Evaluating Effects of Vegetation on the Acoustical Environment by Physical Scale-modeling

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ABSTRACT.—It is generally assumed that vegetation is beneficial acoustically, as well as esthetically, in that it may act as a shield to reduce highway noise impact on a community as in a sound absorber to reduce reverberant noise levels in city streets. Contradictory evidence exists, however, that noise may be increased because of vegetation. We performed field studies and laboratory scale-model experiments to study interaction between sound-scattering by trees and shadowing by barriers. The studies indicate that, while barrier effectiveness may be reduced by addition of trees, propagation through a stand of trees may provide small noise reductions.

RECENT STUDIES of the behavior of vegetation placed on noise barriers have produced contradictory results. A report by Cann and Manning *(1974)*, based on model studies, suggests that trees placed on top of barriers can reduce barrier effectiveness, while field studies by Cook and Van Haverbeke *(1974)* show increased barrier effectiveness with trees. It was decided to use model studies to resolve this discrepancy.

Until recently, the use of scale models in acoustics has been limited to use in the design of concert halls and auditoria. However, within the past 6 years at MIT, modeling techniques have been successfully applied to problems in outdoor noise propagation by DeJong *(1974)* and Blair *(1975)*.

FIELD STUDIES

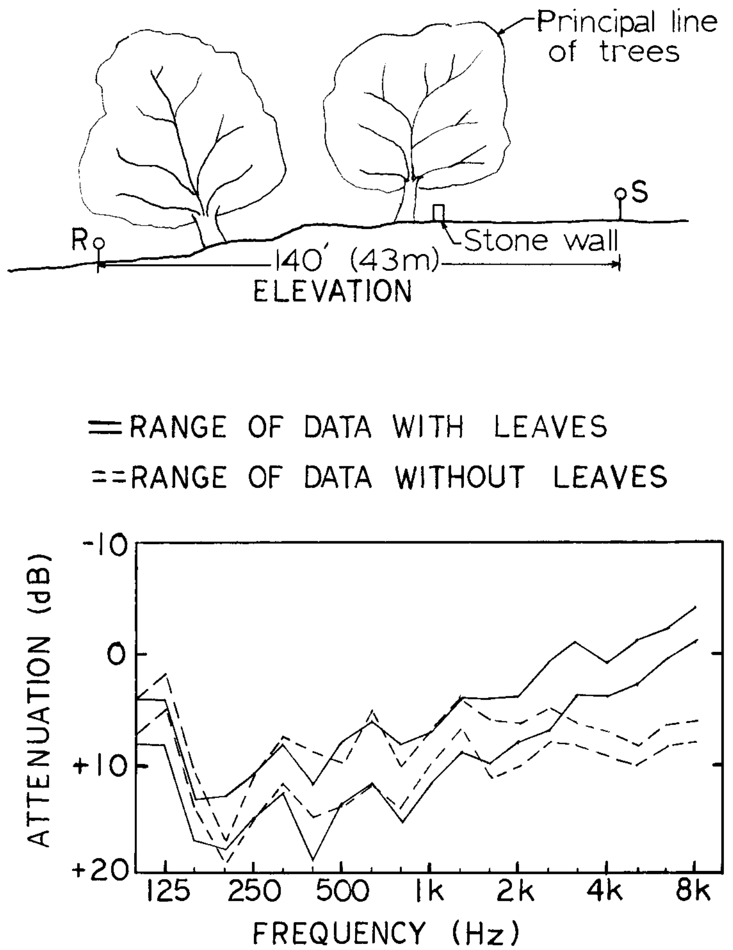
To evaluate the results of the planned model studies, it was necessary to conduct full-scale tests on vegetation configurations not fully covered in the literature, especially those in which the canopy is above the line of direct propagation.

The noise source used was a 12-gage shotgun, carefully studied for its noise spectrum characteristics. The pressure pulse was recorded on magnetic tape, using a Nagra tape recorder and a B&K 1-inch microphone.

Measurements were taken in late spring and early summer to assess the effects of the maple leaves. Care was taken to insure that ground conditions were similar on all measurement dates.

