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Studies in Urban Transportation

Transportation Systems: Noise Generation And Abatement

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TRANSPORTATION SYSTEMS
NOISE GENERATION AND ABATEMENT

by

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ABSTRACT

The report deals with the noise impact of transportation systems and methods that can be used for lessening that impact. An introductory discussion of the physics of noise and noise measurement is given to help the reader in understanding how the noise impact is analyzed.

"…. To declare a national policy which will encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality."

Public Law 91 - 190

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INTRODUCTION

This report deals with the amount and intensity of transportation systems noise generation, and efforts used to lessen the impact of the noise.

Noise is a part of the environment that man has created. Unless a noise is sufficiently high, most of us are unaware that it exists and could care less. Ambient noise levels, that is noise levels that are encountered generally in the environment, have as a major source, various transportation systems. Ambient levels are continually rising year after year. Transportation has been a major contributor to this rise.[7]

The range of intensity of noise is tremendous. It has been found that even relatively low levels of noise do cause humans to respond, even though they may not be aware of that response.[2]

Transportation planners and designers must be aware of the noise assult any proposed system will have on the environment. The mandate for this stems from two laws: The National Environmental Policy Act of 1969 and the Federal Aid-Highway Act of 1970. The Environmental Policy act of 1969 requires an assesment of all projects that are Federally funded to determine any adverse impacts it may have on the environment. Obviously, noise pollution is an adverse impact. Specifically aimed at highways that are funded with Federal monies, the Aid Act of 1970 requires noise assesment of any proposed road that has not received approval before July 1, 1972. An excerpt from the act reads as follows:

> "The Secretary (of the DOT) ... shall promulgate standards for highway noise levels ...and ... shall not approve plans... unless he determines that such plans... include adequate measures to implement the appropriate noise level standards."

This report covers three major topics. The first section deals with a general overview of the physical phenomena associated with noise as sound energy. The second topic deals with the known effects of noise on man. The third topic considers various major transportation systems, (with a primary emphasis given to highway networks) and the noise generated by them. This report will also consider methods that can be used to abate transportation generated noise.

THE NATURE OF NOISE[10]

The key to understanding what noise is, is found in its definition: unwanted or annoying sound. The elementary properties of noise are analogous to those of sound.

From a physical point of view, sound is a disturbance of an elastic medium (such as metal or air) caused by a vibrating object. This disturbance elicits a response by the human auditory system, which is dependent upon the amplitude, duration and frequency of the disturbance. The disturbance travels from its source in waves. This is represented in Figure 1.

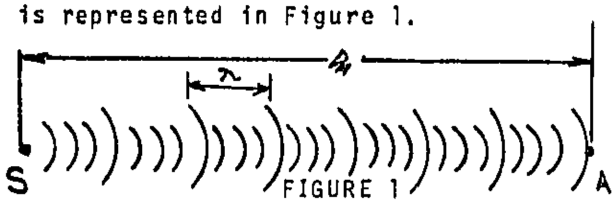

FIGURE 1

If we assume that the sound wave as shown above is traveling in a free field (no obstructions to divert its travel) sound pressure (P_a) from the source varies as the inverse square of the distance (D_a):

$$P_a = k\ 1/D_a^2 ,$$

where k is a constant of proportionality, describing the sound conductivity of the medium.

The range of sound pressures commonly found in nature is quite wide. As an example, the sound pressure near an internal combustion engine may be greater than two hundred microbars*. This pressure is a million times as great as that just audible to the human ear (0.0002 microbars). Because of this tremendous range of pressures encountered, a logarithimic unit of sound pressure, called the sound pressure <u>level</u> is used. This unit of level is called the bel. Bels are quite cumbersome and large to work with, and as a consequence, the decibel is almost universally used (1 decibel is equal to 0.1 bel). The pressure level in decibels (dB) of a sound with an associated pressure P is defined as:

$$L = 10 \log [P/P_o]^2$$
$$= 20 \log [P/P_o]$$

where P_o is a given reference pressure.

The quantity given as L above is often refered to as the sound pressure level (SPL). The reference pressure most commonly used is taken to be the threshold of audibility: P_o = 0.0002 microbars.

Because the decibel is a logarithimic unit, a doubling of sound pressure does not correspond to a doubling of SPL. A doubling of sound pressure would lead to an

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* 1 microbar = 1.0×10^{-6}bar, where 1 bar = 1 atmosphere

increse in SPL of 6 dB. If the sound pressure were increased by a factor of 10, the corresponding change in SPL would be 20 dB as follows:

$$SPL = 20 \log [P/0.0002] = 20 \log [5P \times 10^3]$$

increasing P to 10P;

$$SPL = 20 \log [10P/0.0002] = 20 \log [5P \times 10^4]$$

the difference in SPL being then;

$$\begin{array}{r} 20 \log (5 \times 10^4) + 20 \log P \\ \underline{- 20 \log (5 \times 10^3) + 20 \log P} \\ 20 = \Delta SPL \end{array}$$

Combining two sounds A and B does not lead to the direct addition of their respective SPL's. The combined SPL for the two sounds could be determined by the following:

$$P_{res} = [P_A^2 + P_B^2]^{1/2}, \text{ and } SPL_{res} = 20 \log [P_{res}/0.0002]$$

As a general rule, the SPL_{res} will never be higher than 3 dB greater than the higher of the two combining sources. The nomograph on page 6 allows one to determine the resultant SPL for two combining SPL's.

As sound pressure varies as the inverse square of distance, we can determine that, for point source of noise in a free field, every doubling of distance corresponds to a drop in sound pressure level of 3 dB.

The relationship between sound pressure in microbars and sound pressure level is shown in the chart of

FIGURE 2

CHART FOR COMBINING SOUND PRESSURE LEVELS

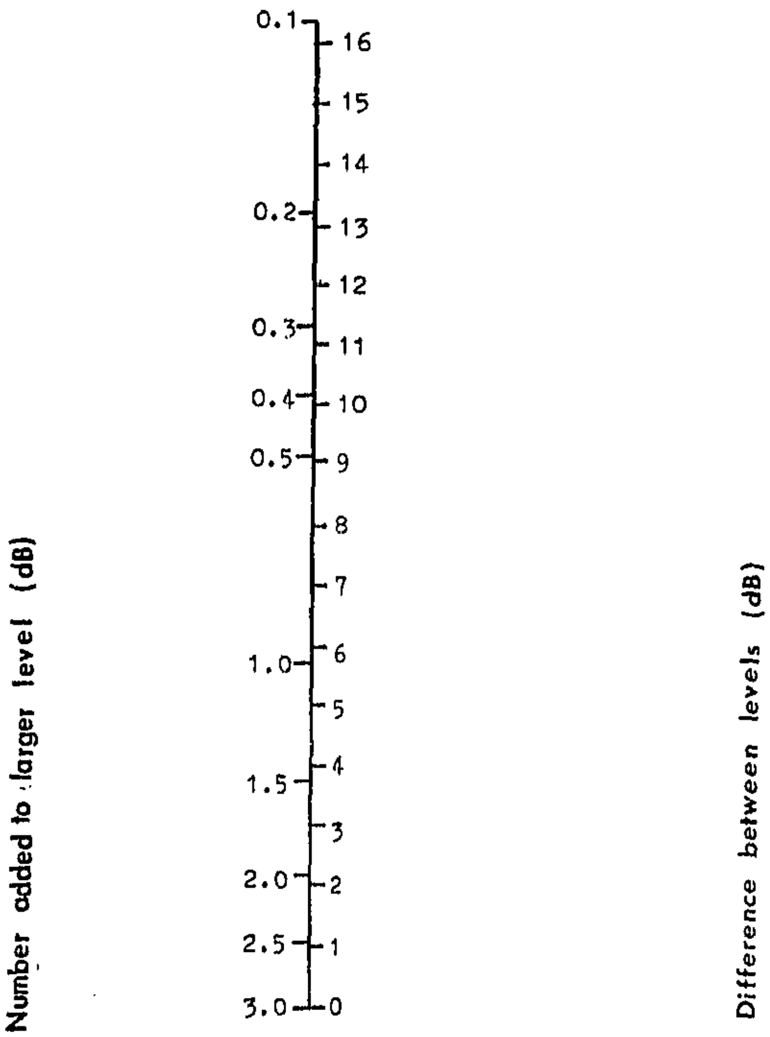
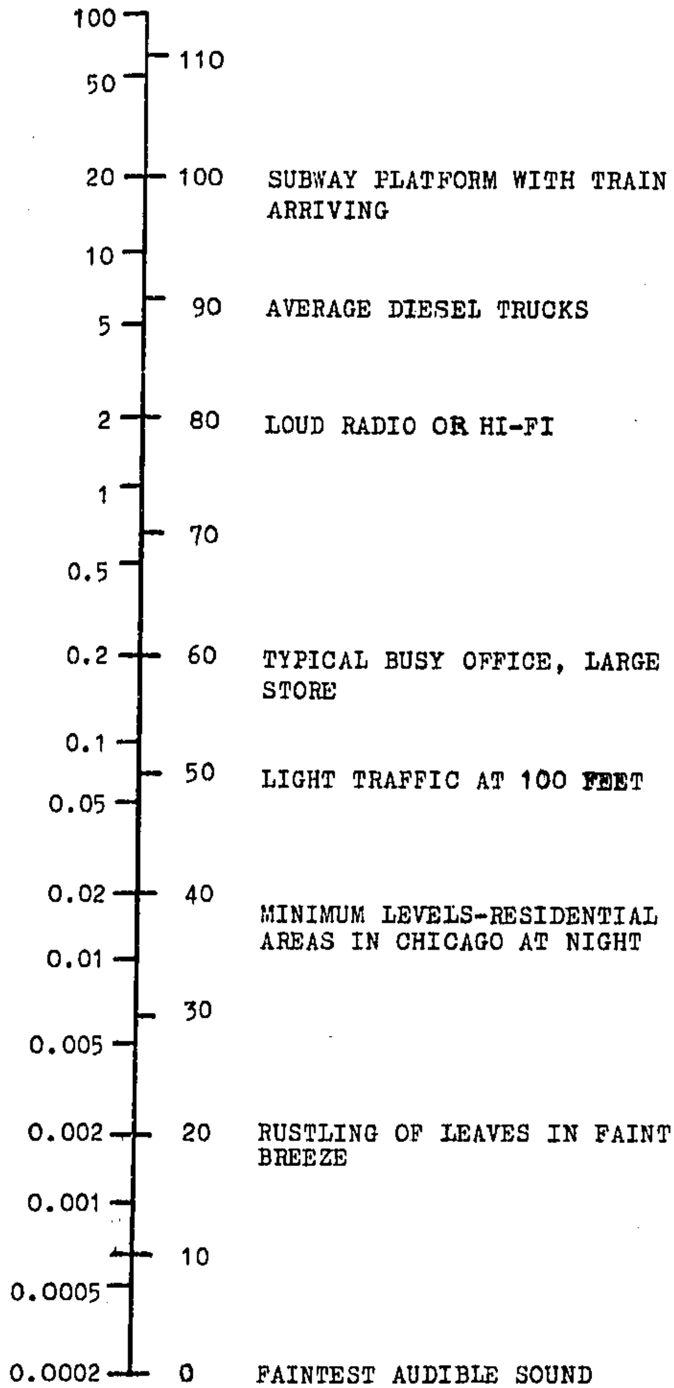


FIGURE 3



<u>SOUND PRESSURE</u> (microbars) <u>vs.</u> <u>SOUND PRESSURE LEVEL</u> (dB)

Figure 3   Various easily identified sounds are included in Figure 3, next to their corresponding levels.

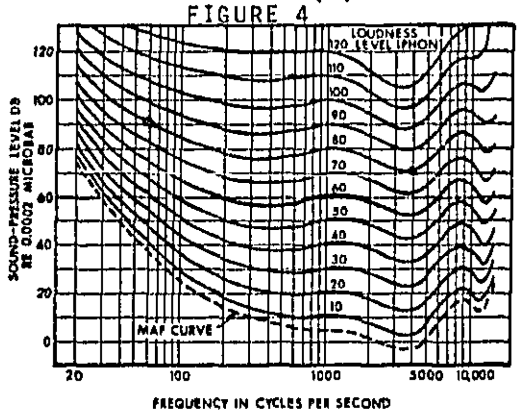
Another physical measurement of sound and noise is frequency. Frequency, which is the measurement of the mumber of cycles per second of oscillation, is measured in Hertz (hz.). It has been determined that normal human auditory response can be associated with frequencies in the range of 20 Hz to 15,000 Hz. It has also been found that auditory response is a function not only of sound pressure, but frequency as well. This is discussed in the next section on measurement techniques.

NOISE MEASUREMENT TECHNIQUES - SELECTION OF A STANDARD

The ultimate ideal in noise measurement is to be able to quantify human response to noise. The level measurement discussed up to this point is a good, repeatable measurement. However, it does not adequately represent actual human response to sound. In Figure 4, a series of equal loudness contours are plotted as a function of both frequency and level. The <u>phon</u>, as described on the chart is a sound that observers judge to be equally loud, at various frequencies and pressure levels, to a pure tone frequency of 1,000 Hz, at a specific pressure level in decibels. For example, a sound at a frequency of 60 Hz.

with a pressure level of 90 dB, is judged to be equal to 80 phons (80 dB @ 1,000 Hz.). Continuing, a sound of 70 dB at a frequency of 5,000 Hz is judged to be equally loud (80 phons). The curve labeled M.A.F is known as the Minimum Audible Field, and is the level of a simple tone that can just be heard in an exceptionally quiet location, under free field conditions.[6]

FIGURE 4[6]



In order to quantify the dependence of auditory response to frequency and level, a weighting system is employed in the pressure level measurement. Various "weighted" sound pressure level scales have been developed. The ones most commonly used are denoted the A, B, C, and D scales. The relative response of the various scales as a function of frequency is illustrated in Figure 5.[6] The A weighted network provides more emphasis on sounds of higher frequencies and has been shown to provide a frequency response roughly similar to that of the human ear. The B network provides somewhat less frequency equalization. The C network is, in essence, a uniform response network over the major portion of the frequency spectrum, and as such it is the same measurement that we have previously refered to as the decibel. Units of measurement are reported as dBA, dBB and dBC (or just dB), respectively.[10]

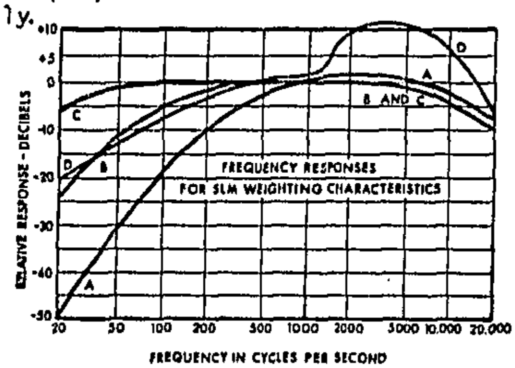


FIGURE 5

A lot of research has been done to determine the subjective response of people to noise. In the following section, a summary of the known physiological and psychological effects of noise is presented, along with research findings that attempt to quantify these responses.

THE PHYSIOLOGICAL EFFECTS OF NOISE

The physical effects of noise on man have been studied for some time. The response to noise can be determined. For example, it has been determined that, for subjects with normal hearing, various thresholds exist. In a range of frequencies from 200 to 20,000 Hz., discomfort is noticed at SPL's in the range of 112 to 117 dB. A threshold of pain exists at approximately 143 dB, in the same frequency range.(10)

Hearing loss is one of the effects of overexposure to noise. Loss of hearing usually appears as a shift in hearing frequency threshold. This shift may be permanent or temporary, depending upon such things as individual susceptability, duration of noise exposure, noise frequency spectrum and level, and the type of noise.(10)

Many allegations have been made thatnoise directly alters human health. Most are vague. The problem that exists in determining if noise has any direct bearing on an individual's health is that it is hard to obtain sound evidence to justify the claim. The problem is coundfounded with individual physiological differences and multivariate exposure problems. While noise has not been found directly related to disease occurance, it is known that noise induces stresses. These stresses reduce immunity and increase susceptability to disease. Hence a causal link does exist.(10)

In his experiments on sleeping subjects, at the Max Planck Institute, Dr. Gerd Jansen was able to catergorize many responses illicited by noise.(1) Recording the EEG patterns ofsleeping subjects, Dr. Jansen would subject their environment to a sound level whose intensity varied. A noise level of 55 dBA illicited a marked response of vasoconstriction in all subjects.

According to many sleep researchers, the most important periods of a person's sleep are the dream stages.(2) These dream stages are marked by a phenomena known as rapid eye movement (REM). Persons deprived of REM sleep stages most often undergo marked psychological changes. Acute psychological breakdown may result from the cumulative effects of a long partial depreviation of REM sleep. The noise level necessary to accomplish this result may be relatively low. Some experiments show that levels as low as 55 dBA can produce the deprivation of REM.(2) The variability in noise level required to illicit these responses from one individual to another are most likely due to individual psychological differences.

THE PSYCHOLOGICAL EFFECTS OF NOISE

People tend to think of noise as being annoying, interfering with sleep or work performance, or impairing communication. These are generally psychological effects.

Annoyance, displeasure or resentment caused by noise is due to the absence or presence of that noise (also the implications arising from it). No real objective measure exists to describe sounds that are likely to be annoying. However, some characteristics of sound that would likely be annoying are:

1. Loudness
2. Pitch (greater than 1,500 Hz.)
3. Intermittent or irregular
4. Localization -- uncertain origin, or hidden source.
5. High level over ambient.
6. Inappropriate to an individual's activity.
7. Feelings about preventability.
8. Personal bias with respect to the noise and/or source.
9. Overall hostility to the environment.
10. Beliefs in regard to the effects of the noise.
11. Extent one associates the noise with feelings of fear.

The effect of noise on sleep has been discussed. One point that should be clarified is that there is a wide variation in adaptability to noise from one individual to another. Experiments by Thessen show that the range of noise levels needed to wake sleeping subjects varied from 40dBA to greater than 70 dBA.[10]

Work efficiency is affected by noise, primarily with noise above 90 dBA. Higher frequency noises have a more profound effect in reducing work efficiency. The sudden, temporary alterations in noise level have the effect of temporarily disturbing work performance. It has also been found that accuracy of work is diminished, probably as a result of interference with concentration.[10]

Noise has a tendency to interfere with communication. Research into this effect by Beranek has resulted in defining the Speech Interference Level (SIL).
The Speech Interference Level is a measurement in decibels which is the average of SPL in three octave ranges: 600 Hz. to 1,200 Hz.; 1,200 Hz. to 2,400 Hz.; 2,400 Hz. to 4800 Hz. The SIL at the location of interest is determined and compared with known values which indicate the maximum distances speech (at various levels) is of a specific intelligibility. This is illustrated in Table 1[10] and Figure 6.[7]

Speech Interference Levels of Noise that just Permit Conversation with Marginal Reliability at the Distances and Voice Levels Indicated

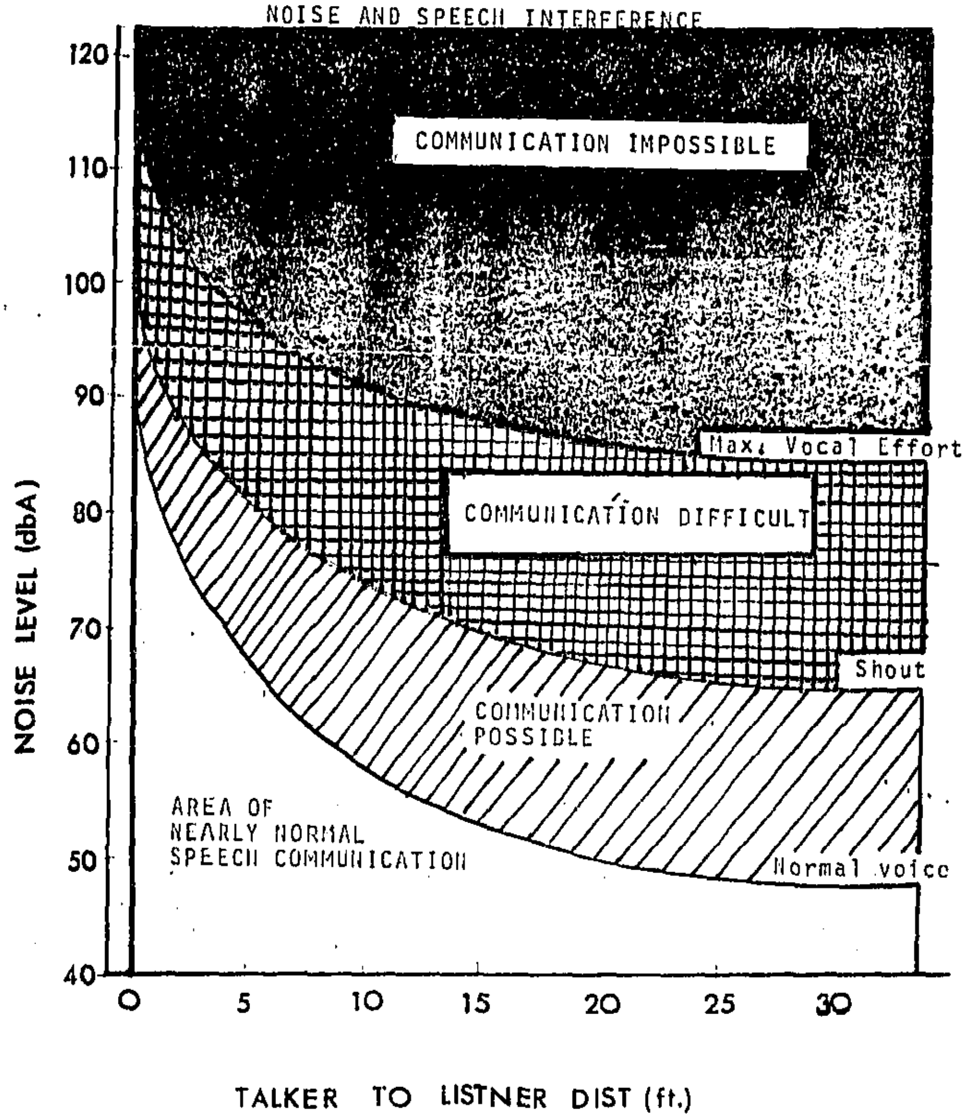
DISTANCE FROM LISTENER (FT.)	SPEECH INTERFERENCE LEVEL (PSIL) IN DB*			
	NORMAL VOICE	RAISED VOICE	VERY LOUD VOICE	SHOUTING
0.5	76	82	88	94
1	70	76	82	88
2	64	70	76	82
3	60	66	72	78
4	58	64	70	76
5	56	62	68	74
6	54	60	66	72
12	48	54	60	66

* Average SPL in db of noise in the octave bands centred at 500, 1,000 and 2,000 Hz. (PSIL) Sound levels in dbA are 7 db greater than PSIL db.

TABLE 1

FIGURE 6

NOISE AND SPEECH INTERFERENCE



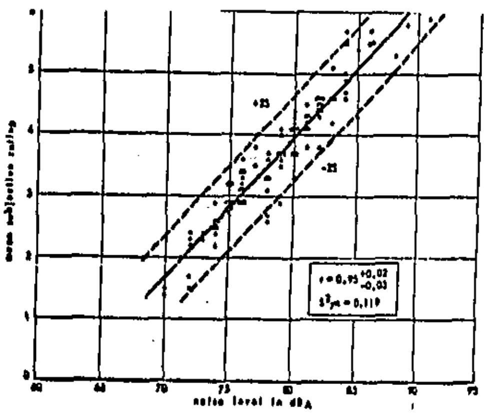
Other measures of noise that are thought to represent human subjective response are summarized below:[8]

1. Loudness - this is a linear measurement of sound intensity in which scale numbers are approximately proportional to loudness. This unit of measurement is the sone.
2. Perceived Noise Level - this measurement rates the "noisiness" of a sound rather than the loudness of a sound. The computational scheme developed by Kryter yields a measurement in perceived noise level units (PNdb). The approach is similar to that of defining the equal loudness level contours.

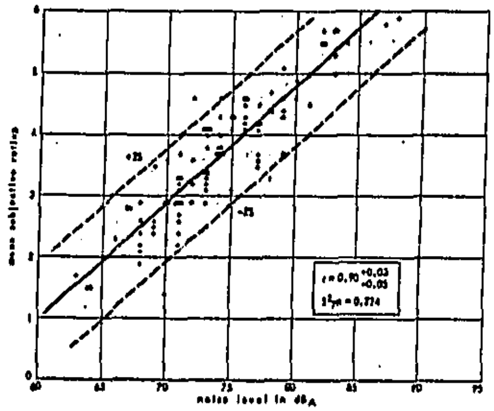
Analysis of subjective responses to motor vehicle noise was done by Galloway, et al.[8] Two tests were analyzed: 1.) The Armour Research Foundation (ARF) tests on truck noise and 2.) The National Physical Laboratory - Motor Industry Reasearch Associations (MIRA) study. The ARF study was an analysis of subjective response to truck noise done in 1953. The MIRA study data were taken in 1960.

In the ARF study, observers were asked to judge the noisiness of a passing truck from "quiet" to "excessively noisy" on a numerical scale of 0 to 6. Scatter diagrams of the responses were plotted, and a least squares regression line plotted. These can be seen in Figure 7. The solid lines on the diagrams represent the envelope for a 2s (std. deviation) confidence about the regression line.

FIGURE 7



. Correlation of subjective ratings of noise from diesel-engined trucks in ARF experiment with noise level in dBA as computed from octave band sound pressure levels.



Correlation of subjective ratings of noise from diesel-engined trucks in ARF experiment with noise level in dBA as reported by ARF.

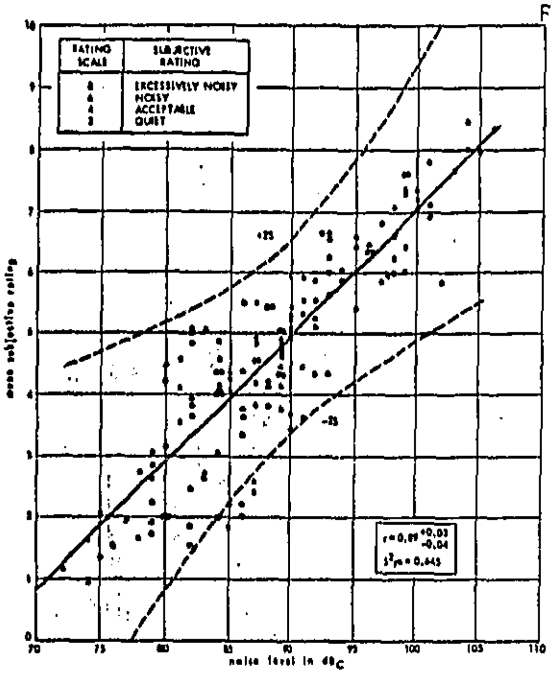
In the MIRA study, vehicles passed an observation point traveling in three modes:

1. Accelerating from a speed of 30 mph
2. Full throtle with brakes applied to give a constant 30 mph velocity
3. In top gear at a constant speed of 30 mph

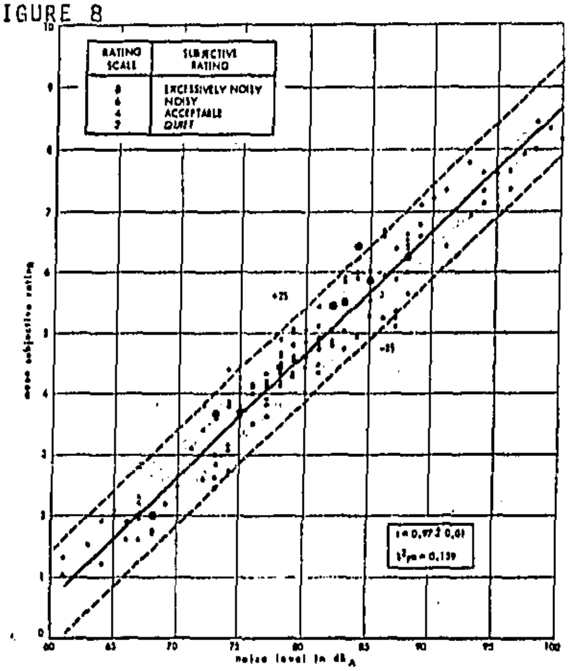
Typical scatter diagrams for this study are shown in Figures 8 and 9. It should be remembered that the more linear the regression line, and the smaller the 2s envelope, the better the correlation between the physical measurement and subjective reaction.

Figure 10 shows the correlation coefficients and standard deviations for both the ARFandMIRA studies. From analysis of the data, it was determined that noise measurement in units of decibels on the A scale (dBA) represented the best physical description of subjective response.

