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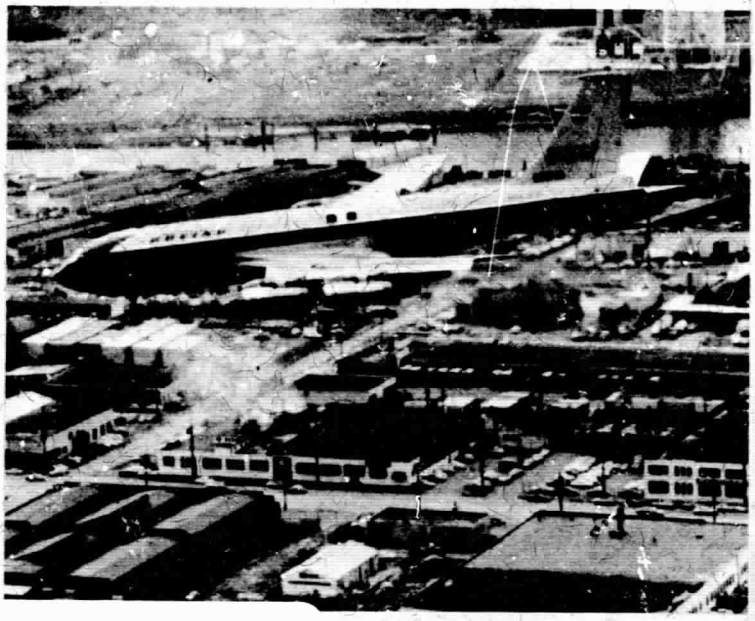

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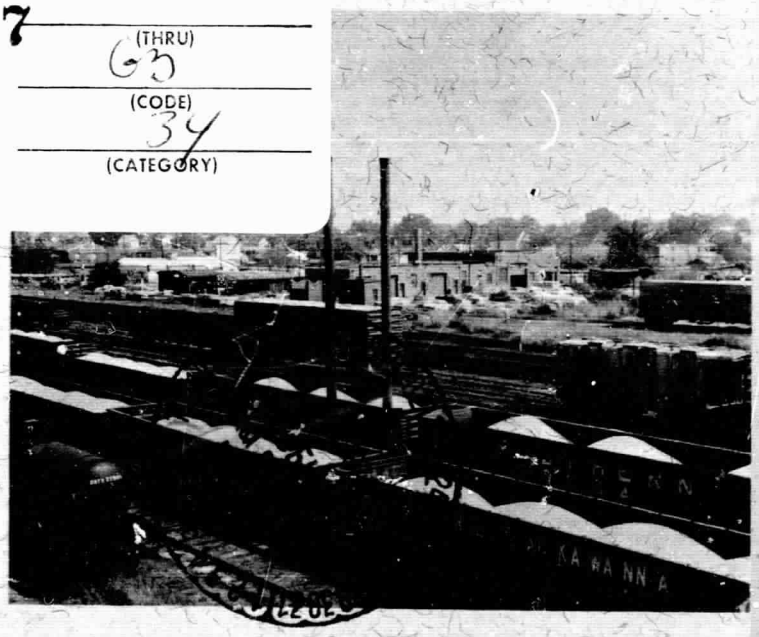

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The cover design was prepared by Mr. David A. Willment, Head of the Technical Illustrating Section at NASA - Langley. The photographs in this design are examples of some of the major sources of transportation noise in our society.

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FOREWORD

This document summarizes the results of the 1970 ASEE-NASA Summer Faculty Program in Engineering Systems Design conducted at the NASA Langley Research Center during the period June 8 through August 21. The program was sponsored jointly by the National Aeronautics and Space Administration and the American Society of Engineering Education through a contract by NASA to the Old Dominion Research Foundation of Old Dominion University

The objectives of this systems design program included the following:

(1) To provide a useful study of a broadly based problem of society that required the coordinated efforts of a multidisciplinary team.

(2) To provide a framework for communication and collaboration between academic personnel and research engineers and scientists in governmental agencies and private industry.

(3) To generate experience and foster interest in participation in and development of systems design activities and multidisciplinary programs at the home institutions of the participants.

These three objectives were met by a group project directed towards the development of a systems design to control transportation noise pollution, culminating in a report communicating the story of transportation noise and its impact on society to the general public and also to governmental bodies for community planning and legislation. To be realistic such a study must consider a wide range of social, technical, legal, and economic questions. To address this study properly a group of 24 people were assembled including faculty members representing 15 universities and 11 disciplines, two law students, and one acoustics graduate student; this comprised a multidisciplinary team well suited for the study at hand.

Transportation is one of the most vital elements of a modern, progressive, and well ordered society. It is both possible and absolutely necessary that the transportation needs of the future be met without further degradation of an environment which is already subjected to many forms of abuse and pollution. It is recognized that noise as a form of pollution has distinguishing characteristics that are different from other forms of environmental deterioration. Noise is an instantaneous and localized phenomenon that disappears whenever the source of pollution is eliminated, whereas air pollution and water pollution are not localized but can build up over a period of time to levels which can be lethal. With all of the complexities of transportation noise, it is felt that the systems concept is appropriate and necessary to save society from ear-shattering and nerve-racking noise pollution.

Chapters I and II of this report introduce the problem and acquaint the reader with the pollutant being discussed. Chapters III through VI point out the general effects of noise on the environment and on people, provide statistical projections of transportation needs to the year 1985, describe noise generation characteristics and abatement technology of present modes, and explain the legal aspects of noise Explicit recommendations for the control and abatement of transportation noise are given in Chapter VII. This chapter is essentially self-contained and can be used by planning agencies as a guide for the implementation of a functional "system" for noise control.

Having a multidisciplinary team has greatly aided the success of the study, but in addition the program has benefited from lecturers and consultants from a number of governmental agencies, universities, and private industries. In particular, it is appropriate to acknowledge the superb cooperation extended by Mr. Charles R. Foster and his staff of the Office of Noise Abatement (Department of Transportation) who helped to plan the program and supplied literature, constructive criticism and general counsel during the course of the study.

Appreciation is expressed for the many courtesies and the comfortable atmosphere provided by the Co-Directors of the ASEE-NASA Summer Institute, Dr. John E. Duberg and Dr. Gene L. Goglia. The support and patience extended by Messrs. Walter Hixon and M. Patrick Clark are also warmly acknowledged.

Mr. Philip M. Edge of the Langley Research Center served as technological advisor to the study program from its conception to its conclusion, and for his thoughful counsel during the course of the study the participants of the 1970 ASEE-NASA Summer Program express their sincere appreciation.

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SUMMARY AND RECOMMENDATIONS

This report was written with the intense hope of serving society in its search for a quieter, healthier, and more pleasant environment. In a comprehensive attack on the problem of transportation noise pollution, this report discusses the nature of noise and its detrimental effects; projected transportation trends for the next fifteen years and the resulting impact on the noise environment; legal and political aspects of the noise problem; and, most importantly, positive recommendations for controlling and abating transportation noise pollution.

The significance of this report can only be measured by the response it generates in those individuals who can make the biggest contribution to noise abatement—legislators, city planners, and other public officials at all levels of government. To these decision makers are presented not only the challenge of the noise problem, but also necessary tools for its solution.

Many specific recommendations for noise control and abatement are presented and discussed in Chapter VII of this document. Some of these recommendations have appeared before, but others have not. Listed below are concise statements of some of the recommendations that are thought to have the greatest potential in alleviating the transportation noise problem.

RECOMMENDATIONS:

- **The public, policy makers, and manufacturers should be educated concerning noise as an annoyance, a health hazard, and, more generally, as an environmental pollutant.**
- **Industry should be encouraged to publicize its positive efforts towards noise control and abatement, in the hope that it will generate similar efforts by other companies.**
- **Pollution control administrators should be appointed at the local, regional, and state government levels, with a primary responsibility for the control and abatement of noise.**
- **A separate federal agency (Environmental Protection Agency) with the power to regulate in the area of environmental pollution control should be established. Noise pollution should be one of its principal concerns.**
- **Buyers and renters of real estate in noisy areas should be advised of this fact by written statement in the escrow, purchase, deed, or lease agreement.**
- **Land use along high-speed highways should be restricted, as much as possible, to less sensitive uses such as warehouses, industrial developments, commercial buildings, etc.**
- **Compatible land uses near airports include:**
  - **(a) activities involving few people**
  - **(b) activities insensitive to additional noise**
  - **(c) indoor activities protected by soundproofing**
  - **(d) activities associated with the operation of the airport.**
- **Equipment and services purchased by government should not exceed specified noise levels.**
- **Specific maximum noise levels should be established and enforced for the sale and use of motor vehicles, aircraft, construction equipment, powered tools, home appliances, and other annoying noise sources.**
- **Acoustical insulation requirements should be incorporated into building codes.**
- **Acoustical treatment should be added to existing hospitals, schools, and other designated noise-sensitive structures.**
- **A satisfactory truck muffler should be required by law and included as a standard item in the vehicle inspection requirements for trucks.**
- **All SST aircraft, domestic and foreign, should not exceed current FAA noise certification levels for subsonic aircraft before being permitted to operate in U.S. airspace. These criteria should be established immediately.**

- The noise certification levels for V/STOL aircraft should not exceed 95 PNdB at a distance of 500 feet in any direction.
- The authority to set noise standards for aircraft should be placed in the proposed Environmental Protection Agency, rather than with the FAA.
- Off-the-road motor vehicles (including snowmobiles) should be prohibited from any wildlife sanctuary.

Chapter I

Introduction

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> As concern with the condition of our physical environment has intensified, it has become increasingly clear that we need to know more about the total environment . . . land, water, and air.

This statement by President Richard M. Nixon to the Congress of the United States (on July 9, 1970) points out the urgency of reducing environmental pollution in all its forms: air, water, thermal, pesticide, land (solid waste), and noise. Of all these forms of pollution, noise is perhaps the most insidious because of its intermittent nature and because its aftermath, however damaging, is not usually visible. However, society has created, as a side effect of advancing technology, an incessant din of noise which contributes to the stress, frustration, hypertension, and anxiety of our lives and affects the ecological balance of our environment. The effect is "pollution of our quiet."

Noise sources are of varied forms, they intrude into our lives in different ways, and they must be controlled by different elements of our social structure. Of paramount importance in today's technologically oriented society are such noise sources as industrial equipment, household appliances, rock music groups, and transportation systems. Industrial equipment noise has long been considered in many plant safety programs. Additional attention to industrial noise has resulted from a new provision of the Walsh Healey Act (1969) which establishes noise exposure limits for employees of plants having contracts with the Federal Government. Although noise exposure levels are established and are effective in covering a company's obligations to safeguard its workers, there may be important additional considerations when the overall problem of the worker's noise-polluted environment is considered. For example, many noise exposure criteria assume that the worker retreats from his noisy work environment to the quiet home environment where he may quickly recover from adverse effects of workday noise.

However, man's escape from noise is not so simple. Today's homes are operational centers for many noisy household appliances—washing machines, dryers, vacuum cleaners, food blenders, loud hi-fi systems, lawn mowers, power saws, etc. Many of these appliances produce noise levels in the 90 dB to 110 dB range (see Chapter II) where there can be adverse effects on man's well-being. For example, it has been found that exposures to noise of over 90 dB can cause blanching, constriction of the stomach muscles, and irritability, and yet domestic food blenders produce up to 93 dB and loud lawn mowers 107! As he becomes more aware of noise exposure problems the individual consumer will, it is hoped, demand household appliances which are amenable to a quiet home environment.

Control of industrial equipment noise and household appliance noise is only a partial solution to man's problem of environmental noise pollution. It is becoming more common to locate company plants (and offices) and residential housing in close proximity to noisy transportation systems. These constitute a very serious form of noise pollution, the control of which reaches far beyond the industrial plant operator or the individual home owner. This form of noise pollution is a challenge to our entire society and to vital systems under which we live. Often the business owner or home dweller is faced with conflicting choices to locate where transportation systems are close at hand and readily accessible or to locate remote from these systems where he may escape adverse noise environments.

There are situations where man no longer has much choice of obtaining an environment free of transportation system noise. This loss of a noise-free environment is attributed to ever-growing highway systems, the rapid development of jet aircraft transportation, and man's continuing desire for mobility via private vehicle systems (motorcycles, automobiles, snowmobiles, and motor boats). High speed highways are being built through established business and residential areas, and new homes are being built in close proximity to highways. Jet transport flight operations have grown to a point where most all commercial airports experience the noise of jet aircraft engines. Residential occupants many miles from the airport runways complain about the noise produced by landing approach and takeoff operations of jet transports. In addition to contributing to the bus and truck noise on highways, automobiles and motorcycles in increasing numbers are increasing the noise problem on secondary roads and in neighborhoods where ambient noise levels are usually quite low. Motor boats and snowmobiles have introduced noise as a pollutant to areas generally untraveled or unspoiled by man.

The need for most of these modes of transportation is clearly established as society continues to demand more and faster transportation. However, with the fantastic growth of transportation, the impact of its noise on society is reaching intolerable levels. Such a situation is not necessary. Steps which are compatible with the continued movement of freight and passengers can and must be taken to ameliorate this pollutant. It is hoped that this report can give indications of the future trends in the dominant modes of transportation and offer some suggestions and recommendations as to how the noise of transportation can be alleviated or abated.

Solutions, however, in order to be totally acceptable to society, must take into account all the interrelated aspects of the problem. This can best be accomplished by an interdisciplinary systems approach which considers the complete environment. The necessity of this method has been pointed out by President Nixon.

> Despite its complexity, for pollution control purposes the environment must be perceived as a single, interrelated system.

Such an interdisciplinary systems approach to the general problem of transportation noise abatement has so far been lacking in this country. The solution to this type of problem requires the successful completion of the following three steps: recognition of the problem, establishment of criteria for the solution, and implementation of the criteria. Each one of these three tasks requires expertise in several different disciplines. It is felt that in the past there has been a neglect of these three steps in regard to transportation noise abatement. The problem has not been sufficiently recognized by society, the necessary standards have not been established for noise level acceptability, and there have not been socially viable systems designed to implement these standards. The inevitable result has been an ever-increasing noisy environment due to transportation sources.

However, solutions are possible. This report attempts to fill the void that exists since it represents the efforts of the diverse professional specialties that are necessary in treating the environment as a single, interrelated system. It then becomes the clear purpose of this document to aid in the recognition of the problem, to provide noise acceptance criteria, and to present a design of a system which can function within legal, technical, social, and economic restraints to control and abate transportation noise.

Chapter II

Noise

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Sound

The sensation resulting from the stimulation of the organs of hearing by vibrations transmitted through the air can be defined as sound. Implicit in this definition are three elements: (1) a source of disturbance causing the vibrations, (2) a path through which the vibrations can be transmitted, and (3) a mechanism for receiving the vibrations. The particular type of vibration that constitutes sound is actually represented by fluctuations in the air pressure above and below the average atmospheric pressure. The physical term **sound pressure** is used to describe the amplitude of the pressure fluctuations. The term **loudness** is a subjective expression of sound level. Similarly, the physical term **frequency** gauges the rapidity of the fluctuations, while **pitch** or **tone** is the subjective measure.

The sensation of sound can produce a wide range of emotional responses from supreme pleasure to extreme irritability. The most common sounds are rarely pure tones but made up of a mixture of many frequencies and amplitudes. Certain mixtures produce music while other combinations are used in communication. Sounds from which no information or pleasure is derived are categorized as undesirable, without value, and are defined as **noise**. Accordingly, most of the sounds associated with transportation may rightly be defined as noise.

The Decibel Scale

As described previously, the physical quantities characterizing a particular sound or noise are the amplitude and frequency of the acoustic pressure fluctuations. The human auditory system is extremely sensitive to sound pressure and can accommodate sounds with pressure amplitudes 10 million times greater than a barely audible sound. Since the range of amplitudes encountered in the everyday environment is so great, a logarithmic scale is used to measure sound pressure called the decibel (dB) scale. The softest sound that can be heard (a very soft whisper) corresponds roughly to zero decibels (dB). With this sound as a comparison, each time the sound pressure increased by a factor of 10, the corresponding decibel value increases by 20 units or dB. Thus, a sound with a pressure 100 times as large as the one that can barely be heard would have a level of 40 dB, and one 1000 times as great would have a level of 60 dB and so forth When the sound pressure becomes very great, pain will normally be experienced. This occurs at sound pressures about 10 million times greater than barely audible ones and corresponds therefore to a sound pressure level of about 140 dB. It is emphasized, however, that sound levels well below the 140 dB pain threshold can cause permanent damage to the hearing mechanism under extended exposure, resulting in hearing impairment or even total deafness. Several common sources of sound and noise along with their associated decibel ratings are listed later on.

Sound Measurements

Sound is measured with a very sensitive pressure-measuring device constructed to give the decibel rating directly. Some instruments examine the frequency mixture of a given sound by electronic frequency filtering, which establishes the decibel rating (or strength of the sound pressure) of particular bands of frequencies. Frequency analysis is ordinarily carried out in the range of audible perception which extends from 20 cycles per second (Hertz) to 20,000 Hertz (1 Hertz = 1 cycle per second). The spread of frequencies in the audible range is divided into particular segments called **octave bands**. Each octave band is identified by its center frequency and is double the preceding one (i.e., 62.5 Hz, 125 Hz, 500 Hz, . . . 16,000 Hz). The results of frequency analysis can be displayed graphically by plotting as illustrated in Figure 2.1.

Human Reaction to Noise

For the hypothetical noise analyzed in Figure 2.1 the frequencies most dominant are centered around 62.5 Hz and 4,000 Hz. The dominant frequencies must be considered when examining the effect that noise has on man because the auditory system does not respond equally to all frequency components. Many hearing tests prove that low frequencies cannot be heard as readily as can some of the higher frequencies. For example, a noise with components in the range around 50 Hz must have a sound pressure level of 40 dB in order to be heard, while a noise with frequencies in the 100 Hz range requires a level of only 20 dB to be heard. When such information is combined for all frequency bands in the hearing range, a threshold of hearing sensitivity is obtained. This is illustrated in Figure 2.2.

The auditory system is relatively insensitive to low frequency components at sound levels well above the threshold of hearing. People react subjectively to the strength of intensity of noise by judging its loudness. Tests have shown that a noise with frequencies around 63 Hz and a decibel rating of 60 dB will be rated (by human observers) as equalling in loudness a noise with a frequency mix centered around 1000 Hz and a decibel rating of 40 dB. A composite of this data for the audible range is shown in Figure 2.3 and demonstrates equal levels of loudness. Of the number of methods devised to account for the subjective attribute of loudness in measuring noise, the most successful employs the levels of equal loudness shown in Figure 2.3 in an electronic design that measures noise according to a particular "weighted" (or fixed) decibel scale referred to as dB(A).

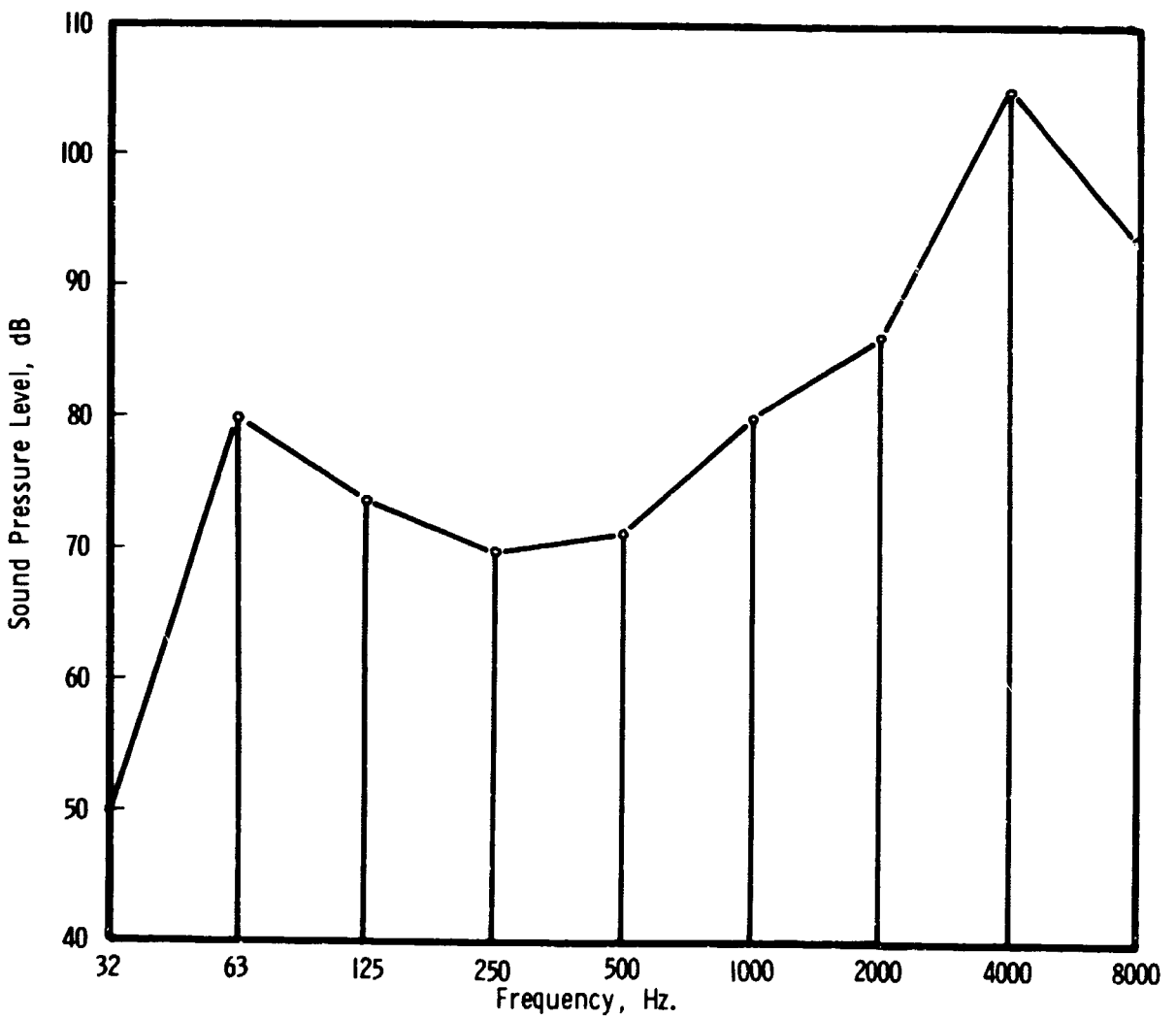


Figure 2.1. Illustration of Noise Frequency Analysis

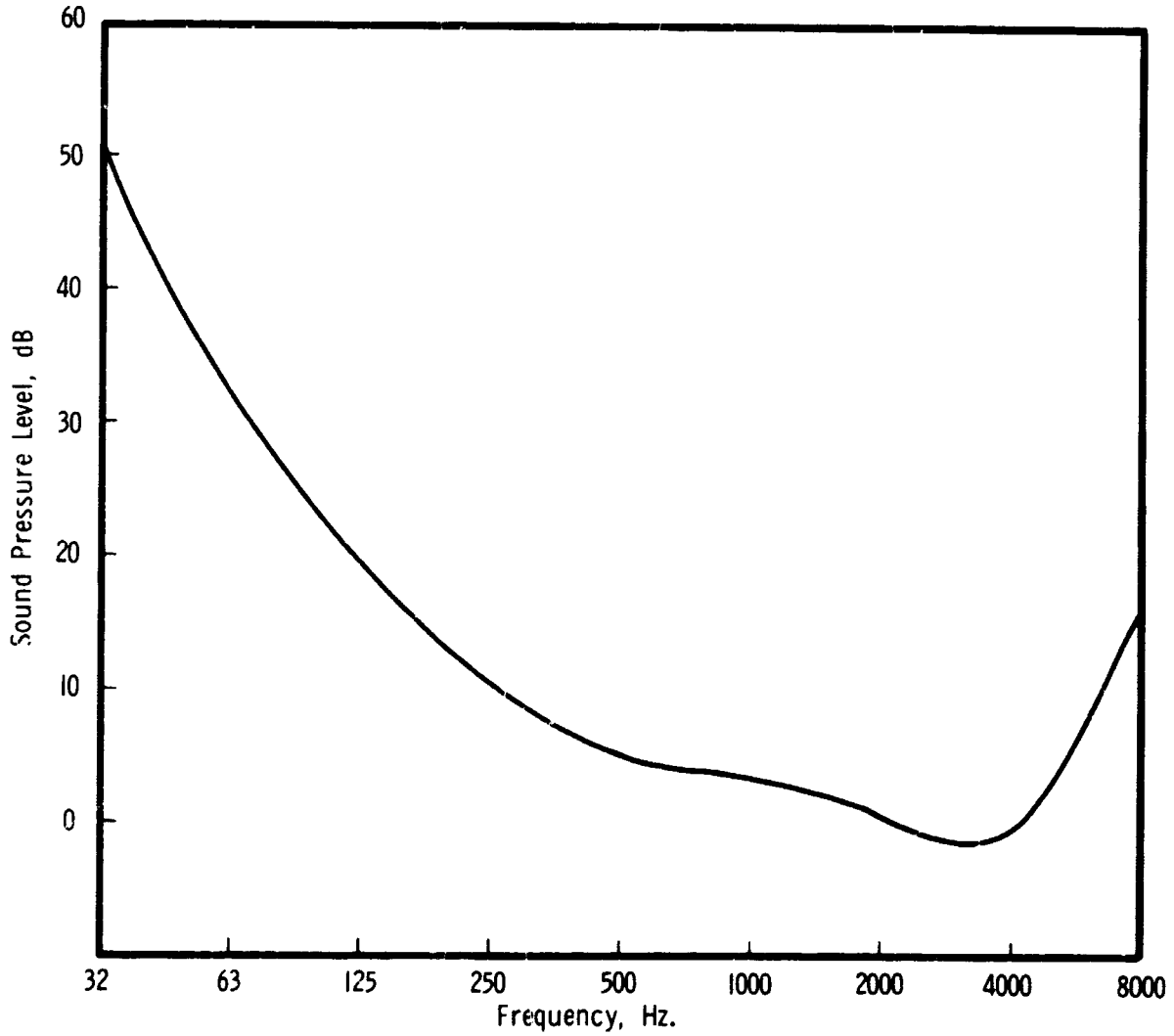


Figure 2.2. Threshold of Hearing Sensitivity

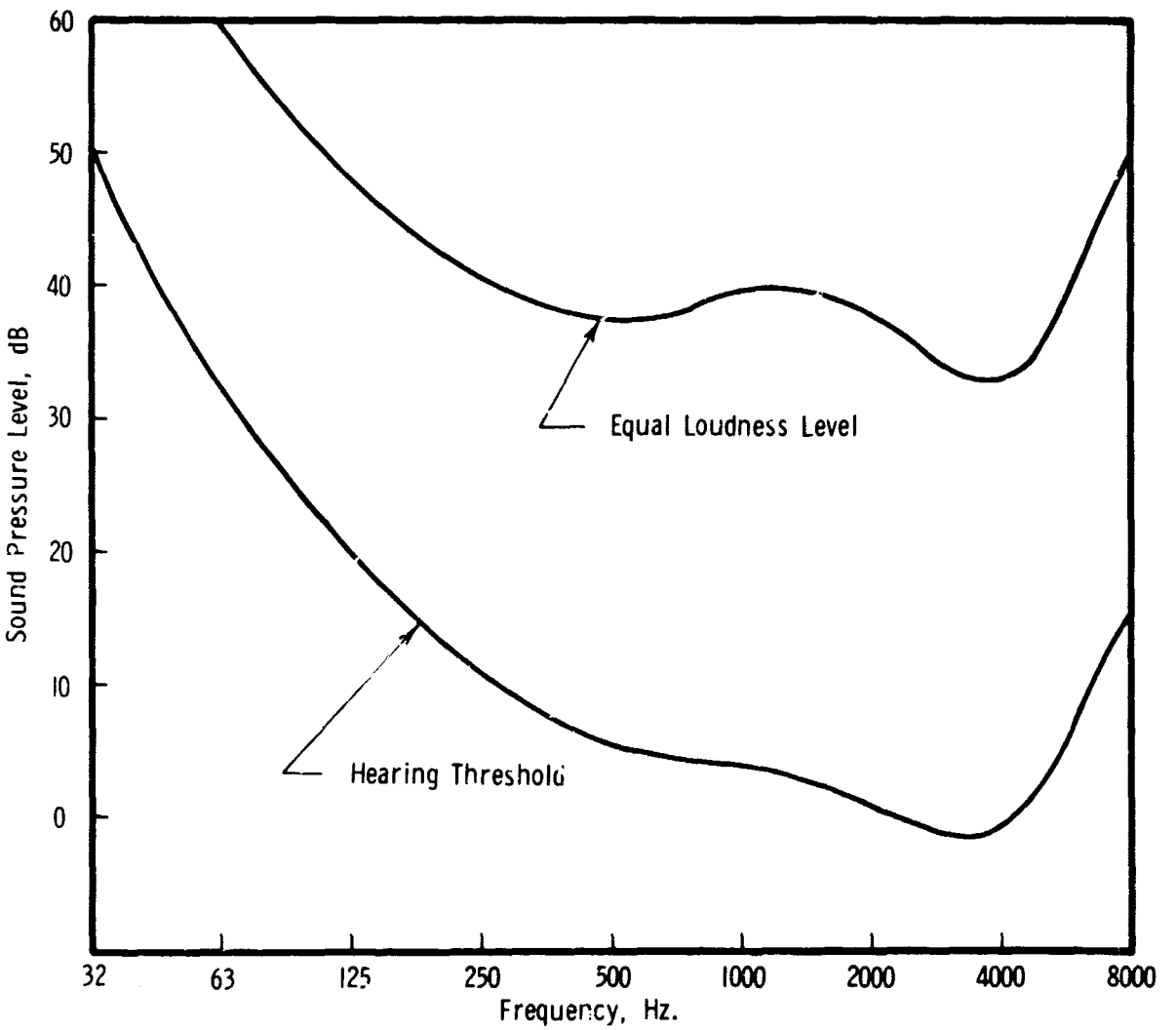


Figure 2.3. Sound Levels of Equal Loudness

Another important subjective characteristic of noise is its capacity to annoy. Tests show that noise with only low frequency components is less annoying than noise with predominately high frequencies. This attribute (similar to loudness) has led to development of curves showing equal annoyance for different frequency bands. A measure of noisiness accounting for amplitude and frequency is the perceived noise level (PNL) with an associated decibel rating, PNdB. For comparison, a curve that exhibits equal noisiness as a function of frequency is shown in Figure 2.4 with an equal loudness level curve and the threshold of hearing sensitivity curve.

Both the dB(A) and the PNdB scales are based on amplitude and frequency alone. While dB(A) is an indication of loudness, PNdB is an indication of annoyance. Tables 2.1 and 2.2 list the sound levels of some common noise sources. These should serve as an orientation to the magnitude of dB, dB(A), and PNdB.

Attempts to make the perceived noise level a more accurate gauge of annoyance have been considered. These include such factors as the duration of exposure to noise, the number of exposures in a given length of time, and the noticeable presence of strong single frequencies. A summary of the resultant rating scales is presented in Table 2.3.

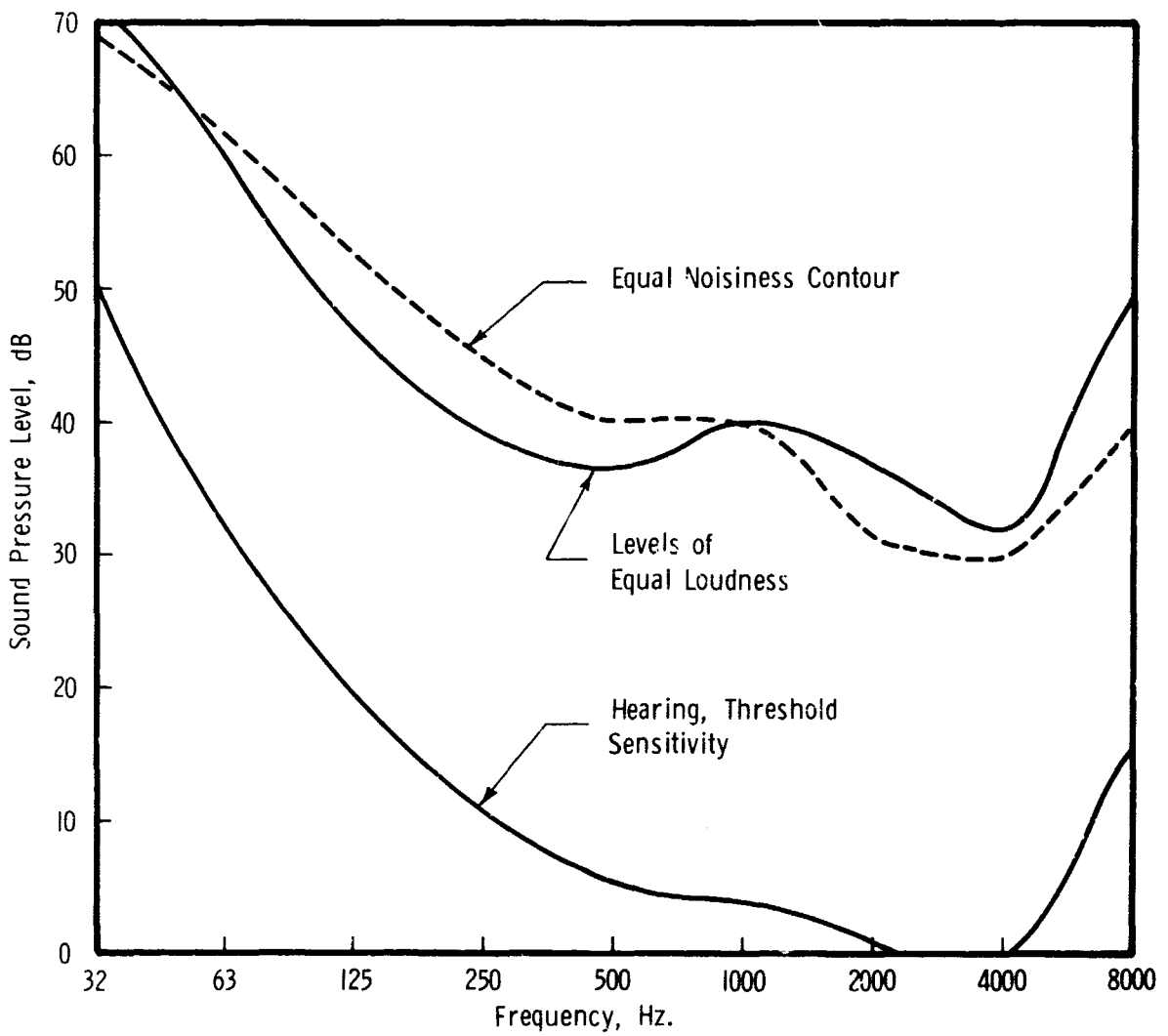


Figure 2.4. Sound Pressures of Equal Loudness

The problem of speech interference caused by noise has particular significance in generating annoyance. The noise levels that cause interference with the reception of speech are well known. Tests have shown that the simple average of the three sound pressure levels for the octave bands around 500 Hz, 1000 Hz, and 2000 Hz provides an adequate description of speech interference as a function of distance between speaker and listener. Figure 2.5 shows the relation between speech interference level and distance for the normal voice level.

