N-96-01
II-A-547

REGULATION OF NOISE IN URBAN AREAS

by

William S. Gatley, Ph.D
Professor of Mechanical and Aerospace Engineering

Edwin E. Frye
Graduate Assistant
Department of Mechanical and Aerospace Engineering

University of Missouri-Rolla

A MANUAL PREPARED FOR WORKSHOPS

in

St. Louis - August 23, 1971

Kansas City - September 1, 1971

Springfield - September 15, 1971

August 1971

reproduced with permission
by the
Environmental Protection Agency
Office of Noise Abatement & Control

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I NOISE LEGISLATION: TRENDS AND IMPLICATIONS

INTRODUCTION

Noise has recently been labelled the 'fourth pollutant' and defined by some as the 'unwanted sound' that pervades our work environments and the privacy of our homes. This concern for noise and its effects has resulted due to our nation's increasing population density, the increasing use of mechanized conveniences, the influx and growing use of mass transportation systems, and the public's awareness that noise not only 'annoys' and can increase everyday tensions and anxieties, but at certain levels can cause permanent hearing loss.

In order to curb the 'noise problem' legislators and public officials began applying legal controls to noisy activities and machines. Noise legislation is usually written to accomplish one or both of two objectives: to minimize loss of hearing, primarily among industrial workers; and/or to reduce irritating or annoying noises to "acceptable" levels.

LEGISLATION TO REDUCE INDUSTRIAL HEARING LOSS

The Federal Council for Science and Technology has stated that at least a million workers now living suffer from some degree of deafness. Estimates are that another 6 to 16 million are exposed to noise levels which may cause eventual hearing loss.

Examples of legislation designed to reduce occupational deafness are the Walsh-Healey Act Amendments (1969); provisions of the Occupational Health and Safety Act of 1970*; and a number of state laws, most of them similar or indentical to federal legislation. Noise exposure limits specified are based on studies of thousands of workers over the past twenty years.

All feasible administrative and engineering controls must be utilized to reduce noise levels to permissible limits; only as a last resort is ear protection to be substituted for noise reduction.

Audiometic testing is an important part of the hearing conservation programs anticipated by federal regulations. Testing of new employees protects the employer from possible compensation for hearing loss incurred prior to employment. Periodic testing thereafter indicates the amount and duration of temporary threshold shift in hearing produced by noise exposure. Even if permissible noise exposures are not exceeded, some employees may experience eventual hearing loss (for which the employer is liable) because they are more "noise sensitive" than others.

Although enforcement of the Walsh-Healey regulations has been relatively minor to date, the future will surely bring increasing application of noise exposure limits to a wider and wider range of industrial activity.

---

*This act applies the Walsh-Healey noise exposure limits to all businesses in interstate commerce.

In turn, equipment manufacturers will experience increasing pressure not only to design quieter machines but also to include meaningful acoustic performance data in equipment specifications. This data will serve as a basis for predicting noise levels within and around new plants during initial design stages. As a result, the acoustic environments will be "designed-in" rather than "added-on" as an afterthought.

LEGISLATION TO REDUCE ANNOYANCE

A second major objective of noise legislation is to reduce irritating or annoying sounds (primarily in urban areas) to "acceptable" levels. Restrictions are usually in the form of city, county, or state ordinances and regulations in several categories:

1. Noise in residential areas, including sources within such areas (air conditioning systems, automobiles, construction equipment, etc.) as well as noise produced at residential area boundaries from external sources.
2. Noise in commercial-industrial areas, primarily at property lines between adjoining businesses and at boundaries between areas zoned for different uses.
3. Noise from aircrafts and airports, including landing, takeoff, and taxiing. The Federal Aviation Administration has specified permissible noise levels at or near airport facilities for individual aircraft, while local regulations attempt to control number of flights and use of runways.

4. Noise from motor vehicles, including certification of new models. California and Connecticut are examples of two states with legislation specifically designed to control freeway noise.
5. Noise in buildings, especially between adjoining units in multi-family dwellings. Materials or performance levels are specified for party walls, floor-ceiling constructions, and other noise paths.

Drafting and enforcing fair, effective legislation to control irritating or annoying noises is a difficult task. The provisions have generally taken the form of nuisance ordinances which restrict or prohibit certain activities or the use of equipment such that they do not create a 'noise nuisance' to the surrounding area. The nuisance ordinance has been effective in many instances, but the subjective analsis inherent in its application has resulted in a questioning of what is unnecessary, unreasonable, or acceptable.

A relative newcomer to noise control legislation has been the performance code. This type of ordinance incorporates maximum noise levels in decibels that are permissible at a given location. The objective criteria of performance codes have given relief from the subjective connotations of the noise nuisance ordinance. However, determining noise levels that are realistic, equitable, acceptable, and enforceable for a given community needs special and careful consideration. In some instances, noise levels that were specified did not relate to the environment or location to which they applied. The noise levels prescribed were, in effect, unrealistic and in some cases physically impossible to achieve in an urban community.

In summary, the control of urban noise is complicated by two factors:

1. What are "acceptable" noise levels? Susceptibility to annoyances varies between individuals and their activities. If the permissible levels are too liberal, the legislation fails to accomplish its intended purpose. If the permissible levels are too restrictive, the legislation is unenforceable and is usually employed as a threat only in extreme cases.

2. What criteria should be employed to evaluate given noises, and how should measurements be obtained? The A-weighted sound pressure level is easiest to measure, but is not a uniformly good indicator of annoyance for all classes of noise. Octave band criteria may be more accurate for assessing annoyance, but are more time-consuming, costly, and difficult to employ.

Within the next two decades, effective regulation and control of urban noise will become commonplace in the United States. Action is now proceeding in several areas to accomplish this objective:

1. Trade associations and professional societies are developing standardized methods and criteria for product noise certification.

2. Land-use planning, the key to containment of objectionable noise within specified boundaries, is growing rapidly.

3. Experience with noise regulation throughout the world is being compiled, analyzed, and disseminated through conferences, reports, and technical journals.

A primary purpose of the text which follows is to provide public officials responsible for drafting, enacting, and enforcing noise legislation with information about the characteristics of noise, methods of measurement and evaluation, and current trends in noise legislation. However, urban noise control goes beyond implementing engineering noise control knowledge into the legal format of a code. Enforcement procedures, land use and urban planning concepts and public attitudes are all part of the total abatement scheme. These areas are investigated in some detail.

II SOME FUNDAMENTALS OF SOUND AND ACOUSTIC TERMINOLOGY

INTRODUCTION

In order to have a better understanding of the characteristics of sound and the meaning of acoustical terms, a foundation of basic principles, definitions, and techniques is essential. However, when one enters into a discussion of the characteristics and properties of sound, it is possible for the discussion to quickly become comprehensive and technical. Such an approach in this manual would be incontrast to its purpose. Therefore, only the basic fundamentals will be presented, sometimes without elaboration but with appropriate references listed, in the interests of simplicity and ease of understanding.

CHARACTERISTICS OF SOUND

Basically, the sound we experience in our everyday lives is a result of objects or bodies being set into vibration. More specifically, a vibrating surface imparts its motion to the medium that surrounds it, in our case air, and a minute variation in atmospheric pressure called 'sound pressure' results. The word "minute" is obviously a relative term and it is of interest to investigate just how small the sound pressure quantity really is.

In order to adequately describe the magnitude of the sound pressure, a measuring unit is needed. Our intuition might suggest the familiar pounds per square inch (psi); however, the terms microbar (ubar) and Newtons per square meter (N/m^2) have become accepted. One microbar is approximately one-millionth of normal atmospheric pressure, and one Newton per square meter equals ten microbars. Using the microbar as our unit, a barely audible whisper and a jet engine at close range would correspond to .0002 and 200 microbars respectively. Clearly, the sound pressures we encounter are extremely small, yet span a very wide range of valves Figure 2-1).

Vibrations of the sound source may be "harmonic", "periodic", or "random" (Figure 2-2). The medium surrounding the source moves in a similar fashion, and the resulting disturbance propagates outward from the source. If the distrubance is harmonic in nature, the number of pressure fluctuations occurring each second is termed the "frequency" of the disturbance. The units applied to frequency are cycles per second (cps), or hertz (Hz); both are equivalent.

Since air can be compressed and rarefied, a "wave motion" occurs and a "sound wave" tends to propagate outward and away from its source. However, as the wave propagates its front spreads out (often in a spherical manner). Thus the sound energy passing through each unit of area becomes less and less, and the sound pressure decreases with distance. The decrease in volume of a sound source with increasing distance is a common occurence we have all experienced.

Perhaps a more easily pictured example of these characteristics is the following 'pond analogy'. Imagine if you will a pebble thrown into a quiet pond. The resulting ripple propagates outward from its point

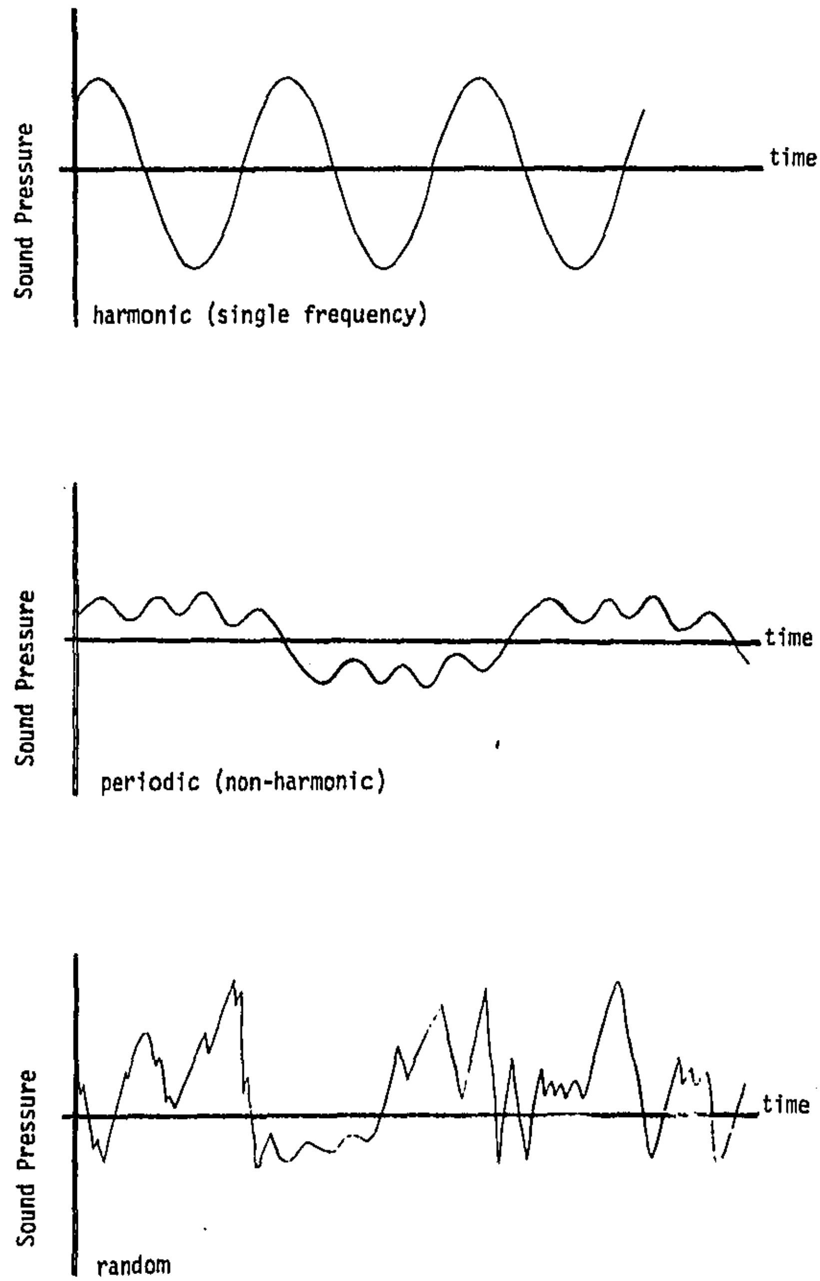


Figure 2-2. Typical Sound Source Vibrations

of origin, and continues outward in the absence of reflecting surfaces (such as the shore). As the ripple continues outward, it is dissipated and eventually fades away.

Thus, the minute pressure disturbances we call sound waves have four characteristics:

1) The magnitude of the sound pressure (normal range: 0.01 - 100 Microbars)
2) The frequency of the sound wave (normal range: 50 - 10000 Hz)
3) The sound wave propagates away from its point of origin
4) The sound pressure of the wave almost always decreases with increasing distance from its source.

ACOUSTIC TERMINOLOGY

DECIBEL

One of the more difficult quantities to define is the decibel. What exactly is it? How is it used and applied?

The decibel (dB) is used universally to describe the level of sound. It is a dimensionless unit which expresses the ratio between two values (i.e. a measured quantity and a reference quantity) logarithmically. The decibel has been applied to the acoustics field for several reasons:

1) If one used the almost unbearable roar of a jet engine at close range and the barely audible whisper as the dynamic range of the human ear, the corresponding sound pressures have a ratio of

1,000,000 to 1. With this tremendous span, it is impossible to manipulate or to have any feeling for the physical quantities involved. Likewise, it would be almost impossible to manufacture an instrument with one million linear scale divisions. By employing the logarithmic feature inherent in the decibel's definition, this tremendous pressure response is resolved into a condensed and more meaningful scale that ranges from 0 dB (by definition) to approximately 120 dB (Figure 2-1).