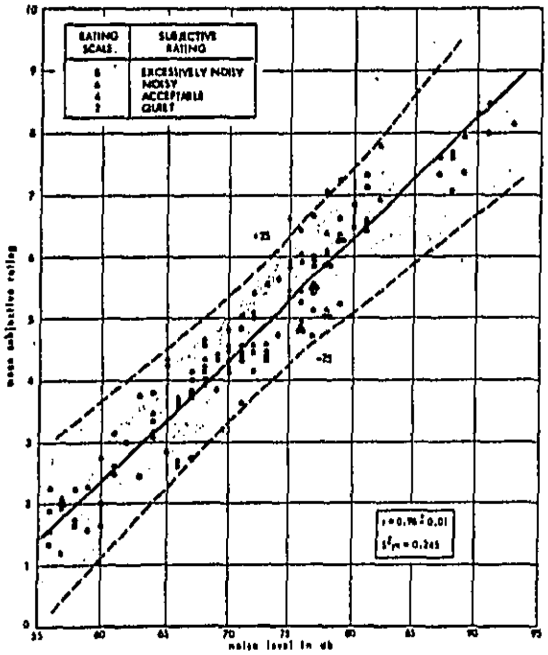
FIGURE 8



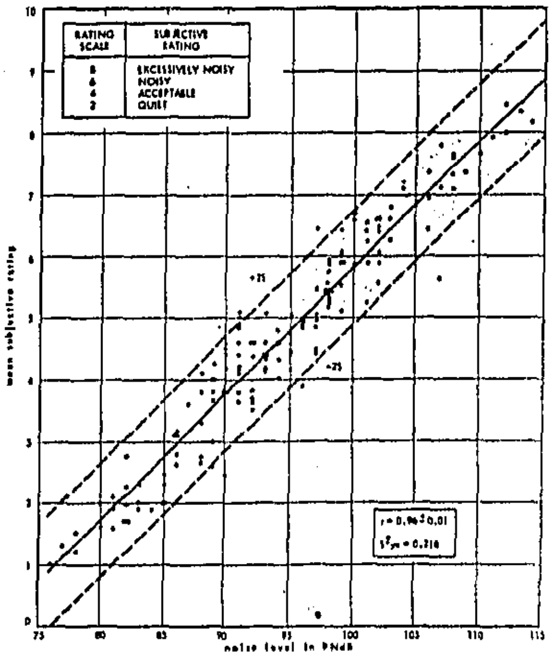
Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with over-all sound pressure level in dBC.



Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with noise level in dBA.

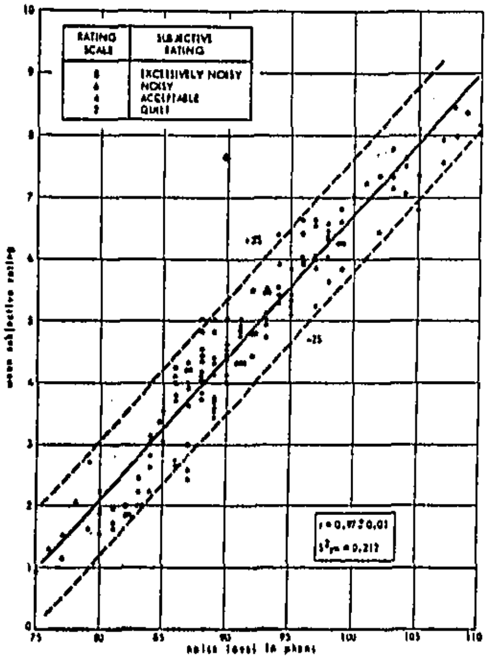


Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with speech interference level in dB.

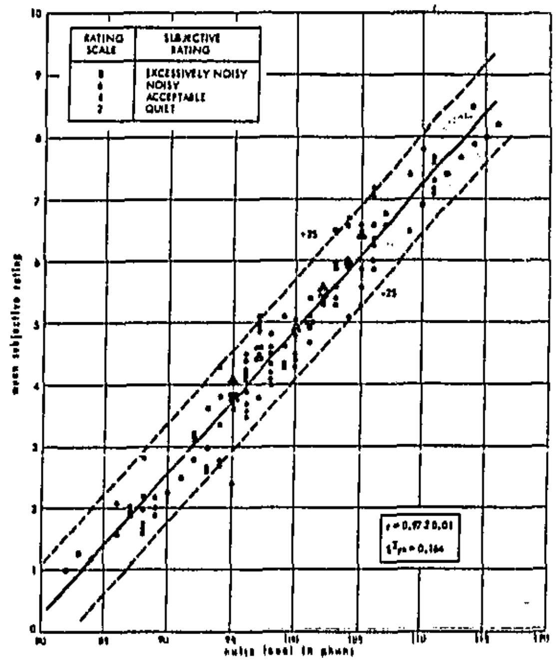


Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with perceived noise level in PNdB.

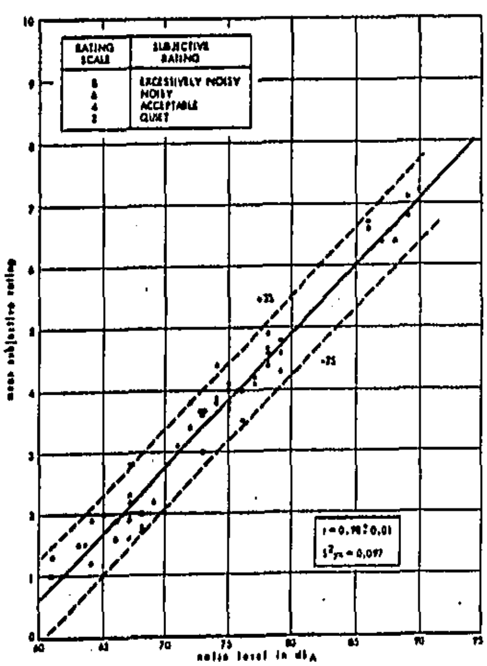
FIGURE 9



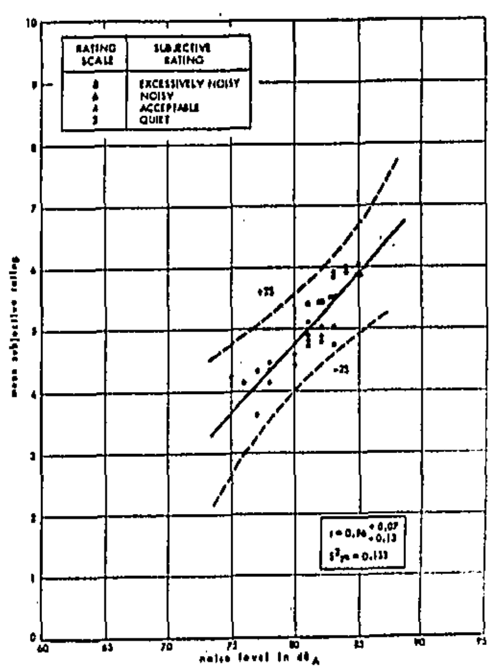
Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with loudness level (Stevens) in phons.



Correlation of subjective ratings of noise from all vehicles in the MIRA experiment with loudness level (Zwicker) in phons.

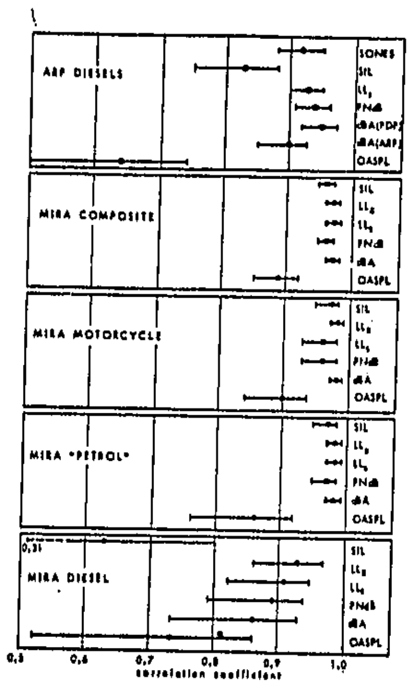


Correlation of subjective ratings of noise from gas-engined vehicles (petrol) in MIRA experiment with noise level in dBA.



Correlation of subjective ratings of noise from diesel-engined trucks in MIRA experiment with noise level in dBA.

FIGURE 10



Correlation coefficients and 2S confidence intervals for various measures of subjective reaction to vehicle noise.

Having seen how noise is measured and its probable effects on humans, we can now examine the methods in which transportation systems generate noise and the magnitude, dispersion and attenuation of the noise generated. For noise generation analysis, transportation systems can be divided into three classes: 1. rubber tired vehicles that travel on fixed right of ways (this would include automobiles, trucks and buses); 2. fixed rail transportation (subway, elevated and at grade trains); 3. aircraft.

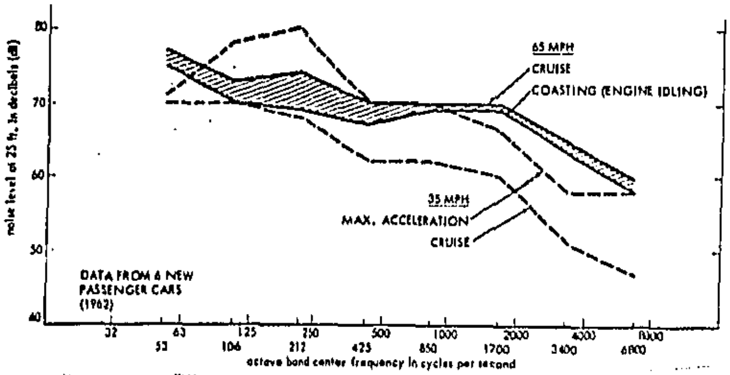
NOISE FROM INDIVIDUAL RUBBER TIRED VEHICLES[8]

Noise generation of an individual automobile will be considered first. Passenger cars make up the bulk of today's vehicles and as such are a large contributor to the overall noise pattern. Although trucks make up only a small percentage of vehicles, the type of noise they generate is usually quite loud and variable. Our analysis will treat each one separately.

There are two main mechanisms that produce noise in automobiles. They are the engine-exhaust system and the tire-roadway interaction. Under some operating conditions (e.g. full throttle), engine fan noise and carburetor intake noise are significant contributions to the overall noise generation.

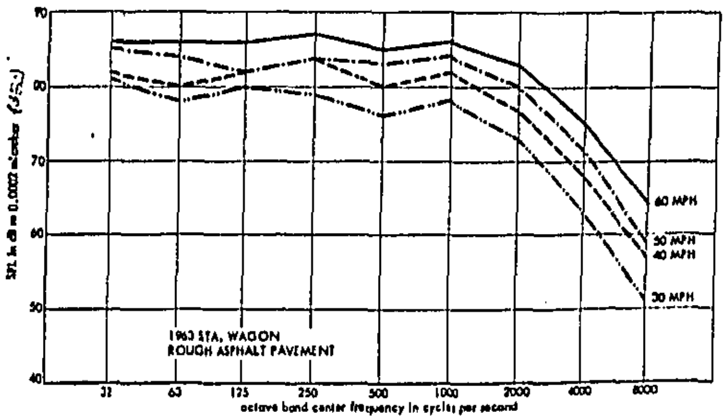
Field measurements showing the relationship between SPL and octave band frequency for a speed of 65 mph, under varied operating conditions is shown in Figure 11. The upper curve represents the road load curve (vehicle drive train engaged and maintaining a constant speed). The lower curve represents the noise generated in a coasting operation (engine at idle and power train disengaged). A second plot is made for an operating speed of 35 mph. In examining the graph for the 65 mph condition, it is interesting to note that there is a relatively narrow band of difference in SPL at high frequencies. This seems to indicate that a major contribution to the generated noise is produced by tire-roadway interaction. At lower frequencies the primary components of noise are the engine and exhaust system. For the 35 mph plots the relatively large band indicates that the engine and exhaust system noises dominate on acceleration. For the cruise condition the noise generated is probably an equal composite of engine exhaust and tire noise.

FIGURE 11
Contributions from Passenger Car Noise Sources



The noise generated by a motor vehicle is dependent upon its speed. A graph of the noise level-frequency band distribution as a function of various speeds is shown in Figure 12

FIGURE 12
Noise Spectra for a Passenger Car at Four Speeds



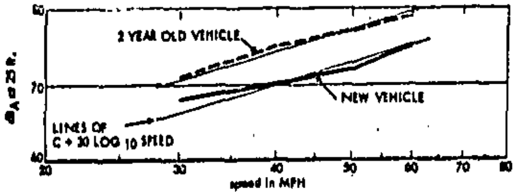
The noise spectra illustrate a consistent increase in each octave band for each increase in speed. The merging of the 40 mph and 50 mph curves at the lower frequency is probably due to a shift in spectra from engine-exhaust to tire roadway dominated.

Because the frequency spectra tend to retain the same shape over a series of speeds, the A weighted scale can be used to generalize the speed dependence of noise levels. The data plotted to a least squares fit, shows a high correlation to the theoretical concept that noise is proportional to power (power being proportional to vehicle speed cubed). Hence, the equation of the line relating speed and noise level in dBA would be:

$$L = C + 30 \log \text{Speed}$$

This relationship is shown below.

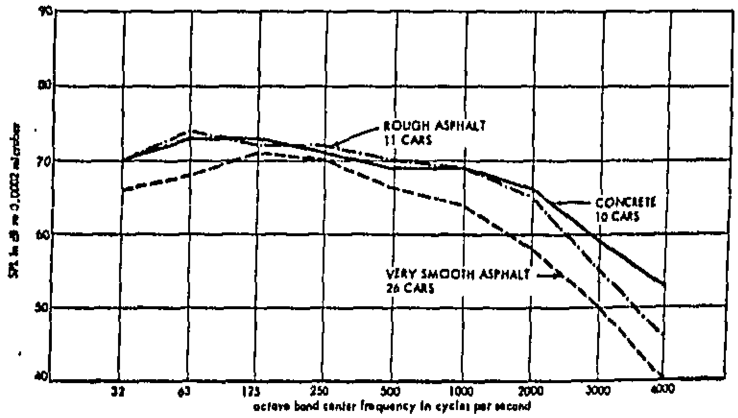
FIGURE 13



It is interesting to note that while both the new vehicle and the two year old vehicle fit the cube of speed relationship, the noise level for the older vehicle is higher. This is to be expected, as ther are variances in muffler design, tire condition and the general maintenance between the two vehicles. The variations from vehicle to vehicle will be taken into account as the general model is developed.

Noise generated by the tire-roadway interaction varies from one roadway type to another. As can be seen from the graph of Figure 14, rough pavements generate higher noise levels at the higher frequencies. The effect of tire-roadway interaction noise can be lessened by employing variations in tire tread design. Manufactures are attempting to design

FIGURE 14
Noise Spectra - Roadway Surface



a "quiet" tire, but no such tire is on the market today. The chief problem with the quiet designs to date is that they tend to be poor from the standpoint of traction and safety.

A Generalized Model of Automobile Noise

By weighting the various data available to them to reflect conditions felt to exist most often in pratice, and using the work of other researchers, Bolt, Beranek and Newman proposed the following generalized model for automobile noise:

$$L_{auto} = 50 - 20 \log d + 30 \log v$$

where: L_{auto} = SPL in dBA, d = distance in feet, and v = vehicle speed in mph

The generalized model equation expresses the noise level generated by an individual vehicle under normal operation in a free field, and is subject to the following constraints:

1. d must be greater than 25 feet.
2. d must be less than several hundred feet, as the generated noise is attenuated by the atmosphere in which it moves.
3. pavement roughness will allow L to vary from -5 for smooth pavements to +5 for rough pavements.

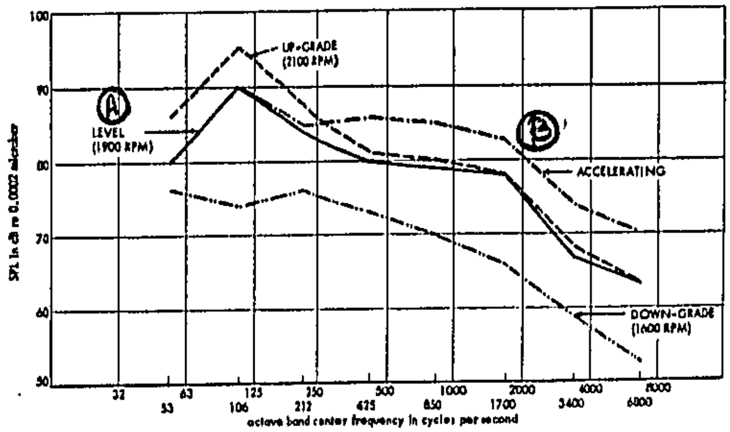
<u>Noise Levels of Trucks</u>

Trucks represent a relatively small portion of the vehicles on American highways. However, their contribution to the total noise environment is very important because the levels they generate are so much higher than passenger cars. A typical diesel powered truck will generate noise levels more than three times that of the passenger car. The typical level of a diesel truck is 18 dBA higher and for a gasoline powered truck, 8 to 10 dBA higher than an automobile.(7)

Buses show many of the same characteristics of noise generation by trucks, however, the noise levels produced by the bus tends to be somewhat lower. This is due primarily to their larger mufflers and fully enclosed engines. At highway speeds, an intercity bus produces noise levels in a range of 80 to 87 dBA at a distance of 50 feet in a free field.(7)

The principle noise source in the diesel truck is the engine exhaust system, which tends to dominate over the tire-roadway interaction. This can be seen from curve A of Figure 15. Noise levels produced by trucks are dependent upon the condition of operation. When a loaded truck is accelerating, the noise levels produced increase about 5 dBA. This is illustrated by curve B of Figure 15.

FIGURE 15
Noise Spectra Produced by a Loaded Truck-Three Modes



In the data presented to date, no clear cut relationship has been found to exist between noise level and truck speed. This is thought to be due to two factors: first, trucks tend to operate at relatively constant rpm, thus producing the same amount of acoustic power irregardless of speed and, speeds of trucks operating on highways in free flowing traffic tend to lie in a very close range.

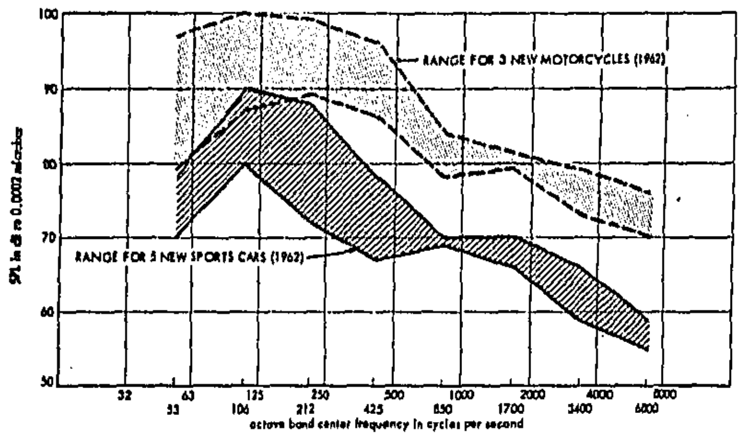
Analysis of a typical truck population seems to indicate that even though large diesels tend to be similar at various road speeds under cruising conditions, there are marked differences in both the spectrum shape and levels between them for conditions of acceleration, and on upgrades or downgrades. However, on the average, the 5 dBA increase in noise for an accelerating diesel seems to hold.

Noise Generation By Motorcycles And Sports Cars

Often cited as prime producers ofnoise pollution are motorcycles and sports cars. Generalized noise spectrum for both types of vehicles for a 65 mph cruise condition can bee seen in Figure 16. The reason for the higher noise levels is the relatively poor standards used in the manufacturing and design of muffling systems for these types of vehicles. Better and more stringent noise standards are need to curb the noise assult of these vehicles.

FIGURE 16

Noise Spectra for Sports Cars
and
Motorcycles



SIMULATION AND PREDICTION OF TRAFFIC NOISE[9]

Up until this point, the discussion of vehicle noise has been directed at the production of noise by individual vehicles acting unincumbered on a level roadway. Unfortunately, this condition is seldom encountered in highway planning, and consideration must be given to the many vehicles operating on roadways at the same time at various speeds, that is free flowing traffic (Analysis of interrupted flow, such as that encountered on arterial streets will be taken up in a later section).

Generally two approaches have been used to yield a quantitative description of noise generated by free flowing traffic:

1. Empirically derived models have been determined, using measured acoustical data obtained from actual traffic flows, and determining mathematical expressions that most nearly describe the observed noise levels as a function of several traffice flow parameters (e.g. speed, vehicle flow rates and observer distance to flow stream).

2. Analytical models derived from knowledge of the acoustical power generated by a typical individual vehicle. The model is derived by superposition of the noise sources along the roadway to constitute flow. Three techniques have been employed in this method:

    i. Assuming an equal distribution of vehicles along a roadway with an equal distribution of acoustic power between vehicles. Hence, the models is a continuous line source of noise with a known acoustic power per unit length.

ii. Assuming that each individual vehicle is a discrete source, and that vehicles are uniformly spaced along a hypothetical single lane equivalent roadway.

iii. Using Monte Carlo simulation methods and determining a statistical expectation of noise generated by randomly occuring flows of vehicles along a hypothetical single lane equivalent roadway.

In order to determine which model best describe the real noise generated by traffic operations, a number of requirements should be examined. First, noise measurements must be made with values that correspond to the actual human response to that noise. As discussed earlier, the dBA measurement produces the "best" fit to this standard. Secondly, the model should account for the statistical time variance in traffic noise. As a third requirement, the simulation model must take into account the variability of traffic noise generators (i.e. the vehicles that make up the traffic mix). As was discussed earlier, generally two distinct groups of vehicles make up the population of noise producers: automobiles and trucks.

An Empirically Derived Model

In 1968, a report was published by Johnson and Saunders in The Journal of Sound and Vibration entitled "Noise from Road Traffic". Using acoustic data measured at various roadsites, an empirical model was developed relating the measured values of noise distribution to traffic flow parameters. This model predicts the mean noise levels, L_{50} for given traffic conditions. Their results showed that at sufficiently low vehicle densities and/or at distances close to the roadway, individual vehicle noise is predominant. Along with this finding, a decrease of 6 dBA per a doubling of observer to roadway distance was found.

At higher densities or at greater distances from the roadway vehicles tend to blend together to form a line source of noise. It was observed that for a doubling of observer to roadway distance under the line source condition, the corresponding reduction in noise was only 3 dBA. This difference in noise reduction occurs when the observer distance from the roadway is greater than 1/2 the vehicle headway. The flow rate considered in this statistical model lies between the range of 400 to 2,250 vph. The expression for mean noise level is given by:

$$L_{50} = 3.5 + \log q - 10 \log D + 30 \log \bar{V}$$

where:

q = flow rate in vehicles per hour
D = observer distance to highway centerline
$\bar{V}$ = average vehicle speed

The data from which the above equation was derived was normalized for a vehicle mix that included 20% trucks. The variance of this expression is $\pm$ 1 dBA in a mix range of 0% to 40%. The speed range considered to accurately reflect the equation is from 33 mph to 55 mph. The constant in the expression is obtained by normalizing the values obtained to a speed of 40 mph. One criticism of the model is that the effect of truck mix on the L_{50} values does not agree with that observed to occur in the United States.

Another simulation model was developed by Galloway et al, of Bolt Beranek and Newman.[8] This model simulates the statistical distribution of noise produced by free flowing traffic on highways.

The model is a simulation of traffic flow using a computer. The analysis is made of a single lane of traffic with a vehicle spacing of various length, being a function of vehicle speed and flow rate. The traffic flow characteristics are expressed repeatedly for each lane in terms of flow, mean speed and percent trucks.

A simulation run on the computer provides a set of "n" noise spectra corresponding to the momentary noise sample at some instant in time. A summary value is also given by measurement in dBA. This snapshot of the traffic situation is then extended to another instant in time, to reflect the changing observer to vehicle distance that results from the flow of traffic. Histograms are then plotted to give the time distribution of noise levels expected from traffic flowing past the point, given the values of the flow employed in the computation. The result of such a computation for various roadway types is shown along with the actual observed field measurements in Figure 17, page 35.

A simplified analytical form of the model can be used for passenger cars on level highways at traffic flows above 1,000 vehicles per hour. The mean noise level (L_{50}) in dBA is given by the equation:

$$L_{50} = 10 \log [q \times 100/d] + 20 \log \bar{V}$$
$$= 10 \log q - 10 \log d + 20 \log \bar{V} + 20$$

where:
q = traffic volume flow rate (vehicles per hour)
d = distance in feet to the pseudo lane
$\bar{V}$ = average traffic speed in miles per hour

The effect of trucks in the vehicle mix can be determined by adding the values as given in Table 2 for the various percentages of trucks given.

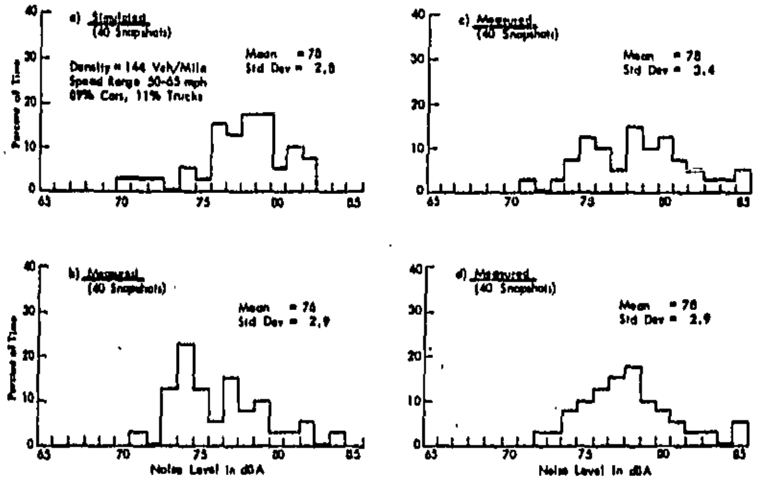
EFFECTS OF ADDING TRUCKS TO VEHICLE MIX

% OF TRUCKS IN TRAFFIC	ADDITIONAL dBA
0	0
2.5	1
5	2
10	4
20	8

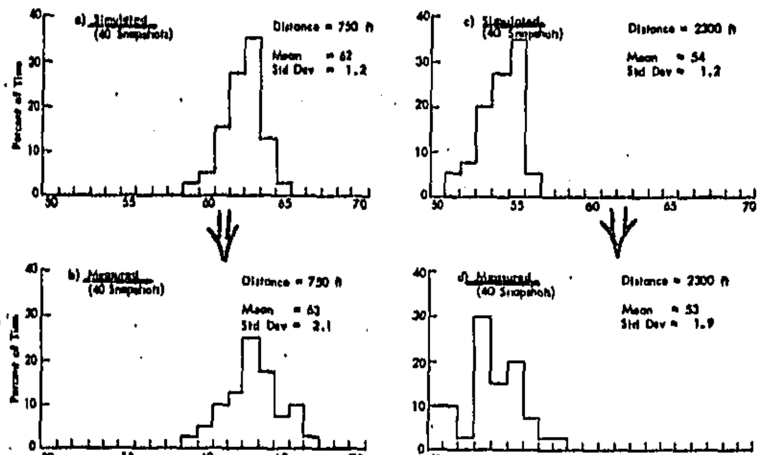
Calculations using the simplified form are expected to be within 2 dBA of that obtained through the use of the more detailed computer simulation.

FIGURE 17

Comparison of Distributions of Simulated and Measured Noise Levels



. *Comparison of distributions of simulated and measured noise levels in dBA from an 8-lane freeway, for a distance of 50 ft from the edge of the nearest lane.*



. *Comparison of distributions of simulated and measured noise levels in dBA from an 8-lane freeway, for distances of 750 ft and 2,300 ft from the edge of the nearest lane.*

Results of the computer simulation technique are shown in Figures 18 and 19, page 37. The density of vehicles on the roadway can be determined by use of the nomogram shown in Figure 20, page 38.

As an example, the value obtained by the simplified method for q = 2,000 vph, $\bar{V}$ = 50 mph, d = 100 ft.

$$L_{50} = 10 \log 2{,}000 + 10 \log 100 + 20 \log 50 + 20$$
$$= \underline{67 \text{ dBA}}$$

If we use the figures given by Galloway for the same conditions, the value of L_{50} taken off Figure 18 is approximately 65 dBA.