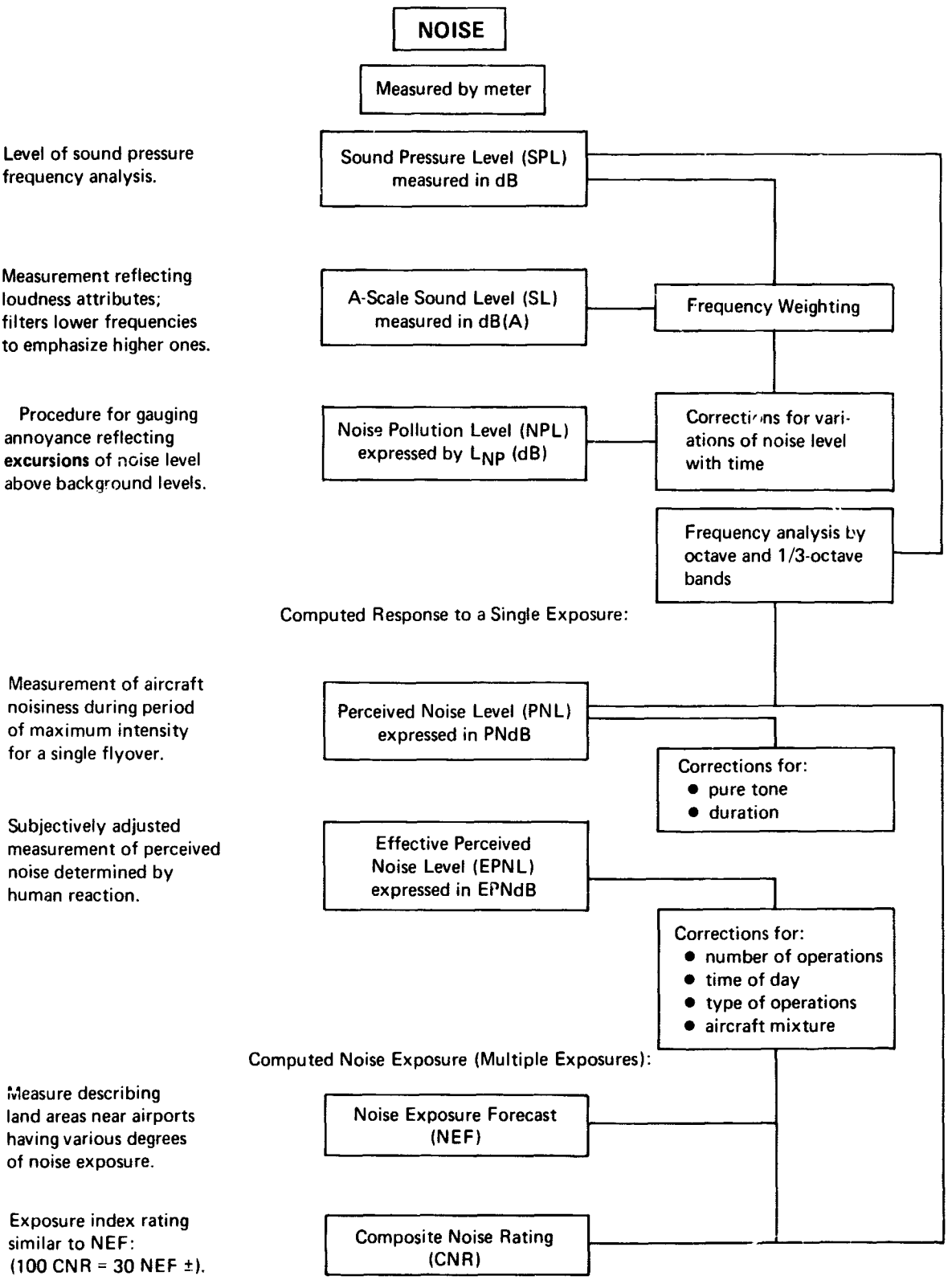
Orientation	dB(A)	dB
Noise in a car that is passing a truck at 60 mph.	95	110
Noise from a Boeing 727 taxiing toward the listener and approximately 350 feet away.	95	107
Briggs and Stratton 3 hp lawn mower at the operator's position.	90	96
Phone ringing 10 feet away	78	79
Electric alarm clock (3 feet)	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 2.1 Noise Level Orientation

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

Source: "VTOL, The Noise Question," **Sikorsky Aircraft, June 1970.**

Table 2.2 Annoyance Level Orientations



Source: Outdoor Noise and The Noise Environment

Adapted from Figure E-1.

Table 2.3 Noise Measurement and Annoyance Scales

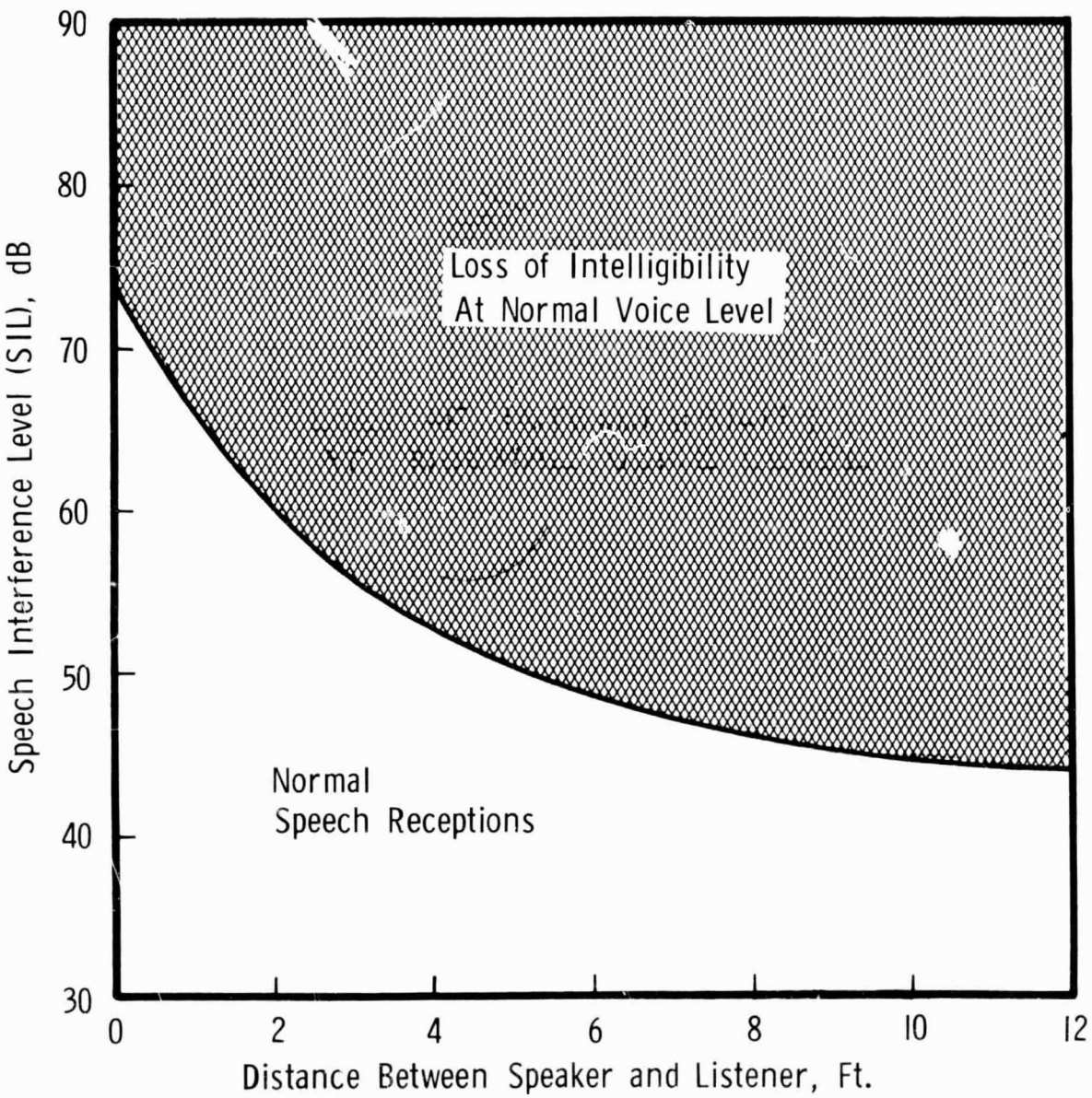


Figure 2.5. Speech Interference Effects of Noise

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Chapter III

Noise Effects

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The Auditory System

It is generally agreed that noise has adverse effects—parents of teen-age rock-and-roll addicts or homeowners near airports and freeways need no convincing. Still, few people can explain precisely why noise detrimentally affects society. If we are to restore our peace and quiet—or merely conserve the last vestiges of our domestic tranquillity—we must have sufficient understanding of the effects of noise to direct us to suitable action. This chapter describes the effects of noise on man and his society, and on the natural environment.

The place to begin, obviously, is with the ear. The ear is a complex mechanism for transforming pressure changes in the air into neural messages to the brain, where these nerve signals are decoded and translated into meaningful "sounds" (sharp noises, pleasant music, a dog barking, etc.). The details of the final operation of decoding are really not well understood.

The "mechanical" components of the hearing mechanism are susceptible to fatigue and damage under extreme or continuous noise bombardment. These parts of the system consist of the outer ear, middle ear, and the inner ear (see Figure 3.1).

The outer ear consists of the fleshy external ear and the auditory canal which terminates in the ear drum (tympanic membrane). Sound waves enter the ear and travel down the ear canal setting the ear drum in motion. The natural resonance of the ear canal amplifies sounds falling into the frequency range from 2000-6000 Hz, while sound energy on either side of this range is partially absorbed.

The middle ear is composed of a set of three connected bones (ossicles) and the Eustachian tube (which acts as a safety valve for pressure increases). Sound waves vibrate the ear drum which is attached to the first bone. The ossicles form a bridge from the ear drum to the oval window of the inner ear. Sound transmission by the ossicles is most efficient around 1000 Hz, near the center of the major speech frequencies.

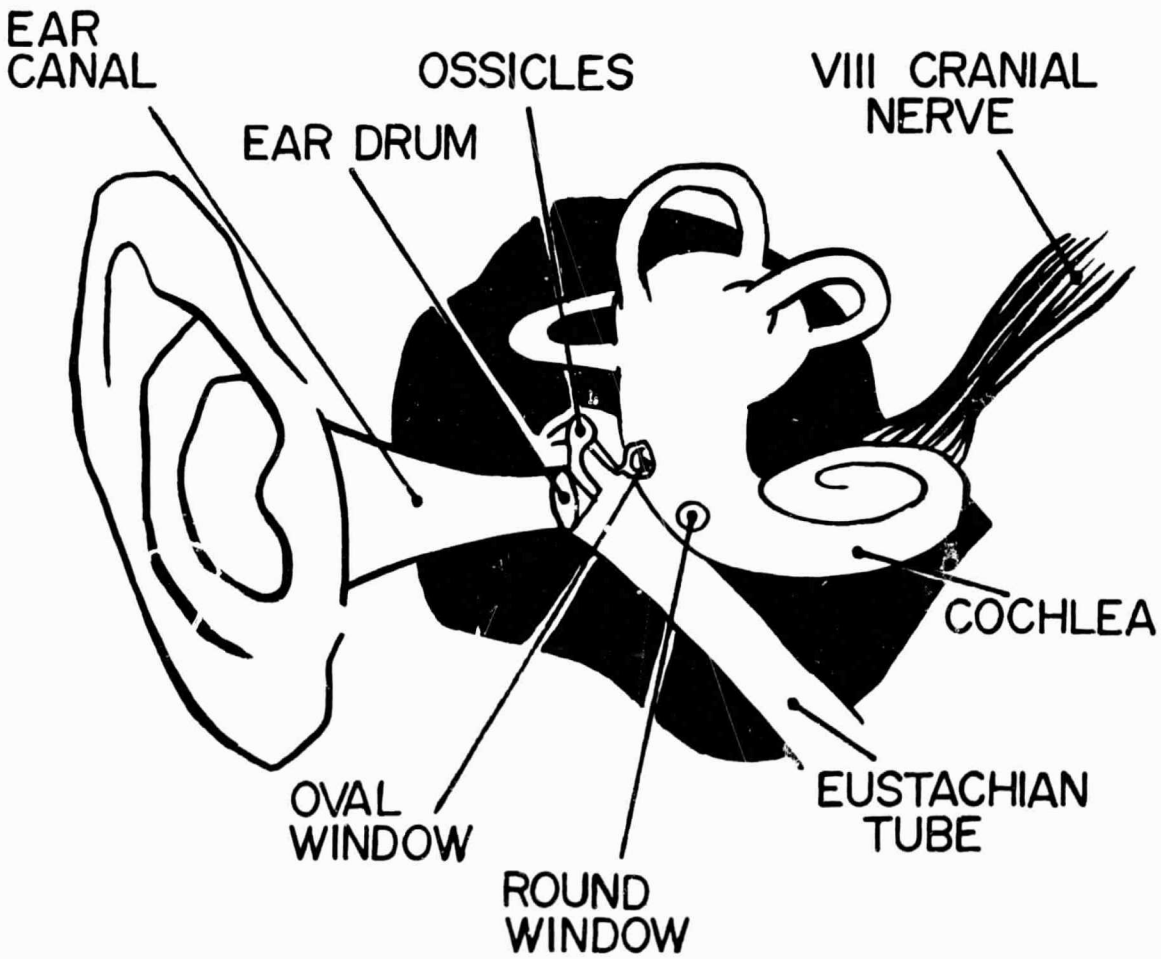


Figure 3.1. Diagramatic Sketch of Auditory Mechanism of Man

The inner ear consists of the snail-shaped cochlea and the eighth cranial nerve which carries information to the brain. The cochlea is a fluid-filled structure effectively divided in half by the basilar membrane. On the basilar membrane are the Organs of Corti, the hairlike neural receptors of hearing.

Over the haircells lies the tectorial membrane. Ossicular pressure on the oval window sets up hydraulic waves in the cochlea, moving the basilar membrane and causing the tectorial membrane to move across the haircells. This bends the haircells stimulating them to discharge neural energy. Intense or prolonged sounds can damage or destroy these receptors with corresponding hearing loss.

The human ear can detect sounds in the frequency range of 20-20,000 Hz. Within this range there is considerable variation in the ear's sensitivity (see Figure 2.2). For example, to be heard, a 50 Hz tone must have roughly ten thousand times the energy of a barely-audible 2000 Hz tone. The most sensitive hearing range is from 500 to 3000 Hz, the human speech range. Sounds falling above and below this range require a greater intensity to be heard. Of crucial importance for normal functioning is man's ability to hear the speech frequencies, and it is in this range that auditory damage is assessed.

Man can hear sounds and function indefinitely without any risk of damage at sound levels up to 80 dB(A). At levels of approximately 120-160 dB strong nonauditory effects occur: sounds are not only heard as extremely loud, but also produce pain, and cause nerve firings in the mucous membranes of the auditory canal, mouth and nose, with consequent itching, burning and disturbing sensations. Sounds in this range are literally felt. They are intolerable for the unprotected human ear and will cause cochlear damage if the exposures are prolonged.

Hearing Loss

Loss of hearing is the most prevalent disability in this country today, and the number of people suffering some degree of hearing loss is greater than for all other disabilities combined. Many working men are hardest hit because of the continual exposure to extreme industrial noise above 95 dB(A). Any estimation of hearing loss attributable to a specific cause (**e.g.**, transportation noises) must recognize the host of possible contributors to the observed loss.

Types of hearing loss may be categorized according to the functional disruption caused in the auditory chain.

Conduction deafness is the result of interference with the passage of sounds through the ear canal, tympanic membrane, and the ossicles to the oval window. Causes range from earwax in the auditory canal or a ruptured eardrum to calcification of the ossicles reducing or preventing their movement (**otosclerosis**). Many of the hearing losses in this class can be corrected.

Nerve deafness is directly attributable to damage to the haircells of the cochlea. This damage is irreversible. Intense sound is one of the prime causes of this damage. A common symptom of an auditor overload is a ringing in the ears, **tinnitus**. Tinnitus occurring after exposure to loud noise should serve as a warning of possible damage if exposures are repeated.

Central deafness is caused by interference in normal brain function and may have either a physiological or psychological origin. An individual experiencing an emotional trauma (**e.g.**, a rape victim) may suffer a functional deafness.

Two other sources of hearing loss, **presbycusis** and **sociocusis**, must be considered when evaluating the effects of noise exposure. Presbycusis is the gradual loss of hearing sensitivity with aging and is marked by a loss in the high frequency ranges. Sociocusis is a hearing loss due to noise exposures that occur in non-work settings and is not the result of aging (**e.g.**, hearing losses of teen-agers exposed to loud music).

All of these factors make any simple analysis of hearing loss difficult. Industrial losses in men exposed for years to high intensity noise must be corrected for the amount of loss that would normally occur without exposure at the same age. Even with this correction, however, individual non-work exposure (**e.g.**, hunters exposed to loud gunblasts) complicates the evaluation process.

Noise Induced Hearing Loss

How much noise can the human ear tolerate? Attempts have been made to answer this question for continuous noise exposure in work environments. The problem of estimating critical noise levels for transportation noise is more difficult because of its irregularities (**e.g.**, airplane departures and landings). However, with background ambient noise levels continuing to rise within some cities .. an estimated rate of one dB a year, the concern about noise increases. [43] Current estimates of city noise levels range upward from approximately 55 dB at night and 67 dB during the day. [49] In many cities heavy ambient traffic noise reaches levels of 90 dB(A). Generally, prolonged exposure to levels lower than 80 dB(A) is presumed safe. [109] The main impact of transportation noise on personal well-being may be its aggravation of hearing impairment already induced by the noisy work environment. For example, an individual exposed to high noise levels at work is exposed to loud noise traveling to and from work, and at home is continually exposed to transient noises when trying to relax or sleep. This endless exposure to noise may

hasten the onset of serious hearing losses, nerve damage and poor health.

Damage Risk Criteria

To assess the effects of noise on hearing it is necessary to define the critical hearing areas. The International Standards Organization (ISO) has stated that the frequency range that encompasses the major speech frequencies is to be used as the basis for noise induced disability and has suggested that losses of more than 26 dB in sensitivity at 500, 1000, and 2000 Hz define the onset of a hearing impairment. [6] Any loss of 93 dB in this range represents a complete loss of hearing. Generally, damage risks are established to protect 90 percent of the population from impairment. [20] A more conservative exposure-risk criterion [64] tolerates only a 10 dB loss at 1000 Hz, 15 dB at 2000 Hz, and 20 dB at 3000 Hz.

Two theoretical positions attempt to determine the energy levels that cause a hearing loss. The **equal-energy** position bases allowable exposures on the total amount of sound energy entering the ear, without considering the ear's differential sensitivity or its capacity to recover sensitivity when given a rest. The **equal-temporary effect** position allows for variations in the ear's sensitivity but assumes (perhaps inaccurately) a direct relationship between sounds causing a temporary loss of sensitivity (TLS) and a permanent loss of sensitivity (PLS). The assumption is that exposure to noise that causes a TLS that does not recover within 16 hours will eventually lead to a PLS. If an individual returns to a noisy work environment and has not recovered from the effects of his previous exposure, re-exposure will further stress his auditory apparatus and over a period of years cause significant hearing losses.

A series of curves using the second position defines the maximum safe exposures depending upon the frequency of the sound source. [69] Partial validation of these curves has come from surveys of workers exposed to known work-noise environments. Their losses after 10 years of exposure correspond to those predicted from equal-temporary effect research. [42], [83] From the curves, it is possible to construct a table of crude cutoff values for critical sound exposure levels (see Table 3.1).

It is presently an extremely difficult task to specify the allowable exposures for brief and intense transportation noise exposures. A maximum tolerable limit can be set at 120-130 dB. Some investigators feel that a 10-second exposure to 135 dB is the maximum the unprotected ear can be subjected to. [35] For transitory sounds at lesser values, Table 3.2 presents the total allowable exposure depending on the intensity and frequency of the sound's occurrence during a 24-hour period. [20] This table is read by determining the number of times the sound occurs during the day and the total time duration of the exposures.

SOUND LEVEL	EFFECTS
78- 80 dB(A)	safe
85 dB(A)	hearing losses begin
90 dB(A)	serious losses begin
95 dB(A)	50 percent probability of a hearing impairment
105 dB (A)	losses in all exposed individuals

These cutoffs refer to damage risks for prolonged exposures to noise over a period of several years.

Table 3.1. Critical Sound Exposure Levels

Current data on transportation noise levels suggest that **by themselves**, these irregular transportation noises will not cause any permanent hearing damage to the exposed citizen. However, if the transportation systems maintain constant high levels of noise (85-90 dB(A) and up for 8 hours per day), then there esists a serious risk of hearing impairment.

Autonomic Responses to Noise

Hearing losses may not be the only danger from exposure to noise. Noise can cause the body to activate its defense system, the autonomic nervous system, which controls many critical bodily processes (**i.e.**, heart output, hormone control, digestion). Noise is responded to as a stress, and any bodily stress that cannot be effectively coped with will result in severe impairment. The more stresses bearing on man at any given time, the quicker the bodily defenses can be overwhelmed. Emotional states can precipitate the stress reaction, which are exemplified by the "executive syndrome," involving ulceration, hypertension, cardiovascular diseases, migraine headaches, insomnia, allergic hypertension, and personality disturbances. [92], [93] Acting in concert with other forms of stress, sound may also be a significant contributor to poor health. Even when sound alone acts as a stressor it may cause serious health effects in man. For example, jet noises have been shown to cause a higher incidence of premature births, slower gain in body weight for children, and chronic fatigue. The **New York Times** recently reported, [8]

> Medical research is beginning to show that loss of hearing is by no means the only ill effect of noise. Loud sounds cause blood vessels to constrict, the skin to pale, muscles to tense and adrenal hormone to be suddenly injected into the blood stream. Dr. Samuel Rosen, Clinical Professor of

Table 3.2. Acceptable Exposures to Dangerous Noise

To use the table, select the column headed by the number of times the dangerous noise occurs per day, read down to the average sound level of the noise and locate directly to the left in the first column the total duration of dangerous noise allowed for any 24-hour period. It is permissible to interpolate if necessary.

Total Noise Duration Per Day (24 hours)	Number of Times Noise Occurs Per Day						
	1	3	7	15	35	75	160 up
8 hrs.	89	89	89	89	89	89	89
6	90	92	95	97	96	94	93
4	91	94	98	101	103	101	99
2	93	98	102	105	108	113	117
1	96	102	106	109	114	125	
30 min.	100	105	109	114	125		
15	104	109	115	124			
8	108	114	125				
4	113	125			A-Weighted		
2	123				Sound Levels		

Otology (the science of the ear) at Mount Sinai School of Medicine in New York, . . . believes that the millions of city dwellers with heart disease, high blood pressure and emotional illnesses need protection from the additional stress of noise. He adds that the ears cannot shut out noise the way eyelids shut out light: The reflex effect which causes constriction of blood vessels occurs with equal intensity during sleep. Dr. Jerome Lukas of Stanford Research Institute says that many people show fatigue from the effort to remain asleep in spite of noise.

The specific effects noise has been shown to have on man, dependent on its intensity and duration, include an increase in muscular tension, sweating, metabolic changes, reduced gastrointestinal activity, nausea, headaches, tinnitus, drowsiness, respiratory irregularities and emotional disturbances. [30], [38], [59], [77], [98], [101] The list was derived from numerous investigations which used prolonged exposure to high sound levels, ranging from 90-120 dB. Although these effects are sings of autonomic arousal, this is not necessarily dangerous to the organism unless the arousal is maintained for prolonged periods of time causing depletion of bodily defenses. [93], [99]

For work environments where prolonged exposures to noise are common and long lasting, chronic changes have been reported: workers have suffered from reduced peripheral circulation, hyperactive reflexes and abnormal brain rhythms, cardiovascular irregularities, insomnia, fatigue, irritability, and even sexual impotence. [11], [45], [58], [94] However, these studies have not differentiated the separate effect that noise has in causing these symptoms from the effect of other industrial environmental variables such as ventilation, temperature, and vibration. Animals have suffered ailments and shown indications of bodily stress when exposed to intense noise levels in the range of 120 to 150 dB. [3], [4], [5] In man, these levels can cause spontaneous neural discharge of the mucous membranes of the ear, mouth and nasal passages, and even aural pain.

Although there is little unequivocal evidence that sound level exposures below 105 dB can cause illness, it is clear that noise can induce a stress response in man. Since the present concern is transportation noise, which is irregular and not continuous, its most probable role will be as an additive stress on man. If man is being bombarded by other physical, social, and personal stresses, then noise may serve as the proverbial straw that broke the camel's back. A professor of neurology at New York University's Medical School says, [44]

> Sufferers from diseases such as heart trouble, asthma, ulcers, and gastrointestinal spasm, may all be adversely affected by prolonged or sudden noise.
>
> Cardiac patients are particularly vul-

nerable. Loud noises, such as a bursting paper bag close to the ear, the backfire of a truck, the blast of an auto horn, may produce an autonomic response which can bring on an anginal seizure in a heart patient.

The information available is suggestive, but one must allow a wide latitude of error in its interpretation. Much research also remains to be done, especially to determine how various subpopulations of our society (the aged, the sick, and the very young) react to noise.

Sleep Disturbance

One of the chief complaints about transportation noise is its disturbance of sleep and relaxation. [76], [81], [112] The major offender is the airplane, owing to its loudness and unexpectedness, and sonic booms will aggravate the problem. Disturbance of sleep is of primary importance because of its **necessity** for normal psychological and physiological functioning. [37], [63], [86] Aggravated sleep loss has a profound effect on body health, particularly for the aged and the sick, and can become a significant variable in personal well-being. Recent testimony before a state legislative committee on jet noise in New York cited paranoid delusions, hallucinations, suicidal and homicidal impulses as some of the possible consequences of continued sleep loss. [44]

Though it is obvious that noises can disturb getting to sleep or can awaken a sleeper, it is not as obvious that noises can reduce the effectiveness of a night's rest without awakening the sleeper. Noise interrupts the cycle of deep sleep stages and results in a less beneficial night's sleep. The difficulty in being dogmatic about the levels of noise that sleepers can tolerate comes from wide variations of sounds and human responses. A mother is awakened by her baby's cries, while the father sleeps peacefully. The dripping of the tap prevents sleep. A jet transport screeches overhead and startles the sleeper awake. What common characteristics do they share? There is no simple answer, but certain fundamental parameters are present; (a) the louder the noise the greater the disturbance of sleep, (b) the more meaningful the sound the greater the probability of disturbance (**e.g.**, a door rattles late at night implying the presence of a prowler), (c) the more unexpected the noise the greater the probability of being awakened, (d) the greater the presence of certain personality variables (**i.e.**, neuroticism), the greater sensitivity to noise, (e) the younger the child, the greater the susceptibility to some forms of interference from aircraft noise, [2] (f) the greater the age or poorer the health, the lower the resistance to noise disturbance.

Since these and other variables can combine in determining a given individual's sensitivity to sleep disturbance it becomes an almost impossible task to set criteria. However, the studies suggest that sound levels of 40-70 db(A) and higher will probably disturb sleep.

Sonic booms generate high noise levels, and the sound energy not only affects ears but also causes houses to reverberate, and people are startled and awakened. A sleeper has an estimated one in ten chance of sleeping through a sonic boom. [46] Thus, sonic booms present one of the most serious potential sources of sleep disturbance from transportation noise.

Transportation noises disturb sleep, and the greater the frequency and intensity of their occurrence the greater the possible serious health consequences. Sleep is necessary, and measures will have to be taken to ensure man's rest, preferably without such crutches as sleeping pills.

Psychological Effects of Noise

If intense and prolonged noise affects man biologically, what are its psychological effects? Does it interfere with his efficiency on the job, his ability to communicate, or his sense of well-being? And if it does, then in what ways?

Noise certainly can have a deleterious effect on these aspects of man's day-to-day existence. Intense noises most obviously disturb an individual, but so do certain frequencies (as in the squeak of chalk or fingernails on a blackboard). Intermittent noise is found to be far more distracting than a constant noise, and a given noise will frequently cause a startle reaction when unexpected but not when expected. Noise coming into one ear (asymetrical) is more disturbing than that coming into both ears (symetrical). And meaningful sounds interrupt concentration more than non-meaningful ones. Thus the difference between "sound" and "noise" is a relative one, mediated by an individual's psychological make-up (tolerances for discomfort, tendencies toward nervousness, distractibility, esthetic taste). To some people rock and roll music will always be music, but to others it will always be noise. However, while what constitutes noise varies with the individual, there is no one who is not negatively affected by noise under some set of circumstances. Thus we can reasonably look at the psychological effects of noise, if not on all individuals **en masse**, at least on individuals in various specific environments.

Studies of noise in the work environment are by no means consistent. [57], [73], [79] In some cases noise levels as low as 65 dB have disrupted performance while in others levels as high as 99 dB have not been disruptive. [27], [53], [69], [97] In a noisy environment, about one-fourth of the people are not disturbed no matter how loud the noise and

about a tenth are disturbed no matter how faint the noise. [13] Controlled laboratory studies suggest that noise may be disturbing without necessarily interfering with performance. [87] A study of noise effects on work [13] found that output increased 37 percent when the work location was shifted away from a noisy boiler shop area. Accuracy increased and absenteeism decreased. Other studies of accuracy demonstrate that vigilance suffers greatly under noise stress. [48], [61] Tests of school children show that noise reduces both the accuracy and the amount of work done. [57], [73], [79].

Other factors not related to noise intensities influence responses to noise. Telling test subjects that noise will affect their performance suggests that it will—as a result of their mental set rather than the noise itself. [107] In some performance tests, noise is found to have an initial negative effect which wears off as the individual habituates. However, several studies show that intermittent noise is very difficult to habituate to, while continuous noise is not so difficult. [48], [54] To some degree a subject may be annoyed by noise, but not necessarily distracted: [62] one study showed subjects to be irritated and uncomfortable at noise above 80-90 dB, but still doing accurate work. [106]

At levels above 90 dB, noise has been shown to cause a significant increase in work errors, particularly after people have been working awhile. [23] Data suggest that routine or repetitive work is less influenced by loud noises than work of a tedious or demanding nature. [62] A physiological study of subjects working under conditions of intermittent quiet, buzzers, and fire gongs showed that under noise stress, subjects exerted more muscle effort and breathed harder, but their work output was not decreased and in some cases even increased. [78] Another study concludes that individuals with high levels of anxiety perform better under noisy than under quiet conditions. [7] These studies suggest the ability of many people to adapt to noise (at least for short periods), and the tendency of some to "overproduce" when the irritant of noise is present. [27], [72] A recent study concludes that the efforts an individual makes in habituating to noise overload his ability to concentrate on other environmental demands, causing a degradation in performance. [39]

The effect of noise on safety is difficult to quantify. It is shown that loud noises can mask audible warning signals and in this sense, are potentially dangerous (Figure 3.2). The startle reaction caused by sudden unexpected noises may contribute to some accidents. [23] Since high intensity noise has been found to increase the number of work errors it is probable (although difficult to substantiate) that high levels of noise may cause a higher rate of accidents.

One of the most common and undesirable effects of noise is its interference with spoken communication. [100], [110] Such measurements as Articulation Index or Speech Interference Level quite accurately predict the effect of various noise levels on face-to-face communication. For example, it has been shown that for every 10 dB additional noise, or for each doubling of the number of talker-listener pairs in a closed area, speech levels increase by 5 dB. [111] Table 3.3 indicates several communication capabilities at various noise exposure levels.

A review of research on individual responses to noise leaves one with certain reservations. Some field studies have not been sufficiently attentive to environmental control factors. (All other factors may not be equal, as, for example, if a study measures performance in a quiet but stuffy room versus that in a noisy but cool one.) Another variable called the "Hawthorne effect" has shown that people will produce more if they know that management is taking an interest in some aspect of their work other than output. [74]

Laboratory studies also have limitations. They may over-control the environmental variables, simulating the working environment only to a degree, but not exactly replicating it. Many laboratory studies use wide-band ("white") noise at various intensities as an independent variable, but the probability of finding such noise in the actual work setting is very low. Further, many laboratory tests use college students or other persons not subject to the actual working conditions for any long period of time. Consequently, it is clear that field and laboratory studies must be coordinated, as checks and balances on each other.

Clearly, then, studies of noise must include such parameters as symetrical vs. asymetrical sound sources, intermittent versus constant noise, predictable versus unpredictable, inappropriateness, reverberation, frequency, and interference with auditory behavior. In a transportation framework, the unexpected honk of a car horn, the high frequency whine of a siren, the sound from an irregular flow of traffic at a busy street corner, and the inability to localize the sound of an ambulance may all be as deleterious to the ability to perform safely, or to the psychological well-being of the individual as is the 94 dB(A) sound of a truck or the 120 PNdB roar of a jet landing.

Natural Environment

Besides irritating or stressing individual persons, noise has effects on the natural and man-made environments. Noise seems to accompany man wherever he goes. Outdoor recreation has become more and more mechanized (for example, evolving from hiking to bicycling to motorcycle-riding), and more and more noisy. When the noise is confined to high-

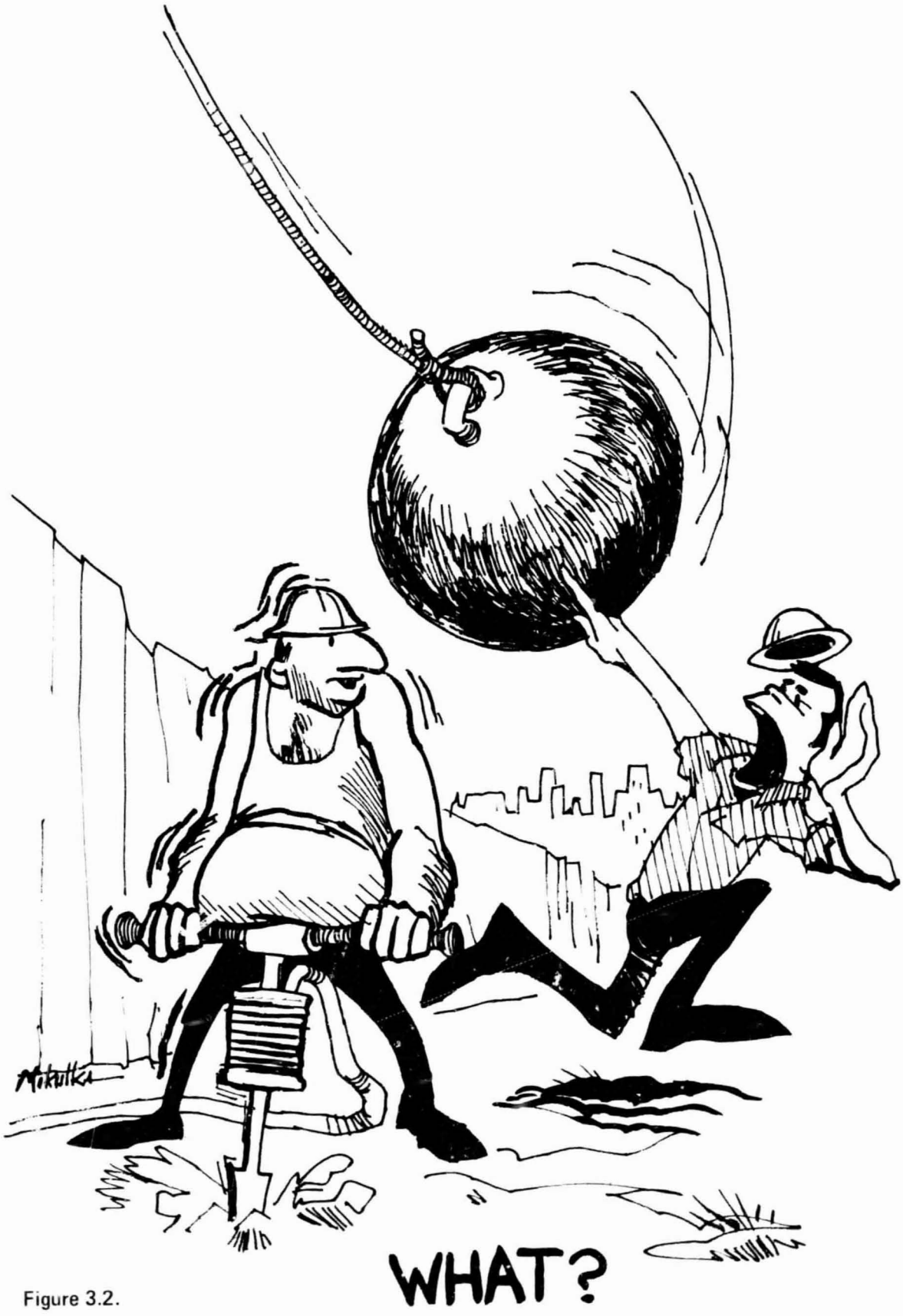


Figure 3.2.

Communication Method	Noise Level Ranges, dB(A)				
	50-70	70-90	90-110	110-130	>230
Face-to-Face	Speakers may be separated by more than 3 feet	Some effort required for good communication to be maintained over 1 to 3 feet	Maximum satisfactory communication distance is 1 foot	Very difficult to impossible	Impossible
Conventional Intercom	Satisfactory to difficult	Unsatisfactory	Impossible	Impossible	Impossible
Conventional Telephone	Satisfactory to slightly difficult	Difficult unsatisfactory	Press-to-talk and acoustic booth needed	Special Telephone needed	Impossible
Loudspeaker	Any loudspeaker satisfactory	Good quality speaker needed for adequate intelligibility	Must be inside helmet or ear protector	Inadequate	Inadequate

Table 3.3. Communication Capabilities in Noise Using Various Communication Methods

ways and roads, wild animals can avoid man. However, the burgeoning popularity of trail bikes (motorcycles) and snowmobiles has taken man into the quiet forests and mountains in a very intrusive and noisy manner.

The noise of snowmobiles terrifies wildlife already immobilized by deep snow and in a weakened condition. The exertion of fleeing through deep snow is harmful and can be fatal. [95] Low-flying subsonic aircraft also constitute a source of terrifying noise. Startle reactions have been observed in farm animals subjected to this noise. (Sonic boom—in a very limited number of tests—have been found to have little short term effects on farm animals.) [15]

In contrast, while surface transportation and subsonic airplane noise have little effect on the earth's surface, sonic booms can cause avalanches. Extensive damage to forest cover in Jackson Hole, Wyoming, during the winter of 1969 has been attributed to sonic boom-triggered snow slides. [65] Reflections of the sonic boom's pressure wave from canyon walls may have combined with the pressure wave to produce a "superboom," causing an unstable slope to slide. Attempts by the U.S. Air Force to start avalanches intentionally with sonic booms have produced inconclusive results so far, however, and the relationship of avalanches and sonic booms needs further research.

Prehistoric Indian dwellings and rock formations in De Chelley National Manument in Arizona, Utah's Bryce Canyon, and Colorado's Mesa VErde National Park have all suffered damage that coincided in time with sonic booms from military aircraft. While the Defense Department has denied the connection, the Air Force admits that sonic booms have become a "fact of life" and that boom intensity and frequency are to be monitored in Yellowstone, Yosemite, Bryce Canyon, and Mesa Verde National Parks.

