which is the acoustic transmission loss between any two specified points, x_2 and x_1, in the forest corrected for spherical divergence and divided by the distance $x_2 - x_1$. The terrain loss coefficient is, therefore, the transmission loss per unit of forest depth.

The results obtained by several investigators are given in figure 1, which is a plot of terrain loss as a function of source octave band frequency. The research was done in natural forests typical of the northeastern United States, which contained considerable rhododendron or mountain laurel in the understory. The important fact is the low absorption at frequencies up to about 500 Hz, with marked increases in absorption with increasing frequency above 500 Hz. Typical truck and automobile noise spectra are fairly flat, with peaks in the 125-Hz octave band (fig. 2). We conclude, therefore, that several hundred feet of forest are required to provide significant reductions in the A-weighted sound levels from vehicular traffic.

The mechanisms of noise propagation and attenuation in forests is complex. Consider a sound wave of, for example, 1000 Hz frequency (with a wavelength of about 1 foot) entering a forest. The tree trunks with diameters comparable to the wavelength will partially reflect and slightly refract the incident wave. This process is called scattering. The low-frequency waves (wavelength large compared to trunks and branches) will

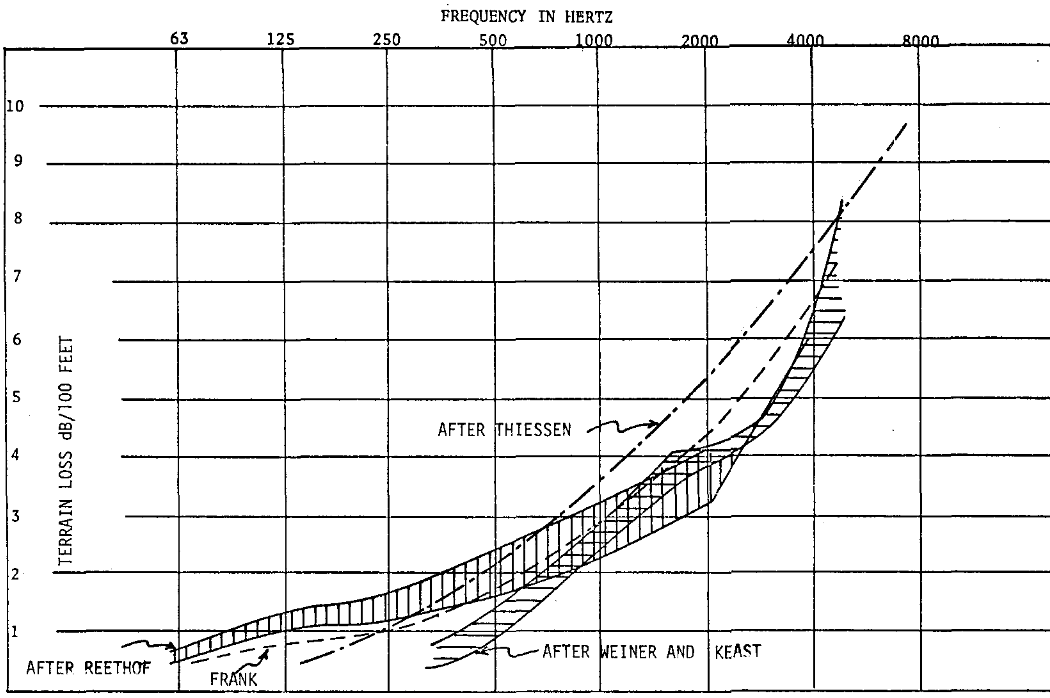
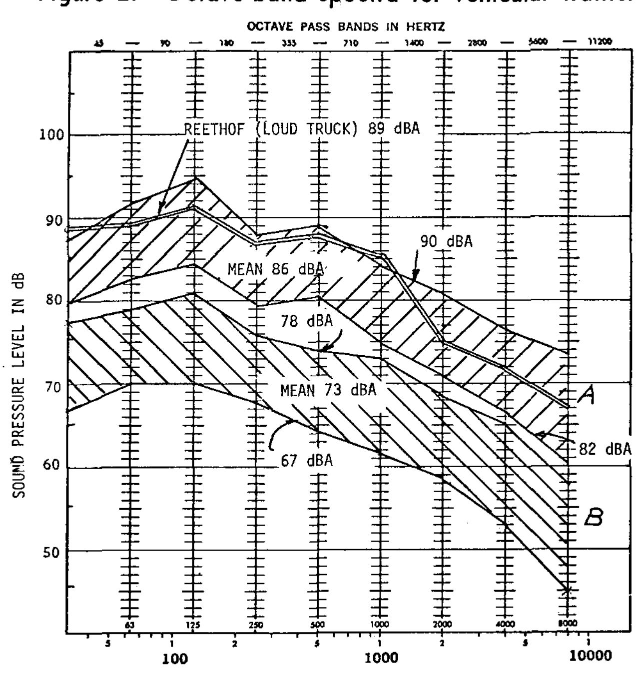


Figure 1.—Terrain loss of typical forests in northeastern United States and eastern Canada as a function of noise frequency (*Frank 1971 and Thiessen 1969*).