Using the model equation given by Johnson and Saunders for the same conditions:

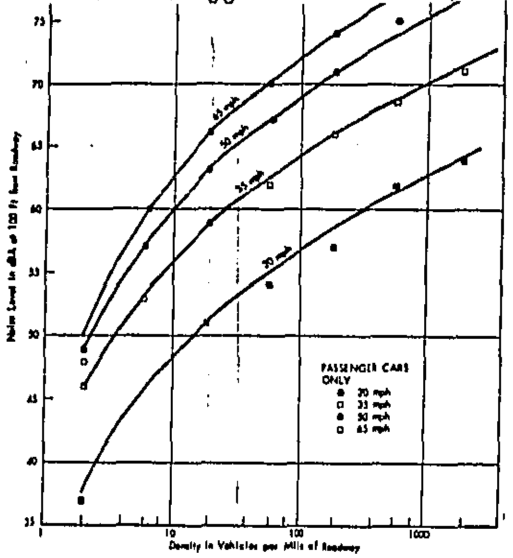
$$L_{50} = 3.5 + 10 \log 2{,}000 - 10 \log 100 + 30 \log 50$$
$$= 67 \text{ dBA}$$

The various computed values for the conditions given are within a very close range. In summary:

Johnson and Saunders Simulation	67 dBA
Galloway Simplified Procedure	67 dBA
Galloway Computer Relationship	65 dBA

FIGURE 18

Estimation of L_{50} for Various Speeds:



Estimation of L_{50} for Various Distances:

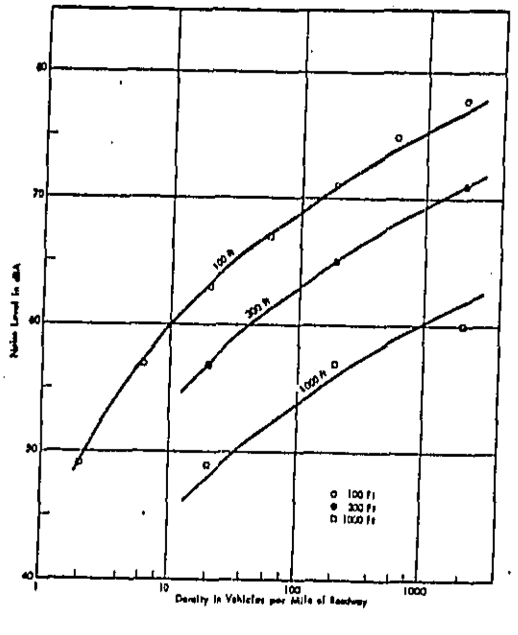
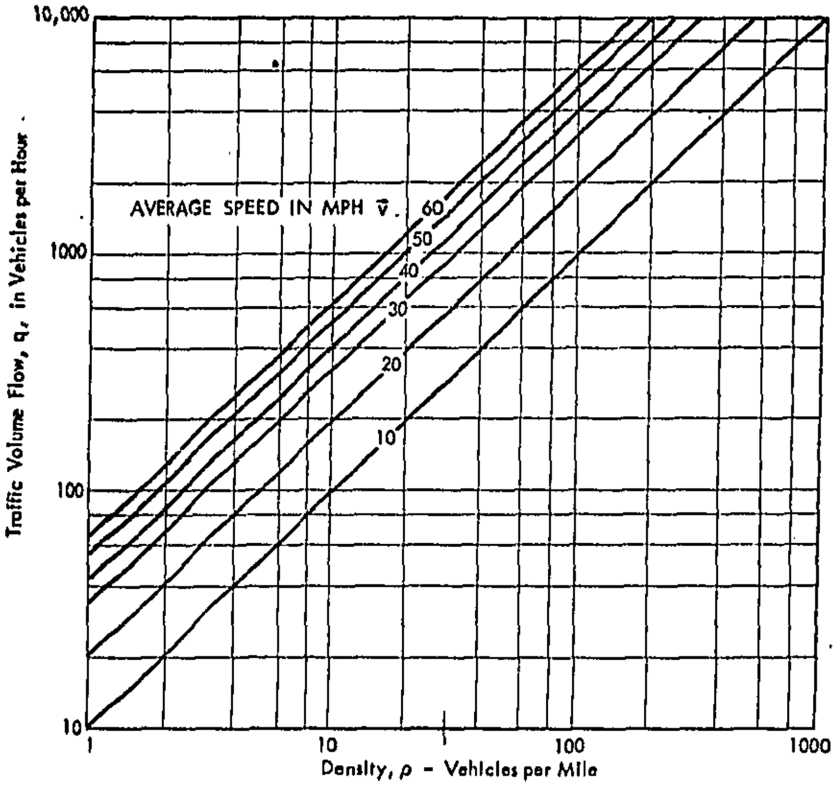


FIGURE 20

Traffic Flow vs. Density



Analytical Models

Attempts have been made by various studies to predict the noise levels generated by free flowing traffic knowing the amount of acoustic power generated by a single vehicle. One type assumes that each vehicle is a constant source of noise power, and that the total noise produced by the traffic flow can be determined by assuming the noise is generated as a continuous line source. The other method employs a summing technique of discrete sources along a roadway, each source being of constant acoustic power.

While the methods used are correct from a theoretical standpoint, there are a number of drawbacks that make their use as predictive tools difficult. First, vehicle flow is assumed to be uniform, with equal headways. This is not correct. Secondly, the absorption of sound by the atmosphere is not considered. Thirdly, the use of a single lane equivalent roadway, for multilane configurations in the derivation of the model is not justified, unless the cumulative effect of each lane could be determined. As a fourth drawback to the analytical models is that they do not allow for the inclusion of the different types of vehicles into a mix that is characteristic of real traffic flow. Fifthly, the analytical models used for traffic noise prediction cannot allow for the statistical distribution of noise as a function of time.

Because of these drawbacks, a detailed description of the analytical models is not included in this report.

The Design Guide Model

In their effort to give transportation planners and highway engineers a "cookbook" method for predicting traffic noise levels, Bolt, Beranek and Newman modified the predictive models to accurately reflect the actual observed noise production on highways with free flowing traffic. The predictive model used in Highway Noise: A Design Guide for Highway Engineers employs the following equation for mean noise levels from a homogeneous population of passengercars:

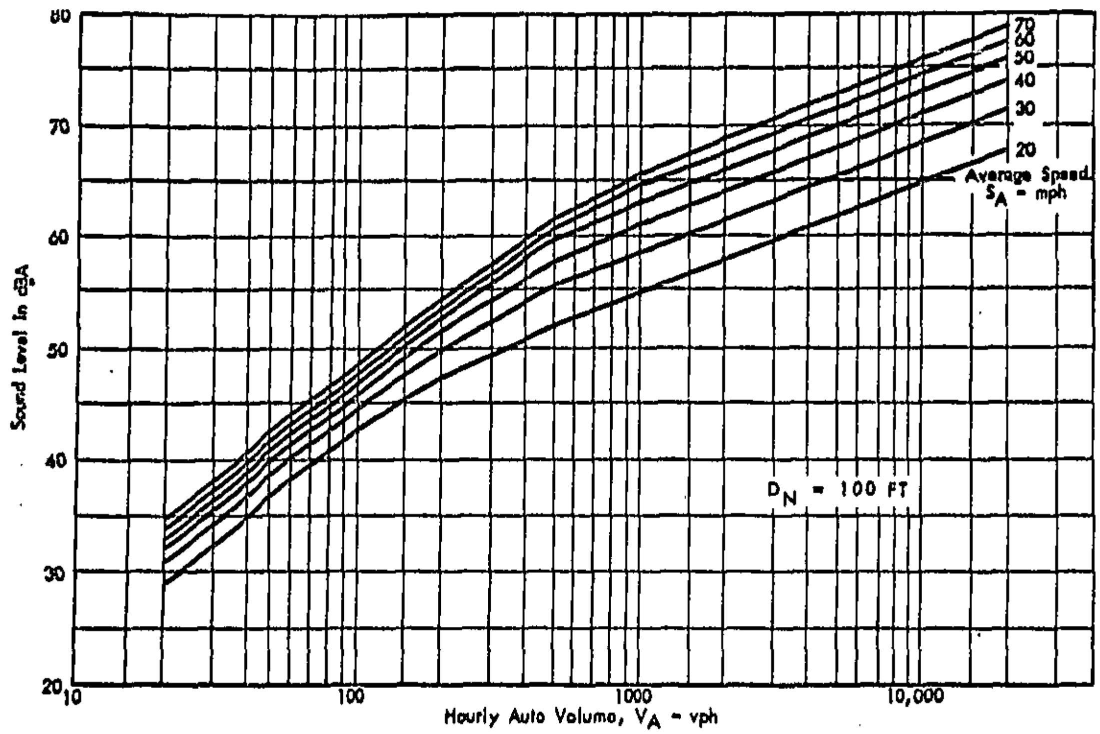
$$L_{50} = 10 \log q - 10 \log S_A - 15 \log D + 10 \log[\tanh (1.19 \times 10^{-3} qD/S_A)] + 29 \text{ dBA}$$

This relationship is plotted for various values of average auto speed (S_A) in Figure 21, page 41.

The analysis of trucks in the vehicle mix is handled by treating them as a seperate population of noise producers, and adding their noise contribution to that determined for the passenger cars. The equation for mean truck noise level is:

$$L_{50} = 10 \log q_t - 10 \log S_t - 15 \log D + 10 \log [\tanh (1.19 \times 10^{-3} q_t D/S_t] + 95 \text{ dBA}$$

FIGURE 21
L_{50} For Automobiles
at
Various Volumes & Speeds



The relationship for various values of S_t is shown in Figure 22, page 43. The apparent paradox of decreasing noise levels with increasing truck speed is due to the fact that truck noise levels are dependent on truck density only. With increasing truck speed at a constant volume of flow, density will decrease.

<u>The Concept of an "Equivalent Lane"</u>

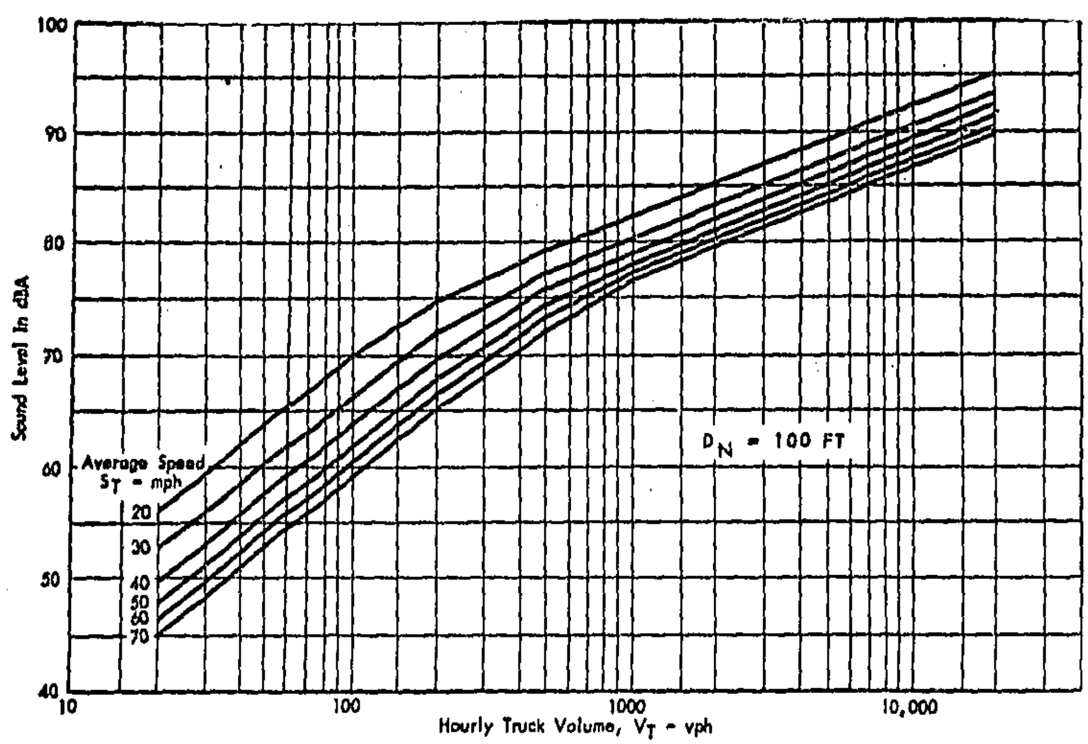
The assumption has been made up to this point that traffic is located at a fixed distance (D) from the observation point. In real life situations, the roadway is more often than not made up of many lanes, each at a different distance from the observer. The width of the roadway also varies.

This obstacle is overcome by the use of the "single lane equivalent" roadway. The equivalent lane is defined to be the imaginary lane on which the total volume flow travels, in order to be <u>acoustically equivalent</u> to the multilane configuration. The observer distance to this lane can be assumed to be equal to the geometric mean of the distance from the observer to the nearest and furthest lane center lines. Expressed mathematically, the equivalent lane distance (D_E) is found by:

$$D_E = [\, D_N D_F]^{1/2}$$

FIGURE 22

L_{50} for Trucks
at
Various Volumes and Speeds



Adjustments for the observer to near lane distance, D_N and the roadway width can then be made to the L_{50} levels for both the automobiles and trucks. This distance adjustment can be determined from Figure 23.

Analysis of the mean noise levels of traffic cannot be considered an adequate discription of the actual noise produced by the traffic flow. Some measurement of the peak level of noise should also be considered. In order to indicate the peak noise the L_{10} level is determined (L_{10} is that level that is exceeded in time only 10 percent of that time). Analysis of the statistical distributions of noise levels for various flow conditions i n the various predicitve models is summarized in Figure 24. Here, the difference in the 10 percent and 50 percent level is graphed as a function of the quantity qD/S, which allows for determination of noise level spread for varying densities and/or observer distances. The selection of the design curve was determined so as to provide the best fit among the various simulation methods. This design curve applies for any homogeneous population of noise sources, hence it can be used for determining the L_{10} levels for both the automobile and truck populations.

FIGURE 23

OBSERVER - EQUIVALENT LANE DISTANCE

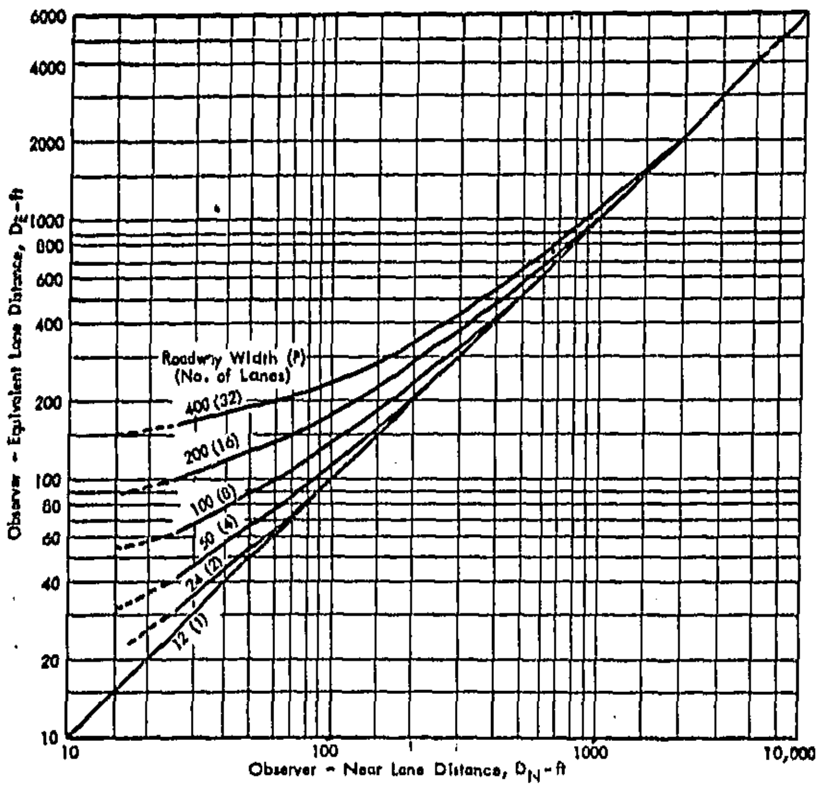
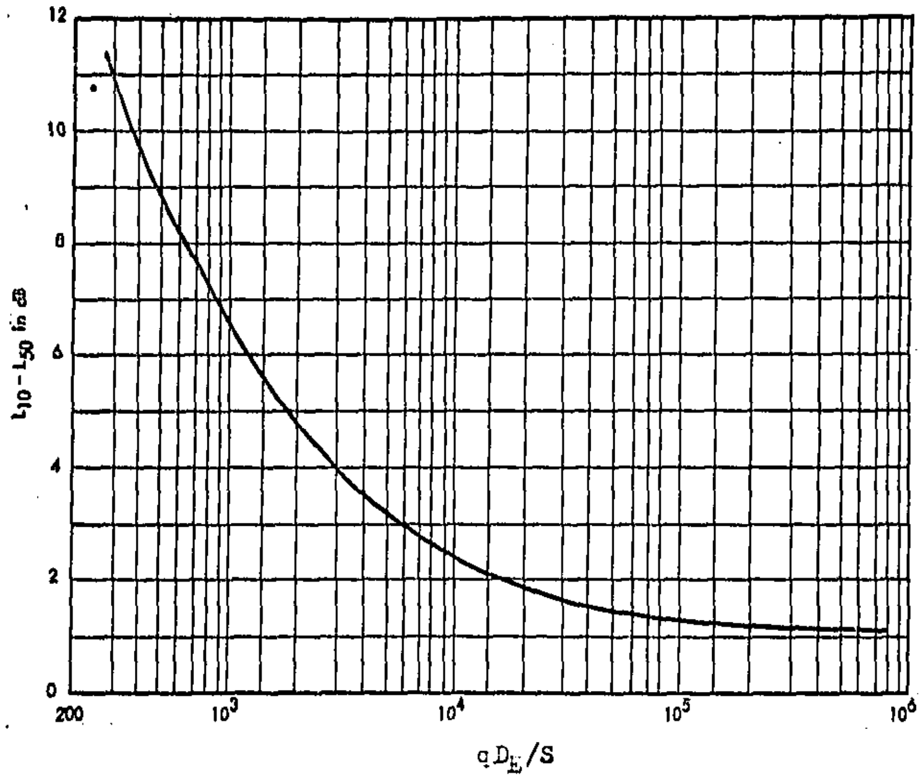


FIGURE 24

Derivation of $L_{10} - L_{50}$

for a

Homogeneous Traffic Population



The methodology for noise level prediction of an idealized roadway can now be summarized:

STEP 1:

Based on the total volume flow and mix parameters, establish the seperate volume flows for automobiles and heavy trucks, and their respective average speeds.

STEP 2:

The L_{50} levels at the 100 foot reference distance for auto and trucks are found respectively in Figures 21 and 22. All the traffic is assumed concentrated on the near highway lane, and the observation distance from this lane is assumed to be the 100 foot reference.

STEP 3:

Using Figure 23, obtain the correction to allow for the desired observation near lane distance and the real number of highway lanes This correction is applied to the L_{50} levels for the truck and auto population.

STEP 4:

Compute the single lane equivalent distance to the highway, and combine this with the traffic volume and speed parameters to obtain from Figure 24 the adjustment needed to compute the L_{10} level for both the auto and truck traffic.

STEP 5:

Using the usual technique of decibel addition, as explained on page 5 of this report, determine the 50% and 10% noise levels of the composite vehicle population.

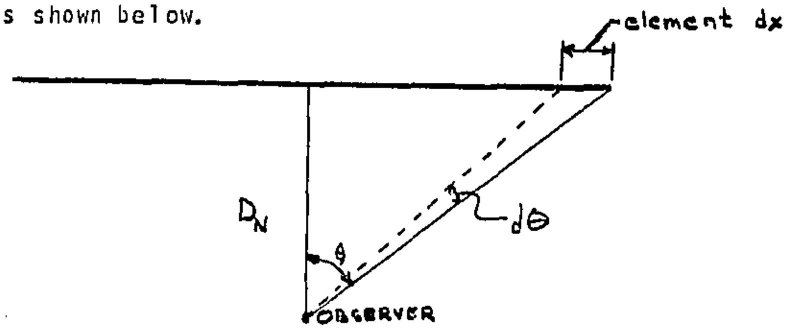
The basic methodology presented above assumes a straight infinitely long roadway, lying at grade on a flat terrain.

The only variables in the model account for flow parameters, roadway widths and observer distance. In reality, the model applies to very few situations.

In order to take into account such things as variations in alignment (both horizontial and verticle), and gradients, adjustments must be made to this model. Complex road configurations are broken down into elements of constant characteristics. Noise levels are analyzed according to the rules developed in the basic model for each element and then adjusted according to the geometry of the element.

Element Adjustment

The contribution of afinite element of roadway to the total noise environment is directly and linearily a function of the angle (θ) subtended at the observer by the roadway element, as shown below.



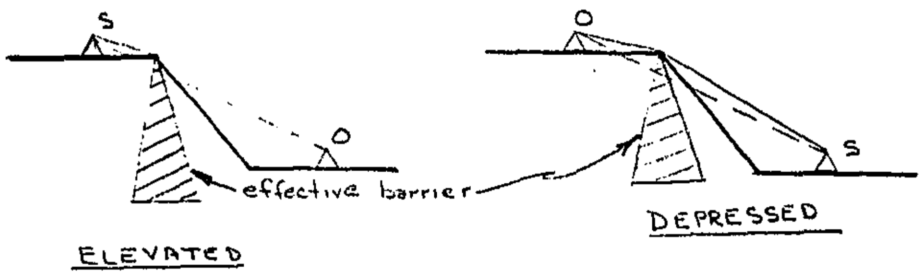
Gradient Adjustment

The gradient adjustment is necessary due to the significant increase in truck noise with an increase in the gradient (the gradient has little effect on automobile noise production at constant speed). Adjustments are made on the following basis:

Percent Gradient	Adjustment
Less than 2	0
3 to 4	+2
5 to 6	+3
Greater than 7	+5

Verticle Configuration Adjustments

Adjustments to the basic model must also be made to account for the elevated and depressed roadway. The effect of an elevated or depressed roadway configuration is the production of an acoustic barrier to noise travel as shown below



The basic principle involved is that of sound diffraction: sound energy spills over the barrier in the shadow zone on the observer side. The diffracted sound energy at the observer location is less than the energy that would reach the location if the noise followed a straight path.

Under the assumptions stated below, the attenuation of the barrier is expressed by the linearised design curve shown in Figure 25:

1. The design curve should be applicable to a lane of traffic as well as single vehicles.

2. All the traffic is assumed to be traveling on the single equivalent lane.

3. The effective wavelength of traffic noise produces attenuation effects which are numerically equal to those produced for a sound of 500 Hz.

4. Auto noise sources are located at or near the roadway. Truck noise sources are located effectively at a distance between the roadway and the top of the exhaust stack.

Although these concepts have not been subjected to rigorous field studies, the theoretical analysis done on this subject would appear to make them reasonable.

FIGURE 25
Attenuation by Acoustic Shielding

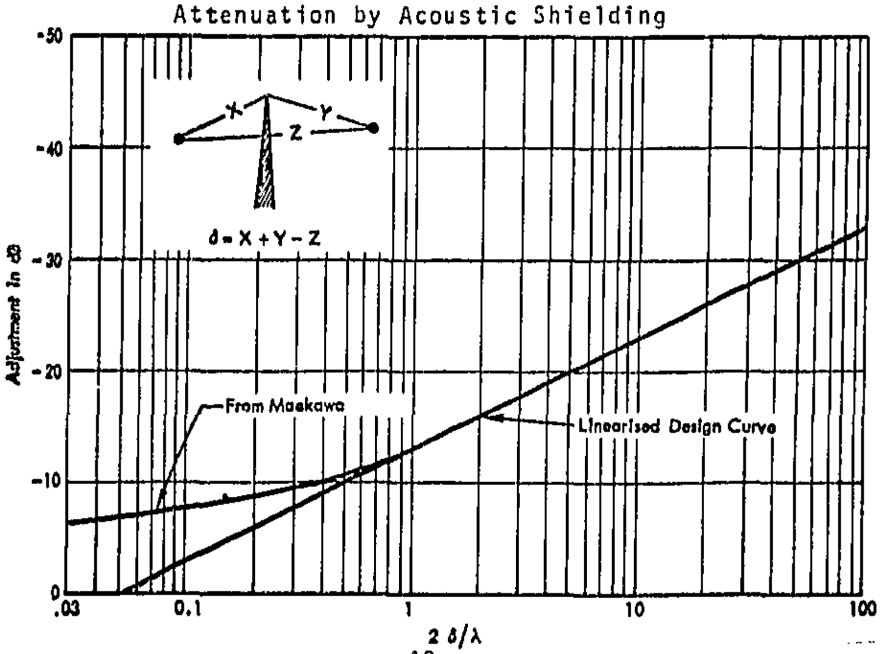


Figure. 26 shows relationships that have been developed on the basis of the linearised design curve for adjustments to the basic model in regard to elevated or depressed configurations. The curves given are for the noise levels produced by automobiles <u>only</u>. Truck noise attenuation due to roadway configuration is assumed to be 5 dBA less.

<u>Adjustments for Barriers and Structures</u>

The attenuation effects of a solid acoustically opaque barrier is due to the same principle of noise difraction as discussed in the preceding section. On the basis of the design curve, attenuation values for barriers are given in Figure 27.

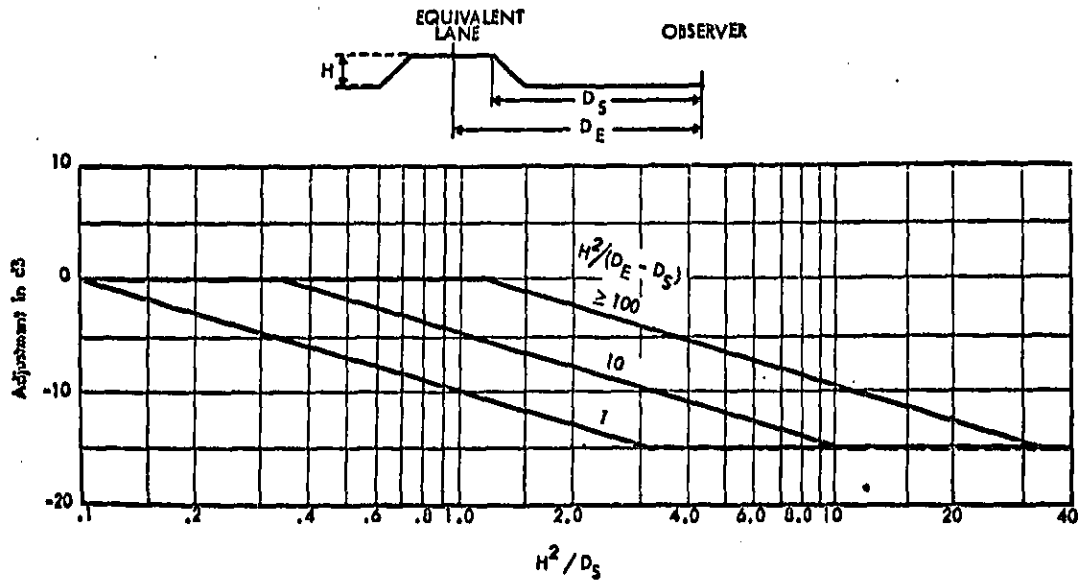
When buildings or structures interupt the sound path between the observer and source, there is significant shielding effects. Although no precise measurements are available in regard to this shielding effect, typical values of 3 to 5 dBA reductions per row of structures can be used, up to the first two or three rows of structures (after this, the sound penetration appears to remain relatively constant).

<u>Adjustments for Landscaping</u>

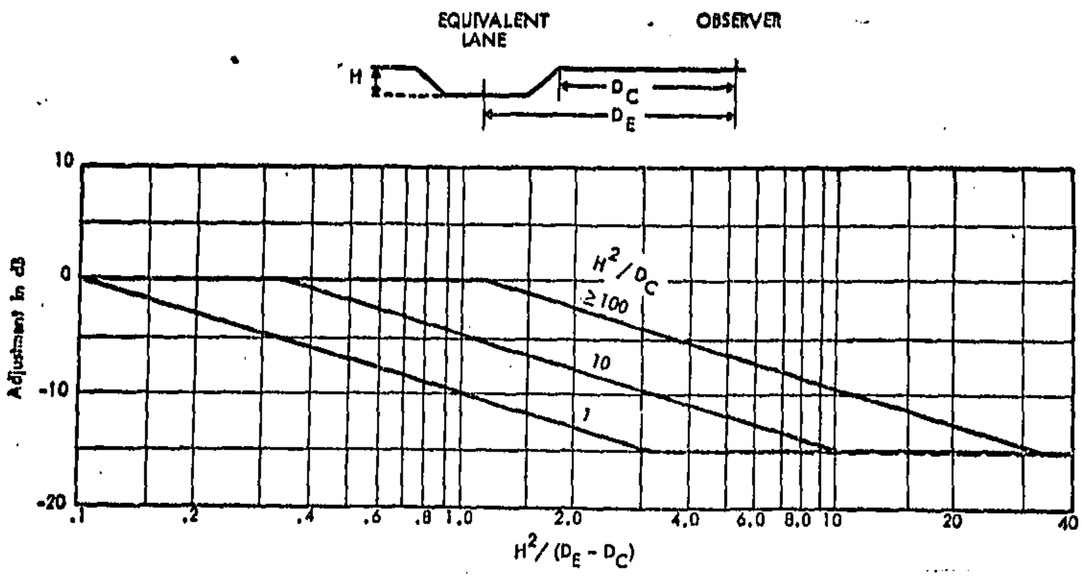
Landscaping has little influence on the propagation of

FIGURE 26

Adjustments for Elevated and Depressed Roadways



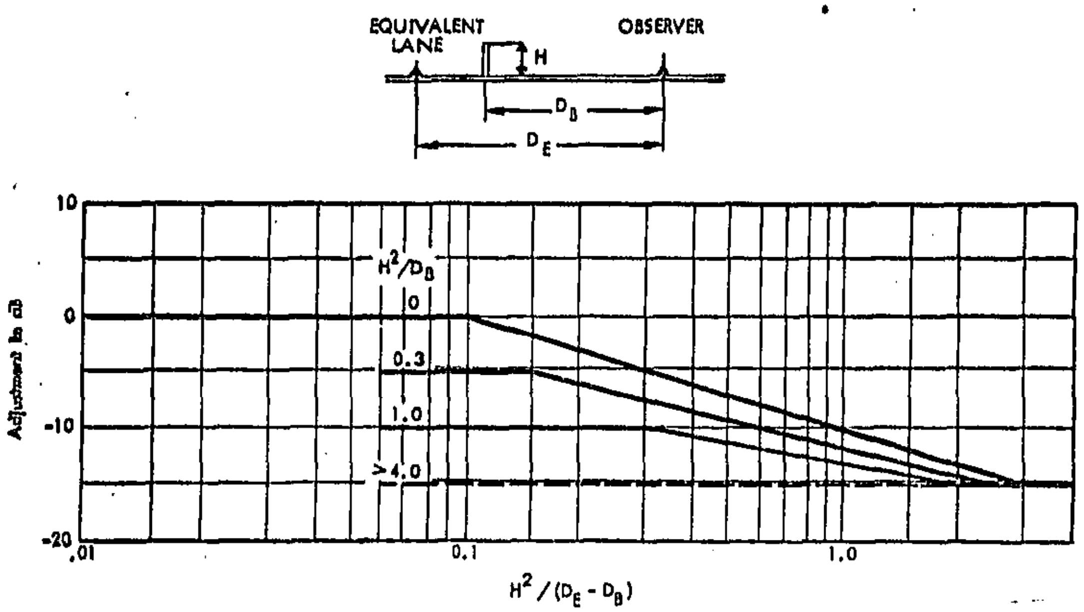
Adjustment for elevated roadway.