Land Use and Man-Made Structures

Most noises have negligible effects on man-made structures. Even sonic booms from current supersonic aircraft have a miniscule effect at normal flight conditions unless shock wave focusing occurs. [51] Shock wave focusing is the combining of two or more in-phase shock waves resulting in what is called a superboom. These can be caused by the merging of an original and a reflected shock wave. A nonhomogeneous atmosphere in which wind or temperature gradients refract the pressure waves, and accelerations of a supersonic aircraft can also cause superbooms. [71] A striking example of the effect of an unusually strong superboom is the damage to the Ottowa airport terminal caused by the low-level flight of a F-104 jet fighter. The aircraft flew at supersonic speed along a curved path over the terminal building after a low-level pass. Windows were broken, the multi-ply roofing was ripped, and exterior plaster fell off or was cracked. Repairs cost the Government of Canada about $300,000. [89]

Public structures like schools and hospitals, built with public funds, are expected to be used a long time. Because of this, funds for relocation if the environment becomes too noisy can be difficult or impossible to find. The voting public is usually reluctant to build a school or hospital to replace an existing one. The noise problem is more acute in areas that have comfortable climates, where school buildings tend to be more open and more vulnerable to exterior noise.

In Los Angeles, the noise from L.A. International Airport has become so loud that Westchester Elementary School and Airport Junior High School were closed. Three schools in Hawaii, Puuhale and KalihiKai Elementary Schools and Kalakana Intermediate School, are about one mile from the takeoff path of planes leaving Honolulu International Airport. They also are close to highways with heavy truck and car traffic. The combined traffic noise sound levels in the classrooms at these schools are so high (65 to 70 dB(A) average) that teachers sometimes must shout to be heard, and the students score very low in listening skills. The solution chosen by the Department of Education in Hawaii is to sound-insulate and air-condition the noisy classrooms. [24]

With three-dimensional mobility, aircraft may spread their noise in more unlimited corridors than highway traffic. However, if the FAA's proposed ruling against sonic boom-producing flights over the United States (including, of course, Alaska and Hawaii) is approved and enforced, the natural environment itself will not be damaged by commercially caused sonic booms. The greater threat is that of trail-bikes and snowmobiles to wildlife. These noise sources must be controlled.

Community Reactions

Noise affects human communities just as it affects animal ones. Even though animals cannot usually escape noise, people sometimes can. Not surprisingly, then, when communities are saturated by noise (transportation or other forms) they initiate action to alleviate their exposure. While community reaction to noise is an overall statistical response which more or less neglects the individual, it is from individual reactions, conscious or unconscious, that an overall community reaction is formed. Such reactions may be classified for convenience as (1) annoyance, (2) complaint and (3) protest. A chain of possible events may result from a noise exposure:

(Exposure)→(Annoyance)→(Complaint)→(Protest)

For any stimulus (such as noise exposure) the general human reaction can be depicted as the solid curve in Figure 3.3. Some people will react at very low exposures to the stimulus; some will not react at even very high exposures; the majority will respond at an "intermediate" level. Thus, the majority of people annoyed with noise (and the majority of complaints) are not found at the highest levels of noise exposure, but at several levels below the peak.

In terms of the stimulus-reaction curve, these other factors make the response less specific. Thus the reaction forms a broad band (dashed lines in Figure 3.3, with the breadth of the curve representing individual differences. [40] The influence of these other factors diminishes at both low and high levels of exposure to the stimulus. At high levels, the effect of the stimulus is so pronounced as to dominate the effect of the social, psychological, and political factors.

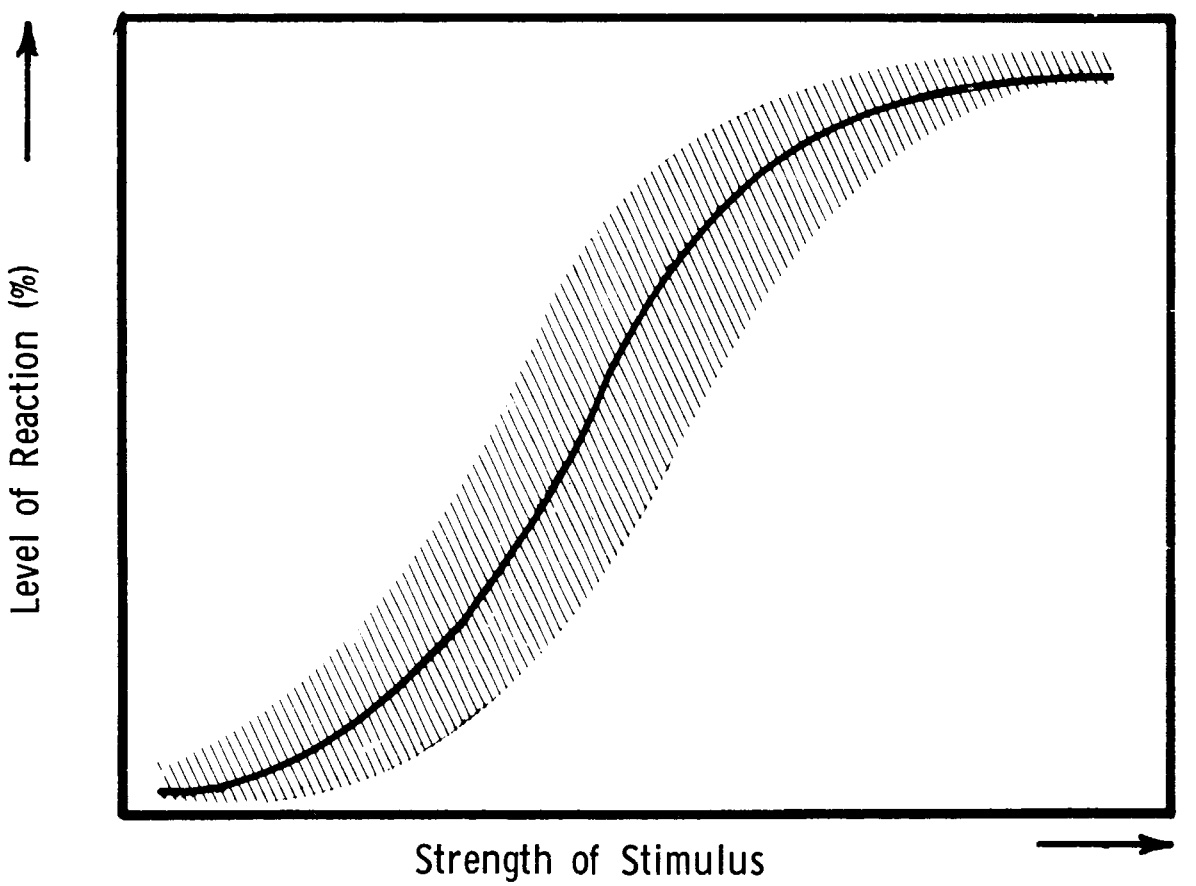
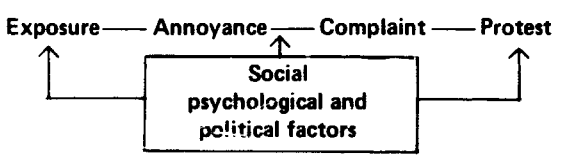


Figure 3.3. Stimulus-Reaction Curve

Studies have shown that the pattern represented by Figure 3.3 is much too simple: many other social, psychological, and political factors contribute to annoyance, complaint and protest activity. The chain of possible events [76] resulting from noise exposure is more properly represented as



Many studies attempting to measure noise annoyance by complaint activity consistently show that the complaint level is not an accurate reflection of the magnitude of the community reaction. Most complainers are highly annoyed, but those highly annoyed are not all complainers. Such factors as occupation, educational level, and property investment distinguish complainers from those equally annoyed and equally exposed to noise but taking no action. Nevertheless, complaint activity can be used to identify major noise problems.

The Airport Problem

The major cause of complaint in the last 15 years is the noise around airports. Community responses to airport noise are in some ways unique but in others resemble complaints about any noise irritation.

Studies of relations between aircraft noise exposure and annoyance have helped determine major acoustical and sociological variables affecting annoyance. [19], [22], [112] It is now possible to establish qualitatively the acceptability of a given noise exposure. Annoyance in general results from interference with normal living activities from the noise itself and from vibrations it causes in structures. Activities commonly disrupted include TV and radio enjoyment, rest and sleep, conversation, reading or concentrating, eating and working.

Disturbances can be more insidious and subtle than we may recognize. In one survey a totally deaf man, using sign language, indicated he was unable to sleep because aircraft caused vibrations which shook the house and bed. Residents near major airports have indicated alterations in social relations due to noise. Speech interference has led to friction and hostility among family members and sometimes deterioration of interfamily relationships. [28]

Some of the more important socio-psychological factors known to affect strongly the annoyance produced by a given aircraft noise intrusion include: [19], [26], [52]

1. Fear of aircraft crashing
2. General attitude about noise
3. General attitude about residential environment
4. Beliefs about the preventability of aircraft noise
5. Belief in the importance and value of airports and air traffic
6. Belief in the possible effects of noise on health

These variables can be as important as the noise exposure itself in determining annoyance reactions. Thus an individual's reaction to noise seems to be only a part of a more general adjustment to the local environment.

Figure 3.4 suggests the indoor annoyance from aircraft flyovers based on the outdoor noise level in

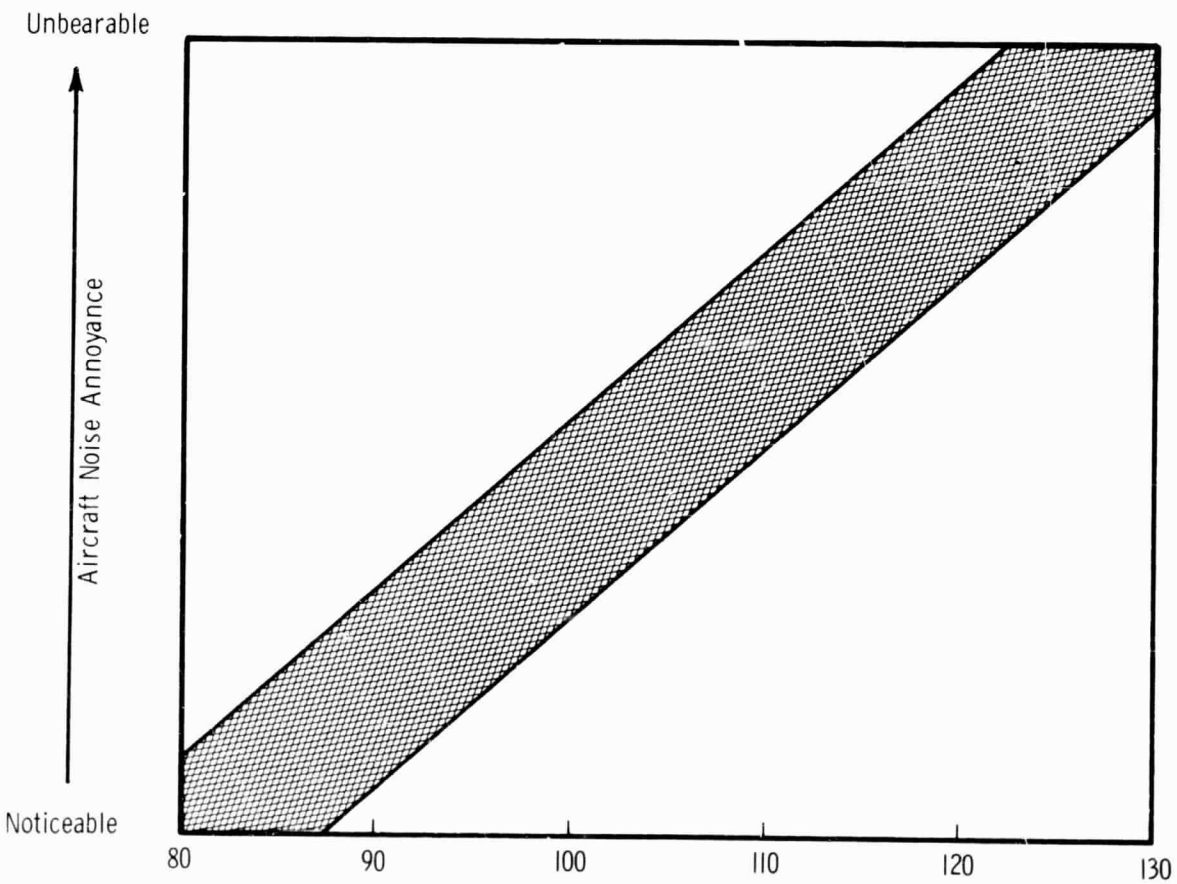


Figure 3.4. PNdB

PNdB. [12] (The PNdB level minus 13 is approximately the dB(A) level.) The wide band of the curve, representing the influence of socio-psychological factors, is in reality not of uniform width for all noise levels. Significant dissatisfaction seems to occur for day-time noise levels above 105 PNdB. At night, when ambient noise is less and people are trying to sleep, significant dissatisfaction occurs for levels above 95 PNdB.

Surveys [19], [22], [112] suggest that initial responses of people sufficiently annoyed with aircraft noise to act vary from complaint to officials to efforts to abate the effects of noise (keeping windows shut, sleeping with earplugs, and insulating homes). These individual responses mold into community efforts as noise levels and exposure times increase and as it becomes clear that the failure of individual remedies makes a larger scale solution necessary.

A noise stimulus-reaction curve based on observed community response is shown in Figure 3.5 (Increasing Noise Exposure Forecast values, NEF, represent increasing noise exposure.) Evaluation of the community reaction to aircraft noise must recognize that the exposure of the population is not uniform. The airport and immediate surrounding area experience the greatest exposure (NEF 40 and up), and here reaction tends to correlate well with the noise itself. People residing at further distances are exposed to progressively lower levels and their reaction is mitigated by outside factors (wide band in Figure 3.5). Community reactions in the areas of higher noise levels (the smaller area with NEF 40 and up) tend to be more bitter, but those in the areas of lower noise levels (the larger area below NEF 40) are of course more numerous.

Studies have shown that the following factors (more often inhibiting than encouraging complaint) can strongly influence the level of complaint activity. [17]

1. Knowledge of where to complain and to whom
2. Belief in the effectiveness of a complaint
3. Level of annoyance
4. Effectiveness of local organizations
5. Influence of other major problems, personal or local.

These factors make the level or number of complaints alone a very misleading guide to the community reaction. Generally complaints are received from people who are highly annoyed. There is no evidence that complainers are extra-sensitive to noise, but they do tend to be more convinced that the noise could be prevented and that it affects their health.

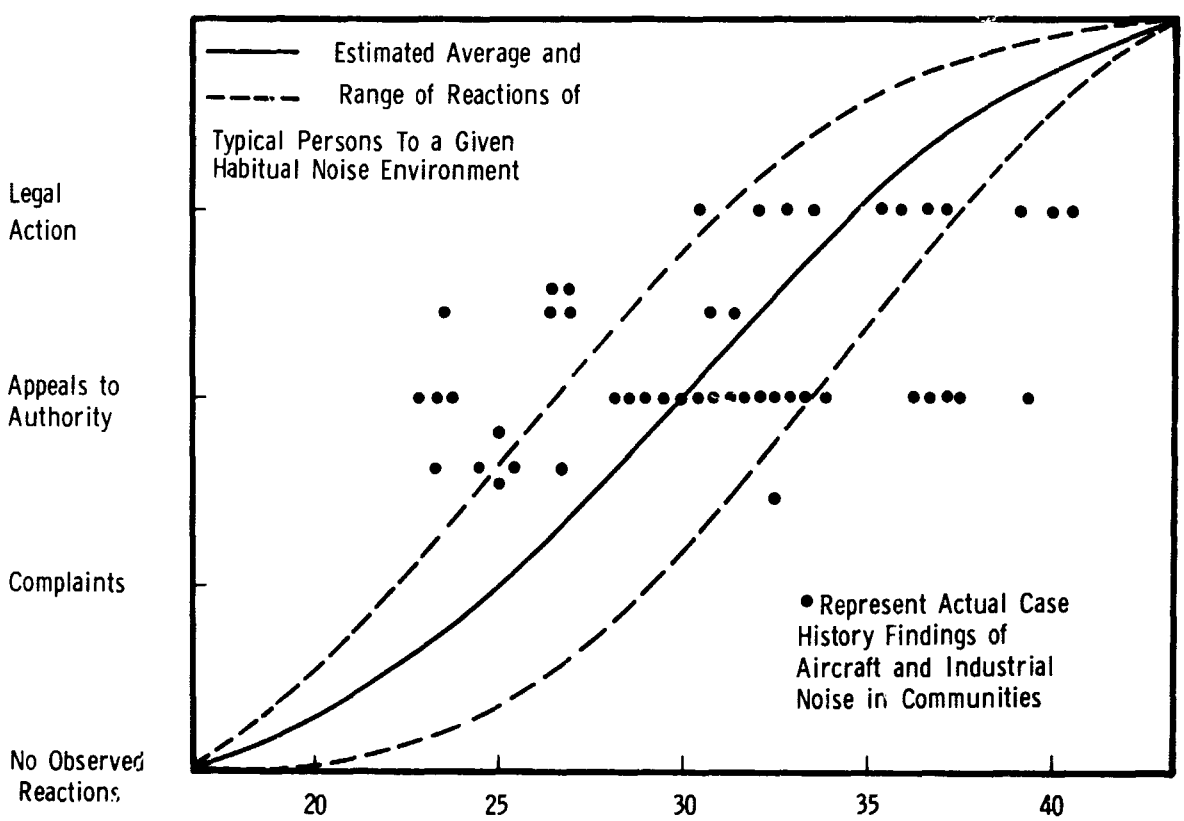


Figure 3.5. Noise Exposure Forecast (NEF)

Figures 3.4 and 3.5 show that both the probability and severity of response increase with the noise exposure level. The wide band in Figure 3.5 suggests a "gray area" in terms of noise exposure, in which one community may organize to protest and another may not. Strong concerted actions may be expected above NEF 35 and very little reaction below NEF 25 Typical data (Figure 3.6) from a British study [112] of people within ten miles of Heathrow Airport rating their area as a poor place to live for various reasons show that these intermediate exposures are subject to influence of other factors; complaint data alone is a very poor and hence insufficient indicator of community reaction.

Sonic Boom

In the early days of infrequent supersonic flights, the sonic boom was considered a minor nuisance compared to the airport noise problem. Growing interest in a commercial SST and the realization that many people might be boomed many times per day aroused concern over the effects and acceptability of sonic booms on communities. Three American studies were conducted—over St. Louis, Missouri, (1961-62), [82] Oklahoma City, Oklahoma (1964), [18] and Edwards Air Force Base, California (1966-67) [88] —and others have been conducted in England and France.

Using surveys of community attitudes and behavior and paired-comparison tests of the relative acceptability of sonic booms to subsonic plane flyover noise, the tests aimed at estimating public reactions to sonic booms at the overpressure levels and frequencies of exposure that might occur if the SST entered commercial service. In the paired-comparison tests, [65] different communities judged boom overpressures of 1.7 pounds per square foot as equally acceptable to subsonic aircraft noise levels of from 109 to 119 PNdB. It was the respondents from

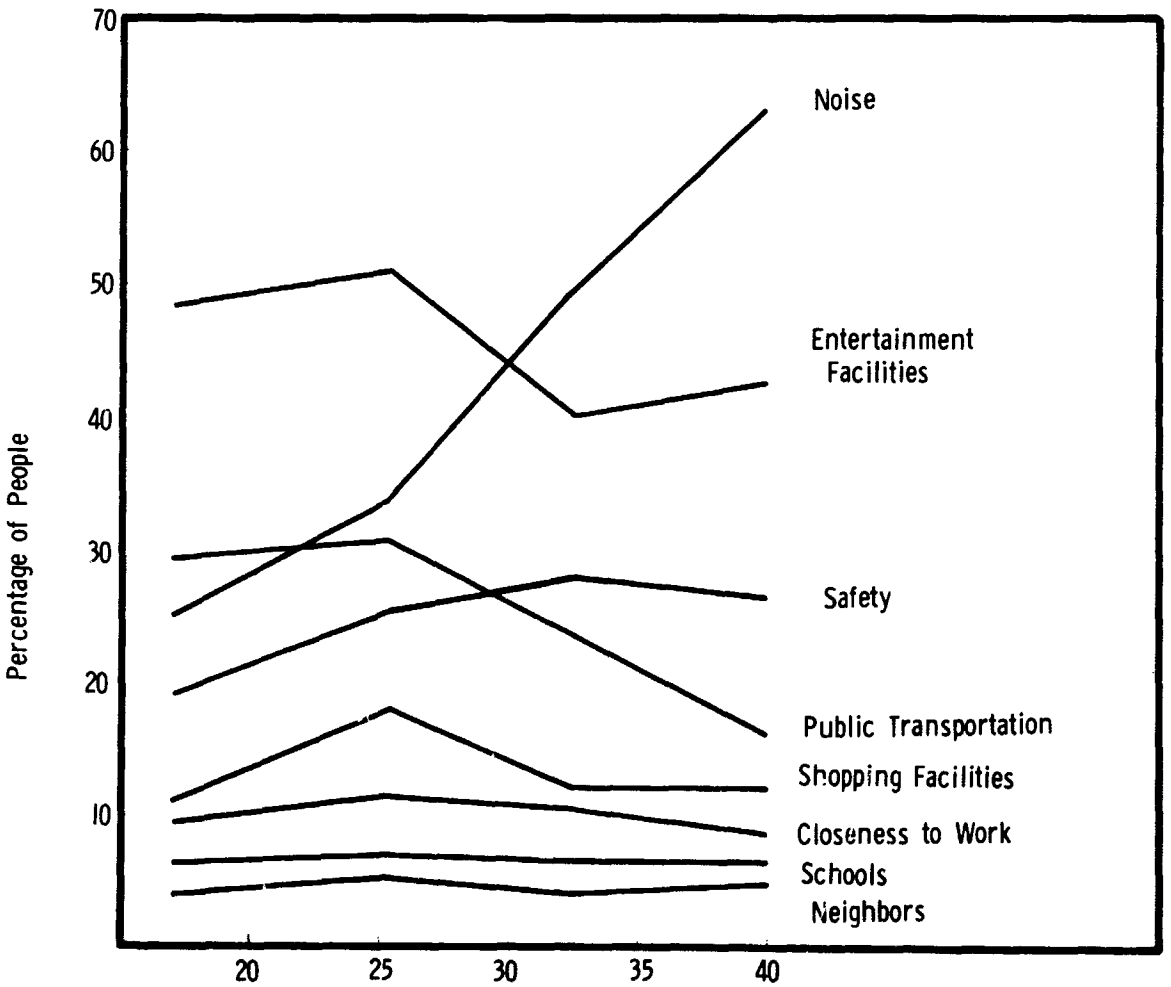


Figure 3.6. Noise Exposure Forecast

areas normally subjected to military booms who chose the lower level.

Surveys of community attitudes and behavior corroborate these findings. The Concorde and Boeing SST's are estimated to produce overpressures of about 2.1 pounds per square foot during supersonic cruise. Factors which might magnify these overpressures (producing "superbooms" of up to twice usual magnitudes), include aircraft design, variations in meteorological conditions, merging of two booms, and aircraft flight maneuvers, as well as the ground terrain and man-made structures.

American and French tests show that even after several years of regular exposure to booms, about 30 percent of the people find them "intolerable or unacceptable," and an additional 50 percent find them "objectionable." [82] Complaints and damage claims related to sonic booms have resulted in restrictions on supersonic flights of military aircraft—and this for boom intensities and frequencies of occurrence much less than would occur if the SST operated commercially overalnd. [84]

If we assume that the SST will produce an equivalent noise exposure of 110 PNdB (a conservative estimate, since the SST in normal flight will produce a boom 20 percent stronger than those used in the tests determing the 110 PNdB equivalent), then a single SST boom will produce an NEF of 34. One to 51 booms per day will produce an NEF of from 34 to 40. (CNR values from reference 65 were converted to NEF values from a plot of NEF vs. CNR.) An estimated 50 million people in a 50-mile wide path could be exposed to such exposures if overland great circle flight paths were used, and the total population exposed would be much larger if direct overland routes were used. NEF exposures above 35 are presently found only in a few areas immediately adjacent to very large airports. The SST could extend such exposures in varying paths across the country. Any study of psychological, sociological, or political effects of airport noise at NEF values above 35 will demonstrate that sonic booms from overland commercial SST operations must be expected to cause widespread annoyance, complaint, and protest.

Road-noise Effects

While aircraft are probably the most conspicuous noise offenders, the roar of surface traffic is the most pervasive of all transportation noise. Traffic noise is most critical in urban areas, especially on arterial roads and freeways which carry 38 percent of U.S. vehicle miles on some 2.5 percent of the total roads. [80] Studies indicate that the most prevalent city noise, even in most industrial areas, is traffic noise. [67], [112]

Road noise affects the general environment in the form of an increased community ambient noise level (caused by increasing vehicle congestion) and large fluctuations in noise levels (caused by noisy vehicles in the traffic stream). [34], [103] Community noise levels, increasing with the density of traffic, are generally too low to cause immediate hearing damage, though studies comparing the hearing of primitive tribes to that of urban dwellers suggests a long-range effect on urban populations. [60]

Traffic noises disrupt many normal activities. On many streets the roar of traffic makes communication almost impossible for persons standing on the sidewalk. Sudden sounds from freeways passing through urban residential areas often disrupt conversation, mask the audio of television, interrupt concentration, and disturb sleep. Surveys indicate that twice as many residents near freeways expressed annoyance with noise than other disagreeable aspects of the roadway.

Prediction of annoyance for highway noise has proved difficult because so many non-physical factors seem to influence an individual's response. [40] Annoyance seems to be related to the individual's sensitivity to sound, his experience and familiarity with the noise, his normal activities, his opinions concerning the usefulness and attractiveness of the highway, his social and economic standing, and many others. Nor are physical factors alone completely reliable. Studies indicate that annoyance from traffic noise is more affected by fluctuations of noise levels above the average than by the absolute level of the average. [90]

Road noises do not seem to generate a great number of complaints, partly because road noise builds up slowly with time and the effects of a particular roadway are limited to small numbers of people spread over large geographic areas. [21] The lack of complaints does not mean that people are not annoyed, however, and, as concern grows over other negative aspects of our environment, there may well be an increase in protests over traffic noise. Several studies suggest criteria regarding community response to traffic noise. One study suggests that average peak sound levels near a roadway above 70 dB(A) may generate complaints. [10] Figure 3.8 indicates the trend found in the relation of community response to peak noise levels.

Community response to a new highway through a residential area is likely to be quite vigorous, as demonstrated in most cities in which new highway routes are under discussion. One study [76] finds that such a highway will have "some impact" if the noise level produced by the highway is 5 dB(A) more than the ambient existing in the community before the highway's introduction and "great impact" if the noise level is more than 15 dB(A) above the prior ambient.

Figure 3.7.

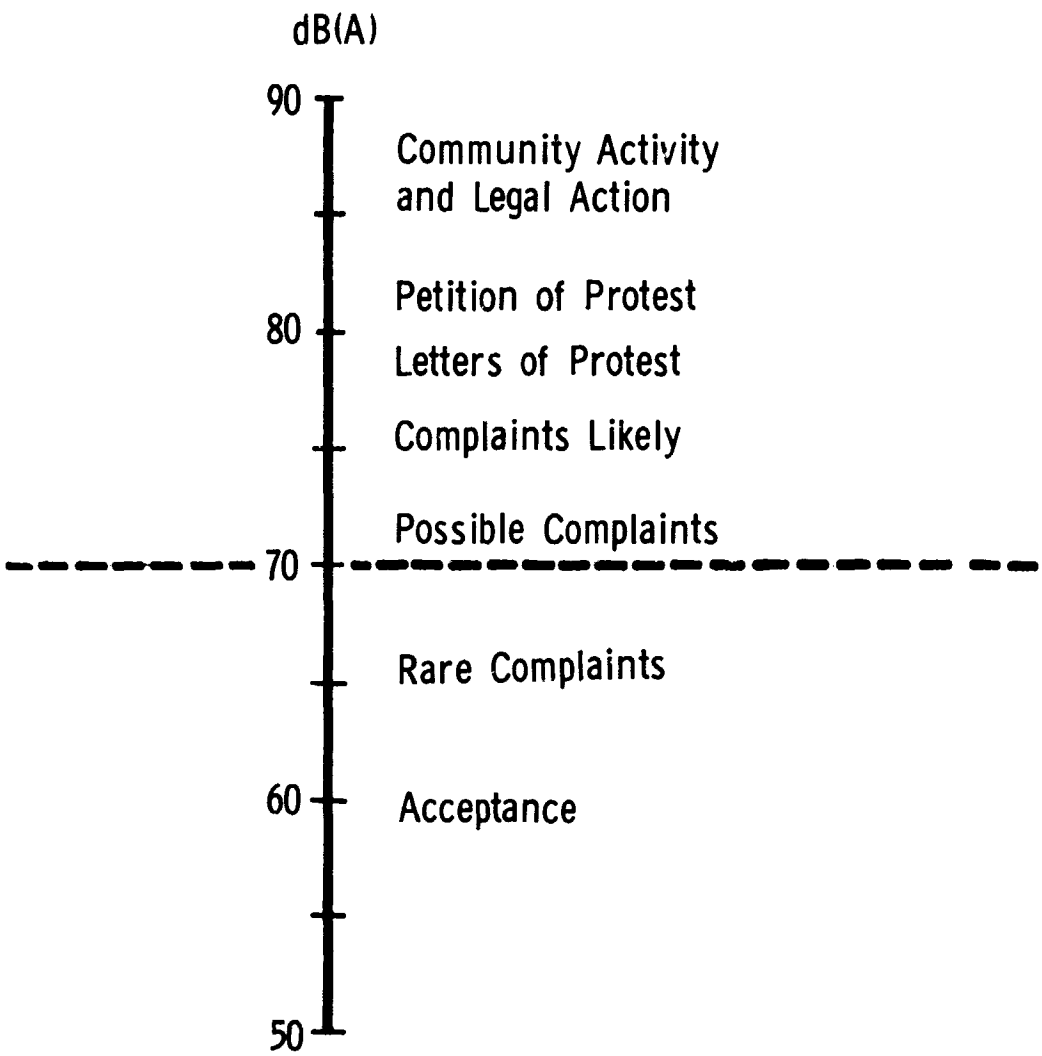


Figure 3.8.

The noise of traffic will be more pervasive in the future. Urban automobile travel is growing at about twice the rate of urban population, and urban vehicle miles are doubling every 20 to 25 years, suggesting a growth of about 70 percent between 1970 and 1985. The results will probably be greater traffic density in urban areas and new urban arterials and freeways, increasing the ambient levels in communities [103] and the noise level beside existing roads. [41]

Since many of the less disturbing sites for freeways have already been used, some new freeways will probably be constructed through residential areas. This will bring to yet undisturbed people the annoyance of road noises. Without specific remedial action, then, it is reasonable to predict an increase in road-generated noises, in the number of activities disturbed, and in the number of people annoyed.

The Effect of Train Noises

Train noise resemble that of aircraft near an airport—it is discrete with periods of noisiness separated by periods of quiet. Figure 3.9 shows that the noise of a diesel freight train at 100 feet is comparable to the noise on approach of a turbofan aircraft at a distance of 1000 feet. Since residences are generally built closer to railroads than to conventional airports, one might expect individual and community response to railroads to be similar to that observed for aircraft.

Unfortunately, no studies appear to have measured or predicted community response to railroad noises. Communities have not reacted to railroads as vigorously as to airports, perhaps because the nation's rail activity has declined while aircraft activity has boomed. Also, railroad right-of-ways have been long

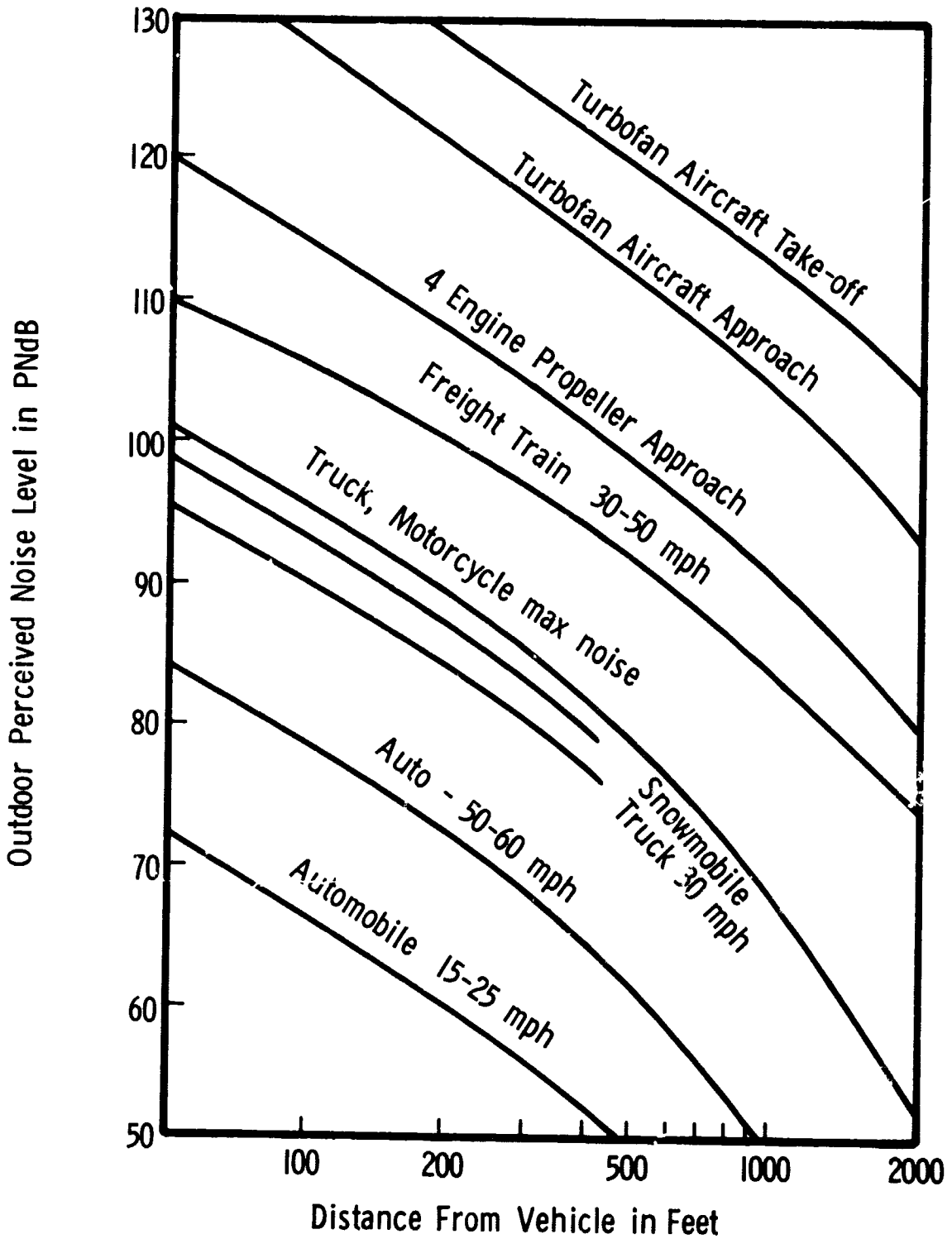


Figure 3.9. Typical Transportation Vehicle Noise Level

established. Persons moving near a railroad are well aware of its presence, and land values and land uses have probably adjusted to reflect the diseconomies of the noise produced by the railroad.

This will not be the case for new railroad rights-of-way for highspeed rail transportation between cities. A study [32] discussing the external costs of several intercity transportation plans in the Northeast Corridor indicates that those involving high speed rail transportation have the greatest external cost due to noise, partly measured by the decrease in land values in residential areas through which the railroad must pass.

Noises caused by diesel freight trains are thunderous. Studies [36] of a track at grade level passing through an urban residential community, using its legal acceptable nighttime sound pressure levels, conclude that for over one mile on either side of the railroad tracks the land is unsuitable for residences if as many as eight trains pass through during the night. If only one train passes in the night, this distance could be reduced to about one third mile.

Rail rapid transit is often considered a partial solution to the increasing urban transportation problem. Such systems are costly in noise generation. Cities contemplating rail rapid transit systems have experienced negative community reaction, and noise and vibration are often the prime concern. The noise generated by the electric propulsion of these systems is not nearly as loud as that produced by diesel trains. Since their routes often pass through heavily populated urban areas, noise and vibration should certainly be an important consideration in the design of rapid transit systems. Noise was an important design parameter for the proposed BART rapid transit system of San Francisco.

Economic Considerations or The Cost of Noise

When present noise exposures or projections of future urban and transportation growth are considered, it is apparent that action will be necessary now or in the future to abate noise. We must decide what an acceptable noise level is, how we can achieve this limit at minimum cost and who should pay the cost.