Figure 2.—Octave-band spectra for vehicular traffic.



A--Trucks

B--Passenger Automobiles

be transmitted almost unaffected by this phenomenon, whereas the high frequencies (> 1000 Hz) will be increasingly scattered with increasing frequency. This means that, with increasing frequency, the transmission paths will become increasingly complex and longer, providing greater opportunities for acoustic energy absorption to take place. Aylor *(1972)* has shown theoretically and experimentally that canopies, branches, and stems should be expected to provide some acoustic energy absorption as a result of viscous damping and thermal excitation. This phenomenon should be effective primarily at high frequencies.

At maturity, trees such as white oak *(Quercus alba)*, black gum *(Nyssa sylvatica)*, eastern hemlock *(Tsuga canadensis)*, and eastern white pine *(Pinus strobus)* have thick layered bark with considerable porosity. The possibility of absorption of substantial acoustic energy by bark in the multiple--scattering process should, therefore, be explored. In this paper we report some results of a study of normal incidence absorption by tree bark.

The effect of the ground is twofold. First, there is acoustic interference between the ground-reflected wave and the direct wave from a coherent source some distance above the ground. This "cancellation" is caused by the fact that the ground-reflected wave has to travel a longer distance than the direct wave, so that there will be a location at a certain distance from the source where the two waves are exactly at opposite phases, thus bucking one another. Acousticians will also recognize that because of the porosity of the ground, the reflected wave, as it leaves the ground, will be at a somewhat different phase than the incident wave at the ground surface.

The second effect of the forest floor is that it is a good absorber of sound because of its porosity. Typical forest-floor surfaces contain much decayed plant matter such as leaves, needles, branches, decayed trunks, and loose soil. Aylor *(1972)* performed grazing-incidence tests on open fields of unplowed, plowed, and disked soils. An excess attenuation of 6 dB per doubling of distance was shown to be possible. To study forest-floor absorption characteristics under more closely controlled acoustic conditions, we performed normal-incidence absorption tests, which will be reported here.

In all, the acoustics of forests are complex in that several forest elements affect the propagation processes in different and interacting ways. A study of the acoustic characteristics of the individual elements of the forest such as bark, canopies, shrubs, and forest floor should provide needed insight into the acoustic absorption mechanisms. Such insight will then permit the cultivation of the most important elements to maximize acoustic absorption.

BARK AS A SOUND ABSORBER IN FORESTS

Normal (perpendicular) incidence absorption of tree bark was measured with a standard impedance tube, also known as a standing-wave tube, manufactured by Brüel & Kjaer Instruments, Inc. Cylindrical test samples were cut from slabs of tree boles, leaving the wood intact behind the bark. Six species were tested: northern red oak *(Quercus rubra)*, mockernut hickory *(Carya tomentosa)*, eastern white pine, American beech *(Fagus grandifolia)*, eastern hemlock, and a cork oak *(Quercus suber)*.

The standing-wave tube is used to determine the fraction of the incident acoustic energy absorbed by a material in order to compare the effectiveness of various materials as acoustic absorbers. The apparatus generates pure tone waves that travel down the tube and strike the sample. Part of the acoustic energy is absorbed within the material, then the remaining energy is reflected and travels back up the tube. The superposition of the incident wave and the reflected wave establish a standing wave, which occurs as a result of the interaction of two waves of the same frequency traveling in opposite directions. The amplitude maxima and minima, measured from the standing wave, are used to calculate the absorption coefficient. A typical axial pressure pattern is shown in figure 3.

Figure 4 shows a schematic diagram of the apparatus. The sample holder is mounted at one end of the 10-cm diameter, 1-meter long impedance tube. A loudspeaker is mounted in a box at the other end of the tube. A frequency oscillator produces selected tones, and a frequency counter monitors the tone sent to the speaker to insure accuracy within ± 1 Hz. During operation, a ⅛-inch diameter microphone probe tube is moved longitudinally and centrally into the impedance tube. The microphone, located in the movable carriage, monitors the magnitude of the sound pressure of the standing wave. The signal from the microphone goes through a preamplifier to an audio frequency spectrometer. The absorption coefficient is then read from a calibrated scale on the

Figure 3.—A typical axial pressure pattern of the standing wave in the impedance tube.