One of the sites chosen for propagation studies was a line of maple trees located at the top of a hill (fig. 1). Acoustic measurements were taken at various points beyond the tree line. Although there was a stone wall along the tree line, the tip of the shotgun muzzle was visible at all receiver points. An example of the measurements shows that the observed spectra with and without leaves begin to diverge above 2,500 Hz corresponding to a wavelength of about 5 inches (12.7 cm), approximating the tip-to-tip breadth of the leaves. The high-frequency excess attenuation observed with leafless trees may be attributed to backscatter from the trunks

Figure 1.—Excess attenuation in the sound propagating across a line of maple trees.

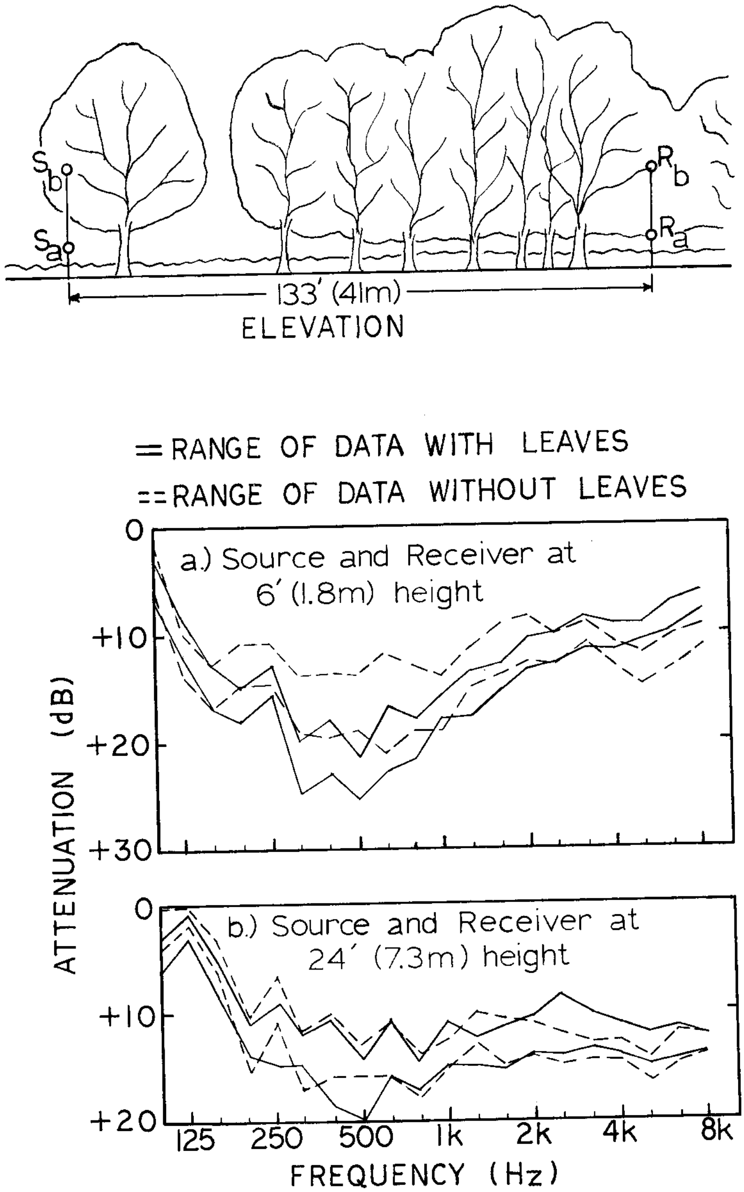


and branches and the effects of the stone wall almost intersecting the line of propagation.

The backscattering effects of trunks and branches were further studied in the following experiment. Sound propagation was measured along a line of trees at various heights in the canopy (fig. 2). Shotgun and microphone were suspended in the trees, and the line of sight was completely obscured by the trunks and branches. The large excess attenuations observed are due to backscattering from trunks and branches. At the position just below the canopy, leaves scatter some additional high-frequency sound to the microphone. In the canopy, however, leaves appear to have little effect. One may hypothesize that any additional attenuation offered by the leaves along the line of propagation is offset by scattering from leaves in other portions of the canopy.

In a third example of propagation under the canopy (fig. 3), shots were fired at various distances into a homogeneous mature maple stand and picked up by a microphone on the edge of the woods. At all times there was unobstructed visibility from source to receiver. As before, the leaves have a pronounced effect above 2,000 Hz, and

Figure 2.—Excess attenuation in the sound propagating through a canopy of maple trees.

