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Propagation of Environmental Noise

More theoretical and experimental work could permit the prediction and subsequent control of environmental noise.

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Sound propagation is a general term that embraces the myriad of processes that occur in the transmission of acoustical energy from the place where it is generated to the point of observation. It includes the phenomena of refraction and geometric spreading, air and surface absorption, and scattering, reflection, and diffraction. All of these are important and particular examples of environmental noise propagation. The main problem in studies of noise propagation is that of determining which mechanisms are dominant in any particular situation.

The process of observing the sound by measuring it with a microphone or listening to it has little interaction with the propagation process, except that the strategy for making accurate observations is affected by our understanding of the propagation. There is not such a distinct separation between the processes of generation and propagation, however. The location of a source may affect both its sound power output and the transmission of the sound. Location affects the directivity of the sound source.

As an example, let us consider an ordinary fan operating in an open window. If the window is closed, the sound power radiated by the fan may increase because of the impact of flow upon the window pane, while the propagation path is also very markedly changed. Nevertheless, with most environmental noise, we assume that the sound output of the sources such as cars, jackhammers, and aircraft remains nearly unchanged as the sources move about.

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The Phenomena That Comprise Propagation

The physical phenomena that are associated with sound propagation have been mentioned. Most practical situations include at least two or three of these phenomena. In this section, I give a brief description of each phenomenon and an indication of the kind of propagation problems in which it occurs.

Geometric spreading. This refers to the spreading of sound energy in space as a result of the expansion of the wave fronts, as shown in Fig. 1. It (almost) always causes an attenuation in sound levels by a certain amount when the propagation distance is changed by a fixed ratio. This ratio is ordinarily the distance doubled, abbreviated *dd*. Geometric spreading is generally considered to be independent of frequency and has a major effect in all situations of sound propagation (*1*).

Refraction. Refraction is the bending of sound rays caused by gradual changes in the speed of sound that are brought about principally by wind and temperature gradients in the atmosphere (*2*). Humidity also changes the speed of sound by changing the average molecular weight of the gas. Since the speed of sound is shown by $c = (\lambda RT/M)^{1/2}$, the effects on sound of changes in molecular weight, M, and temperature, T, are equivalent (R is the gas constant and λ is the ratio of specific heat). This equivalence is expressed by deriving an "acoustic temperature" for purposes of sound speed calculation (*3*). An example of refraction with temperature lapse and wind gradient is shown in Fig. 2. Refraction is important when the change in the path of sound may affect shielding of the observer from the source as shown in Fig. 3. Refraction effects are usually only observed for distances of a few hundred meters (1 foot = 0.3 meter) or more.

Air absorption. The absorption of sound in air is caused by (shear) viscosity, heat conduction, and molecular vibrational relaxation (*4*). The effect is commonly expressed as a change in sound level in a fixed distance. Commonly chosen distances are 1000 feet or 1 kilometer. The attenuation is frequency dependent and typically amounts to a few decibels per 1000 feet in the most audible frequency bands, 500 hertz to 2 kilohertz. This form of attenuation is most significant for the noise of aircraft landing and taking off or for other noise problems in which the propagation distance is rather long.

Surface absorption. Sound levels are affected by surface reflections in two distinct ways. When the source and receiver are both close to the ground, the ray reflected from the ground may interfere destructively with the direct ray as shown in Fig. 4 (*5*). This effect is usually noticeable over ranges of propagation from a few hundred to a few thousand feet in the frequency range from 100 to 500 hz. When the source is very close to the ground as in the case of snowmobiles or lawnmowers, the effect is even more important and can affect sound levels very close to the source. An example of this attenuating effect is shown in Fig. 5 (*6*).

Sound levels are also affected by the loss of energy upon reflection. This process is called surface absorption in acoustics. The effect is of paramount importance in room acoustics for the sound strikes the walls many times (*7*). In outdoor propagation the losses upon reflection are also important. When sound propagates along a city street, for example, multiple reflections from building faces occur. Sound that would reach the observer if the buildings were perfect mirrors is reduced because of absorptive reflection losses (*8*) and because of redirection of the acoustical energy. The redirection of sound is more properly included in the subject of scattering.

Scattering. When sound waves encounter a region of inhomogeneity in the medium (a local variation in sound speed or air density) some of their energy is redirected into many other directions. This process is called scattering and is distinct from refraction and reflection. In those processes, the redirection is essentially into one direction. Scattering is produced in environmental noise situations by turbulence (*9*), rough or irregular surfaces (*10*), and obstacles in the path such as trees and other vegetation (*11*). In industrial situations pipes, machines, and other obstacles scatter and redirect the acoustical energy.

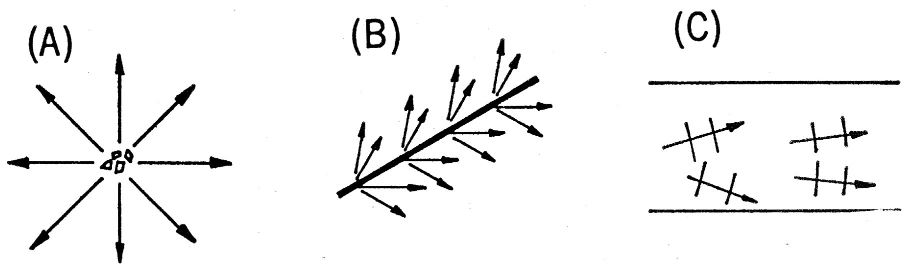
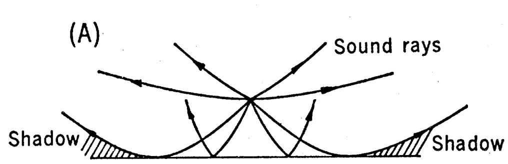


Fig. 1. Geometric divergence of sound waves and resulting attenuation. (A) Spherical spreading, 6 dB/*dd*; (B) cylindrical spreading, 3 dB/*dd*; (C) sound in channel, 0 dB/*dd*.