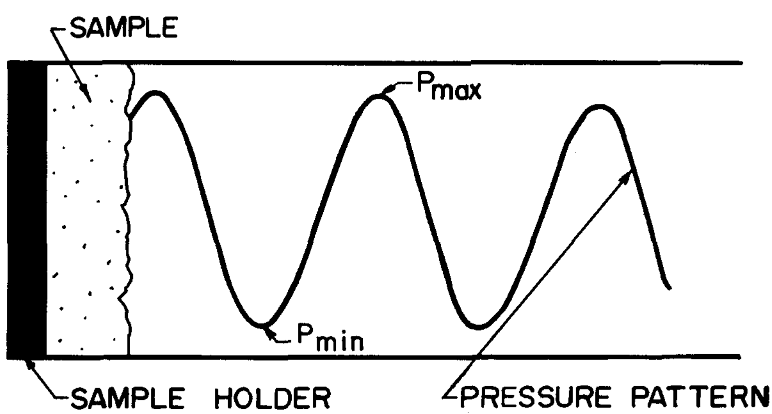


Figure 4.—Schematic diagram of the impedance tube apparatus.

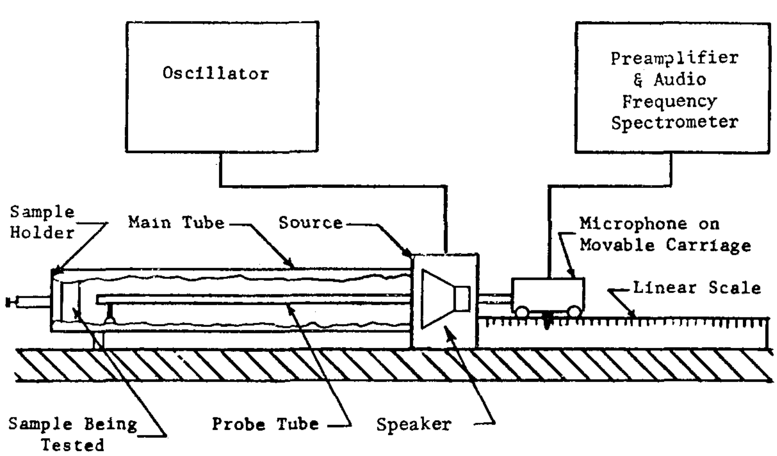


Figure 5.—Absorption of normal-incidence sound by bark of northern red oak.

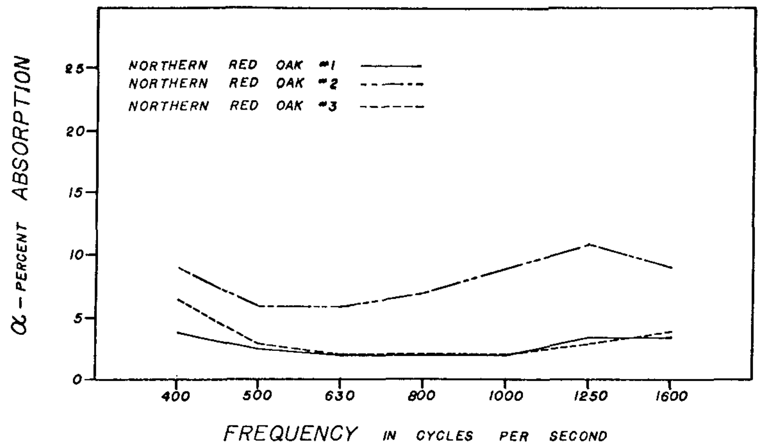


Figure 6.—Absorption of normal-incidence sound by bark of mockernut hickory.