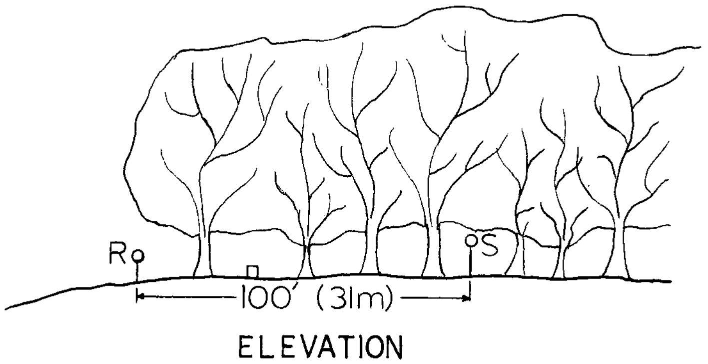


backscattering from the trunks of leafless trees results in high frequency attenuations. The large dip around 315 Hz is due to ground effect.

MODEL STUDIES

Model studies were then undertaken to facilitate more detailed studies of various tree-barrier configurations. Scale-modeling involves reducing all the dimensions in the system being studied by a scaling factor. Acoustical modeling requires that the wavelength of the sound be reduced by the same ratio as all other dimensions. This is most easily done by increasing the frequency of the sound used. Then, for example, in a 1:32 scale model, a full-scale frequency

Figure 3.—Excess attenuation in the sound propagating under a canopy of maple trees.



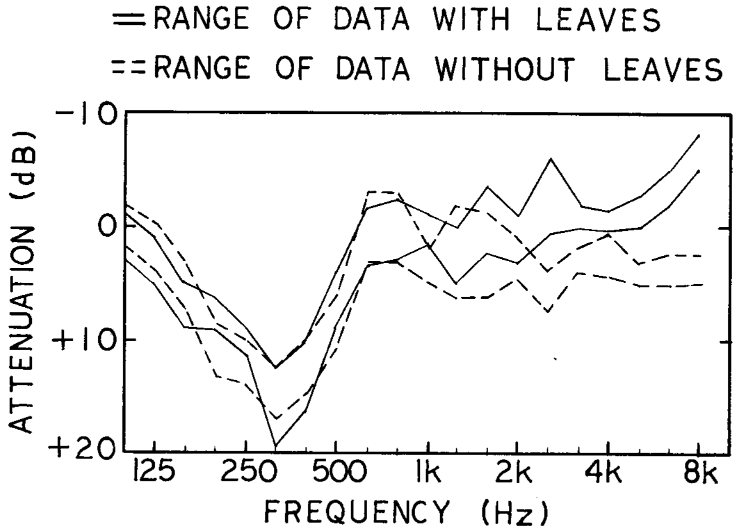
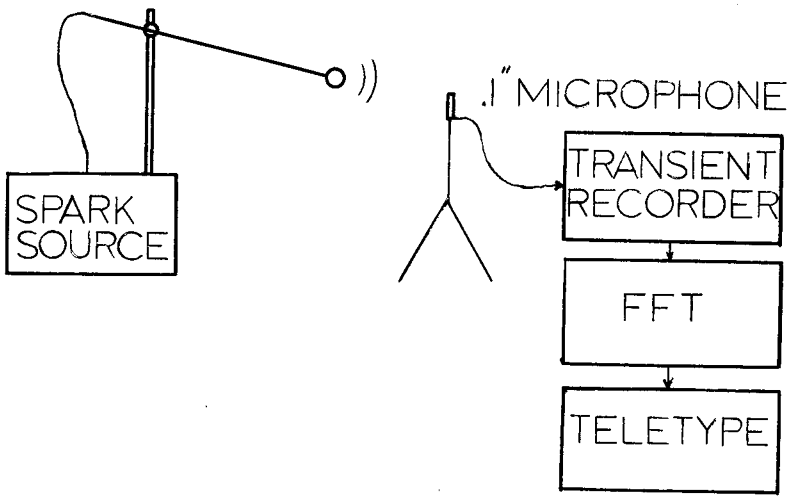


Figure 4.—Elements of the modeling system.

