WASHINGTON STATE HIGHWAY DEPARTMENT RESEARCH PROGRAM
REPORT **24.4**

VEHICLE NOISE RADIATION

EFFECTIVE HEIGHT AND FREQUENCY MEASUREMENTS

RESEARCH PROJECT
Y-1663

AUGUST 1976

PREPARED FOR
WASHINGTON STATE
HIGHWAY COMMISSION

R. N. FOSS
APPLIED PHYSICS LABORATORY
UNIVERSITY OF WASHINGTON

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle VEHICLE NOISE RADIATION, EFFECTIVE HEIGHT AND FREQUENCY MEASUREMENTS		5. Report Date August 1976 6. Performing Organization Code
7. Author(s) Rene N. Foss		8. Performing Organization Report No. APL-UW 7615
9. Performing Organization Name and Address Applied Physics Laboratory University of Washington 1013 N.E. 40th Seattle, Washington 98105		10. Work Unit No. 11. Contract or Grant No. Y-1663
12. Sponsoring Agency Name and Address Washington State Highway Commission Department of Highways Highway Administration Building Olympia, Washington 98504		13. Type of Report and Period Covered Research Project 14. Sponsoring Agency Code

15. Supplementary Notes

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Actual vehicle measurements indicate that the best single frequency approximation for "A" weighted noise is 650 Hz. For light vehicles, the effective source height is 0.2 m (0.7 ft) above the lane surface. For heavy vehicles, the effective source height is 0.8 m (2.6 ft) above the lane surface.

17. Key Words	18. Distribution Statement
Highway acoustics Noise suppression Fresnel diffraction	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	25	

Form DOT F 1700.7 (8-69)
HWY FORM 341-004 6/72

CONTENTS

ABSTRACT

This work was undertaken to determine the best value to use for the effective height and frequency of the noise emanating from cars and trucks when calculating the effect of roadside walls on the diffraction of highway noise. The experiment consisted of measuring the A-weighted sound levels at various microphone positions behind an actual wall as different types of test vehicles were driven past the instrumented site. Then for each vehicle a single frequency and height were found that would yield a calculated signal level closest to the A-weighted levels actually measured in the test.

The results show that the best assumption for cars and pickup trucks is a frequency of 650 Hz at a height of 0.2 m (0.66 ft) above the center of the lane in which the vehicle is traveling. For the two trucks used in the tests (a diesel cement mixing truck and a diesel semi-tractor without a trailer), the best assumption is 650 Hz at a height of 0.8 m (2.62 ft) above the center of the lane.

INTRODUCTION

Fresnel's equations can be used to predict the effect of a wall or screen on sound, provided the geometry and frequency are known. In order to predict the effect of a wall on the noise emitted from highway vehicles, it is therefore necessary to know the <u>effective</u> radiating height and frequency of the vehicles using the highway. It is quite obvious, simply by listening to a vehicle that it does not radiate a single frequency (pure tone) but rather a fairly wide spectrum. In addition, the sound does not emanate from a single point but rather from a variety of sources, such as tires, exhaust, engine, transmission, and generalized wind flow around the vehicle. The task of the study reported here was twofold: (1) to determine whether the assemblage of these source locations (each with its own spectrum) on typical vehicles would produce the same A-weighted sound pressure, when diffracted over a wall, as a pure-tone point source located at some specific height, and (2) if this assumption proved reasonably true, to determine these effective source heights and frequencies. (For highway noise studies, it is not too important to know the fore-aft position of the noise from a particular vehicle with much accuracy, only its effective height.)

It seemed quite likely that different classes of vehicles--e.g., large diesel trucks and subcompact automobiles--would radiate at different effective heights and frequencies. We therefore undertook to measure the effective radiating heights and frequencies of selected vehicles which were thought to be representative of the types of vehicles actually found on the roads of this country.

One theoretical (but impractical) way to accomplish such measurements is to utilize a highly directional vertical array of microphones capable of resolving the position of a noise source to within perhaps ±6 in. and then drive the test vehicle past the array. The problem comes in constructing a directional system with such wondrous properties. We were interested in frequencies as low as 100 Hz, which would have a wavelength of over 11 ft (≈3.4 m) in air. At first glance, it might seem that an array with sufficient resolving power would have to extend at least 5 or 10 wavelengths (considerably more than this if the processing were not sufficiently sophisticated); this would involve a structure at least 50 to 100 ft high for 100 Hz. However, this would still leave the test vehicle well within the near-field, where the beam-forming properties of a simple array are not sufficiently developed to obtain the desired resolution.

Since the goal was to obtain information concerning the effective radiating height and frequency which, when used in Fresnel's equations, would yield the actual A-weighted sound level received at the far side of a wall, a more direct method was indicated. We decided to use a wall itself as the large-dimensioned object required by the laws of physics and to directly measure the A-weighted sound levels received at various heights behind this barrier. Ideally, we would have liked to measure the signal level received with the wall absent, then erect the wall and measure the reduced level. This approach was not practical with the type of walls and financial resources available for the experiment. One alternative would have been to try to find road sections identical in every respect except that one contained an adjacent wall and the other did not. However, even if such seemingly complementary test sites could be found, it would be very difficult, if not impossible, to determine whether all the parameters were sufficiently identical during each test run for our purposes.

We finally decided to measure the sound level received at four microphones located at various heights on a tower behind a wall. We originally sought to place the top microphone sufficiently high that the sound reaching it would not be affected by the wall and could thus be used as a standard for the unimpeded sound level. In actual practice, it was not practical to make the top microphone quite that high for all cases. In addition, using the top microphone as a reference standard implies that all of the noise sources on the vehicles are omnidirectional (or at least do not change in character throughout the vertical angle involved in the microphone height); the higher the microphone, the less likely this assumption is to be valid. The net result of all these considerations was the microphone placement shown in Figure 1. The top microphone was sufficiently high that the wall had only a small effect on the sound level received at that position. The bottom microphone was located well below the top of the wall, with two other microphones at intermediate positions. The spacing between the bottom three microphones was considerably closer than between the top microphone and its nearest neighbor.

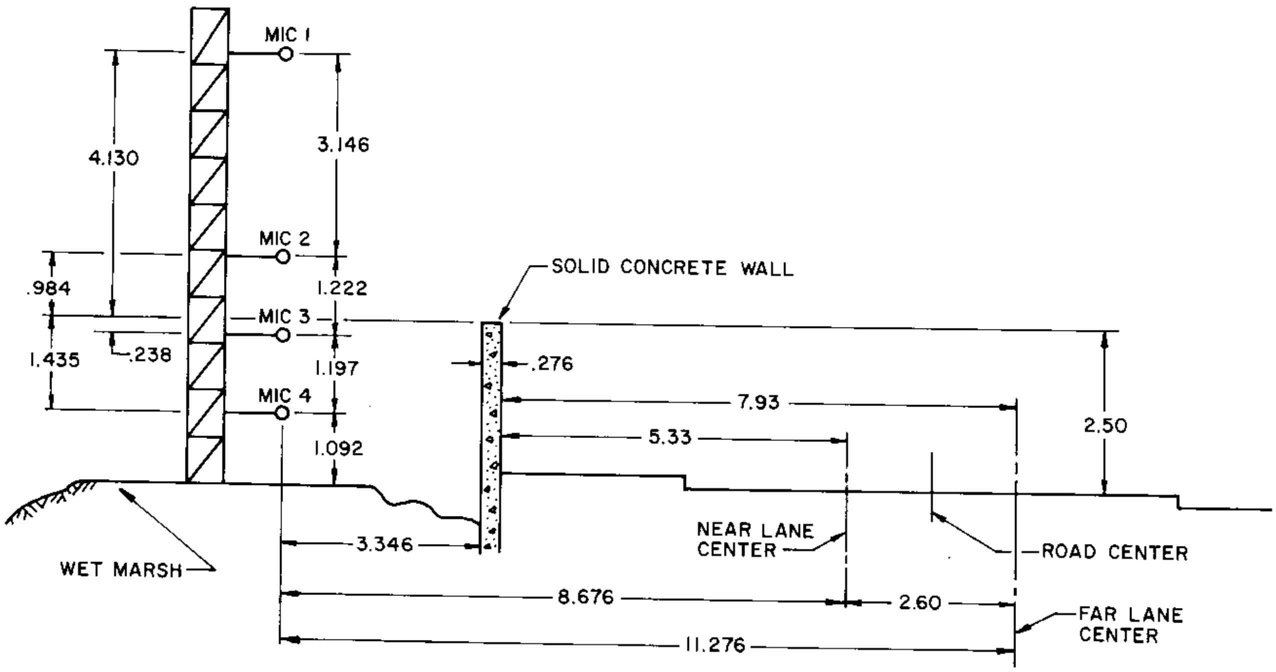


Figure 1. Geometric cross section of experiment test site. (Dimensions in meters.)