2) The ear tends to respond in a logarithmic manner. The human auditory response to a given increase in sound pressure is approximately proportional to the ratio of the increase in sound pressure to the sound pressure already present. To give an example: the ear is capable of detecting a very small increase in sound pressure when the ambient level is low; with high ambient level, a much larger increase is necessary to give the ear the same sensation. (1)

3) Under ideal laboratory conditions, the average ear can detect a minimum sound pressure level change of 1dB. In everyday encounters, a 3 dB change in sound pressure level is just perceptable, whereas a 5 dB change is clearly noticeable. (2)

SOUND PRESSURE LEVEL

When sound pressure is expressed in decibel form (Sound Pressure Level, SPL) we are measuring it with respect to a reference. The reference that has been agreed upon is the minimum audible sound pressure for humans, or .0002 microbar. The sound pressure level (measured in decibels) is defined mathematically as follows:

$$\text{Sound Pressure Level (dB)} = 20 \log_{10} \frac{P}{P_{ref}}$$

Where: P = Sound pressure microbars

P_{ref} = The minimum audible sound pressure for humans, .0002 microbar.

As will be shown later, instruments which measure sound pressure level are currently available and in wide use.

An important point to illustrate is that the sound pressure level of a source will, in general, vary with a change of the local surroundings. A typical example would be parking a car in a garage. The sound level we hear inside the garage is different from that which we hear while parked on the driveway. Another example is the household vacuum cleaner. From experience we know that this appliance appears to produce different levels of sound when used in a carpeted living room and in the tiled recreation room.

To obtain a better appreciation for the sound pressure levels of typical noise sources, refer to Figure 2-1. These noise levels can be considered to be 'representative', although it must be remembered that sound pressure level readings are dependent upon local surroundings and distance from the noise source. The sound pressure level readings given are those that would be typically present in the environments specified.

COMBINATION OF SOUNDS

The total sound at a given location is usually a combination of sounds from many different sources. For example, the listener may be exposed simultaneously to the sounds from a barking dog, a power mower, a garbage disposal, and a ringing telephone. What is the total sound that the listener hears? For most types of sounds, the total is obtained by summing the acoustic energies, produced by each source, that arrive at the listener's ear in a given time interval. This combination yields an "effective sound pressure" that can be easily converted to decibels SPL. In fact a "sound level meter" is an instrument that performs this operation automatically and displays the result (in SPL) on a meter.

Let us now consider what happens when two sources produce identical sound pressure levels at the location of a sound level meter. This means that the same amount of acoustic energy is arriving per unit time from each source. If the SPL from either one of the sources is, say, 80 dB, what does the meter read when both sources are operating? Because SPL values are logarithmic, the answer is <u>not</u> 160 dB. Combining the two sounds on an energy basis shows that the total SPL is 83 dB.

We have just seen that, for most types of sounds, a 3 dB change is barely noticeable; yet this change represents a halving or doubling of the acoustic energy. Table2-1 shows the reduction in acoustic energy radiated from a source that is required to obtain a specified decrease in sound pressure level.

Table 2-1

Acoustic Energy vs. SPL

Change in SPL (dB)	Percent decrease in acoustic energy
0	0
-1	20
-2	37
-3	50
-4	60
-5	68
-6	75
-7	80
-8	84
-9	87
-10	90

Note that significant reductions in acoustic energy are needed to obtain even modest decreases in SPL.

For comparison consider a sound source that radiates into an area that is relatively free from buildings or other large obstructions. Under these circumstances, the SPL decreases about 6 dB for each doubling of distance from the source.

Sound pressure in bar	Sound level in dB		Environmental conditions
		140	
1 mbar	134		Threshold of pain
		130	
			Pneumatic chipper
		120	
100 μbar	114		Loud automobile horn (dist. 1 m)
		110	
		100	
10 μbar	94		Inside subway train (New York)
		90	
			Inside motor bus
		80	
1 μbar	74		Average traffic on street corner
		70	
			Conversational speech
		60	
0.1 μbar	54		Typical business office
		50	
			Living room, suburban area
		40	
0.01 μbar	34		Library
		30	
			Bedroom at night
		20	
0.001 μbar	14		Broadcasting studio
		10	
			Threshold of hearing
0.0002 μbar		0	

Figure 2-1. Some Commonly Encountered Noise Levels (3)

SOUND POWER LEVEL

Since the sound pressure level is a function of environment, a characteristic of a sound source that is absolute and independent of its surroundings would be useful. One such characteristic is the "sound power" of a source. The sound power of a source (at specified operating conditions) is a measure of the acoustic energy it produces per unit time, a fixed valve which is usually independent of source location. The measuring unit that is applied is the acoustin watt. Like sound pressure, sound power has an overwhelming range of values. Typical values for the very soft whisper and jet engine are .000,000,0001 and 100,000 watts, respectively. Again, the logarithmic character of thedecibel is advantageous. When sound power is measured in decibels (Sound Power Level), a reference quantity is mandatory, as was the case with sound pressure. The universal sound power reference level is 10^{-12} watts. The formal definition of sound power level (measured in decibels) is as follows:

$$\text{Sound Power Level (PWL)} = 10 \log_{10} \frac{W}{W_{ref}} \text{ dB}$$

Where: W = Sound power of the source in Watts

$W_{ref} = 10^{-12}$ Watts, reference level.

The sound power and corresponding sound power level of some typical noise sources are shown in Figure 2-3.

If sound power is a non-variant with respect to source location, one might ask: "Why do we measure the sound pressure level of a source instead of the sound power level? There are at least two reasons for doing so:

1) Sound power level measurements require special test

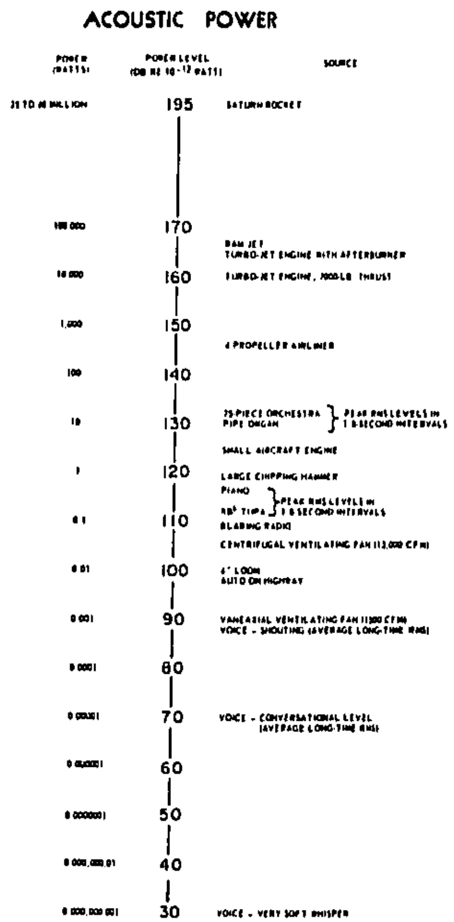


Figure 2-3 Typical Power Levels for

Various Acoustic Sources (4)

conditions and environments that often are not available on location.

2) Sound power levels, at the current state of the art, can not be obtained directly, but must be calculated from sound pressure measurements.

The primary purpose of determining the sound power of a source is that once this value is known, the sound pressure level can be estimated, knowing the sound qualities of the proposed or actual surroundings. An example might be wanting to know how much the sound pressure level will increase if an air-conditioner is added to an already noisy office.

In summary, then, two quantities have been described that are measured in decibels: sound pressure level (SPL), and sound power level (PWL). When either of these quantities is used, the reference value is understood. In all other cases, the reference value must be stated if the decibel value is to have meaning.

FREQUENCY ANALYSIS

As was shown earlier, one of the important chaaacteristics of sound is its "frequency" or "frequency content". The spectrum (or range) of frequencies of interest to us is the human auditory range. This spectrum typically extends from approximately 20 to 20,000 Hz but for mose persons the range is 40 - 13,000 Hz, and decreases with age. This spectrum can be thought of as a contiguous band of frequencies each 1 cycle wide.

The simplest of all sounds are those composed of a single frequency. These sounds are called 'pure tones'. However, the sounds to which we are usually exposed are much more complex than pure tones. These sounds are composed of many frequencies, each occurring simultaneously at its own sound pressure level. The striking of a chord on the piano or guitar are examples. Often, the sound does not appear to have any 'tonal quality'. Examples of this category would be ventilating duct noise or the sound produced by escaping steam. The important point to remember is that our world of sound is composed of many frequencies, each at a given sound pressure level, occurring simultaneously and generally changing with time. In order to investigate the frequency content of a sound, a procedure known as a 'frequency analysis' can be performed. This procedure enables us to obtain a sound pressure level versus frequency "picture" or "spectrum" of a sound source.

When a frequency analysis is performed, the auditory spectrum is electronically divided into adjoining frequency bands and an average SPL is computed for each band, called "band level". The basic scheme employs "octave bands" to divide the spectrum into ten continuous and adjoining frequency bands (Figur 2-4). The upper frequency of each band is twice the lower frequency, and the middle (or "center") frequency of each band is twice and one-half, respectively, of the adjoining frequency bands. The precision instrument which divides the spectrum and measures the SPL for each octave band is known as an "octave band analyzer".

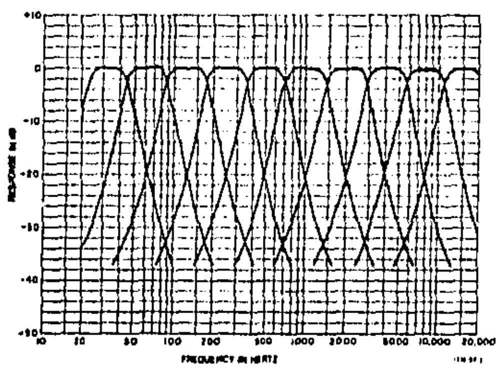


Figure 2-4. Typical Octave Band Filter Characteristics (4)

Instead of naming the upper and lower frequencies of each band, it has become standard practice to specify a 'center frequency' within each band. The standardized octave band center frequencies in use today (the "Preferred Octave Bands") are as follows: 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, 16,000 Hz. An older series of octave bands is sometimes encountered in noise standards and codes. This older series is comprised of the following frequency bands: 37.5-75, 75-150, 150-300, 300-600, 600-1200, 1200-2400, 2400-4800, and 4800-9600 Hz. It is importanct to note that the band levels for these two series of octave bands cannot be interchanged. In other words, the 75-150 Hz band level can not be substituted for the preferred 63 Hz band level. For detailed procedures concerning manipulation and conversion of the older series, see Appendix A.

In summary then, a frequency analysis defines two characteristics of a sound source:

1) The frequency distribution of the sound
2) The amount of sound energy concentrated in the various frequency bands.

MASKING

Masking is the "covering up" of one sound by another. Specifically, masking also makes comprehension of speech difficult and obsecures waring signals. The masking process is most effective when the frequency composition of the sound source is similar to that of the masking sound.

AMBIENT NOISE

Ambient noise is defined as 'the all encompassing noise associated with a given environment, being usually a composite of sounds, from many sources far and near'. (12) When noise emitted by a source is measured, we may justifiably question wheteher the resulting decibel value is truly due to the source alone or is possibly the source plus ambient noise. A simple rule-of-thumb has become accepted and is quite accurate: "If the sound pressure level in all octave bands is 10 dB SPL or greater than the ambient level with the source operating, the contribution due to the ambient noise is negligible." The decibel values thus obtained are essentially those due to the source. This same rule applies to weighted sound level readings as well. Table 2-2 shows the effect on overall SPL when two sources are combined.

Table 2 - 2

Change in SPL from Combination of Two Sources

Difference in source levels, SPL	Increase in SPL due to addition of weaker source
0	+ 3
1	+ 2.5
2	+ 2.2
3	+ 1.8
4	+ 1.4
5	+ 1.2
6	+ 1.0
7	+ 0.8
8	+ 0.6
9	+ 0.5
10	+ 0.4

CLASSES OF SOUNDS

The types of sounds that people are exposed to in an average working day are indeed many and varied. Thus, in an attempt to differentiate or classify these sounds, similar sounds have been 'typed' and are generally grouped together under the following categories which describe their character. Typical octave band frequency analyses for the first three categories are shown in Figure 2-5.

Broad Band - Continuous Noises

As the name inplies, Broad Band noises have a frequency spectrum which encompasses a large portion of the auditory range. The added condition of being continous implies that the noise is not intermittent or transient, but occurs over a long period of time. Some common examples of these noises are:

1) community background noise
2) ventilating duct noise
3) air-conditioned noise

Narrow Band - Continuous Noises

Narrow Band noise sources generally have a frequency spectrum of only a few hundred cycles in width. This spectrum of frequencies can be located anywhere in the auditory range; the important fact being that the width of the spectrum is considerably smaller than Broad Band sources. Examples are:

1) transformer noise
2) circular saw noise

Pure Tones

Pure tones are sounds that consist of a single frequency. Examples are the striking of a single piano note*, or the

*Providing that only the fundamental (lowest) frequency of the note is considered.