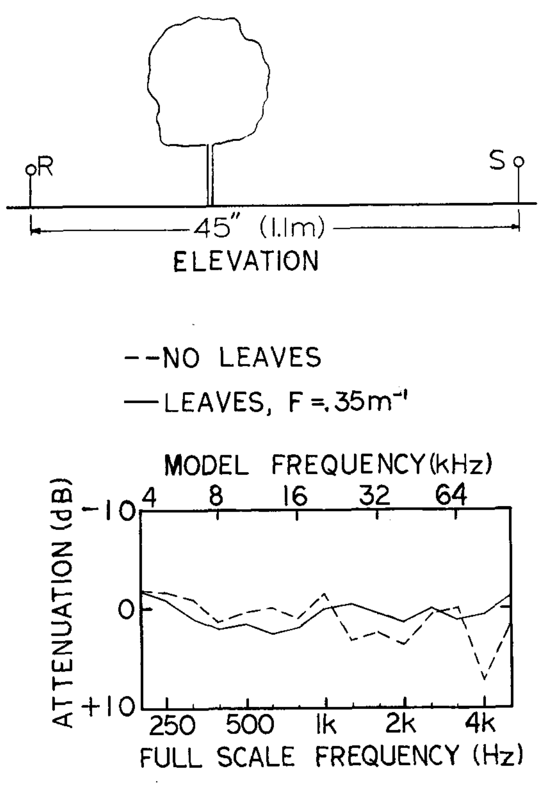


of 1,000 Hz would be modeled with 32 kHz.

To produce noise at these high frequencies, an electric spark discharge in air was used (fig. 4). Operating at 3,000 volts, this spark source produces an acoustic impulse with energy over a frequency range of 4 kHz to 150 kHz.

The sound was detected with a 1/10-inch piezoelectric microphone and recorded in a digital transient recorder. The recorder was interfaced with a digital computer, which performed a fast fourier transform (FFT) on the signal. The FFT values were then combined into a ⅓ octave band level and printed out on the teletype. These levels correspond to the levels that would be obtained using a steady state source in an anechoic chamber. However, by using an impulsive source, an anechoic chamber is not needed since the reflections off the walls arrive at the microphone after the desired signal is recorded. An oscilloscope was used to monitor the recorded signal to observe the arrival times of the pressure pulses at the microphone. This allowed the identification of different propagation paths from the source to the microphone.

Figure 5.—Excess attenuation in the sound propagating across a line of model trees on a flat plain.



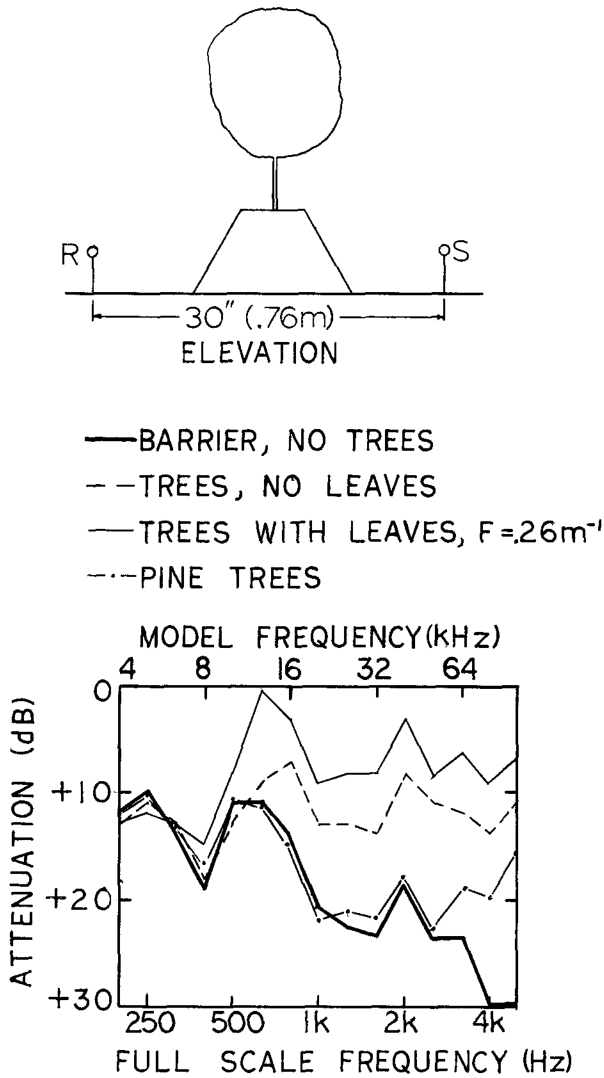
The materials used in constructing the models were selected to have the same absorption at the scaled frequencies as the real materials being simulated have at audio frequency. The ground was modeled with a soft pressed fiberboard covered with flocked paper.