DESCRIPTION OF THE TEST SITE

The tests were conducted using an existing wall on North Northlake Street near the Gas Works Park on the north shore of Lake Union in Seattle. Figure 2 is a view from the top of the wall looking east down the road and showing the road, the wall, and the test tower. Figure 3 is a similar view looking west. Figure 4 was taken from the road looking south toward the wall; Figure 5, taken from the opposite direction, shows the tower and the back side of the wall.

TYPES OF VEHICLES STUDIED

Data on five types of test vehicles are presented. More than five types of vehicles were used at various times, but some of the early data were unusable due to the pickup of excessive 60-Hz noise from high-voltage transmission lines between the tower and the recording instruments (see Figure 2). This extraneous noise was later eliminated by increasing the preamplifier gain and did not appear in subsequent measurements. The types of vehicles analyzed were as follows:

Figure 2. Photograph of test site looking east.

Figure 3. Photograph of test site looking west.

Figure 4. Photograph of test site looking south.

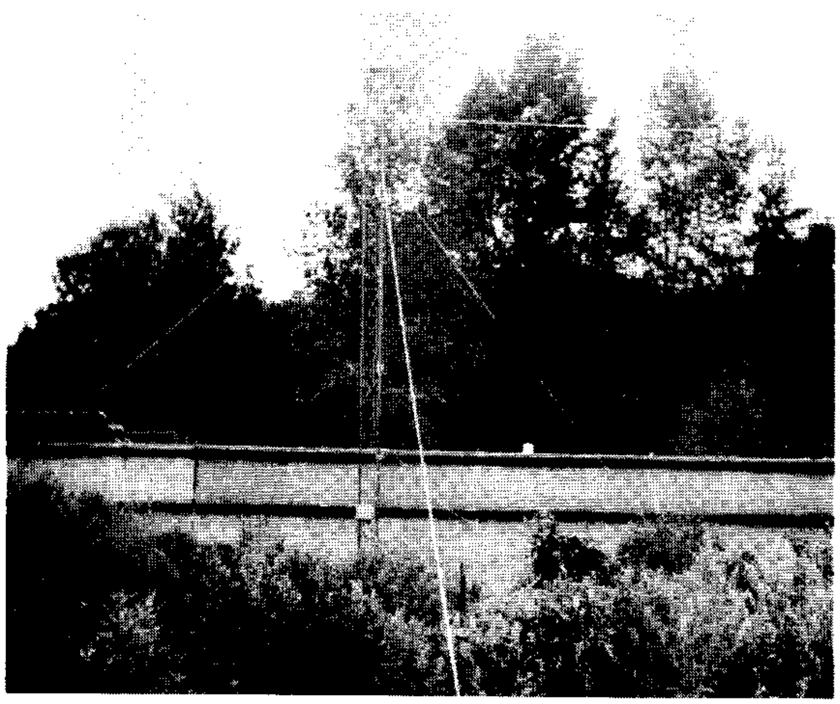


Figure 5. Photograph of test site looking north.

(1) Car: A 1974 AMC Hornet

(2) Subcompact car: A 1974 Audi Fox.

(3) Full-sized pickup: A full-sized pickup truck with manual transmission. This vehicle is also probably representative of a full-sized heavy car in its noise output.

(4) Diesel-driven cement truck*: A cement mixer truck normally used by the Glacial Sand and Gravel Company. There was no cement in the mixer portion of the truck during these tests.

(5) Full-sized diesel semi-tractor* with two large, vertically oriented, Donaldson mufflers. This tractor was not pulling a trailer during the tests, but for many of the tests, particularly the higher speed ones, it was operating at maximum acceleration.

MEASUREMENT PROCEDURE

The tests were run very early in the morning, usually beginning at dawn (around 4:30 a.m. that time of year) and continuing until perhaps 6:30 in the morning. The early morning was necessary for several reasons.

First, to get good data, we needed a substantial signal-to-noise (S/N) ratio on all of the channels. The most severe S/N problem was with the lowest microphone, particularly on low-speed passes of relatively quiet automobiles. We found that the general background noise level was such that we could not depend on data taken during normal working hours, or in the early evening. The early morning, however, was, for the most part, sufficiently quiet for our undertaking. In general, the extraneous noise from freeway traffic, local industry, trains, aircraft, etc., did not begin to build up until after about 6:30 a.m. In spite of the urban setting, the otherwise relatively quiet dawn was punctuated by the calls of local wildlife, particularly ducks and other birds. Fortunately, the birdcalls appeared on the stripcharts as well-defined, isolated spikes which could be easily removed from the data upon visual inspection. This process was greatly augmented by monitoring the tapes aurally.

* The straight run available at the test site was such that at the higher speeds the trucks were still under full acceleration and not yet in top gear when they passed the test site. As a result, there was probably a somewhat greater proportion of the noise radiating directly from the gear box than there would have been at a constant velocity.

Second, the speed limit on the road immediately in front of the wall was 30 mph. We wished to make passes at considerably greater speeds. (It turned out that about 50 mph was as fast as could be reasonably handled with the straight-away available.) We had special permission from the local police to conduct overspeed tests; however, it was very inconvenient to do so while much traffic was on the road, and during the early morning hours there was very little other traffic.

Third, it was desirable to have weather as calm and wind-free as possible. In general, calm conditions are more likely at dawn than at other times of the day.

A block diagram of the data recording system is shown in Figure 6. B&K wind screens were installed on each of four General Radio 1-in. diameter Electret-Condenser microphones which were coupled to a General Radio P-42 preamplifier. The output of each microphone preamplifier was brought to a junction box on the tower (see Figure 7). A multiconductor microphone cable was then used to connect the junction box with the tape recorder interface box which was located in the back of a van parked near the wall. The interface box contained suitable gain for each channel so that the highest signals of interest could be brought up to a level of approximately 1 V, which was near the top of the dynamic range of the FM tape recorder. The interface box also contained an accurate 2 dB/step potentiometer for each of the four channels. In addition, a trim pot (available by removing a chassis cover) on the early preamplifier stage of each channel allowed the gain to be adjusted to equalize any inherent sensitivity differences between the microphones. This adjustment was effected by placing a General Radio slip-on calibrator (set to 1 kHz) on each of the microphones and adjusting each of the trimmers, in turn, until the same signal output was obtained for each microphone. Care was taken that none of the amplifier stages were saturated or nonlinear at the time. Each channel also had a level meter for immediate visual indication of the operation of that channel; this allowed on-site adjustment of the step attenuators so that each channel would be in a good dynamic range for the FM tape recorder.

A switch on the interface box allowed insertion of either a 1-volt peak sine wave at 1 kHz or a 1/10-volt peak sine wave at the same frequency to all four FM channels of the tape recorder simultaneously. Calibration signals at both these levels (going back and forth between them several times) were placed at the beginning of each tape and, in addition, other calibration signals were recorded at both levels during lulls in the action. The settings were such that, when a vehicle passed, most of the peak signals fell between these two tape recorder calibration levels. Not only did the presence of these calibration tones on the recording make accurate setup of the rest of the recording and processing system possible, but the frequent up-dating of this calibration information provided increased confidence in the results.

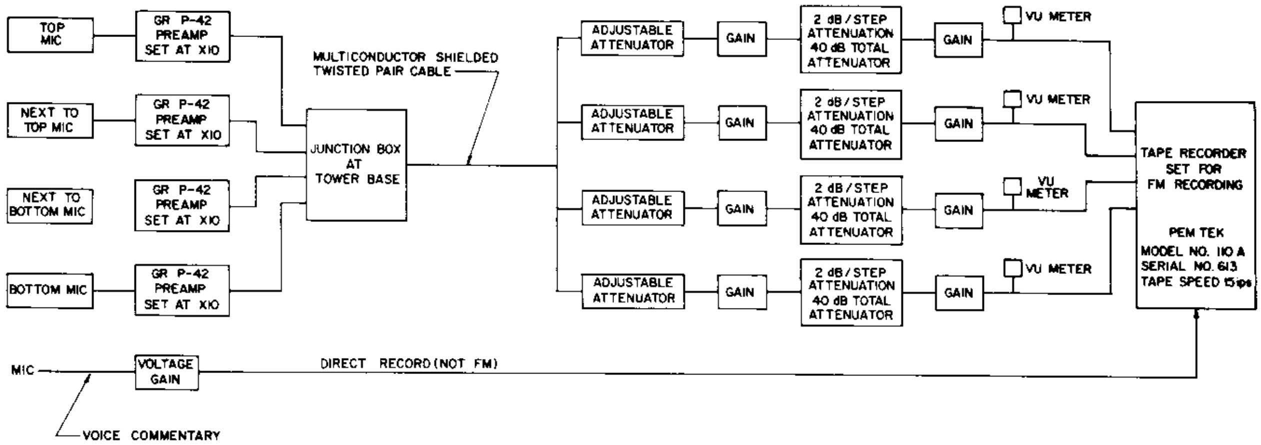


Figure 6. Block diagram of the data recording system.