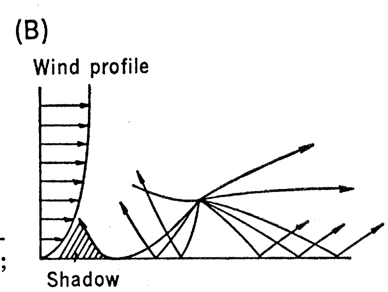


Fig. 2. Refraction of sound by wind and temperature gradients. (A) Temperature lapse, no wind; (B) temperature lapse, with wind.

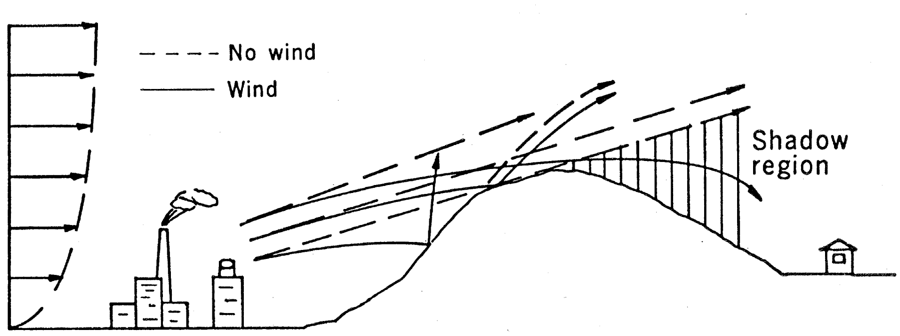


Fig. 3. Destruction of barrier effect by wind refraction.

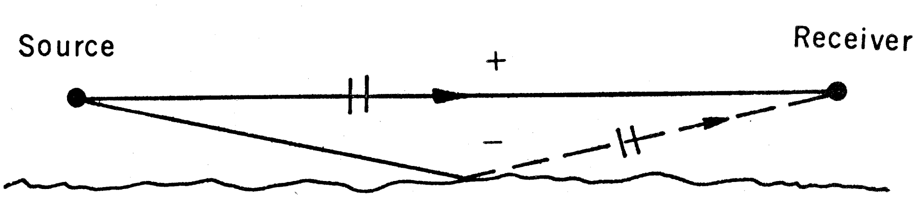


Fig. 4. Reflection of grazing wave from ground showing possibility of destructive interference.

Scattering can cause quite remarkable changes in sound levels. When sound would normally be shielded from some region by a barrier, turbulence can cause the effectiveness of the barrier to be greatly reduced. Barriers rarely provide more than 15 dB of shielding in field situations because of the sound energy scattered into the shadow region by turbulence (*12*). On the other hand, turbulence scattering does not cause losses in energy great enough to compete with other attenuation processes in directly illuminated regions.

The scattering of sound by rain, fog, or snow, for example, at ordinary frequencies is not great enough to be significant (*13*). The effects of precipitation are far more important in changing sound transmission by changing the humidity and the temperature distributions in the lower atmosphere.

Reflection. When the sound encounters a surface that is several wavelengths in extent, the entire wave is redirected. This results in increased sound levels for positions illuminated by the rebounding wave and reduced levels at other positions, as shown in Fig. 6. Barriers reduce sound levels by reflection; the orchestra shell of a concert hall enhances sound by the same process.

As mentioned before, reflections are of particular importance in propagation along city streets. Experiments show that significant amounts of sound energy may still be present after a wave makes four or five reflections from the surfaces of a building. In most outdoor situations, however, reflection and scattering take place simultaneously because of the rough texture of the surfaces. The actual absorption of sound from masonry walls is generally less than 10 percent, but the amount redirected by scattering may be significantly greater than this (*14*).

Diffraction. In a shielded region (behind a house that faces a busy street, for example) sound levels may be limited by diffraction. Diffraction and scattering are very similar phenomena. Diffraction may, in fact, be defined as the scattering that occurs at a region of inhomogeneity at the bounding surface of the medium, such as where there is a rapid change in impedance or radius of curvature (*4*, p. 449). Thus, a finite wall forms a boundary to the medium. The flat surfaces of the wall result in reflection, but the sharply curved surfaces at the edges of the wall cause the scattering termed "diffraction."

Because the pipes and machines in

a factory might be defined as part of the "bounding surface" of the medium, it is evident that the distinction between scattering and diffraction may be somewhat artificial. Diffraction in outdoor sound propagation is important in transmitting sound energy into shielded areas, although the absolute amount of sound power redistributed by diffraction is quite small.

Wall transmission. The phenomena already discussed are of principal importance to people outside of buildings. Because most people spend much of their time within buildings, the transmission of sound through the exterior walls, windows, and doors of these buildings is of prime importance in establishing the noise levels to which people are exposed. In this article I discuss the prediction of noise levels outside buildings; once the exterior sound levels are known it is possible to predict the noise within buildings by reference to standard transmission values (*15*).

To show how the various phenomena that affect sound propagation enter into practical noise situations I will consider several examples. In each example there are aspects to the propagation that are well understood and there are others that are uncertain. Active research is under way in this field and we may hope that some of the uncertainties will soon be removed.