Adjustment for depressed roadway.

FIGURE 27

Adjustments for Acoustic Barriers



traffic noise. In general, the effects of roadside plantings can be considered to be psychological, removing the offending noise source from view. In general, a desing value of 5 dBA for every 100 feet of planting depth can be used, if the trees are at least 15 feet tall and sufficiently dense so that no visual path between the observer and source exists.

A SUMMARY OF THE DESIGN GUIDE METHOD FOR TRAFFIC NOISE PREDICTION

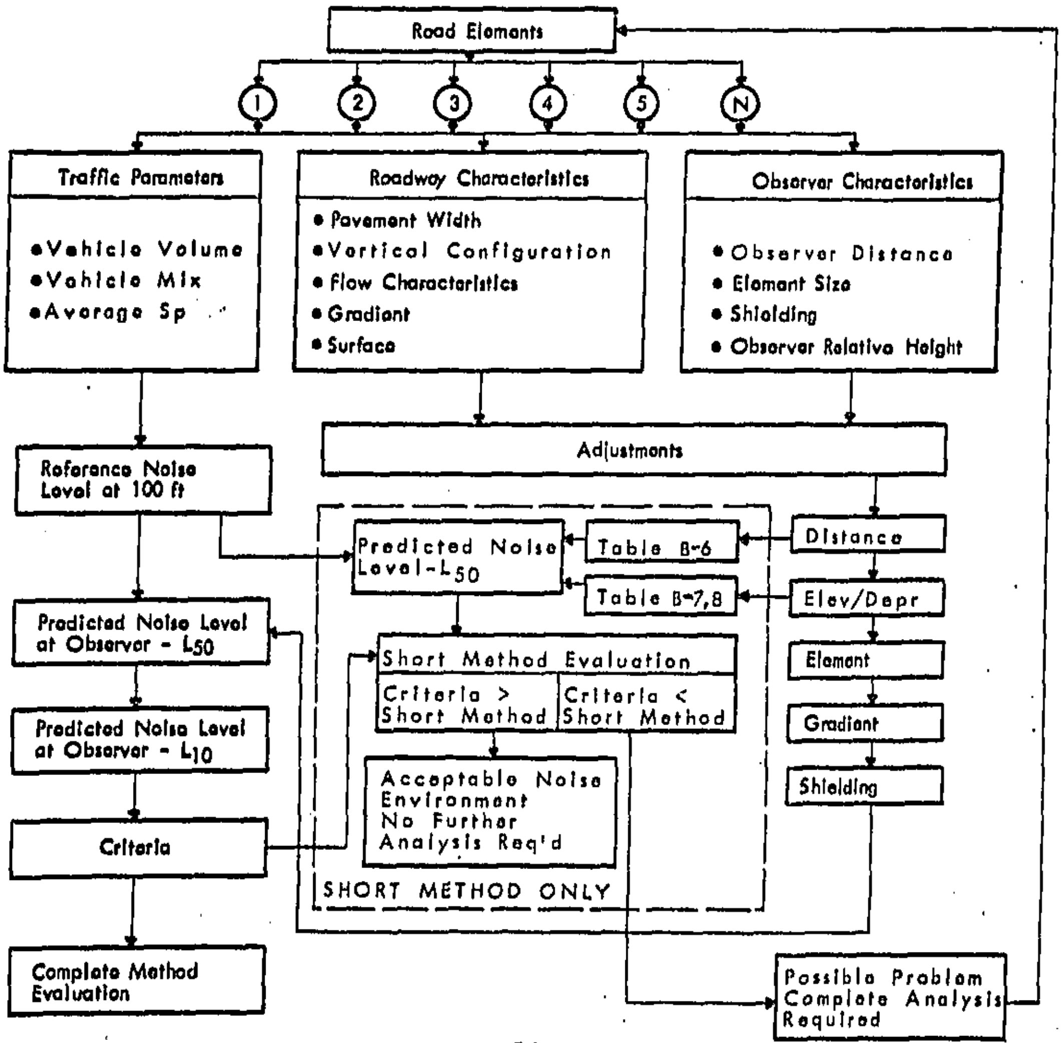
This section is intended to summarize the total methodology of traffic noise prediction as presented in the Design Guide.(9) Actual computational instructions are not given, as it is assumed that the interested reader will procure a copy of the manual to aid him in his particular noise prediction problem.

Refering to Figure 28, a flow chart is presented to represent the methodology of noise level prediction.

Two methods are used to predict highway noise levels. The short method is intended to render a quick calculation of probable noiselevels to indicate areas that may be noise sensitive. After these potentially troublesome areas are identified, the complete analysis can be carried out to yield a more precise value, and to analyze any noise abatement procedures applied to the design of the roadway.

FIGURE 28

DESIGN GUIDE METHODOLOGY
FOR
TRAFFIC NOISE PREDICTION



The use of the Design Guide method requires identification of roadway elements with constant geometric characteristics. Each element that is identified is then described by a series of parameters. The parameters required for utilization of the method can be grouped as follows:

I. Traffic Parameters

vehicle volume in vehicles per hour
vehicle mix (percent trucks)
average speeds for autos and trucks

II. Roadway Characteristics - define the geometry of the element with regard to its surroundings. Items included:

pavement width (not including emergency lanes)
verticle configuration (elevated or depressed)
flow characteristics (any flow interuptions imposed by the design of the road)
gradients greater than 2%
surface roughness of the pavement

III. Observer Characteristics - to describe the location of the roadway element with respect to the observer to account for attenuation;

perpendicular distance to near lane
element size (defined by the angle subtended at the observer)
shielding (describe all acoustical barriers between the observer and road element).
observer relative height (describe the verticle position of the observer with regard to the road element).

Once allthese parameters have been identified for each element, the reference level can be determined for autos and trucks. Adjustments are then made to the reference levels. They are then added logrithimically, and compared with the design criteria. As can be seen from the Flow Chart of

Figure 28, the short method makes adjustments for observer distance and verticle configuration only. If the L_{50} level as computed is greater than the established criteria, a complete analysis is made, and any abatement procedure considered feasible is analyzed. The topic of noise criteria is considered in the next section.

SELECTION OF NOISE CRITERIA FOR SURFACE TRANSPORTATION

As was seen from the noise prediction methodology, the predicted noise level is compared to a criteria-the standard of alowable noise levels. This section examines what the criteria are and how they were derived.

The letter of transmittal for the Noise Standards and Procedures issued by the Federal Highway Administration states in part:

> "The design noise levels in the standards represent a balancing of that which may be desirable and that which may be achievable. Consequently, noise impacts can occur even though the design noise levels are acheived. ...the values should be viewed as a maximum..."

Clearly, some tradeoff has been made between the incremental benefit of additional noise abatement and the additional cost involved. But the question of how the design values were obtained is not answered.

The principle consideration in the establishment of criteria should be the response of humans to the noise criteria levels selected. To reflect this consideration, the criteria should be based upon concern for the following:(9)

1. Relation of highway generated noise to the ambient level without the highway source.
2. Task interference associated with sleep, speech, learning and other on-going activities.
3. General annoyance or the subjective dissatisfaction wit the noise environment.

Research into noise levels that tend to illict response by the general public has been done by a number of researchers. From the studies conducted it was found that annoyance with traffic noise generally was absent at levels below 70 dBA.(15) The trend of the public in reaction to noise levels of the ambient are shown in Figure 29.

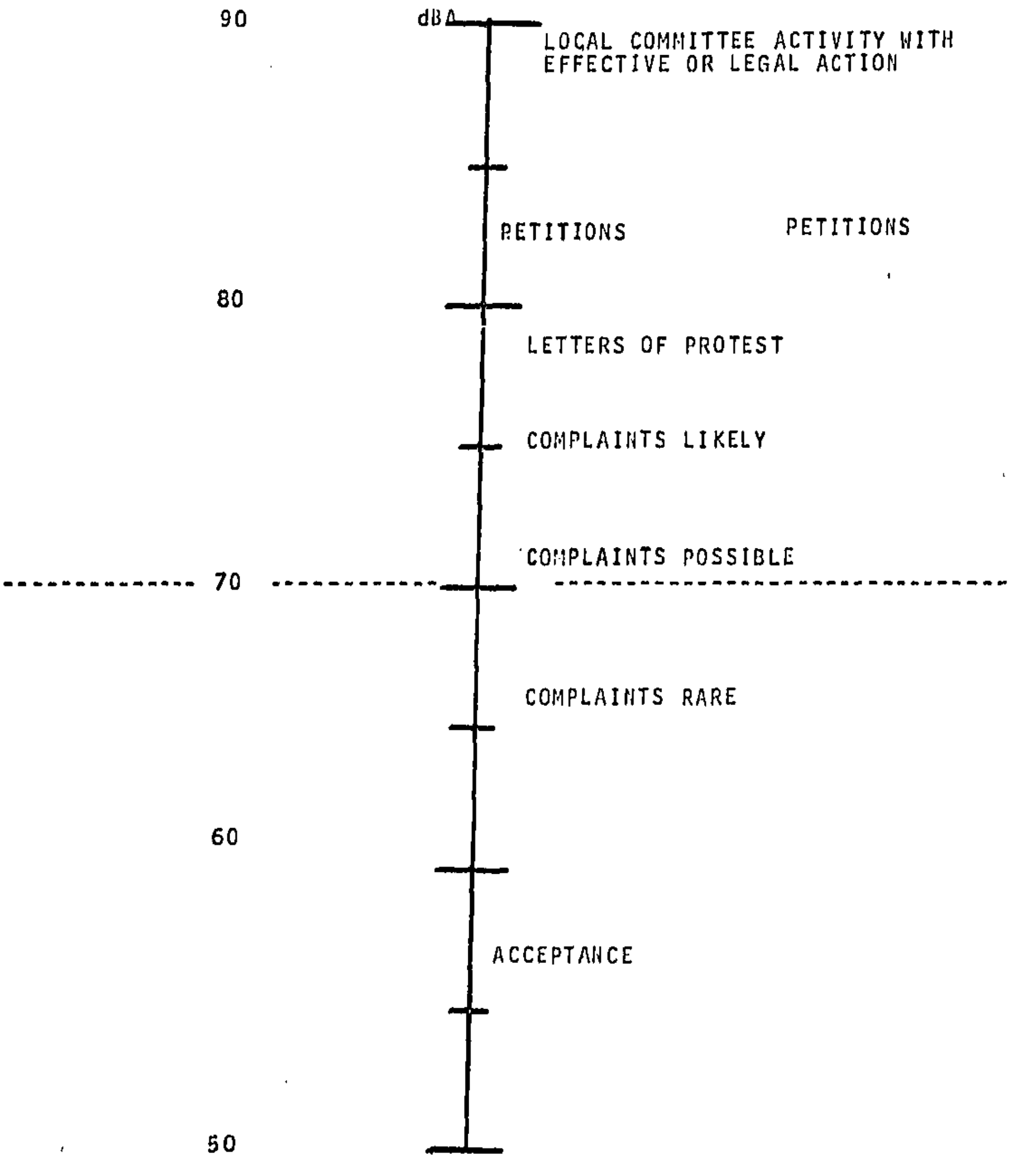
Conclusions as to the numerical criteria to use in design purposes as proposed by the Design Guide (9) are shown below;

RECOMMENDED DESIGN CRITERIA

OBSERVER CATEGORY	STRUCTURE	•	L_{50} (dBA)		L_{10} (dBA)	
			DAY	NIGHT	DAY	NIGHT
1	Residences	Inside*	45	40	51	46
2	Residences	Outside*	50	45	56	51
3	Schools	Inside*	40	40	46	46
4	Schools	Outside*	55	—	61	—
5	Churches	Inside	35	35	41	41
6	Hospitals,	Inside	40	35	46	41
7	convalescent homes	Outside	50	45	56	51
8	Offices:					
	Stenographic	Inside	50	50	56	56
	Private	Inside	40	40	46	46
9	Theaters:					
	Movies	Inside	40	40	46	46
	Legitimate	Inside	30	30	36	36
10	Hotels, motels	Inside	50	45	56	51

* Either inside or outside design criteria can be used, depending on the utility being evaluated.

FIGURE 29



PUBLIC REACTION AND NOISE LEVELS

The criteria presented by the Guide reflect concern for task performance and existing land use (being derived in part from analysis of speech interference), and considerations of ambient levels that would exist if the proposed roadway were not to be built.

COMPARISON OF THE FHWA AND GUIDE CRITERIA

Below in tabular form is a comparison of the Federal Highway Administration's noise standards and those presented in the Desing Guide. The Federal Highway Administration's Policy and Procedure Memorandum 90 - 2, from which the standards are taken is reproduced in this report in Appendix A.

STRUCTURE TYPE	FHWA L_{10}	Design Guide L_{10}
Residence (interior)	55 dBA	51 dBA*, 45 dBA**
Residence (exterior)	70 dBA***	56 dBA*, 51 dBA**
Schools (interior)	55 dBA	46 dBA*
Schools (exterior)	70 dBA***	61 dBA*
Hospitals (interior)	55 dBA	46 dBA, 41 dBA**
Hospitals (exterior)	70 dBA	56 dBA*, 51 dBA***

*DAY **NIGHT ***Varies with building construction in a range between 90 dBA to 65 dBA to meet the 55 dBA interior criteria.

The Federal Department of Housing and Urban Development Noise Criteria, reproduced in this report as Appendix B, specifies maximum noise levels and durations for various hours of the day, and at specific locations in housing. It should be noted that the FHWA criteria and the HUD criteria are not the same. Here a conflict of interest exists. It seems that noise levels in the residences that need no HUD approval can be greater than noise levels in HUD approved housing. A redefinition of the HUD standards that would make them compatable with noise analysis techniques for urban freeways would seem to be in order.

THE FEDERAL HIGHWAY ADMINISTRATION NOISE PREDICTION METHOD

In its Manual for Highway Noise Prediction FHWA presents two methods for prediction of highway noise levels The first method is a "pen and ruler" method employing a nomograph for noise estimates. The second, more refined method uses a computer program technique for a more accurate and complex analysis of the noise environment. A listing of the computer program can be found in Appendix C of this report. Both the nomograph and the computer program employ the following simplyifing assumptions:

1. free flowing traffic
2. uniform standard atmosphere
3. All noise sources are assumed to be incoherent, and can be added without consideration of possible phase relationships.
4. Noise sources are omnidirectional

5. first order approximations are used in procedures to represent ground cover effects of attenuation. In essence, this means that the attenuation effects of smooth surfaces such as dirt and relatively short grass are the only things considered. However, in the computerized model, there is an allowance for trees and shrubs.
6. The basic computational scheme employed calculates the mean energy level of noise, notthe median level of sound (L_{50}), and then is related to the L_{10} level of noise, per the criteria of the Federal standards.

The Approximate Nomographic Method

The nomograph of Figure 30 consists of a set of calibrated scales for vehicle speed, percent trucks, vehicle volume and distance fromt he roadway. The use of the nomograph is illustrated by an example.

Parameters in the problem include:

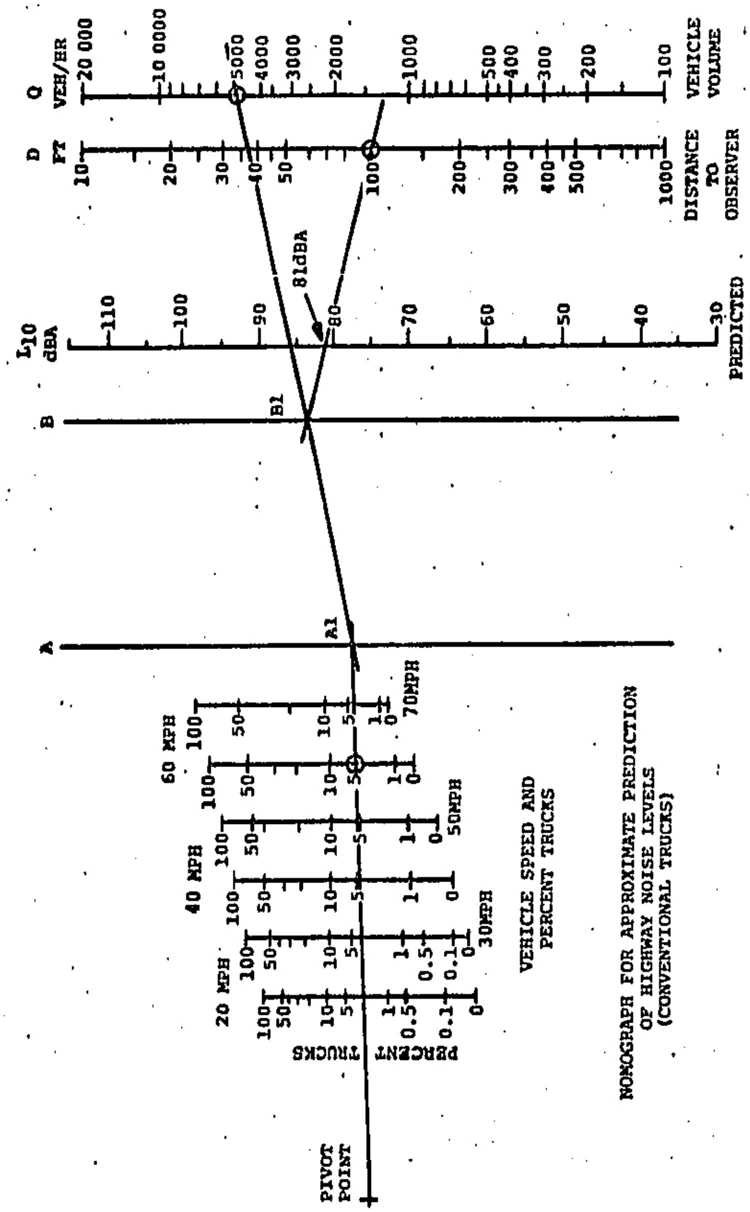
q = 5,000 vehicles per hour
V = 60 miles per hour
5% truck type vehicles
Roadway to observer distance (effective) = 100 ft.

The solution is shown as Figure 31. Starting from the left pivot point, an isopleth is drawn through the "5% trucks" on the 60 mph scale. The point at which it intersects the line A is designated a pivot point A1. An isopleth is then extended from point A1 through "5,000 vph" on the Q scale the in tersection of it with line B being designated as point B1. A second isopleth is drawn from B1 through 100 feet on the D scale. The resulting L_{10} level is read on the intersection point of this isopleth with the L_{10} scale.

FIGURE 30

Nomograph for Approximate Prediction of Highway Noise Levels (Conventional Trucks).

FIGURE 31



Nomograph for Approximate Prediction of Highway Noise Levels (Conventional Trucks).

In this case the L_{10} level is estimated to be 81 dBA. The manual emphasizes the fact that the method used here is an approximation, used to determine areas where the noise standards would not be met. After this is completed an analysis of the location is made by the computer technique.

In the previous example,worked out by the methods suggested by Johnson and Saunders, Galloway and the Design Guide, an average value of 67 dBA was obtained. In that problem, q = 2,000 vph, v = 50mph, and D_E=100 feet. The FHWA nomograph yields a value of approximately 74 dBA for these parameters.

The Computer Prediction Model

As documentation of the computer method used for noise analysis arrived to late in the term for its incorporation into this report, the simulation problem originally planed to be included inthis report is absent. A short description of the methodology is given.

Five blocks of data are required for the computer simulation and prediction. The first data block required is known as the initalization parameters, which include data on receiver relative height, number of band center frequencies used in noise analysis, standard deviation of of noise levels for truck and autos, and source height adjustments for the trucks. The next data block required are the traffic and road parameters which account for the physical layout of the roadway in a three dimensional space and the character of the vehicle mix. Barrier and Ground cover parameters are then inputed to define the attenuation effects of the surrounding terrain and any natural or man made barriers to noise transmission. Receiver data is then inputed, to determine the relative horizontial and verticle position with respect to the roadway. The program allows for redefining and running. multiple problems.

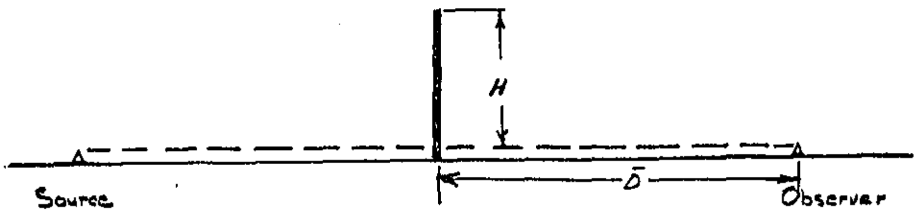
The computer prints out the L_{10} level for the specified conditions. It can also be programed to print out the median (L_{50}) level, and the ninety precentile level (L_{90}). The output can also be printed in a value known as the noise pollution level (L_{NP}). The noise pollution level is numerically equal to the mean energy level plus 2.56 times the standard deviation of the sound levels around tha mean. L_{NP} is purported to be a rating of the level of annoyance from fluctuating noises. It assumes that the measure of public disatisfaction with noise can be said to be a function of the mean energy level of the noise and the amount of variation from that level.

NOISE ABATEMENT - PERFORMANCE OF BARRIERS

Sound barrier walls have been constructed at a number of highway and freeway sites. This section of the report deals with a summary of two sudies.

As was mentioned in discussion of the Design Guide model, the effect of an acoustic barrier is to diffract sound waves and by so doing, reduce the sound energy at the observer. The amount of sound level reduction is a function of the effective height of the barrier (H), the distance from barrier to observer ($\bar{D}$) and the frequency of the sound attenuated. The physical parameters are shown in the illustration, Figure 32.

FIGURE 32



In the study done in Toronto by Harmelink & Hajek[11], two roadways were analyzed. The pre-barrier field measurements of L_{10} were made, barriers of four different materials were constructed, and the after L_{10} noise measurements were taken. Noise measurements were made for the before and after condition during times of similar traffic volumes and vehicle mix. The barrier height was limited to ten feet.

It was felt that a reduction of L_{10} to a 60 dBA level would be desireable. According to their calculations, in order to achieve the desired reductions, barriers of 20 to 25 ft. would have to be constructed (at estimated costs of around $100/foot). Construction of the 10 foot barriers used cost $25 - $50 per foot, depending upon the material.

The L_{10} levels for a 10 lane facility, built essentially at grade ranged from 70 to 80 dBA near the first row of houses surrounding the facility. The second facility studied was a four lane freeway. The L_{10} levels near the residences around this facility were in a range of 65 dBA through 80 dBA. The terrain in this location is gently rolling.

Predictions of noise reductions due to the barriers agreed within a range of 4 dBA to those actually measured. Unfortunately, the reductions encountered typically were 3 dBA with 6 dBA being maximum. The conclusion of the report shows barriers, at least in these two instances, have limited effectiveness, and nc strong justification existed for building more barriers.

They conclude further, that noise level reduction methods that might be more effective should be studied. They suggest a number of methods that might be tried: reducing the noise generated through the production of more quiet cars and trucks, reduction of noise at the reciever by using remodeling of existing residences to include double glazed windows and centeral air conditioning, and by applying more stringent land use controls to the areas surrounding highway facilities, such as setbacks and restrictive zoning.

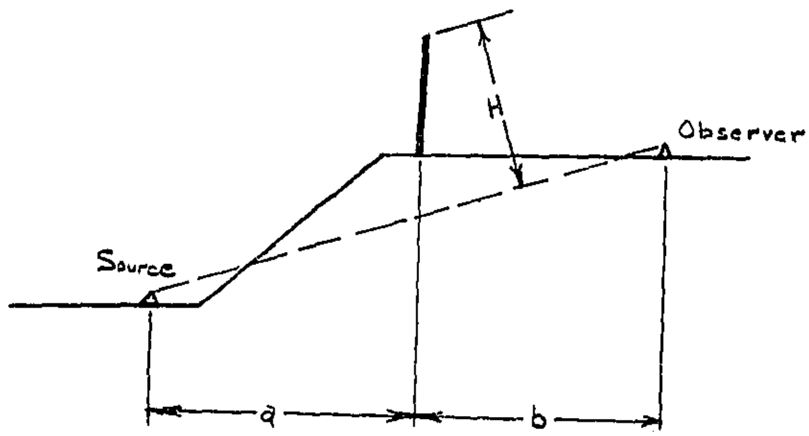
The second study, conducted by Young and Woods[18], compared field measurements at two different sites with calculated data for barrier wall reductions in noise levels. Noise reduction calculations were based on work done by Fehr. The method calculated the noise reduction factor (Y) for a given set of barrier parameters. The modified Fehr equation used is:

$$Y = 2/\lambda \; [a(1 + H^2/a^2)^{1/2} + b\,(1 + H^2/b^2)^{1/2} - b]$$

or, if $b \gg a \geq H$

$$Y \approx H^2/\lambda a$$

where λ is the sound frequency and the parameters H,a,b, are as shown in the illustration on the next page.



The noise reduction factor (Y) can then be converted to a corresponding decibel reduction from the relationship shown in Figure 33, on page 67. From these relationships, series of curves can be drawn for various effective barrier heights, at various distances. Such a series of curves for an effective barrier height of 10 feet is shown in Figure 34, page 68.

The first site analyzed by the study was at the location of the Sacramento Community Drive-In Church. The church had constructed a ten foot earth berm adjacent to Route 99. This is shown in Figure 35, which also indicates measured and calculated noise levels. The calculated values were obtained by using the Design Guide method for the distance from the roadway, and the modified Fehr's equations for the noise attenuation of the barrier.