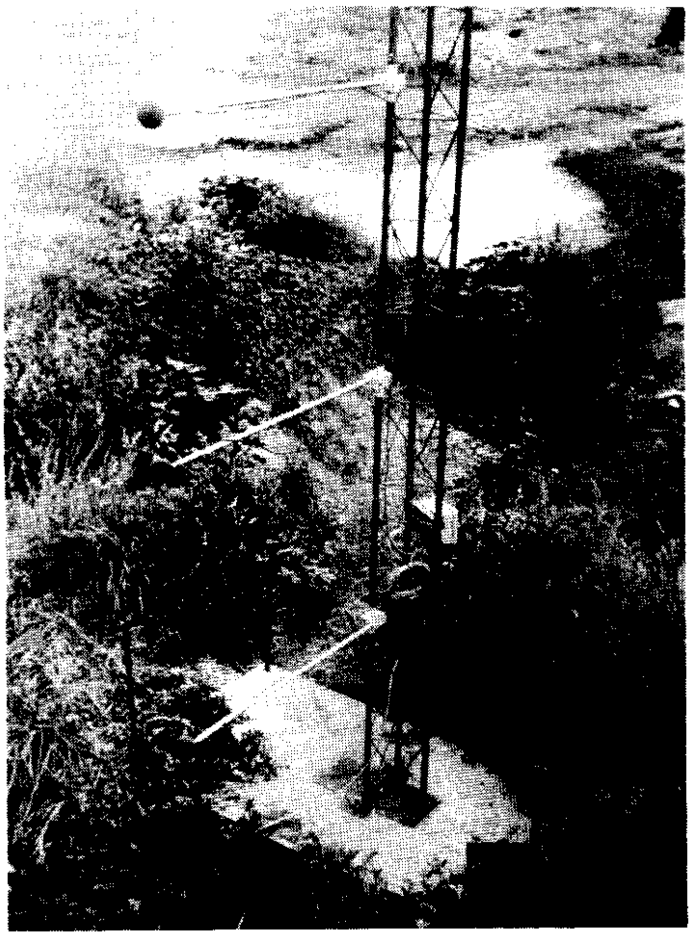


Figure 7. Closeup photograph of tower showing junction box and lower microphones.

In addition to the four FM channels used for recording the actual acoustic data, two additional channels were used--one for recording the voice commentary identifying vehicle speeds, etc., and one for recording a "bleep" which was triggered manually as the vehicle passed a mark 45° from normal incidence, as it passed a mark directly perpendicular to the microphone tower, and as it passed another mark 45° on the other side. This procedure yielded independent information about the position of the vehicle for correlation with the noise level trace.

There was no frequency weighting at the time the actual acoustic data were recorded. Since the FM channels were "flat" to direct current, there was no low frequency reduction caused by the recording instrumentation itself; the low frequency limitation was primarily due to the microphones and the interface box. The microphones were reasonably good down to 1 or 2 Hz, and the interface box was flat to below 10 Hz.

The test itself consisted of driving the test vehicles back and forth in both directions at various speeds and recording the resulting noise, at the microphones, onto the tape.

The recordings were then brought back to the Laboratory where they were reproduced, two channels at a time, on a dual-channel strip chart recorder. An interface box between the tape recorder and the dual-channel strip chart recorder contained two identical processing chains as follows: amplifiers, 2 dB/step precision potentiometers, "A" weighting network, true rms ac/dc converters, and accurate logarithmic converters (see Figure 8). After this analog processing in the interface box, the

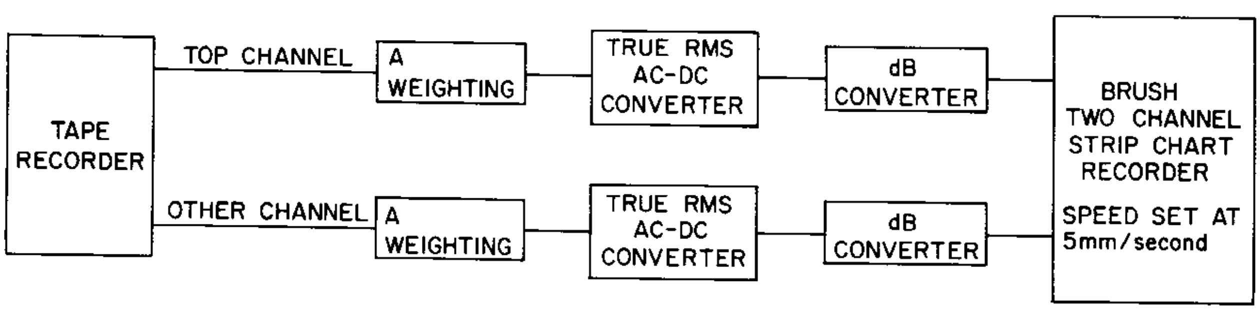


Figure 8. Block diagram of analog processing system.

channels were then reproduced on the stirp chart in pairs; typically, the channel from the top of the tower was paired, in turn, with each of the other channels. For the first run-through, the scale on the chart paper was set so that the total dynamic range of the chart equaled that of the tape recorder (i.e., 5 dB/major division, or a total dynamic range of 50 dB). This allowed us to examine the signal levels before and after the passage of the vehicle to ascertain whether the signal-to-noise ratio at each channel was suitable for further processing. The charts were then re-run at 2 dB/major division, or a total dynamic range of 20 dB. These more sensitive charts were used for reading the data. The settings were such that either the high or the low calibration signal always appeared on the chart to indicate the absolute level.

The maximum signal on the top microphone was used as the time reference for each set of measurements. This position usually correlated well with the hand-marked signals, indicating that the vehicle was near normal incidence to the wall and the tower when maximum noise was received. The sound levels indicated on the strip chart pairs at this time were then measured and recorded. Some typical strip chart sections are shown in Figures 9 and 10. As might be expected from the type of noise sources under investigation, the noise curves are jagged rather than smooth. Therefore there was a small amount of human interpretation required when assigning a specific value to the signal level existing when the top channel was at a maximum. To assure that there were no spurious noise peaks caused by chirping birds, airplanes, etc., occurring at this instant, the channels were also monitored aurally. These disturbing influences were easily detected, and such contaminated data were rejected. The calibrated maximum sound level (in A-weighted decibels) at each of the four microphones was recorded for each pass of all the vehicles analyzed.

For this program, we were not primarily concerned with the actual sound levels emitted by the vehicles, but rather with how the wall was affecting the sound. We were therefore interested in the difference (in decibels) between the levels received at the test microphones, taking the top-most microphone as the standard. For every pass of the test car or truck, three values were determined: the difference, in decibels, between the top microphone and the next to the top one, between the top microphone and the next to the bottom one, and between the top microphone and the bottom microphone. These three relative values indicated the effectiveness of the wall in blocking vehicle noise (from that particular vehicle on that particular pass). Our goals, once again, were to discover whether the effect of the wall could be predicted by representing the vehicle as a pure tone traveling at a specific height and, if so, to determine the best specific heights and frequencies for the vehicles involved in the study.