Of course, it is impossible to put a dollar sign on the cost of noise, but we can point out significant factors to consider in gauging the burden of noise on society. [56] The problem is complicated by the fact that a given noise may be acceptable to some, objectionable or physically harmful to others. Any noise abatement procedure will tend to be more costly to some groups than others, and those groups can be expected to resist change, while those who endure the noise will act to encourage change. A solution should seek to balance the gains to the people affected against the losses of the people creating the effect. To make this balance we must know the cost of noise to society and the cost to abate it.

Six major monetary costs of noise can be identified:

1. Depression of residential property values
2. Exclusion or increased cost of public services (e.g., insulation of schools)
3. Reduction in efficiency and increase in social conflict of people in high noise area
4. Cost of litigation
5. Costs of research and development of abatement techniques
6. Costs of physical damage.

These costs should be analyzed and quantified as the basis for an administrative decision on noise abatement, weighing both social and economic considerations in the choice. The abatement techniques chosen depend not only on costs, but also on the ability of the affected groups to finance the costs and in a long or short range investment. Thus the choice of an effective long or short term noise abatement plan depends on the level of technology, the financial capabilities of the groups and political pressures of society.

Since many local and state governments lack mechanisms for implementing noise abatement, the federal government should prepare supporting information. [1] In addition, the federal government may be called upon initially to finance a portion of the noise abatement costs to preserve the solvency of the affected groups. Federal funds should be provided for noise abatement as loans rather than subsidies, since noise abatement is a cost of doing business. Federal funds should stimulate further local action to alleviate transportation noise. The equipment industry and ultimately its users will bear the noise abatement cost as well as the resulting benefits.

As previously stated, it is impossible to quantify a relation between dollars and decibels. Quantitatively the cost of noise will increase as noise exposure increases. Furthermore, the cost of control and abatement increases as the permissible level of exposure goes down. These qualitative aspects are illustrated in Figure 3.10. The point where the curves cross identifies the exposure level corresponding to the optimum trade-off between noise costs and control costs. To determine this point in any practical situation requires extensive analysis.

Group Dynamics

Organized community response to transportation noise is one of the least understood components of community action. Such group action becomes more concerted, and individual differences

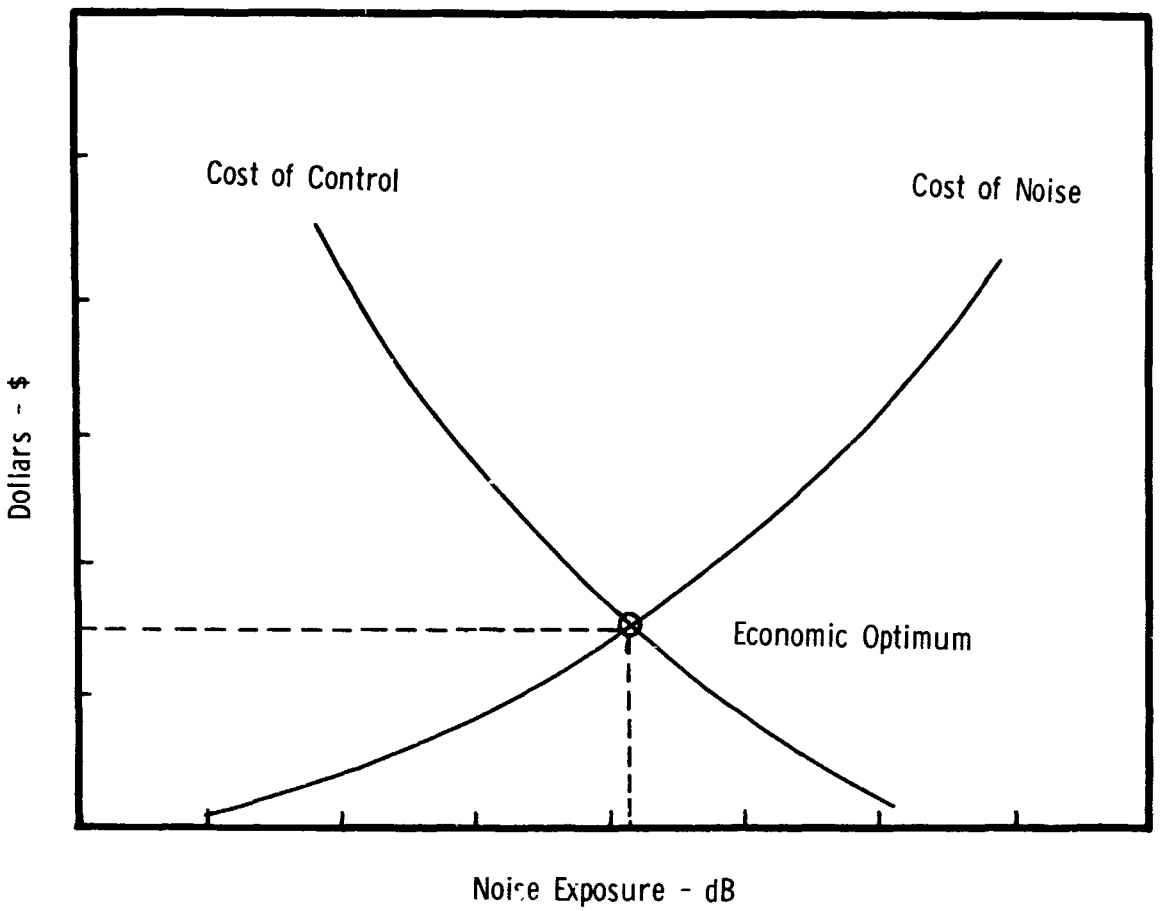


Figure 3.10. Qualitative relation of the cost of noise and its control and the noise exposure level.

of group members become less important, as the magnitude of an external stress increases. Inhibiting the group's communication with the stress producer further unifies and motivates group action, even if the restriction of communication is unrelated to the original stress. Group effectiveness depends strongly on its leader's ability to initiate action and to represent the group's thinking to outside individuals and groups. A group's methods will depend on the source of external stress and the stressor's response to their actions.

In a typical community controversy when a minority group is able to enlist the support of a normally quiet majority, serious community conflict may develop. The specific issue in question normally develops into a more general local conflict. The resulting political dispute falls away from the initial issue and centers on hostility between community factions. To date, the noise groups have not been greatly successful in obtaining mass support and the issue in question has been limited to noise. One of two conclusions presents itself: (1) the issue is sociologically different from other community controversy or (2) the controversy is in the initial stages where a minority group is working to obtain support from the majority.

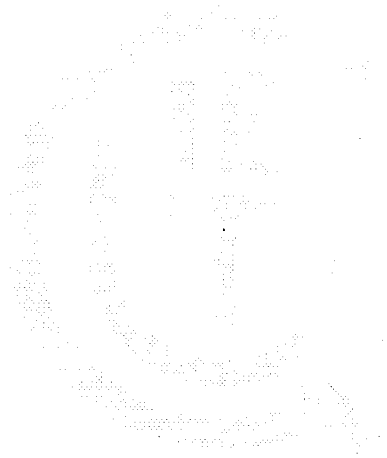
Such recent developments as protest action at some of our larger airports reinforce the second conclusion. If we accept the likelihood that there cannot be substantial abatement of transportation noise in the near future, we can conclude that local officials, equipment operators, transit companies, and the Federal government will have a substantially more difficult community reaction problem in the future.

Community Reactions

The effects of noise on man are undesirable and inescapable. A considerable body of data predicts and evaluates noise-induced hearing loss and speech interference. Studies of other physiological and psychological effects of noise are less unanimous, but should caution us against the hazards of uncontrolled exposures to high intensity noise.

Noise may affect any environment in which it occurs. Sonic booms have damaged structures and environmental features. The sound of such vehicles as snowmobiles can terrorize wildlife and may lead them through startle responses to fatal actions. Communities react against noise in a multitude of ways, mediated by social, psychological, and political variables. While responses remain somewhat unpredictable, individual annoyance and complaint may escalate into community protest, and each level of response is roughly proportional to the noise exposure. The most conspicuous noise offender is the airplane—and the SST could extend intolerably high noise exposures to any part of the U.S.—but the most ubiquitous offenders, currently exposing most of the population to more sustained, though often lower levels of noise, are the highway vehicles.

Noise is expensive, though total social and economic costs can only be estimated. Increasing concern for environmental quality, increasing local bitterness over high noise exposures, and increasing sophistication in the techniques of protest and direct action—all these and other factors guarantee that those who have been made to pay the high costs of noise will force the noise-makers to share in those costs and/or reduce the noise. For many reasons, complaints about noise are certain to increase, and decision-makers must consider noise as one of the "costs" of any proposal, must both minimize these costs and spread them equitably across the society, and must labor unstintingly to effect comfortable rather than tolerable levels of noise. Finally, however, it will not be so much the concern of the engineer, the scientist, or the politician that will curb noise pollution—it will be the concerted action of the millions of concerned and nearly-deafened citizens who will be organizing to demand noise-abatement.



Chapter IV

Trends in U.S. Transportation Needs, Modes, and Noise

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Introduction

To quantify transportation noise, one must determine the numbers of transportation noise makers. This chapter forecasts transportation needs for 1985, explaining assumptions on which these projections are based. Some of the more significant totals are summarized in the conclusions to this chapter. Readers familiar with U.S. transportation and projections concerning it might move on to these conclusions or to Chapter V.

Transportation involves the movement of people and things from one location to another. Transportation needs are influenced by many factors, some fairly constant and easily measured but others quite unpredictable. Demographic, socio-economic, and technological forces all influence transportation demand, but so do public preferences for particular modes. Transportation exists to serve people, who must travel from one place to another for business or for personal reasons. And if people are to be housed and fed, goods must be moved from manufacturer to consumer. In a primitive society, the need to communicate or to transport people and goods from one place to another is not so acute, but as more complex societies develop, the need becomes much greater.

It may be assumed that many of the factors determining transportation needs in the past will influence the next fifteen years. It is also assumed that the United States will avoid major war or depression.

The transportation modes examined here are those which individually create considerable noise or are so extensively used that their very number contributes substantially to the noise problem. Military transportation is both significant and noisy, but reasonably exempt from civilian regulation, and often even classified. Thus, while such transportation may well need to be made quieter, both practical and security considerations suggest its exclusion from this study.

Projections for 1970-85 must consider prior developments to help determine relative degrees of change (if any), average annual rates of growth or change, and reliability of past and present transportation forecasts. Like assumptions, projections can also be dangerous, but if present trends continue, transportation noise by 1985 could become so intolerable that increasing members of those adversely affected will be tempted to resort to direct action and violence.

Background Factors

Factors affecting **quantitative** transportation needs (regardless of modes) include such things as population size, growth rate, distribution, density, age and education levels, economic condition (i.e., family and disposable personal income in relation to gross national product), as well as over-all political, social, and economic development. The degree of mobility of the population is observable in percentages of the population traveling, the frequency of trips taken, average trip lengths, and geographical travel patterns. Existing transportation facilities can either encourage or limit the mobility of people and freight.

Qualitative demands must also be considered, as certain transportation modes are more attractive than others for transportation of freight or passengers. Consequently, the suitability of a given mode of transportation is a determinant of transportation needs. People travel and goods are moved for various reasons, and so the purpose of the transportation affects the mode needed.

The safety of the passenger or the security of the goods transported may be an important consideration in selecting modes. The distance and the time may be crucial factors. The cost and availability of a particular mode are important too. Other factors include convenience, comfort, reliability, efficiency, frequency of service, and even psychological and personal idiosyncrasies. The final choice may be a balance of any number of factors, varying from person to person. At least for passengers, quietness and consequently comfort help determine the choice of mode. Public demand for quieter transportation will increasingly influence transportation needs and modes. Unfortunately, of all the innumerable modes for transporting freight or people, the dominant ones, the motor vehicle and the airplane, are the leading noise makers. Expanding use of these modes points to an increasingly noisy transportation environment.

Present and Projected Needs and Modes

For convenience, travel modes will be considered in three major categories: ground, water, and air. Each mode in these categories can be rated for effectiveness among facilities currently available. At the same time, past and present modal use and current trends give some idea of what to expect in the future. Before considering specific modes, however, some of the factors that influence overall transportation needs, irrespective of individual modes, should be examined.

National Population, Growth Rate, and Travel

The basic nature of man changes only over an extremely long period of time if at all. The short-term adaptations he makes to his environment cannot be

considered as a fundamental change in his nature. Since transportation is a device created to meet the needs of man the nature of the system must in some way relate to the number and nature of the people it serves. The population of the United States has increased from 152.3 million in 1950 to an estimated 201.2 million in 1968. During the period 1960-1968 the average yearly increase declined slightly to 1.30 percent, as summarized in Table 4.1.

Population (million)		Average Percent Change Per Year	
Year	Actual	Period	Percent Change
1951	154.9	1951-1968	1.38
1960	180.7	1951-1960	1.40
1968	201.2 (est.)	1960-1968	1.30

Table 4.1

In projecting future population, various fertility rates, or the average number of children per 1,000 women at end of childbearing, are assumed. The U.S. Census Bureau assumes a fertility rate of 3,350 per 1,000 (the 1962-66 average) in making the projections shown in Table 4.2.

Year	Population Projection (million)	Average Annual Rate
1970	208.6	1.5
1975	227.9	1.6
1980	250.5	1.7
1985	274.7	1.8
1990	300.1	1.8

Table 4.2

Assuming more conservative fertility rates, the range of estimates would be as shown in Table 4.3.

Rate	1985 Pop. (million)	Average Annual Rate
2450 per 1000	241.7	1.11
2775	252.9	1.39

Table 4.3

A projection at the average annual rate of increase from 1960-68 would yield a 1985 population of 250.6 million.

The per capita domestic intercity passenger miles increased from 3,350 in 1951 to 5,280 in 1968. Comparison of Tables 4.1 and 4.4 shows that demand rate for transportation has increased at about twice that of population size.

Year	Per Capita Intercity Passenger Miles	Average Percent Change Per Year	
		Period	Percent Change
1951	3,350	1951-1967	2.88
1960	4,280	1951-1960	2.76
1967	5,280	1960-1967	3.05

Table 4.4

The annual in passenger miles change during this period remained relatively stable at 3½ to 4 percent except from 1957 to 1961 when the change ranged from 11 percent increase in 1957 to a 6.5 percent decrease in 1959. Since 1961, however, the increase has ranged from 3½ to 4 percent per year with the exception of 1967 when the increase was 7½ percent. Conservatively projecting increases at 4 percent per year, Table 4.5 lists actual and projected intercity passenger miles:

Figure 4.1 shows common carrier intercity travel by each carrier. (Comparison with Table 4.6 will show that this accounts for less than ten percent of all intercity passenger miles.) The dominant role of the airplane is readily apparent.

As population increases, the volume of domestic intercity freight transportation has increased also, although not as much as passenger travel, and it is expected that the rate of change per year will drop. Table 4.6 shows actual and projected intercity ton miles:

Population Distribution

Transportation needs are influenced as much by population distribution as by gross population totals. The continuing westward movement and the concentration of U.S. population within a limited number of geographic areas, especially on the East and West Coasts, has increased demands for urban-intraurban and short haul intercity transportation and has also increased the need for long-range, high-speed transportation between the coasts.

Regional demands for both passenger and freight transportation in recent years show that the Northeast quadrant of the country (14 states) still accounts for about 50 percent of the population, production, trade, and manufacturing, requiring a substantial amount of short haul transportation. The

Total Intercity Passenger Miles (Billions)			Average percent Change per Year	
Year	Actual	Forecast	Period	Percent Change
1951	520		1951-1967	4.50
1960	773		1951-1960	4.48
1967	1051		1960-1968	4.49
1975		1380		
1980		1680 Based on 4 percent change per year		
1985		2047		

Table 4.5

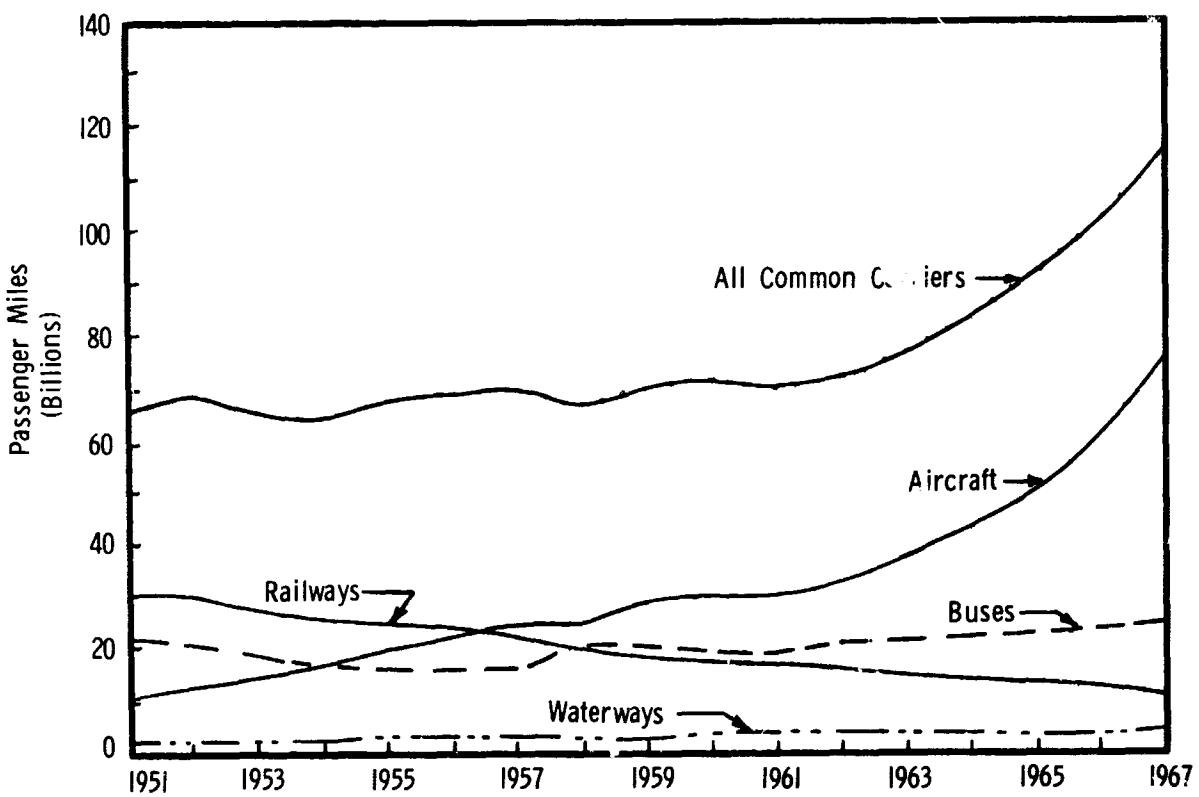


Figure 4.1. Domestic Intercity Travel by Common Carriers

Total Intercity Ton-Miles (Billions), both Public and Private				
			Average percent Changer per Year	
Year	Actual	Forecast	Period	Percent Change
1950	1094.2		1950-1968	+1.29
1955	1298.1		1950-1960	+1.22
1960	1314.0		1960-1967	+4.17
1965	1651.0			
1966	1758.6			
1968	1834.0			
1975		2180.0		
1980		2466.0 Based on 2.5 percent change per year		
1985		2790.0		

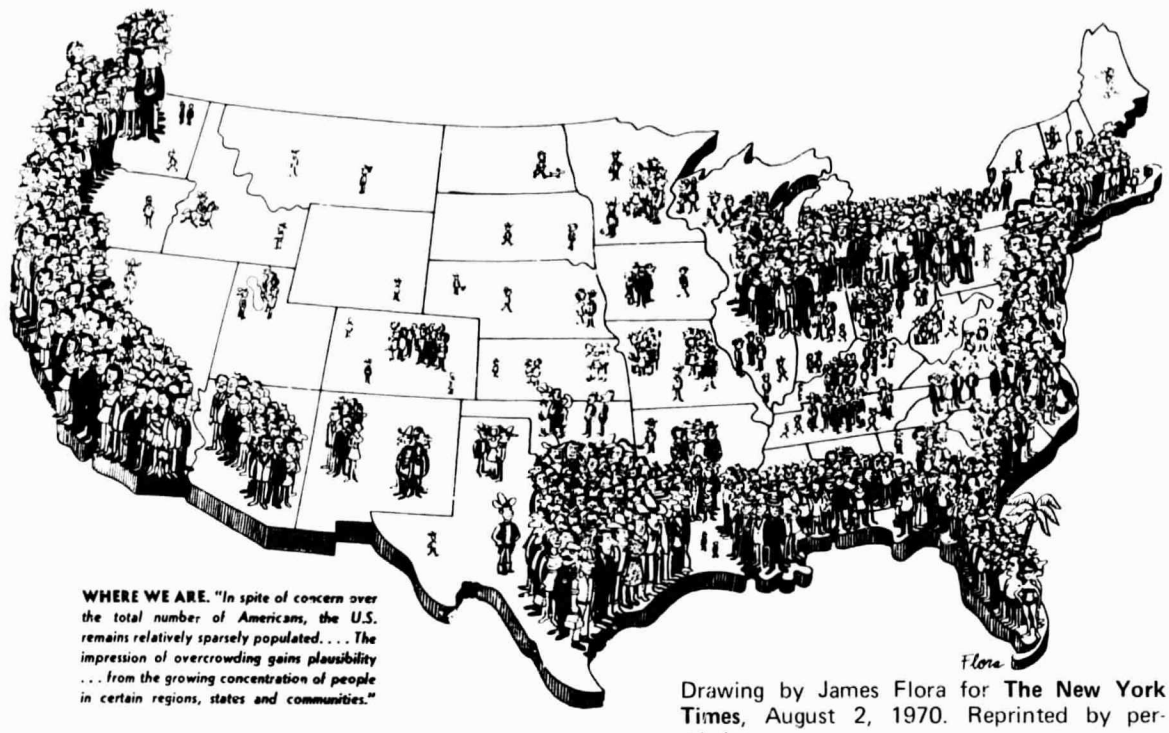
Table 4.6

rapid growth in population of the Pacific states from about the same size as New England in 1938 to what is expected to be nearly three times New England by 1985 points out increases in long haul transportation needs also. Table 4.7 indicates regional variations in population growth.

It is in the already congested urban areas that the greatest population growth is expected. By 1985, it is estimated 77 percent of the population will be living in urban areas and by 2000, perhaps 90 percent. The greatest concentration will be in only 38 metropolitan areas with populations of from 1 to 20 million each, accounting for 40 percent of the population increase and containing 45 percent of the total population. [27] Figure 4.2 emphasizes population concentration in a few congested regions. By the 1980's, the 140 million people living in the 38-40 urban complexes may be concentrated within 2 percent of the total land area of the U.S., although, as Figure 4.3 shows, average population densities in central urban areas are expected to continue declining.

Region	Year			
	1935	1960	Percent Change	1985 Projection
New Engl.	6.6	5.9	-10.6	5.5
Mid. Atl.	21.3	19.2	- 9.9	17.7
E. North Central	20.3	20.2	- 0.5	19.9
W. North Central	10.6	8.6	-18.9	7.1
South At.	13.3	14.6	+ 9.8	16.0
E. South Central	8.1	6.8	-16.0	5.4
W. South Central	9.9	9.5	- 4.0	9.2
Mountain	3.0	3.9	+26.7	4.5
Pacific	6.9	11.4	+65.2	14.7

Table 4.7: U. S. Population
Percentage Distribution by Geographic Division



Drawing by James Flora for **The New York Times**, August 2, 1970. Reprinted by permission.

Figure 4.2. Population Distribution

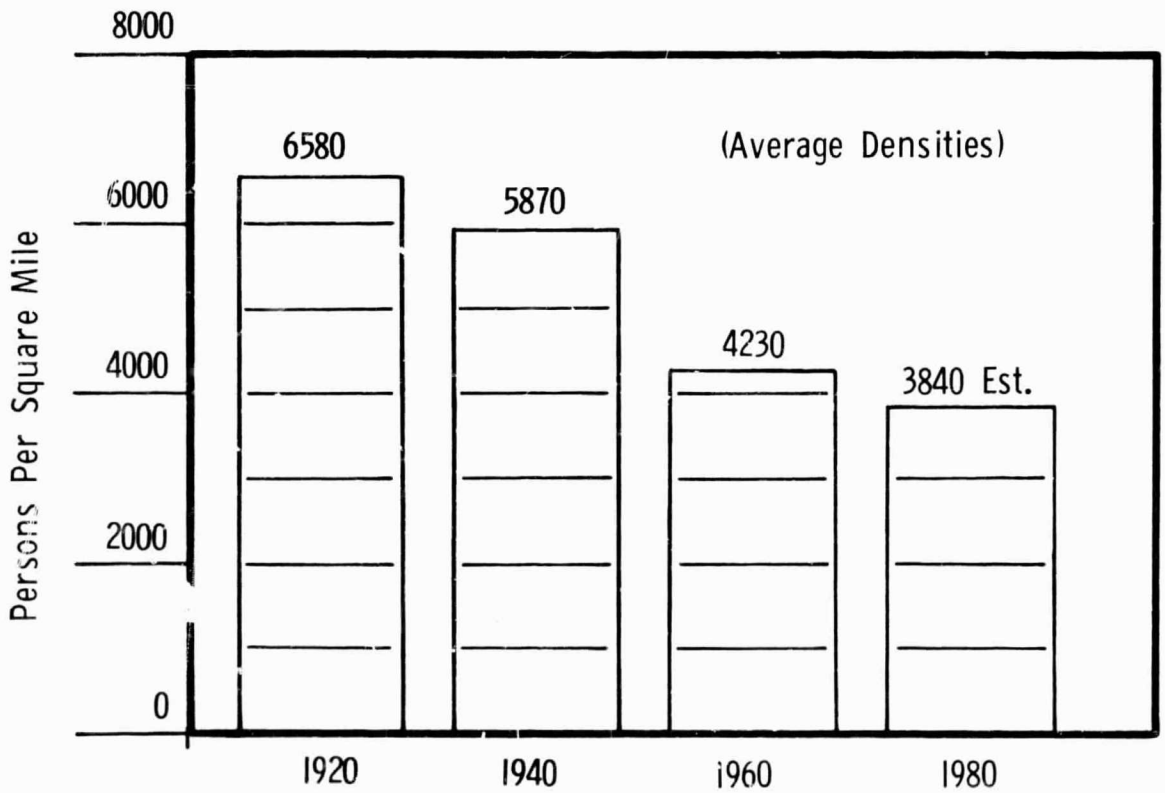


Figure 4.3. Urban Density Decline, U.S. Department of Housing and Urban Development, Tomorrow's Transportation.

Preliminary population figures for the 1970 census (completed for 29 of the 50 states) corroborate this. None of the 5 largest states and only 2 of the 15 largest were included, but these figures show that the population of central cities and farm areas is stationary or declining while the suburbs and western states are making substantial gains. Since the 1960 census, a 9.4 percent gain in population has taken place in these states.

On the whole, the regional and urban character of population growth indicates transportation needs are likely to become more acute in the very parts of the country which already suffer the most from traffic congestion and noise.

Age and Education

As Table 4.8 shows, the population of 1985 is expected to include increased proportions of persons in their teens and twenties, and also more persons 65 years of age and older, especially females.:

	Percent Increase	
Age Group	Males	Females
14-19	71	69
20-24	90	88
25-34	75	70
35-44	33	26
45-54	14	12
55-64	32	38
65 and over	59	80

Table 4.8
Population Change
by Age Groups, 1968-1985 [27]

Expansion among older groups with greater leisure for travel can be expected to increase total population mobility, as will large increases in the percentage of young people reaching driving age, entering the labor force, and establishing families.

The expected higher average level of education will probably contribute to increased travel also. A 1963-64 domestic survey showed that 8 out of 10 air passengers had attended college. [25]

Economic Factors

It is taken for granted that the U.S. is approaching a trillion dollar economy—the only question is how fast. From 1958 to 1966, the Gross National Product (GNP) increased from 264.8 billion to 739.6 billion (in current dollars). Forecasts of the growth rate almost universally expect growth to exceed the 3 percent average from 1900-1963. Some estimate the rate as slightly above the 3.4 percent average from 1947-63; others estimate as high as 4.25 percent annually. [34] One estimate places GNP at $1,268 billion by 1985 (an increase of over 150 percent from 1960). [27] Figure 4.4 summarizes a number of predictions of U.S. GNP.

Perhaps more significant than GNP, however, is individual disposable income. From 1950 to 1966, per capita disposable income rose from $1,646 to $2,794 (in constant 1958 dollars). [34] Extrapolation would suggest a per capita disposable income of $3,064 in 1985. The growth was from $1,883 to $2,294 from 1960 to 1966, however, and extrapolation from this rate would suggest a per capita disposable income of about $3,564 in 1985.

While the average person's amount of leisure time has been increasing, so also have commuting times, Consequently, the average person in 1985 may have no more daily leisure than he has today. However, lengthened vacations, including more three-day weekends as a result of manipulating holidays, will contribute significantly to increased travel. Average vacation length for Americans in 1963 was 2½ weeks. Moreover, the average American work week has been decreasing and is expected to continue to do so; the over-all average work week is predicted to be 33 hours in 1985.

The anticipated rise in family income to an average of over $12,000 a year (constant dollars) by 1985 suggests that nearly all U.S. families will be able to afford private motor transportation by then. (Past studies show that expenditures for transportation increase even faster than family incomes.) [27]

Travel and Trip Length

Studies of intercity travel in 1963 indicated that about 60 percent of all passenger-miles by all modes were accomplished by trips under 100 miles, 70 percent by trips under 250 miles, 80 percent by trips under 500 miles and 90 percent by trips under 1000 miles. In 1962 less than 2 percent of the adult population travelled outside of the U.S., though this number continues to increase. [27]

Urban trips average less than 2 miles, and the average commutation trip for work is between 3 and 4 miles each way. The average commuting trip is expected to increase from 4 miles in 1965 to 8 miles in 2015, [23] while commuters from the suburbs to the central business district are expected to increase from 6.3 million in 1960 to 7.5 million in 1985. In all U.S. metropolitan areas, commutation trips from suburb to central city are estimated to average between 10 and 12 miles. [12] In most cities about one-half of the day's total transit traffic is carried during the four peak-hours of the day; 7 to 9 a.m. or 4:30 to 6:30 p.m. Urban trip lengths are expected to

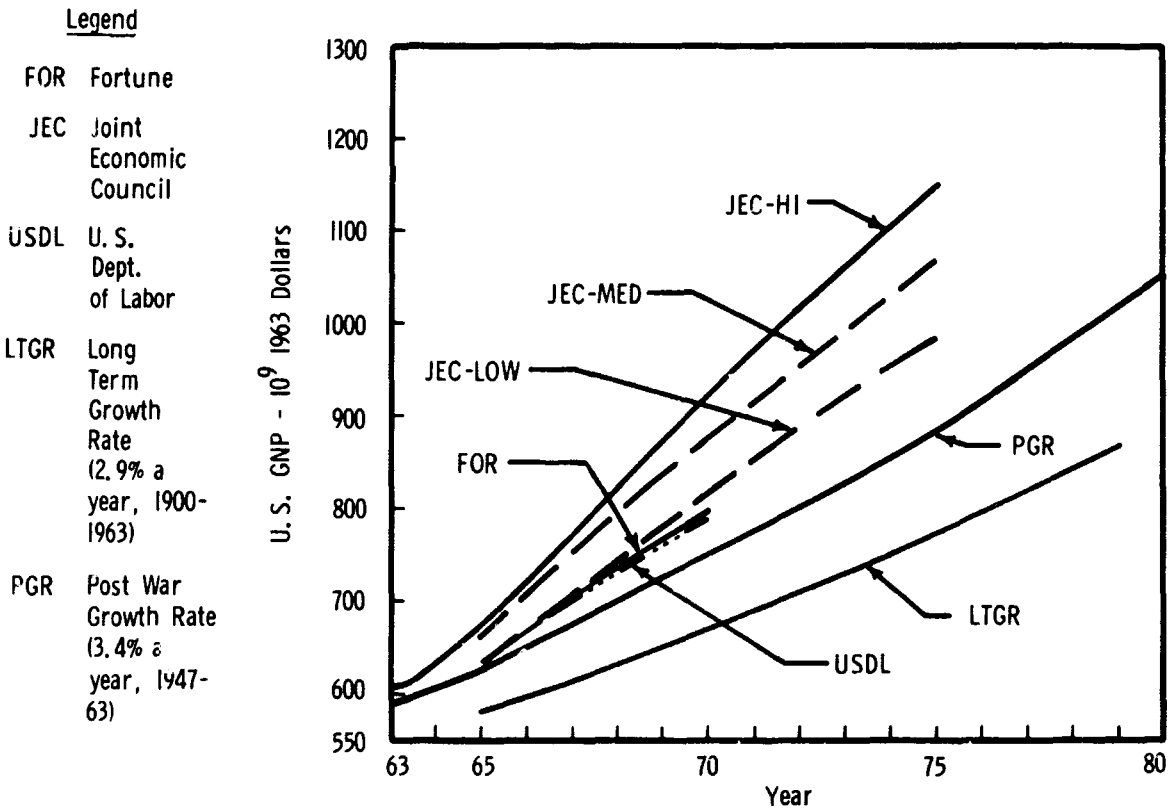


Figure 4.4. Projections of U.S. GNP, adapted from Schriever, Air Transportation 1975 and Beyond.

increase as urbanized areas spread out, and opportunities for longer trips will increase faster than those for short trips. By 1985, however, the average suburb-to-city center commuter is expected to travel no more than 14 miles one way on a straight line basis. Commuters to urban work should increase from 39 million in 1960 to over 60 million by 1985, an increase of about 53 percent. Urban commuters to suburban jobs in 1985 should increase by about 50 percent from 1960 to around 3.9 million persons.

The National Travel Survey for 1967 indicated that someone in about 63 percent of all U.S. households took at least one overnight out-of-town trip, or one trip to a place at least 100 miles away returning home the same day, and about 55 percent of all civilians traveled some time during the year. The third quarter of the year (July-September) was found to be the peak season, accounting for about 36.5 percent of total annual person-trips. The largest volume of travel was in the North Central regions, and the South was second. Larger percentages of persons in the West did at least some traveling, however.

All of these factors are certain to affect future transportation needs, but more directly relevant data are the way specific modes of available travel meet these needs, and the noise made by these modes.

Pipelines

Pipelines, moving freight in slurry, liquid, or gas form, are our most efficient transporter of petroleum products (80 percent of U.S. crude and 20 percent of finished products). In 1940, pipelines accounted for 10.5 percent of intercity freight, and in 1964, 17 percent—which is about the current proportion. In 1966, half a million miles of pipeline provided 250 billion freight ton miles. By 1973, over a million miles of pipeline will be in service.

Slurried minerals are moved by pipeline, and even foodstuffs—one West Coast cannery gets its fish supply by pipe. Shipment of slurried commodities from gravel to sugar cane and rice are being considered. Pipeline mileage is expected to continue

increasing, with the share of intercity freight remaining roughly constant. Relatively inexpensive to build and maintain (compared to railroads or highways), and requiring only one-tenth the receiving personnel of railroads, pipelines can contribute significantly toward economical, **quiet** transportation of gaseous, liquid, or slurried freight.

Water Transportation

Historically our earliest "freeways," inland waterways have always received various forms of government aid. In 1960, when direct government expenditures for waterways and terminals totaled $1,142 million, inland water transportation was credited with 235 billion ton-miles of freight. With negligible passenger traffic, the bulk of inland waterways movement is freight, like pipelines accounting for about 17 percent (10 percent on rivers and canals, 7 percent on the Great Lakes) of the total intercity freight traffic. In 1964 the inland waterways handled 457 million tons of freight, the Great Lakes 151 million tons and coastal vessels 206 million tons—a total of 814 million tons, compared with 422 million tons in foreign trade. Some 4,000 towboats and 16,000 barges operate on the 29,000 miles of navigable rivers and canals in the United States. A total of 250 rivers and canals have traffic of 50,000 or more tons, and the upper bay of New York Harbor alone has more than 133 million tons. More rivers and canals are being opened, but the proportion of total freight handled by this mode is projected to remain fairly constant.

Inland water transportation is essential to move heavy, low-value commodities for which rapid delivery is not crucial, and it can help somewhat in relieving other crowded noisy modes of transportation. Freight carrier capacities have been increased, too, with million-gallon tank barges or 100,000-bushel grain barges. A coal barge, the **Maryland**, with a capacity of 22,800 tons, was recently christened.

Also on the increase are the small private pleasure craft in use in the United States. Outboard motor boats totaled 2,811,000 in 1950, and this number jumped to 6,390,000 in 1963. Used essentially for recreation, these craft may be more annoying to the peace-and-quiet-seeking people whom they bother than the larger, more productive freight traffic.

Ground Transportation
Recreational

Such modes as motorcycles, bicycles, and snowmobiles are so limited in carrying capacity as presently constructed that their contributions to overall transportation is relatively minor. While motorcycles and bicycles are used for school, shopping, or business trips, they are more likely to be associated with recreational purposes along with the snowmobile or dune buggy. In 1970, the U.S. has some 60 million bicycle riders of all ages. While unlikely to replace the automobile, the bicycle is sometimes a tempting solution to problems of congestion and air and noise pollution.

Motorcycles in use have increased from 417,578 in 1952 to 574,000 in 1960, and to 1,953,000 in 1967, 3½ times the figure for 1960. They produce very little air pollution, but inordinate amounts of noise pollution—perhaps out of proportion to their benefits to society. A number of states already regulate them for noise.