FIGURE 33

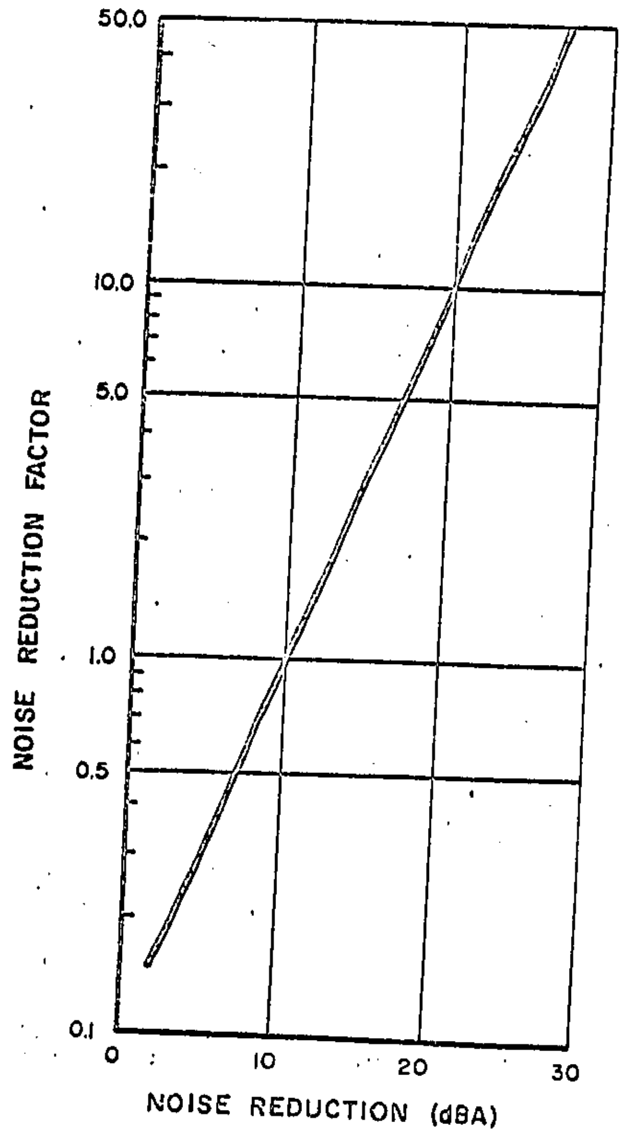
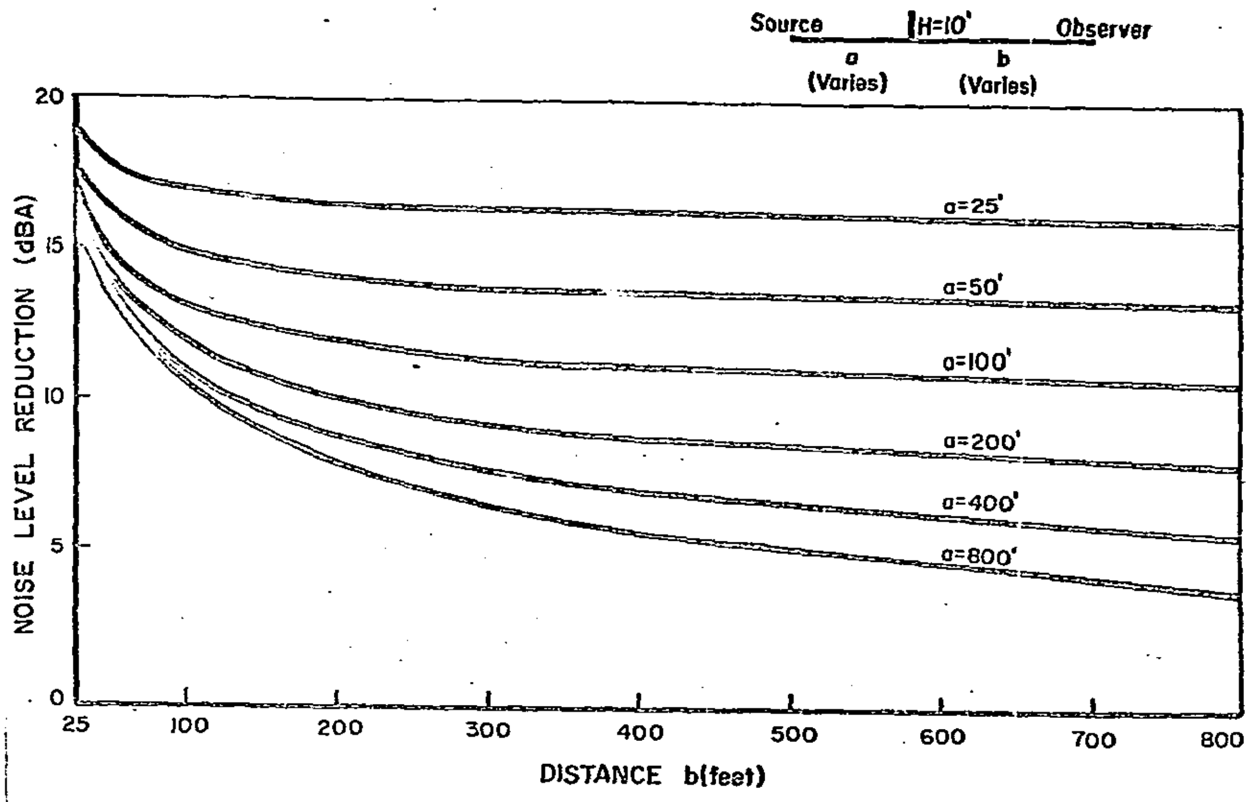
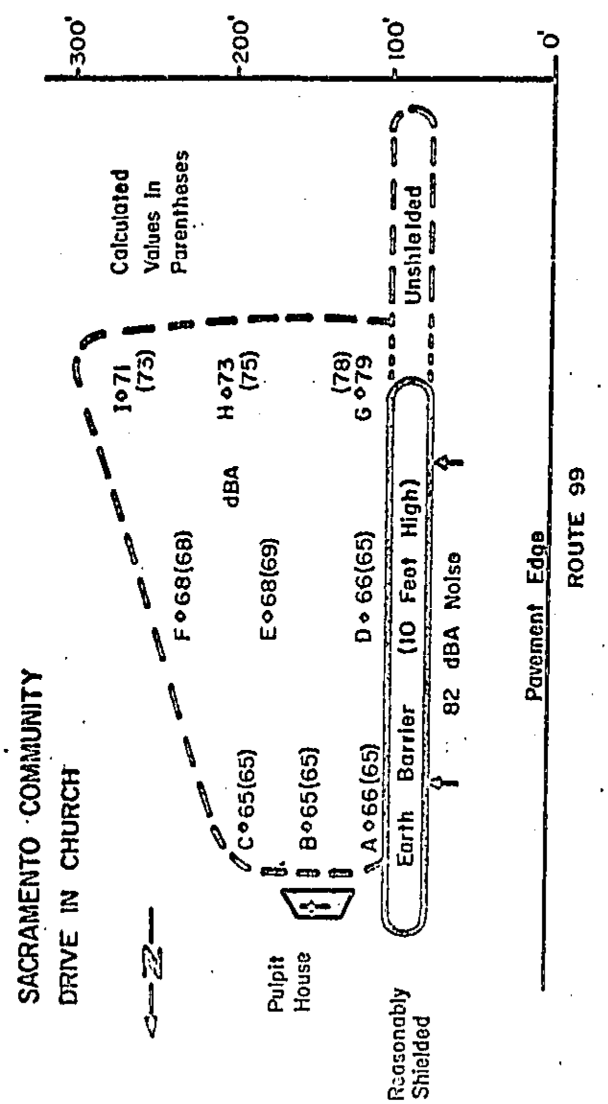

50.0
10.0
5.0
1.0
0.5
0.1
NOISE REDUCTION FACTOR
0
10
20
30
NOISE REDUCTION (dBA)

FIGURE 34



Source
H=10'
Observer
a
(Varies)
b
(Varies)
a=25'
a=50'
a=100'
a=200'
a=400'
a=800'
NOISE LEVEL REDUCTION (dBA)
20
15
10
5
0
25
100
200
300
400
500
600
700
800
DISTANCE b(feet)

FIGURE 35


SACRAMENTO COMMUNITY
DRIVE IN CHURCH
N
Pulpit
House
Reasonably
Shielded
Calculated
Values In
Parentheses
300'
200'
100'
0'
C 65(65)
B 65(65)
A 66(65)
F 68(68)
E 68(69)
D 66(65)
dBA
I 71
(73)
H 73
(75)
(78)
G 79
Unshielded
Earth Barrier (10 Feet High)
82 dBA Noise
Pavement Edge
ROUTE 99

The second site studied was two lacations of the Katy Freeway in Houston, Texas. At the points studied, the roadway is located in a cut section, thus providing an effective barrier at the intersection of the slope with the street grade above the level of the road. At location A of the study, the effective barrier height due to the slope is 5 feet and at location B it is 13 feet. The table below shows a comparison between the field measurements and values obtained by various estimation techniques. There seems to be a good correlation between the calculated and measured data, the variance being due to the simplifying assumptions used in the estimation procedures.

COMPARISON OF SOUND PRESSURE LEVELS ON RADCLIFFE STREET

Location	Sound Pressure Level Estimation Method (dBA)	Design Guide Method (dBA)	Complete Analysis with Data Recorder (dBA)	Sideslope as a Barrier (dBA) p.64
A (200')	67,68	67	68	68
B (400')	61	60	63	59

NOISE AND VIBRATION - RAIL TRANSPORTATION

Rail transportation systems can be divided into two classes for the purpose of noise generation analysis:

1. Railroads, including long distance freight and passenger trains and high speed inter-city commuter trains.
2. Rail transit systems for urban areas, including rapid transit subway and elevated systems.

Railroads

Noise in railroad systems is made up of the contributions from the locomotive power systems and the train vehicles that are hauled by the locomotion system.

Approximately 99% of the locomotive power plants in use throughout the United States today are of the diesel-electric type. Sources of noise from this type of power-plant, ranked from highest contributor to lowest are:(7)

* Diesel exhaust system
* Diesel engine and surrounding casing
* Wheel - rail interaction and slip
* Electric generators

All electric locomotives, that draw power from overhead wires, are considerably quieter than the diesel type.

Train cars produce noise primarily from the vehicle-wheel-rail interaction and slip. The magnitude of the noise produced is largely a function of the condition of the car wheel, track, and whether or not the track is welded. The welded track produces less noise from rail slip.

Perhaps the most insidious source of noise from rail transportation is the braking system conventionly used. The iron-composition brake system produces a high frequency noise that can be in excess of 120 dBA near the source.(7)

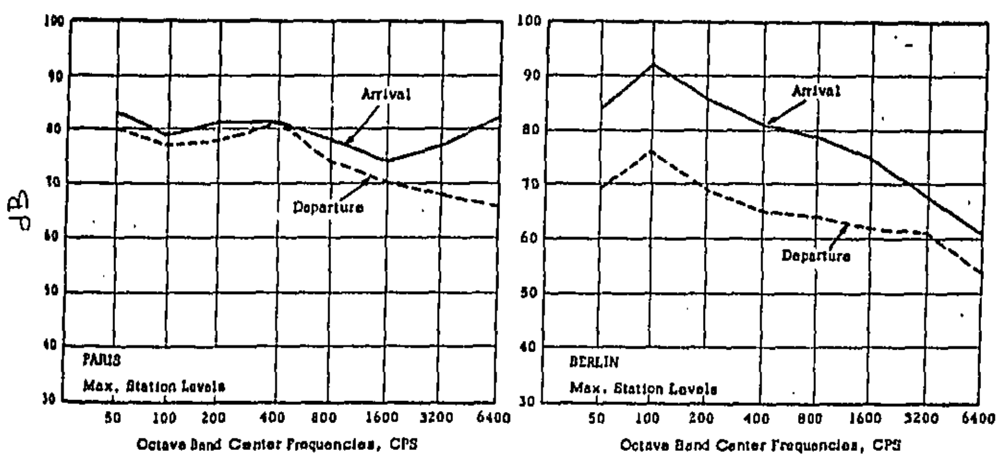
Rapid Rail Systems

The rail rapid transit systems found most commonly in larger urban areas utilize electric multiple unit rail cars, hence the largest contribution to overall noise generation is produced in the rail-wheel interaction. Other systems that employ rubber tires on conctete roadbeds do not produce as high a level from wheel interaction. The characteristics of the rubber tired vehicle are similar to that of an automobile or truck which was discussed previously. In conjuction with the fixed rail system, the use of welded rail, good maintenance of cars and track, and the incorporation of sound absorption materials in the roadbed will all tend to reduce the total noise pollution generated by fixed rail systems.

Subway noise generation is a more serious problem and hazzard, due to the fact that noise produced by the system enclosed in a tunnel is reverberated and magnified. The application of noise absorption materials to the inside of the tunnel would lessen the impact.

The noise levels experienced by persons waiting to embark on a subway platform is characterized by large variations and sudden changes. The magnitude and amount of these changes varies widely from system to system.[4] Comparison of two systems in shown in Figure 35.

FIGURE 35



These values tend to be quite high and can represent a substantial degree of risk of annoyance and discomfort to passengers waiting to embark in these stations.

The designer of rapid transit systems must be concerned with minimizing the noise exposure for both the passenger and non-passenger. Hence, design considerations for the vehicle and roadway must take both the exterior and interior noise levels into account. The analysis of interior noise levels and their abatement is a subject for mechanical and acoustic engineers and designers, and is not treated in this report. Table 3 shows the probable ranking of rapid transit system noise components and Table 4 describes the rail transportion noise and vibration sources, and methods used for noise supression.(10)

RAPID TRANSIT NOISE SOURCES
TABLE 3

COMPONENT	EXCITATION BY	RADIATOR
WHEEL	STICK-SLIP, WHEEL TO RAIL	SIDES OF WHEEL
RAIL	STICK-SLIP, WHEEL TO RAIL	SIDES OF RAIL
CONCRETE ROADBED	VERTICAL IRREGULARITIES IN RAIL, WHEEL	ROADBED
AERIAL STRUCTURE	WHEEL-RAIL VERTICAL IRREGULARITY, STICK-SLIP	GIRDER, ROADBED
RUNNING GEAR	CAR VIBRATION, RATTLES	CAR BODY, DOORS, GATES, COUPLING
POWER COLLECTOR	FRICTION ON CONDUCTOR	SHOES, ATTACHED PARTS
PROPULSION	UNBALANCE; GEAR AND BEARING IRREGULARITY; MAGNETOSTRICTION	MOTOR, CAR BODY, GEAR BOX
BRAKE	STICK-SLIP, AIR	SHOE, BRAKE DISK OR WHEEL TREAD, AIR EXHAUST
SWITCHES, CROSSOVERS	DISCONTINUITY OF RAIL	WHEEL, ROADBED, RAIL
CAR BODY	VIBRATION FROM RUNNING GEAR, COUPLINGS	LARGE SURFACES
WIND	BOUNDARY LAYER TURBULENCE	AIRSTREAM
VENTILATING FANS IN CAR	BLADE TURBULENCE, UNBALANCE MAGNETOSTRICTION	AIRSTREAM, ROOF

TABLE 4

..., Rail Transportation Noise and Vibration Sources and Methods of Suppression

SOURCE OF NOISE AND/OR VIBRATION	CAUSES OF NOISE OR VIBRATION GENERATION	METHODS OF SUPPRESSION
1. POWER CONDUCTING AND GENERATING EQUIPMENT, BRAKES, FANS (VEHICLE AND STRUCTURE)	A. PICKUP AND CONDUCTION OF ELECTRIC POWER, MOTOR SLIDING OR ROLLING CONTACT - VIBRATION SIMILAR TO WHEEL ON RAIL - GENERALLY 10-15 db BELOW PRESENT TRAIN NOISE LEVELS	A. VIBRATION ISOLATION; LOW DENSITY, LOW SOUND VELOCITY CONTACT(S); DAMPING MATERIAL APPLIED TO RADIATING BARS AND CONTACTS; ACOUSTIC ISOLATION OF CONTACT BAR FROM SUPPORT STRUCTURE; GRAPHITE LUBRICATION
	B. GENERATING EQUIPMENT - MECHANICAL ENGINE OR ELECTRICAL MACHINE WITHOUT MOVING PARTS (TRANSFORMER)	B. VIBRATION ISOLATION FROM SUPPORT, DAMPING PROCEDURES, OR NOISE-ABSORBENT ENCLOSURES
	C. COMPRESSORS - THUMPING EFFECT, NOISE OF ESCAPING AIR	C. COMPRESSOR DESIGN CHANGES, VIBRATION ISOLATION, ACOUSTIC ENCLOSURE, REDESIGN OF A R-RELEASE, ORIFICES, AIR ESCAPE CHAMBER
	D. VENTILATING AND COOLING FANS - FOR VEHICLE AND FOR VENTILATION OF UNDERGROUND STRUCTURE	D. DESIGN, DECREASE OF AIR VELOCITY, VIBRATION ISOLATION, LOCATION, BAFFLING AND DUST ACOUSTIC TREATMENT, SILENCER INSTALLATION
	E. GEAR NOISE - FAIRLY MAJOR SOURCE OF PROPULSION NOISE	E. STIFFENED AREAS AROUND THRUST BEARINGS, LUBRICATION, MAINTENANCE, VIBRATION ISOLATION.
	F. BEARING NOISE	F. PRECISE MANUFACTURING; LUBRICATION, MAINTENANCE OF ALIGNMENT IMPORTANT
	G. DIESEL LOCOMOTIVES - ENGINE AND EXHAUST IMPORTANT SOURCE	G. ACOUSTICAL ABSORPTION AROUND ENGINE COMPARTMENT; MUFFLER DESIGN AND MAINTENANCE
	H. BRAKES - BRAKE SHOES - HISSING, SQUEALING - IMPORTANT SOURCE	H. ASBESTOS COMPOSITION BRAKE SHOES (REDUCE FROM 95 db TO 90 db); USE OF DYNAMIC BRAKING DOWN TO LOW SPEED; VIBRATION ISOLATION FROM CAR BODY
	I. COUPLING	I. REDUCTION OF SLACKNESS OF COMPONENTS, LUBRICATION
2. WHEEL AND RAIL NOISE (VEHICLE/TRACK)	IMPACTS DUE TO CONTINUAL STRIKING OF RAIL BY ROLLING WHEELS. MANY FACTORS AFFECT IT, PRODUCE VARYING EFFECTS. THE MOST IMPORTANT SOURCE OF RAIL NOISE AND VIBRATION	
	A. ROLLING OF WHEEL ON RAIL - NON UNIFORMITY OF WHEEL AND RAIL - WORSE ON JOINTS, SPECIAL TRACKWORK (SWITCHES)	A. REDUCE UNSPRUNG WEIGHT; REDUCE TOTAL VEHICLE WEIGHT; HEAT TREATED RAIL (MORE WEAR RESISTANT); CONTINUOUS WELDED RAIL (SMOOTHER, NO JOINTS); RAIL LUBRICATION; ELASTOMERIC MATERIAL BETWEEN WHEEL AND RAIL
	B. RAIL CORRUGATION AND WHEEL IRREGULARITIES CAN OCCUR TO AGGRAVATE THE PROBLEM	B. RAIL AND WHEEL GRINDING, THIS ALSO REDUCES RAIL AND WHEEL LIFE. HOWEVER MAINTENANCE IS COSTLY
	C. INSULATED RAIL JOINTS (FOR ELECTRICAL ISOLATION IN POWER AND SIGNAL CIRCUITS)	C. PROBLEM NOT YET SOLVED; DIAGONAL JOINT OR PRE-ASSEMBLED GLUED JOINT SHOULD BE TRIED
	D. WHEEL AND RAIL SQUEAL ON CURVES - DUE TO WHEEL STOPPAGE, BEARING OF WHEEL FLANGE ON RAIL, WHEEL MOVEMENT ACROSS RAIL HEAD, OR RAIL AND WHEEL RESONANCE. BECAUSE OF STRUCTURE OF CAR TRUCK (4 WHEELS OF EACH TRUCK BEING RIGIDLY FIXED IN RELATION TO ONE ANOTHER), WHEEL SKIDDING ON THE RAIL IS CAUSED ON CURVES BECAUSE OF DIFFERENT OUTER AND INNER WHEEL PATH LENGTHS.	D. RAIL LUBRICATION ON CURVES; FLATTER CURVE DESIGN WHERE POSSIBLE; REDUCE TOTAL VEHICLE WEIGHT DAMPING MATERIAL ON TRUCKS CHANGES IN TRUCK DESIGN NO CONTROL METHOD YET AVAILABLE, EXCEPT DESIGN FOR ELIMINATION OF RETAINING RAIL
	E. ALL OF ABOVE (A TO D) MAY BE TRANSMITTED TO STRUCTURE THROUGH TRACK FASTENINGS, DEVICES FOR FASTENING TRACK TO STRUCTURE.	E. DESIGN VIBRATION ISOLATION OF RAIL FROM SUPPORTING STRUCTURE BY RUBBER OR ELASTOMERIC PADS
	F. ROAD BED, AS CARRIER OF NOISE AND VIBRATION - TIES AND BALLAST VS. CONCRETE	F. TIES AND BALLAST MORE ABSORPTIVE; CONCRETE CHEAPER WITH CONCRETE. PADS TO ISOLATE ROAD BED FROM MAIN STRUCTURE CAN BE USED (LEAD-ASBESTOS) IN SPECIAL AREAS
	G. RESONANCE OF CAR WHEEL AT NATURAL FREQUENCY (~600 Hz)	G. CONSTRAINED DAMPING ON WHEELS
3. VEHICLE	A. AERODYNAMIC NOISE, ESPECIALLY AIR TURBULENCE IN TUNNELS	A. VEHICLE DESIGN; LAYING BOARDS OVER TIES
	B. RUBBING TOGETHER OF CAR-VESTIBULE END FRAMES	B. DESIGN, VIBRATION ISOLATION
	C. VIBRATION OF SIDE PANELS OF VEHICLE, DUE TO TRANSMISSION OF STRUCTURE-BORNE NOISE FROM BENEATH (WHEEL, RAIL, TRUCK)	C. ACOUSTIC MATERIALS, DAMPING

AIRCRAFT NOISE AND SONIC BOOM

The most publicized and most discussed source of noise in our environment today eminates from the air transportation systems. Citizen complaints have be registered for years, ever since the advent of the jet propulsion system in the military and commercial aviation industry.

The major source of noise annoyance associated with aircraft has as its cause large commercial aircraft operating from airports near urban communities. The noise produced by aircraft is unique from other transportation sources in regard to its spectral content, amplitude, duration an propagation.[(3)]

Propulsion System Noise

The dominant source of noise from the early turbojet engines was the jet exhaust gases mixing with the surrounding air, producing a turbulent mixing and high noise levels. Sound pressure is known to increase rapidly with increases in jet velocity, hence high noise levels are produced.

The turbofan engine, which has to a great extent replaced the turbojet engine, has decreased the noise level associated with the exhaust jet velocities. However, turbofan engines create a high frequency, high intensity fan whine, which is considered to be their prime noise generator.[(3)] Figure 36 shows the various types of major commercial aircraft in use throughout the United States today, and the typical noise levels associated with each.(7)

Noise Abatement through Improved Engine Technology (13)

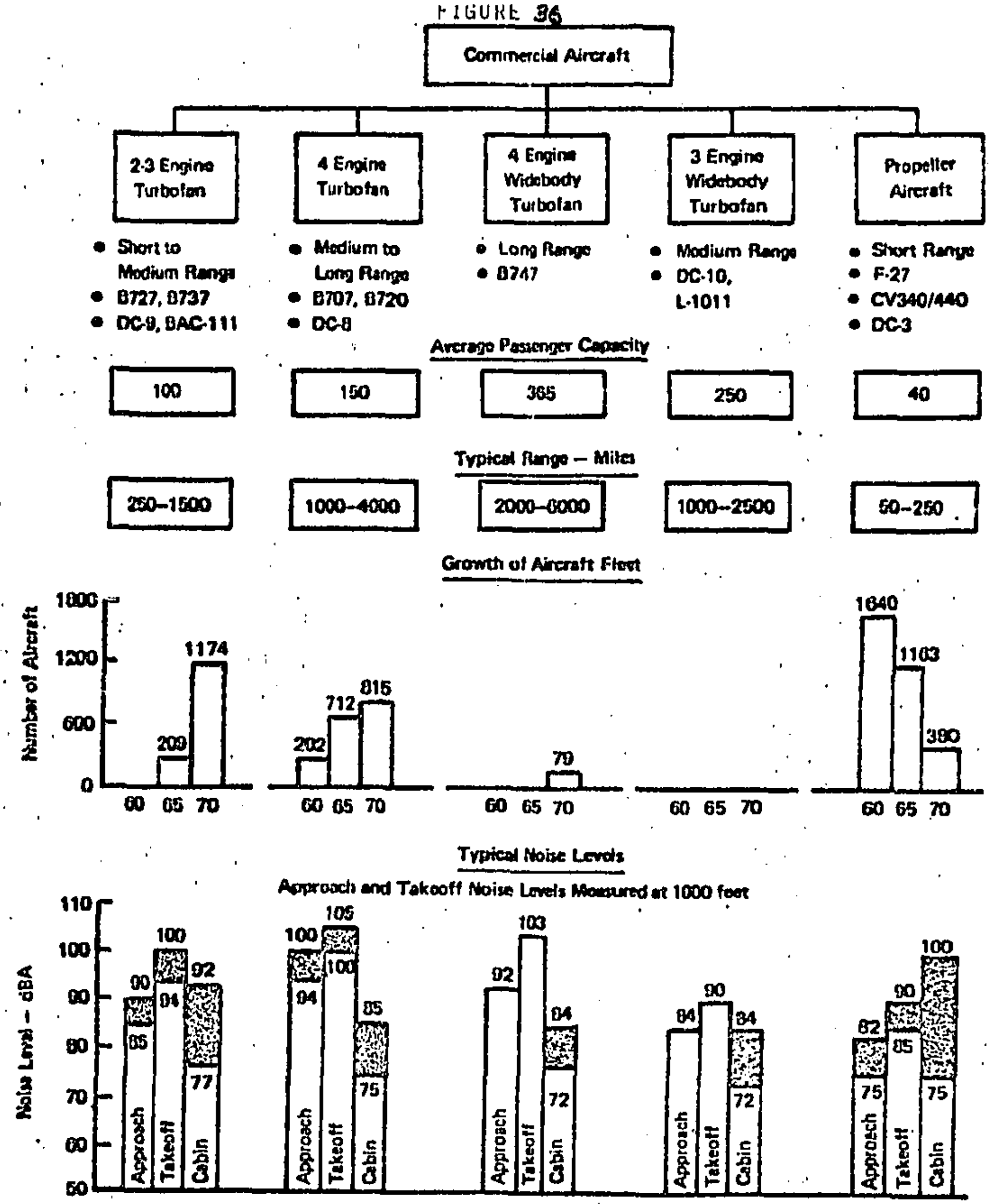
Recently, with the introduction of the Boeing 747 and the McDonnel Douglas DC-10, new turbofan engines were designed to reduce the noise levels generated by exhaust gas velocity and fan whine. Modifications made to these engines to reduce the noise levels have not appreciably increased engine weight or fuel consumption.

In the future, with technological advances, a greater thrust-to-weight ratio is hoped for. These gains can then be traded off for lower noise generation in many ways:

* oversize engines, relative to minimun for takeoff, to permit faster climb rates
* Lower fan speeds to produce lower approach and takeoff whine.
* Lower turbine inlet temperatures, which yield lower average jet velocities.

Although the transportation planner may not be directly concerned with improvements in aircraft noise abatement on the mechanical side, there is much he can do to minimize the noise impact on the communities surrounding the aircraft terminal.

FIGURE 36

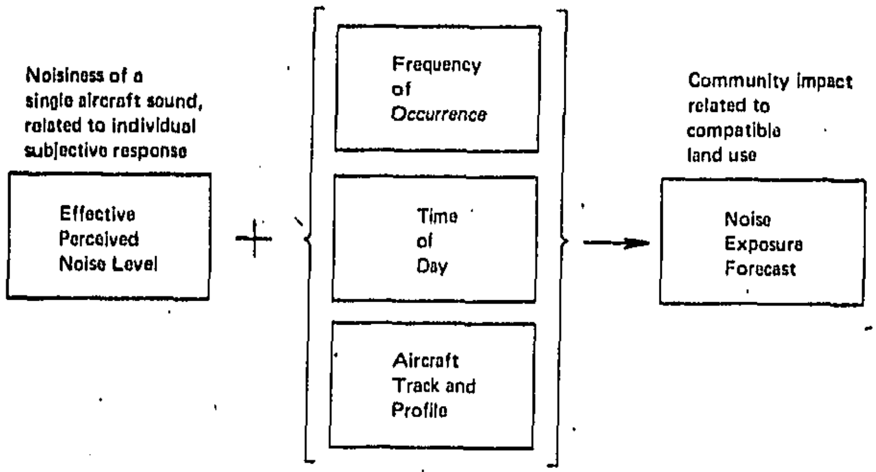


Commercial Aircraft
2-3 Engine Turbofan
4 Engine Turbofan
4 Engine Widebody Turbofan
3 Engine Widebody Turbofan
Propeller Aircraft
• Short to Medium Range
• B727, B737
• DC-9, BAC-111
• Medium to Long Range
• B707, B720
• DC-8
• Long Range
• B747
• Medium Range
• DC-10, L-1011
• Short Range
• F-27
• CV340/440
• DC-3
Average Passenger Capacity
100
150
365
250
40
Typical Range — Miles
250–1500
1000–4000
2000–6000
1000–2500
50–250
Growth of Aircraft Fleet
Number of Aircraft
1800
1200
600
0
1174
209
815
712
202
79
1640
1103
380
60 65 70
Typical Noise Levels
Approach and Takeoff Noise Levels Measured at 1000 feet
Noise Level – dBA
110
100
90
80
70
60
50
Approach
Takeoff
Cabin

Scientific studies of the reaction of people to aircraft noise have led to a quantative measurement for annoyance to it. This numeric value is defined to be the NOISE EXPOSURE FORECAST (NEF). This measure takes into account a number of variables in forecasting annoyance due to aircraft flyovers:

1. Loudness of noise from the individual aircraft.
2. Quality of the noise (broad band characteristics)
3. Duration of noise.
4. Frequency of occurance.
5. Time of day the noise occurs.

The noise exposure forecast is determined by integrating the factors as schematically shown below:



At each level of the NEF scale an average respose of people to aircraft noise is predicted. As an example and NEF of 30 correspond to a condition where conversations are repeatedly interrupted, for a total duration of thirty minutes during a day. At this same NEF about 50% of the people will experience sleep interuption (for populations of older people, this proportion is higher).

To use the NEF as a planning tool, it is necessary to compute its value at locations surrounding the air terminal. Equal NEF contours can then be drawn on a plan map. Figure 37 is an example of this. Figure 38 , taken from the Jamica Bay - Kennedy Airport report is a more detailed map showing not only the NEF contours, but also noise sensitive areas in the impact area. A land use compatibility criteria, such as that suggested in the Jamica Bay report and shown below, can be used to determine the location of land use types. Of course for areas that surround air termininals and are already built up, the criteria cannot apply. However, the criteria can still be used for any future development or re-development of the area.