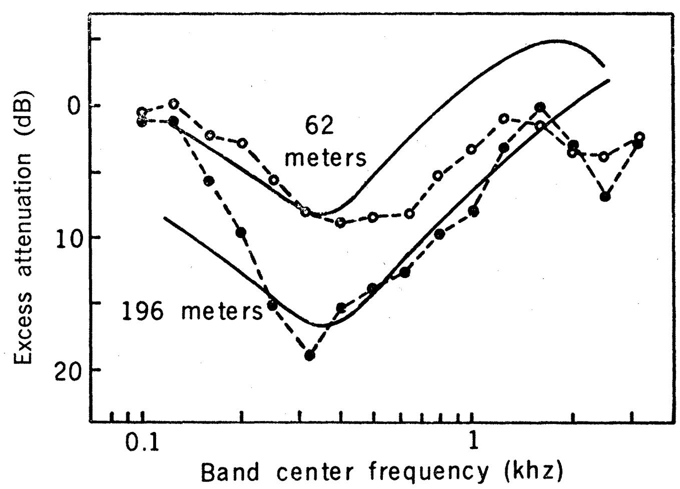
Aircraft Take-Off Noise

In Fig. 7 an aircraft is shown taking off along the path ABC, and we are interested in the sound levels heard by the observer at O. The principal determinants of the sound at O are (i) the power of the source (in octave bands), (ii) the directivity of the source, (iii) geometric spreading, (iv) air absorption, and (v) ground reflection (*16*). Determinants (i) and (ii) are source characteristics and not propagation effects; (iii) and (iv) are the principal propagation effects that must be evaluated for this situation; (v) is important, but is easy to evaluate—the ground reflection simply adds 3 dB to the received sound level at a normal height of the observer's ear above the ground.

Geometric spreading for "point" sources is simply 6 dB of loss per doubling of distance (6 dB/*dd*). Refraction of the sound may change this slightly. There is more uncertainty in the air absorption. In calculations of aircraft noise at distances of several kilometers, the sound levels in the higher frequency bands have been consistently overestimated (*17*), probably because of incorrect estimates of air absorption at these frequencies.

Recent investigations of air absorption over wide ranges of frequency and humidity indicate that the role of nitrogen in producing attenuation in the lower frequency bands has been underestimated (*18*). Although a single relaxation theory of molecular vibration for oxygen and nitrogen molecules appears to fit the form of the absorption data, the role of water molecules in catalyzing this energy transfer alters the temperature dependence of the absorption (*19*). Also, the reaction can become complicated in that there may be several different modes of energy transfer to the molecules. These multiple transfer processes together with the catalyzing effect of the water vapor tend to conceal the temperature de-

Fig. 5. Excess attenuation caused by ground absorption; receiver height, 1.83 meters; source height, 1.52 meters. Symbols: ○, theoretical data; ●, experimental data. Parameter on curves is source-receiver distance. [From Delaney and Bazley (*6*); courtesy of the *Journal of Sound and Vibration*]



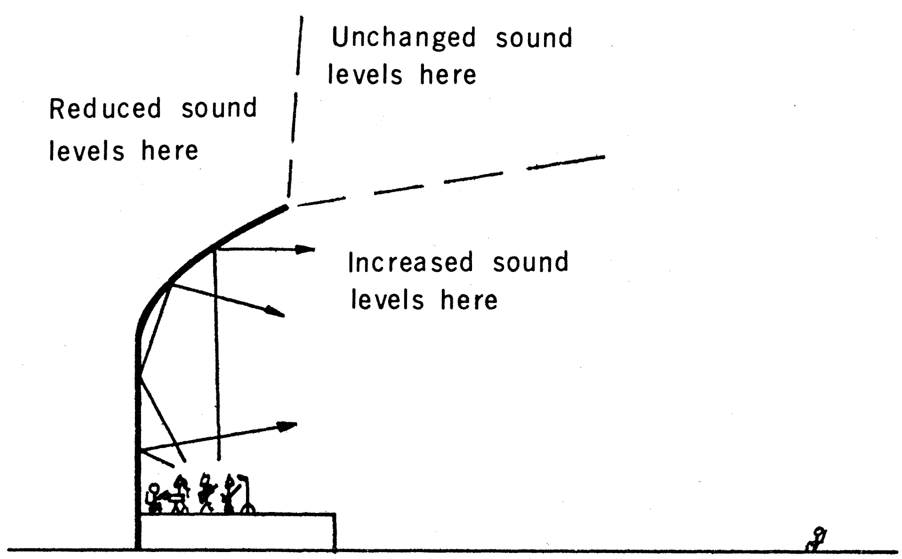


Fig. 6. Reflection of sound energy by orchestral shell.

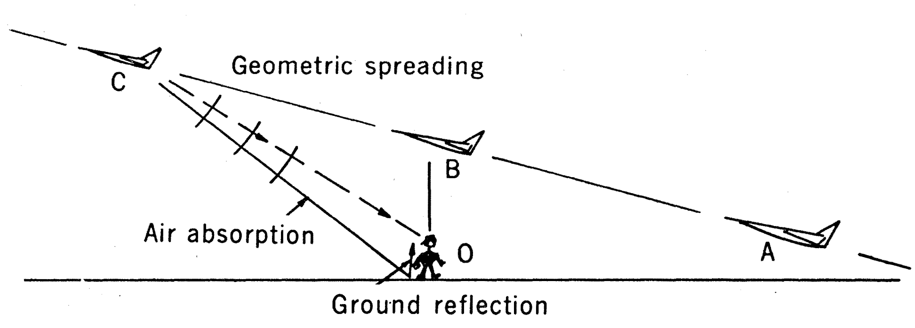


Fig. 7. Sources of attenuation of aircraft noises.