Snowmobiles are new and seem to be very popular with some people. In 1968-1969, 250,000 were sold in the United States, and an estimated 1.5 million are presently operating. While seasonal and even regional (depending on good snow coverage), they have already caused great concern to environmentalists and have been responsible for tremendous numbers of noise complaints. Minnesota has initiated noise abatement legislation to control the estimated 160,000 in use there, and other states appear to be following.

Trucks

The versatility of the truck has allowed the trucking industry to increase its share of U.S. freight traffic from 16 percent in 1950 to 22 percent today. By 1985 trucks are expected to carry 25 percent of intercity and nearly 100 percent of intracity freight. They provide economical transportation of an infinity of goods to the doorsteps of a widely dispersed population.

Seventeen million trucks were operating in 1968, and if the fleet expands at the rate GNP has grown (an average of 3 percent a year, 1900-1963), there will be over 18 million by the end of 1970, and 28 million in 1985. In 1968 large tractor-trailer combinations were only 5 percent of the total fleet, but accomplished 18.6 percent of the total miles. The trucks regulated by I.C.C. averaged 51,999 miles annually (compared to an over-all truck average of 11,200 miles). [9] Most of their **total hours** operated (194 million) were in population centers: 86 percent of the time in pickup and delivery service and 14 percent in line haul service. And 39 percent of **all** truck miles is on urban streets. [9] Since truck noise is largely independent of speed, heavy trucks are contributing considerably to urban noise. In 1966, trucks represented only 16 percent of all registered motor vehicles, but it is claimed that one truck with a defective muffler produces as much noise as 90 or 100 passenger cars traveling simultaneously. [10] Consequently, trucks are a major target in any program of transportation noise abatement.

Buses and Urban Transit

The 352,000 buses in the U.S. in 1968 traveled nearly 15,000 miles each. [9] About 80 percent of the total were school buses, but they accounted for only about half the total mileage. Decreasing numbers of intercity passengers leave the driving to the bus driver: buses accounted for 27.3 million passenger miles (4.2 percent of the commercial total) in 1967. For this and other reasons the bus population is projected to increase only very slightly by 1985.

The urban rapid transit industry carried 248 million passengers by trolley coach, 1,828 million by electric railway, and 5,723 million by bus in 1967, for total railway vehicle miles of 37,434 and bus miles of 1,526 million. These figures are not expected to increase remarkably over the next 15 years, and have been declining in recent years. The automobile has encouraged urban diffusion until population densities (Figure 4.3) often will not support urban mass transit. Studies have shown that the suburban dweller often would not use rapid transit even if it were available. Even though buses, trolleys, and subway trains are noisy, greater reliance on their efficient use in urban areas could reduce traffic, air pollution, and even noise pollution.

Railroads

In 1943, 71.3 percent of intercity freight traveled by rail but the proportion declined to 40 percent in 1969, [24], [26] where it seems to be stabilizing. Of the 575 railroads in 1966, the 76 Class I railraods (with annual operating revenues of $5 million or more) operated 96 percent of rail mileage, and performed 99 percent of all intercity rail service. Railroads operate about 10,000 freight trains with an average of 1.9 billion ton-miles of freight service each day. [24]

Railroad freight is typically long-distance and low-grade, producing relatively less revenue than higher grades, (many of which have been taken over by trucks). The aggregate fleet capacity is now an estimated 117.5 million tons, only 8 percent higher than ten years ago. Table 4.9 inventories rail equipment, showing that freight equipment is slowly declining while passenger equipment is dropping sharply. Antiquated methods and featherbedding still plague the industry, and about a third of the total locomotive fleet is more than fifteen years old. Piggybacking (with a growth rate of 11 percent from 1964-1969), containerizing, and unitized trains may improve the position of railroads in the 1970's and 1980's but the industry is having great difficulty operating at a profit.

Freight trains do make noise, but far less noise per freight ton-mile than trucks (which have caused more complaints). A great deal could (and should) be done to reduce railroad noise, and increased freight-handling by rail could reduce over-all community noise exposure.

A number of passenger trains provide commuter or other service, carrying about 820,000 passengers daily. During 1965 the railroads carried 299 million passengers a total of 17 billion miles, about 17 percent of the passenger-miles of all commercial carriers, but the railraod share of all intercity passenger-miles (commercial and private vehicles) railroad has declined from 6.4 percent in 1950 to 1.5 percent in 1967, and the decline will surely continue. [37]

In 1969, 93 percent of federal transportation expenditures were on highways and airways, with only 1 percent for railways, [20] partly reflecting public preference for faster, more convenient modes. Improvements in comfort, speed, and service are possible but not likely without outside help. One of the few bright spots is the very successful high-speed metro-liner between Washington, D.C. and New York City. If passenger trains are to hold their own or even recover some of the traffic lost to other modes, sizeable government loans and grants may be needed and some even suggest that the industry be nationalized.

As noted, rail rapid transit has not held its own against other modes, but greater use of rail travel could solve a number of traffic and pollution problems.

Automobiles

The American is firmly committed to the automobile. It has changed his sexual mores and his shopping habits, spawned drive-in banks—and drive-in churches, changed the shape of his cities, and relocated industries. It is his primary mode of transportation. Of the 1,135 million domestic passenger miles predicted for 1970 [27] nearly 90 percent will be by private automobiles. Over 80 percent of all auto travel is in trips of less than 10 miles, and 25 percent of total auto travel is in trips under five miles. In 1968 over 83 million passenger cars and taxis were registered, and the total is projected to be 130-135 million in 1985. [27] In recent years the average number of miles per auto has been slightly over 9,000 miles.

Figure 4.5 shows the distribution of road mileage and road usage in urban areas in New York State. If total vehicle miles are divided by total mileage to suggest indices of road usage, these are 5.6 for expressways, 2.4 for arterials, and 0.3 for collector and local streets. Such indices of traffic concentration, probably representative of all U.S. urban areas, suggest why noise levels reported for local streets range from 56 to 65 dB(A) and for arterials from 63 to 85 dB(A).

For all SMSA-size groups including central cities and suburbs, 66.7 percent of all work trips are

Inventory of Railroad Equipment—1959-1969 [33]					
December 31	Freight cars	Passenger cars (incl. Pullman)	Head-end passenger train cars	Diesel Locomotive Units	Other Locomotive Units
1959	1,982,110	17,459	13,208	28,238	1,288
1969	1,968,771	16,181	12,818	28,369	774
1961	1,907,723	15,004	12,345	28,240	614
1962	1,852,992	14,240	11,788	28,170	505
1963	1,817,026	13,732	11,369	27,969	478
1964	1,802,582	12,507	11,154	27,879	433
1965	1,803,227	11,371	10,502	27,433	399
1966	1,834,963	10,665	9,932	27,516	378
1967	1,827,376	9,845	9,147	27,317	353
1968	1,804,712	8,736	6,746	27,045	331
1969 (est.)	1,796,000	6,700	5,300	26,850	330

New Railroad Equipment Installed—1959-1969				
Year	Freight cars	Passenger train cars	Diesel Electric Units	Other Locomotives
1959	46,023	74	835	7
1960	58,322	239	440	13
1961	34,241	204	242	32
1962	39,822	285	754	28
1963	48,255	143	806	13
1964	83,266	408	1,116	–
1965	89,653	577	1,440	–
1966	106,058	103	1,394	–
1967	100,181	138	1,067	–
1968	68,836	89	1,055	–
1969 (est.)	76,000	50	1,100	–

Table 4.9

by automobile. The percentage of households owning cars in 1962 was 83.8 percent in the West, 81.8 percent in North Central, 74.9 percent South, and 70.6 percent Northeast. California had the largest total of cars (over 7.2 million), and New York was second with almost 4.8 million. [3], [37]

The private automobile has revolutionized the movement of passengers in the U.S. Barring development of a true land-sea-air vehicle, it remains the most versatile of transportation modes, permitting door-to-door service, departure times at the driver's convenience instead of by timetable, and speed exceeded only by airplanes among competitive modes. Most people can (or **do**) afford an auto for reasonably economic, reliable, safe, confortable, and convenient transportation. Extra passengers and luggage add negligibly to travel costs. Car ownership provides independence and enhances status. Highways provide great flexibility as compared to trains, and are constantly being improved and expanded through public expenditures.

But the automobile is blamed for many things, too. The internal combustion engine is a primary source of air and noise pollution, and highway traffic deaths exceed battlefield deaths. Automobile transportation is termed inefficient because it requires each driver to occupy 200 square feet of street space and drag with him 2 tons of steel and rubber wherever he goes. Highways and city streets, drastically changing existing land patterns, lowering land values and destroying esthetic values, are expensive to construct. Urban overdependence on this mode especially contributes to traffic congestion, greater air and noise pollution, difficulty in parking, and difficulty in maintaining more than horse and buggy speeds. The limited passenger capacity makes the private auto-

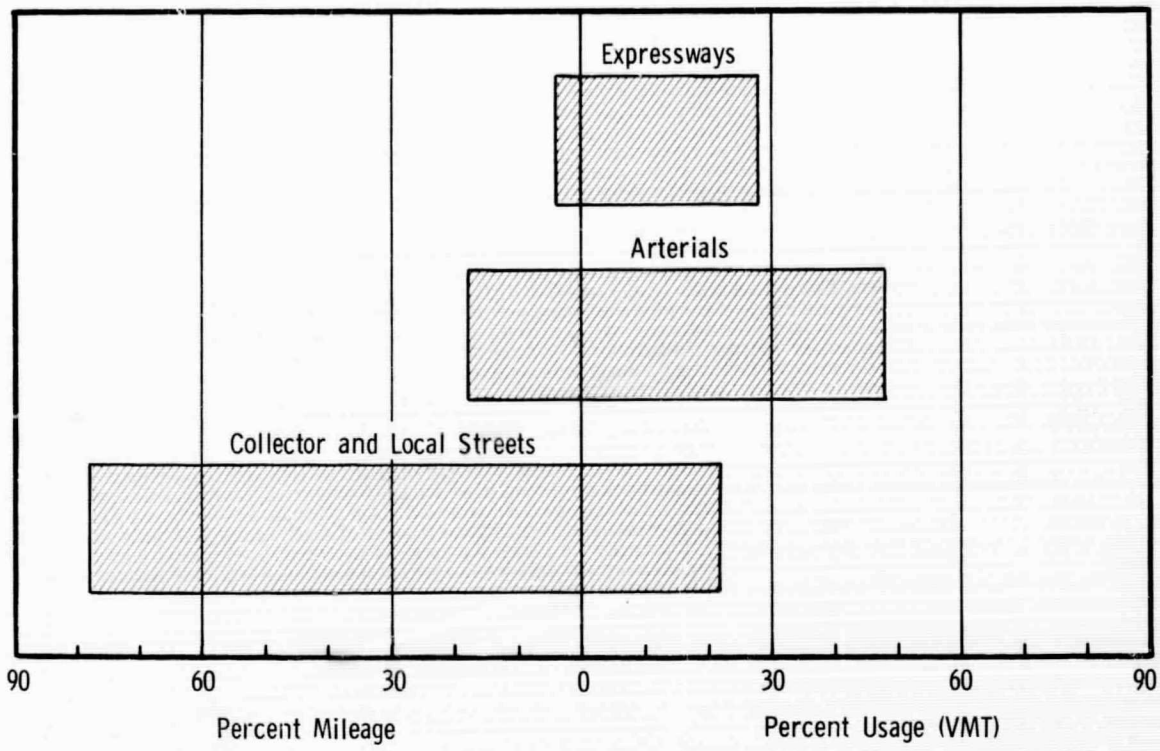


Figure 4.5. Road Use, New York State Department of Transportation, Policies and Plans for Transportation . . .

mobile inadequate for present urban mass transportation needs, and problems will worsen if projections for 1985 have any validity.

Airplanes

Aircraft transport a small portion of total freight and passengers but receive special attention as noisemakers because they are very loud, very conspicuous, and increasingly numerous. As Figure 4.1 has shown, airplanes have been capturing a rapidly growing share of the commercial intercity travel market. Of the 111.4 billion intercity passenger-miles by common carrier in1967, 75.5 billion or 67.7 percent was by scheduled air. Growth rates of purchased intercity travel from 1951 to 1967 with forecasts to 1985 are shown in Figure 4.6. During the period under study, these growth rates are expected to change, with air travel increasing but at a lesser rate, rail travel declinding at a decreasing rate, and bus travel remaining roughly constant.

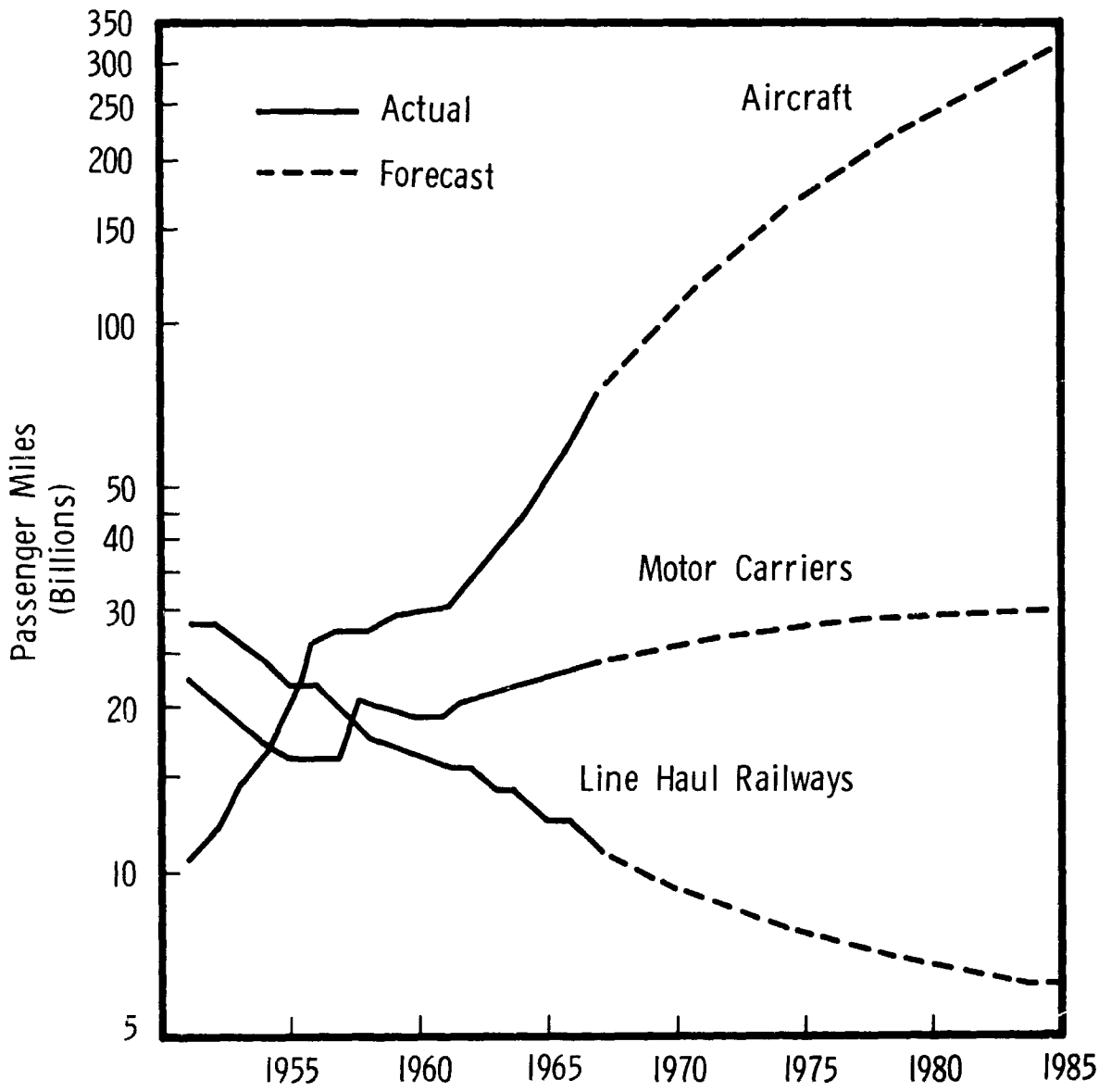


Figure 4.6. Rates of Growth of Domestic Intercity Passenger Miles by Rail, Common Carrier Motor Vehicles and Common Carrier Aircraft.

Air Passengers

Figure 4.7 shows that total intercity passenger miles have increased at a rate greater than population but less than gross national product. In forecasting air carrier traffic, total passenger travel is assumed to continue increasing at about 4.0 percent per year, and transportation by user operated vehicles to level off to about 3.5 percent increase per year, roughly the rate forecast for disposable income. Travel by aircraft is expected to increase at an average rate of 8.2 percent per year. On this basis, Table 4.10 forecasts total passenger intercity travel for the years 1975, 1980, and 1985:

Forecast of Intercity Passenger Traffic (Billions of Passenger Miles)

	Year			Percent Change Per Year
	1975	1980	1985	1968-1985
User Operated	1235	1480	1750	3.5
Scheduled Air	172	216	315	8.2
Others	36	38	40	.2
Total	**1443**	**1724**	**2105**	**3.9**

Table 4.10

Air Freight

It would be foolhardy to ignore airfreight, even though present volumes are conparatively small and predictions are risky. One has only to remember that from a modest beginning the trucking industry grew to capture 22 percent of the total freight ton-miles and perhaps 35 percent of the total dollar value of all goods transported in 1967. Air transport in 1967 totaled 2.6 billion ton-miles (0.2 percent of the total) but is increasing at more than 12 percent per year (Table 4.11):

Volume of Domestic Intercity Freight Traffic by Type of Transport

	Year			Average Percent Change Per Year		
Type Transport	1951	1960	1968	'51-'68	'51-'60	'60-'68
Total Ton-miles (Billions)	1,178	1,314	1,834	2.64	1.22	4.36
Rail	655	579	757	0.85	(3.02)	3.41
Motor Vehicles	188	285	396	4.48	4.73	4.16
Inland Waterways	182	220	287	2.71	2.13	3.37
Pipelines	152	229	391	5.72	4.66	6.96
Airways	0.38	0.78	2.90	12.70	8.32	17.84
Source: Statistical Abstract, 1969						

Table 4.11

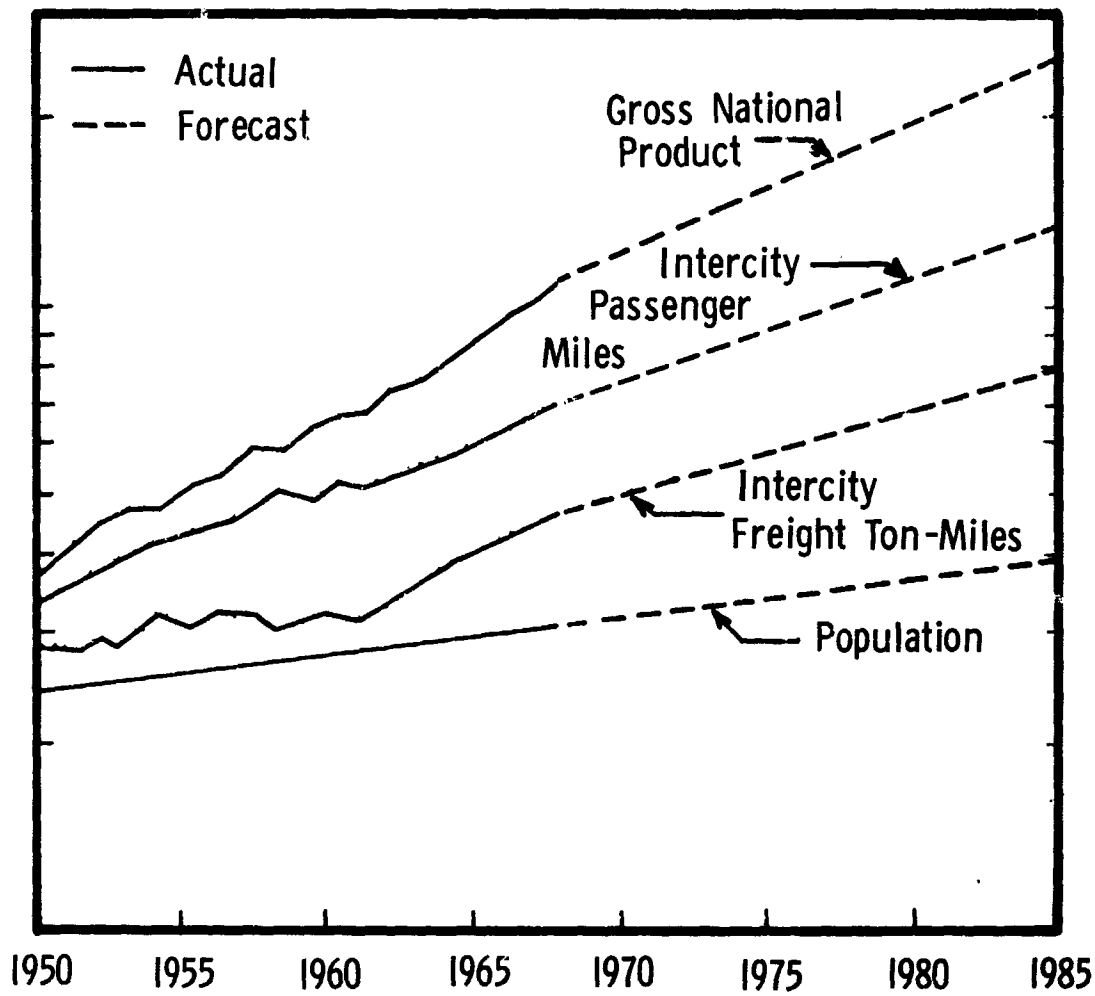


Figure 4.7. Rates of Growth. (For actual data, see Table , Appendix .)

Figure 4.8 compares the rates of growth of intercity freight ton-miles by type of transport. Once again the impact of the airplane is evident. The keys to increased growth of airfreight are reduced weights of manufactured goods, standardization of shipping cartons, and development of mechanized freight handling and off-airport containerization. As manufactured items become more sophisticated, more complex, and of greater value per unit of weight, they tend to become eligible for air shipment. Air cargo enplanements increased at 13 percent per year from 1954-68, but Table 4.12 projects a more conservative increase of 7.5 percent annually over the next 15 years:

Tons of Air Cargo Enplaned in the 48 Contiguous States and D. C. (Thousands)

	Actual			Forecast Total
Year	Mail	Freight	Total Cargo	
1954	114	311	425	
1968	735	1619	2354	
1975				3700
1980				5600
1985				8050

Table 4.12

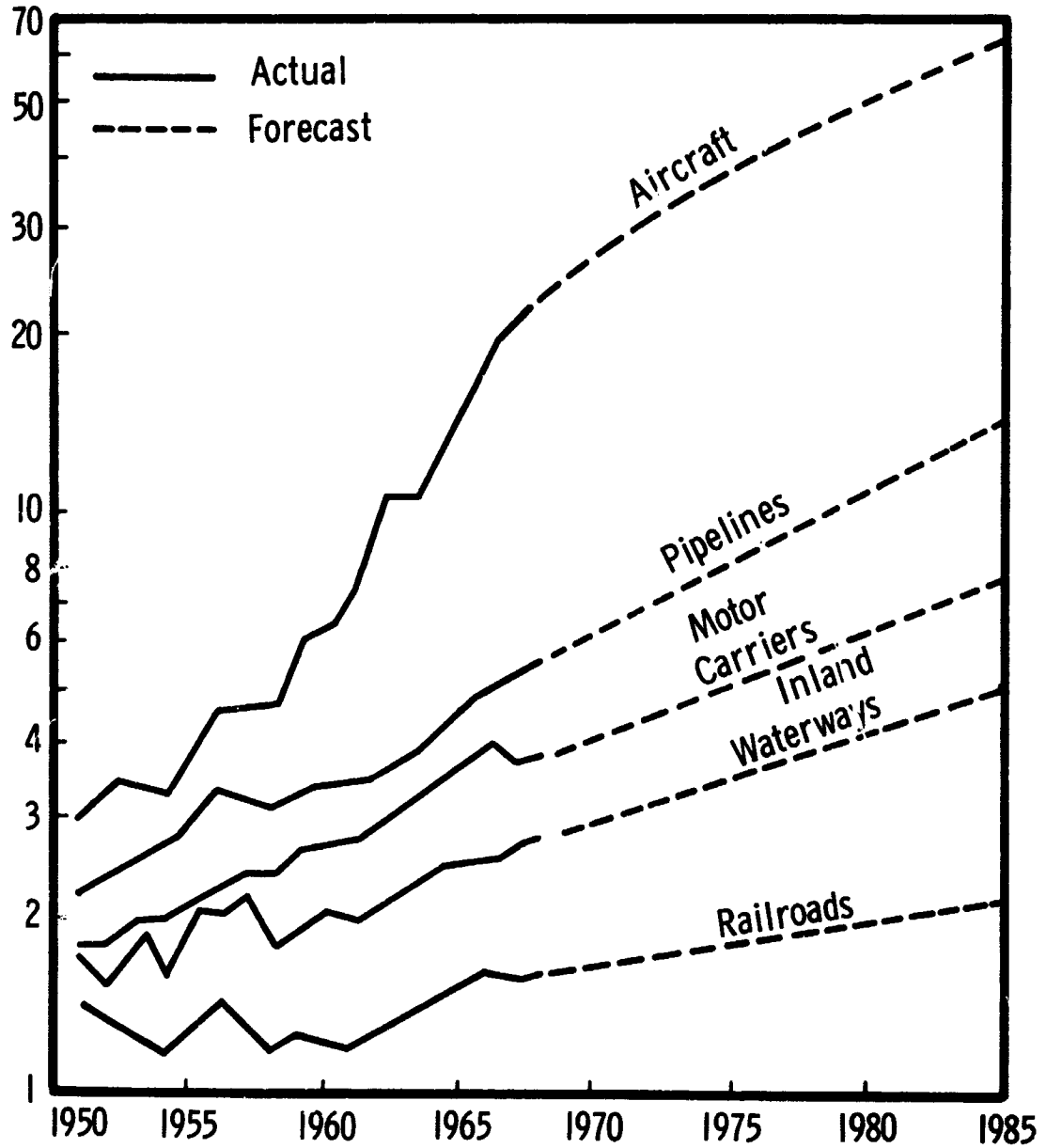


Figure 4.8. Showing Comparison between Rates of Growth of Intercity Freight Traffic by Rail, Inland Waterways, Motor Carriers, Pipelines, and Aircraft.

Motor vehicle carriers have the initial advantages of terminals nearer the center of the city, and quicker response for short hauls. Thus another requirement for airfreight growth may be a change in the physical structure of cities. The "Fly-In" concept might be a forerunner of this change. It is predicted that future cities will focus on airports in the way older cities located on harbors or railroad and highway junctions. [11] A new industrial city's central runway would be surrounded by industrial and commercial sites, company general office headquarters, etc. Mobile young executives, for whom air travel is as routine as the telephone, may insist on increased shipment of goods by air, citing economic as well as psychological reasons: reduction in inventory, production lead time, and investment, effecting savings in spare parts inventory, and increased efficiency for general office and sales personnel. Another unpredictible factor is the effect of new jumbo jets, which are expected to make more money from freight than from passenger service. [36]

General Aviation

From 1950 to 1967 the total number of hours flown by general aviation increased from 9.7 million to 22.2 million. At this rate, general aviation will be flying an estimated 53.5 million hours per year in 1985. [23] Of greater importance than total aircraft or flying time is the composition of the fleet. The general aviation fleet will increase from 58,790 aircraft in 1955 to 315,600 in 1985, and the greatest rate of growth is among jet and multi-engine aircraft. The composition of the fleet is projected in Table 4.13, and charted in Figure 4-9.

Comparison of General Aviation Fleet By Aircraft Type

Type Aircraft (000)	1955		1967		1985	
	No.	% of Total	No.	% of Total	No.	% of Total
Single engine≤ 3 places	35.7	60.8	41.7	34.3	67.0	21.2
Single engine≥ 4 places	19.2	32.7	61.1	50.1	160.0	50.8
Multi engine	3.3	5.7	14.4	11.9	49.0	15.5
Turbine/Jet engine			1.6	1.3	25.0	7.9
Rotary	0.2	0.4	1.9	1.5	12.0	3.8
Other	0.2	0.4	1.2	0.9	2.6	0.8
Total	**58.8**	**100.0**	**121.8**	**100.0**	**315.6**	**100.0**

Table 4.13

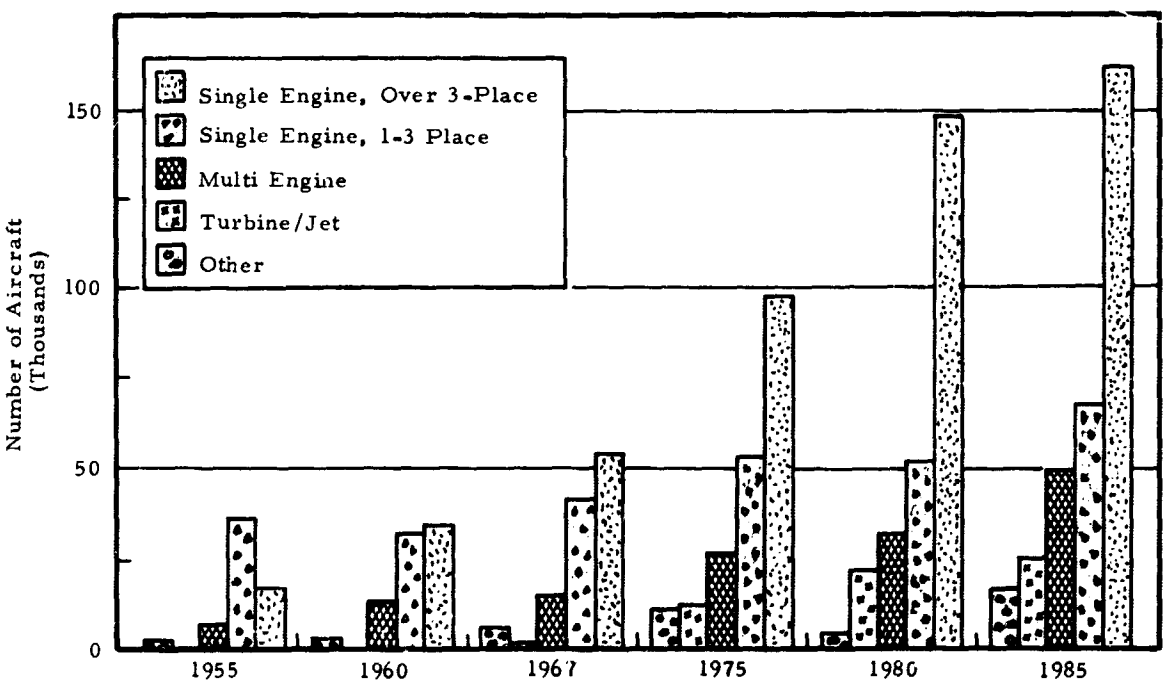


Figure 4.9. Number of General Aviation Aircraft, by Type, on December 31, with Projections for 1975, 1980 and 1985.

Another important trend of general aviation is its concentration in the population hubs (SMGA's) of the U.S. In 1960, 42.8 percent of the fleet operated in these 75 areas, but by 1985 the proportion will be 57.2 percent (Table 4.14). These figures are represented by engine type in Figure 4.10.

Distribution of General Aviation Aircraft			
Area	**1960**	**1967**	**1985**
SMSA's	32,676	54,111	179,000
All other areas	43,739	67,689	136,600
Total	**76,415**	**121,800**	**315,600**
% in SMSA's	42.8	44.4	57.2

Table 4.14

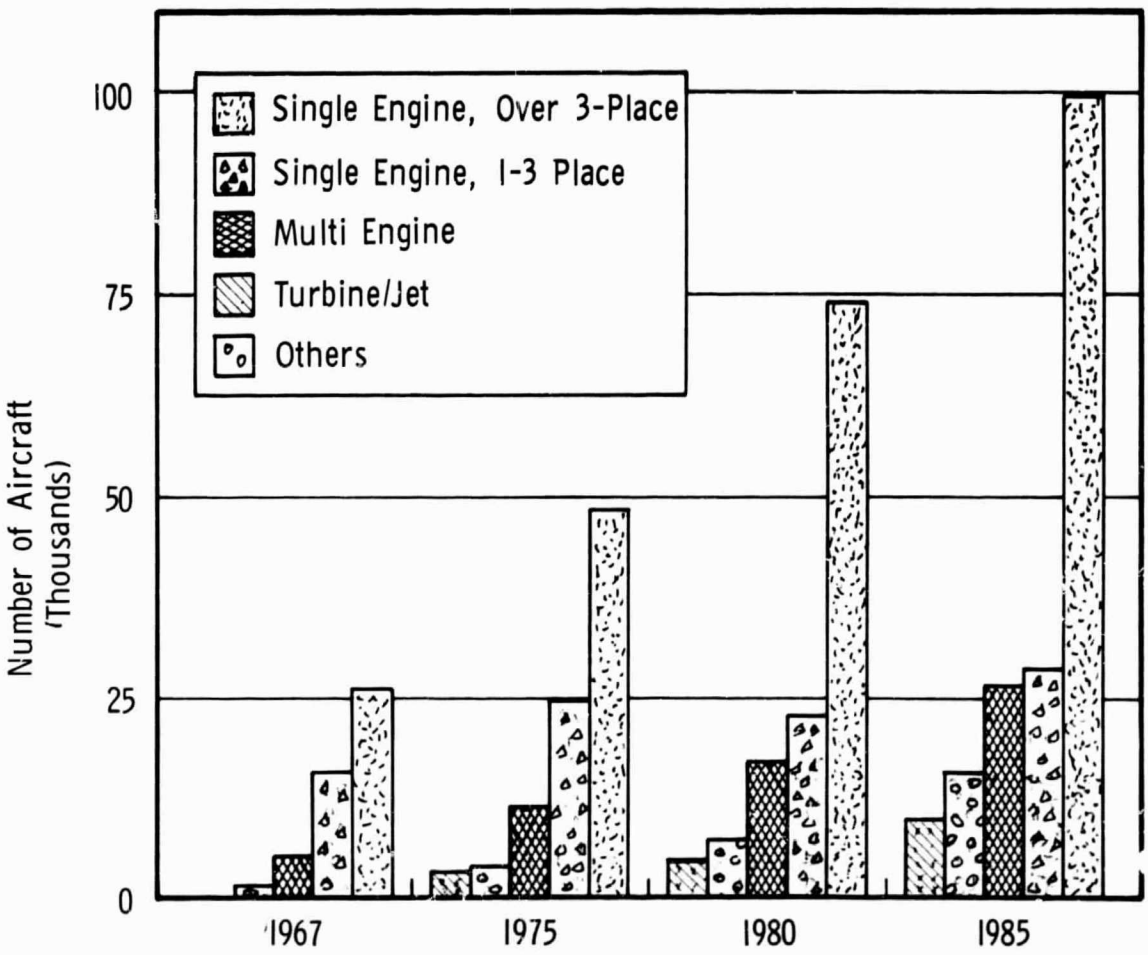


Figure 4.10. Number of General Aviation Aircraft Operating in Standard Metropolitan Statistical Areas, by Type Aircraft, on December 31, with Projections for 1975, 1980 and 1985.

The FAA estimates that the U.S. Air Carrier fleet will number 3,860 in 1978. [4] Projection to 1985 suggests a fleet totalling 4,560. The total aviation fleet for 1985, including general and commercial aviation, is projected in Table 4.15.

U.S. Civil Aviation Fleet
Number of Operating Aircraft Dec. 31

	1975			1980			1985	
	U.S. Carrier	Gen. Aviation	Total	U.S. Carrier	Gen. Aviation	Total	U.S. Carrier	Gen. Aviation	Total
Single Engine, 1- to 3-Place		55400	55,400		58700	58700		67000	67000
Single Engine; Over 3-Place		98200	98200		143,900	143900		160000	160000
Multi Engine, Piston	135	24500	24635	40	35200	35240		49000	49000
Multi Engine, Turbine	3007	6000	9007	3645	11600	15245	4300	25000	
									29300
SST	24		24						
				85		85			
							200		200
Rotary Wing	24	4200	4224	30	8700	8730	60	12000	12060
Total	3190	188300	191490	3800	258100	261900	4560	312400	316960

Table 4.15

The Federal Administration considers aircraft operations the best measurement of air traffic, and for noise estimations, aircraft operations are surely more significant figures than either total numbers of aircraft, passenger-miles or ton-miles of cargo. Table 4.16 forecasts total annual operations for the entire civil aviation fleet, projecting air travel according to existing type aircraft only:

U.S. Civil Aviation Fleet
Estimated Total Aircraft Movements Millions by Type Aircraft

	1975			1980			1985	
	U.S. Carrier	Gen. Aviation	Total	U.S. Carrier	Gen. Aviation	Total	U.S. Carrier	Gen. Aviation	Total
Single Engine- 1 to 3-place		72.0	72.0		82.4	82.4		100.5	100.5
Single Engine- Over 3-Place		73.7	73.7		115.1	115.1		136.0	136.0
Multi Engine- Piston	0.1	42.9	43.0	0.1	61.6	61.7		88.2	88.2
Turbine/Jet	12.8	16.2	29.0	18.6	33.1	51.7	21.9	77.5	99.4
Rotary Wing	0.6	1.7	2.3	0.8	3.5	4.3	1.1	4.8	5.9
Total	13.5	206.5	220.0	19.5	295.7	315.2	23.0	407.0	430.0

Table 4.16

U.S. airline traffic is heavily concentrated at 23 communities (classified as large hubs) which in 1965 accounted for 68 percent of all domestic passengers enplaned and 79 percent of all domestic air cargo carried by U.S. scheduled airlines. [33] Three hubs—New York/ Newark, Chicago, and Los Angeles—accounted for over 25 percent of all the 1965 passenger enplanements. [33] Both commercial and general aviation operations will increase more rapidly at the already noisy and overcrowded large hubs than at the smaller ones. (From 1962 to 1968 increases of more than 70 percent in air carrier traffic occurred at 12 of the 23 large hubs. Between 1958 and 1969 general aviation traffic showed an increase of 210 percent at the large hubs.) As a suggestion of the noise-concentration problem, Figure 4.11 shows itinerant aircraft operations at FAA traffic control towers by size of hub.