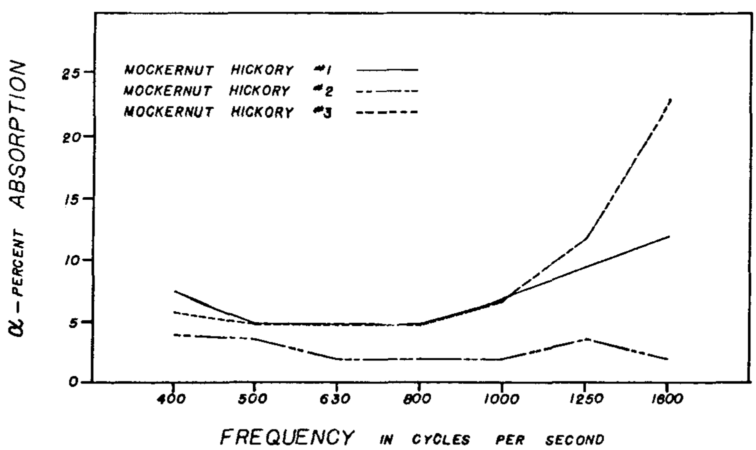
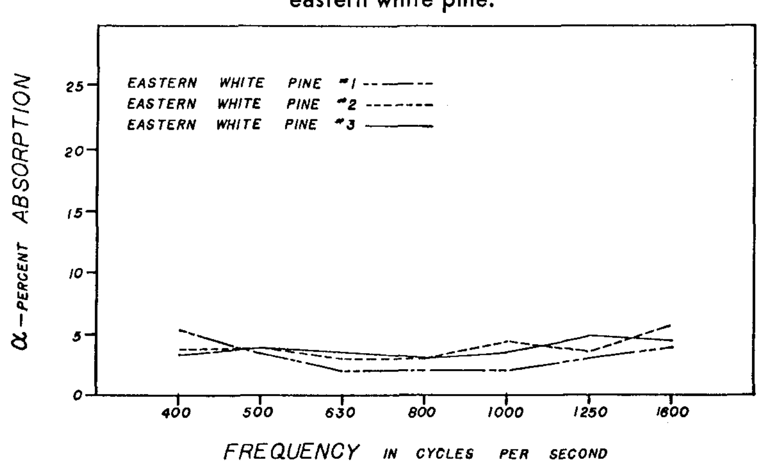


Figure 7.—Absorption of normal-incidence sound by bark of eastern white pine.



spectrometer. The samples were sealed in the holder by pouring paraffin between the sample cylindrical surface and the holder wall. It was determined that freshness of sample had no noticeable effect on the absorption coefficient.

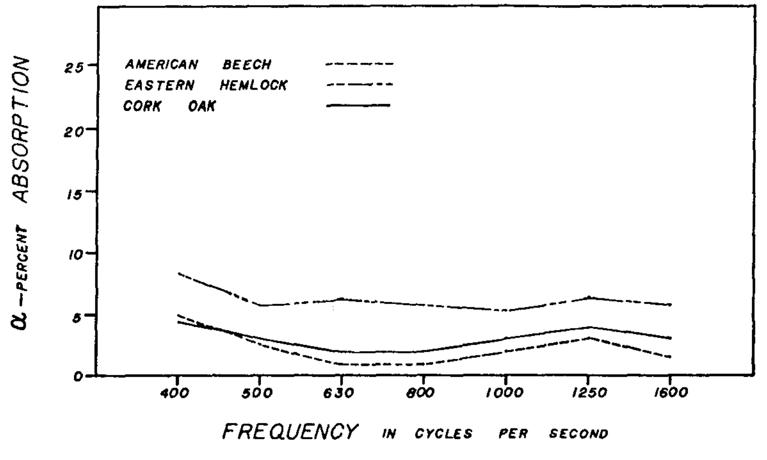
The 1-meter-long impedance tube is normally capable of providing reliable absorption data down to frequencies of 125 Hz. However, the presence of irregularities in the bark's surface made it advisable to record the maximum and minimum acoustic pressures at a greater distance away from the sample than otherwise possible during normal testing. This increased the lower limiting frequency, which depends on the length of the impedance tube available for measurement, to 400 Hz. The upper limiting frequency, which assures existence of plane waves, is determined by the diameter of the tube. Since sample surface irregularities do not affect the wave pattern far away from the sample, the upper limiting frequency of 1,600 Hz remained the same with the 10-cm-diameter tube.

The absorption coefficients versus frequency for samples of red oak, mockernut hickory, and white pine are plotted in figures 5, 6, and 7 respectively. Each figure shows the results for three samples, each checked for repeatability. The results of the repeated testing of each sample seldom deviated more than 1 percent. The absorption coefficients for all the samples of the three species was less than 10 percent, except for the hickory at frequencies above 1,250 Hz. One hickory sample absorbed a maximum of 12 percent, another 23 percent. The high absorption of mockernut hickory bark may be due to its shale-like layers with spaces between them. The spaces may allow vibration of the individual layers, and the air movement may result in acoustic absorption. This is a mechanical transformation of the incident acoustical energy, and most probably accounts for the additional absorption.