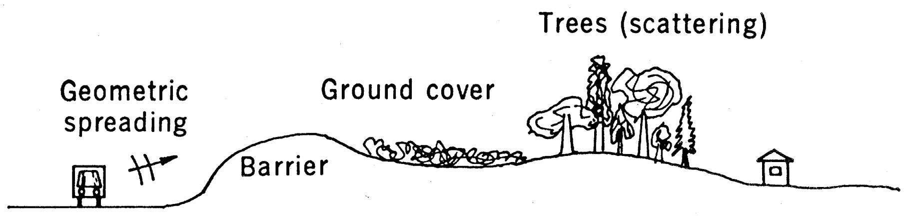


Fig. 8. Sources of attenuation of traffic noise.

pendence. Thus, although air absorption is well understood at a temperature of 20°C it is not understood how the absorption should vary as one departs from this temperature.

Highway Noise

The noise from trucks or automobiles is generated close to the ground and usually the receiver is also near the ground. Figure 8 shows some topographical features that may occur near a highway and affect sound propagation. These features act as barriers to the sound. Ground cover and trees may produce low-frequency attenuation as a result of absorptive reflection and sound scattering.

Attenuation caused by geometric spreading of the sound waves from a single vehicle increases at 6 dB/*dd*. A line of traffic, on the other hand, produces an average noise level that decays at 3 dB/*dd* (*20*). Theoretical and experimental studies have been conducted on the statistics of noise from lines of traffic composed of different numbers of the principal classes of noise sources: trucks, passenger cars, and motorcycles (*21*). In making a precise determination, a different geometric attenuation factor must be applied to each statistic of the noise field. This is an area in which it is very difficult to separate source characteristics from "propagation."

The attenuation produced by topographical features is treated as a simple barrier diffraction problem in most calculations (*22*). Much more work needs to be done in this area since earth berms, road cuts, and barrier walls can be used in the control of noise from roadways. The use of standard diffraction formulas for "thick barriers" such as buildings or elevated roadways is not a resolved issue at present. In most calculations the thick barrier is treated as a single, equivalent, taller, thin barrier (*23*); in other calculations the theory of double diffraction is applied (*24*). It is evident, however, that a rounded earth berm covered with short vegetation is not adequately accounted for if it is treated as a simple rigid wedge. The use of diffraction studies of absorbing cylinders would represent a step forward (*25*), but studies of diffraction by layered cylinders would be even better.

There has also been a series of studies regarding the attenuating power of trees, but the results of these studies are inconclusive (*26*). Most acousticians agree that (aside from esthetics) ringing one's yard with trees presents very little barrier to neighborhood noise. Studies of propagation through various kinds of wooded regions show attenuation factors that differ by a factor of 10. Even the proper form of attenuation dependence is uncertain.

An interesting study of sound attenuation by vegetation and ground was reported recently by Aylor (*27*). In this study, major mechanisms of attenuation by vegetations were identified as scattering by leaves, stems, and trunks, and ground interference. Aylor attempted to identify the relative importance of various mechanisms and presented some theoretical considerations that support his conclusions. Although a fully developed scattering theory could probably account for such data, the problem of presenting the results in a manner intelligible and useful to noise control engineers would remain.

Thus road traffic noise over open flat ground is reasonably well understood. Reduction in noise levels can certainly be achieved by the use of topographical features, including ground cover, but the quantitative prediction of such reduction may be substantially in error.