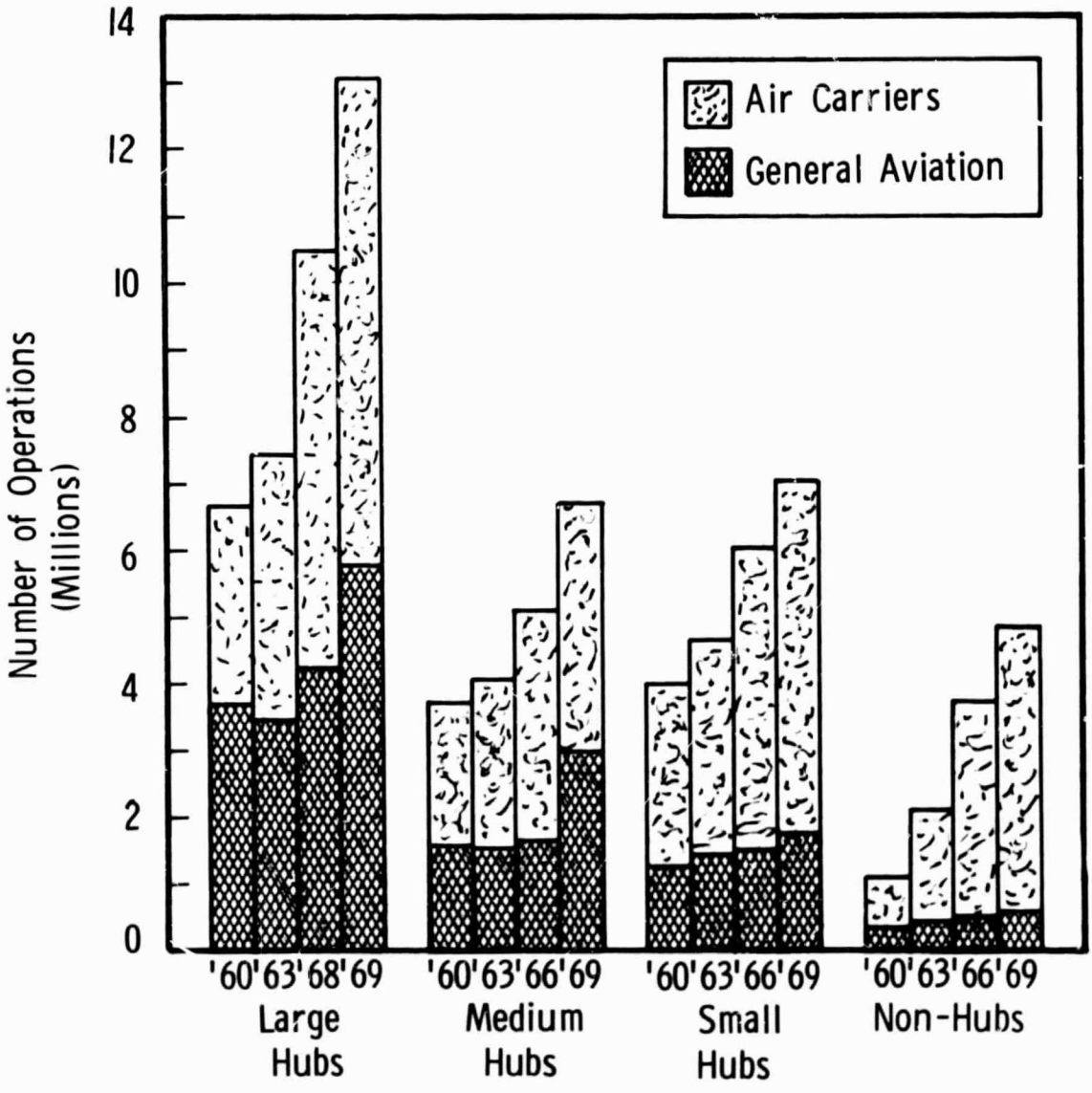


Figure 4.11. Itinerant Aircraft Operations at FAA Traffic Control Towers, by Size of Hub.

Conclusion

This chapter has reviewed present transportation modes and projected their use to 1985. (Further transport statistics are contained in Appendix I.) A summary of major population and transportation figures affecting noise is presented in Table 4.17.

These figures suggest something of the magnitude of the transportation noise problem in 1985. While this chapter has mentioned characteristics of specific transportation modes only in very general terms, Chapter V, to provide a technological basis for abatement, discusses present and projected noise levels for the several modes, proposals for reducing their noise, and possible modal innovations and combinations.

Population and Transportation Totals		
	1968	1985
People	201 Million	250-260 Million
Passenger Miles (Common Carriers)	1,092 Billion	1,540 Billion
Ton-Miles of Freight	1,834 Billion	2,900 Billion
Automobiles	83 Million	130-135 Million
Trucks and Buses	18 Million	28-29 Million
Motorcycles	2.1 Million	8.9 Million
Aircraft	132 Thousand	317 Thousand
Aircraft Operations	80 Million	430 Million

Table 4.17

Chapter V

Technological Approaches To Transportation Noise Abatement

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Introduction

The effect of noise on society having been established, this chapter examines the noise generation characteristics of the current modes of transportation and their potential for noise abatement over the next 15 years. Future transportation system proposals are treated along with their projected noise characteristics. Finally an analysis to optimize modal splits using noise as a major design parameter is presented. This analysis assumes that the public's additional travel needs can be satisfied in many ways using different combinations of modes, some of them more desirable from noise considerations.

Noise Generation Characteristics of Current Modes of Transportation

Commercial Aviation

The classification by powerplant of the current and projected fleet of aircraft in the United States through 1985 (Table 4.15, Chapter IV), suggests several trends. By 1985 the commercial piston aircraft will be phased out, and only a small percentage of the fleet will be 1- and 2-engine turboprops. About 95 percent of the 1985 fleet will be jet-powered, most of the aircraft having 2 or 3 engines. It should be noted that the majority of today's jet aircraft are powered by the quieter turbofan, rather than turbojet, engines. By 1985, with the notable exception of the SST, the turbojets will be essentially nonexistent.

Sources of Noise

The primary noise-generating characteristics of each type of aircraft must be considered briefly, with emphasis on turbojet and particularly turbofan engines. In piston aircraft the two main sources of noise are the propeller and the power plant, with the propeller noise being dominant. For turboprop aircraft, measurements indicate that propeller noise far exceeds jet noise.

Turbojet noise comes primarily from two sources, the compressor and the jet exhaust. Jet exhaust noise, caused by the turbulant mixing of the high speed exhaust gases with the atmosphere, is quite high in turbojet engines.

One obvious way of reducing jet exhaust noise is by decreasing the jet exhaust velocity by diverting a portion of the entering air around the combustion chamber by means of a fan, hence the name fanjet or turbofan. The sources of noise from a turbofan engine are indicated in Figure 5.1. Note that the fan itself becomes an additional source of noise. In fact as the bypass ratio (the ratio of the secondary air flow rate to the primary flow rate) and the diameter of the fan increase, the fan noise can become the dominating noise. Fan noise is particularly annoying on landing where the fan gives rise to the familiar engine whine. A comparison of fan noise and jet noise may be seen in Figure 5.2.

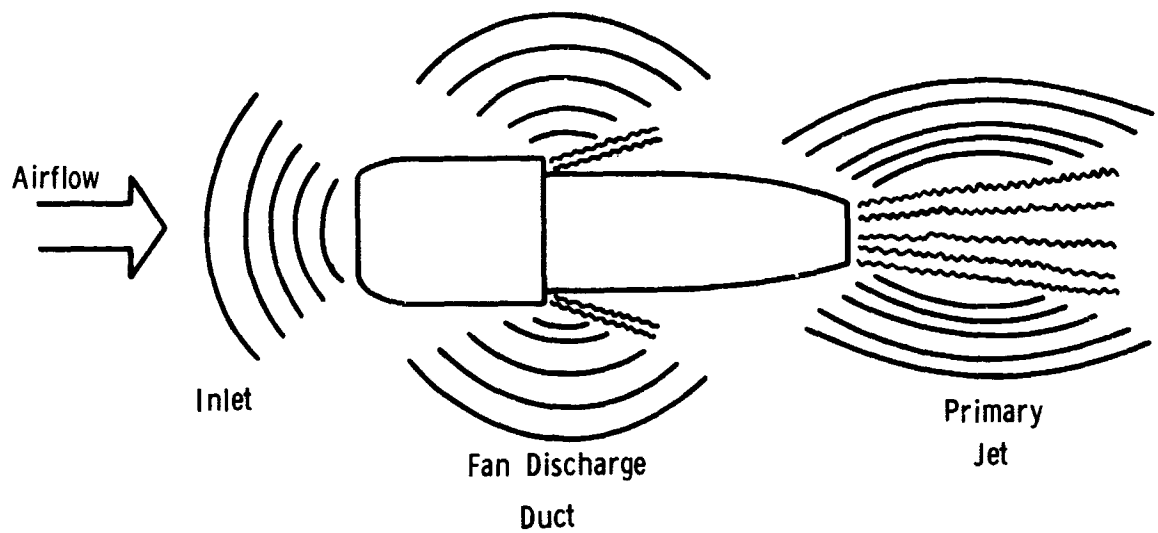
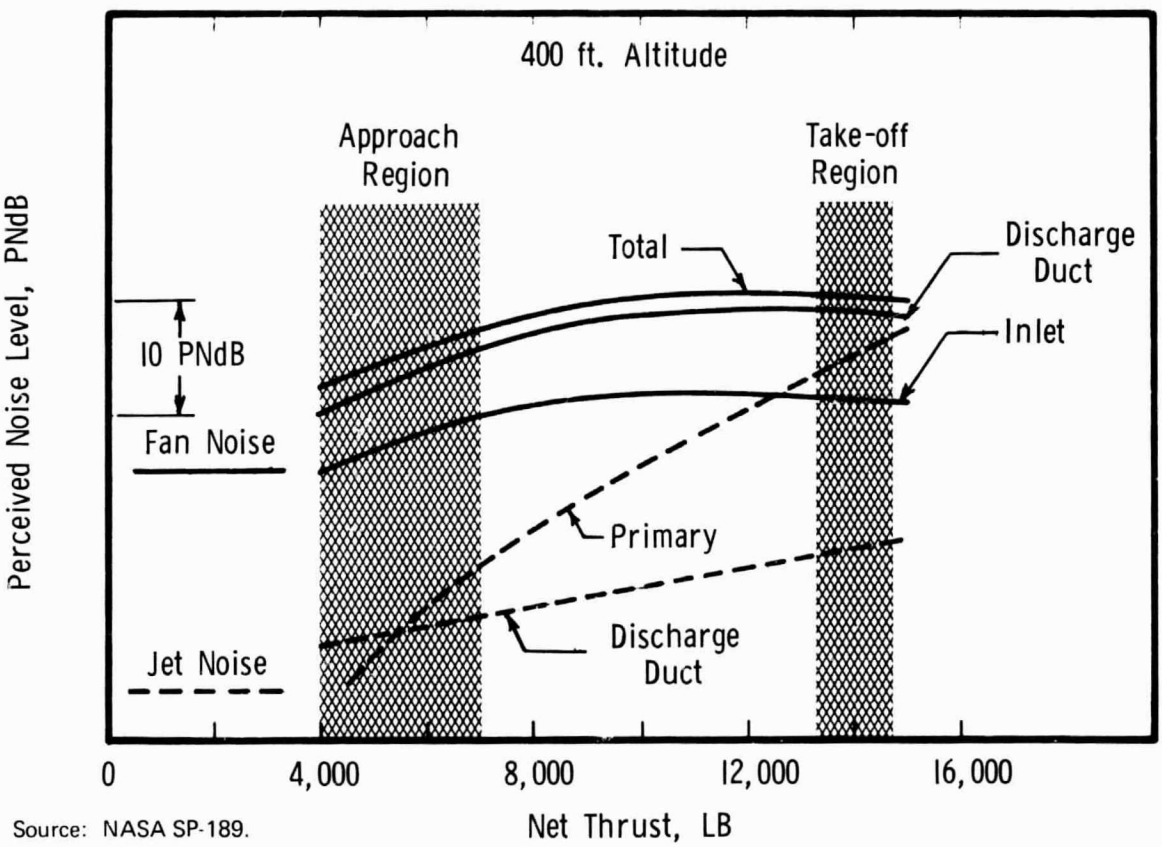


Figure 5.1. Turbofan Engine Noise Sources.



Source: NASA SP-189.

Figure 5.2. Turbofan Engine Noise.

Noise Levels

The takeoff and approach noise levels for current aircraft are shown in Figure 5.3, expressed in terms of the Effective Perceived Noise Level (EPNdB), which modifies the perceived noise level (PNdB) to include: (1) the effects of pure tones (discrete frequency components), and (2) the duration of the noise exposure. For all future aircraft, the FAA has established maximum allowable approach, sideline, and takeoff noise levels, also indicated in Figure 5.3. These levels are substantially lower than those of all present subsonic, commercial aircraft. The aircraft noise levels are measured at the following certification locations:

1. takeoff noise at 3.5 nautical miles (n.m.) from brake release.
2. sideline noise at 0.25 n.m. for 2- and 3-engine aircraft, 0.35 n.m. for 4-engine aircraft, from center of runway.
3. approach noise at 1.0 n.m. from the point of touchdown.

The Boeing 747 will become the first plane to be certificated for noise by the FAA, with compliance expected by December 1971. The new jumbo tri-jets—McDonnell Douglas DC-10 and Lockheed 1-1011 (Figure 5.4)—will also meet the FAA noise standards by the time they fly commercially in 1971.

Airport Operations

In addition to the noise levels of individual aircraft, an important variable in assessing the annoyance due to aircraft noise is the number of operations (takeoffs or landings) at a given airport. As noted in TAble 4.16, Chapter IV, the number of commercial aircraft operations in the United States is expected to double in the next 15 years.

Noise Exposure Forecasts (NEFs)

At present, the best method for describing the total aircraft noise exposure in the vicinity of an air-

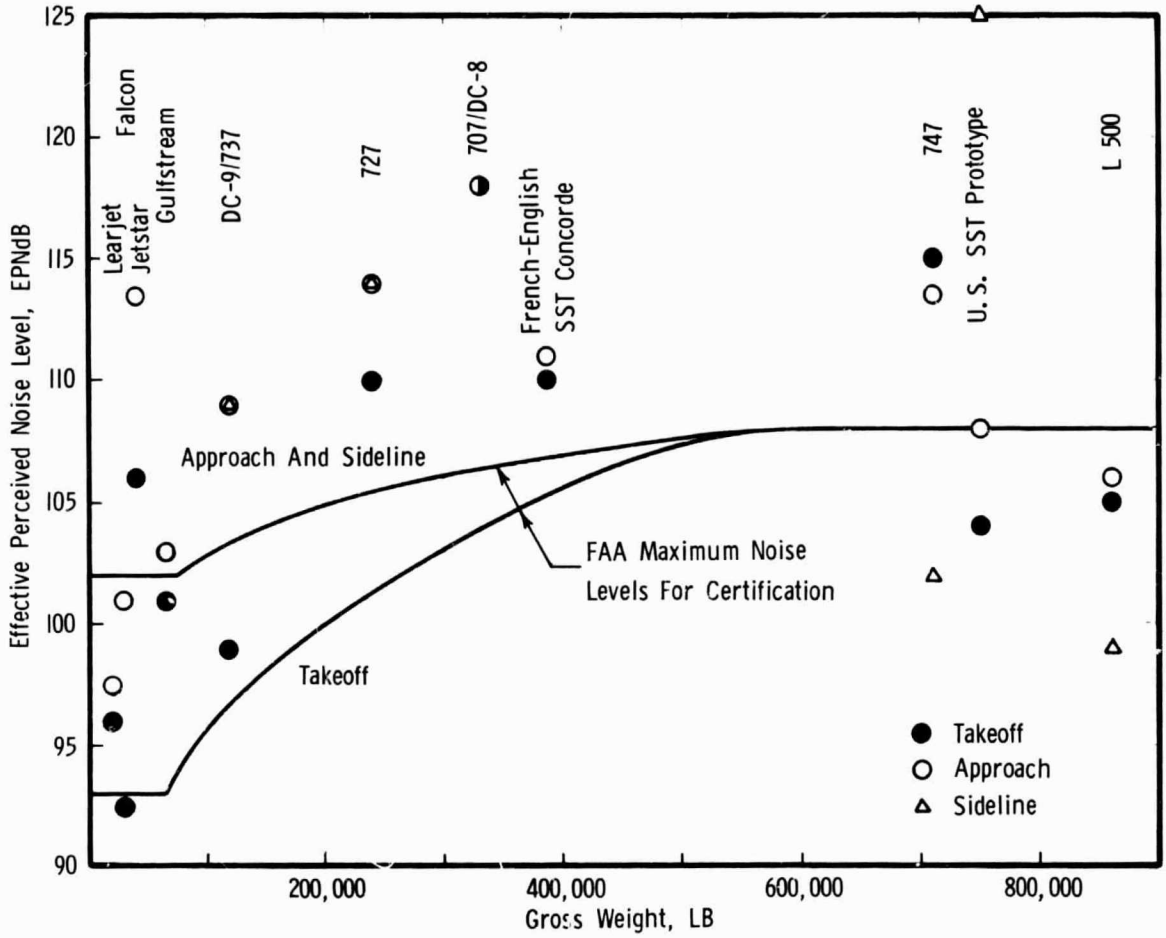


Figure 5.3. A Comparison of Representative Aircraft Noise Levels with Present FAA Subsonic Certification Levels.

Source: Eastern Airlines.

Figure 5.4. Artist's Conception of the Lockheed L-1011 Jumbo Tri-Jet.

port is the Noise Exposure Forecast (NEF). As its name implies, the NEF is a tool to predict the future (as well as present) impact of aircraft noise on the surrounding community (Figure 5.5). Such information provides an invaluable aid in land-use planning and zoning around airports.

Because of the usefulness of the NEF, the FAA is preparing Noise Exposure Forecasts for a number of airports throughout the country. NEF areas consist of a map of a given airport and surrounding land with NEF contours—curves of constant NEF values—superimposed onit.

NEF contours consider a number of factors, including:

1. Effective perceived noise level, EPNdB.
2. Number of daytime and nighttime operations.
3. Aircraft track and profile.

In general, the EPNdB value will vary from plane to plane depending upon type, and will, of course, also depend upon the distance between the observer and the aircraft.

Some important general conclusions concerning NEFs:

1. In general, NEF values decrease as the distance from an airport increases.
2. NEF areas may be divided into 3 more or less distinct regions:
   a. NEF less than 30—should be little annoyance due to aircraft noise.
   b. NEF greater than 40—could be considerable annoyance due to aircraft noise.
   c. NEF greater than 30 but less than 40—intermediate range.
3. If the number of operations at a given airport is doubled while all other variables are held constant, the NEF value at any given point increases by 3.
4. If the noise level per aircraft at a given airport increases by a given EPNdB, all other variables remaining constant, the NEF value at any given point also increases by the given EPNdB. The same is true for a given decrease in EPNdB.

Items 3 and 4 indicate that an NEF value, and hence annoyance, are far more sensitive to the noise levels of individual aircraft than to the number of airport operations. A simple example may help to clarify this point.

Suppose a person near an airport lives at a residence where the NEF value is 40. If the number of operations at the airport is doubled (a very significant increase), the NEF will, in turn, increase rather modestly to a value of 43. If on the other hand, at the original number of operations with NEF 40, the noise level of each aircraft is now reduced by 5 EPNdB (generally regarded to be a modest decrease), the new NEF value will be 35, which represents a significant decrease.

NEF areas for representative large and medium size airports are presented in Figures 5.6 and 5.7 for John F. Kennedy International and Raleigh-Durham (North Carolina) Airports for 1970 and 1975. At JFK Airport, there is very little difference between the 1970 and 1975 NEF contours, while the Raleigh-Durham Airport shows a substantial growth. The noise situation at some large airports, then, where the number of operations is reaching the saturation point, probably will not become significantly worse and, in some cases, may actually improve as new and quieter aircraft, such as the Boeing 747 and the jumbo tri-jets are introduced. The only new aircraft in design that will be noisier is the SST which is discussed later in this report.

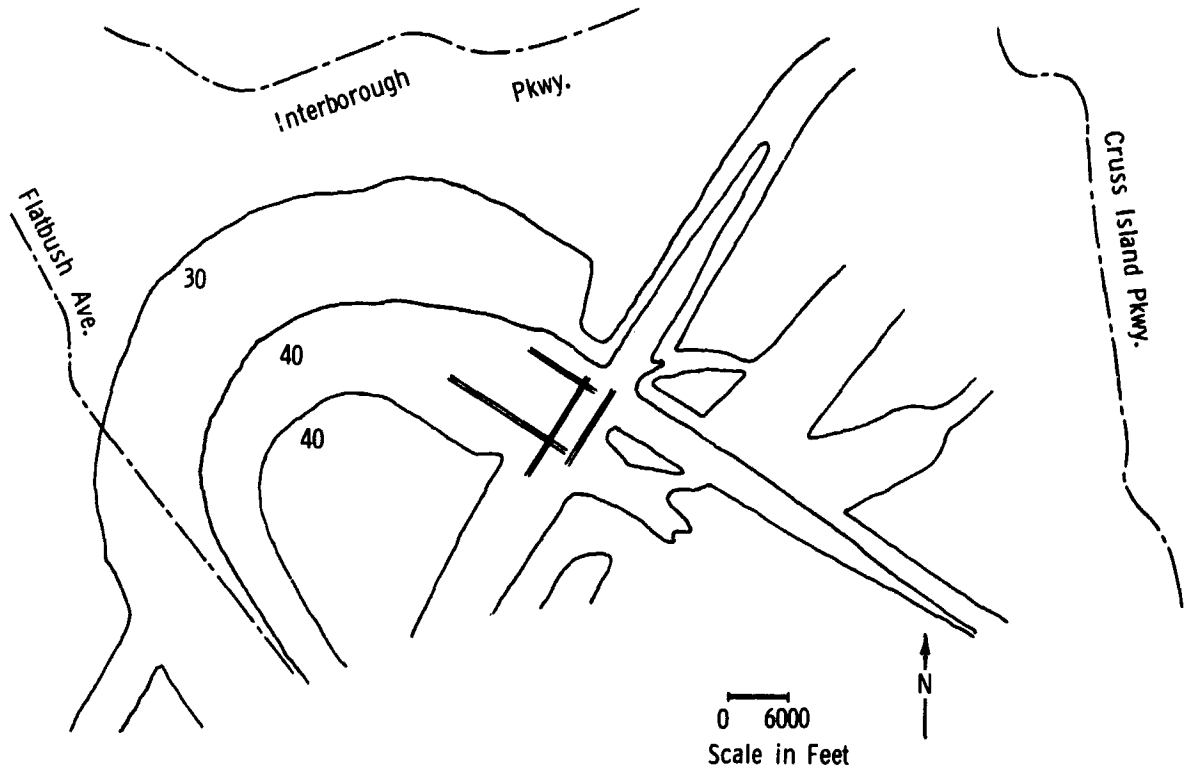
On the other hand, the noise levels at small and medium size airports during the next 15 years can be expected to increase because of a significant increase in the number of operations and in the percentage of jet-powered aircraft, and (in some cases such as at Raleigh-Durham) an expansion of the airport itself.

General Aviation

The general aviation fleet as incicated in Tables 4.15 and 4.16 has grown at a rapid pace over the past 15 years and will continue to grow at an accelerated rate to at least 1985. What is more important than the total growth in the fleet from a noise consideration is the growing number of multi-engine reciprocating aircraft, turbo-prop and turbo-jet aircraft in and projected for the fleet. These aircraft are not major noise polluters at the hub airport since they are so much quieter than the commercial 2-3-4 jet aircraft, but they can be the main source of noise at smaller airports which have historically catered to the prop type aircraft. Thus even though the new private jet planes may generate lower noise levels on take-off and landing than the big jets, the will significantly increase the usually lower noise levels at the general aviation airport. For instance a Lear jet on sideline and approach generates 98 EPNdB and on takeoff 95 EPNdB. FAA certification noise levels are 102 EPNdB on approach and sideline, but only 93 EPNdB on takeoff for an aircraft of the Lear weight class. At the Morristown, New Jersey, airport, for example, where an average of four company jets a day land or take off, a court-imposed curfew prohibits nighttime use of the facility by jet aircraft. The ruling judge further deplored the flying habits of the corporate jet-jockies.

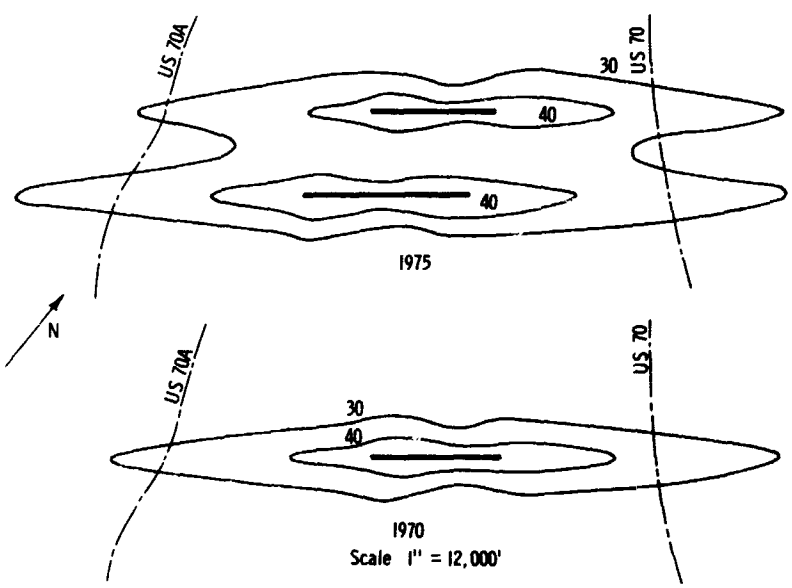
This section examines general aviation noise problems at existing or planned utility airports, as it is here that general aviation noise effects may, if not controlled, reach a pollution level.

Figure 5.5.



Source: **Noise Exposure Forecast Contours.**

Figure 5.6. Noise Exposure Forecast (NEF) Contours for 1970 Operations at John F. Kennedy International.



Source: Bishop and Horonjeff, **Noise Exposure Forecast Areas.**

Figure 5.7. Noise Exposure Forecast (NEF) Contours for 1970 and 1975 Operations at Raleigh-Durham (North Carolina) Airport.

The Noise Exposure Forecast (NEF) as discussed previously is a computational procedure which takes into account peak noise level, duration, pure tone corrections, number of events and time of day. While the exact calculation of NEF contours requires a computer to analyze a real airport situation, an estimate in the changes in area enclosed by a given NEF contour level can be made by the following simplified calculation procedure, assuming that:

1. The shapes of the PNdB contours are similar for all three types of general aviation aircraft.
2. The piston twin and the single engine piston have PNdB values 12 and 18 respectively below the business jet.
3. A time duration correction is made of -3 PNdB.
4. The number of night and day operations are chosen such that they have equal NEF weights.

Using these assumptions, a PNdB contour which corresponds to a given NEF contour can be determined graphically for a given mix of general aviation aircraft and given level of operation. The expected change in the NEF 30 contour around a general aviation runway, assuming aircraft mixes corresponding to expected 1970 adn 1985 national averages, is shown in Figure 5 8. Also shown in this figure is the magnitude of the NEF 30 contour if the operations at the airport became exclusively fan jet as has become the case for air carrier ports.

Air Cushion Vehicles

Air cushion vehicles (frequently called Hovercrafts) are part airplane, part ground vehicle and part ship in that they ride on a cushion of air and are capable of moving over both land or water. To date they have been used and developed for commercial applications primarily in England and for military purposes by the United States in Vietnam. Updated versions of the Hovercrafts are the Hovermarines which utilize a rigid sidewall and marine propeller, with carrying capacities up to 125 tons and speeds in excess of 35 knots. The noise generated by this class of vehicles is significantly less than the air propeller-driven early versions. Another recent development in air cushion vehicle (ACV) technology is a semi-amphibious Hovercraft (the VT1). Its marine propeller drive produces lower noise levels, and its segmented flexible sidewall and propellers protected by landing skids enable it to land on beaches to discharge its passengers.

Passenger applications of these vehicles in the U.S. have been limited to a few subsidized experiments. The most extensive trial, using a Bell SK-5 propeller-dirven craft, was a regularly scheduled service across San Francisco Bay linking San Francisco International and Oakland Airports. Throughout its trial period it never carried enough passengers to pay its own way. One reason for its failure was the high noise level (110 dB) in the passenger compartment.

This class of vehicles usually does not create a community noise problem since its normal operation is over water. Its noise level (110 dB at 50 feet) could become a problem, however, if it were used on the smaller inland waterways or if an extension of the concept, the tracked air cushion vehicle (TACV), discussed later in this report, is placed in operation.

Surface Vehicle Noise

The noise generated by road traffic depends on many factors; the most obvious being the number, type, speed, and condition of vehicles using a given

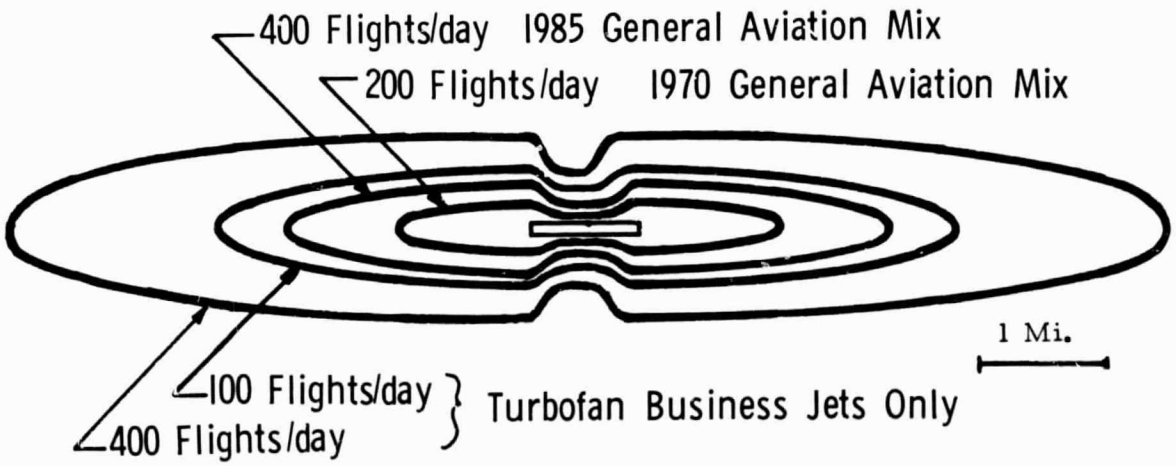


Figure 5.8. NEF 30 Contours for Smail General Aviation Airport.

road. This section discusses the noise characteristics of today's trucks, passenger card, buses, sport cars, and motorcycles.

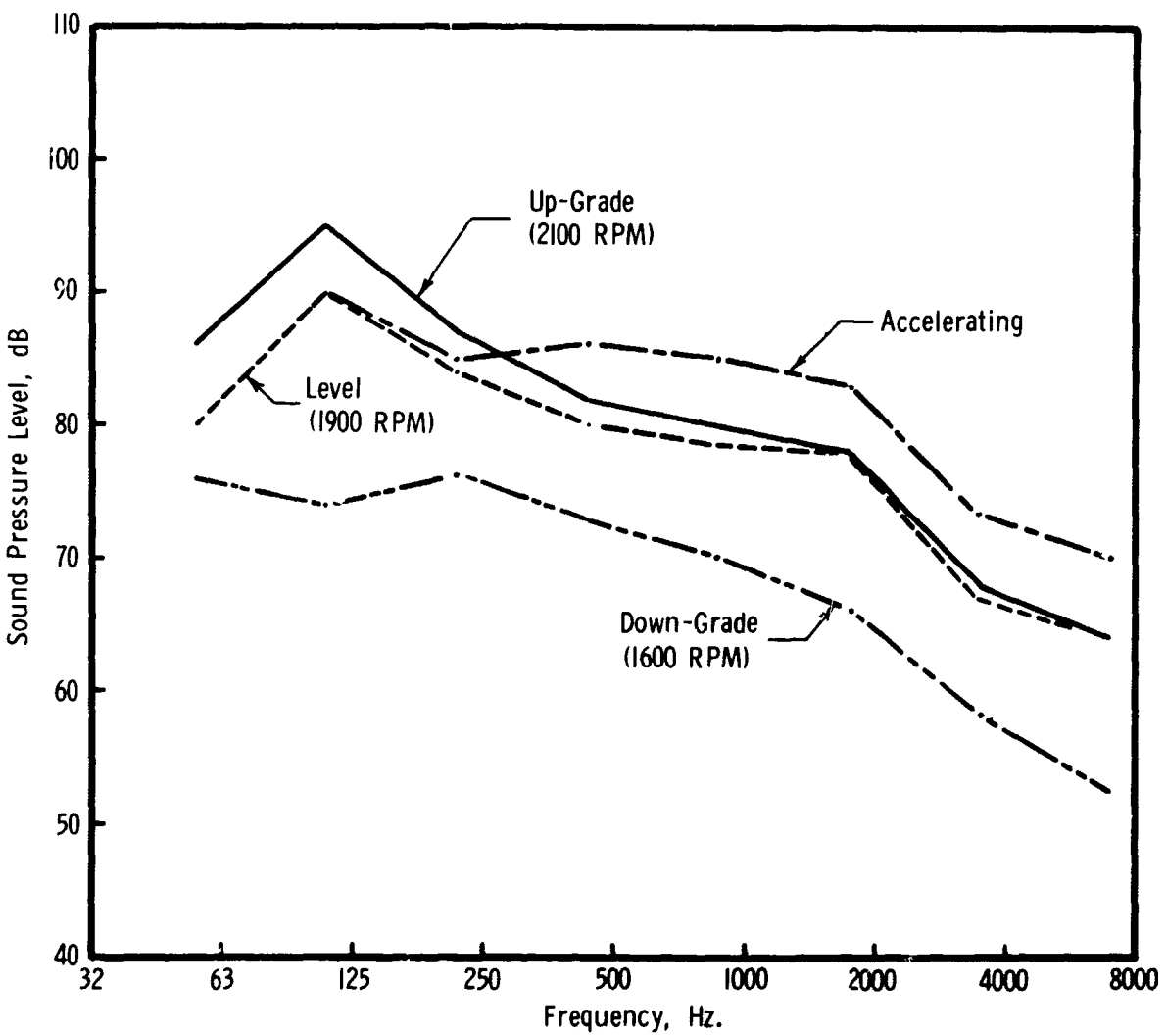
Trucks

In response to demands for versatile freight transportation, the number of trucks in use has increased from 7.5 million in 1950 to 14.9 million in 1967 [100] and 17 million in 1968. [28] Internal-combustion engines, gasoline and diesel, are almost exclusively used in today's trucks and will no doubt continue to be for the next 15 years. Gasoline engines powered 97.5 percent of the trucks in 1968, and diesel engines the remianing 2.5 percent.

The present truck fleet is proportioned by age as follows: 28.7 percent greater than 10 years old, 28.7 percent between 5 and 10 years old, 15.6 percent between 3 and 4 years old, and 27.0 percent less than 3 years old. This has a twofold significance for noise considerations: the noise level of trucks increases with age, and with almost 60 percent of the operational fleet more than 5 years old, the lag time between the introduction of new, quieter vehicles and the phasing out of the old would be 5 to 10 years.

Noise signatures indicate that diesel trucks are approximately 8 dB(A) louder than gasoline powered trucks, and 12 to 18 dB(A) louder than automobiles. [28] This implies that diesel exhaust noise (resulting from ineffective muffler design) is a prime source of excessive noise in trucks. The application of effective muffler design to diesel trucks could easily reduce this exhaust noise to acceptable levels and remove one of the major sources of traffic noise.