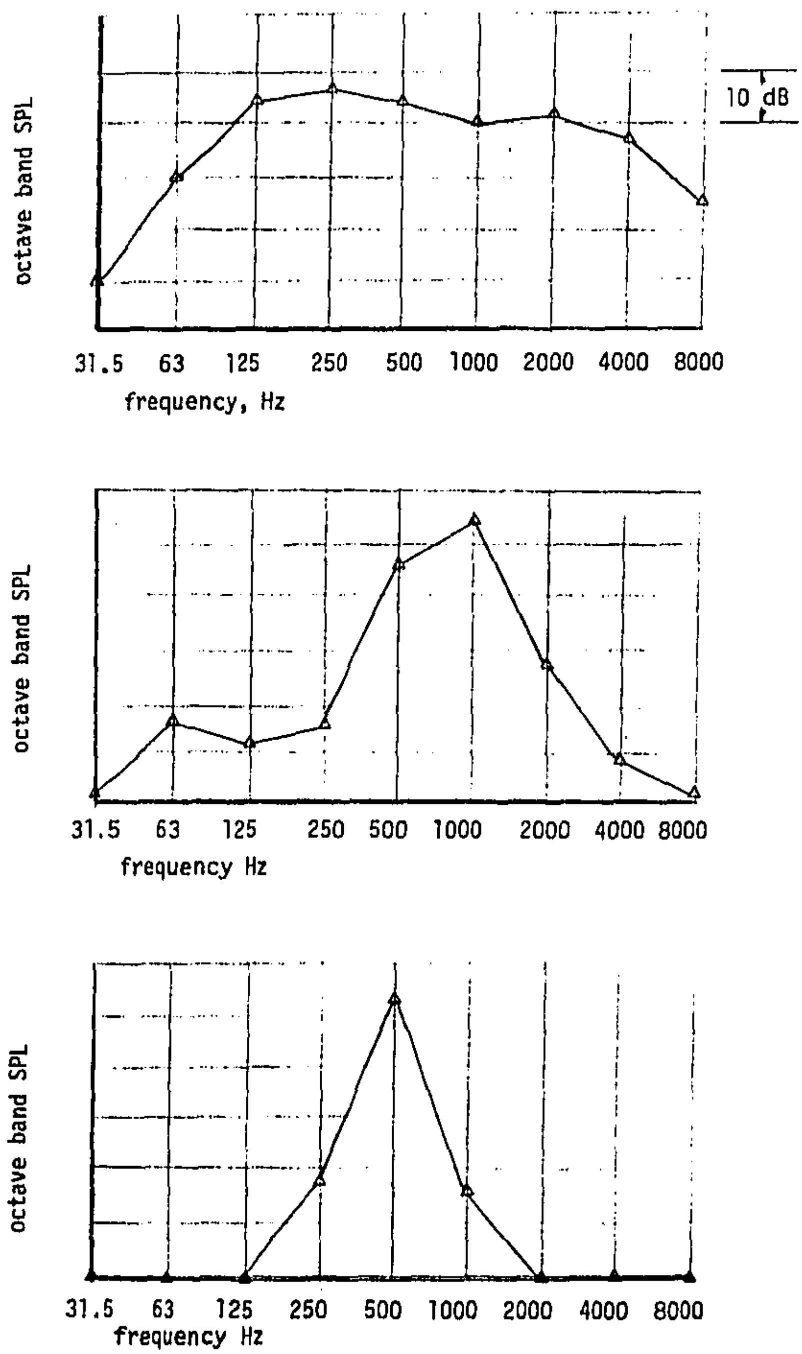


Figure 2-5. Frequency Spectra for Representative Sounds

sound produced by a tuning fork. Pure tones often do not occur by themselves, but can be thought of as being 'superimposed' upon broad or narrow band noise. When this occurs, the noise is said to have a 'pure tone component'. Noises with pure tone components are particularly annoying. Oftentimes these noises are below acceptable levels for broad band noise, but are still considered disturbing or unacceptable . Examples of this last category are:

1) noise from an unbalanced fan or pump impeller.
2) turbine or gear noise.

Impulsive (Impact) Noises

Impulsive noises are those which occur over a very short time period (i.e. 5 to 200 microseconds). These noises are often thought to be loud and startling; however, this need not always be the case. Examples are:

1) a sonic boom
2) a gun shot
3) a barking dog
4) a single bounce of a golf ball on the floor
5) the dropping of a pencil

Repeated Impulsive (Impact) Noises

These noises exhibit the same characteristics as impulsive noises but are repeated (often rapidly) in time. Examples are:

1) typewriter noise
2) pneumatic hammer or pavement breaker noise
3) machine-gun noise

Transient or Intermittent Noises

Transient noises occupy the realm between the continuous and impulsive classifications. Transient noises are usually of short duration but not as short as the impulsive category. Transient noises may be broad or narrow band and may or may not have pure components. Examples are:

1) aircraft flyovers
2) the passing of a train or ambulance

III CRITERIA FOR RATING SOUNDS

INTRODUCTION

As was mentioned earlier, the only objective characteristics of sound that our present day equipment can measure are the sound pressure level and the frequency content. Thus the subjective response of the public to various sounds and noise sources must be correlated in some manner to these two quantities, in addition to the number of occurences within a given period, and whether these sounds occur during the day or night.

Much work has been done in this area and although the optimum method has yet to be contrived, numerous methods of approach have become accepted and widely used. As will become evident in the discussion which follows, it seems that there is no single measuring method which accurately describes or has been found to correlate well with the public's reaction to all sounds and noise sources. Thus, several methods have been devised, each with its own refinements and proposed area(s) of application. To the uninitiated it might appear that acousticians have devised noise measuring methods that are too limited in application and have lost sight of the ultimate goal. In reality, all of their efforts have a common purpose: to produce reaiable measuring or rating methods which correlate well with the subjective response of the public to the various classes of urban noise.

All of the rating methods are based upon the level and frequency content of the noise. Some also include effects from pure tones, duration of the noise, number of occurrences, and time of day.

RESPONSE CHARACTERISTICS OF THE HUMAN EAR

Before delving into the various measuring methods it would be best to investiage the response characteristics of the human ear.

The perception of the loudness of pure tones of different frequencies was first investigated by Fletcher and Munson almost 40 years ago. Basically, their procedure was to place an observer in a very quiet room and subject him to a 1000 Hz reference pure tone. The sound pressure level of another pure tone of a different frequency was then adjusted until it was judged 'equally loud' by the observer. The results of their research were a set of curves similar to those in Figure 3-1. These contours have been verified and internationally standardized and are called 'equal loudness level contours for pure tones.'

Each contour is given a value in 'phons' which corresponds to the sound pressure level in decibels of the 1000 Hz reference tone. These contours illustrate that the response of the human ear is dependent upon not only the frequency of a tone, but also the sound pressure level. Two examples of the use of the contours are shown below.

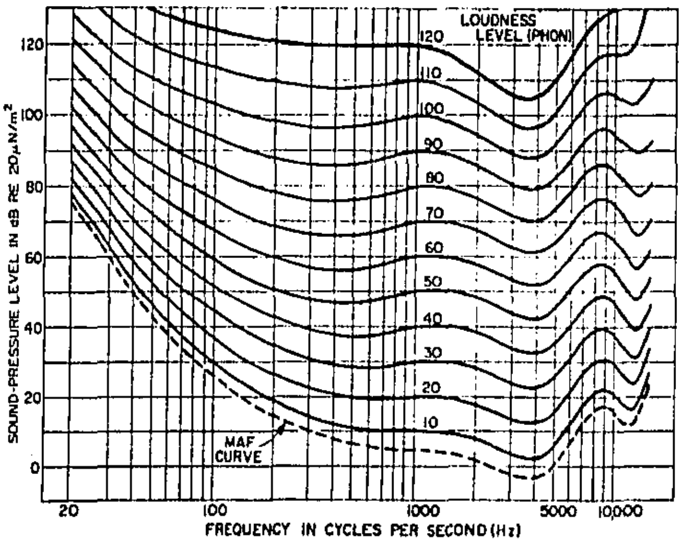


Figure 3-1. Equal Loudness Contours for Pure Tones (4)

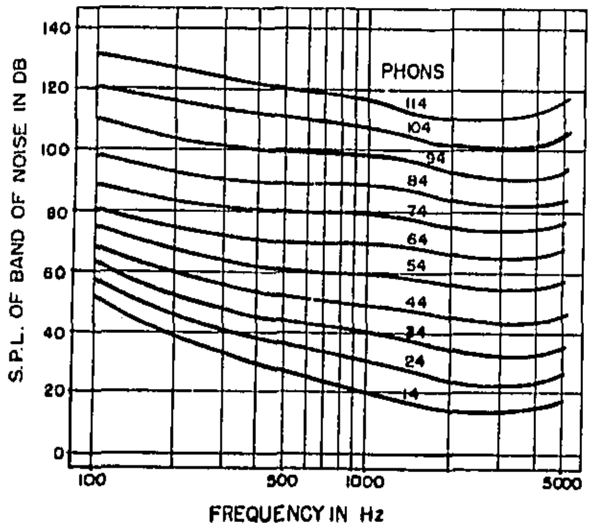


Figure 3-2. Equal Loudness Contours for Relatively Narrow Bands of Random Noise (4)

1. An observer would nominally judge a 30 dB SPL, 125 Hz, pure tone to be equally loud as a 20 dB SPL, 1000 Hz, pure tone. Thus the 30 dB tone has a 'loudness level' of 20 phons.

2. An observer would nominally judge an 80 dB SPL, 31.5 Hz pure tone to be equally loud as a 50 dB SPL, 1000 Hz pure tone. The 80 dB tone has a 'loudness level' of 50 phons.

It can be seen that the response of the human ear is complex and non-linear. At lower sound pressure levels, the ear is not as responsive to low frequencies as at higher frequencies. However, as the sound pressure level increases, the response of the ear become flatter.

As was mentioned earlier, the sounds we experience rarely consist solely of pure tones. To take this into account, equal loudness level contours for narrow bands of noise have been developed and are similar in appearance to those for pure tones. (Figure 3-2).

If the sounds we are exposed to are composed of pure tones or narrow bands of noise, a phon value for these sounds can be obtained directly from either Figures 3-1 or 3-2 . If the sounds are complex,(i.e. broadband with or without pure tone components) an equivalent phon value can be calculated from an octave band analysis of the noise.

Although the phon scale covers the large dynamic range of the ear, it does not fit a subjective loudness scale. Doubling **the number** of phons. does not correspong to a subjective loudness increase of two. For loudness levels of 40 phons and greater, an increase of 10 phons corresponds to a subjective doubling of loudness. To obtain a quantity proportional to "loudness", a scale has been defined in which the unit is called a 'sone'. This loudness scale (in sones) corresponds fairly closely to our subjective sensation of loudness. Using this scale we can say that a jet aircraft at takeoff is approximately 50 times as loud as loud as normal conversation. Stating that jet aircraft generated 120 phons in contrast to 60 phons for ordinary conversation probably conveys less meaning. Table 3-1 gives some typical loudness levels in phons and loudness in sones.

SINGLE-NUMBER RATINGS FOR NOISE

The simplest noise measuring technique would be to measure the noise level using a 'sound lever meter', SLM. This instrument includes a microphone, an amplifier, an output meter, and frequency weighting networks. The frequency weighting networks are referred to as the 'A', 'B', or 'C' scales.* The frequency characteristics of these scales have become internationally standardized and are show in Figure 3-3.

As shown in the figure, the 'A' scale attenuates those frequencies below approximately 500 Hz. In other words, frequencies above 500 Hz are weighed more heavily in an attempt to parallel the response characteristics of the human ear. Careful comparison of the A weighing network and the equal loudness level curves will reveal that the A weighting approximates

*On some sound and level meters, a 'D' weighting network has been added to provide an indication of "perceived noise decibels" (PNdB). See p.III-7.

Loudness Level (phons)		Loudness (sones)
140	Threshold of pain	1024
120	Jet aircraft	256
100	Truck	64
80	Orator	16
60	Low conversation	4
40	Quiet room	1
20	Rustling of leaves	
3	Hearing threshold	

Table 3-1. Representative Values of Loudness Level and Loudness (6)

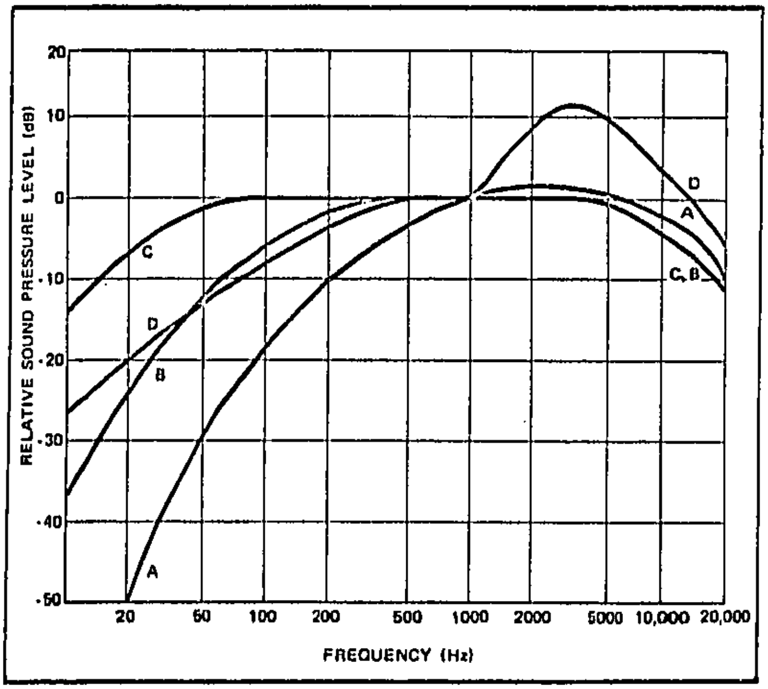


Figure 3-3. International Standard A, B, and C Weighting Curves for Sound Level Meters (6)

an'inverted' 40 phon contour. Likewise, the B weighting network approximates an inverted 70 phon contour. The C network is essentially flat and approximates the response of the ear to intense sound pressure levels.