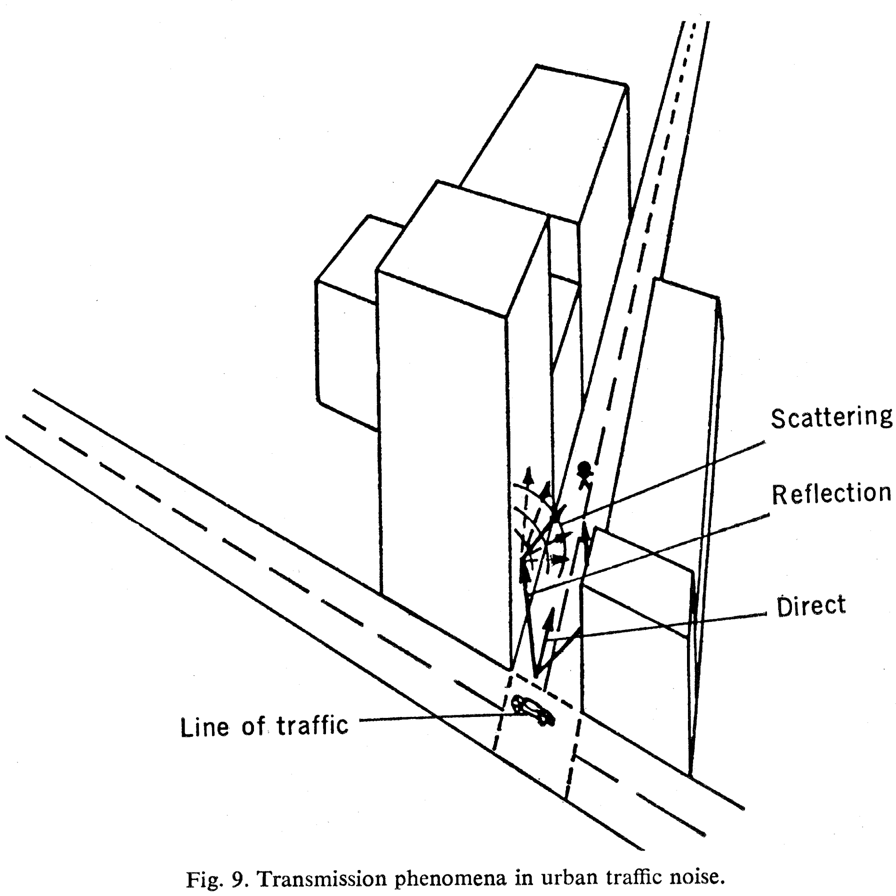
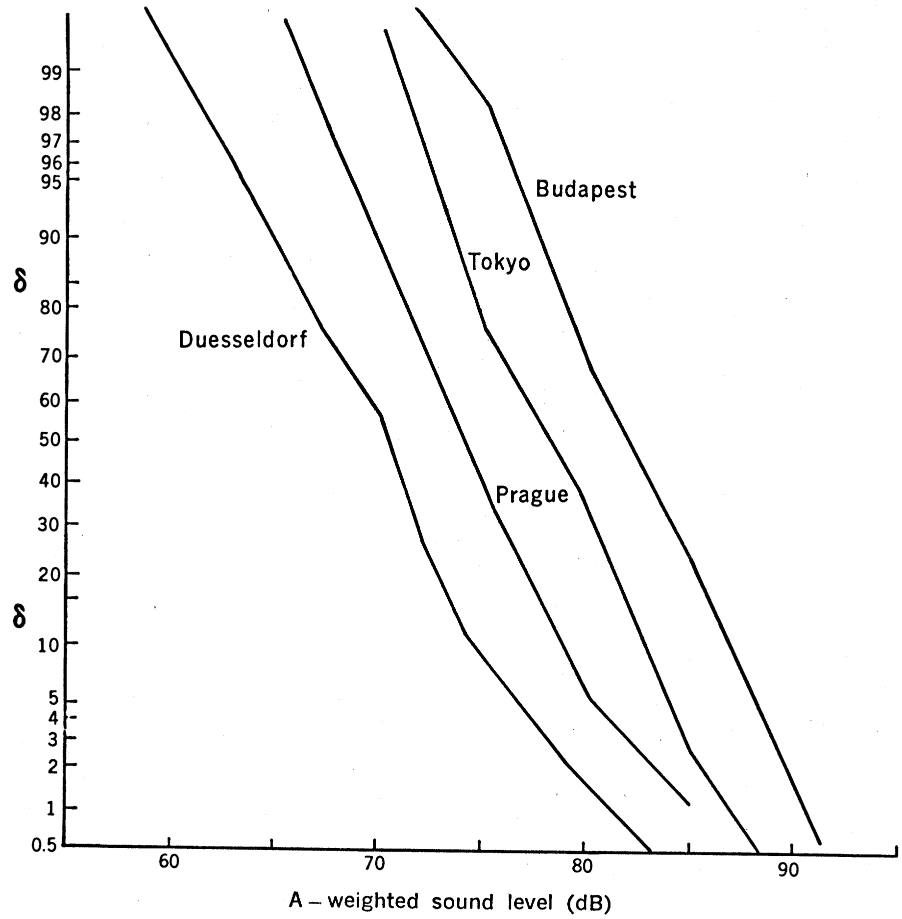


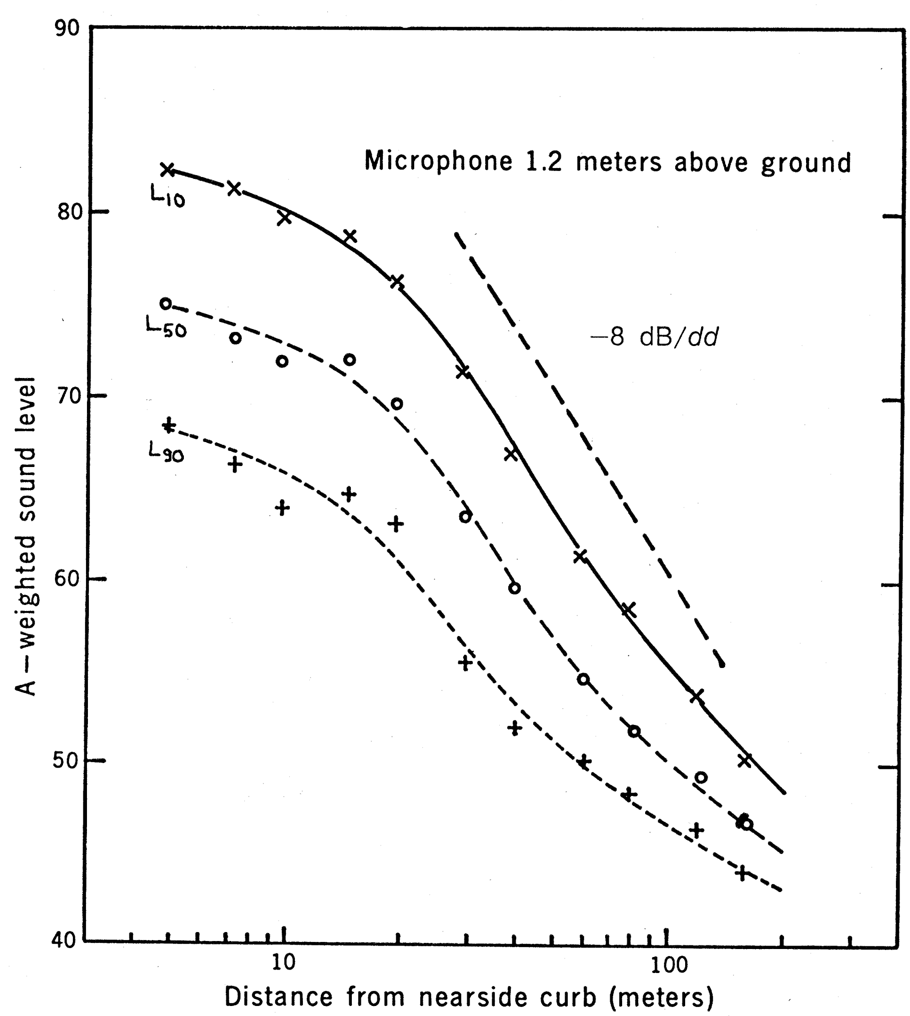
Fig. 9. Transmission phenomena in urban traffic noise.