Land Use Compatibility Chart for Aircraft Noise

	Land Use Compatibility								
Noise-Exposure Forecast Areas	Residential	Commercial	Hotel, Motel	Offices, Public Buildings	Schools, Hospitals, Churches	Theaters, Auditoriums	Outdoor Amphitheaters, Theaters	Outdoor Recreational (Nonspectator)	Industrial
<30	Yes	Yes	Yes	Yes	•	•, •	•	Yes	Yes
Between 30 and 40	•	Yes	•	•	No	No	No	Yes	Yes
>40	No	•	No	No	No	No	No	Yes	•

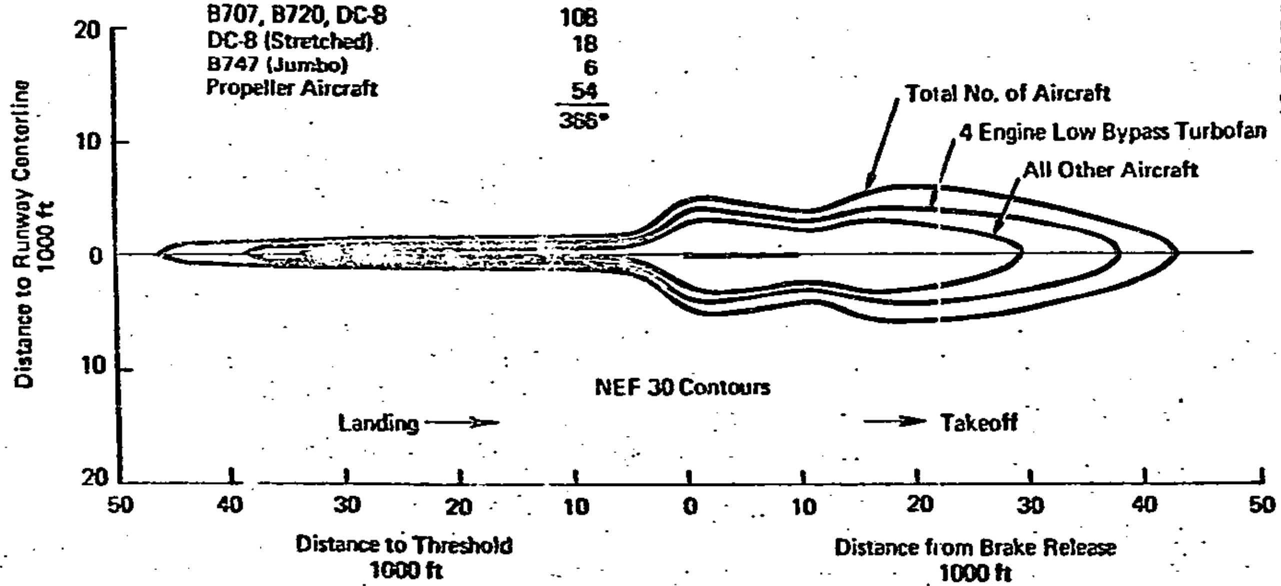
• A detailed noise analysis should be undertaken by qualified personnel for all indoor or outdoor music auditoriums and all outdoor theaters.
• Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible. New single-dwelling construction should generally be avoided. For apartment construction,• applies.
• An analysis of building noise reduction requirements should be made, and needed noise control features should be included in the building design.

FIGURE 37

Representative Large Airport (1970)

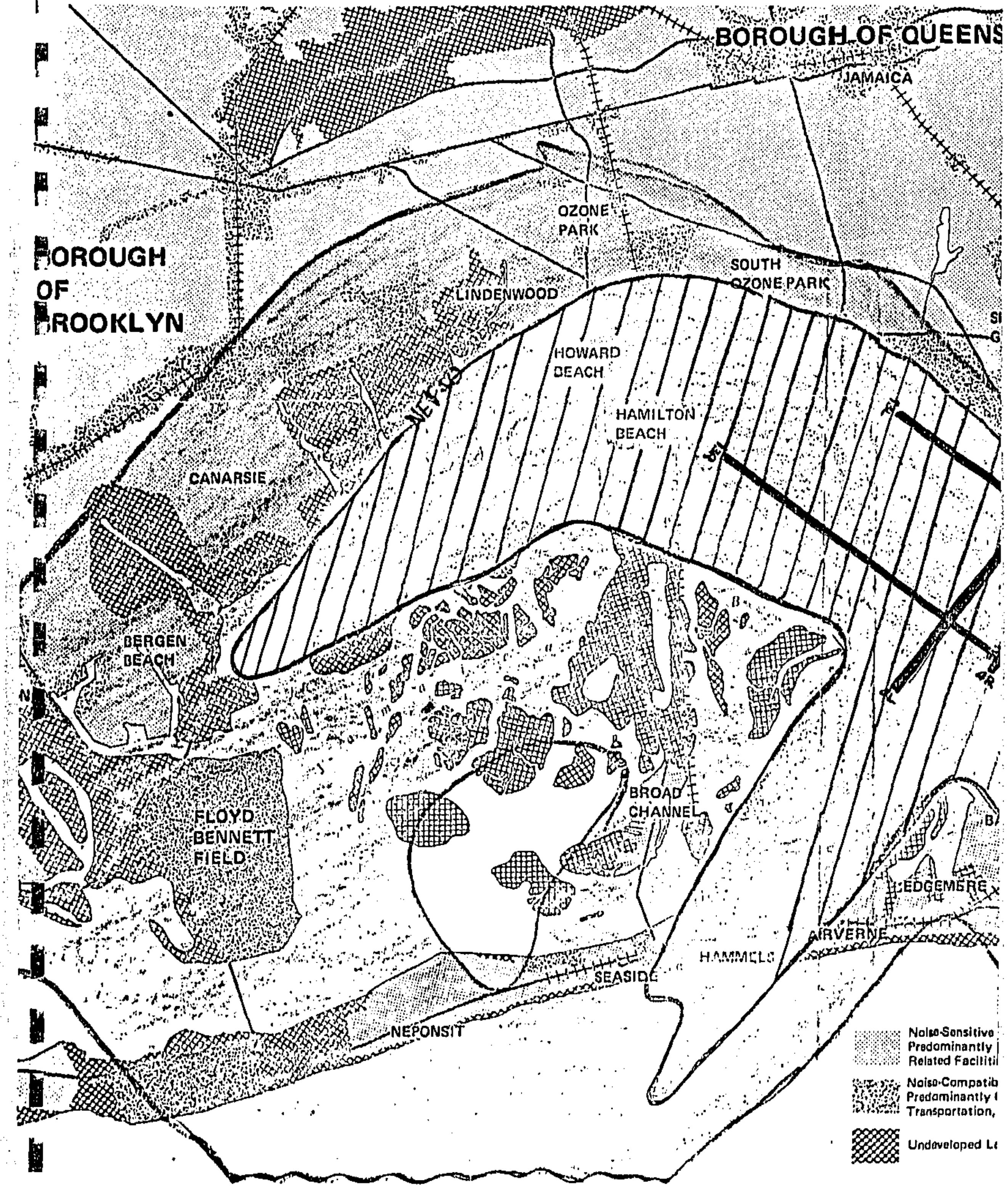
Commercial Aircraft Type	Number of Operations/Day
B727-100, B737, DC-9	140
B727-200	40
B707, B720, DC-8	108
DC-8 (Stretched)	18
B747 (Jumbo)	6
Propeller Aircraft	54
	366*

*Total operations, 86.3% of which occur during daytime (0700-2200 hours) and 13.7% of which occur during nighttime (2200-0700 hours).



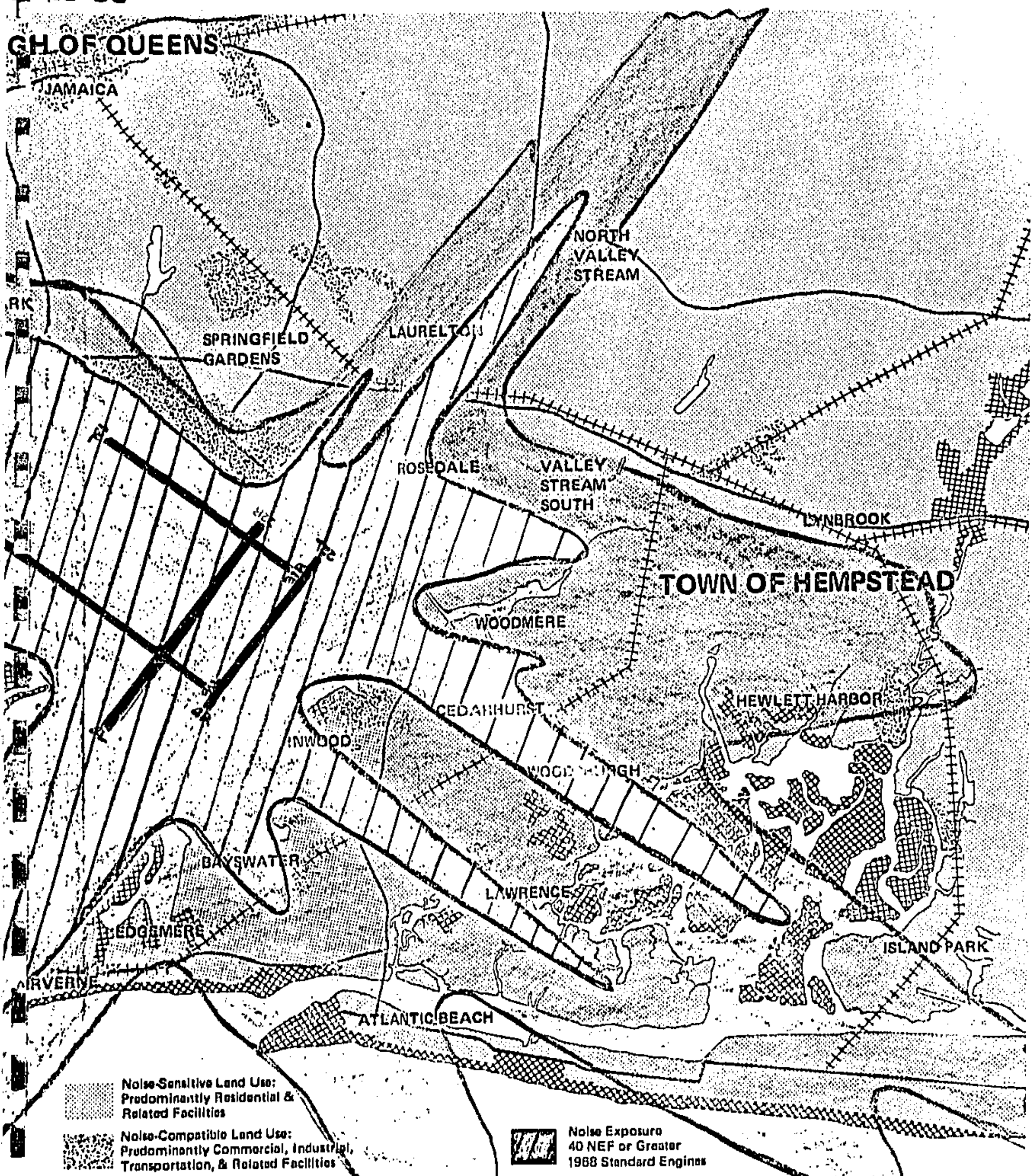
Areas currently exposed to NEF 30 and 40. Scale: 1" = 1 Mile

FIGURE 38



POOR COPY

FIGURE 38



JAMAICA
NORTH VALLEY STREAM
SPRINGFIELD GARDENS
ROSEDALE
VALLEY STREAM SOUTH
LYNBROOK
TOWN OF HEMPSTEAD
WOODMERE
HEWLETT HARBOR
INWOOD
BAYSWATER
LAWRENCE
EDGEMERE
ISLAND PARK
ATLANTIC BEACH
Noise-Sensitive Land Use: Predominantly Residential & Related Facilities
Noise-Compatible Land Use: Predominantly Commercial, Industrial, Transportation, & Related Facilities
Undeveloped Land and Major Parks
Noise Exposure 40 NEF or Greater 1968 Standard Engines
Noise Exposure 30 NEF or Greater 1968 Standard Engines

Sonic Boom

Sonic booms are shock waves that propagate through the atmosphere from the region around an aircraft traveling at supersonic speeds. The amplitude and duration of the boom are affected by the aircraft volume, weight, length and lift characteristics. To alesser extent the boom is affected by the Mach number or speed of the aircraft.

The general characteristics of the atmosphere, temperature, wind gradient and the amount of turbulence, have the effect of distortion of the boom signature.

Under normal flight conditions, the amplitude of a sonic boom reache a mazimum of about two pounds per square inch. Sonic booms have short durations, measured in milliseconds. The detection of a sonic boom does not require the observer to be directly under the flight path. Indeed, the distance over which a boom propagates has been known to reach thirty miles and more. The dispersion of the boom is a function of aircraft altitude, speed and the general condition of the atmosphere.

The spectrum shape of a sonic boom shows a high level of sound energy concentrated belwo 100 Hz. This would indicate the potential of a sonic boom to produce structural vibrations and associated damage, depending on structural strength.

Ath this point in time, there seems little that can be done to reduce the impact of sonic booms.

CONCLUSION

This report has summarized the noise impact of major transportation systems on the environment.. It is not all inclusive in its scope. Such a report would be volumes in length. Instead, its main thrust is to illustrate the state of the art in assement of noise pollution as it pertains to transportation systems.

It would seem that the task faced by transportation system planners is not one of noise abatement only, but one of providing for the movement of goods and people on various networks, with the least environmental intrusiveness as possible.

The concern for noise abatement and transportation systems is relatively new. Planners now find themselves at a point where they must be concerned with another variable in the problem of route location, terminal design and location,and construction. Integration of planning techniques that include a deep concern for environmental impacts has now begun. However, the ultimate goal should be the enhancement of the environment while achieving the primary goal of providing needed mobility to a nation's people. Indeed, the two goals may be forever in direct oposition to each other, in which case we are led back to a situation of trading off increased transportation efficiency for a decrease in environmental quality.

However, in regard to transportation noise pollution, much can be done to improve the situation. Positive steps have already been taken, in the form of criteria that have to be met in planning for new networks. Assuming that modes of transportation will remain relatively constant in the forseeable future, I believe the key to noise abatement lies in re-engineering two components of the problem: the source and the receptor.

In regard to the source, technological advances in desing of vehicles, propulsion systems and locomotion could be employed with an eye twords less energy loss through radiated noise. The interaction of the vehicle wheel with the roadway seems to be the place where much improvement can be made. One recent advance in tire design brought to my attention by a representative of Firestone Tire and Rubber Company, involves the incorporation of a skewed tread design which is claimed to radiate less noise. If methods like this one prove to be effective, they may be applied to truck tires as well. In regard to rail transportation, replacement of old track with welded rail and new designs of braking systems would be an aid in reducing the amount of generated noise. These measures will take some time to implement, as old vehicles are removed from service. As for the aircraft transportation industry, it has been demonstrated that noise abatement at the source can be accomplished. Continued effort in this area should lead to further reductions.

There can be no change in the human auditory system. We will still perceive noise in the same way we always have. However, modifications of the noise we do perceive, and its intensity can be accomplished by altering the medium through which the noise travels. In regard to highway networks, the use of barrier walls has been shown to have limited effectiveness, at least in one study. However, it should be remembered that a reduction in noise level of 6 dBA is an apparent halving of sound intensity, and therefore barriers may be an attractive way to effect the reduction. Perhaps the most effective way of reducing the noise level that annoys people is to move them further from the source, by integrating the highway system into land use areas that are not noise sensitive. Of course in every case this may not be practicle. Where origin-destination surveys and other planning tools dictate that a facility pass through areas that are particularily noise sensitive (school zones; hospitals and established residential areas) every effort should be made to provide a wider right-of-way and depressed designs to produce larger distances between the noise source and observer. Of course incorporation of acoustic barriers will further decrease the generated noise. Costs will increase when these methods are employed. It is suggested that an intensive economic analysis of the proposed plan include not only the benefits to road user but also the benefits to the populations surrounding the facility planned. Restrictive land use policies around air terminal facilities seem to be the best means of reducing noise impact at the observer. Where facilities are planned consideration of surrounding land use is paramount. Zoining should be restricted to forms that are not noise sensitive: industrial, light manufacturing and commercial. In areas that are built up around an air terminal, every effort should be made to replace existing land use that is noise sensitive,at its retirement,with one that is not.

These measures will not be a total cure for the problem of noise pollution, but they will tend to create less noise impact on the human community, and hopefully lead to an improved environment.

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APPENDIX A

FEDERAL HIGHWAY ADMINISTRATION

POLICY AND PROCEDURES MEMORANDUM 90-2

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
WASHINGTON, D.C. 20590

POLICY AND PROCEDURE MEMORANDUM

Transmittal 279
February 8, 1973

HEV-10

1. MATERIAL TRANSMITTED

PPM 90-2, Subject: Noise Standards and Procedures

2. EXISTING ISSUANCES AFFECTED

Supersedes Advance Copy of PPM 90-2 dated April 26, 1972.

3. COMMENTS

PPM 90-2 has been revised to incorporate suggestions and respond to comments resulting from circulation of a draft environmental statement. Significant changes are:

a. Table A, Low Noise Level Highways, has been deleted
b. The level of detail required during location phase has been clarified
c. The use of quiet vehicle noise prediction methods has been deleted

The design noise levels in the standards represent a balancing of that which may be desirable and that which may be achievable. Consequently, noise impacts can occur even though the design noise levels are achieved. The values in Table 1 should be viewed as maximum values, recognizing that in many cases, the achievement of lower noise levels would result in even greater benefits to the community. Highway agencies are urged, therefore, to strive for noise levels below the values in Table 1 where the lower levels can be achieved at reasonable cost, without undue difficulty, and where the benefits appear to clearly outweigh the costs and efforts required.

Projects which received location approval prior to July 1, 1972, are not required to adhere to the standards provided design approval is

NOTE: This PPM is being reissued due to incorrect assembly of the original printing obtained before July 1, 1974. However, the Federal Highway Administration encourages application of the noise standards to such projects whenever possible.

For a 12-month period beginning with the date of this issue, copies of each exception approval letter together with the State's request shall be forwarded to both the Regional Administrator and direct to the Washington office (HEV-10), unless advised to the contrary by the Regional Administrator.

4. Effective Date

The effective date of this PPM is the date of issuance.

R. R. Bartelsmeyer

R. R. Bartelsmeyer
Acting Federal Highway Administrator

DISTRIBUTION:
Basic

Remove	Page(s)		Insert	Page(s)
	1 thru 6	April 26, 1972		1 thru 4
Attachment 1	1	April 26, 1972	Appendix A	
Attachment 2	1 thru 2	April 26, 1972	Appendix B, B-1 thru B-4	
Attachment 3	1 thru 4	April 26, 1972		

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

POLICY AND PROCEDURE MEMORANDUM

Transmittal 279

90-2

February 8, 1973

NOISE STANDARDS AND PROCEDURES

1. PURPOSE

To provide noise standards and procedures for use by State highway agencies and the Federal Highway Administration (FHWA) in the planning and design of highways approved pursuant to Title 23, United States Code, and to assure that measures are taken in the overall public interest to achieve highway noise levels that are compatible with different land uses, with due consideration also given to other social, economic and environmental effects.

2. AUTHORITY

Sections 109(h) and (i), Title 23, United States Code, state that guidelines shall be promulgated "to assure that possible adverse economic, social, and environmental effects relating to any proposed project on any Federal-aid system have been fully considered in developing such project, and that the final decisions on the project are made in the best overall public interest, taking into consideration the need for fast, safe and efficient transportation, public services, and the costs of eliminating or minimizing such adverse effects and the following: (1) air, noise, and water pollution; . . ." and that "The Secretary, after consultation with appropriate Federal, State, and local officials, shall develop and promulgate standards for highway noise levels compatible with different land uses and after July 1, 1972, shall not approve plans and specifications for any proposed project on any Federal-aid system for which location approval has not yet been secured unless he determines that such plans and specifications include adequate measures to implement the appropriate noise level standards."

3. NOISE STANDARDS

a. Noise standards are appended as Appendix B. Federal Highway Administration encourages application of the noise standards at the earliest appropriate stage in the project development process.

b. There may be sections of highways where it would be impossible or impracticable to apply noise abatement measures. This could occur where abatement measures would not be feasible or effective due to physical conditions, where the costs of abatement measures are high in relation to the benefits achieved, or where the measures required to abate the noise condition conflict with other important values, such as desirable esthetic quality, important ecological conditions, highway safety, or air quality. In these situations, highway agencies should weigh the anticipated noise impacts together with other effects against the need for and the scope of the project in accordance with other FHWA directives (PPM's 20-8, 90-1, and 90-4).

4. APPLICABILITY

In order to be eligible for Federal-aid participation, all projects to which the noise standards apply shall include noise abatement measures to obtain the design noise levels in these standards unless exceptions have been approved as provided herein.

a. Projects to which noise standards apply. The noise standards apply to all highway projects planned or constructed pursuant to Title 23, United States Code, except projects unrelated to increased traffic noise levels, such as lighting, signing, landscaping, safety and bridge replacement. Pavement overlays or pavement reconstruction can be considered as falling within this category unless the new pavement is of a type which produces more noise than the type replaced.

b. Approvals to Which Compliance with Noise Standards Is Prerequisite

(1) Projects for which location was approved prior to July 1, 1972: Compliance

with noise standards shall not be a prerequisite to any subsequent approval provided design approval is secured prior to July 1, 1974. If design approval is not secured for such a project prior to July 1, 1974, compliance with the noise standards shall be a prerequisite to securing both design approval and approval of plans and specifications. However, such compliance shall not be a basis for requiring reconsideration of the highway location or any other approval action which has previously been taken for such projects.

(2) Projects for which location is approved on or after July 1, 1972:

(a) If location approval was requested on or before December 31, 1972, compliance with the noise standards shall be a prerequisite to obtaining design approval and approval of plans and specifications. Compliance with the noise standards shall not be a prerequisite to obtaining location approval, nor shall such compliance be a basis for requiring reconsideration of the highway location or any other approval action which has previously been taken for such projects. Combined location and design approval shall be handled in the same manner as separate design approval.

(b) If location approval is requested after December 31, 1972, compliance with the noise standards shall be a prerequisite to obtaining location and design approvals as well as approval of plans and specifications.

5. PROCEDURES

The noise standards should be implemented at the earliest appropriate stage in the project development process. These procedures have been developed accordingly:

a. Project Development. A report on traffic noise will be required during the location planning stage and the project design stage. The reports may be sections in the location and design study reports, or they may be separate. The procedures for noise analysis, identification of solutions, coordination with local officials, and incorporation of noise abatement measures are as follows:

(1) Nonapplicable Projects. If a State highway department determines (in accordance with paragraph 4a that noise standards do not apply to a particular project, the requests for location approval and design approval shall contain statements to that effect, including the basis on which the State made its determination.

(2) Noise Analysis. For applicable projects, analyses of noise and evaluation of effects are to be made during project development studies using the following general steps:

(a) Predict the highway-generated noise level as described in the standards for each alternative under detailed study.

(b) Identify existing land uses or activities which may be affected by noise from the highway section.

(c) By measurement, determine the existing noise levels for developed land uses or activities.

(d) Compare the predicted noise levels with the design level values listed in the standards. Also compare the predicted noise levels with existing noise levels determined in paragraph 5a(2)(c). These comparisons will be the basis for determining the anticipated impact upon land uses and activities.

(e) Based upon the noise impacts determined in paragraph 5a(2)(d), evaluate alternative noise abatement measures for reducing or eliminating the noise impact for developed lands.

(f) Identify those situations where it appears that an exception to the design noise levels will be needed. Prepare recommendations to be included in the traffic noise report. (This report may be a portion of the location and design study reports or it may be a separate report.)

(3) Location Phase and Environmental Impact Statement Requirements. To the extent this PPM is applicable to the location phase of projects under paragraph 4, the noise report shall describe the noise problems which may be created and the plans for dealing with such problems for each alternative under detailed study. The level of detail of the noise analysis in the location phase should be consistent with the level of detail in which the location study itself is made. This information including a preliminary discussion of exceptions anticipated, shall be set forth in the location study report and summarized in the environmental impact statement (if one is prepared) and, as appropriate, at the location hearing (for location hearings after December 31, 1972). Studies and reports for highway locations approved before December 31, 1972, need not include an analysis and report on noise. In such instances, the noise analysis and report will be required only for the design approval.

(4) Design Phase Requirements. The noise analysis prepared for the location phase is to be updated and expanded using the refined alignment and design information developed during the design studies. The report on traffic noise will include a detailed analysis of the anticipated noise impact, alternative or proposed abatement measures, discussion of coordination with local officials, and recommended exceptions.

(5) Coordination with Local Officials on Undeveloped Lands. Highway agencies have the responsibility for taking measures that are prudent and feasible to assure that the location and design of highways are compatible with existing land use. Local governments, on the other hand, have responsibility for land development control and zoning. Highway agencies can be of considerable assistance to local officials in these efforts with a view toward promoting compatibility between land development and highways. Therefore, for undeveloped lands (or properties) highway agencies shall cooperate with local officials by furnishing approximate generalized future noise levels for various distances from the highway improvement, and shall make available information that may be useful to local communities to protect future land development from becoming incompatible with anticipated highway noise levels.

(6) Noise Abatement Measures for Lands Which are Undeveloped at Time of Location Approval

(a) Noise abatement measures are not required for lands which are undeveloped at the time of location approval; however, the highway agency may incorporate noise abatement measures for such undeveloped lands in the project design (if approved by FHWA) when a case can be made for doing so based on consideration of anticipated future land use, future need, expected long term benefits, and the difficulty and increased cost of later incorporating abatement measures.

(b) For land uses or activities which develop after location approval, noise abatement measures should be considered for incorporation in the project in the following situations:

1 It can be demonstrated that all practicable and prudent planning and design were exercised by the local government and the developer of the property to make the activity compatible with the predicted noise levels which were furnished to the local government and especially that a considerable amount of time has elapsed between location approval and highway construction thus limiting local government's ability to maintain control over adjoining land uses.

2 The benefits to be derived from the use of highway funds to provide noise abatement measures is determined to outweigh the overall costs.

3 The noise abatement measures can be provided within the highway's proposed right-of-way or wider rights-of-way or easements acquired for that purpose.

(c) There are some situations where the design noise levels should be applied to lands which are undeveloped at the time of location approval. Some of these instances occur where the development of new land uses or activities is planned at the same time as the highway location studies. Other instances occur where planning for the new development has preceded the highway location studies but the development has been delayed. These types of situations should be treated as though the land use or activity were in existence at the time of location approval provided:

1 The State highway agency is apprised of such prior planning.

2 The construction of the new land use or activity is started prior to highway construction or there is good reason to believe that it will start before highway construction.

(7) Incorporation of Noise Abatement Measures in Plans and Specifications. For those projects to which the standards apply, the plans and specifications for the highway section shall incorporate noise abatement measures to attain the design noise levels in the standards, except where an exception has been granted.

(8) Requests for Exceptions. Requirements and supporting materials for requests for exceptions to the design noise levels are described in paragraph 2 of Appendix B to this PPM. To the extent possible, consistent with the level of detail of the location study, identifiable exceptions should be reported in the location study report. The request for location approval shall contain or be accompanied by a request for approval of exceptions that have been identified in the location stage. Supporting material may be contained in the location study report. Subsequent requests for review and approval of additional exceptions, if any, will be similarly processed in conjunction with design approval.

b. Federal Participation

(1) Shifts in alignment and grade are design measures which can be used to reduce noise impacts. The following noise abatement measures may also be incorporated in a project to reduce highway-generated noise impacts. The costs of such measures may be included in project costs.

(a) The acquisition of property rights (either in fee or a lesser interest) for providing buffer zones or for installation or construction of noise abatement barriers or devices.

(b) The installation or construction of noise barriers or devices, whether within the highway right-of-way or on an easement obtained for that purpose.

(2) In some specific cases there may be compelling reasons to consider measures to "sound-proof" structures. Situations of this kind may be considered on a case by case basis when they involve such public or non-profit institutional structures as schools, churches, libraries, hospitals, and auditoriums. Proposals of this type, together with the State's recommendation for approval, shall be submitted to FHWA for consideration.

c. Approval Authority

(1) Exceptions to the Design Noise Levels. The FHWA Division Engineer is authorized to approve exceptions to the design noise levels and alternate traffic characteristics for noise prediction as provided in paragraph 3b, Appendix B.

(2) Noise Prediction Method. Noise levels to be used in applying the noise standards shall be obtained from a prediction method approved by FHWA. The noise prediction method contained in National Cooperative Highway Research Program Report 117 and the method contained in Department of Transportation, Transportation Systems Center Report DOT-TSC-FHWA-72-1 are approved as of the date of this issue for use in applying the noise standards. Other noise prediction methods or variations of the above should be furnished to the FHWA Office of Environmental Policy together with supporting and validation information for approval.