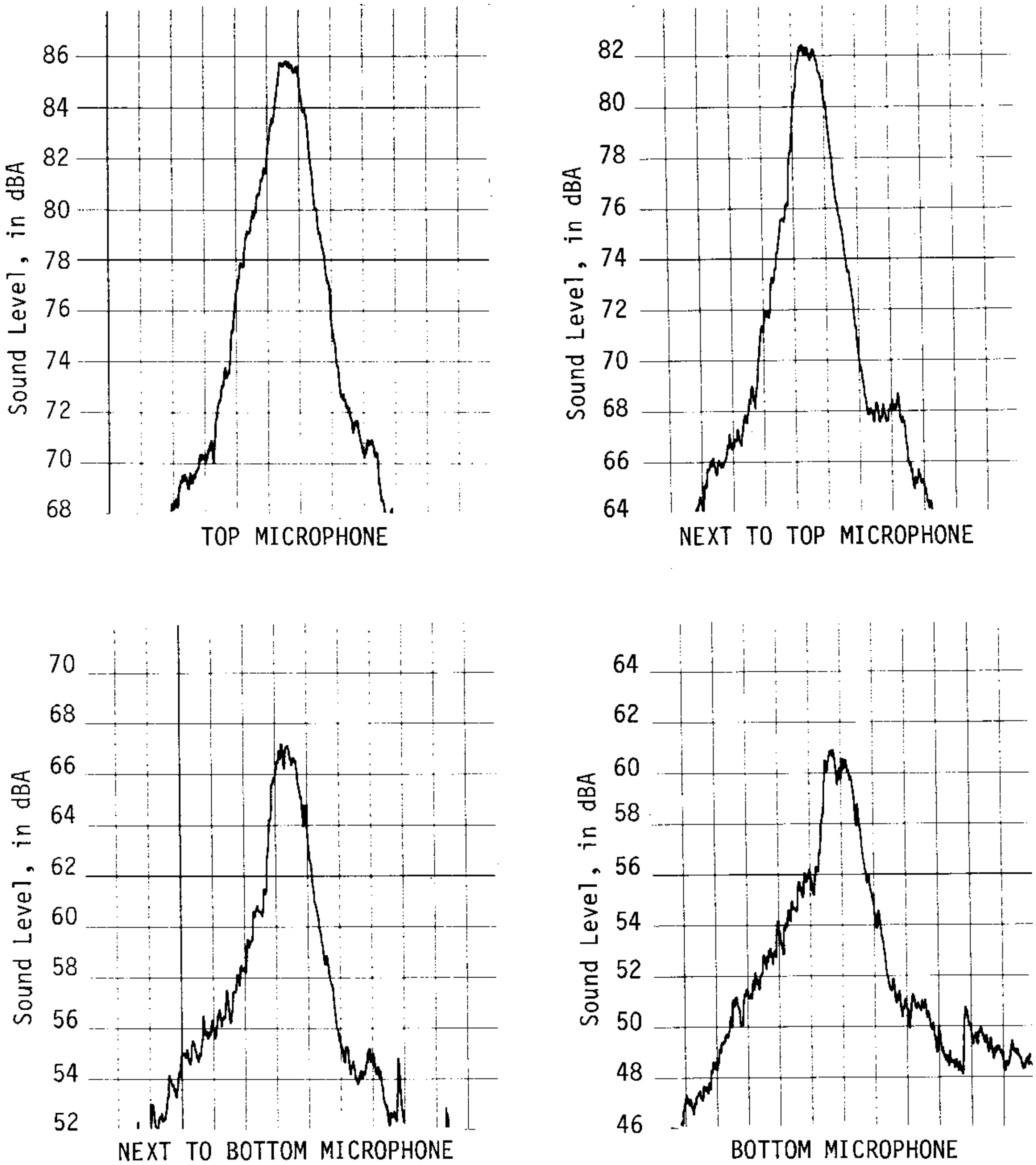


Figure 9. Example of strip chart recordings for the semi-tractor. (Horizontal scale = 1 sec/div.)

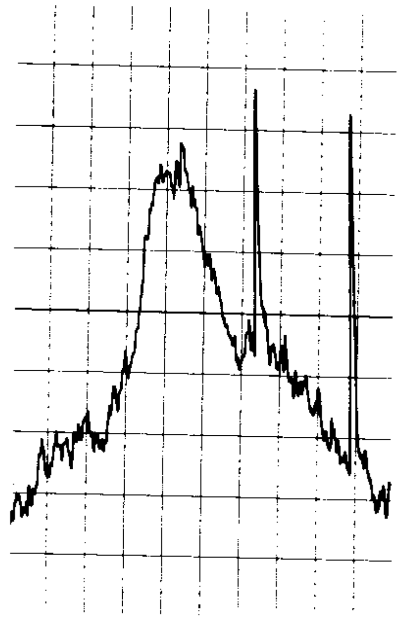


Figure 10. Typical strip chart recording showing duck quacks (sharp peaks). These peaks were ignored in the data reduction process.

DATA REDUCTION

The data reduction proceeded as follows:

(1) It was assumed that the vehicle was acting as though it were a point source at some specific frequency and height; e.g., 500 Hz at 1 ft above the center of the lane in which the vehicle was traveling.

(2) We then calculated the difference in the sound levels, in decibels, that would be received at each of the bottom three microphones compared to that received at the top microphone using the Fresnel equations for the geometry involved in the experiment and the assumptions of (1) above.

(3) The three relative differences calculated from Fresnel's equations were then subtracted from the corresponding values experimentally measured on one of the vehicle passes.

(4) This process was repeated for all of the passes of vehicles of a given type (e.g., all pickup truck passes).

(5) The mean and standard deviation of the resulting values were calculated. The results indicated how well that particular height and frequency assumption would predict the results experimentally obtained for that particular vehicle.

(6) To obtain a meaningful numerical value with regard both to the scatter of the data and to the mean difference between the experimental results and the calculations, we then added the standard deviation to the absolute value of the mean. The result was a number representing the "largest likely error"* that would have accrued in this series of runs if the initial assumption had been used as the basis for computing the effectiveness of this wall against this particular vehicle using Fresnel's equations.

(7) This whole process was then repeated using a different height and/or frequency assumption. With the aid of a computer, a wide range of height and frequency assumptions was investigated--specifically from 0.5 m below the pavement (due to reflections off the pavement, it is possible for a source to act as though it were below the surface) to 2.5 m above the roadway, and from 300 Hz up to 850 Hz.

(8) The results of all the calculations from (7) above were then plotted as shown in Figure 11. The ordinate of the plot is the sum, in decibels, of the standard deviation and the absolute value of the mean difference between the experimental data and the calculated values. The abscissa is the assumed frequency of the source. Each curve shows the result for a specific height assumption in meters. The computation was done in both 1/4-meter and 1/10-meter steps, yielding 37 curves for each plot. Since it would have been too confusing to plot 37 curves on one graph, only five height curves were selected for plotting. These included, of course, the curve that at some frequency had the lowest total mean plus standard deviation, and also the curves immediately adjacent to it. In addition, curves on either side but somewhat further removed were included to show the result of using poorer height values.

---

*Assuming a Gaussian distribution, the chance that the error would exceed this value is less than 10%.

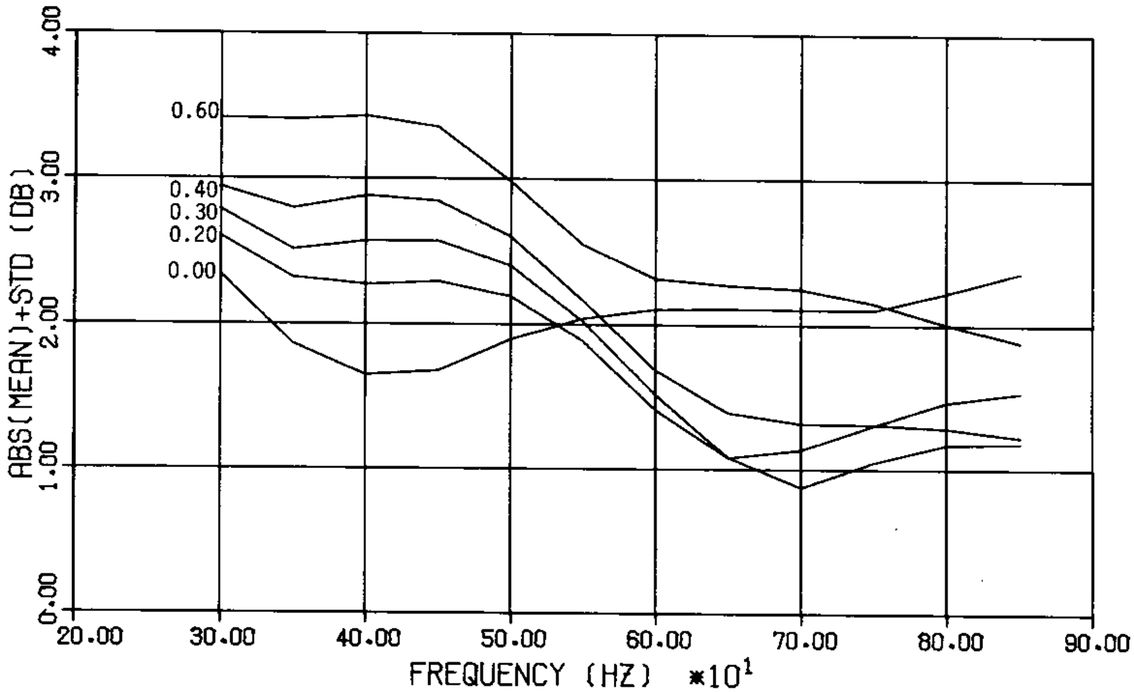


Figure 11. Representative plot of calculations from Step (7).