Noise Propagation in the City

A possible reaction to this topic is that urban noise does not have to propagate—it is everywhere! It is true that noise sources in the city are ubiquitous. Nevertheless, there are quiet regions in which the background noise is set by the general distribution of noise sources throughout a city (*28*). There are also quiet streets that have intrusive noise that is produced on a busy adjoining thoroughfare (*29*). In addition, there are intensive noise sources that may dominate the sound in a particular vicinity, even in busy areas. In all of these situations, the combined effects of reflection and shielding by buildings are

Fig. 10 (top). Cumulative distributions of traffic noise in the loudest streets of Budapest, Tokyo, Prague, and Duesseldorf. Fig. 11 (bottom). Variation of noise level with distance from main road along cross road. [From Delaney *et al.* (*29*); courtesy of National Physical Laboratory]





(aside from geometric spreading) the dominant propagation factors that determine sound levels for the observer.

As an example, let us consider sound propagation along a city street as shown in Fig. 9. Specular reflection from building facades produces the effect of an infinite line of sources (images of the real source) which has a 3 dB/*dd* decay along the street. The scattering and capture of sound by the spaces between building acts as an absorption effect, which means that the sound levels should eventually decay at 6 dB/*dd* (*8*). In fact, however, experiments show that there are ranges near the source along which the sound decays at 7 to 8 dB/*dd*, a rate that is impossible with a model that contains only specular reflection and absorption (*29*). This discrepancy can probably be accounted for by the effect of scattering both in enhancing the sound levels near the source and acting as an excess absorption effect, but such conclusions are very speculative.

Propagation in Relation to Noise Criteria

If it is important for us to identify the major features of propagation for various environmental noise situations, it is equally important that we understand what questions we should ask the propagation model once the phenomena are identified. Our asking the right questions depends on our knowing what are the features of the noise pattern in space and time that are related to annoyance, task interference, loss of hearing acuity, or some other undesirable effect. Thus, although we can separate the physical processes of propagation and observation, we cannot make such a separation when we have to predict noise impact. Most calculations of propagation losses for sound waves are computed or expressed for average sound levels. When other statistics of the noise are of interest, the effect of propagation is not the same as it is for average values. Thus, by examining some of the measures of noise levels that are based on these statistics we can formulate some questions that might be asked of the propagation model.

Psychoacoustic Criteria

The term "criterion" in environmental matters is used in two ways (*30*). First, it is an expression of an allowable limit for some effect, for example, "my understanding of speech should not be interfered with more than 10 percent of the time," or "my hearing should not be impaired so much, that while I may not be able to hear some musical features very well, my understanding of speech should be unaffected." On the basis of laboratory and psychoacoustical field tests, these "performance criteria" are then translated into physical measures such as speech interference level (SIL) or A-weighted sound levels (measured by the "A" setting on a sound level meter) according to the Occupational Safety and Health Act of 1970 (*1*, p. 546). Second, the numerical values of the disturbance of these physical scales that correspond to the performance criteria are also referred to as "criteria." Although this has often resulted in confusion, it is very difficult to change the dual usage of the term.

Psychoacoustical criteria have to do with both the physical effects of sound on the biological or nervous system and the subjective aspects of sound. Physical effects include such criteria as loss of hearing, disorientation, and pain. This class of criteria is not generally thought to be of prime significance in urban noise. The subjective aspects of sound, which include loudness, annoyance, speech interference, startle, and task interference, are so termed because the degree to which they are apparent depends upon the attitude of the listener toward the noise and on his familiarity with it. The establishment of standards for urban noise must include consideration of several subjective criteria and not just a single one.

The proliferation of scales for measuring noise appropriate to these criteria is a cause of some embarrassment to acousticians. It is the source of the "alphabet soup" one encounters in the literature on environmental noise: the A-weighted sound level [units dB(A)]; perceived noise level, PNL (with various suffixes, prefixes, and subscripts to note corrections for duration, presence of tones, and impulse); noise criterion curves (NC curves); noise exposure forecast (NEF); composite (or community) noise rating (CNR); community noise equivalent level (CNEL), and so on. Out of these, the simple A-weighted reading of the sound level meter appears to be gaining credibility as a general scale for noise. The A-weighting filter in the meter gives an importance to various frequency components of the noise in accordance with the loudness sensitivity of the ear at moderate sound levels.

The A-weighted sound pressure level, L_p^A, will vary in time and place, however, in a random—or at least unpredictable—manner. In the following discussion I will assume that the "A" notation is understood; that is, all levels are A-weighted. The variability of the noise has been shown to have an influence on its acceptability. Studies of traffic and aircraft noise have led to a rating scale for noise called the noise pollution level, L_{NP}, that takes account of this variability (*31*).