Noise spectra from a diesel truck are shown in Figure 5.9. The lower curve is taken as the truck



Source: Galloway, **Highway Noise.**

Figure 5.9. Noise Spectra at 50 feet from a Loaded Diesel Truck.

coasted on a down-grade and therefore is an indication of the tire noise. The increases in noise associated with acceleration, climbing an up-grade, and level operations are due to the increased exhaust noise as the engine is loaded. The difference in tire noise and exhaust noise as indicated in Figure 5.9 is subjectively very great, with the exhaust noise effectively masking the tire noise.

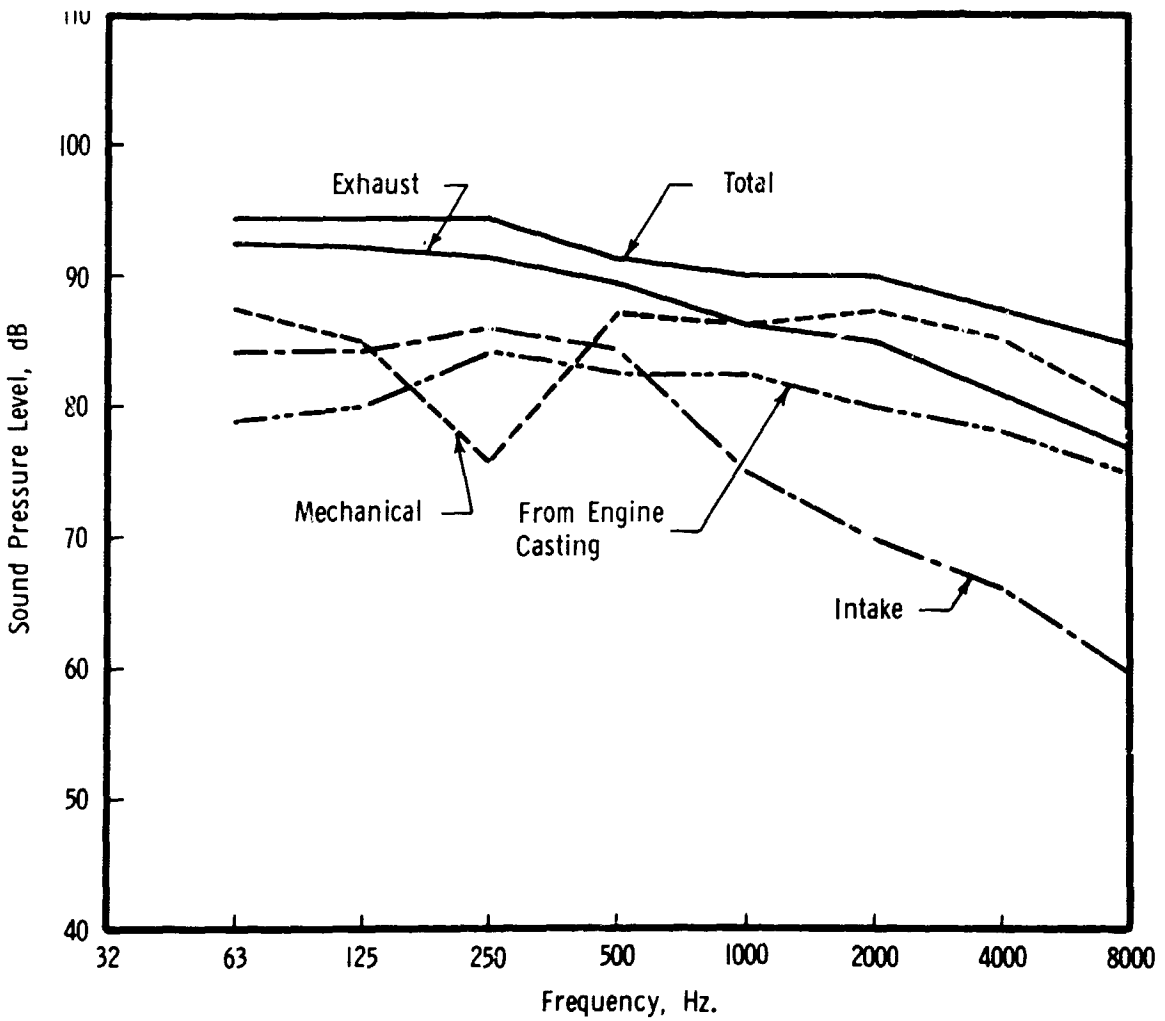
The variation of Perceived Noise Level with distance from the vehicle (Figure 3.9) shows that a reduction in speed has less effect on the noise level generated by trucks than passenger cars.

The contributions of the various engine components to the total noise from an internal combustion engine are shown in Figure 5.10. The loudest ingle source of noise is exhaust.

Automobiles

From 1950 to 1967, the number of automobiles in use increased from 36 million to 77 million [100] while the number registered increased from 49.3 million to 98.0 million. [112] It is projected that the number in use by 1985 will be around 135 million. [81] Today's automobiles are almost exclusively driven by internal-combustion engines, which produce a major share of urban air and noise pollution, but less pollution per vehicle than yesterday's and they will no doubt improve in the near future.

Of the total number of automobiles in use, 32.5 percent are under 3 years old, 61.7 percent under 5 years old, and 81.7 percent under 8 years old. [100]



Source: Broch, **Acoustic Noise Measurements.**

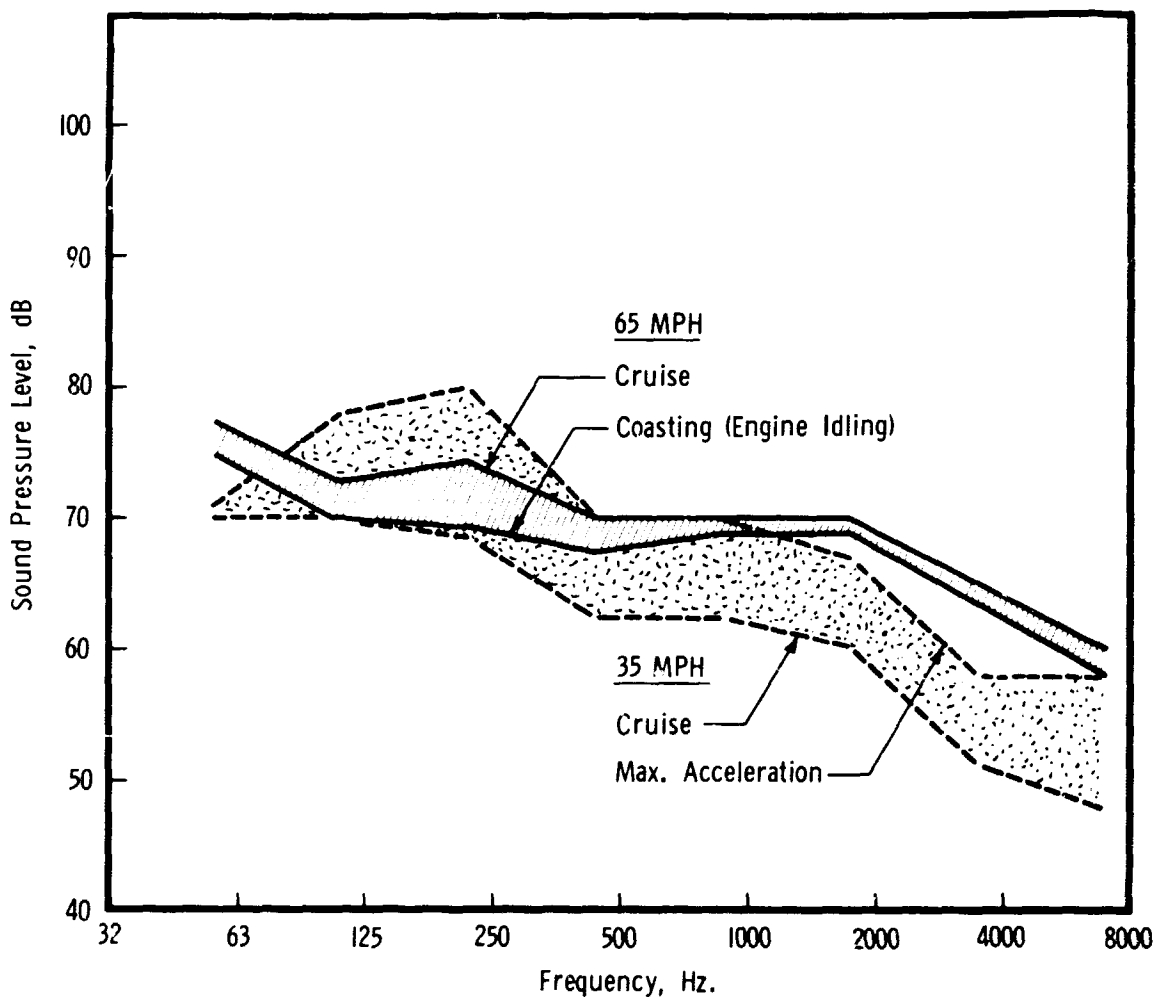
Figure 5.10. Total Noise from a Combustion Engine and Contributions of Various Engine Components.

For vehicle speeds between 30 and 60 mph there is typically a 5 dB(A)increase, at 25 feet, in the drive-by noise produced by a two-year-old vehicle over that produced by a new vehicle. [45] This is probably due to a general deterioration of the exhaust system and the response of the vehicle to pavement roughness.

The noise emitted by individual automobiles has several components: exhaust, intake, mechanical vibrations, fan, and tire-roadway interface. At 60 mph, today's passenger cars generate from 66 to 72 dB(A) in tire noise, and, depending on the acceleration, from 75 to 90 dB(A) in engine noise. [24] Noise generated by automobiles increases with cruising speed from 20 mph and up due to increasing tire noise. [48] For comparison, it would take 30 cars generating noise levels of 67 dB(A) each to produce a noise level generated by a single truck at 82 dB(A). [45]

Noise generated by mechanical vibration increases with frequency up to 2000 Hz and generally decreases in the higher frequency bands. Fan noise is not considered significant, particularly with the disengaging fan available in most cars. Tire noise increases uniformly with speed over the entire frequency range; for every doubling of vehicle speed the noise level increases by approximately 12 dB.

While automobiles are not as noisy as trucks, buses, and motorcycles, their total effect on traffic noise is significant because of their large number. The characteristic noise spectral distribution for automobiles is shown in Figure 5.11, for two vehicle speeds. At 65 mph the difference between the coasting and cruise condition, 3 to 5 decibels, indicates the relatively small contribution of engine and exhaust noise. The greater difference at the lower frequencies suggests the presence of low frequency exhaust noise.



Source: Galloway, **Highway Noise.**

Figure 5.11. Noise Spectra at 25 feet from Six New Passenger Cars.

For the slower 35 mph speed, tire noise is much less, and engine noise predominates over the entire spectrum. This suggests that the major variations in noise from passenger cars could be expected to occur when accelerating from rest at intersections instead of on the open road. [45] Different roadway surfaces (very smooth asphalt to concrete) can vary the tire noise in the 2000 to 4000 Hz range by as much as 8 dB. [45]

Buses

As of 1968 there were 351,804 buses operating in the United States, 286,062 powered by gasoline engines and the remaining 65,742 powered by diesel engines. [28] Truck and bus engines share basic characteristics and design developments so that many of the same recommendations for truck engine noise reductions can be essentially carried over and applied to buses. The differences in buses are due to demands for a lower interior noise level (quieter engines, tires, and better mufflers), smoother ride (fewer gear changes and automatic transmissions), and increased reliability (two engines).

Sports Cars and Motorcycles

The sports car and the motorcycle have often been singled out as prime sources of offending traffic noise. Motorcycles in particular produce noise levels entirely out of proportion to the number of passengers that they carry. In 1966 there were a reported 1.7 million motorcycles [28] in the U.S. and an unknown number of automobiles classified as sports cars. Both almost exclusively employ the gasoline internal combustion engine although many Japanese motorcycles imported into the United States utilize a 2-stroke engine instead of the usual 4. The engine size of motorcycles varies from small to something larger than that found in some compact and sports cars. Table 5.1 lists some of the various motorcycle makes, engine size, and type, and the noise level experienced with two different mufflers. For both standard and modified mufflers, no particular correlation exists between the engine and the noise output. Even the smallest motorcycle is capable of disturbing all the families within each residential block that it passes through. In practice the exhaust muffling varies greatly from manufacturer to manufacturer, and varies even more when in the hands of the user. [45]

Typically motorcycle tire noise increases with speed from 60 dB(A) at 35 mph (measured at 50 feet) to 70 dB(A) at 65 mph. The engine noise also increases with speed from 77 dB(A) at 35 mph to 90 dB(A) at 65 mph. [28]

Sports car tire noise is less than the tire noise from the heavier passengar cars and is around 62 dB(A) at 65 mph. Engine noise from sports cars increases with speed and is considerably greater than tire noise. At 35 mph it is approximately 61 dB(A) and at 65 mph, 73 dB(A).

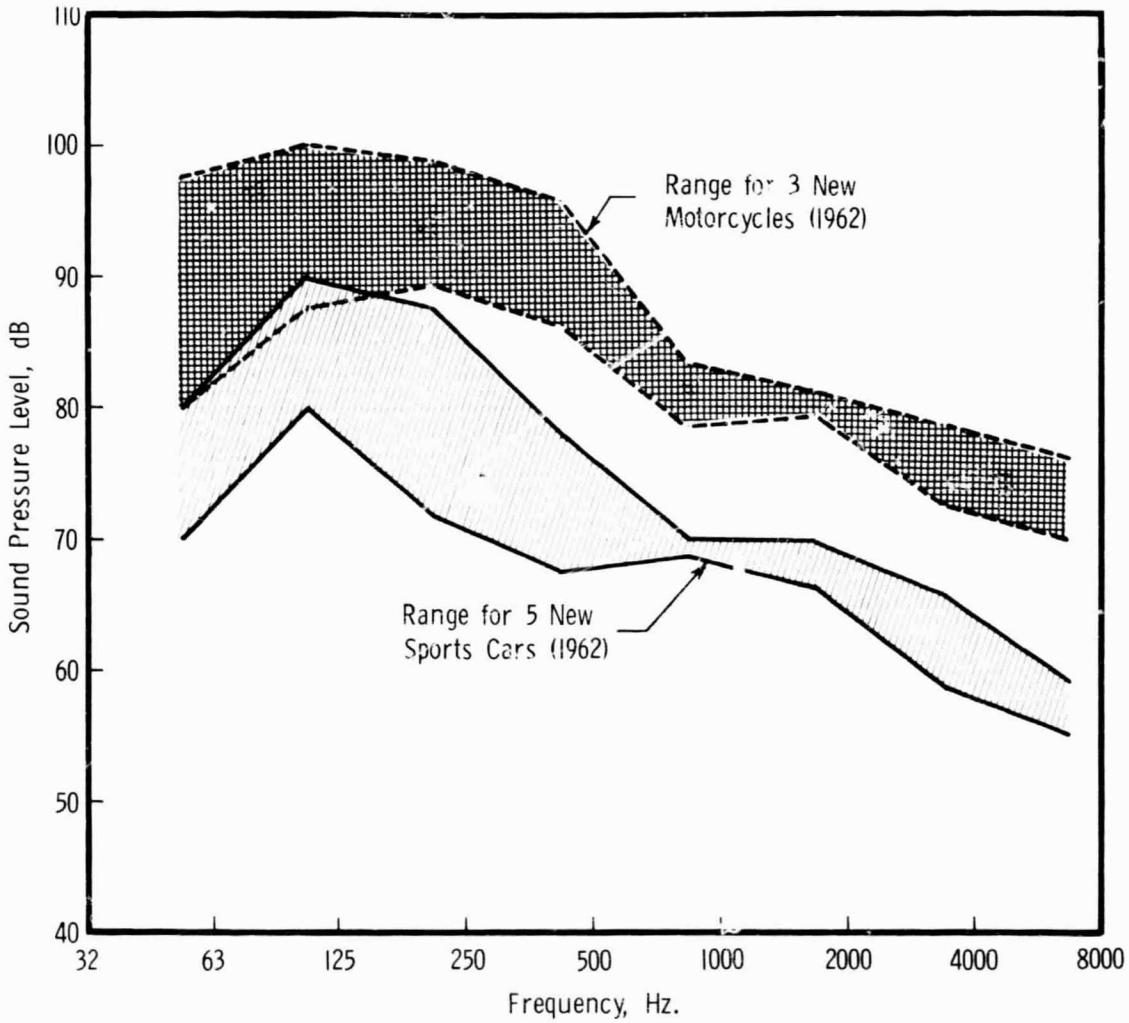
MOTORCYCLE NOISE LEVELS [28]
ISO R362-1964 TEST

Motorcycle				Maximum Noise Level dB(A) at 50 feet	
Make	Displacement	Cylinders	Stroke	Standard Muffler	Modified Muffler*
Harley-Davidson	1200 cc.	2	4	96	103
B.S.A.	650 cc.	2	4	96	96+
Honda	175 cc.	2	4	90	90+
Suzuki	250 cc.	2	2	87	90
Yamaha	250 cc.	2	2	82	100
Suzuki	120 cc.	1	2	81	90
Honda	90 cc.	1	4	79	82
Suzuki	80 cc.	1	2	78	88
Honda	65 cc.	1	4	74	90

*An interior baffle tube was extracted in all cases, except the Harley-Davidson, where "straight-through" tail pipes, a standard accessory item, were fitted.

Table 5.1

Figure 5.12 indicates the noise spectra for motorcycles and sport cars, measured at 25 feet and 65 mph. These spectra are characteristic of exhaust noise where the majority of noise is generated in the low frequency range. The noise produced by motorcycles and sports car exhaust systems is such that it almost completely masks the tire noise.



Source: Galloway, **Highway Noise.**

Figure 5.12. Illustrative Noise Spectra for Motorcycles and Sport Cars (25-ft. distance, 65 mph speed).

Railroads

To date, complaints about railway noise have been relatively few in number. A recent London survey to determine which noises disturb people at home, outdoors, and at work revealed that train noise ranks a distant third behind road traffic noise and aircraft noise. Only 5 percent of the persons questioned considered train noise disturbing at home; one percent complained of train noise while outdoors; and no one considered train noise disturbing at work.

A major rebirth of passenger rail travel is being considered by the Department of Transportation in its Northeast Corridor study ; ojec High speed rail transportation, perhaps by turbine-po ed locomatives, may well raise the volume of public complaints and stress the need for effective muffling of railroad noise.

The rolling stock inventory in Chapter IV (Table 4.9) enumerates mobile rail noise sources in

the U.S. Unfavorable economic conditions in the rail industry and tight anti-inflationary economic policies have severely curtailed purchases of additional rolling stock. The sizeable reduction of passenger cars reveals the accelerating demise of rail passenger service. Although the number of freight cars has been dropping, railroad revenue-ton-miles have been growing over the past decade primarily because the average size of a freight car has increased from 70 to 80 tons. [78] Also, the average speed of American rail lines is rising as locomotive power increases (from the 1700-2000 horsepower range in 1959 to 3300-3600 hp in 1970). It is estimated that this power will have to grow by 50 percent by 1975 to maintain present train schedules. [78] Since track noise levels rise by 9 dB with a doubling of speed, a continued emphasis on both size and speed can be expected to increase railroad noise levels.

Studies indicate that the overall sound level of diesel trains at 30-40 mph is approximately 90 dB for a receiver 100 feet from the track center-line. [7] The fact that these high noise levels are typically in the low frequency ranges may partially explain the low volume of complaints against rail noise since it is high frequency noise which is more annoying. Noise levels, of course, vary considerably depending on the size and speed of the train, the type of equipment used, the distance between source and receiver, the path through which the noise travels, and other variables.

Present data show that propulsion and track noise are the principal forms of outdoor noise generated by rail systems. The Department of Transportation has determined that train whistle noise ranges from 118 dB at 25 feet from the source to 95 dB at 200 feet. [7] The third leading form of railroad noise is ground vibration noise transmitted to buildings adjacent to the rail site.

Snowmobiles

A recent entry into the winter recreation business in many states, snowmobiles were introduced in 1958 and have increased in speed and power over the years. The early vehicles had 7 horsepower engines and speeds of 30 mph. Some 1970 models have engines of 32 hp and speeds over 100 mph (Figure 5.13). Increase in horsepower has brought increased

Source: Evinrude Motors.

Figure 5.13. 1970 Evinrude "Skeeter" Snowmobile.

noise which is further increased in many instances when the owners remove the factory-installed mufflers to obtain more power. In many instances this results in less power and more noise. [118] Some manufacturers have recognized the severe impact that snowmobiles have had on the ecology and have even established specific departments for the purpose of eliminating the deleterious environmental effects of their products. All too often, however, the senseless operators have been responsible for the poor reputation of these vehicles.

The measured noise levels of the 1970 models are approximately 82 dB(A) at 50 feet (96 PNdB). The fact that early models produced 100 dB(A) at 50 feet indicates the manufacturers' concern for the noise problem.

The noise of the snowmobile can be attacked several ways. Probably the most effective is for the states to legislate a maximum noise level for any new snowmobile sold in that state, and to require maintenance of the vehicles to prevent increasing noise levels with use. Minnesota has set a maximum level of 86 dB(A) measured at 50 feet for any snowmobile offered for sale after June 30, 1970, and further requires that all snowmobiles in use in the state have a muffler in good operating condition. Such legislation stimulates manufacturers to apply effort and engineering talent (which probably would not otherwise be applied) to suppress noise. The manufacturers can meet the legislated noise levels by bonding sound-absorbant materials to the inside of the engine hood and by optimizing the engine-muffler system. The Donaldson Muffler Company advertises that their tuned muffler can bring exhaust noise down to 82 dB(A) this year and 75 dB(A) (the goal of the snowmobile industry) eventually. At 75 dB(A) track noise would be the largest noise contributor.

Water Transportation

Commercial

The inland waterway fleet does not significantly contribute to community noise. The prime noise problem is onboard the towboats themselves. Measurements on a river barge towboat have shown levels of 101-112 dB(A) in the engine room, 94-98 dB(A) in the steering room and 73-78 dB(A) in other rooms. [24]

Private

The increasing number of motorboats used for recreational purposes has been shown previously. Noise levels at a 50-foot distance for pleasure boats at cruise speed range from 65 to 95 dB(A) with the mean value being 73.5 dB(A). [22] These figures describe approximately equal numbers of outboards, inboard-outdrive, and inboards at operating speeds of 10-30 mph. In nearly all cases the major source of noise was the engine and its exhaust which indicates that the operator is subjected to a high noise level. Measurements made onboard many pleasure boats ranged up to 104 dB(A) in a 15-foot open boat with a 35-hp motor at maximum speed. [21] This study concludes that at cruising speeds the noise level onboard lies in the 73-96 dB(A) range, significantly above the speech interference level and approaching the hearing loss level, for significant exposure times. The operators of racing boats using tuned mufflers are exposed to noise reaching 130 dB(A) which is equivalent to a jet plane at 50 feet. At a distance of 50 feet spectators to speed boat races are exposed to noise levels in excess of 119 dB(A).

The noise of pleasure boats is not so much a community problem as an operator problem, but with the rapid increase in boating enthusiasts, such noise may become a community problem unless some steps are taken to abate engine and exhaust noise at the source.

Traffic Noise

The noise eminating from a roadway is a cacophony from the moving stream of many different types of vehicles. Study of individual vehicles presents useful information about maximum noise levels and noise abatement possibilities, but provides little information about the sounds a listener will hear a given distance from an actual roadway.

Road traffic may be free flowing or congested. Vehicles in a free flowing stream move at relatively constant speeds, and there is little interaction between vehicles. Congested traffic is characterized by stop-and-go movement and considerable interaction. Particularly irritating congestion noises are due to acceleration, gear changes, braking, and horns. The sounds are often accentuated in local areas by reflections from buildings and walls near the roadway. Indications are that congestion does not increase the mean level of free flowing traffic noise, but it does increase considerably the number and magnitude of the peak noises in the traffic stream. These peaks are most apparent near the roadway.

The noise from freely flowing traffic has more often been measured, and procedures are available to estimate it for particular roadways. The noise of free flowing traffic and the effects of changes in several traffic parameters is shown in Table 5.2. The base example assumes a traffic volume of 1,000 vehicles per hour each way at 25 mph; no trucks; no attenuation due to buildings or trees; a level arterial highway with 2 lanes each way and no median strip. No allowance has been made for ambient noise other than traffic noise since it would add little to the levels indicated.

Free Flowing Traffic Noise						
Case	Distance from Edge of Highway To Selected Noise Level					Noise Level at 100 Ft. Distance in dB(A)
	80dB(A)	75dB(A)	70dB(A)	65dB(A)	60dB(A)	
1. Base Case				30 ft.	70 ft.	59 dB(A)
2. Volume Doubled			25 ft.	60	160	62
3. Speed Doubled, i.e., 50 mph with base case separation		30 ft.	70	190	400	68
4. 20% Trucks	50 ft.	140	300	650	1500	76
5. 20% Trucks 5% Grade	70	200	500	1000	2200	79
6. Volume Doubled with 20% Trucks	100	220	470	1000	2500	80

Table 5.2

A highway with 6 lanes, carrying 10,000 vehicles per hour of which 5% are trucks, at a speed of 40 mph would generate a median noise level of 70 dB(A) at a distance of 300 feet from the highway. Figure 5.14 illustrates the effect of one such highway crossing over another. No provision has been made in the contour calculation for the effect of elevating or depressing one or the other of the highways to allow the crossover, or for connecting ramps. Note that the 70 dB(A) line moves considerably further away from the highway than for the single road, demonstrating the increased noise produced by the confluence of high speed roads. The addition of connecting ramps would increase noise levels, as these ramps are curved and often at steep grades. Tire squeal and acceleration noise would thus be added to the already high level of traffic noise. The area where the median sound level is greater than 70 dB(A) has been identified as "the maximum limit of exposure in a residential area before public complaint ensues," [5] but in this figure the contours describe median levels, not maximum limits. The median level of 70 dB(A) to indicate public reaction is perhaps conservative. In several of the cases considered in this section, the 70 dB(A) contours fall further than 300 feet from the road. Many residences lie within this distance near urban arterials and freeways.

The data shown here are meant to be suggestive rather than descriptive of actual situations. The road designer or real estate developer concerned about the noise that will be created by a proposed roadway will do well to investigate the detailed analytic procedures that are available. [65], [61], [45], [106]

Ambient Noise Levels

During the past 40 years urban transportation noise has increased so enormously that the term "ambient noise level" can be interpreted to mean steady-state transportation noise. [53] In certain noise pollution pockets, the ambient levels have increased at the alarming rate of 1 dB per year. [62]

Ambient noise levels can be important for a number of reasons. Annoyance and general dissatisfaction created by noise are strongly dependent upon the deviation of the noise level above the ambient level. [49] A deviation above the ambient of 15 dB(A) can initiate strong complaint while excursions of less than 5 dB(A) have little significance. [48] Planners, architects, and engineers who incorporate noise control into their design cirteria require information on average ambient noise levels, [33], [66], [90] Also, prediction of future levels of ambient noise can act as a measure for the overall seriousness of the problem of transportation noise, its relation to technological advances, and the noise control-abatement that would be most effective.

Because of the great amount of time, effort and cost of continuously monitoring noise levels at numerous sites throughout the metropolitan areas, few extensive noise surveys have been conducted. The outstanding exception is the recent work of Donley, [37] who compares the results of his community surveys to the comprehensive surveys conducted by Stevens [102] 15 years ago.

An alternative approach to obtaining community noise data consists in formulating an analytic-

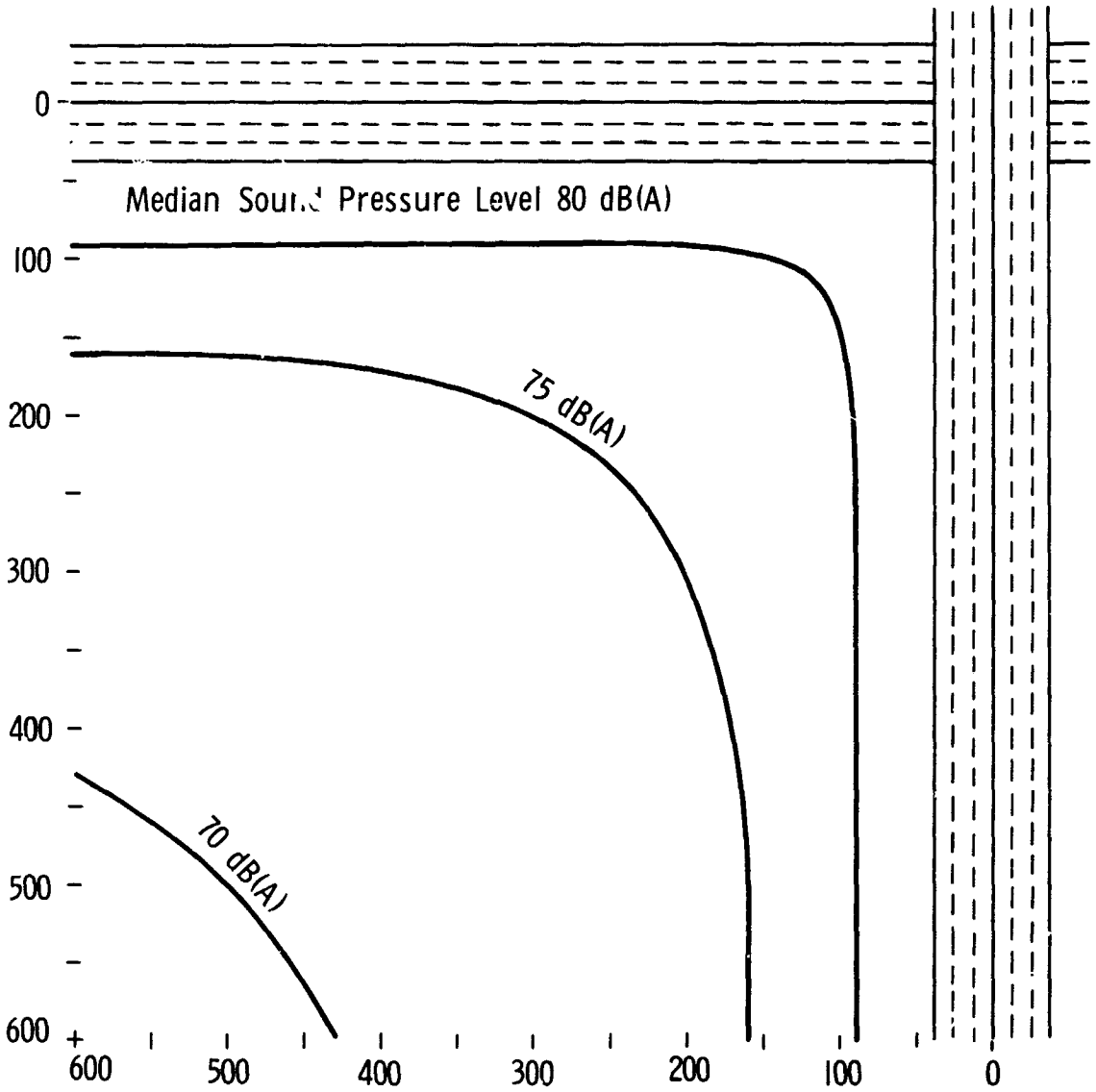


Figure 5.14. Median Sound Pressure Level Contours at the Intersection of Two Highways.
Traffic Flow: 5000 vehicles/hr in each direction on each road.
Traffic Mix: 5% Trucks
Traffic Speed: 40 mph.

al model which takes into account the major factors influencing noise in order to estimate the existing levels of ambient noise. The advantages of such a formulation lie in its inherent capacity to predict future levels of noise from existing trends and different possible mixes of transportation modes.

One such model for estimating past, present and future levels of ambient noise has been developed in Appendix G. Average ambient noise levels computed from Appendix G for metropolitan areas with initial population densities of 1000, 5000, and 10,000 people per square mile are shown in Figure 5.15. As noted, the ambient levels increase at a rate of about 0.4 dB(A) per year. The 5000 population density curve has been represented in Figure 5.16 to show the separate contributions of cars, light trucks, and heavier trucks. Although the heavier trucks comprise less than 5 percent of the total vehicle population, their total noise output is about equal to that of all the other vehicles combines. Compared to heavier

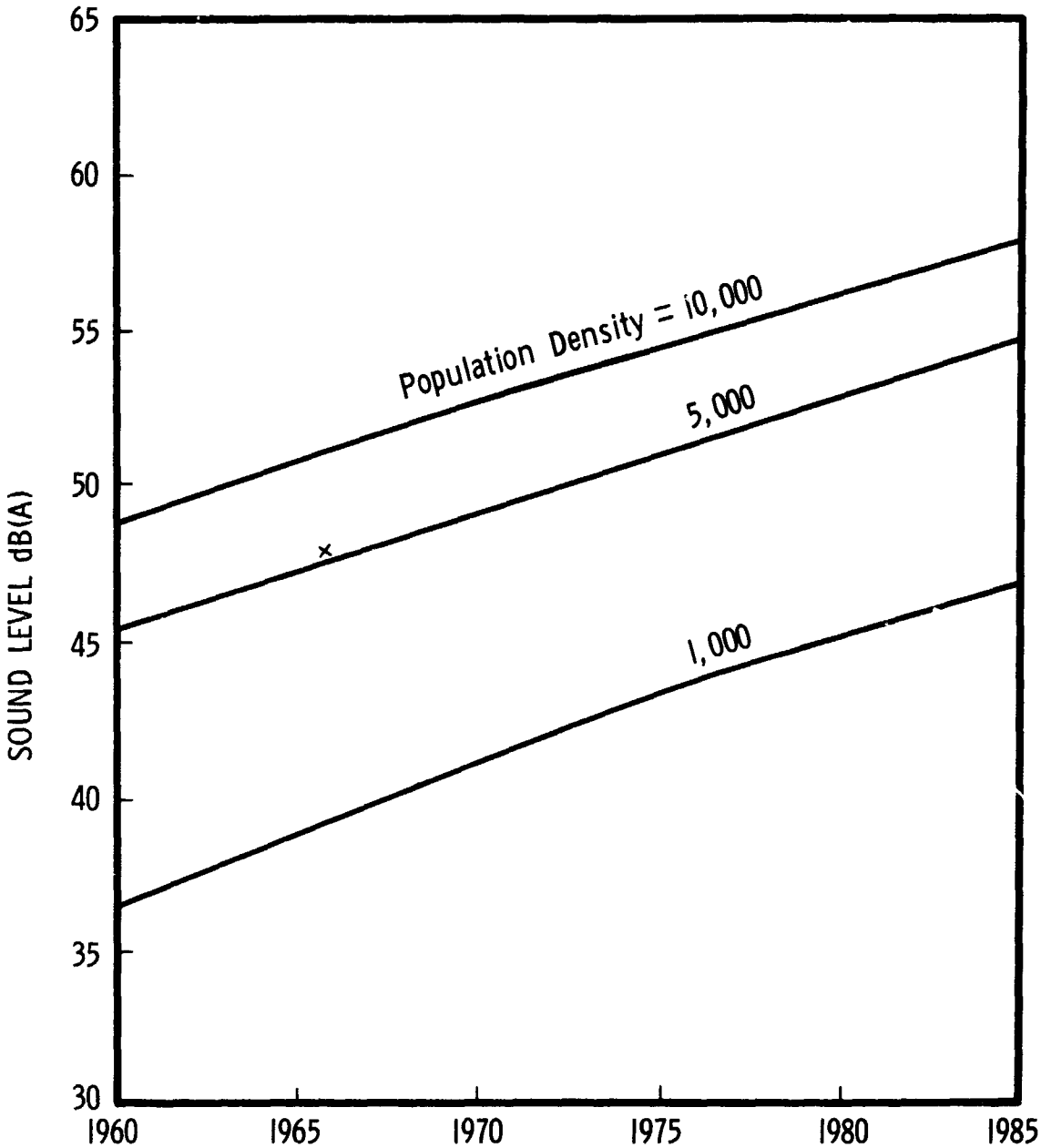


Figure 5.15. Ambient Noise Level for Three Different Population Densities.

trucks, the contribution from light trucks to ambient noise levels is extremely small. However, despite its relative insignificance, it is interesting to note that by 1985 the noise from light trucks alone will exceed the total level of noise produced by all vehicles in 1960.

The expected increases in levels of ambient noise agree with the community noise surveys of Stevens [102] and Donley [37] which find the median annual increase in ambient noise levels by octave bands to range between .3 and .7 dB. A source of empirical data that reports population density as well as ambient noise levels for a metropolitan area is a study by Thiessen [24] which reports that in Ottawa, with a population density of about 5,000 per square mile, the average ambient daytime noise level in 1966 was 48 dB(A). This experimental value, marked by the cross in Figure 5.15, corresponds to the value predicted by the theoretical curve for 1966.