R. R. Bartelsmeyer

R. R. Bartelsmeyer
Acting Federal Highway Administrator

DEFINITIONS (As used in this PPM)

Design Approval - the approval (described in PPM 20-8) given by the Federal Highway Administration (FHWA) (at the request of a State highway department) based upon a design study report and a design public hearing or opportunity therefor. This action establishes FHWA acceptance of a particular design and is prerequisite to authorization of right-of-way acquisition and construction.

Design Noise Level - the noise levels established by the noise standards set forth herein for various land uses or activities to be used for determining traffic noise impacts and the assessment of the need for and type of noise abatement treatment for a particular highway section.

Design Year - the future year used to estimate the probable traffic volume to be used as one of the primary bases for the roadway design. A time 20 years from construction is common for multilane and other major projects. Periods of 5 or 10 years are not uncommon for low volume roads.

Developed Land Uses or Activities - those tracts of land or portions thereof which contain improvements or activities devoted to frequent human use or habitation. The date of issue of a building permit (for improvements under construction or subsequently added) establishes the date of existence. Park lands in categories A and B of Table 1, Appendix B, include all such lands (public and private) which are actually used as parks on the date the highway location is approved and those public lands formally set aside or designated for such use by a governmental agency. Activities such as farming, mining, and logging are not considered developed activities. However, the associated residences could be considered as a developed portion of the tract.

Highway Section - a substantial length of highway between logical termini (major crossroads, population centers, major traffic generators, or similar major highway control elements) as normally included in a single location study.

L_{10} - the sound level that is exceeded 10 percent of the time (the 10th percentile) for the period under consideration. This value is an indicator of both the magnitude and frequency of occurrence of the loudest noise events.

Level of Service C - traffic conditions (used and described in the Highway Capacity Manual-Highway Research Board, Special Report 87) where speed and maneuverability are closely controlled by high volumes, and where vehicles are restricted in freedom to select speed, change lanes, or pass.

Location Approval - the approval (described in PPM 20-8) given by the FHWA (at the request of a State Highway Department) based upon a location study report and a corridor public hearing or opportunity therefor. This action establishes a particular location for a highway section and is prerequisite to authorization to proceed with the design. (Concurrent location and design approval is sometimes given for projects involving upgrading existing roads. In these instances, location approval is not a prerequisite to authorization of design.)

Noise Level - the weighted sound pressure level obtained by the use of a metering characteristic and weighting A as specified in American National Standard Specification S1.4-1971. The abbreviation herein used is dBA.

Operating Speed - the highest overall speed at which a driver can travel on a given highway under favorable weather conditions and under prevailing traffic conditions without at any time exceeding the safe speed as determined by the design speed on a section-by-section basis.

Project Development - studies, surveys, coordination, reviews, approvals, and other activities normally conducted during the location and design of a highway project.

Truck - a motor vehicle having a gross vehicle weight greater than 10,000 pounds and buses having a capacity exceeding 15 passengers.

NOISE STANDARDS

1. Design Noise Level/Land Use Relationship

a. The design noise levels in Table 1 (page B-4) are to be used during project development of a highway section to determine highway traffic noise impacts associated with different land uses or activities in existence at the time of location approval. In addition, the table is to be used to determine the need for abatement measures for traffic generated noise for developed land uses and activities in existence at the time of location approval. Exceptions to the design noise levels may be granted on certain types of highway improvements or portions thereof when the conditions outlined in paragraph 2 are met.

b. The exterior noise levels apply to outdoor areas which have regular human use and in which a lowered noise level would be of benefit. These design noise level values are to be applied at those points within the sphere of human activity (at approximate ear level height) where outdoor activities actually occur. The values do not apply to an entire tract upon which the activity is based, but only to that portion in which the activity occurs. The noise level values need not be applied to areas having limited human use or where lowered noise levels would produce little benefit. Such areas would include but not be limited to junkyards, industrial areas, railroad yards, parking lots, and storage yards.

c. The interior design noise level in Category E applies to indoor activities for those situations where no exterior noise sensitive land use or activity is identified. The interior design noise level in Category E may also be considered as a basis for noise abatement measures in special situations when, in the judgment of FHWA, such consideration is in the best public interest. In the absence of noise insulating values for specific structures, interior noise level predictions may be estimated from the predicted outdoor noise level by using the following noise reduction factors:

Building Type	Window Condition	Noise Reduction Due to Exterior of the Structure	Corresponding Highest Exterior Noise Level Which Would Achieve an Interior Design Noise Level of 55 dBA
All	Open	10 dB	65 dBA
Light Frame	Ordinary Sash		
	Closed	20	75
	With Storm Windows	25	80
Masonry	Single Glazed	25	80
Masonry	Double Glazed	35	90

Noise reduction factors higher than those shown above may be used when field measurements of the structure in question indicate that a higher value is justified. In determining whether to use open or closed windows, the choice should be governed by the normal condition of the windows. That is, any building having year round air treatment should be treated as the closed window case. Buildings not having air conditioning in warm and hot climates and which have open windows a substantial amount of time should be treated as the open window case.

2. Exceptions

a. The design noise levels set out in these standards represent the highest desirable noise level conditions. State highway departments shall endeavor to meet the design noise levels in planning, locating, and designing highway improvements. However, there may be sections of highways where it would be impracticable to apply noise abatement measures. This could occur where abatement measures would not be feasible or effective due to physical conditions, where the costs of abatement measures are high in relation to the benefits achieved or where the measures required to abate the noise condition conflict with other important values, such as desirable esthetic quality, important ecological conditions, highway safety, or air quality.

b. A request for an exception to the design noise levels can be approved by the FHWA provided the highway agency has supported its request by a written summary report demonstrating that the following steps have been taken and outlining the results.

(1) Identified noise sensitive land uses along the section of highway in question which are expected to experience future highway traffic noise levels in excess of the design levels.

(2) Thoroughly considered all feasible measures that might be taken to correct or improve the noise condition.

(3) Weighed the costs or effects of the noise abatement measures considered against the benefits which can be achieved as well as against other conflicting values such as economic reasonableness, esthetic impact, air quality, highway safety, or other similar values, and thereby established that reduction of noise levels to desirable design levels is not in the best overall public interest for that particular highway section.

These decisions must ultimately be based upon case-by-case judgment. However, every effort should be made to obtain detailed information on the costs, benefits and effects involved to assure that final decisions are based on a systematic, consistent and rigorous assessment of the overall public interest.

(4) Considered lesser measures that could result in a significant reduction of noise levels though not to the design levels, and included such partial measures in the plans and specifications to the extent that they meet the test of economic reasonableness, practicability, and impact on other values, in the same manner as outlined in paragraph 2b(3).

c. In reviewing request for exception, the FHWA will give consideration to the type of highway and the width of the right-of-way. New freeway projects and most projects for the major reconstruction or upgrading of freeways allow for the use of noise control measures. Noise control measures are progressively more difficult to apply on other highways, particularly on local roads and streets because of numerous points of access, at-grade intersections, limited ability to acquire additional right-of-way as buffer zones, and the impossibility of altering roadway grades, constructing noise barriers and taking advantage of the terrain and other natural features.

d. Except in the most unusual situations, exceptions will be approved when the predicted traffic noise level from the highway improvement does not exceed the existing ambient noise level (originating from other sources) for the activity or land use in question.

3. Noise Level Predictions

a. Noise levels to be used in applying these standards shall be obtained from a predictive method approved by the FHWA. The predictive method and the noise level predictions should account for variations in traffic characteristics (volume, speed, and truck traffic), topography (vegetation, barriers, height, and distance), and roadway characteristics (configuration, pavement type, and grades). In predicting the noise levels, the following traffic characteristics shall be used:

(1) Automotive volume - the future volume (adjusted for truck traffic) obtained from the lesser of the design hourly volume or the maximum volume which can be handled under traffic level of service C conditions. For automobiles, level of service C is considered to be the combination of speed and volume which creates the worst noise conditions. For those highway sections where the design hourly volume or the level of service C condition is not anticipated to occur on a regular basis during the design year, the average hourly volume for the highest 3 hours on an average day for the design year may be used.

(2) Speed - the operating speed (as defined in the Highway Capacity Manual) which corresponds with the design year traffic volume selected in paragraph 3a(1) and the truck traffic predicted from paragraph 3a(3). The operating speed must be consistent with the volume used.

(3) Truck volume - the design hourly truck volume shall be used for those cases where either the design hourly volume or level of service C was used for the automobile volume.

Where the average hourly volume for the highest 3 hours on an average day was used for automobile traffic, comparable truck volumes should be used.

b. There are instances where activities associated with a particular land use (such as churches, schools, and resort hotels or residences) do not coincide with design hourly volumes. This may be particularly true when the design hourly volumes are seasonally oriented or where the activity associated with the land use is somewhat infrequent. There are other instances where changes in land use can be reasonably expected to occur before design year volumes are realized. In such instances, State highway agencies may request approval to compute noise predictions using traffic characteristics different from those specified in paragraph 3a. Such requests should be made on a project-by-project basis and should be accompanied by a justification.

TABLE 1

DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

Land Use Category	Design Noise Level - L_{10}	Description of Land Use Category
[illegible]	60dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5a(5) and (6), this PPM.
E*	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

* See paragraph 1c of this Appendix for method of application.

TABLE 1

DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

Land Use Category	Design Noise Level - L_{10}	Description of Land Use Category
A	60dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5a(5) and (6), this PPM.
E*	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

* See paragraph 1c of this Appendix for method of application.

TABLE 1

DESIGN NOISE LEVEL/LAND USE RELATIONSHIPS

Land Use Category	Design Noise Level - L_{10}	Description of Land Use Category
A	60dBA (Exterior)	Tracts of lands in which serenity and quiet are of extraordinary significance and serve an important public need, and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose. Such areas could include amphitheaters, particular parks or portions of parks, or open spaces which are dedicated or recognized by appropriate local officials for activities requiring special qualities of serenity and quiet.
B	70 dBA (Exterior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, picnic areas, recreation areas, playgrounds, active sports areas, and parks.
C	75 dBA (Exterior)	Developed lands, properties or activities not included in categories A and B above.
D	--	For requirements on undeveloped lands see paragraphs 5a(5) and (6), this PPM.
E*	55 dBA (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals and auditoriums.

* See paragraph 1c of this Appendix for method of application.

APPENDIX B

FEDERAL DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
DEPARTMENTAL POLICY: NOISE ABATEMENT AND CONTROL

U. S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

TRANSMITTAL NOTICE

1390.2

8/4/71

1. This Notice transmits the following:
Departmental Circular 1390.2, Noise Abatement and Control: Departmental Policy, Implementation Responsibilities, and Standards.

2. Explanation of Material Transmitted:
This Circular establishes noise exposure policies and standards to be observed in the approval or disapproval of all HUD projects. This Circular supersedes those portions of existing program regulations and guidance documents which have less demanding noise exposure requirements. The Circular (see paragraph 3) calls for prompt administrative actions both by Assistant Secretaries to incorporate new noise policies and standards in their program regulations and other central office instructions, and by Regional Administrators to identify existing problem cases.

3. Filing Instructions:
Insert:
1390.2

UDE:DISTRIBUTION: W-1, W-2, W-3, W-4
R-1, R-2, R-3, R-4, R-5

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

CIRCULAR

1390.2

8/4/71

SUBJECT: Noise Abatement and Control: Departmental Policy, Implementation Responsibilities, and Standards

1. PURPOSE AND AUTHORITY. It is the finding of the Department of Housing and Urban Development (HUD) that noise is a major source of environmental pollution which represents a threat to the serenity and quality of life in population centers. Noise exposure may be a cause of adverse physiological or psychological effects as well as economic losses. Accordingly, it is the purpose of Departmental policy to call attention to this threat, to encourage the control of noise at its source in cooperation with other Federal departments and agencies, to encourage land utilization patterns for housing and other municipal needs that will separate uncontrollable noise sources from residential and other noise-sensitive areas, and to prohibit HUD support to new construction on sites having unacceptable noise exposures.

   This circular thus provides policy to guide the exercise of discretion afforded in legislation on the various HUD programs. The circular is based on authority provided in:

   a. The Department of Housing and Urban Development Act of 1965 (PL 89-174) which provides that the Secretary may make such rules and regulations as may be necessary to carry out his functions, powers, and duties, and sets forth, as a matter of national purpose, the sound development of the Nation's communities and metropolitan areas; and

   b. The National Environmental Policy Act of 1969 (PL 91-190) which directs Federal Agencies to develop procedures to carry out the purposes of this Act.

2. POLICY

   a. Foster Standards and Consumer Protection. It is HUD's general policy to foster the creation of controls and standards for community noise abatement and control by general purpose agencies of State and local governments, and to support these activities by minimum national standards by which to protect citizens against the encroachment of noise into their communities and places of residence.

(1) Planning assistance. HUD requires that noise exposures and sources of noise be given adequate consideration as an integral part of urban environments in connection with all HUD programs which provide financial support to planning. This consideration shall be of a form that provides assurance that new housing and other noise sensitive accommodations will not be planned for areas whose current or projected noise exposures exceed the standards cited herein. In this regard, HUD places particular emphasis on the importance of compatible land use planning in relation to airports, other general modes of transportation, and other sources of high noise, and supports the use of planning funds to explore ways of reducing environmental noise to acceptable exposures by use of appropriate methods. Reconnaissance studies, and, where justifiable, studies in depth for noise control and abatement will be considered allowable costs.

(2) New construction. HUD discourages the construction of new dwelling units on sites which have, or are projected to have, unacceptable noise exposures*, by withholding all forms of HUD's assistance for such dwelling units. This policy applies also to college housing, group practice facilities, non-profit hospitals and nursing homes. (*See paragraph 4, Standards).

(3) Existing construction (including Rehabilitation). HUD considers environmental noise exposure an important factor in determining the amounts of insurance and other assistance. Within cost restrictions, including those set by market forces, HUD encourages modernization efforts for buildings in noisy environments when such efforts improve the noise exposure environments without substantially increasing the life of the structure. When modernization or rehabilitation would substantially increase the life expectancy of the structures, it is HUD's policy to apply noise exposure standards closer to those applicable to new construction.

(4) Grants and allowances. HUD extends such assistance to State and local governments for the alleviation of community noise as may be provided for by the Congress and as appropriate.

HUD-Wash., D. C.

(5) Information and guidance (Research and publication). HUD maintains a continuing program designed to provide new knowledge of noise abatement and control to public and private bodies, to develop improved methods for anticipating the encroachment of higher noise exposures and to deal with this encroachment and to foster better understanding of the consequences of noise. Dissemination will be made through appropriate channels.

(6) Construction equipment, building equipment and appliances. HUD encourages the use of quieter construction equipment and methods in population centers, the use of quieter equipment and appliances in buildings and the use of appropriate noise abatement techniques in the design of residential structures and other structures with potential noise problems. In appropriate circumstances, HUD will allow certain additional costs for quieter construction equipment.

(7) Acoustical privacy in multifamily dwellings. HUD encourages the use of building design and acoustical treatment to afford acoustical privacy in multifamily dwellings.

(8) Advice and cooperation. HUD welcomes advice and counsel on improved methods for dealing with the noise problem, and encourages cooperation with other units of government as well as with appropriate private and voluntary organizations.

b. Promulgate Minimum Standards. It is HUD's further general policy to promulgate minimum standards and guidelines with respect to noise abatement and control, to utilize such standards and guidelines as a uniform national policy to guide HUD program decisions, and to support appropriate existing policies and standards of State and local governments designed for noise control and abatement. In this regard, noise exposures will be divided into three groupings (to be defined in "Standards"):

(1) acceptable

(2) discretionary
--normally acceptable
--normally unacceptable

(3) unacceptable

3. IMPLEMENTATION RESPONSIBILITIES

a. Assistant Secretaries. Each Assistant Secretary shall promptly incorporate by reference the Departmental noise abatement and control policy, standards and guidelines into appropriate regulations, guidance documents, and administrative forms and procedures for programs under his jurisdiction, including guidance for A-95 notification and review. Further, each Assistant Secretary shall evaluate the effects of, and compliance with, Departmental policy, and identify program areas under his jurisdiction in which additional noise control and abatement standards or guidelines are needed.

b. Regional Administrators and Area and Insuring Office Directors

(1) One-time Report of Existing Problem Cases. Using this policy statement as a common interpretation of existing HUD program policies, each Regional Administrator based on surveys by Area and Insuring Office Directors, shall identify active and pending applications in his region which are problem cases. Any cases for which the Regional Administrator intends to seek an exception action by the Secretary should be forwarded to the Deputy Under Secretary, along with a draft Environmental Statement. This should be accomplished within 90 days of the effective date of this policy.

(2) General Policy Implementation. Regional Administrators and Area and Insuring Office Directors shall assure that this policy and the prevailing standards and guidelines are implemented in relation to all decisions and recommendations taken in their jurisdiction, effective from the date of this policy, and that specialized noise abatement and control policies now associated with individual HUD programs are conscientiously enforced.

(a) Exceptions to this policy, e.g., the approval of actions in the range of unacceptable noise exposures, are strongly discouraged. Any exception to approve sites with unacceptable noise exposures must be accompanied by a Section 102(2)C Environmental Statement (see para 3c below), and must be concurred in by the Secretary with the advice of the appropriate Assistant Secretary. Such matters should be referred to HUD Headquarters in the earliest possible stage in the decision process. After common interpretation has been established, the possibility of further delegation will be reviewed.

(b) Authority to Approve New Sites. Administratively, decisions with respect to proposed housing sites with clearly acceptable noise exposures should be delegated to the lowest possible levels within field offices. Certain positive decisions to go ahead with sites with intermediate noise exposures are to be concurred in by the Regional Administrator (see para. 4b(1). The Regional Administrator shall use his discretion, and if he is of the opinion that an important precedent or issue of national significance is involved, he shall refer the case, with recommendations, to the Secretary prior to decision. (See also paras. 3c and 4c).

(c) Surveillance of Noise Problem Areas. Regional Administrators, Area and Insuring Office Directors and all field personnel, as appropriate, shall maintain surveillance on possible noise problem areas and advise local officials and planning groups of the unacceptability of sites for noise reasons at the earliest possible time in the decision process. Subsequent to the cleanup of backlog pursuant to paragraph 3b(1) above, it is not anticipated that there will be a need to make exceptions to this policy on the basis that the unacceptable sites have been "in planning" for numerous years.

(d) Assessments and Projections of Sound Exposures. In order to assure adherence to the guidelines and standards, it is the further responsibility of each Regional Administrator to require by appropriate means assessment or authoritative measurement and projections of sound exposures for at least five years (and longer if, there is a factual basis), with respect to applications and projects under review. Recommended measurement and procedures will be provided in the issuance of each new standard or guideline.

(e) Notice to applicants. At the earliest possible stage, HUD program administrators shall determine the suitability of the acoustic environment of proposed projects, and shall notify the applicant, existing or prospective, of any adverse or questionable situations.

(f) Interdepartmental Coordination. Regional Administrators shall foster appropriate coordination with other departments and agencies in the field, particularly the Environmental Protection Administration, the Department of Transportation, military base commanders and the Veterans Administration. The field offices of the Department of Transportation should be consulted for data on existing and projected noise in the vicinity of transportation media, including airports.

c. Environmental Statements. Detailed Environmental Statements, as defined by Section 102(2)C of PL 91-190 and implementing guidelines of the Council on Environmental Quality and this Department, shall be prepared to accompany any request for an exception to this policy circular and its standards and to accompany requests to approve those cases which fall into discretionary noise exposures which are "normally unacceptable." Final Environmental Statements shall be filed with the Council on Environmental Quality 30 days prior to making decisions on the exceptional cases.

d. Office of the Secretary. The Deputy Under Secretary in the Office of the Secretary shall review and coordinate the efforts under Assistant Secretaries, and provide Departmental Evaluation of compliance with this policy.

4. STANDARDS.

a. Standards, incorporating both technical and policy considerations, will be promulgated on the basis of review of the nature of problem cases identified in the regions pursuant to paragraph 3b(1) above, and advice from consultants, R&D contracts as appropriate and further study by the Departmental Working Group on Noise. Technical noise assessment manuals may be issued by HUD to provide further guidance on noise assessment and measurement to facilitate implementation of this circular.

b. Interim Standards. The following interim standards are established. In applying these interim standards, projected noise exposures shall form the basis for decision. (See Appendix 1 for explanations of terms, definitions, and for background discussion.)

(1) External Noise Exposures: Sites for New Residential Construction (single or multifamily)

(See Chart, External Noise Exposure Standards for New Construction Sites, on following page)

CHART: EXTERNAL NOISE EXPOSURE STANDARDS FOR NEW CONSTRUCTION SITES (Measurements and projections of noise exposures are to be made at appropriate heights above site boundaries)

GENERAL EXTERNAL EXPOSURES dB(A)	AIRPORT ENVIRONS CNR ZONE */	AIRPORT ENVIRONS NEF ZONE */
UNACCEPTABLE		
Exceeds 80 dB(A) 60 minutes per 24 hours Exceeds 75 dB(A) 8 hours per 24 hours	3	C
(Exceptions are strongly discouraged and require a 102(2)C environmental statement and the Secretary's approval)		
DISCRETIONARY -- NORMALLY UNACCEPTABLE		
Exceeds 65 dB(A) 8 hours per 24 hours Loud repetitive sounds on site	2	B
(Approvals require noise attenuation measures, the Regional Administrator's concurrence and a 102(2)C environmental statement)		
DISCRETIONARY -- NORMALLY ACCEPTABLE		
Does not exceed 65 dB(A) more than 8 hours per 24 hours		
ACCEPTABLE		
Does not exceed 45 dB(A) more than 30 minutes per 24 hours	1	A

*/ See Appendix 2 for explanations of Composite Noise Rating (CNR) and Noise Exposure Forecast (NEF).

(2) Interior Noise Exposures (for new and rehabilitated residential construction).

(Note: the standards listed below are performance standards. The means required for achieving them will depend on, among other things, the external noise levels, the equipment and layout used in the building, and the noise attentuation characteristics of the building's floors and walls. These standards assume open windows unless other provision is made for adequate ventilation.)

(a) "Acceptable":

Sleeping Quarters. For the present time, HUD field personnel should consider existing and projected noise exposure for sleeping quarters "acceptable" if interior noise levels resulting from exterior noise sources and interior building sources such as heating, plumbing, and air conditioning

--do not exceed 55dB(A) for more than an accumulation of 60 minutes in any 24-hour period, and

--do not exceed 45dB(A) for more than 30 minutes during night time sleeping hours from 11 p.m. to 7 a.m., and

--do not exceed 45dB(A) for more than an accumulation of eight hours in any 24-hour day.

Other Interior Areas. HUD personnel should exercise discretion and judgement as to interior areas other than those used for sleeping. Consideration should be given to the characteristics of the noise, the duration, time of day, and planned use of the area.

(3) Insulation Between Dwelling Units

(a) "Unacceptable"

For multifamily structures, including attached single family units, floors and dividing walls between dwelling units having Sound Transmission Class (STC) of less than 45 are always unacceptable.

(4) Other land uses and existing housing. Until HUD establishes a broader range of noise exposure standards, HUD administration at all levels shall take noise into consideration in the development of policies and guidelines and in the review and decisions on specific projects. Wherever feasible, standards along the lines of the above shall be employed in a manner consistent with proposed uses, densities and construction types.

c. Philosophy in Application of Standards. HUD personnel in the exercise of discretion should be guided by a desire to prevent noise problems from coming into being and by an overall philosophy of encouraging the control of noise at its source. Particular attention should be paid to fostering land utilization patterns for housing and other municipal needs that will separate uncontrollable noise sources from residential and other noise-sensitive areas. HUD personnel should encourage use of the A-95 notification and review processes to detect potential noise problems as early as possible.

Richard C. Van Dusen

Richard C. Van Dusen
Acting Secretary

APPENDIX 1. EXPLANATION OF TERMS, DEFINITIONS AND ADDITIONAL BACKGROUND

1. Measurement and Noise Assessment Procedures. Technical definitions of acoustical terminology shall be those contained in the related current documents of the American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM). There has been a proliferation of concepts and mathematical techniques relating to sound and human response to sound. Fundamental to most all noise assessment procedures are the physical measurement of sound pressure and the concept of a level expressed in decibels. (See Appendix 2.)

   a. Sound Pressure Level Expressed in Decibels. Noise ("unwanted sound") affects the human ear through physical changes in sound pressure superimposed on the static atmospheric pressure in the presence of sound. Sound pressure has units of force per unit area.

   When a sound level meter is used, Sound Pressure Level can be determined and expressed in decibels, dB. In this case, the decibel is a logarithmic value which is referenced to the faintest sound pressure detectable by the human ear. Those requiring a more precise definition or understanding of these terms are referred to the forthcoming HUD noise assessment manuals for further discussion.

   In this circular, the decibel values, dB(A), are for those sound levels measured using the A-weighting network of a standardized sound level meter. The A-weighting network most closely approximates the response of the human ear to noise.

   Relatively inexpensive and portable metering equipment is available for purchase or, in some cases, rental. Some of the portable metering equipment also permits the accumulation of time for which the noise level at the site exceeds a given decibel setting. Sound level meters shall conform to the specifications set forth in the appropriate documents of the American National Standards Institute.

   The sound level meter is useful for measuring steady state or persistent noise and for identifying maximum sounds of intermittent noise. The A-weighted sound level, dB(A), has also been used as a first approximation in characterizing transportion noise. More sophisiticated evaluations of aircraft noise include some modifications which consider additional factors and are expressed as perceived noise in decibels such as PNdB or EPNdB. These refinements are discussed at greater length in the HUD noise assessment manuals.

b. Noise Exposure. "Noise exposure" as used in this circular is generally a combination of a noise level in decibels and a time duration for that noise level. For example, sites where existing and prolonged noise exposures do not exceed 45 dB(A) for more than 30 minutes in any 24-hour period are acceptable.

c. Composite Noise Rating (CNR). The CNR is a calculated rating for aircraft noise based on maximum sound pressure levels during a flyover, frequency of occurrence, time of day and other variables. It has been adopted by the Federal Aviation Administration (FAA) to describe the noise produced by aircraft operations in the vicinity of airports. In FAA usage, the CNR takes into account the magnitude of the sounds of individual aircraft types, the number of operations of each type on each runway, and the time of day. The numerical value of CNR is related to an expected range of community response.

The FAA has calculated CNR's for a number of domestic airports, and has divided CNR's into three zones -- corresponding to our acceptable discretionary, and unacceptable, respectively -- according to the expected community response, as shown in the following chart:

Chart for Estimating Response of Residential Communities from Composite Noise Rating.

Composite Noise Rating		*Zone*	*Description of Expected Response*
Takeoffs and Landings	*Runups*		
Less than 100	Less than 80	1	Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.
100 to 115	80 to 95	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.
Greater than 115	Greater than 95	3	Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

When advice and guidance are required in the analysis of property sites in the vicinity of military airports, the request for existing data and projections should be made initially to the Commander of the military base and subsequently to his designee.

Definition and Calculation of Noise Exposure Forecasts (NEF) or Composite Noise Ratings (CNR) shall be in accordance with the current DOT-FAA practices.

d. Noise Exposure Forecasts (NEF). The NEF is a calculated environmental rating which refines and replaces the CNR calculations for aircraft by including corrections for the presence of pure tone and duration of peak levels within the composite of intermittent noise. As currently used, it has validity only for airports.

The Department of Transportation (DOT) is converting from CNR to Noise Exposure Forecasts (NEF's). DOT has a contract for the calculation of NEF's at some 29 commercial and general aviation airports, and will soon have an intramural capability for producing NEF's for any civil aviation airport. The new NEF ratings for areas around commercial airports should be sought through FAA Airport Regional Offices.*/

The following categories correspond roughly to the categories of community response calculated originally for CNR's (see above).

Noise Exposure Forecasts

Category	Rating	Disposition in HUD
A	less than 30	Acceptable
B	30 to 40	Discretionary
C	more than 40	Unacceptable

For data on anticipated noise levels in the vicinity of military airports, the request should be made initially to the Commander of the base and subsequently with his designee.

*/ Until December 31, 1971, interim requests for NEF's should be made directly to FAA's Office of Environmental Quality (Attention EQ-1, Washington, D. C. 20590. Requests should be limited to applicants' sites within about three miles of a runway during this period.

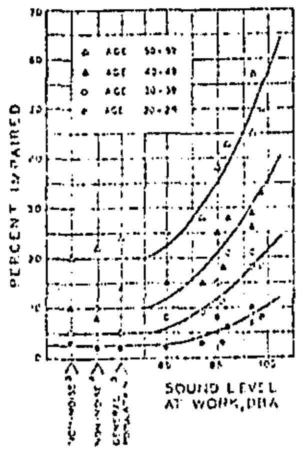
e. Sound Transmission Class (STC) is a single-number rating which provides an estimate of sound transmission loss performance of a wall or floor as related to airborne sound generated by a limited class of household sound sources. The higher the number the better the performance.