After the tests on oak, hickory, and white pine, we looked for bark characteristics that might alter absorption of sound and selected three other species for testing: American beech, eastern hemlock, and a cork oak (fig. 8). The hemlock sample had a higher absorption coefficient than the beech or cork oak, but all still indicated less than 10 percent absorption.

The percent absorption of the six

Figure 8.—Absorption of normal-incidence sound by American beech, eastern hemlock, and cork oak.



species we tested is quite low and largely independent of frequency. Although our six species provide a fairly wide representation of the characteristics of tree bark, tests on other species would certainly be warranted. Considering the small variation between species, it seems unlikely that any species would be found where the bark absorption would be so high that the sound attenuation of forests (or trees of that species) would be unique because of bark characteristics alone.

Although each tree surface may absorb only a small percentage of the incident wave, this effect is repeated as the sound wave is scattered towards the next tree, and so on repeatedly. The addition of the small absorption percentages is accumulative, yet we do not know how the total bark absorption will compare with that of the shrubs, foliage, branches, or the canopy as a whole. It can be assumed that the multiple-scattering principle will at least make the sound available to more surface area above the ground, since its path length is longer with each consecutive reflection. This gives the ground more chances at absorbing the scattered acoustic energy.

FOREST FLOORS AS A SOUND-ABSORBING SURFACE WITHIN A FOREST

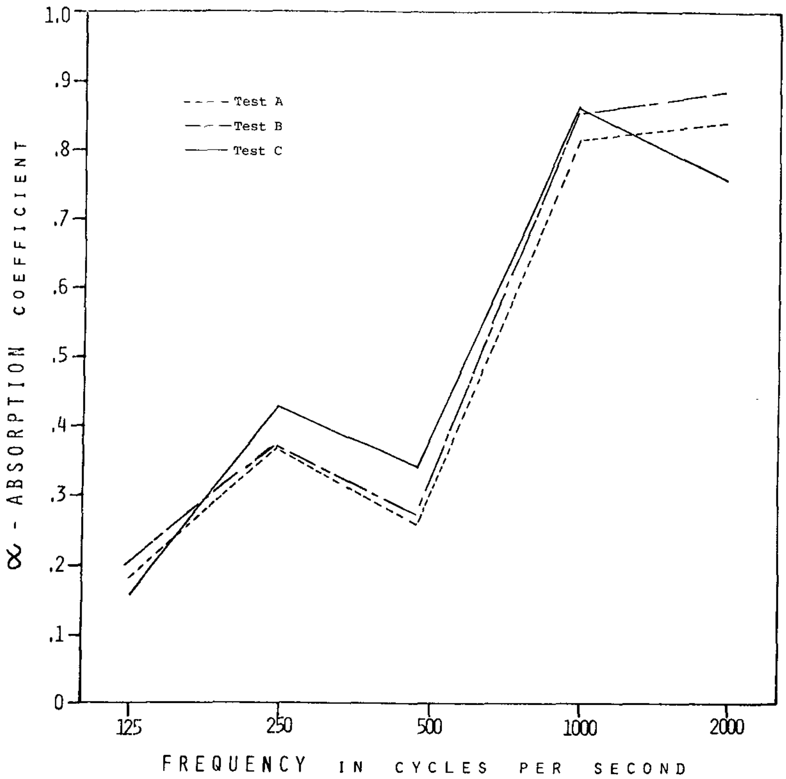
Normal incidence absorption of various forest floors was measured with a specially modified standing-wave tube that could be driven vertically into the ground without disturbing the soil within the 10-cm-diameter tube. The tube was 5½ feet long and permitted measurements in the frequency range of 125 to 2,000 Hz. The loudspeaker was located in a box mounted on top of the impedance tube. A frequency oscillator generated the pure tone sound signals. The ⅛-inch diameter microphone probe was moved longitudinally and centrally into the tube. The sound signals of various vertical locations of the probe inside the 10-cm tube were measured with an octave-band-filtered sound level meter. Again, the maxima and minima, were noted and the acoustic absorption coefficients were calculated. At the end of the five frequency measurements, the sample was ejected and another sample nearby was measurd to give an indication of the repeatability of the test.

All the field equipment is portable and battery operated. We used a four-wheel-drive vehicle to transport the equipment to various measurement sites within the forest.

To determine to what extent the various physical parameters of the soil (porosity, moisture content, surface configuration) will affect the measured absorption coefficient, each parameter was investigated separately. This was done by taking measurements with one parameter as the variable while all the others were held constant. The above was accomplished by noting the soil conditions at the time of the test and matching all but one of these conditions in the repeated testing. This procedure was adequate for determining the range of acoustic absorption controlled by each parameter with respect to the overall absorption of the sample. An analysis of this type of data leads to a better understanding of the mechanisms of absorption. The parameters exerting the most control or yielding the largest absorption variations are then identified quantitatively.