When a sound is measured with a sound level meter, the weighting network must always be stated. For example, if a measurement was performed using the 'A' scale, the results should be specified as dB (A) or dBA. Noises can also be measured without using a weighting network. When this is done all frequencies are admitted unattenuated to the sound level meter and what is termed an 'overall SPL' results. When an overall reading is taken it can correctly be described as follows: The noise was 50 dB SPL (overall); or 50 dB overall SPL; or 50 dB OSPL.

A similar situation occurs when we obtain octave band data. The decibel values we obtain from each band are SPL's, since all frequencies within each band are admitted unattenuated. Thus we can conclude by saying that when a weighting network is employed, the resulting decibel values are 'sound levels' and the appropriate weighting must be specified. When no weighting is employed, the decibel values are either 'Overall SPL' for sound level meters or just sound pressure levels for octave band data.

Before we continue to other noise measuring methods, two important points concerning 'Overall SPL' and A, B, or C weighted sound levels must be presented.

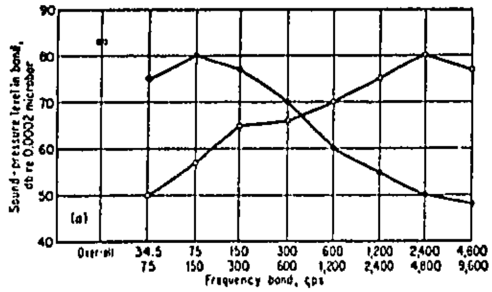
1. It is possible for two different noise sources to produce identical Overall SPL's or identical dBA values, since different frequency distributions can produce identical overall sound levels. (Figure 3-4). Thus when we specify a limiting OSPL or dBA level we really have no control over the frequency distribution of the sound. Specifying limiting octave band levels does, however, significantly restrict the frequency distribution of the sound.

2. The OSPL by definition provides no insight as to the frequency content of the sound. The weighted sound levels on the other hand are designed to closely approximate the response characteristics of the human ear to pure tones. Thus the weighted sound levels provide additional qualitative information that the OSPL does not.

The remaining noise measuring methods require octave band data in order to be evaluated. A brief description of these methods follows.

CALCULATED LOUDNESS

The calculated loudness method is used for obtaining s sone value for complex sounds and primarily applies to steady, wide band noise. Two methods of performing calculated loudness are currently in use; the Steven's procedure and the Zwicker procedure. Figure 3-5 shows the curves for obtaining the sone value of a noise according to the Stevens method when its octave band sound pressure levels are known. The sone value for each center frequency is obtained from the figure. The equivalent sone value is then calculated from:



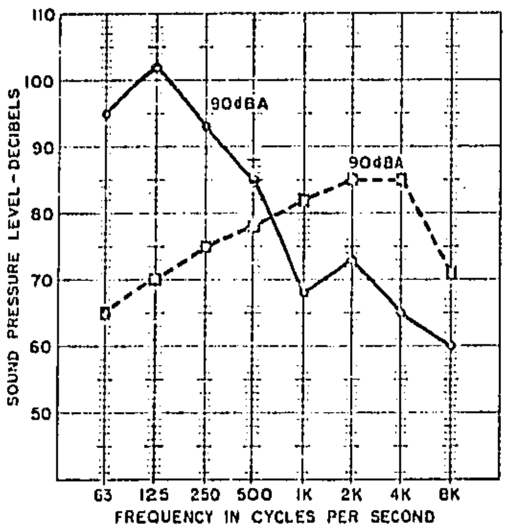


Figure 3-4. Frequency Spectra for Identical Overall Sound Levels

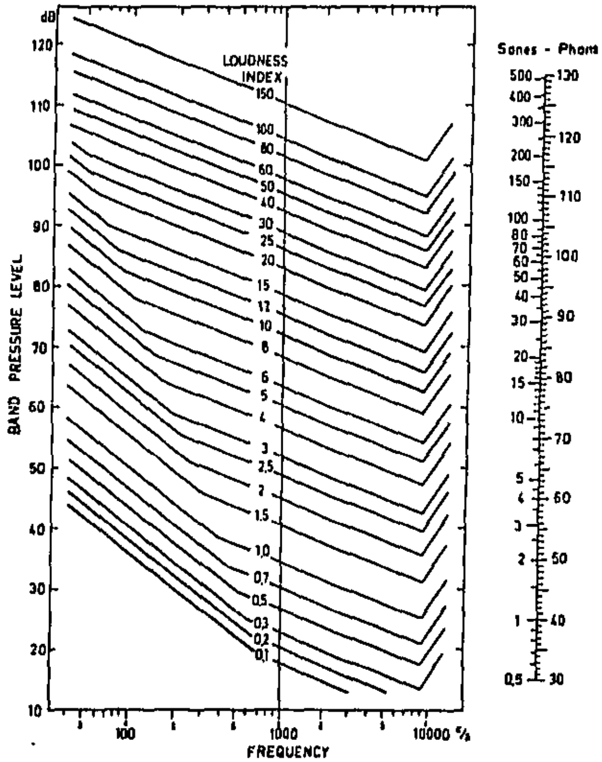


Figure 3-5. Equal Loudness Contours (3)

$$S_{eq} = (\sum 0.3Sn) + 0.7\, S_{max}$$

Where S_{eq} = equivalent sone value

S_n = octave band sone value

S_{max} = maximum octave band sone value

The equivalent phon value can be obtained from the conversion chart supplied with Figure 3-5.

One advantage of the calculated loudness method is that some people tend to indentify more readily with the sone unit rather than the decibel. They grasp the concept of one sound being twice or three times as loud as another more easily than the decibel scale.

PERCEIVED NOISE LEVEL (PNL)

"Kryter has followed a procedure similar to that used for loudness, but he asked the observer to compare noises on the basis of their acceptability or their 'noisiness.' The judgements were found to be similar to those for loudness, but enough difference was observed to give a somewhat different rating for various sounds. On the basis of these results, Kryter has set up a calculation procedure for 'perceived noise level.' (11) In essence, then, the PNL concept accounts for the "noisiness" or "intrusiveness" rather than the loudness. The perceived noise level is registered in perceived noise decibels, PNdB; it has found particular use in gaging response to aircraft noise.

The calculation procedure for PNdB is identical to that used for calculating loudness, except that curves of constant 'noy' values are used (Figure 3-6). The effective noy value is given by

$$N_t = (\sum 0.3N_n) + 0.7\ N_{max}$$

where N_t = effective noy value

N_n = noy value corresponding to each octave band SPL

N_{max} = maximum octave band noy value

An equivalent PNdB value is obtained by using the conversion chart provided in Figure 3-6. On some sound level meters, the 40 noy curve has been incorporated into an additional weighting network (D weighting) to provide a direct approximation to PNL. The proposed D weighting curve is shown in Figure 3-3.

THE "EFFECTIVE" PERCEIVED NOISE LEVEL (EPNL)

The "effective" perceived noise level (EPNL) is similar to the PNL concept and is again applicable mainly to measurement of aircraft noise. This method, however, adjusts the PNL to account for two additional factors which affect subjective evaluations:

1) the effects of pure tone components or narrow bands of high frequency noise generated by today's commercial jet aircraft.
2) the time history of the event (such as a flyover, takeoff, or landing).

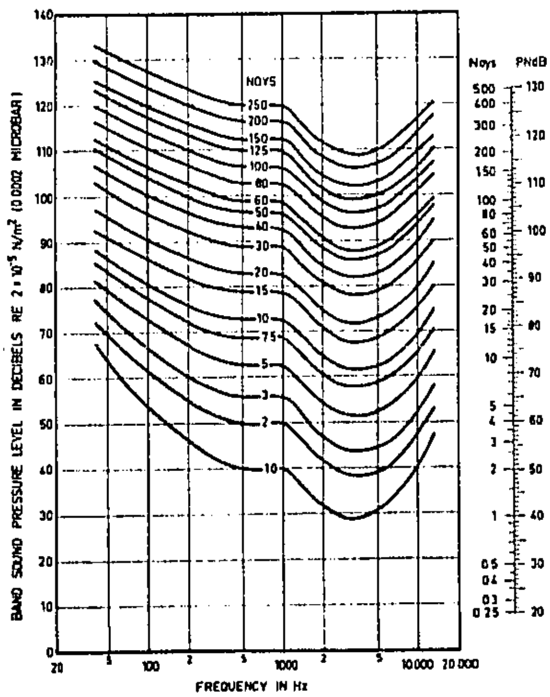


Figure 3-6. Equal Noisiness Contours (3)

NOISE AND NUMBER INDEX (NNI)

Several single-number ratings include corrections for number of events and in some cases, time of occurence. One example of these is the Noise and Number Index (NNI), which is based upon surveys and sociological investigations made near London's Heathrow Airport and is used for measuring aircraft noise. Conceivably it could also be used to gage the response to other transient noise sources such as trains. Essentially, the NNI takes an average peak PNL and adjusts it in relation to the number of events that occur, day or night; i.e. number of aircraft flyovers. Since this method was conceived for use in a particular geographical area with possibly unique air traffic densities and flight patterns, it may not be universally applicable to other airport situations.

SPEECH INTERFERENCE LEVEL (SIL)

The Speech Interference Level (SIL) predicts the masking effect of noisy environments. The inability to converse or to hear adequately at normal distances is a common occurence at cocktail parties or conventions. Also the inability to hear telephone conversations is characteristic of many office and/or industrial work areas.

"The region of intelligibility for the human voice is roughly from 300 to 3000 Hz." (13) Thus the SIL is defined as the arithmetic average of the 500, 1000, and 2000 Hz octave band levels, since noise in these bands interferes with (masks) effective speech communication more than the rest of the spectrum. When this averaged number (in decibels, SPL) exceeds a certain value, speech comprehension becomes difficult or impossible (Figure 3-7). For example, an SIL of 66dB would require a very loud voice level for reliable conversation at a distance of 6 ft. An SIL of 65 to 80 dB makes telephone use difficult.

NOISE RATING NUMBER (N)

The Noise Rating method is based on a set of curves as shown in Figure 3-8. This family of curves is similar to the 'equal loudness contours', and attempts to approximate the subjective characteristics of the ear to various types of sounds. These curves are used to judge the acceptability of noises for different environments with primary emphasis on the annoyance character of the noise. The method of approach is to plot the octave band sound pressure levels on the family of curves. The noise rating number of the noise is the number of the curve that lies just above the plotted spectrum. Specific noise rating criteria for various environments have been established and are shown in Figure 3-8. A sample spectrum also has been plotted in Figure 3-8; its N value is 45.

The "corrected noise rating " is an N number that has been corrected for specific environments or circumstances. Corrections for dwellings are indicated in Figure 3-8.