In performing the foregoing computations, simple Fresnel diffraction was used to calculate the reduction in the sound received at the various microphones because of diffraction. The microphones were not, however, all an equal distance from the top edge of the wall so that, in addition to diffraction, the differences in the sound levels at the various microphones also included a spreading loss due to the differing distances; e.g., if there had been no wall between the source and the microphones, the top microphone would have received less sound than the other microphones simply because it would have been a greater distance from the source. With the wall in place, there was, of course, no direct path between the source and the bottom microphone. Since the sound reaching this microphone, of necessity, had to go to the top of the wall and back down again, the amount of spreading in the portion of the sound path between the source and the top of the wall was substantially the same for all of the microphones. Thus, this part of the spreading loss was of no consequence to our measurements which were concerned only with the difference in the levels received at the microphones. The spreading loss between the top of the wall and the individual microphones would, however, in principle, be different for each microphone.

Since the spreading loss was reflected in the values measured in the experimental part of the program it should be duplicated in the calculated part. The sound could be considered as one system from the source to the vicinity of the top of the wall; at that point, Huygens' principle could be applied and the sound considered to come from a new, reradiating source. This assumed reradiator would not now, of course, be a point source. For purposes of the calculations, it was considered to be a cylindrical source which would result in a spreading loss of 10 log distance for the remainder of the sound's journey to each of the microphones. Calculations were then performed using three assumptions for the effective axial center of reradiation: at the top of the wall; 30 cm above the wall (approximately one-half wavelength for the frequency range we were primarily concerned with); and 60 cm (approximately one wavelength) above the wall. The complete calculations and curves were plotted for each of these three assumptions; it was found that the best height and frequency approximation for any given vehicle was only very weakly dependent on which assumption was used.

Figures 12-17 show the plots containing the best height and frequency values obtained for each type of vehicle using these three assumptions. The height labeled on the lowest curve on any graph is the best equivalent height value. The frequency at which the lowest point on that curve occurs is the best equivalent frequency value. The position of the point on the ordinate of the graph is the maximum likely error in decibels.

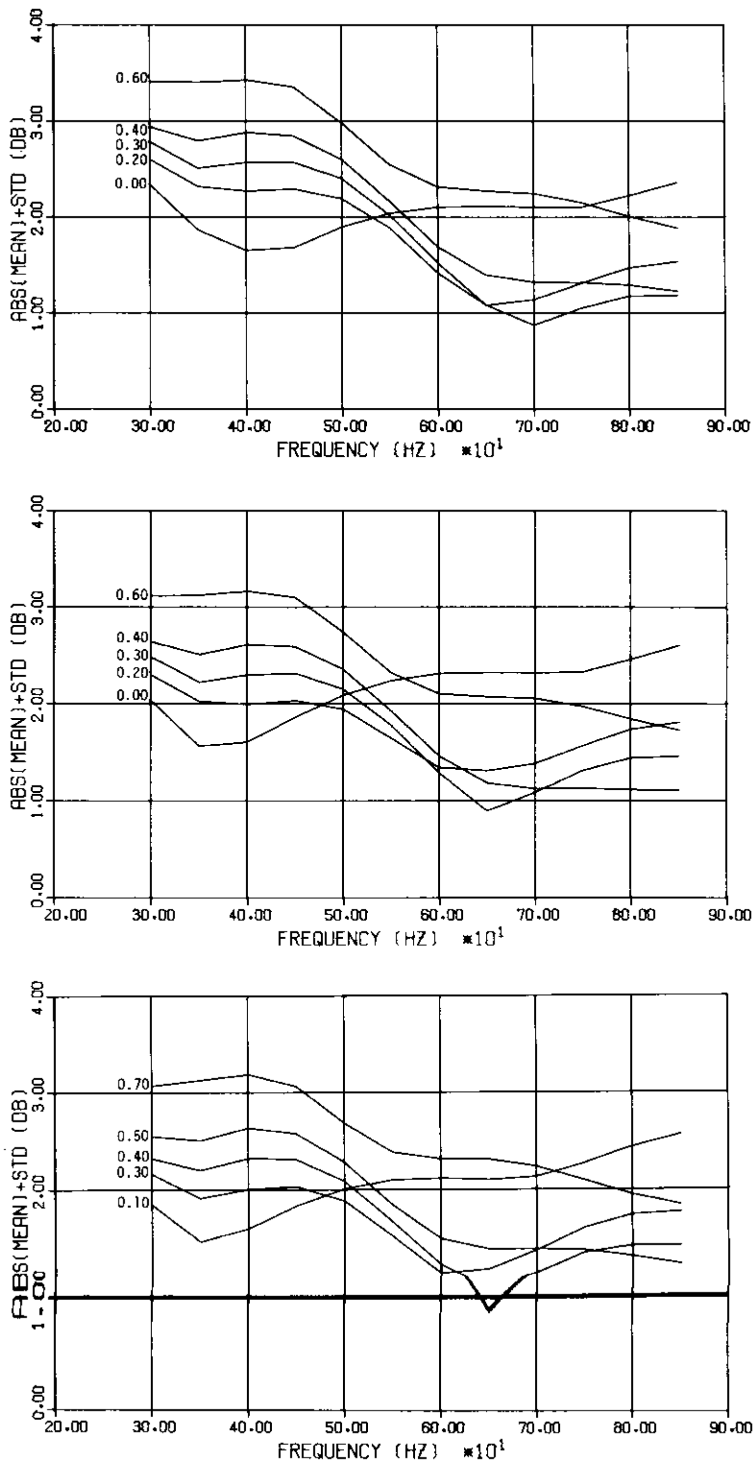
For convenience, the best values for the equivalent height and frequency for each vehicle are also shown in Table I. Note that even the best choice of height and frequency can still yield an error of up to 1 dB. It is somewhat surprising that the degree of deviation is as small as it is considering that:

(1) The ground plane produces reflections (particularly from the paved portion) which make the sonic image a combination of the vehicle noisescape and a blurred, attenuated mirror image "below" the ground.

(2) The various noise sources on the vehicles are not actually all at the same height.

(3) The noise sources actually are not at a fixed frequency and do not even have the same frequency spectrums.

(4) Each of the sources on a given vehicle is unlikely to be truly omnidirectional, particularly at the higher frequencies.

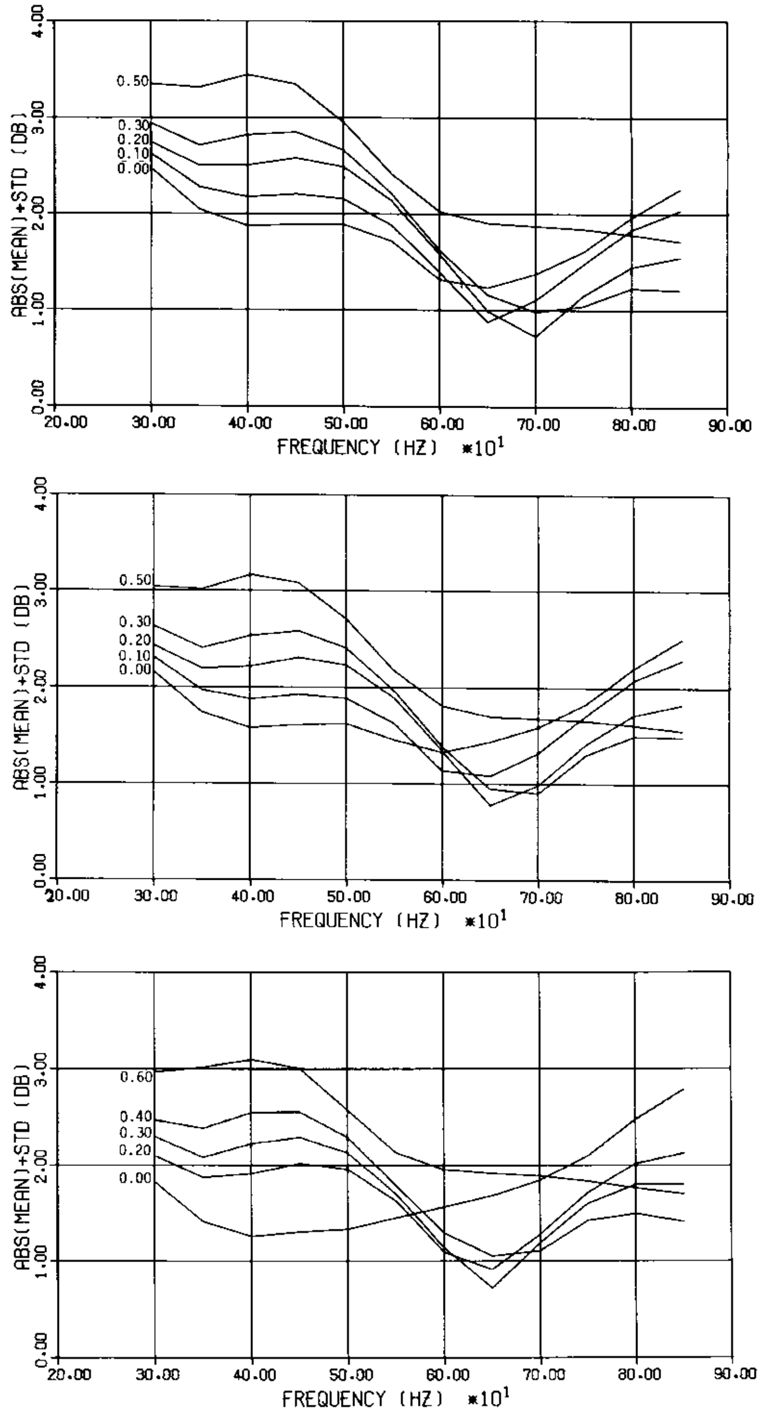


a. Spreading attenuation from top of wall.

b. Spreading attenuation from 30 cm above wall.

c. Spreading attenuation from 60 cm above wall.