Figure 9 shows a typical curve of the absorption of a sample of the forest floor, the abscissa showing frequency in Hz and the ordinate showing the absorption coefficient α. The absorption shown here displays a primary peak (maximum value) at 1,000 Hz, a secondary peak at 250 Hz and a dip (low value) at 500 Hz. A particular forest-floor absorption curve can be compared to that of another location, in order to obtain an indication of the relative effectiveness of the floor as an absorber over the frequency range of interest.

Figure 9.—Absorption of normal-incidence sound by a forest floor—test for repeatability of measurements on one sample.



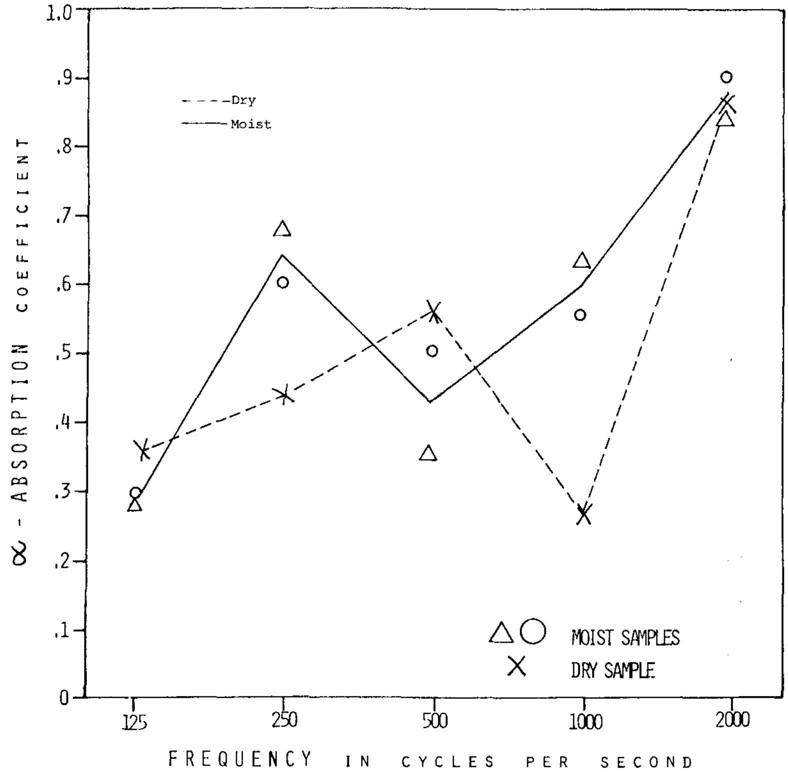
In figure 9, you can see that the three curves are nearly identical. This is the result of a test for repeatability of the same sample before its removal from the impedance tube. This variation is typical of acoustical measurements where data points within a few percent of each other are considered to be within the accepted range of tolerance. If there was a variation at a particular frequency of more than 0.05, the test was repeated before removal of the sample to confirm the results.

Each measurement condition was repeated by testing a comparable sample located approximately 2 feet away. This provides an indication of the variation between samples under the same conditions. The comparison of the absorption curves of either two or three measurements confirmed good repeatability for nearby tests.

A sample was tested when the ground was dry, without any rain for 2 weeks. The same locality was then retested when the ground was moist, 2 days after a heavy rain. The absorption curves for these tests are displayed together in figure 10. Since the sites were identical, we assume that all parameters remained constant except the moisture content of the soil. There is an indication from these two absorption curves that the ground was relatively more efficient at absorbing sound when it was moist than when it was dry.

An examination of several other sets of comparisons for identical localities with varying moisture conditions revealed some interesting trends. The sound absorption by the ground was noted immediately after rain; the amount of absorption increased after a couple of days of drying and then pro-

Figure 10.—Absorption of normal-incidence sound — same forest floor with two different moisture contents.



gressively decreased day by day as drying progressed. When the ground became saturated with the next rainfall, the cycle started over again. Thus, the time for maximized absorption was about 2 days after a rainfall.

The magnitude of the variations of acoustic absorption in the comparisons was, of course, frequency- and time-dependent, and the variations at some frequencies were much larger than at others. An overall increased or decreased absorption for the frequencies considered was the criterion for evaluation. An explanation for this observed phenomenon presumably is a change in the porosity of the ground as it becomes saturated with water. It is known that the porosity of an acoustically absorbent material is an important factor in the absorbing mechanism. These results indicate that the moisture content is a parameter to be considered in further investigation.