It is given by

$$L_{NP} = L_{50} + (L_{10} - L_{90}) + \frac{1}{60}(L_{10} - L_{90})^2 \qquad (1)$$

when the A-weighted sound levels are distributed in an approximately normal distribution (the tendency of environmental levels of pollutants to be distributed in a log-normal fashion has also been noted in air and water pollution problems). Statistical distributions of some traffic noise levels are shown in Fig. 10. The quality L_n is the *n*th percentile value of the cumulated variable, the value that is exceeded *n* percent of the time. Equation 1 shows that wide variations in sound levels will increase the value of L_{NP}.

As mentioned earlier, propagation effects will cause differing changes in these various statistics as the observer (or source) moves from one place to another. Most studies of acoustical propagation have been concerned with changes in average signal energy only. In a traffic noise situation, we might want to determine the effect of a barrier, say, on the 10 percentile noise level (L_{10}), which may be quite different from its effect on L_{50}. Generally, a barrier has a greater noise-reducing effect on nearer sources than more distant ones. Since there are more sources at a distance, the effect of the barrier is to reduce the variance of the sound levels and to decrease L_{10} values more than L_{50} values are reduced (*32*). Similar calculations have also been made for sound transmission through walls and windows (*33*).

Delaney *et al.* (*29*) have shown that a row of houses facing a busy street will reduce the noise entering their

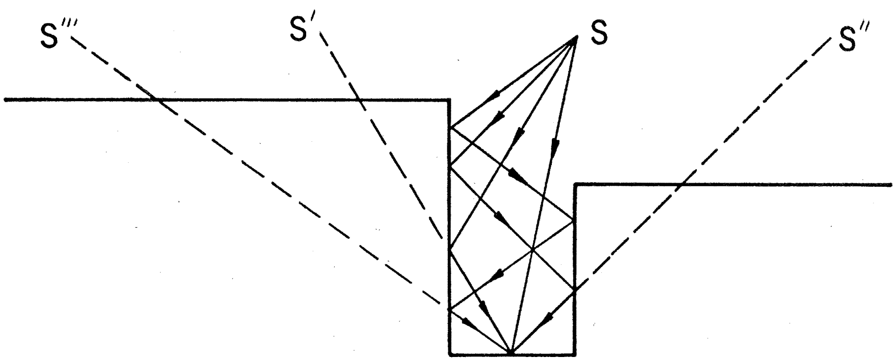


Fig. 12. Scale drawing showing acoustical images heard by listener. The sound generated at *S* is preserved at ground level on a simulated city street. The points *S'*, *S''*, and *S'''* are acoustical images of the source point.

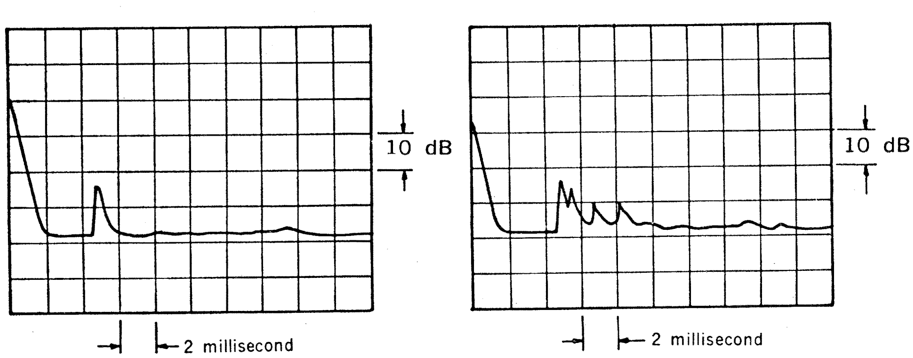


Fig. 13. Time pattern for received sound level in the 32-kilohertz band; (A) with sound absorbing material on the walls; (B) no sound absorbing material.

back yards by 10 to 15 dB. The noise reduction for the 10 percentile levels is about 5 dB more than it is for the 90 percentile levels. This would appear to confirm the suggestion that nearby sources (that are more effectively blocked by the houses) are responsible for the 10 percentile levels and that more distant sources dominate the 90 percentile levels.

If a particular kind of noise source is prevalent (such as surface vehicular traffic) these various statistics of the noise will be interrelated in the sense that the form of the distribution is known. Examples of traffic noise distributions in city streets are shown in Fig. 10 (*34*). In this event, one may represent the sound field by a single statistic, such as the L_{10} value. The English use L_{10} because it is not so dependent on infrequent, very loud noises in the way that L_1 or L_5 might be, and tends to be determined by noise sources that are generally in the vicinity of the observation point. Thus, one can avoid setting noise standards on the basis of the general prevailing background noise of the city in the way that L_{50} prescription might tend to do.

How Well Do We Understand Propagation?

In my discussion of what propagation effects are, and how we should use propagation information to predict noise measures of interest, I have only suggested some of the limitations that exist in predicting the numerical effect of propagation in particular situations. I will now discuss in more detail the problems of identification of propagation effects and the evaluation of those effects.

The first problem, that of identification, is the most crucial one. Practical field measurements rarely allow the kind of control of source parameters and variation in path properties that would be ideal. Thus, although we know that geometric spreading, reflection, and scattering are the important processes occurring in Fig. 9, for example, we cannot tell from the data just what the contribution of each will be. The data of Delaney *et al.* that apply to this situation are shown in Fig. 11 (*29*). As explained earlier, these data cannot be explained on the basis of reflection and geometric spreading alone.

One way of identifying propagation paths and effects is through the use of scaled models. In acoustic scaling, we select the frequency of operation so that the ratio of wavelength to dimension is preserved. If the modeling medium is air at ordinary temperatures, this means that high frequencies must be used. Typically, scaling ratios from 1 : 10 to 1 : 100 may be employed for propagation modeling, which may require that one generate and sense sound signals at frequencies up to about 200 khz.