Figure 12. Plots containing the best height and frequency values for the first Audi test sequence for each spreading assumption.

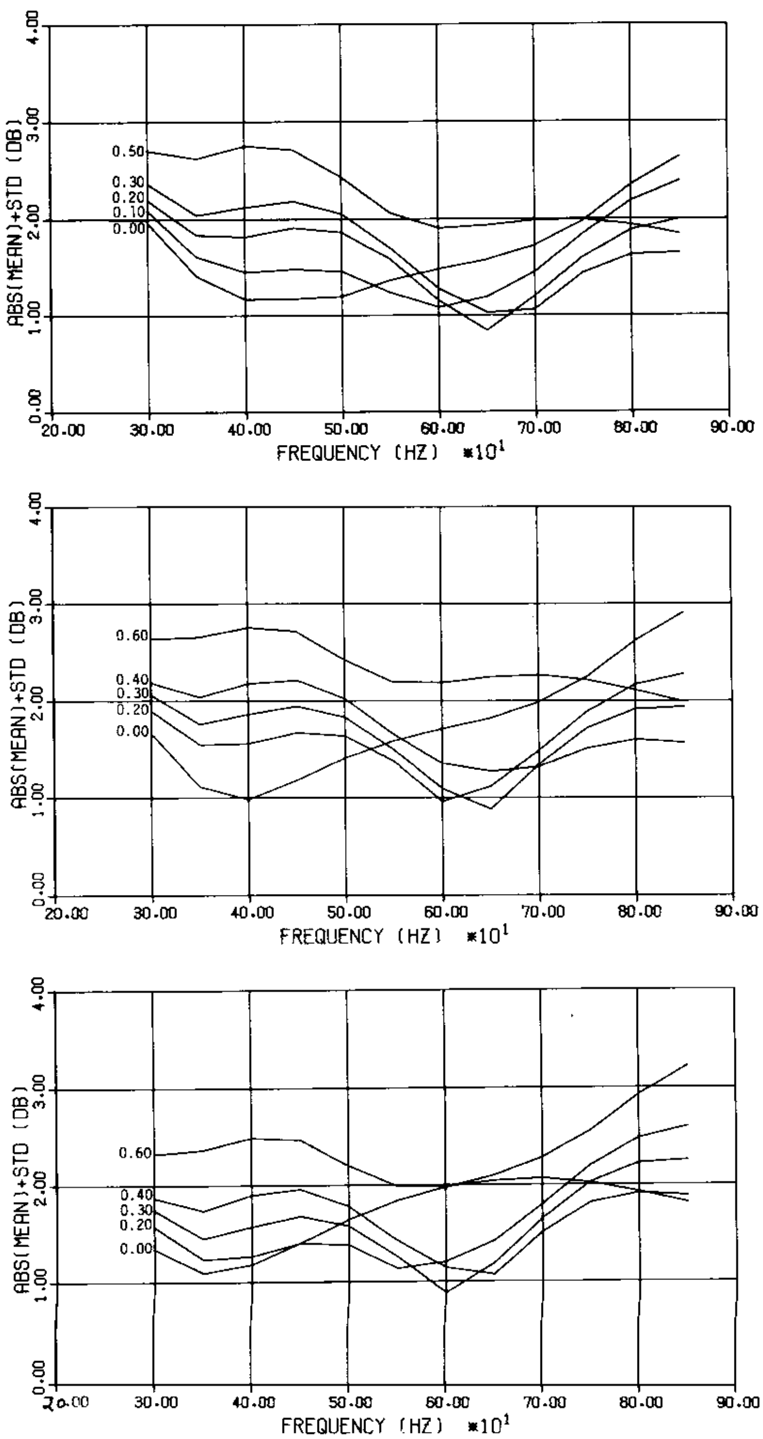


a. Spreading attenuation from top of wall.

b. Spreading attenuation from 30 cm above wall.

c. Spreading attenuation from 60 cm above wall.

Figure 13. Plots containing the best height and frequency values for the second Audi test sequence for each spreading assumption.

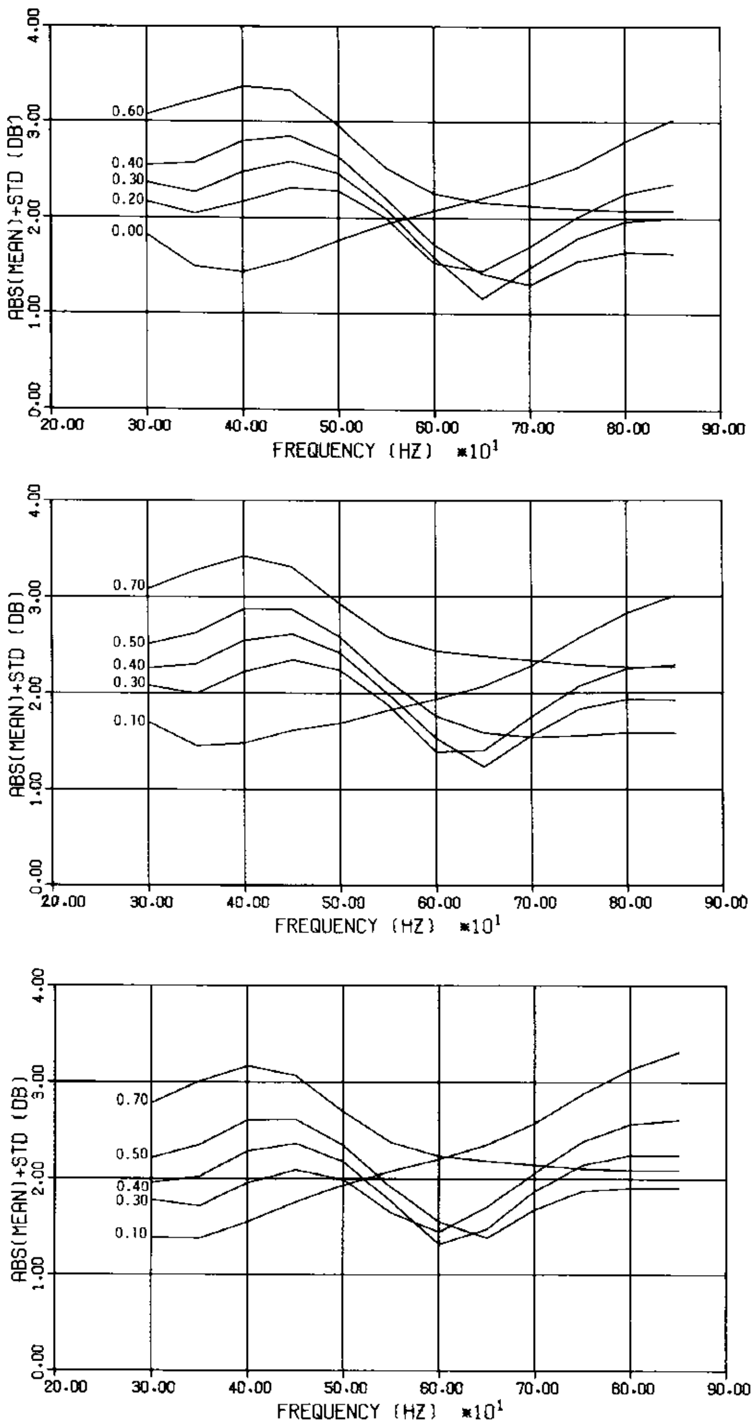


a. Spreading attenuation from top of wall.

b. Spreading attenuation from 30 cm above wall.

c. Spreading attenuation from 60 cm above wall.

Figure 14. Plots containing the best height and frequency values for the Hornet test sequence for each spreading assumption.