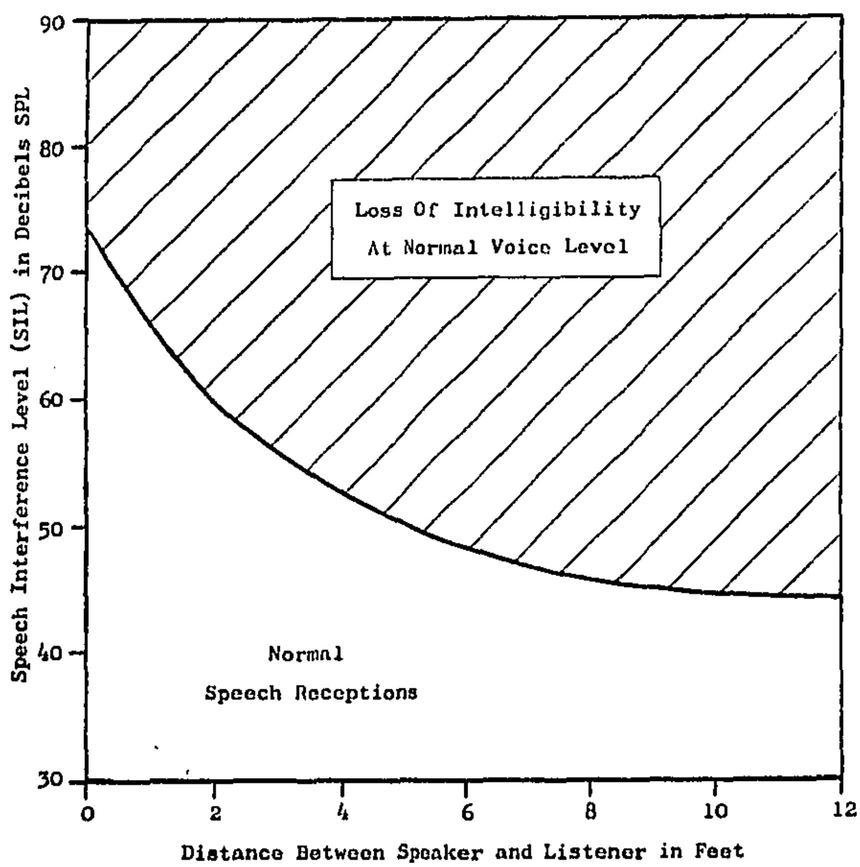
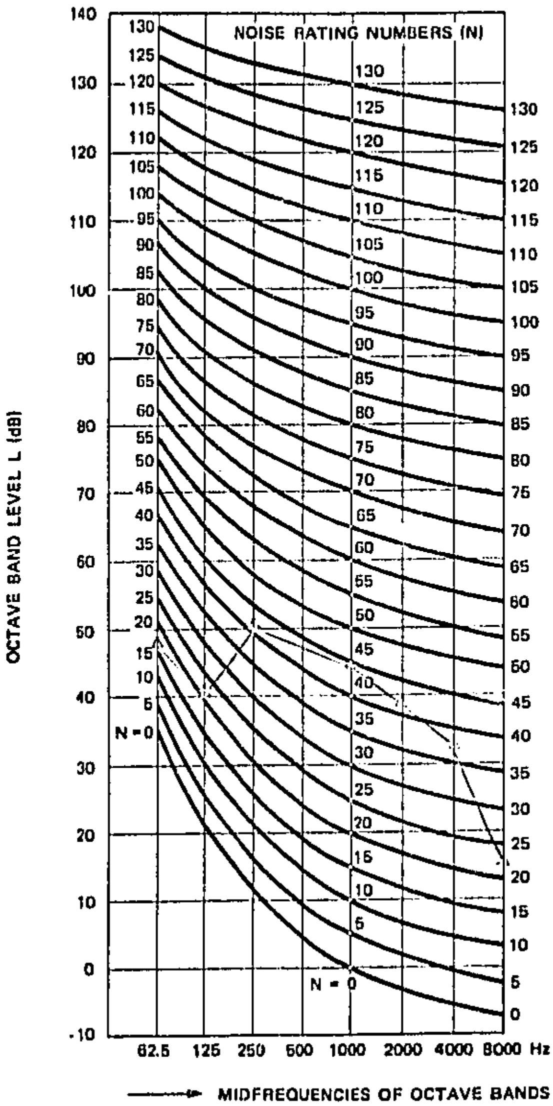


Figure 3-7. Speech Interference Effects of Noise (9)



	Cri-terion
broadcasting studio	15
concert hall, legitimate theatre 500 seats	20
class room, music room, TV studio, conference room, 50 seats	25
sleeping room (see corrections below)	25
conference room 20 seats or with public adress system, cinema, hospital, church, courtroom, library	30
living room (see corrections below)	30
private office	40
restaurant	45
gymnasium	50
office (type writers)	55
workshop	65
Corrections for dwellings	
a) Pure tone easily perceptible	-- 5
b) Impulsive and/or intermittent	— 5
c) Noise only during working hours	+ 5
d) Noise during 25 % of time	+ 5
6 %	+ 10
1.5 %	+ 15
0 %	+ 20
0.1 %	+ 25
0 02 %	+ 30
e) Very quiet suburban	-- 5
suburban	0
residential urban	+ 5
urban near some industry	+ 10
area of heavy industry	+ 15

Estimated Community Reaction	*Corrected Noise Rating*
No Observed Reaction	Less than 40
Sporadic Complaints	40-50
Widespread Complaints	45-55
Threats of Community Action	50 60
Vigorous Community Action	Above 65

Figure 3-8. Noise Rating Number Curves (6) and Criteria (3)

An illustration of this procedure follows:

Suppose, for example, that a municipal maintenance crew was removing a diseased or dying tree from your immediate neighborhood. The maximum Corrected Noise Rating that should be allowed in your living room under this criterion would be:

N = 30 for living rooms

+ 5 correction for assuming removal work occurred during the daytime

+ 5 correction for assuming removal work occurred 25% of the time (of each hour)

+ 5 correction for assuming a residential urban neighborhood

Corrected Noise Rating Number = 45

NOISE CRITERION NUMBER (NC)

The Noise Criterion method is almost indentical to the Noise Rating Procedure but applies mainly to "...the steady, continual ambient levels within a space or neighborhood, as opposed to specific noises or intermittent activities occurring there." (2) The family of curves, however, are slightly different. The NC contours are more lenient from the 500 Hz octave band up through the 8000 Hz octave band. The process of plotting the local noise spectrum on the family of curves is identical for both NR and NC ratings. Representative NC values for different spaces are shown in Table 3-2. The NC number for the spectrum plotted in Figure3-9 is: NC = 49

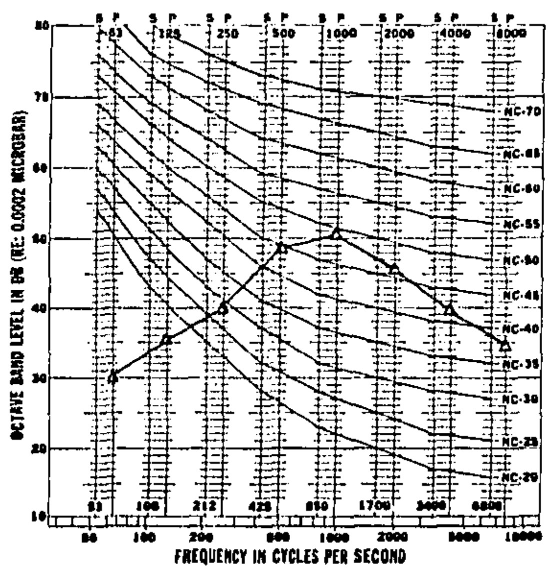


Figure 3-9. Noise Criterion Curves (8)

Table 3-2 Representative Noise Criteria (NC) Values For Different Spaces (2)

Subjective Classification	Function	Space	NC Level
Quiet	Sleeping	Bedrooms	30
		Hospital Rooms	30
Critical Hearing And Listening	Music	Concert And Recital Halls	25-30
Normal	Dicussion	Classrooms	30
		Conference Rooms	25-30
	Mental And Creative Tasks	Executive Offices	30
		Study Rooms	35
Noisy	Dining	Restaurants	45
		Kitchens	55
	Clerical	Stenography And Duplicating	50
Very Noisy	Sports	Stadiums	55
	Transportation	Railroad Stations	55-65
	Computing And Calculating	Computer Rooms	70
	Production	Factories And Shops	50-75

SUMMARY

Perhaps the best explanation for the use of the various noise rating methods and their associated acronyms was given by Preston Smith, a respected acoustician:

"Because of the complexity of that all-too-human experience which is assault by noise, the process of organizing raw information to achieve a scientific description of noises and their effects on man has taken many paths.

"A large number of methods have been invented for rank-ordering sounds, to the point where the choice between them might be called the game of Criteria.

"And it is a game --a curious but serious one. It is a game where we know the rules by which to score, but must invent the implements to play with. The score is simply the success with which the test by criterion yields a correct judgment respecting the noise.

"We have the misfortune to be playing the game while designing the implements. For some time to come, we will have to live with a variety of rating schemes, distinctions between which will not always be clear. The process of re-evaluation, modification, and refinement of existing schemes will continue. This will be an awkward period.

" The engineer interested in applications must study these changes and adapt his procedures to the new methods. Old conclusions based on earlier methods may be upset; that will be the price of progress and a reflection of inaccuracies in the old methods." (22)

IV THE CHARACTER OF URBAN NOISE

INTRODUCTION

Now that the physical nature of noise and some of the criteria for its evaluation have been described, some general trends in urban noise will be examined.

"Urban noise" is a variable mixture of transportation, construction, manufacturing, industrial, and residential noises. Its primary impact occurs in residential areas and is felt in two ways:

1) as a gradual increase in the ambient level
2) as a disturbance or intrustion that is superimposed upon, and distinguishable from, the ambient level.

In most urban areas, the ambient noise is predominantly steady-state ground transportation noise.* However, growing sales of aircraft, air conditioning units, and power lawnmowers have also contributed to increasing ambient levels (Figures 4-1 -4-3). According to one study, average ambient levels in urban areas have been increasing at about 0.5 dB per octave band per year (Figure 4-4), with increases in some critical areas reaching 1 dB (A) per year.

---

*Although heavier trucks presently comprise less than 5 percent of the total vehicle population, their noise output almost equals that of all other vehicles combined.

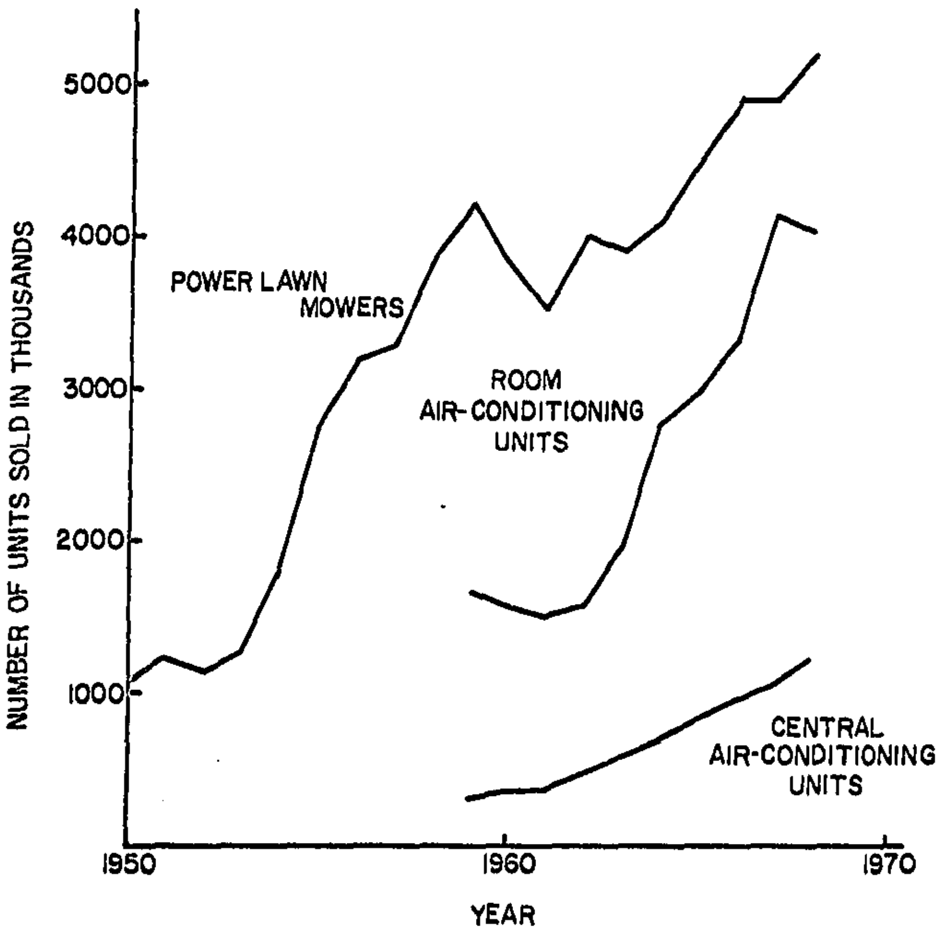


Figure 4-1. Manufacturer's Sales of Selected Products (19)

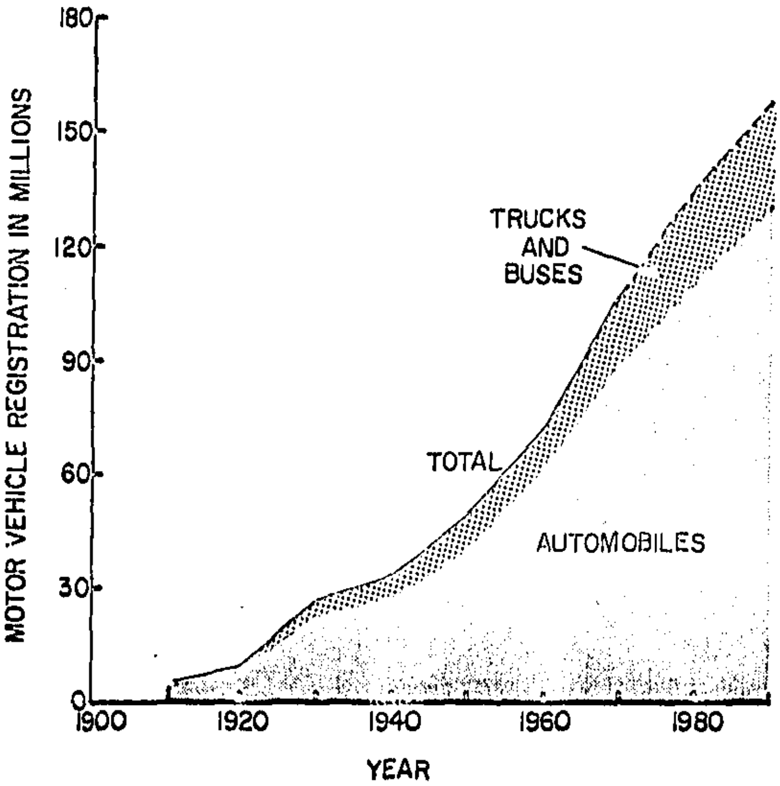


Figure 4-2. Motor Vehicle Registration Trends In The United States (19)