The model was constructed to a 1:20 scaling to allow analysis of full-scale frequencies as high as 5,000 Hz. Using trees actually encountered in the field studies as subjects, models were built representing 14-foot (4.3 m) pine and 30-foot (9.1 m) maple trees. Serpentine was used to model maple leaves; although it did not perfectly model leaf characteristics found in the field, the serpentine was determined adequate for qualitative analysis of leaf effects. Various leaf-area-per-unit-volume densities (F) could be modeled by changing the amount of serpentine placed in the canopy.

The basic experimental approach was to set up a line of trees in various configurations, with and without barriers, and measure the insertion loss of the vegetation at various distances behind the tree line. Results of excess attenuation across a line of model trees on a flat plain (fig. 5) are in good agreement with observed field data. Without leaves, the tree trunks appear to offer some attenuation above 1,000 Hz, but the presence of leaves scatters additional acoustic energy downward, resulting in reduced or even negative attenuation.

Next the attenuation of a barrier with and without trees on top was measured (fig. 6). In the case of the model maple trees, the scattering contribution of the

Figure 6.—Attenuation of sound by a barrier with and without trees on top.



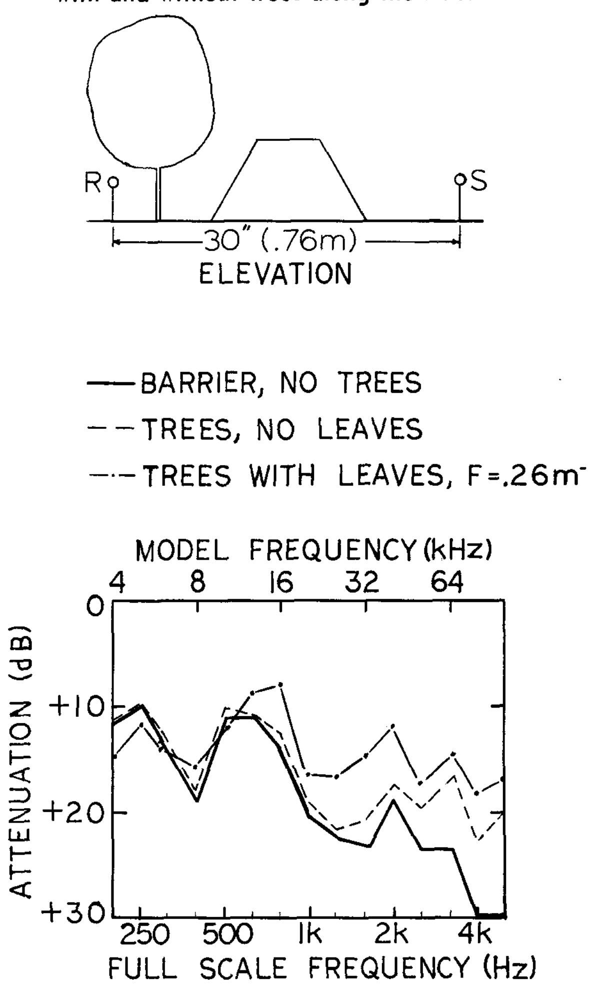
leaves occurs at a lower frequency than noted in the field data. This anomaly is due to the imperfect modeling characteristics of the serpentine, which is a long continuous tape rather than many small patches. The negative attenuation contributions of leafless maples are due to the scattering off of the major horizontal branches. The pines, which scatter sound at a higher frequency corresponding to the pine's smaller and more concentrated branches, display similar characteristics. As can be observed, planting a single row of trees on top of a barrier can be devastating to the barrier's effectiveness.

By moving the trees from the top of the barrier to behind it, the barrier effectiveness is not so severely damaged (fig. 7). Only about half of the canopy is exposed to direct sound from the noise source explaining this result.