The determination of the effects of absorption by grass were measured in the manner just mentioned. Figure 11 shows the absorption curves of two samples, one of bare soil and the other with several inches of dry matted grass. As can be seen by comparison, the grass-covered sample provides more absorption and would attenuate noise more effectively. Other comparisons of similar sets of curves show the same results. It should be noted, however, that though the planting of grass would add some absorption to the environment, this might in turn affect the absorption by the soil. If the grass were to change the moisture content of the soil through its growth process, or through any changes in the irrigation of the forest floor, this change in moisture would affect the soil

Figure 11.—Absorption of normal-incidence sound for grass-covered and bare soil.

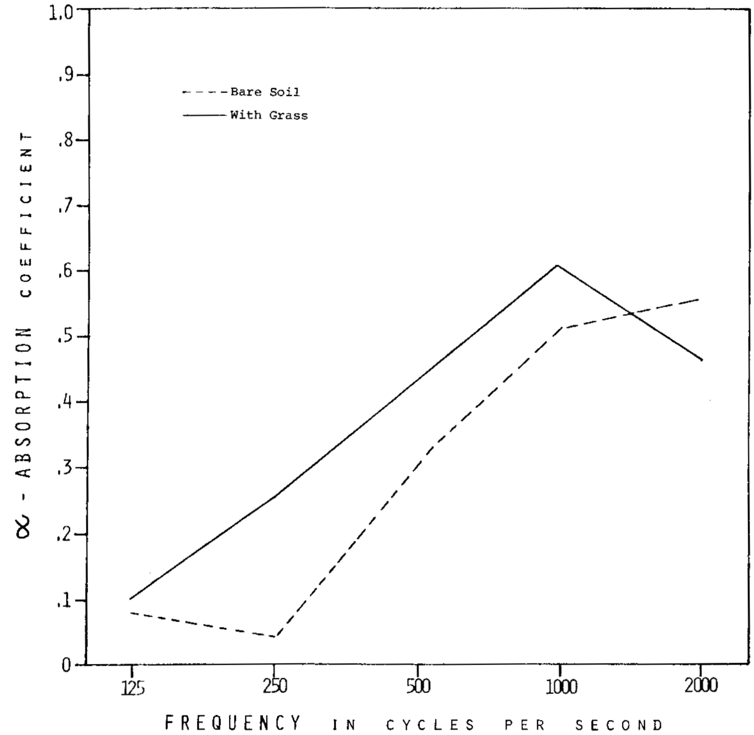
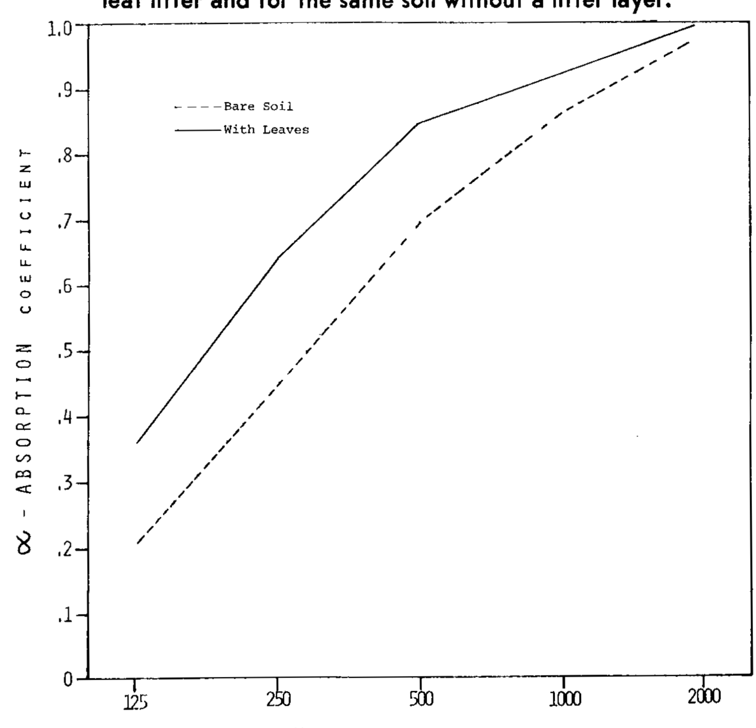


Figure 12.—Absorption of normal-incidence sound for soil with leaf litter and for the same soil without a litter layer.