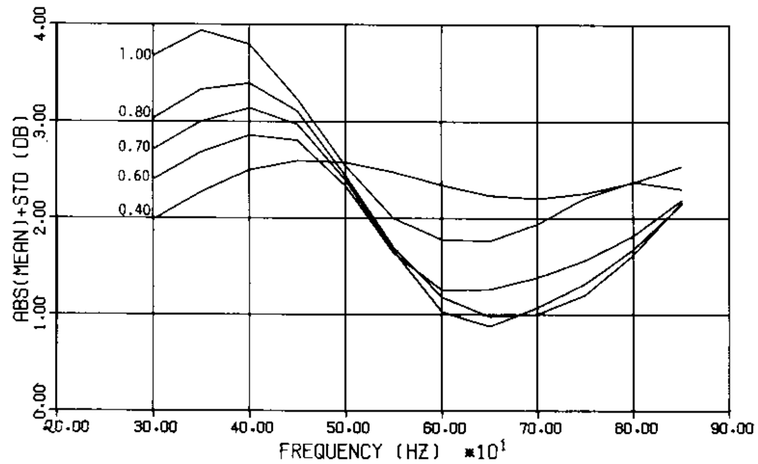


a. Spreading attenuation from top of wall.

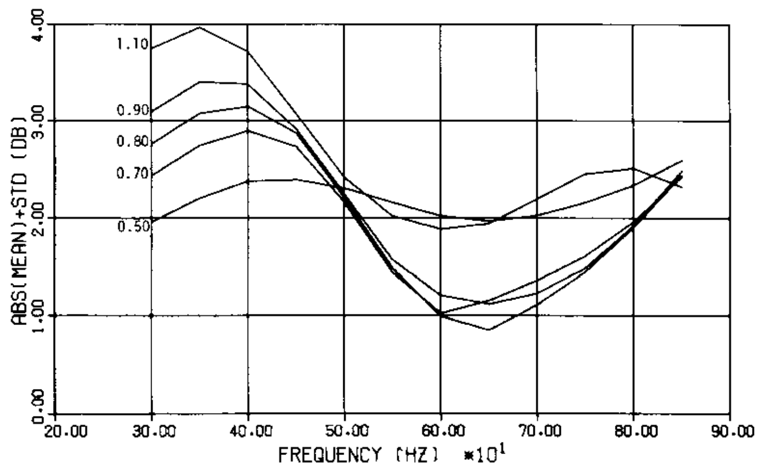
b. Spreading attenuation from 30 cm above wall.

c. Spreading attenuation from 60 cm above wall.

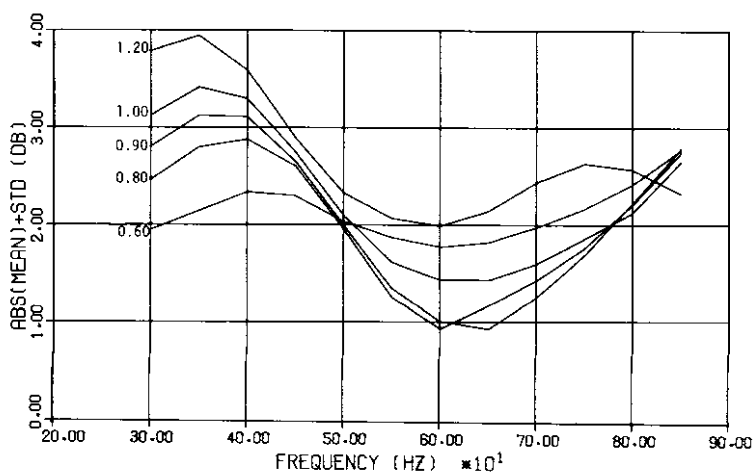
Figure 15. Plots containing the best height and frequency values for the pickup test sequence for each spreading assumption.



a. Spreading attenuation from top of wall.

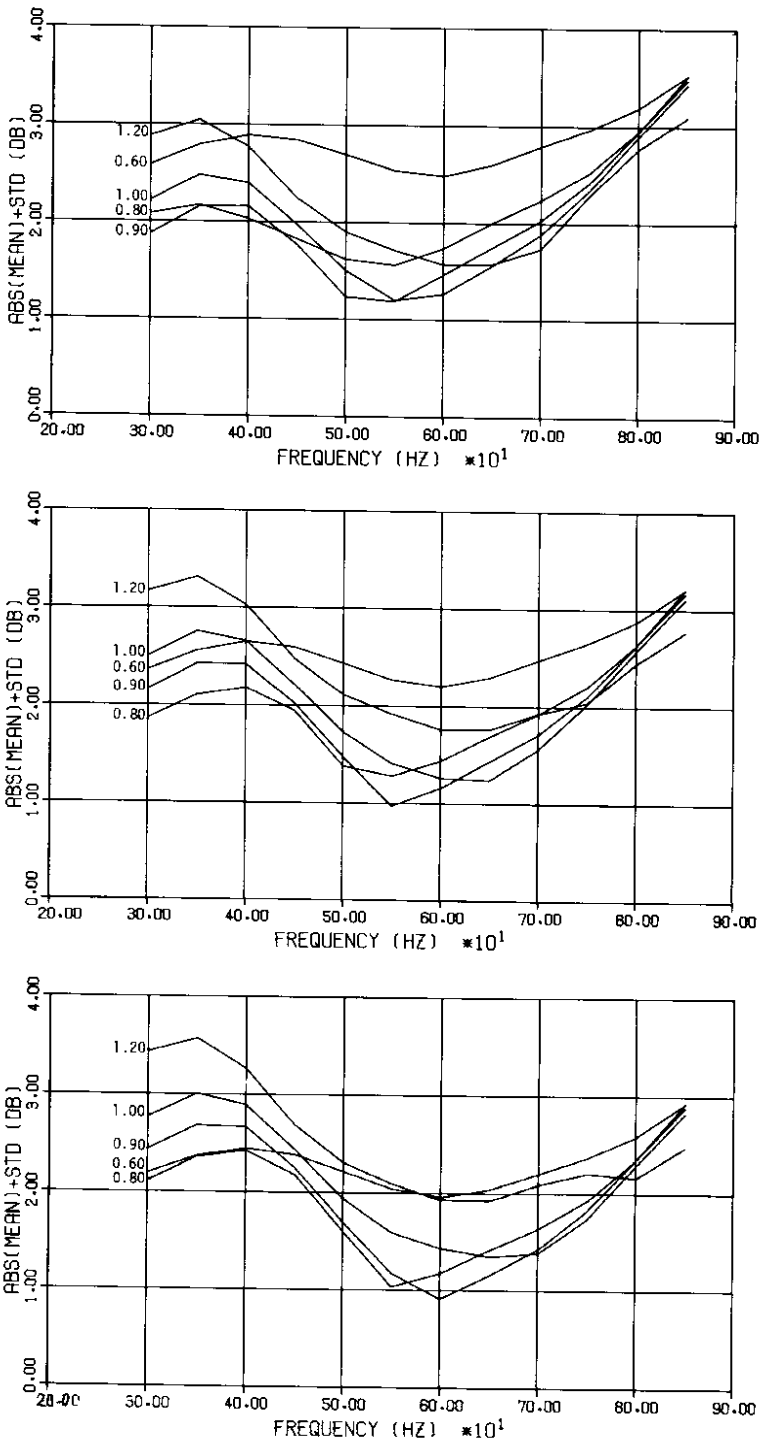


b. Spreading attenuation from 30 cm above wall.



c. Spreading attenuation from 60 cm above wall.

Figure 16. Plots containing the best height and frequency values for the cement truck test sequence for each spreading assumption.



a. Spreading attenuation from top of wall.

b. Spreading attenuation from 30 cm above wall.

c. Spreading attenuation from 60 cm above wall.

Figure 17. Plots containing the best height and frequency values for the semi-tractor test sequence for each spreading assumption.

Table I. Optimum heights and frequencies.