DISCUSSION

The frequency dependence of the scattering effectiveness is consistent with dimensions of the scattering bodies: the smaller the leaf or branch, the higher

Figure 7.—Attenuation of sound by a barrier with and without trees along the side.



the frequency at which scattering becomes effective. Thus the presence of a plant with small branches and leaves will not appreciably affect noise levels in the frequency range of primary interest in noise-control circles.

Plant geometry also appears to be important. A tree with vertically hanging leaves and few horizontal branches, placed on top of a barrier, will scatter less sound downward into the shadow zone behind the barrier than other tree configurations.

The effects of the introduction of vegetation on the sound field beyond it can be generalized graphically (fig. 8). The leaves and branches scatter a portion of the incident acoustic energy to the side and backwards, resulting in a shadow zone behind the vegetation.

The introduction of a solid barrier between source and receiver complicates the analysis somewhat. The leaves and branches of the tree may now be considered as noise sources, and any portion of the canopy not shielded from the receiver will reduce the barrier's effectiveness through scattering.

However, if the barrier extends upward into the shadow zone behind the tree (fig. 9) another counteracting mechanism becomes important. The

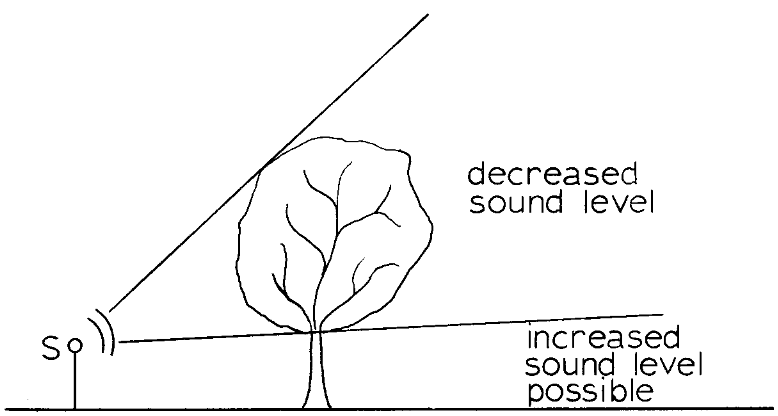


Figure 8.—The screening of sound by vegetation.

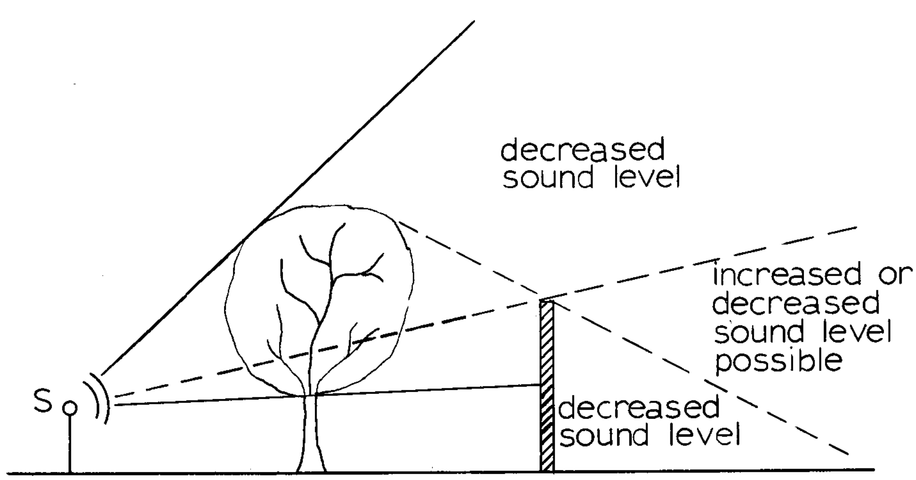


Figure 9.—Effects of vegetation upon barrier performance.

noise observed at the receiver point is dependent on the sound-field conditions above the barrier. If this sound field is reduced in intensity due to screening effects of the tree, barrier effectiveness is increased. Estimation of these scattering and screening components is essential in predicting the behavior of tree and barrier configurations. Since theoretical calculations are complex, this is best done by using model studies.

CONCLUSIONS

The results of this report show that scale-modeling can be a useful tool in evaluating the effects of vegetation on the acoustic environment. In particular, the positioning of trees around a barrier has an important influence on the barrier's effectiveness. Further work is being done at MIT to develop a simplified modeling-instrumentation system to facilitate the general use of modeling for the evaluation of a wide range of community noise problems.

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