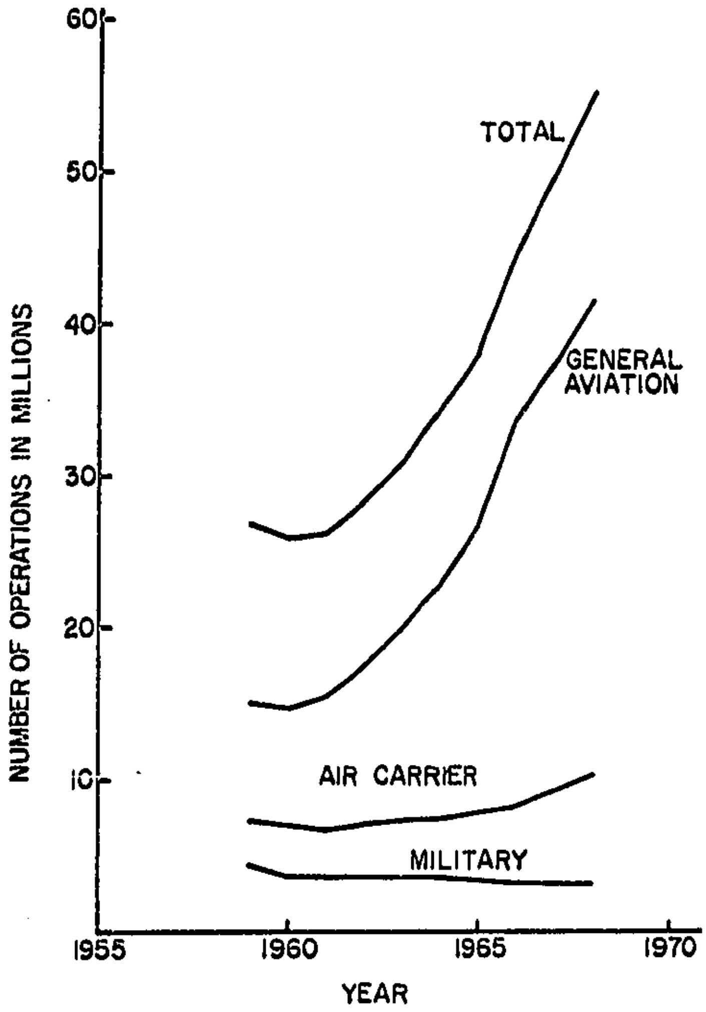


Figure 4-3. Total Aircraft Operations At Airports Having FAA Traffic Control Service (19)

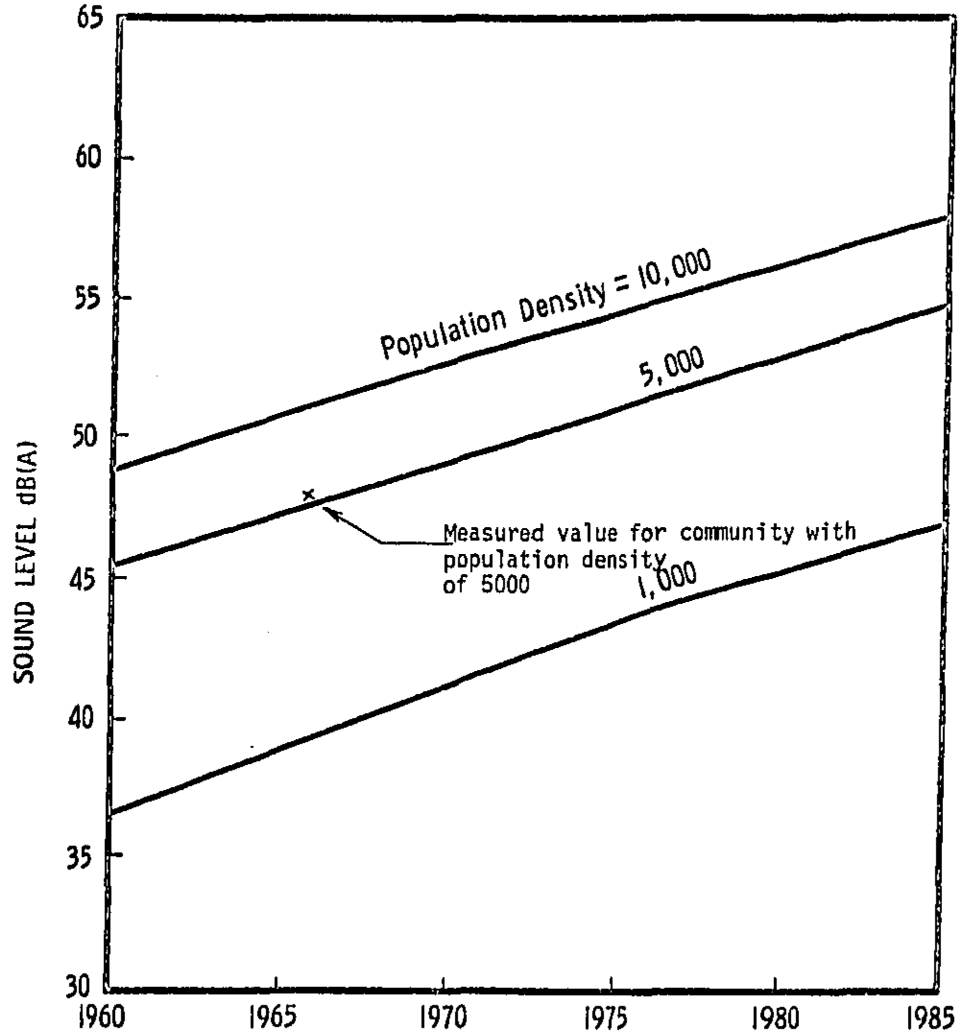


Figure 4-4. Calculated Ambient Noise Levels For Three Different Population Densities (9)

FACTORS AFFECTING NOISE LIMITS

Before reasonable and effective limits for urban noise can be established in a given area, several factors must be considered:

1) The level of ambient noise in the area. Requiring that the source be submerged in the ambient noise, so that it contributes nothing to the overall level, is difficult to ascertain and may be impossible to achieve. On the other hand, allowing the source to exceed the ambient level by a specified margin may create an ambient level that continually creeps upward as more sources are added.

2) The sensitivity of persons in the area to noise (Figure 4-5). This is a highly subjective matter that is determined by social, economic, and personal factors, among others. However, it has been shown that deviations of the noise level above the ambient level, including duration, number of occurrences, and character of the distrubance, have a strong influence on general public reaction. Deviations of 5 dB (A) or less have little significance, while a 15 dB (A) increase can produce strong complaints. However, the levels at which various degrees of annoyance occur depend to some extent on the noise source (Figure 4-6). Figure 4-7 suggests probable community response to the peak levels (primarly from traffic) indicated.

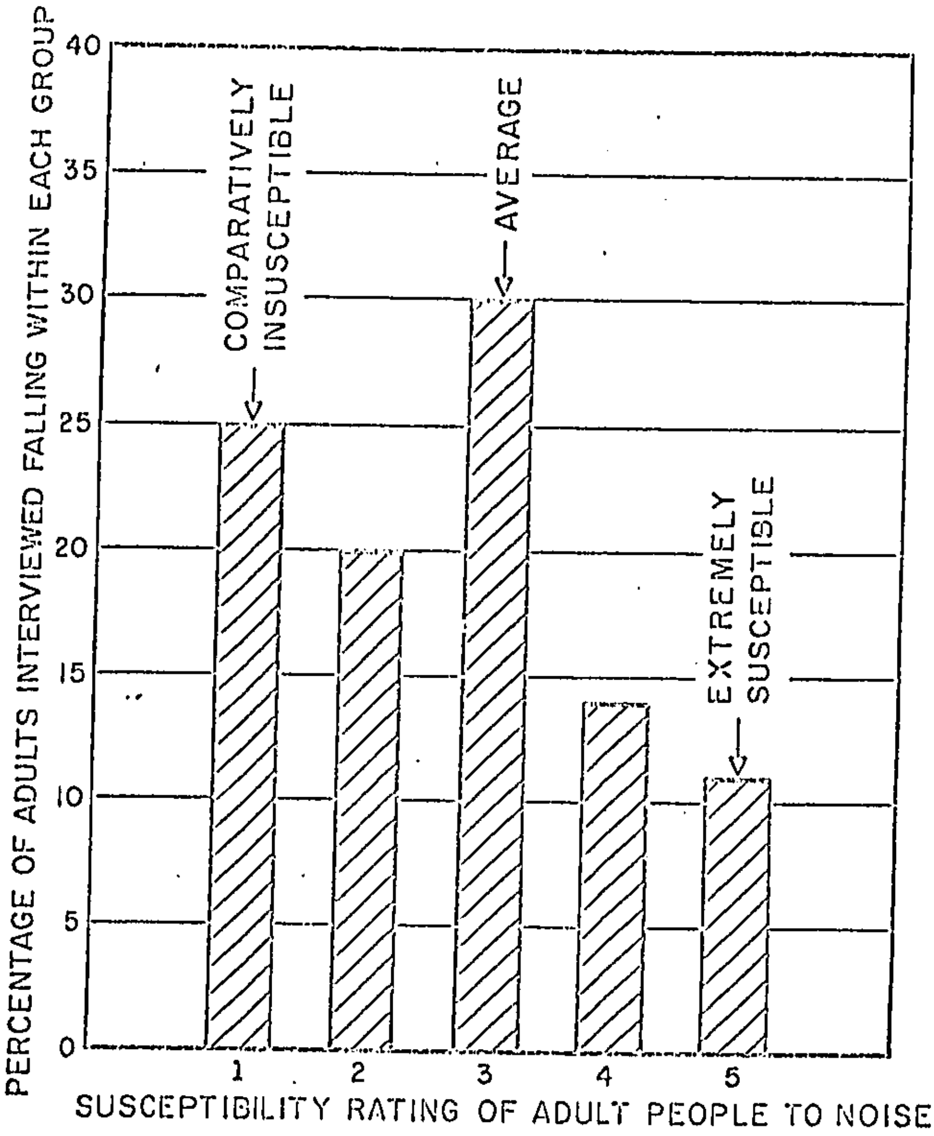


Figure 4-5. Susceptibility of Adults to Noise

This bar graph shows the percentage of 1377 residents interviewed in depth in a 1961 Central London survey for each of five categories of noise susceptibility rating. The susceptibility rating was derived from the answers to six questions on a 40-item questionnaire that evoked statements from the interviewees about their sensitivity to noise (23).

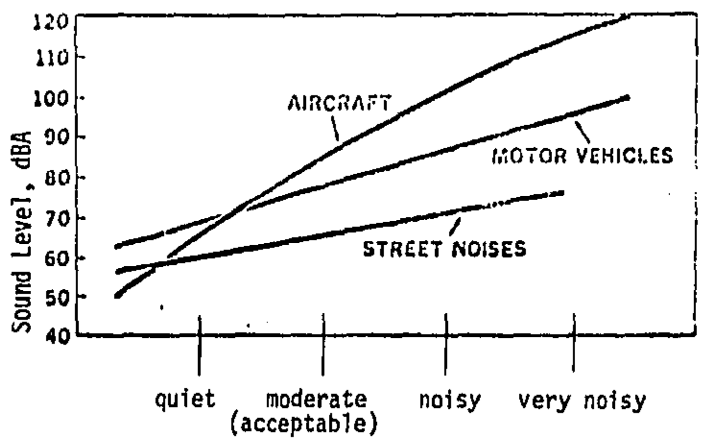
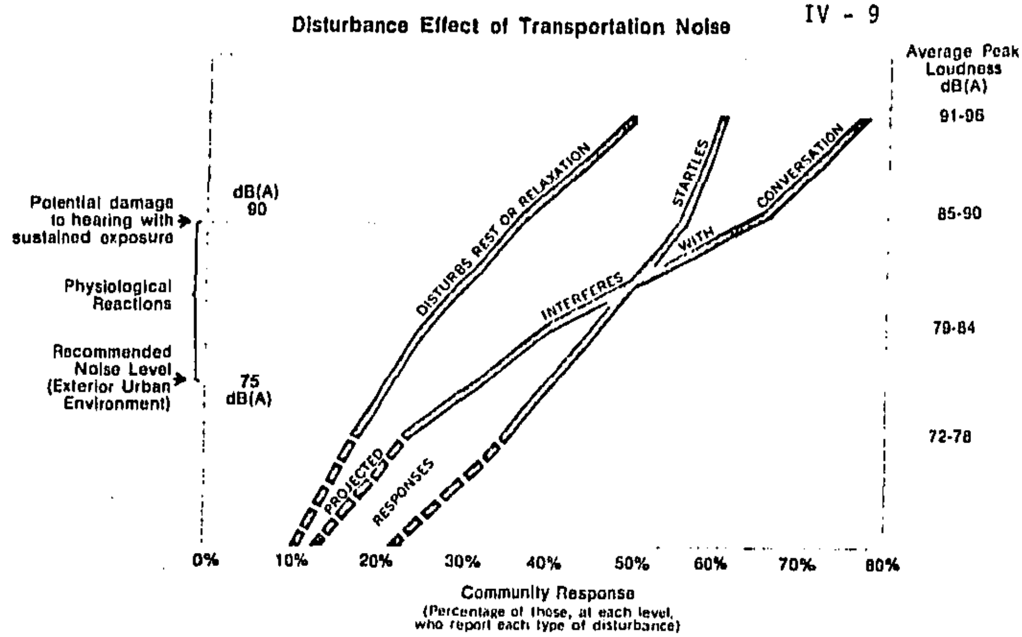