An example of path identification by modeling is shown in Figs. 12 and 13 (*35*). In this experiment, a spark is used to generate an impulsive sound and the sound is measured at the ground in a model of a city street. The relative contribution of the reflections from building surfaces is determined by covering them with absorbing material. When this is done, only the direct pulse is evident at the microphone.

This experiment is a relatively simple example of an important advantage provided by the use of models. Changes may be made in the propagation path, walls may be made absorbent, rough, or of different shape, for example, in ways that could not be done in a field experiment. The field experiment is necessary as a baseline, however, and is used as a guide to establish realism in the model. Once the sound patterns in the model and the field data are found to correspond, variations in the surfaces, source, and receiver locations can be made. By changing from smooth building surfaces, for example, we can see the effects of surface scattering without changing other acoustical parameters such as path length or surface materials.

The phenomena associated with propagation can be discerned from laboratory or field data on the basis of time or spatial patterns of the sound. The quantitative prediction of the effect of each process may not be so quickly obtained. For example, the theory of surface scattering that has been so well developed for underwater sound (nonspecular reflection from the upper free surface and the bottom) has not been developed for the nonspecular reflection from the faces of buildings, or reflection from an irregular ground. In fact, most of the ordinary processes of sound propagation in the outdoors have obviously not had the degree of theoretical or experimental effort applied to them that the more defense-related problems have.

Conclusions

Although the basic processes associated with the propagation of environmental noise, such as reflection, scattering, and spreading are well known, numerous theoretical problems remain. The propagation processes that are significant in different situations have yet to be identified, and criteria for evaluating their relative importance in each situation must be developed. In evaluating the noise of aircraft, for example, attenuation caused by the spreading of energy may exceed 60 dB, with atmospheric attenuation accounting for another 10 dB or so. In the propagation of highway noise, on the other hand, spreading may account for only 10 dB of attenuation, air absorption for 1 dB, and absorption by ground may account for 10 to 15 dB of attenuation. If those problems are approached systematically, we should be able to predict accurately the effects of noise sources and barriers and thus control the distribution of noise levels in cities and suburban areas.

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Diprionid Sawflies: Polymorphism and Speciation

Changes in diapause and choice of food plants led to new evolutionary units.

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Sawflies are the more generalized members of the order Hymenoptera that owe their popular name to the well-developed, saw-like ovipositor in the female. The structure is adapted for sawing and boring and for the insertion of eggs into plant material. The adults of the group are easily recognized by the broadly sessile abdomen, so different from the slender waists of their better-known relatives, the wasps, bees, and ants. The specialized habits and instincts of these relatives have never developed in sawflies, despite a long evolutionary history, dating back to the Permian (*1*). But the group presents us with a challenge: its plant-feeding nature has brought it on a collision course with man's interest in his natural resources and its phylogenetic position is of great theoretical value for the study of an order so peculiarly adapted to social life.

The Diprionidae represent only a small fraction of all the sawflies known, but they share the habits of most other leaf feeders. The family is interesting mainly because of the diversity of distinct races or physiological strains that are adapted to specific host plants, and because of the social behavior exhibited by the larvae in aggregations. Both phenomena illustrate various evolutionary mechanisms at work, simultaneously providing examples of newly emerging biologic units and of the origin of some of the most primitive social behavior found in insects.

Diprionid Biology and Behavior

Diprionid sawflies are a well-defined group credited with relatively few morphological and behavioral variations. The family is closely associated with the northern coniferous forest; one subdivision of the family, the Diprioninae, feeds exclusively on the plants of the Pinaceae and Cupressaceae in Eurasia and North America (*2*). All the diprionids are considered destructive, but in North America the greatest damage is done by species introduced from Eurasia. Introduced species temporarily escape their parasites and predators and can thus increase unchecked in the new environment. Few native species reach harmful population densities and the losses they cause do not compare with the losses caused, for example, by the spruce budworm in eastern North America. Outbreaks of native species usually last only a few years before viruses, fungi, and parasites cause a collapse of the infestation (*3*).

There are about 85 diprionid species recognized today, and over half this number belong to the genera *Neodiprion* and *Diprion* (*4*). The latter is widely distributed in Eurasia but is also represented in the nearctic region by the introduced *D. similis* (Hart.), *D. frutetorum* (Fab.), and *D. hercyniae* (Hart.). North America was undoubtedly the center of evolution for the *Neodiprion* species. Few attempts to evaluate the many biological and genetic units have been made and a number of unrecognized species may be disclosed by more intensive studies.

The life cycle of these sawflies is fairly uniform. The females lay eggs in pockets excavated with their saw-like ovipositors in the living needles of conifers. Old needles are preferred and only a single species, *N. swainei* Midd., lays its eggs in the growing needles of jack pine (*5*). The eggs are sealed as they are laid, and are protected by the needle tissue from adverse climatic conditions. The pattern of oviposition is often specific as far as the number of eggs per needle is concerned. *Diprion frutetorum* and *N. abietis* (Harr.) rarely put more than one egg into a needle, whereas *N. lecontei* (Fitch) and *N. rugifrons* Midd. may lay rows of up to 20 eggs in a single pine needle. Intermediate conditions are found in the rest of the species. Subtle differences are shown in the spacing of eggs in relation to one another. *Neodiprion pratti* (Dyar), for example, leaves spaces of several millimeters between the eggs, whereas *N. rugifrons* lays them with ends almost touching. The latter method is also used by *D. pini*

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