	Assuming Cylindrical Spreading from Top of Wall						Assuming Cylindrical Spreading from 30 cm Above Wall						Assuming Cylindrical Spreading from 60 cm Above Wall					
	Lowest Point on Lowest Curve			Lowest Curve at 560 Hz		Max. Likely Error at 560 Hz & 0 Height in dB (2.5 m for Trucks)	Lowest Point on Lowest Curve			Lowest Curve at 560 Hz		Max. Likely Error at 560 Hz & 0 Height in dB (2.5 m for Trucks)	Lowest Point on Lowest Curve			Lowest Curve at 560 Hz		Max. Likely Error at 560 Hz & 0 Height in dB (2.5 m for Trucks)
	Height	Frequency	Max. Likely Error in dB	Height	Max. Likely Error in dB		Height	Frequency	Max. Likely Error in dB	Height	Max. Likely Error in dB		Height	Frequency	Max. Likely Error in dB	Height	Max. Likely Error in dB	
Audi, Test 1	0.30	700	0.873	0.20	1.80	2.06	0.30	650	0.894	0.20	1.58	2.26	0.40	650	0.952	0.30	1.45	2.49
Audi, Test 2	0.20	700	0.731	0	1.65	1.65	0.20	650	0.776	0	1.43	1.43	0.30	650	0.719	0	1.47	1.47
Hornet	0.20	650	0.840	0.10	1.20	1.40	0.30	650	0.880	0.20	1.30	1.62	0.30	600	0.883	0.20	1.16	1.86
Pickup	0.30	650	1.156	0.20	1.92	1.97	0.40	650	1.234	0.30	1.68	2.19	0.40	600	1.315	0.30	1.61	2.45
Average of Cars & Pickup	0.20	650	0.946	0.10	1.55	1.60	—	—	—	—	—	—	—	—	—	—	—	—
Cement Truck	0.70	650	0.877	0.70	1.56	6.70	0.80	650	0.848	0.70	1.36	6.54	0.90	650	0.923	0.80	1.19	6.35
Semi-tractor	0.90	600	0.912	0.80	1.05	6.10	0.90	550	0.972	0.90	1.01	5.94	0.90	550	1.187	1.00	1.21	5.75
Average of Trucks	0.80	650	0.998	0.70	1.33	—	—	—	—	—	—	—	—	—	—	—	—	—

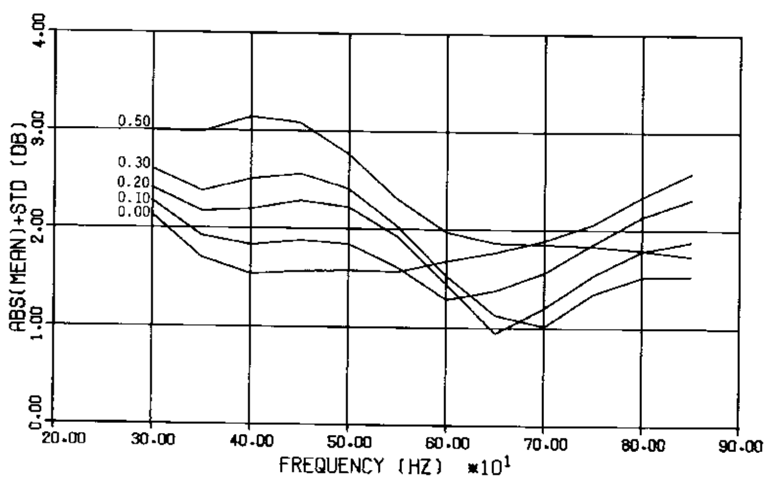
CONCLUSIONS

Figure 18a is a plot of the data for all the cars (and the pickup truck) taken together. Figure 18b is a similar plot of the data from the two trucks. The results show that for cars and pickup trucks the "best" equivalent source is:

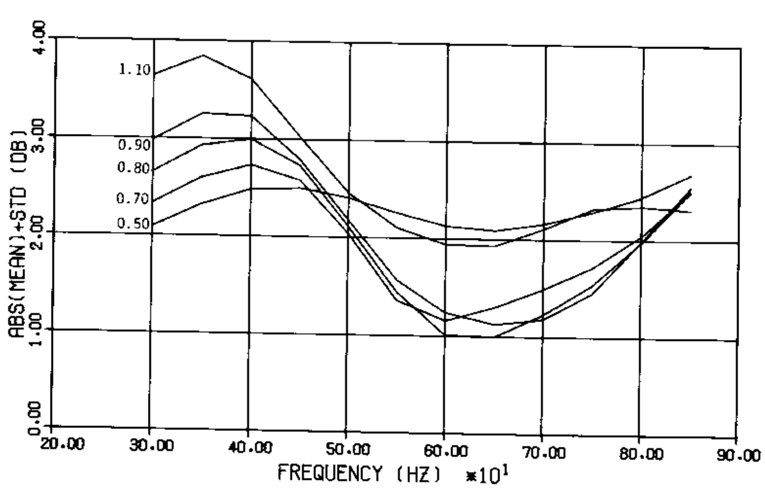
650 Hz at a height of 0.2 m (0.66 ft).

For trucks, the "best" equivalent point source is:

650 Hz at a height of 0.8 m (2.62 ft).



a. Combination of data for cars and pickup.



b. Combination of data for diesel trucks.

Figure 18. Maximum likely error for various assumptions of frequency and radiating height (in meters). (Spreading attenuation is from top of wall.)

The present assumption of the Washington State Computer Program, which is based on National Cooperative Research Program Report 117, uses an equivalent source frequency of 566 Hz for both cars and trucks. This does not appear to be the best choice, but, on the other hand, it is not all that bad.

For automobiles, the current computer program assumes 0 height. Examination of Table I indicates that an assumption of 560 Hz at 0 height would yield a maximum likely error of 1.6 dB for all of the automobiles and pickup trucks included in the experiment compared to a maximum likely error of 0.95 dB for the best choice indicated in the study for this class of vehicle (650 Hz at an assumed height of 0.2 m (0.66 ft) above the road). A difference of 0.65 dB is not very significant.

For the trucks, the effective radiating frequency was considerably higher than expected before the tests were conducted. The optimum frequency for the two trucks taken together was 650 Hz, at a height of 0.8 m (2.62 ft) above the road. It is my understanding that the current Washington State computer program uses an effective height of 8 ft for trucks. Examination of Table I shows that for the cement truck this assumption would yield a maximum likely error of 6.7 dB. This compares to a maximum likely error of 0.9 dB using an effective height of 2.6 ft at a frequency of 650 Hz, or about 1.5 dB using 2.5 ft at 560 Hz; this means that the 8-ft assumption is about 5 dB worse than the lower height assumption. For the semi-tractor, the 8-ft assumption yields an error of 6.1 dB, which again is about 5 dB worse than the lower height assumption.

It is of course possible that the two trucks tested were not typical of trucks in general. Also, the test conditions may not have been typical, particularly at the higher speeds when the trucks were still accelerating and not yet in top gear when they passed the test area. Nevertheless, the data clearly indicate that the assumption of a radiating height of 8 ft is much too high.

If a reduction from 8 ft to below 3 ft, as the test data indicate, appears too radical a change for the present, it is recommended that a height of 4 ft be adopted for truck noise calculations. It is true that a completely unmuffled truck with an 8-ft high exhaust would act as though it were radiating from a height greater than 4 ft. However, the new vehicle noise regulations now going into effect around the country will at least force all trucks to have mufflers. This will reduce the average effective radiating height, and should make it closer to that found in these experiments.

BIBLIOGRAPHY

Embleton, T.F.W., J.E. Piercy and N. Olson; "Outdoor Sound Propagation Over Ground of Finite Impedance." J. Acoust. Soc. Am., 23(5): 546-550 (September 1951)

Hunt, F.V.; "Investigation of Room Acoustics by Steady State Transmission Measurement." J. Acoust. Soc. Amer., pp. 216-227 (1939)

Ingard, N.; "On the Reflection of a Spherical Sound Wave from an Infinite Plane." J. Acoust. Soc. Amer., V23, pp. 329-335 (1951)

Ingard, N. and G.G. Maling; "On the Effect of Atmospheric Turbulence on Sound Propagation Over Ground." J. Acoust. Soc. Amer., V35, pp. 1056-1058 (1963)

Kriebel, H.R.; "Refraction and Attenuation of Sound by Wind and Thermal Profiles over a Ground Plane." J. Acoust. Soc. Amer., V51, #1 - pp. 19-23 (1972)

Lawhead, R.B. and I. Rudnick; "Acoustic Wave Propagation Along a Constant Normal Impedance Boundary." J. Acoust. Soc. Amer., V23, #5, pp. 546-550 (September 1951)

Lawhead, R.B. and I. Rudnick; "Measurements on an Acoustic Wave Propagated Along a Boundary." J. Acoust. Soc. Amer., V23, #5 - pp. 541-545 (September 1951)

Piercy, J.E., T.F.W. Embleton and N. Olson; "Effect of the Ground on Near-Horizontal Sound Propagation." J. Acoust. Soc. Amer., V53, p. 340A (1973)

Piercy, J.E. and T.F.W. Embleton; "Effects of Ground on Near Horizontal Sound Propagation." SAE Paper 740211: Detroit (February 1974)

Rudnick, I.; "Propagation of an Acoustic Wave along a Boundary." J. Acoust. Soc. Amer., V19, pp. 348-356 (1947)

Wenzel, A.R.; "Propagation of Waves Along an Impedance Boundary." J. Acoust. Soc. Amer., V55 #5 - pp. 956-963 (May 1974)