Figure 4-6. Comparative Judgements of Different Noises (23)



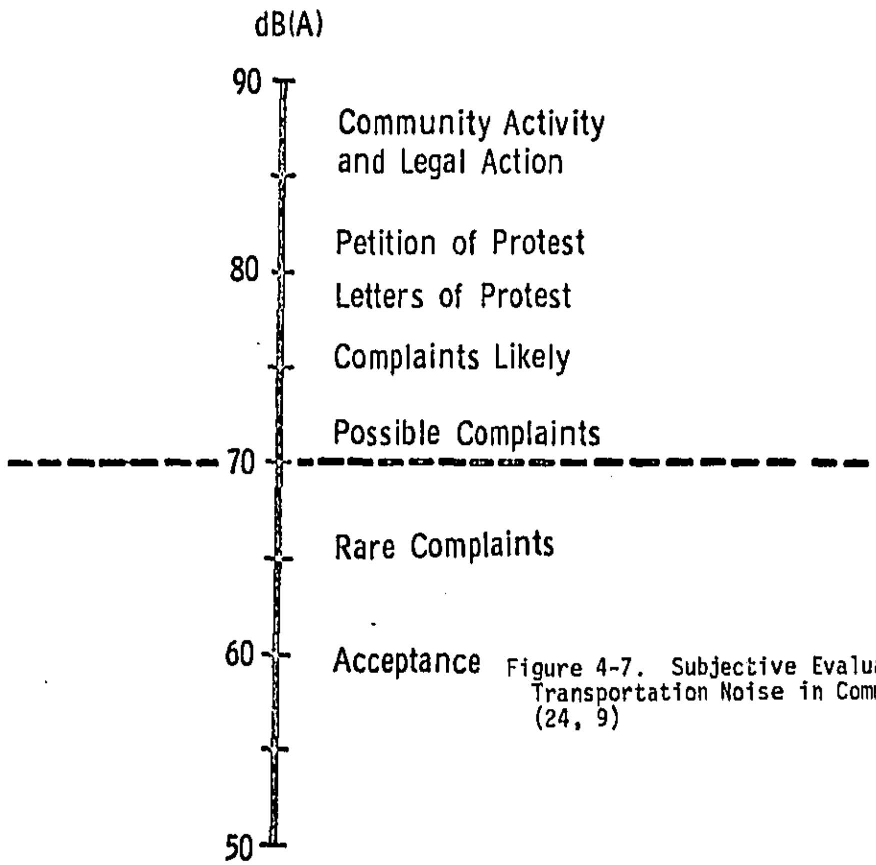


Figure 4-7. Subjective Evaluations of Transportation Noise in Communities (24, 9)

3) The type of rating scale to be specified. For monitoring purposes, peak dB (A) and PNdB* criteria generally show good correlation with community response, although octave band levels may be more useful for identifying sources and establishing proof of violation. Other criteria, such as the Traffic Noise Index (TNI) and Composite Noise Rating (CNR), include the influence of noise duration and/or number of occurrences, as well as peak level.

PRESENT LEVELS OF AMBIENT NOISE AND DISCRETE NOISE SOURCES

Table 4-1 and Figure 4-8 indicate source and ambient noise levels (in PNdB) for a typical urban area. A recent survey in residential areas of Detroit, Boston, and Los Angeles (selected to include a variety of traffic situations) showed a 41-65 dB (A) range in daytime levels and a 30-60 dB(A) range in nighttime levels. Differences in day-night noise patterns and sources of discrete noise were noted.

Typical levels in residential areas of common noise sources are presented in Figure 4-9 and Table 4-2. Many of the levels shown cause underlying dissatisfaction and annoyance among significant numbers of residents, Table 4-2a.

* For community noise, it has been shown that PNdB = 1.02 dB(A) + 11.5, approximately.

Table 4 - 2a

SOURCES OF RESIDENTIAL NOISE ANNOYANCE SOCIAL SURVEY RESULTS

LONDON SURVEY[1]		TRACOR[2]	CHICAGO[3]	CHICAGO[4]	MINN-ST.P[3]	4 WESTERN CITIES[4]	4 EASTERN CITIES[4]
ROAD TRAFFIC	36%	AUTOS/TRUCKS	32%	22%	29%	22%	18%
		MOTORCYCLES/ HOT RODS	36%	26%	26%	24%	33%
AIRCRAFT	9%	AIRCRAFT	37%	40%	33%	39%	62%
		SONIC BOOMS	12%	8%	13%	18%	16%
TRAINS	5%	TRAINS	7%	7%	3%	3%	3%
BELLS/ALARMS	3%	SIRENS	8%	6%	15%	14%	17%
INDUSTRIAL/CONST.	7%	CONSTRUCTION	3%	2%	6%	2%	6%
OTHER PEOPLE	19%	PEOPLE ACTIVITIES	33%	32%	32%	26%	20%
(CHILDREN)	(8%)	(NEIGHBOR CHILDREN)	(18%)	(13%)	(13%)	(14%)	(9%)
PETS/ANIMALS	3%	DOGS, OTHER PETS	10%	8%	13%	13%	15%
NUMBER SURVEYED	1,400	NUMBER SURVEYED	1,064	872	901	3,590	3,217

1/ NOISE FINAL REPORT (WILSON REPORT) 1963
ORIGINS OF EXTERNAL NOISE WHICH DISTURB PEOPLE AT HOME-% OF PEOPLE QUESTIONED
2/ PERCENT OF RESPONDENTS REPORTING UPPER TWO LEVELS OF ANNOYANCES FOR EACH NOISE SOURCE
3/ PUBLIC REACTIONS TO SONIC BOOMS, 1969 - GENERAL CITY AREAS AND BOOM COMPLAINANTS
4/ COMMUNITY REACTION TO AIRPORT NOISE, 1970 - AIRPORT ENVIRONS ONLY

Table 4-1. Annoyance Level Orientations (9)

PNdB	Sounds	Acceptability	Annoyance
132	Ear damage 30 min. exposure		
128			Very annoying
118	Subsonic jet at 700 ft.		Annoying
115			
113			Moderately annoying
		Unacceptable	
109			Intrusive A little annoying
105			
100	Blast furnace	Barely acceptable	
96	Truck at 50 feet		
94			Noticeable
92	City Center background	Acceptable	
87	Ringing phone at 8-10 feet		
		Of no concern	Not at all annoying

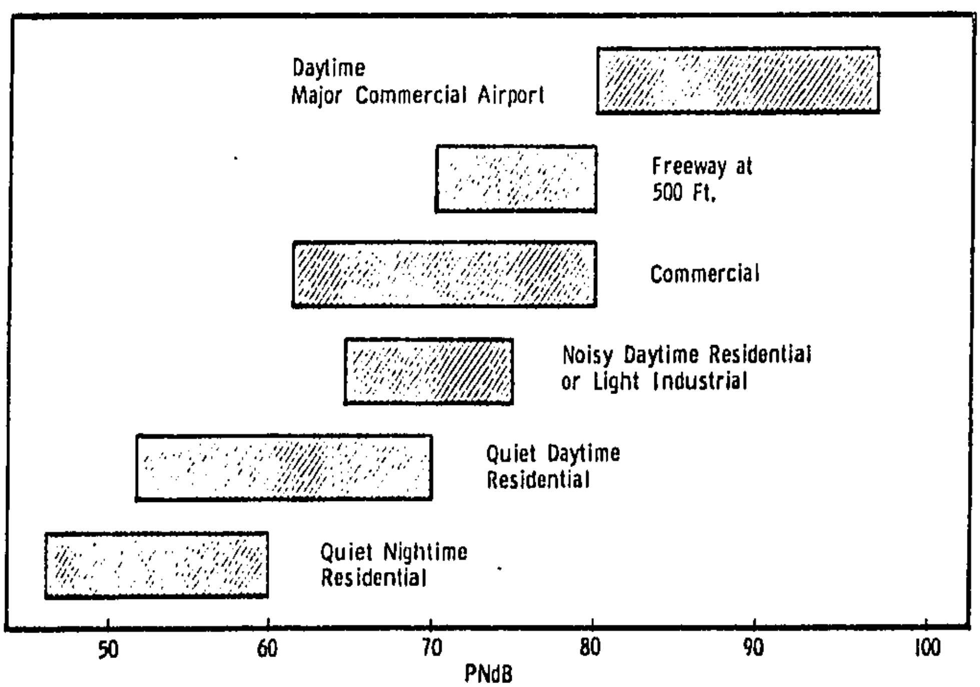


Figure 4-8. Representative Ambient Noise Levels (9)

Orientation	dB(A)	dB
Noise in a car that is passing a truck at 60 mph.	95	110
Noise from a Boeing 727 taxiing toward the listener and approximately 350 feet away.	95	107
Briggs and Stratton 3 hp lawn mower at the operator's position.	90	96
Phone ringing 10 feet away	78	79
Electric alarm clock (3 feet)	64	66
Exhaust from an 8000 BTU air-conditioner at 7 feet away.	59	68
Residential area at 7 p.m.	48	63
Inside a house at night, windows closed, no appliances running.	33	56

Table 4-2. Noise Levels of Typical Sources in Urban Areas (9)

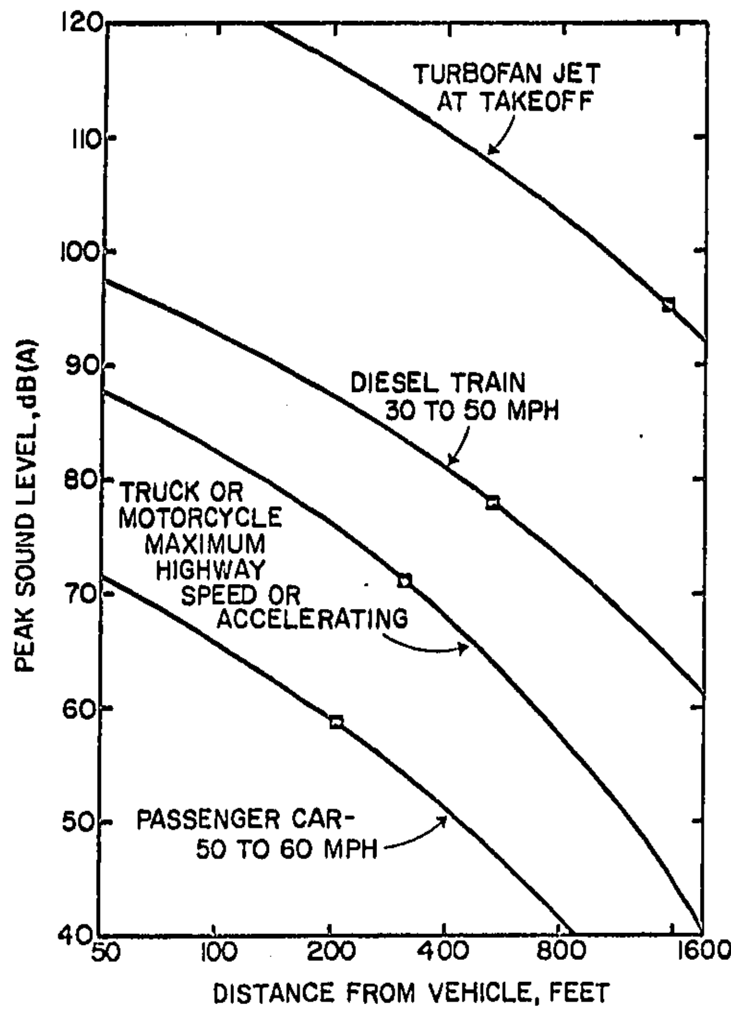


Figure 4-9. Typical levels of outdoor noise produced by transportation vehicles. Squares represent the estimated levels at houses typically nearest the noise sources.

PROPOSED LEVELS FOR AMBIENT AND DISCRETE NOISE SOURCES

Many investigators have proposed maximum ambient levels for urban noise as well as permissible levels for common sources of discrete noise. Representative examples are shown in Tables 4-3 - 4-7. In addition, noise levels specified in existing performance codes are summarized in Section VII. While most or all of these requirements may be highly desirable, it must be remembered that:

1) Some of the levels specified are not technologically or economically feasible at the present time.
2) Other unregulated or unidentifiable sources may essentially determine the ambient level, even when specifically regulated sources are operating at levels greater than those recommended.

However, the data in Tables 4-3 - 4-7 are indicative of an international trend to impose increasingly severe restrictions on permissible noise levels in urban areas. Although not all limits are reasonable, realistic, or effective, their collective impact should produce a noticeable reduction in urban noise within the next decade.

Table 4-3. Recommended Community Noise Criteria (25)

	Airports (at property line)		Industrial		Commercial		Urban Residential		Suburban Residential		Rural Residential		Critical Noise Areas		
													Hospitals		Churches
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day
Outdoor	80*	80*	65⊕	55⊕	60	50	50	45	45	40	40	30	40	35	40
Indoor			80**	80**	50	50	45	35	45	35	40	30	40	35	50

* With current technology this limit can probably be met only by expanding airport land areas greatly.
⊕ Levels specified to protect residents in and near this area.
** Maximum for unprotected ear.