2. Concepts Relating to Adverse Consequences of Noise. Noise is objectionable for commonsense reasons because it destroys the serenity of one's environment. Beyond that there are a number of specific concepts or ideas relating to noise. Current research efforts are directed toward establishing firm findings about certain noise phenomena and their consequences.

a. General Hearing Loss or Damage. High intensity noises even of relatively short duration such as blasts or explosions are known to have destroyed or severely limited the hearing sense. Moreover, highly amplified rock-and-roll music, sports shooting, and other recreational uses might produce sound levels capable of producing hearing loss especially if exposures are prolonged or recurrent. Continuing exposures to levels exceeding 100dB(A) lead to temporary and, eventually, to permanent hearing loss.

b. Impaired Hearing for Speech Communication. Prolonged exposure to less intensive noise is known to impair hearing of speech communications. The following table shows the hearing impairment resulting from 8-hour exposures to industrial noise over a long period.

FIG. 1. Prevalence of impaired hearing in various populations. Each point indicates on the vertical scale the percentage of individuals having impaired hearing in a group exposed continuously at work to the A-weighted sound level indicated on the horizontal scale.



c. Speech Interference Levels. Background noise above certain levels interferes with one's ability to understand oral communication. The following figure illustrates some current knowledge of this phenomenon.

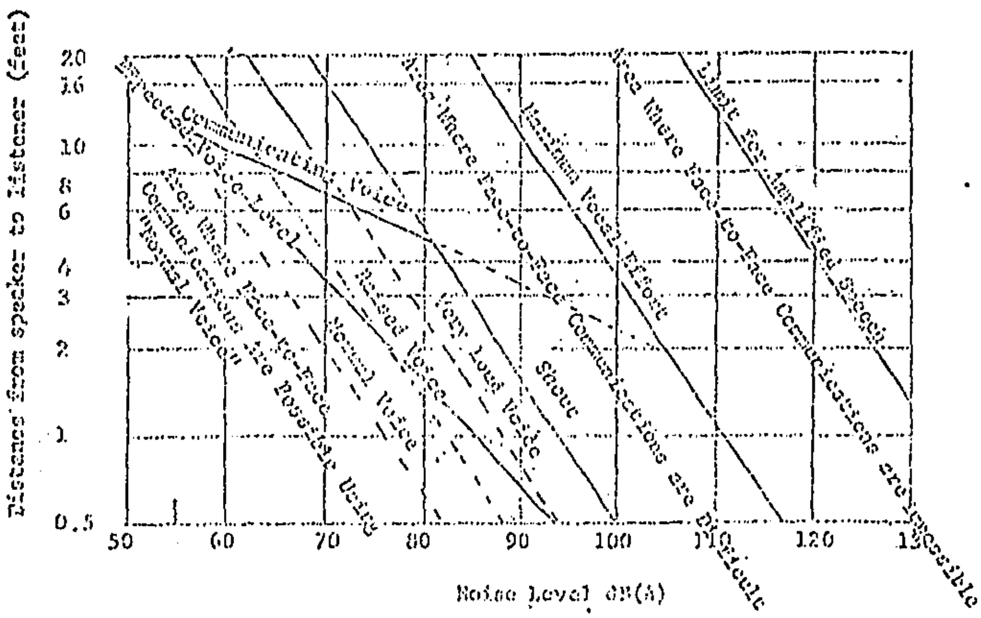


Figure 2 - Voice level and distance between talker and listener for satisfactory face-to-face speech communications as limited by ambient noise. Along the abscissa is the A-weighted sound level meter reading (dB(A)).

(SIL-Past, Present, and Future, J. C. Webster, Sound and Vibration, August, 1969)

d. Sleep Interference. Knowledge is less firm in this area and a series of qualifications is associated with many of the findings, including significant individual difference and becoming inured to certain noise levels (perhaps by hearing loss). Nevertheless, "sleep interference" would seem to

APPENDIX C

FEDERAL HIGHWAY ADMINISTRATION

COMPUTER SIMULATION - TRAFFIC NOISE PREDICTION

4.0 METHOD FOR COMPUTERIZED PREDICTION OF HIGHWAY NOISE LEVELS

This section of the manual constitutes a user's manual for the computerized procedure for highway noise level prediction. It is written in the form of a step-by-step set of instructions for formatting input data to the computer program. For clarity, a sample problem is presented along with each portion of the instructions.

FORMAT AND SEQUENCE OF DATA INPUT

The computer program is written to accept input data from a card reader. Three types of input data are allowed by the program:

1. Integer - A fixed-point number written without a decimal point. All integers must be right-justified within the allotted field of the input card.

2. Real constant - A floating point number written with a decimal point. The real number may normally be situated anywhere within its allotted field on a card.

3. Alphanumeric - Any combination of alphabetic and numeric characters. Alphanumeric data may be situated anywhere within the allotted field on a card.

The first card read by the program is a title card, with arbitrary alphanumeric descriptive information in columns 2 through 60. Up to five blocks of data may then follow, in arbitrary sequence, with information describing the following:

1. Program initialization parameters

2. Road and vehicle parameters

3. Barrier parameters

4. Ground cover parameters

5. Receiver parameters.

Each of these five data blocks must be preceded by a control card containing an integer between 1 and 5, located in column 5. A card with the integer 6 in column 5 indicates the end of the input data set for one problem. Multiple problems may be run back-to-back, with each new problem starting with a title card and ending with a card having the integer 6 in column 5. The entire situation need not be redefined for each new problem. It is sufficient to specify only those aspects of the new problem which differ from the problem immediately preceding. Any blocks of input data not redefined for the new problem will assume the same values as that in the preceding problem.

The first of a series of problems must specify initialization parameters, vehicle and road parameters, and receiver locations. If no information is entered for barrier parameters or for ground cover parameters for the first problem, the computer program will assume that no barriers or additional ground cover exists, and all calculations involving barriers or additional ground cover will be bypassed. If barrier or additional ground cover parameters are entered for a problem, however, the same parameters will be included in subsequent problems until these parameters are redefined or set to zero.

Specifications for each of the five blocks of data input, accepted by the computer program, are given below.

PROGRAM INITIALIZATION PARAMETERS

Initialization parameters must appear in the first of each *series* of problems, but need not be repeated for succeeding problems in the same series. A control card must precede the block of data cards to identify the type of data being entered. This control card must have the integer 1 in column 5. Six or nine cards must follow, in the indicated sequence to enter initial information about:

1. Receiver height adjustment
2. Number of frequency bands
3. Standard deviation of noise levels of passenger cars
4. Source height adjustment for passenger cars
5. Standard deviation of noise levels of highway trucks
6. Source height adjustment for highway trucks
7. Standard deviation of noise levels of "new vehicles"
8. Source height adjustment for "new vehicles"
9. Source noise spectrum for "new vehicles".

For highway noise level predictions considering only passenger cars and highway trucks of the type in common use in 1972, only the first six cards need be included in the data block. If a "new vehicle" is to be considered in the predictions (for example, a future quieter truck conforming to anticipated regulations), nine cards must be included, using the formats described below.

For the first eight data cards, an initialization parameter is entered as a real constant (that is, with a decimal point included) in columns 1 through 10 of each data card. Column 15 must contain an integer (that is, with no decimal point) between 1 and 8 inclusive, to identify the parameter as indicated in the above list.

If desired, alphanumeric information may be included in columns 31 through 80, for convenience and specific indentification. If no alphanumeric information is included in columns 31 through 80, parameter identification in agreement with the above list will be printed automatically in the output listing. The last of the set of six cards (if only the first two types of vehicles are being considered) or eight cards (if the "new vehicles" are being included) must contain the letter L in column 20 to signify the end of the initialization parameters.

If the "new vehicle" option is to be included in the series of problems for which initialization information has been entered, and eight data card entries have been included above, a ninth card must also be included to contain the overall A-weighted noise level of the desired "new vehicle", and the eight A-weighted octave-band noise levels, all at the standard reference distance of 50 feet. These values are entered as nine real constants (that is, with decimal points), each left-justified in the fields bounded by columns 1 through 5, 6 through 10, 11 through 15, etc. Thus, five columns are allowed for each of the nine values including the required decimal point.

To indicate more clearly the use and purpose of each of the initialization parameters, they are discussed in more detail below. The receiver height adjustment (Item 1) is a height in feet to be added to the Z-coordinate of all receivers specified in data block 5. For normal conditions, it will be 0.0. For special cases, such as the comparison of noise levels at the ground floor of a building with noise levels at a higher floor, a height adjustment of 10.0 feet per floor is recommended. Similarly, to adjust for the normal ear height of a person standing at each of the specified receiver locations, a height adjustment of 5.0 feet is recommended. Negative height adjustments are allowable, and will not cause the program to assume that the receiver is shielded by the ground.

The number of frequency bands for which calculations are to be performed is indicated by a real constant from 1.0 through 9.0. By using the number 1.0, all attenuations due to atmospheric absorption, ground absorption, and barrier diffraction will be calculated for a frequency of 500 Hertz, and the overall A-weighted noise level of each vehicle type will be considered as the source level. Calculations using only the frequency band centered around 500 Hz provides a fair approximation for typical road traffic noise conditions. By using the number 9.0 for this initialization parameter, calculations will be made for all eight octave-bands, with center frequencies from 62.5 through 8,000 Hz. The final results will be more accurate, with some increase in total computer time. By using any number N between 1.0 and 9.0, the attenuations will be calculated for the 500 Hz. band and for N - 1 octave-bands, beginning with the 62.5 Hz. band. Normally, all octave-bands are specified (that is, the number 9.0 entered) to obtain maximum accuracy in the resulting noise level predictions.

The standard deviation for the vehicular noise sources is the standard deviation of the reference noise levels at the reference distance (r_0 = 50 feet). The value recommended for passenger cars is 2.5 (dB), and for highway trucks is 3.5 (dB).

The height adjustment for the vehicular noise sources represents the effective height above the roadway from which the individual vehicle's noise may be considered to originate. Proper selection of source height is particularly important for situations in which barriers are located near the roadway, since the higher the effective noise source, the less effective is a barrier of fixed height. A source height adjustment of 0.0 is recommended for passenger cars, since tire noise is assumed to be the dominant noise source. Other height adjustments for engine or fan noise should not be made. A height adjustment for highway trucks of 8.0 feet is recommended, to represent exhaust stack noise.

If the "new vehicle" option is to be included in the calculations, the A-weighted octave-band levels and overall A-weighted noise level of the assumed vehicle must be estimated and entered in the initialization parameter data block. The corresponding standard deviation and source height adjustment must also be estimated and entered. Usually, the source height adjustment will be closely related to the octave-band spectrum used. For example assume that substantial advances are made during the next five years in reducing exhaust, intake, fan, and overall engine noise levels for trucks, so that the dominant noise signature becomes the tire noise. In this case, the A-weighted spectrum levels associated with tire noise alone may be used for an assumed "new vehicle" truck, and a source height of 0.0 feet assigned for the "new vehicle". Lacking any other guidance, a standard deviation of 3.5 (dB) should also be assigned the "new vehicle".

The following illustration represents a sample input data block for program initialization parameters, with a "new vehicle" included. The "new vehicle" information represents an estimate of a future quiet highway truck, for which tire noise has become the dominant noise source and is similar to currently-used tires with a neutral rib tread pattern.

1 Name 5	6	10 Operation 14		16 20	Operand 25	30	35	40	45
SAMPLE		HIGHWAY							
1									
5.			1						
9.			2						
2.5			3						
0.			4						
3.5			5						
8.			6						
3.5			7						
0.			8	L					
77.0	52.0	62.0		68.0	72.0	72.0	70.0	64.0	50.0

ROAD AND VEHICLE DATA

This data block describes the roadways and the vehicular traffic flowing on each roadway. The identifying control card preceding this data block must have the integer 2 in column 5, and a second integer right-adjusted in columns 6 through 10 to indicate the number of roadways.

The number of roadways to be specified depends on the number of traffic arteries with constant hourly traffic flow and the relative distance of the observer points at which noise levels are to be predicted. For a receiver located far from a multi-lane highway without ramps, consideration of a single roadway is sufficient, with that single roadway assigned the total traffic flow of the multi-lane highway. For receiver locations close to the highway, each parallel traffic lane should be described individually. Ramps onto highways and independent nearby highways are treated as separate roadways.

Following the control card, a set of one or more cards is required to provide vehicle data for the first roadway. Each such vehicle card must contain a real constant (that is, with a decimal point included) in columns 1 through 10 to indicate the traffic flow in vehicles per hour, a real constant in columns 11 through 20 to indicate vehicle operating speed in miles per hour, and the integer 1, 2, or 3 in column 25 to indicate the vehicle type. The final card of the vehicle input set must have, in addition to the other information, a letter L in column 31.

An integer 1 in column 25 indicates that the described vehicle data on that card are for passenger cars, an integer 2 indicates highway trucks, and an integer 3 indicates that the vehicles are "new vehicles". Up to five cards can be used for each vehicle type for each roadway section, in random order, to specify traffic flow at different operating speeds. Unless the speed distributions are known from measurements, the Highway Capacity Manual 1965 is recommended for determining the average operating speed from the hourly traffic volume assumed.

Following the vehicle information for the first roadway, the end-points of that roadway are defined by Cartesian coordinates, assuming a straight-line section. The X-Y plane is parallel to sea level, and the Z-coordinate specifies the height above sea level or any other reference plane parallel to sea level. All coordinates are in feet. The X-, Y-, and Z-coordinates are entered as real constants (that is, with the decimal point included) in the fields bounded by columns 1 and 10, 11 and 20, and 21 and 30, respectively. The card with the last end-point of a roadway must have the letter L in column 31. A roadway may consist of as many as ten straight-line sections (that is, have eleven end-points defined). A roadway containing more than ten sections should be treated as two or more roadways, each have ten or fewer sections.

Vehicle and road data are specified for the remaining roadways in a similar manner. Data must be specified for as many roadways as indicated by the second integer on the control card at the beginning of this data block. The following illustration represents a sample input data block for road and vehicle data.

Name (1–8)	Operation (10–14)	16–20	Operand (21–25)	26–30	31–35
2	4				
1350.	50.		1		
75.	50.		2		L
0.	6.		0.		
10000.	9.		0.		L
1250.	50.		1		
50.	50.		2		L
-10000.	6.		0.		
0.	6.		0.		L
100.	45.		1		
25.	45.		2		L
-10000.	5000.		0.		
0.	6.		0.		L
500.	60.		1		
50.	60.		2		L
-10000.	-6.		0.		
10000.	-6.		0.		L

BARRIER PARAMETERS

The data block with information about obstacles (i.e., "barriers") in the sound propagation paths is headed by a card having a 3 in column 5 and an integer right-justified in columns 6 through 10 to indicate the number of barriers.

The top contour of a barrier is approximated by a straight-line segment, and no sound is assumed to penetrate below this contour. A single barrier may contain up to ten sections. The end points of these sections are specified in the same format as the end points of road sections, except that the last point of a line is identified by an A or an R in column 31 (rather than L as for roads).

An R in column 31 indicates that the preceding points describe the top line of a rigid plane oriented perpendicularly to the ground, such as artificial barriers without absorbing material, facades of buildings, rigid walls of a depressed highway, etc. (i.e., a reflecting barrier).

An A in column 31 inidcates that the preceding points describe the top line of a tilted barrier, a barrier with absorbing material, an earth berm, a hill, or some other obstacle that reflects sound either weakly or towards the sky, directly or via a ground reflection (i.e., an absorbing barrier).

The following illustration represents a sample input data block for barrier parameters.

3	2		
-100.	-20.	20.	
200.	-20.	20.	R
100.	20.	6.	
10000.	20.	6.	A

GROUND COVER PARAMETERS

The control card for this data block must contain the integer 4 in column 5 and an integer right-adjusted in columns 6 through 10 to indicate the number of absorptive ground strips. The areas of ground cover are described by the center line and the width of rectangles. The X-, Y-, and Z-coordinates of one end point of the center line are given as real constants in the fields between columns 1 and 10, 11 and 20, and 21 and 30, respectively of a single card. The same card contains the width of the rectangle in real constant format in the field between comumns 31 and 40. The X-, Y-, and Z- coordinates of the other end point of the center line are written on the next card together with a G or a T in column 31.

A G identifies the ground cover as high grass or shrubbery, and a T identifies the ground cover as trees. The rectangles with ground cover must not cross a road.

The following illustration represents a sample data block for ground cover parameters.

```
Name             Operation       Operand
1          8 10      14 16    20       25        30     35
    4    1
0.        50.       0.        50.
-200.     150.      0.        T
```

RECEIVER DATA

The control card preceding input data for receiver locations must contain the integer 5 in column 5, and an integer right-adjusted in columns 6 through 10 to indicate the total number of receivers desired. A card is provided for each receiver to indicate the X-, Y-, and Z-coordinates for each receiver location. These data are entered as real constants in the fields bounded by columns 1 and 10, 11 and 20, and 21 and 30, respectively. In the computer program listed in Appendix B of this manual, a maximum of fifteen receivers is allowed. This, of course, can be easily increased by appropriate changes in the program dimensions.

A receiver cannot be located on a road, nor on, over, or under the top line of a barrier, nor on a ground absorbent strip. In each case, the distance from that receiver to the roadway, barrier, or ground strip would be zero, and the computer program cannot handle a zero distance. A receiver can be located between two adjacent ground absorbent strips, if the location is not identical with an end point of the ground strip center line.

The following illustration represents a sample data block for receiver locations.

```
Name             Operation       Operand
1          8 10      14 16    20       25        30     35
    5    5
0.        100.      0.
50.       100.      0.
100.      100.      0.
150.      100.      0.
200.      100.      0.
    6
```

ERROR MESSAGES

Errors are detected by the computer in the following cases.

1. If the top line of an obstacle intersects a roadway, the computer prints out

   ILLEGAL BARRIER INTERSECTS ROADWAY

   together with the following data: receiver number, roadway number, road section number, barrier number, barrier section number.

   The computer then proceeds with the next case.

2. If the center line of a ground absorbent strip intersects a roadway, the computer prints out

   ILLEGAL GROUND STRIP INTERSECTS ROADWAY

   together with the following data: receiver number, roadway number, road section number, ground strip number.

   The computer then proceeds with the next case.

3. If the number of reflections contributing to the sound level at a receiver exceeds 10, the computer prints out

   TOO MANY REFLECTIONS

   together with the following data: receiver number, roadway number, road section number.

   The computer then proceeds with the next receiver.

4. Should the geometry of the situation be such that a line segment that is needed for computation appears to have zero length, the program continues with the next receiver without giving an error message.

DATA OUTPUT

The data output starts immediately after the input file is read. The heading TRAFFIC NOISE PREDICTION is typed and input data are then typed in the following order:

Title card;

Program initialization parameters (for the first of a series of cases only);

Vehicle and road parameters, where all parameters of Type 1 vehicles (passenger cars) on a given road are typed first, following by parameters for Type 2 vehicles (trucks), and Type 3 vehicles ("new vehicles").

Barrier parameters, with the type of barrier, A or R, given in parentheses after the barrier number;

Ground cover parameters, with identification G or T following the ground strip number in parentheses;

RECEIVER DATA

The title card is then printed out again together with a headline for the receiver identification. The output consists of the following data for each receiver. After the sound pressure level for a given receiver has been calculated, the receiver number and coordinates are typed. The octave band center frequencies are typed out; underneath them are the calculated A-weighted octave band levels. The final typeouts consist of the A-weighted overall level of the energy mean, LE(A), the noise pollution level, LNP, and percentile levels, L90, L50, and L10. These levels appear after the octave band center frequencies and the calculated octave band levels of the A-weighted mean energy are typed out. Note that L10-L50 = L50-L90, since a first-order approximation based on a Gaussian distribution of A-weighted sound pressure levels is used.

RECOMMENDATIONS FOR USAGE

The computation time required to compute sound levels at a given receiver increases with the number of roadways, barriers, and ground strips, but it is independent of the total number of receivers. Therefore, if one wishes to analyze a situation in which many receivers and barriers are located along or near a highway many miles in length, we suggest that the problem be modularized so that a smaller geographical area can be associated with each receiver.

Maps showing the elevation of the terrain should be used for a detailed description of the roadway and of top lines of hills (barriers of Type A). It should be borne in mind that the computer program accounts for 5 dB attenuation for sound rays grazing over hills.

Results obtained when ground absorption is considered should be interpreted with caution. Because of the lack of reliable data in this area, results from the first-order approximations used in the computer program are intended for comparison with field data rather than for accurate prediction purposes.

SAMPLE CASES

In order to illustrate the proper coding of problems for the prediction of highway traffic noise levels, and to provide sample cases for use by potential users of the computerized procedure in verifying the proper operation of their computer program, four sample cases are explained below. The second, third, and fourth sample problems also illustrate the back-to-back use of the program, through changes only to those portions of the preceding problem for which another situation is desired.

Figure 9 illustrates a sample highway situation, consisting of a two-lane highway, with 12-foot wide lanes and no median strip. A single feeder lane joins the highway, and traffic flow consists of passenger automobiles and highway trucks. A 20-foot-high barrier wall is located on one side of the intersection, with the inner side of the wall relatively smooth and vertical. Thus, this wall will act as a reflecting surface. A six-foot-high earth berm is also located near the highway, acting as an absorptive barrier. A stand of trees is located along the feeder lane. Noise levels are desired at five locations along the highway, at a distance of 100 feet from the highway centerline. This is the sample case which has been used for illustration of each of the five data blocks, previously shown in this section of the manual.

The input data for this sample problem are repeated below, and the resultant output data are also shown.

As Sample Problem 2, it is desired to determine the effect of the 20-foot-high reflecting barrier wall alongside the highway. To determine this effect, the first sample problem can be repeated, eliminating that barrier, and the results compared. This new problem may be run simply by redefining the barrier parameter data block only, using a new title card for identification, and the remainder of the input data from the first problem will be retained. This is illustrated as Sample Problem 2 input, with the output results following Sample Problem 1 below.

As a third comparison, it is desired to determine if the stand of trees alongside the feeder lane has any effect on the predicted noise levels. Again, this third problem may be run back-to-back with the two preceding problems, by eliminating the tree absorbing strip. In this instance, data block 4 is redefined after the new title card by entering the integer 0 right-adjusted in the field bounded by columns 6 through 10, as shown in the data input coding below. Again, all other input data are retained, and the third sample problem is then run as shown.

As a final example, it is desired to determine if the possible future introduction of quieter trucks will reduce the predicted noise levels significantly. Again, the fourth sample problem may be run back-to-back with the three preceding problems by redefining only the road and vehicle data block. In this case, the initialization parameter data block already contains the estimated description of the noise characteristics of the predicted quieter highway trucks. If this were not the case, the initialization parameter data block, and the entire problem situation, would have to be reentered as input data. In this case, however, the anticipated quieter truck was estimated on the basis of tire noise becoming the dominant source of noise, and that tires similar to currently-used neutral rib tread pattern types would be standard. Thus, the height adjustment for this source was assumed to be 0.0 feet, and the standard deviation was assumed to be 3.5 dB. The road and

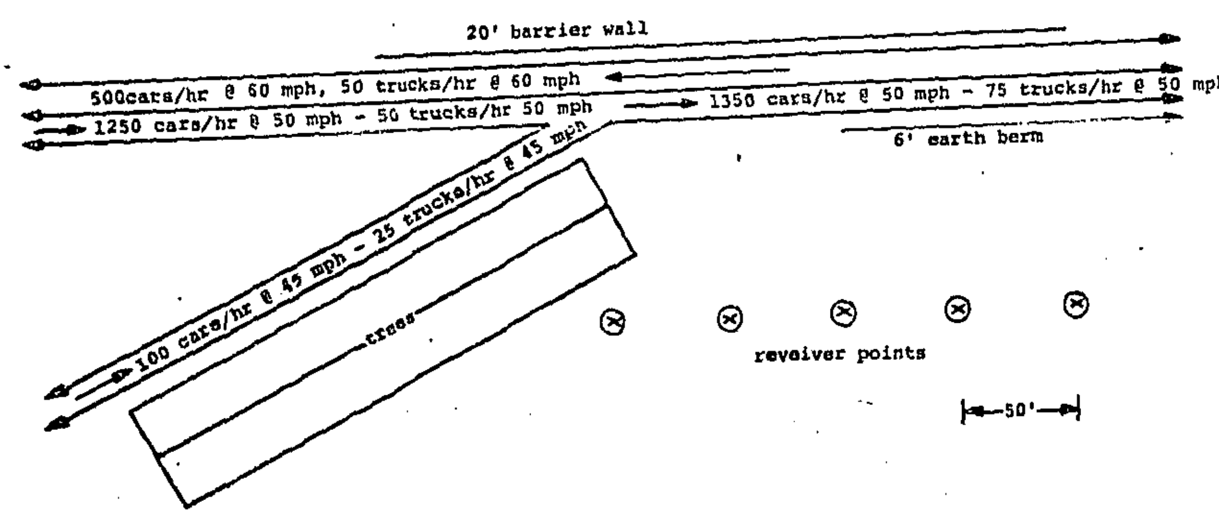


Figure 9. Sample Problem

vehicle data block are redefined, following the new title card, and the fourth sample problem then run as shown.

For general information using the IBM 7094 computer at the Transportation Systems Center, these four sample problems required 1.50 minutes of computer time to compile and execute.

Quite often, a rough data work sheet is useful in translating engineering data from maps or charts into the general format for coding as computer input. An example of such a work sheet is also included in the following example for the first sample problem described above. Because of the vast variety of possible highway situations, a uniform work sheet may be impractical. Users may find it convenient to prepare similar work sheets for their own particular repetitive situations.

It is of interest to compare the results of the four sample problems, to obtain some feeling for the relative importance of the reflecting barrier and tree strip in the magnitude of the predicted noise levels, and also to compare the relative advantages to be gained through the use of quieter trucks on a highway such as the case assumed. Removal of the reflecting wall opposite the receiver locations reduced the median (L_{50}) noise levels by approximately 1 1/2 dBA at the receivers nearest the feeder lane intersection, and approximately 1/2 dBA opposite the end of the barrier wall. The ten-percentile-levels were similarly reduced. Removal of the tree strip increased the levels at the first receiver location by approximately one decibel, but had little effect on the more distant receiver locations. The introduction of the quieter trucks, even though trucks constitute only about 7% of the vehicular traffic in the sample problems, reduced the median noise levels roughly 3 to 5 dBA, and the ten-percentile-levels roughly 6 to 7 dBA. The greater reduction in the L_{10} levels was expected, since trucks are the major contributor to the higher value, less frequent noise levels.

WORK SHEET

HIGHWAY NOISE PREDICTION

PROBLEM TITLE: Sample Problem 1

INITIALIZATION PARAMETERS:

RECEIVER HEIGHT ADJUSTMENT = 5. FT

NUMBER OF FREQUENCY BANDS = 9. BANDS

STANDARD DEVIATION FOR PASSENGER CARS = 2.5 dB

SOURCE HEIGHT ADJUSTMENT FOR PASSENGER CARS = 0. FT

STANDARD DEVIATION FOR HIGHWAY TRUCKS = 3.5 dB

SOURCE HEIGHT ADJUSTMENT FOR HIGHWAY TRUCKS = 8.0 FT

STANDARD DEVIATION FOR "NEW VEHICLES" = 3.5 dB

SOURCE HEIGHT ADJUSTMENT FOR "NEW VEHICLES" = 0. FT

NOISE SPECTRUM FOR "NEW VEHICLES" AT 50': OVERALL SPL = 77.dBA

OCTAVE-BAND LEVELS = 52., 62., 68.,

72., 72., 70., 64., 50., dBA

ROADWAY AND VEHICLE PARAMETERS:

ROADWAY #1

1350 CARS/HR @ 50 MPH

75 TRUCKS/HR @ 50 MPH

\- NEW VEHICLES/HR @ - MPH

X = 0, Y = 6, Z = 0 FT

X = 10^4, Y + 6, Z = 0 FT

ROADWAY #2

1250 CARS/HR @ 50 MPH

50 TRUCKS/HR @ 50 MPH

\- NEW VEHICLES/HR @ - MPH

X = -10^4, Y = 6, Z = 0 FT

X = 0, Y = 6, Z = 0 FT

WORK SHEET PAGE 2

ROADWAY #3	100 CARS/HR @ 45 MPH
	25 TRUCKS/HR @ 45 MPH
	- NEW VEHICLES/HR @ - MPH
	X = -10^4, Y = $-5x10^3$, Z = 0
	X = 0, Y = 6, Z = 0
ROADWAY #4	500 CARS/HR @ 60 MPH
	50 TRUCKS/HR @ 60 MPH
	- NEW VEHICLES/HR @ - MPH
	X = -10^4, Y = -6, Z = 0
	X = 10^4, Y = -6, Z = 0
BARRIER PARAMETERS:	X = -100, Y = -20, Z = 20
BARRIER #1(R)	X = 200, Y = -20, Z = 20
BARRIER #2(A)	X = 100, Y = 20, Z = 6
	X = 10^4, Y = 20, Z = 6
GROUND COVER PARAMAMETERS:	X = 0, Y = 50, Z = 0
STRIP #1 (T)	X = -200, Y = 150, Z = 0
	WIDTH = 50

RECEIVER PARAMETERS:

RECEIVER #1	X = 0, Y = 100, Z = 0
RECEIVER #2	X = 50, Y = 100, Z = 0
RECEIVER #3	X = 100, Y = 100, Z = 0
RECEIVER #4	X = 150, Y = 100, Z = 0
RECEIVER #5	X = 200, Y = 100, Z = 0
RECEIVER #6	X = -, Y = -, Z = -