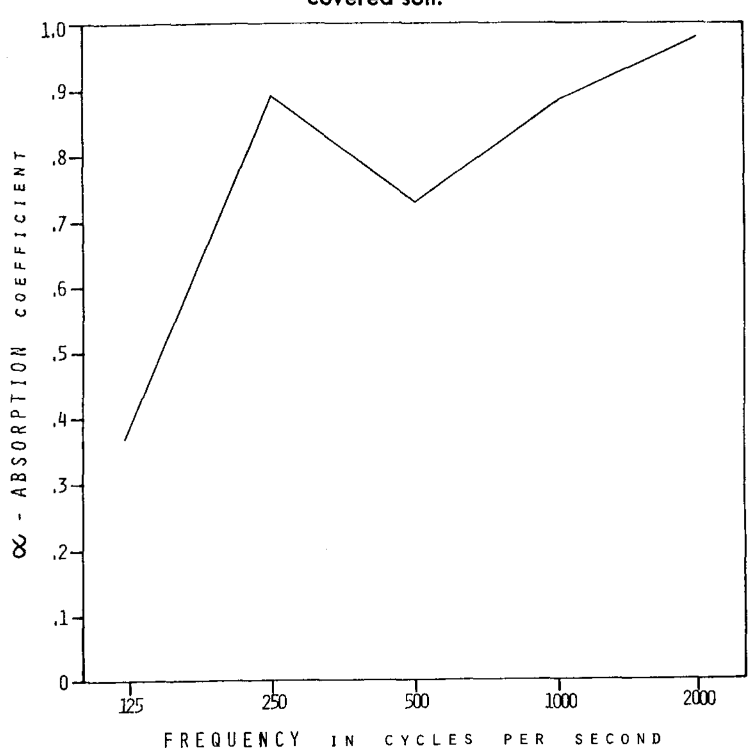
absorption. Whether or not this factor increases absorption has not been determined as of this time.

Similarly, the contribution of the absorption of the leaf layer in a deciduous forest was investigated. One such set of comparisons appears in figure 12. Like that of grass, the leaf layer adds to the absorption and in comparable amounts. Various isolated tests determined that the thickness and state of decay of the leaf layer were important factors. The comparisons of these tests show that, the thicker the layer of leaves present, the higher the percentage absorption obtained for a similar moisture content and thus the greater attenuation that would be provided. Similar tests were conducted in a coniferous forest with similar results.

In an attempt to investigate the absorption of the forest floor with a moss covering, the preceding method of testing a particular area with and without the vegetative covering did not give consistant or repeatable results. This may be due in part to the fact that the moisture content of the soil where moss grows is probably greater than that of nearby soil where there is no moss. Thus the inconsistancies would depend not only on the absorption by the moss, but also on the variations in absorption provided by different moisture contents of the soil underneath. Rather than a comparison in this case, the results can be summarized by stating that the absorption by a moss-covered ground is greater than that of bare soil or soil covered with leaves. A typical result can be seen in figure 13, a curve showing the absorption of moss-covered loam.

The results provide good indications of the normal incidence absorption characteristics of a typical forest floor. Forty-seven samples were tested, many of which were similar, providing indications of repeatability of the results.

Figure 13.—Absorption of normal-incidence sound by a moss-covered soil.



Some tests occurred with nonrepeatable results which we believe were caused by sample peculiarities. For example, a few samples were found to include rocks and roots. These samples were rejected from the analysis.

The question then arises, why forests do not attenuate sound to the magnitude that would be expected from all these results, as the percent absorption is quite high in some cases. This situation occurs because not all of the sound that passes through the forest actually comes in contact with the ground. Only those rays that strike the forest floor are partially absorbed by the ground. Here is where the trees become effective, as they act as sound scatterers, increasing the effective path length of each sound wave as it traverses through the forest. This gives the porous ground more chances to absorb the noise.

The results confirm that the ground is a significant absorber of sound in the forest. Moisture content and ground-cover structure have been found to cause variations in the absorption. The quantitative relationships of the effect of moisture, soil porosity, soil surface makeup, and extent of decomposition on absorption still need to be established.

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Acknowledgments. Leslie Frank made contributions to essentially all phases of this research, including equipment development and data collection and analysis. Formerly a graduate assistant at The Pennsylvania State University, he is now with Ostergaard Associates, Caldwell, N. J. Permission to use The Pennsylvania State Forests was obtained from the Commonwealth of Pennsylvania Department of Environmental Resources, Bureau of Forests. Assistance on location was provided by the A. D. Renninger Lumber Company of Richfield, Pennsylvania.