Table 4-4. Recommended Transportation Noise Criteria for Los Angeles (24)

Noise Sources	MAXIMUM PERMISSIBLE NOISE LEVEL				DEVIATIONS/24 HRS.			FINES
	Sound Measurement Scale	Max. Reading at End of 3 Yrs.	Max. Reading at End Next 3 Yrs.	Place of Measurement	Max. Number 8 A.M.-6 P.M.	Max. Number 6 P.M.-8 A.M.	Max. Duration Each Occurrence	Dollars Each Violation[4]
AIRPORTS ALL TYPES	dB(A)	80	75	Airport Property Line	3	2	2 Min.	500
URBAN OVERFLIGHT (FEDERAL)	dB(A)	75	70[1]	Ground Level Throughout City	3	2	2 Min.	(500)
PASSENGER CARS (STATE AND LOCAL)	dB(A)	80	75	25 Ft. Distance[2]				(50)
TRUCKS AND BUSES (STATE AND LOCAL)	dB(A)	85	80	25 Ft. Distance[2]				(100)
MOTORCYCLES (STATE AND LOCAL)	dB(A)	80	75	25 Ft. Distance[2]				(50)
CONSTRUCTION EQUIPMENT	dB(A)	80	75	25 Ft. Distance[3]	3		2 Min.	50
OTHER VEHICLES, EQUIPMENT, TOOLS, ETC.	dB(A)	80	75	25 Ft. Distance[3]				25

1 For explanation and justification of this noise level criterion, see p. 75: Appendix A, Rationale for Overhead Aircraft Noise Limit.

2 Approximate: (a) distance from automobile in the moving traffic lane nearest the sidewalk to the front of buildings set back 15 feet from the property line; (b) distance of pedestrian on sidewalk from truck in the nearest lane beyond a parking lane. Sound reading taken at power output and tire noise equal to 65 mph on level ground in still air.

3 Sound reading taken at maximum operating power output.

4 Fines collected from owner or user of aircraft, automotive vehicle, or powered equipment, tools, and toys as indicated in Recommendation 3 above.

Table 4-5. Recommended Outdoor Noise Levels - Switzerland (18)

	Background Noise		Frequent Peaks		Rare Peaks	
Area	Night dB(A)	Day dB(A)	Night dB(A)	Day dB(A)	Night dB(A)	Day dB(A)
Health resort	35	45	45	50	55	55
Quiet residential	45	55	55	65	65	70
Mixed	45	60	55	70	65	75
Commercial	50	60	60	70	65	75
Industrial	55	65	60	75	70	80
Traffic arteries	60	70	70	80	80	90

Measurement with microphone at open window recommended.
Desirable values 10 dB less, but not more than 30 dB less.
Background noise: mean value (average noise value without peaks).
Frequent peaks: 7-60 peaks per hr.
Rare peaks: 1-6 peaks per hr.

Table 4-6. Tolerated Construction Noise Levels at Nearest Window - England (18)

Situation	Level
Rural, Suburban, Urban Areas, Away from Main Road Traffic and Industry	70 dB(A)
Urban Areas, Near Main Roads and Heavy Industrial Areas	75 dB(A)

Table 4-7. Recommended Indoor Noise Levels - England (18). Levels shown should not be exceeded more than 10% of the time.

	Level	
Situation	Day	Night
Country Areas	40 dB(A)	30 dB(A)
Suburban Areas, Away from Main Traffic Routes	45 dB(A)	35 dB(A)
Busy Urban Areas	50 dB(A)	35 dB(A)

LIST OF REFERENCES

1. Randall, An Introduction to Acoustics, Addison - Wesley, 1951.
2. Yerges, Sound,Noise and Vibration Control, Van Nostrand, 1969.
3. Brock, Acoustic Noise Measurements, B & K Instruments (Cleveland), 1969.
4. Peterson and Gross, Handbook of Noise Measurement, General Radio Company, 1967.
5. Donley, "Equipment and Techniques for Noise Measurements," Sound and Vibration, January, 1967.
6. Acoustics Handbook, Hewlett - Packard Co., Palo Alto, Calif, 1968.
7. "Aircraft Noise Measurement, Evaluation, and Control," B & K Technical Review, no. 4, 1965
8. Acoustics in Air Conditioning, The Fane Company (La Crosse, Wisconsin), 1967.
9. Transportation Noise Pollution: Control and Abatement, Langley Research Center, 1970.
10. Blazier, "Criteria for Control of Community Noise", Sound and Vibration, May 1968.
11. Architectural Acoustics, B & K Instruments (Cleveland), 1968.
12. American National Standards Institute, Acoustical Terminology, 1960.
13. Newby, Audiology (2nd ed.), Meredith, 1964.
14. Baron, "The Noise Receiver: The Citizen," Sound and Vibration, May 1968.
15. Congressional Record,91st Congress, Volume 115, Rumber 176, Page E 9036 ff, October 29, 1969.
16. Donley, "Community Noise Regulation", Sound and Vibration, February 1969.
17. Noise in Urban and Suburban Areas, FT/TS-26, Dept. of HUD, March 1968.

18. Noise As a Public Health Hazard, American Speech and Hearing Association, June 1968.

19. The Noise Around Us, U.S. Dept. of Commerce, COM 71-00147, Sept. 1970.

20. American Refrigeration Institute, New York, 1967.

21. Botsford, paper presented at Acoustical Society Meeting, Nov. 1967.

22. Lynch ,"Noise Control," International Science and Technology, April 1966.

23. Morse, "Community Noise - The State of the Art," presented Acoustical Society Meeting, Nov. 1967.

24. Outdoor Noise and the Metropolitan Environment, Los Angeles, 1970.

APPENDIX A CONVERSION OF OCTAVE BAND DATA FROM OLD SERIES TO PREFERRED SERIES

For broad band noises, the corrections are

To Convert From Old Octave Band With Cutoff Frequencies	To Preferred Octave Bands With Center Frequencies	Add
18.75 - 37.5	31.5	1 dB
37.5 - 75	63	1 dB
75 - 150	125	1 dB
150 - 300	250	1 dB
300 - 600	500	1 dB
600 - 1,200	1,000	1 dB
1,200 - 2,400	2,000	1 dB
2,400 - 4,800	4,000	1 dB
4,800 - 9,600	8,000	1 dB
9,600 -19,200	16,000	1 dB

APPENDIX B DRAFT OF A MUNICIPAL ORDINANCE TO REGULATE SOUND PRODUCED BY AIR CONDITIONING AND AIR HANDLING EQUIPMENT

(AREAS ZONED RESIDENTIAL)

Air Conditioning and Refrigeration Institute
1815 North Fort Myer Drive
Arlington, Virginia 22209

1. This ordinance is designed to control loud and objectionable sounds which may be produced by air conditioning and air handling equipment installed in or adjacent to a dwelling unit located in an area zoned residential. Sound levels of 60 dBA or less, measured in accordance with Par. 3, with the equipment in operation and regardless of source(s) are not considered loud and objectionable within the scope of this ordinance.

2. However, should the sound level exceed 60 dBA, as measured per Par. 3 with the equipment in operation, additional measurements shall be made with the equipment not operating in order to determine its contribution to the sound level above 60 dBA. Then, if the difference in levels exceeds 5 dBA with the equipment operating and not operating the equipment shall be considered as contributing to loud and objectionable sounds and shall be modified or controlled so that the difference does not exceed 5 dBA.

3. Measurements of sound levels required by this ordinance shall be as follows:

a. Sound levels shall be measured on the A weighting network of a sound level meter meeting the requirements of USA Standard S1.4-1961 for <u>General-Purpose Sound Level Meters</u>, or latest revision, (published by the United States of America Standards Institute, New York, New York), using the slow meter response. The meter shall be calibrated and used according to the manufacturer's instructions.

b. Measurements shall be taken with the microphone located at any point on the property line, but no closer than three (3') feet from any wall and not less than three (3') feet above the ground.

c. A minimum of 3 readings shall be taken at 2 minute intervals. The sound level shall be the average of these readings.

4. This ordinance shall become effective immediately upon approval by the Mayor (or City Manager) and shall apply to equipment installed on or after the effective date.

Note: United States of America Standards Institute (USASI) is the former name of:

American National Standards Institute, Inc. (ANSI)
1430 Broadway
New York, New York 10018

DRAFT OF A MUNICIPAL ORDINANCE TO REGULATE SOUND

PRODUCED BY AIR CONDITIONING AND AIR HANDLING EQUIPMENT

(AREAS ZONED FOR APARTMENTS)

Air Conditioning and Refrigeration Institute
1815 North Fort Myer Drive
Arlington, Virginia 22209

1. This ordinance is designed to control loud and objectionable sounds which may be produced by air conditioning and air handling equipment installed in or adjacent to a dwelling unit located in an area zoned for multiple dwellings or apartments. Sound levels of 55 dBA or less, measured in accordance with Par. 3, with the equipment in operation and regardless of source(s) are not considered loud and objectionable within the scope of this ordinance.

2. However, should the sound level exceed 55 dBA, as measured per Par. 3 with the equipment in operation, additional measurements shall be made with the equipment not operating in order to determine its contribution to the sound level above 55 dBA. Then, if the difference in levels exceeds 5 dBA with the equipment operating and not operating, the equipment shall be considered as contributing to loud and objectionable sounds and shall be modified or controlled so that the difference does not exceed 5 dBA.

3. Measurements of sound levels required by this ordinance shall be as follows:

a. Sound levels shall be measured on the A weighting network of a sound level meter meeting the requirements of USA Standard S1.4-1961 for General-Purpose Sound Level Meters, or latest revision, (published by the United States of America Standards Institute, New York, New York), using the slow meter response. The meter shall be calibrated and used according to the manufacturer's instructions.

b. Measurements shall be taken with the microphone located outside the window of a room within the dwelling unit where the sound is alleged to be loud and objectionable. The microphone shall be positioned not more than 3 ft. from the window opening but at least 3 ft. from any other surface.

c. A minimum of 3 readings shall be taken at 2 minute intervals. The sound level shall be the average of these readings.

4. This ordinance shall become effective immediately upon approval by the Mayor (or City Manager) and shall apply to equipment installed on or after the effective date.

Note: United States of America Standards Institute (USASI) is the former name of:

American National Standards Institute, Inc. (ANSI)
1430 Broadway
New York, New York 10018

APPENDIX C CITIES SURVEYED IN THE CONTROL OF NOISE IN URBAN AREAS PROJECT

The survey relied heavily upon the noise legislation compilation in the CONGRESSIONAL RECORD - SENATE, October 29, 1969, pages E9031 through E9112.

The total listing of cities upon which the compilation was based is shown below:

Action, Massachusetts
Akron, Ohio
Albany, New York
Albuquerque, New Mexico
Anaheim, California
Anchorage, Alaska
Atlanta, Georgia
Batavia, Illinois 2 - 3
Bayport, Texas 2 - 3
Beverly Hills, California 4
Birmingham, Alabama
Boulder, Colorado
Boston, Massachusetts
Buffalo, New York
Chicago, Illinois 1 - 2
Cincinnati, Ohio
Columbus, Ohio 2 - 3
Concord, New Hampshire
Coral Gables, Florida 4
Dallas, Texas 1 - 2 - 3 - 4
Dayton, Ohio 1 - 3
Denver, Colorado
Detroit, Michigan
Downer's Grove, Illinois 2
Englewood, New Jersey
Fair Lawn, New Jersey 4
Farmington, Connecticut 4
Fort Lauderdale, Florida
Geneva, Illinois 2 - 3
Hartford, Connecticut
Hemet, California
Hinsdale, Illinois
Honolulu, Hawaii 1 - 3
Houston, Texas
Indianapolis, Indiana
Inglewood, California 4
Irving, Texas
Kansas City, Missouri
Little Rock, Arkansas
Las Vegas, Nevada
Los Angeles, California
Maderia Beach, Florida
Maywood, Illinois 2 - 3
Memphis, Tennessee
Miami, Florida 4
Milwaukee, Wisconsin
Minneapolis, Minnesota 2 - 3
Newark, New Jersey
New Haven, Connecticut
New Orleans, Louisiana
New York, New York
Norfolk, Virginia
Oakland, California
Oklahoma City, Oklahoma
Orlando, Florida 2 - 3 - 4
Park Ridge, Illinois
Peoria, Illinois 2 - 4
Philadelphia, Pennsylvania
Pittsburgh, Pennsylvania
Portland, Oregon
Raleigh, North Carolina
River Forest, Illinois
Rochester, New York
Sacramento, California
St. Louis, Missouri 4
St. Petersburg, Florida
Salt Lake City, Utah
San Antonio, Texas
San Diego, California
San Francisco, California
San Jose, California
Santa Barbara, California
Seattle, Washington
Syracuse, New York
Trenton, Michigan
Tucson, Arizona
Warwick, Rhode Island 1
Washington, D.C. 2 - 3

1. Cities surveyed in Figure 6-5.
2. Cities surveyed in Figure 6-6.
3. Cities Surveyed in Figure 6-7.
4. Cities surveyed in Figure 6-8.