A number of papers, including the Wilson report, [80] suggest that the 24-hour average ambient

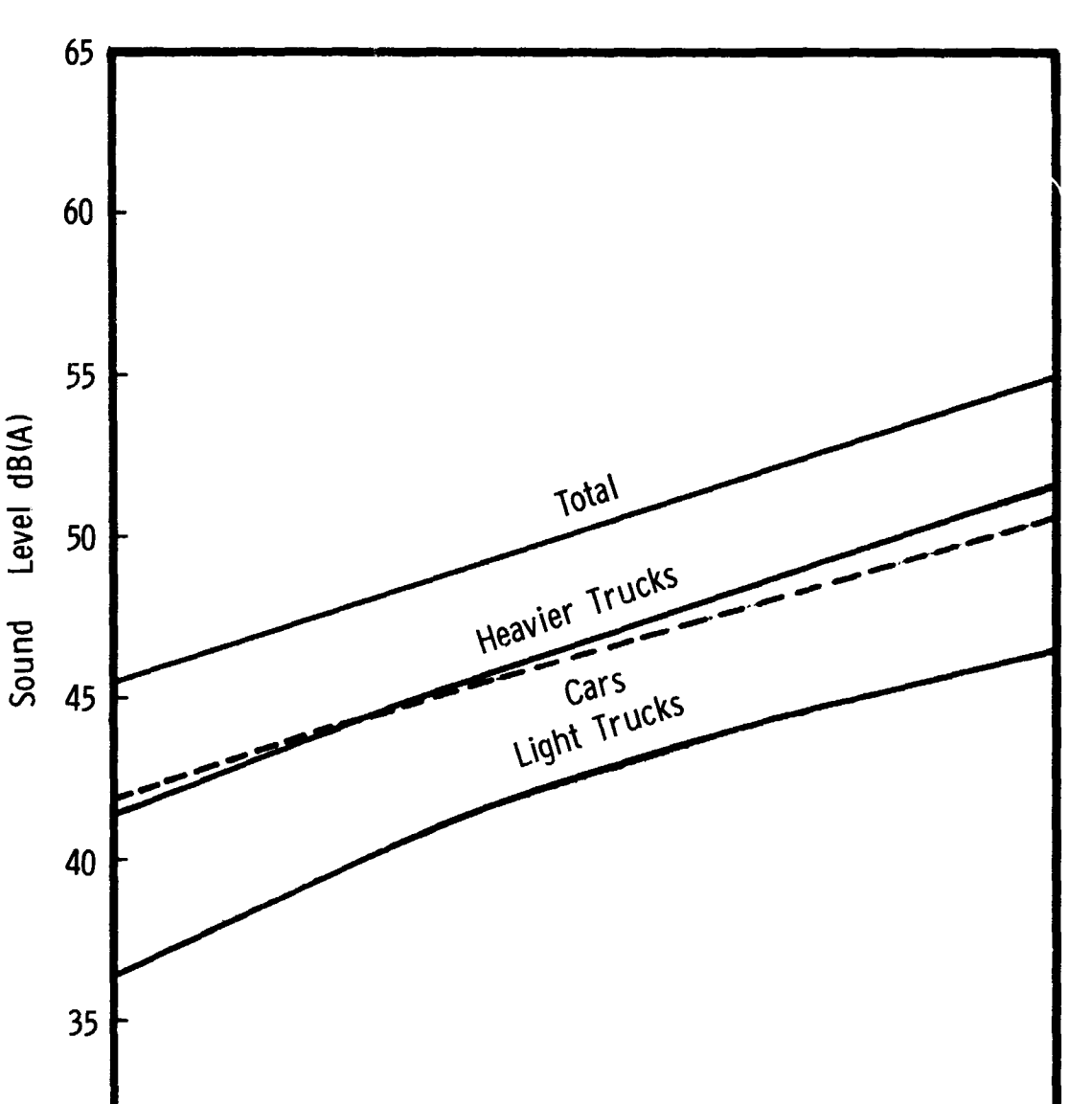


Figure 5.16. Contribution of Separate Vehicles to Ambient Noise Levels, Assuming a Population Density of 5000 in 1960.

noise level that should not be exceeded, or at which appreciable percentages of individuals are considerably disturbed, is 55 dB(A). Extrapolating the curves of Figure 5.15 to reach a value of 55 dB(A) in 1960 shows that only areas containing 30,000 or more people per square mile received average ambient noise levels higher than 55 dB(A). However, in 1985, all areas with population densities greater than 5,000 people per square mile in 1960 will receive average ambient noise levels higher than 55 dB(A).

Extrapolation of the city population figures tabulated in the Statistical Abstracts [100] implies that populations in the U.S. living in areas exposed to "disturbing" levels of average ambient noise will quadruple from 1960 to 1985. This agrees with the London surveys of 1948 and 1961 which showed that the number of people disturbed by external urban noise more than doubled in the 13 years. [80]

NOISE ABATEMENT POTENTIAL

Aircraft

Methods for the control and abatement of noise from aircraft operations include reduction of aircraft noise at the source, aircraft/airport operational procedures, and reduction of aircraft noise at the receiver. Each of these will be discussed in more detail.

Reduction of Aircraft Noise at the Source

While early retirement of current aircraft—especially the noisy turbojets—is one possibility for abatement, it may be undesirable from an economic standpoint. The brightest ray of hope lies with future engines and aircraft in essentially three areas: acoustical retrofit, quiet engine, and airplane design.

Retrofit

The NASA Acoustically Treated Nacelle Program attempted to reduce fan noise radiating from the inlet and the discharge ducts of 4-engine turbofan aircraft by treating the nacelle (the shell surrounding the engine) with sound absorbing material. Independent studies were carried out on both Boeing and McDonnell Douglas on 707320B and DC-8-55 aircraft. The important results obtained from these studies are summarized in Table 5.3.

Quiet Engine

The NASA Quiet Engine Program aims at designing a new high-bypass-ratio turbofan engine with takeoff and approach noise levels significantly lower than those of the current JT3D and JT8D engines, but compatible with the Boeing 707 and McDonnell Douglas DC-8. An up-to-date progress report [76] indicates that the desired reduction of approximately 15 PNdB and probably more will be achieved, and with the addition of acoustically treated nacelles, takeoff and approach noise levels can be reduced to about 94-95 PNdB.

The Quiet Engine Research Program is to be completed sometime during 1973. Even though the results look very promising for the next generation of aircraft, the airlines are not expected to re-engine current aircraft with the quiet engine because of the high cost, estimated to be about $6 million per 4-engine aircraft.

Airplane Design

Proper design of the wing and fuselage structure of an aircraft should shield the ground observer from some of the engine noise. In such aircraft the engines would probably be located above rather than below the wing, aiding aerodynamic performance but creating a problem with high-temperature exhaust gases weakening the wing structure. Unfortunately, this type of design is believed to be most feasible for small, rather than large, aircraft. [59]

NASA Acoustically Treated Nacelle Program [75]

Variable	Boeing	McDonnell Douglas
Reduction of Approach Path Noise (3° approach at 1 n.m.)	15.5 EPNdB	10.5 EPNdB
Range Effect	200 n.m. loss	150 n.m. gain
Weight Penalty	3140 lb.	332 lb.
Cost of Retrofit per Aircraft (300-400 aircraft)	$1,000,000	$655,000
Increase in Direct Operating Costs	9.6 percent	4.2 percent

Table 5.3

This program achieved a significant reduction in approach noise (also a slight—3.5 EPNdB maximum—decrease in takeoff and sideline noise). However, the prospect of retrofitting current aircraft with nacelle treated engines remains in doubt because of the cost and weight penalties involved.

Aircraft/Airport Operational Procedures

A number of aircraft operations, some in use and others under consideration, can help alleviate the noise problem near airports. In some cases a system

of preferential runways, or perhaps judiciously chosen flight patterns, can be used to avoid flying over densely populated areas. Fortunately for those airports which are situated adjacent to a river, a lake, or an ocean, a natural flight path is provided. Some airports require a "reduced thrust takeoff," in which after a full-thrust takeoff and a steep initial climb, the aircraft climbs over heavily populated areas at a reduced thrust for some distance before resuming a normal climb. Using this procedure, a maximum noise reduction of about 10 PNdB can be expected at 3.5 n.m. from brake release. This procedure, however, subjects more people to a lower level noise as the aircraft is at a lower aititude for a longer period of time.

Under a proposed "two-segment" landing procedure, the initial approach angle is about 6°, in contrast to the conventional 3° approach. Then, at some as yet unspecified distance from the end of the runway, the standard 3° approach is adopted. In NASA studies, a reduction of 10 PNdB or more was achieved at 1½ n.m. from the runway threshold (and beyond) for profiles with an intercept altitude of 400 feet. [91]

In considering the above procedures—or, for that matter, any aircraft operational procedures—the important role which safety plays cannot be underestimated. If a choice between noise abatement and safety must be made, it should be recognized that safety comes first.

A number of airports have adopted partial curfews in an attempt to reduce nighttime aircraft noise. Heathrow (London) Airport limits operations of jets between 11 p.m. and 6 a.m., while Toronto International Airport forbids newly scheduled turbojet flights between 12 a.m. and 7 a.m. At Washington National Airport no jets are permitted at night (and 4-engine jets are prohibited altogether), while a number of airports limit ground runups during the nighttime to a minimum. This is only a partial list of airports with some type of curfew—but if total nighttime curfews were established at all airports, some international flights would become impossible.

Reduction of Aircraft Noise at the Receiver

Good land-use planning and zoning can prevent the use of land near airports for residential areas, using it more wisely, for example, as an industrial site, a golf course, or a farm. The more serious problems occur in those areas near an airport where houses, apartment buildings, schools, and hospitals are now situated. Noise levels inside buildings near airports may be reduced by acoustic insulation or muffled by the background noise from air-conditioners. Outside of buildings, however, little can be done in reducing aircraft noise at the receiver.

Noise Abatement Potential: Trucks

As mentioned previously the exhaust noise of internal combustion engines is generally the largest single contributor to the over-all engine noise. Proper design of mufflers and exhaust pipes can significantly reduce exhaust noise levels. As shown in Figure 5.17, a diesel truck operated with (1) no muffler, (2) the stock muffler, and (3) a special experimental muffler produced corresponding 50-foot noise levels of 95 dB(A), 80 dB(A), and 78 dB(A). [45] With muffler design becoming more scientific, truck exhaust noise can be substantially reduced.

The noise generated by vibrating sheet metal parts can be reduced by a "sandwich" of 2 rigid steel layers separated by a thin viscoelastic damping layer. This can reduce the noise-producing vibration of a resonating steel plate by a factor of 30, with only an 18 percent increase in weight. [121] Fan noise can be reduced by aerodynamic design that insures smooth air flow with reduced turbulence. Fortunately, many vehicles today are equipped with fans that disengage at high engine speeds. The prime motivation for this (increased economy of operation, not noise reduction), points out the fact that noise abatement does not necessarily imply higher cost.

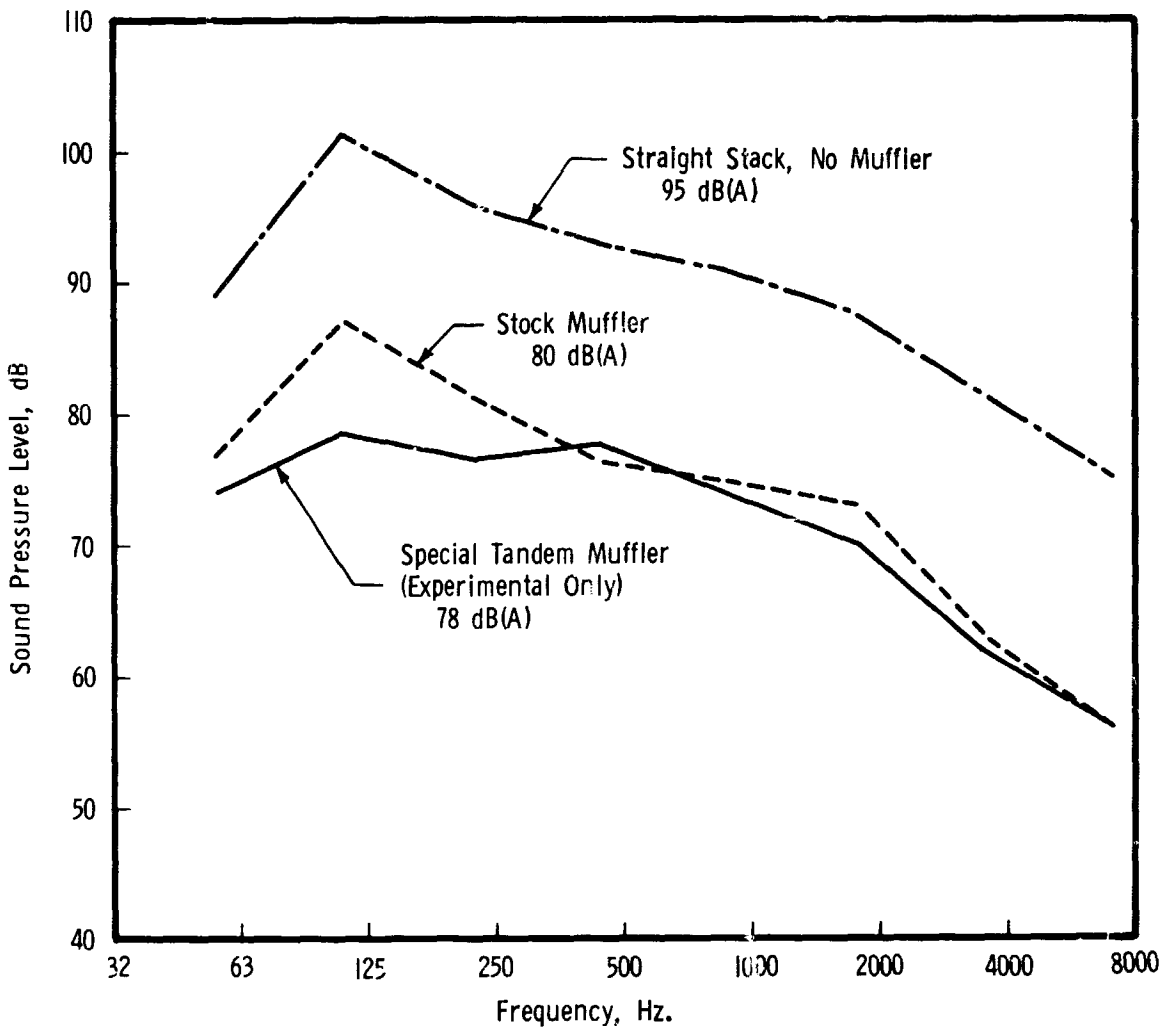
While tires need to be made quiet, it is more important that they be safe. Improved tread designs (for example, randomness of tread element sparing) has already reduced tire noise. Other considerations are important to the carrier, however, such as initial cost, tread life, wear characteristics, and traction.

Noise Abatement Potential: Buses

Noise abatement for buses should be very similar to that for trucks. Improved exhaust systems will particularly reduce noise in buses with diesel engines. [121] Another possible means of noise reduction for highway buses is streamlined body shapes, reducing the so-called "wind noise," which results from excitations in the turbulent boundary-layer, by streamlining the air flow, and reducing the load on the engine as a consequence of decreased pressure drag on the vehicle, resulting in a reduction in engine noise. This is likely only for buses in intercity service since slower local buses cannot profit from improved streamlining. (It might be noted that streamlined designs are judged impractical for trucks because of loading and unloading considerations.)

Noise Abatement Potential: Automobiles

Noise is presently one of the design cirteria for automobiles. The problem of passenger car traffic



Source: Galloway, **Highway Noise.**

Figure 5.17. Illustration of the Effect of Three Exhaust Configurations on the Noise Spectrum.

seems to result from overwhelming numbers, not the noise generated on an individual basis. A number of improvements would further reduce the noise. Mufflers could be improved, sound absorbent materials could be utilized more effectively (for example, as engine enclosures), and viscoelastic materials could be employed to attenuate the noise producing vibrations.

Noise Abatement Potential: Sports Cars and Motorcycles

The obvious means of effective noise abatement for sports cars and motorcycles is the use of higher standards for exhaust muffling. One notable exception is the 2-cycle engine which is susceptible to performance loss by effective muffling. The greatest problem in effective muffling of sports cars and motorcycles, however, seems to be the operator's association of engine noise with personal sex appeal. The annoyance associated with these vehicles is a result of the occasional peak they produce in an otherwise uniform background noise level treated by the flow of automobiles. Trucks, with their loud exhaust noise, have a similar effect but are generally judged to be more necessary and therefore somewhat less annoying.

Attenuating Rail Noise

The wide variations in rail noise levels suggest that the noise levels of some lines might be reduced A review of actual accomplishments in attenuating direct airborne and vibration noise emissions from rail systems clearly demonstrated that these reductions are possible. Several techniques can reduce track noise. Thorough grinding of pitted steel wheels and track have reduced noise levels by about 10 dB. [6] Substituting welded for riveted rail joint track reduces track noise about 8 dB and reduces costs by $12 per joint. Bay Area Rapid Transit tests of elastomeric damping materials on wheels have reduced wheel squeal occurring on sharp radius curves by 5-6 dB(A).

Elevated structures affect noise levels. The quietest type, an earthen embankment, is 30 dB quieter than the noisiest, a light steel bridge. Concrete bridges are only 6 dB noisier than the earthen embankment. Ballast between the cross ties and the structure may also reduce airborne noise slightly, but such barriers as walls and embankments are more effective, reducing noise up to 25 dB depending on barrier height and the distances between source and barrier, and receiver and barrier (Figure 5.18). Depressing the track in earthen cuts gives similar attenuation, but the depth of a cut must be greater than the height of a barrier to achieve the same results. A trench with sloped and planted walls combined with a partial roof has reduced noise by about 23 dB at 100 feet.

Trees and shrubbery are often mentioned as possible barriers, but studies show that hundreds of feet of dense trees are required for any sizeable attenuation. Land values along the right of way in urban areas would dictate against this method. The problem of whistle noise is under study by the Department of Transportation. Because the train's warning whistle must be heard inside a closed automobile with interior sound levels of 85 dB or more, railroads have historically increased the sound level of their whistles to combat sound dampening in automobile technology. However, DOT research is attempting to find a whistle frequency spectrum more audible to the motorist but less annoying to the community. Moreover, if high speed rail service eliminates most highway grade crossings, part of the whistle problem will thus be solved.

Railroads and subways also transmit low frequency rumbling sounds to nearby or overhead buildings. However, the City of New York remarkably isolated Philharmonic Hall from these vibration sounds to the extent that subway noise could not be heard even during the quietest portions of performances. In accomplishing this goal vibration isolation pads were inserted under all of the building's columns. In addition vibration isolation joints were inserted in many of the walls near basement level. The process was completed by placing a resilient lining of glass-fiber pads and crushed stone along the underground sides of the building facing the subway. The result was a 15-30 dB reduction from the levels measured in Harvey's BAr which previously graced the site.

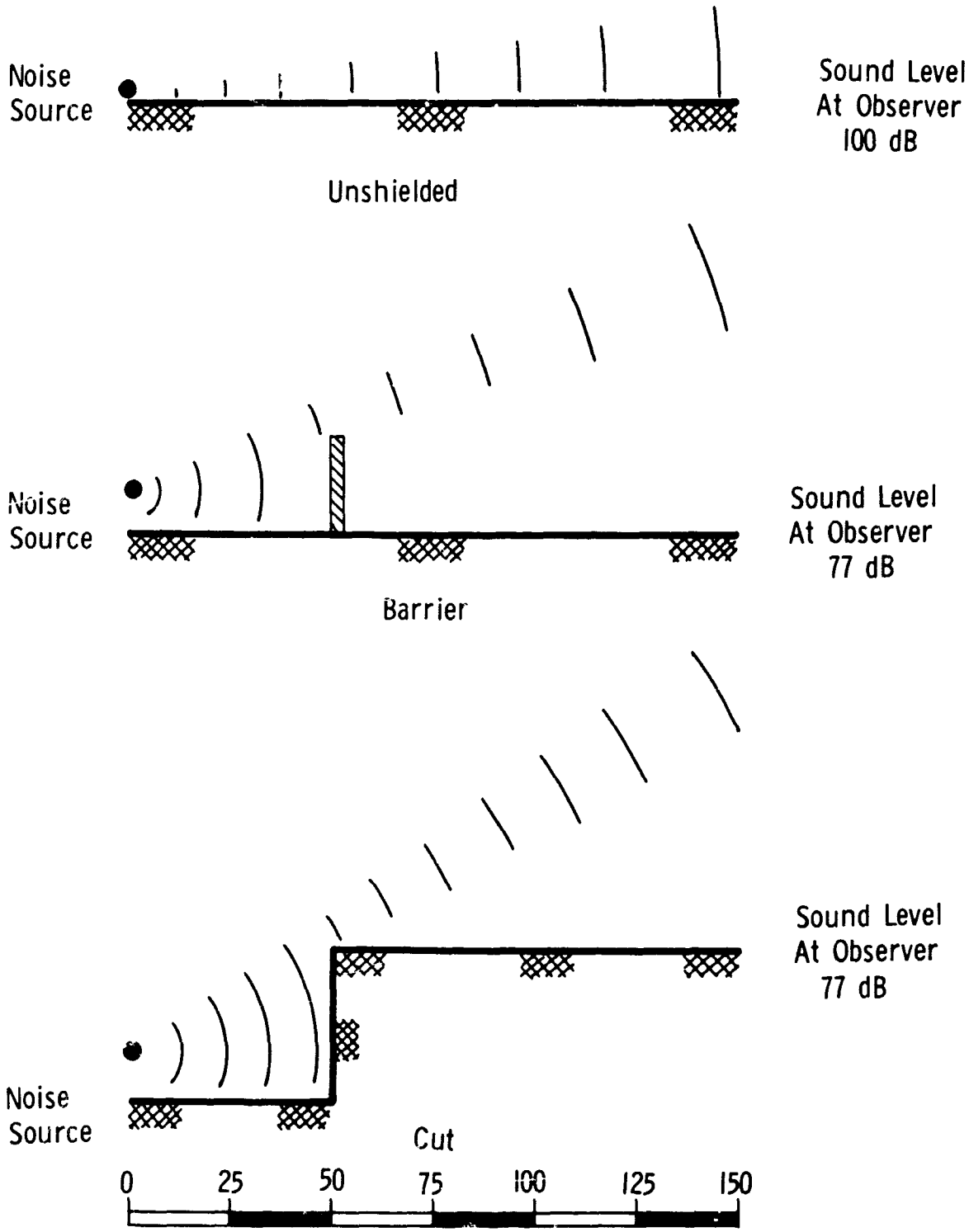
Railroad noise also radiates into passenger coaches, annoying passengers. These internal noise levels vary with materials of the car wells and floor, sound absorption materials inside the car, and the characteristics of openings allowing any airborne noise into the car. But for a car in good condition, these noise levels range from 70 to 85 dB, concentrated in the low frequency band. Much of the noise is transmitted through the floor of the car. Vibration isolators between the compressor and car floor provide reductions of 20 to 30 dB, and a floor weighing 10 pounds per square foot has been shown to attenuate noise striking the underside of the car floor by an average of 37.5 dB.

One of the world's quietest subways, Toronto's, separates tunnel walls with a center wall covered with glass wool in aluminum mesh. At 40-foot intervals along the wall are two five-by-seven-foot apertures, allowing some of the airborne noise to be released into the adjacent treated tunnel. Inside the station, where train arrivals are accompanied by high frequency sounds of screeching wheels and brakes, acoustically-treated skirt enclosures just off the track and acoustically undercoated platforms provide 10 to 15 dB reductions.

THE ABATEMENT OF TRAFFIC NOISE

Abatement alternatives for traffic noise fall into four general classes: vehicle noise reduction, highway designs which provide acoustic shielding of the highway, land use control and building design control.

The effect of reducing individual vehicle noise on traffic noise is difficult to predict in general since the noise level near a particular road is dependent on so many factors. It is apparent, however, that since truck noise so often is the determinant of peak and median traffic noise levels, a reduction in automobile noise levels will not significantly affect traffic noise but a reduction of truck noise will. At 50 mph a 20 percent mix of trucks in a traffic stream yields a 6 dB(A) greater median noise level than a traffic stream of the same volume with no trucks. [45] Subjectively the 20 percent truck mix is half again as noisy as the traffic with only passenger cars. Thus if trucks could be made as quiet as automobiles, a 6 dB(A) reduction in median traffic noise would be realized. Peak noise levels are determined primarily by the noisiest vehicles. Since trucks generate sound levels about 15 dB(A) greater than automobiles, peak levels could be reduced by about this amount by making trucks as quiet as automobiles. While the average truck (which



Source: Cohen, **Location-Design Noise Control.**

Figure 5.18. Sound Attenuation Provided by a Barrier and Depression as Compared with Unshielded Case.

is as noisy as thirty average cars) cannot be made this quiet, lesser reductions will have a beneficial effect on traffic noise.

Several powerful means of noise reduction for limited access highways are in the hands of the highway designer. Most of these involve some solid barrier which interrupts the line of sight (and hearing) from the highway to the observer. Figure 5.19 illustrates some highway design alternatives with the peak noise levels which one would experience at 60 and 100 feet for each. [5] An elevated structure, as in designs B_1 and C_1, shields property close to the road but for property further from the road is less effective because the shoulder does not interrupt the line of sight. This is illustrated in Figure 5.20 which was empirically designed from measurements taken near 6- or 8-lane divided highways. [45] Highway depression, and in design D_1 (Fugure 5.19) provides sound level reduction varying from 7 to 11 dB(A) [45]. The use of walls or earth embankments to shield adjacent residences from highways reduces sound level by a significant amount.

Other factors important to the highway designer concerned with noise include the effects of reflections from noise shield and adjacent buildings, the effects of long steep grades on the noise output of trucks, the noisiness of interchanges where two or more high speed flows come together, and the effects of acceleration lanes and approach ramps. The remedies shown above are meant to be suggestive of the level of abatement that can be expected. The interested highway designer should certainly consult more detailed references, [45], [5], [65]

Besides preventing the construction of homes near noisy highways, zoning may reduce residential noise by interposing commercial or industrial buildings near the road. Each row of these may reduce noise by 3 dB, up to a total of 10 dB. Proper insulation of residences may reduce inside noise 10-20 dB(A) with windows open and 20-25 dB(A) with windows closed. More extensive window treatment may provide further reduction.

Another control of traffic noise is to limit operations. Truck and bus routes should be designed where possible to pass through less sensitive areas. Truck traffic might be banned for the nighttime hours in portions of urban areas. The noise of passenger cars depends to a great extent on speed. Speed limits should reduce noise from this source. Since congestion contributes to peak noise levels along city streets and arterials, the traffic light system should be designed to minimize the stop-and-go of traffic flow. An English report [80] suggests that road noises in the U.S. were less than those in England primarily because of the better traffic flow in the U.S.

None of the alternatives for the reduction of road generated noise is perfect. The one chosen in any particular situation must consider many other factors including the cost of abatement, the effect on traffic flow, the effect on drivers, and the social climate of the community.

Pleasure Boats

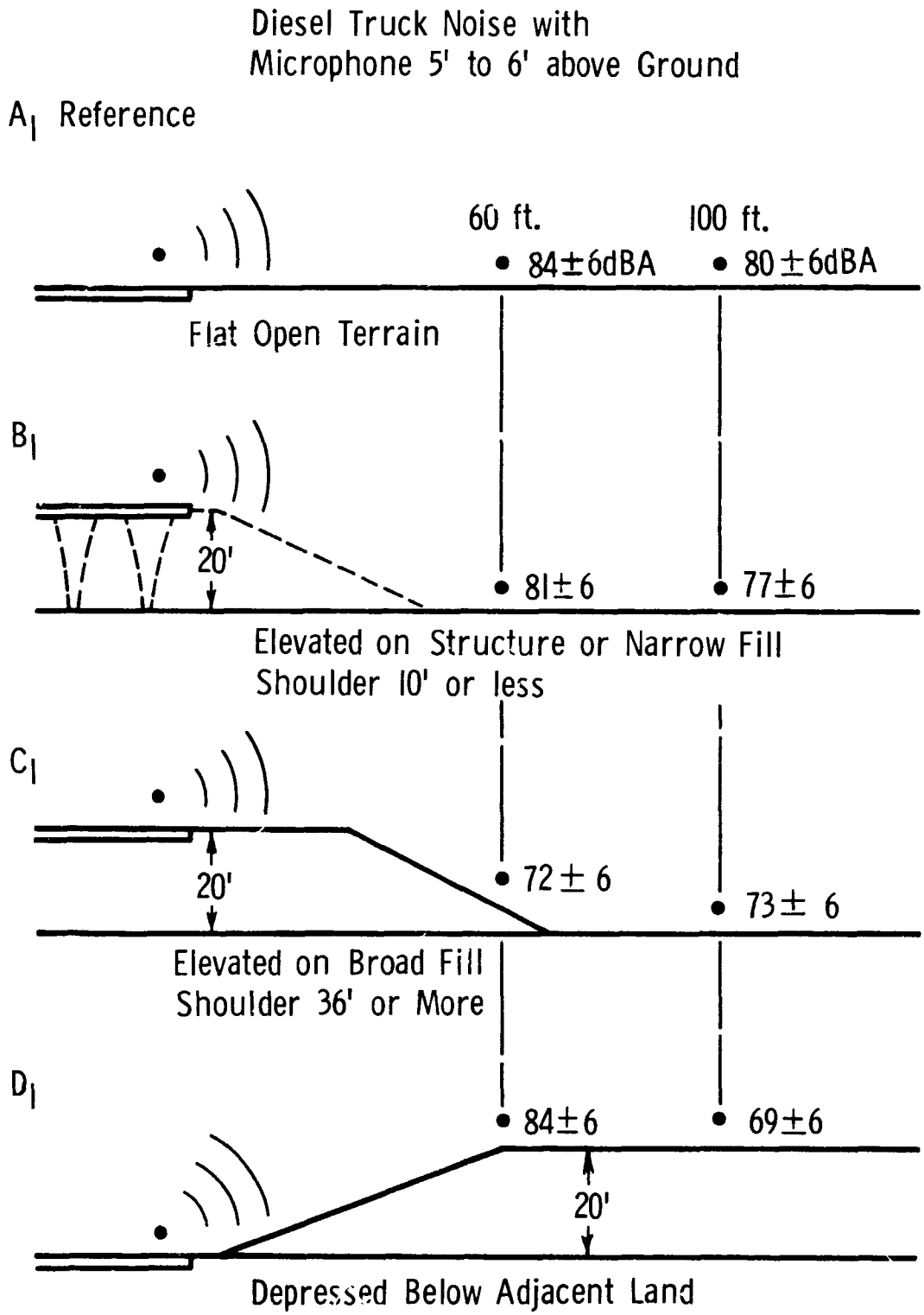
The noise generated by pleasure boats can be abated in the same manner as that of snowmobiles since both are usually powered by two-cycle engines. For outboards the application of a proper muffler and the lining of the motor casing with a sound absorbent material can bring the noise levels down into the 75 dB(A) range. The four- or six-cycle motors used on some boats are also easily muffled. State noise regulations would spur the manufacturers of outboard motors to produce a quiet motor. It should be pointed out, however, that many have already significantly silenced their outboards. One boating enthusiast with an acoustical interest was able to reduce by 73 percent the noise level on his 35-foot cruiser by installing a transom-type muffler in series with the original muffler, inserting flexible couplings between the engine and propeller shafts, applying sound insulation to the engine room, and lining the underside of the passenger compartment with acoustical tile. [69], [70]

FUTURE TRANSPORTATION SYSTEMS

V/STOL Transportation

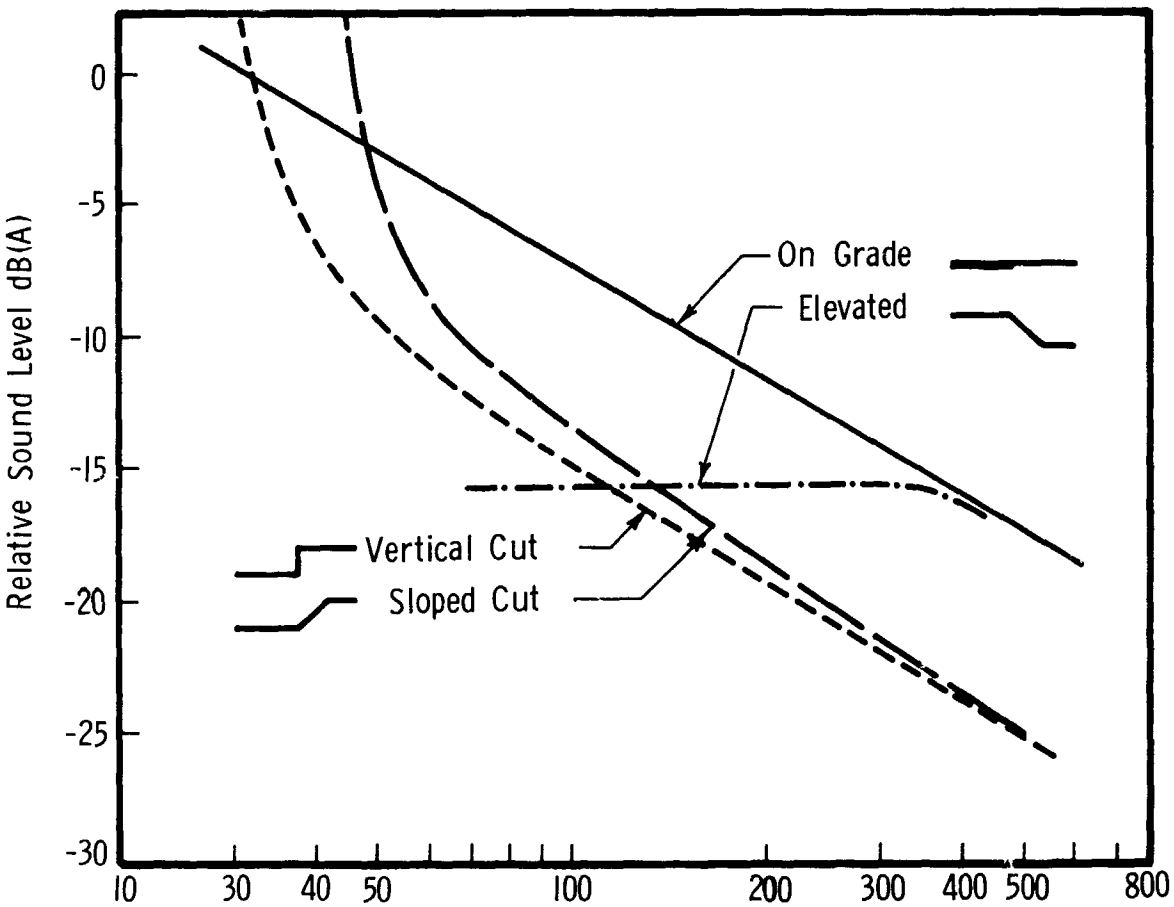
Earlier sections of this report have demonstrated that growing travel demands are quickly saturating present air terminals. In addition, these facilities face problems of community protests over noise, congestion of access streets, being deprived of growing room by urban sprawl, as well as the air traveller's sturdy insistence on better and better service. in such congested areas as the Northeast Corridor and Central and Western Europe, some alternative to conventional take-off and landing (CTOL) air travel must be considered, most notably either high speed trains or vertical or short take-off and landing (V/STOL) aircraft. Both modes will be noisy, and difficult to implement.

V/STOL operations must control noise levels during cruise, takeoff, and landing. Aircraft of this type considered feasible range from VTOL jets and helicopters to STOL turbofans and turboprops (Figure 5.21). The similarity of all CTOL jet noise signatures permits correlation of annoyance with EPNdB and frequency of flights to yield Noise Exposure Forecasts (NEF's). V/STOL configurations vary both in noise levels and in annoyance at the same noise levels due to differing frequency spectra. The FAA is attempting to define V/STOL certification, but is having difficulty.



Source: Beaton and Bourget, **Noise Radiation.**

Figure 5.19. The Noise Attenuation Near Various Highway Designs.



Source: Galloway, **Highway Noise.**

Figure 5.20. Noise Reduction as a Function of Distance Provided by Various Highway Configurations.

The planner should carefully examine the expected PNdB levels and NEF contours around V/STOL port sites being considered. The difficulties encountered by groups interested in establishing a STOL port on Manhattan Island underscores the low noise levels required for a V/STOL system. Political observers in that area believe that aircraft noise levels in the range 90-95 PNdB at 500 feet should be the maximum permissible for operations in such congested areas. Since the Manhattan area is the key to the implementation of V/STOL transportation system, considerable leverage will be exerted to lower the noise levels of V/STOL aircraft designs.

The expected perceived noise levels (PNdB) for a 100-150 passenger V/STOL aircraft are given in Figure 5.22. The broad band of uncertainty reflects the difficulty encountered in noise level prediction. Figure 5.23 shows typical takeoff and landing 95 PNdB contours for three STOL aircraft configurations. VTOL contours resemble STOL contours in shape since climb-out and landing paths are approximately the same, except noise levels will be 3 PNdB greater than the STOL mode. These contours can be scaled roughly as follows: 3 PNdB per doubling of number of passengers and -7 PNdB per doubling of distance from sound source.

To put these aircraft noise levels in perspective, Figure 5.24 shows the present noise levels in various sections of a typical community. The intrusion of an additional short period sound source appears to be noticed when the source level is about 10 PNdB above the background. A large metropolitan and a suburban site were chosen as typical V/STOL ports. Comparisons of the noise levels of these STOL configurations are shown for these sites in Figures 5.25 and 5.26.

Figure 5.21. Sikorsky S-65-200 and McDonnell Douglas 210: Proposed Designs for V/STOL Operations.

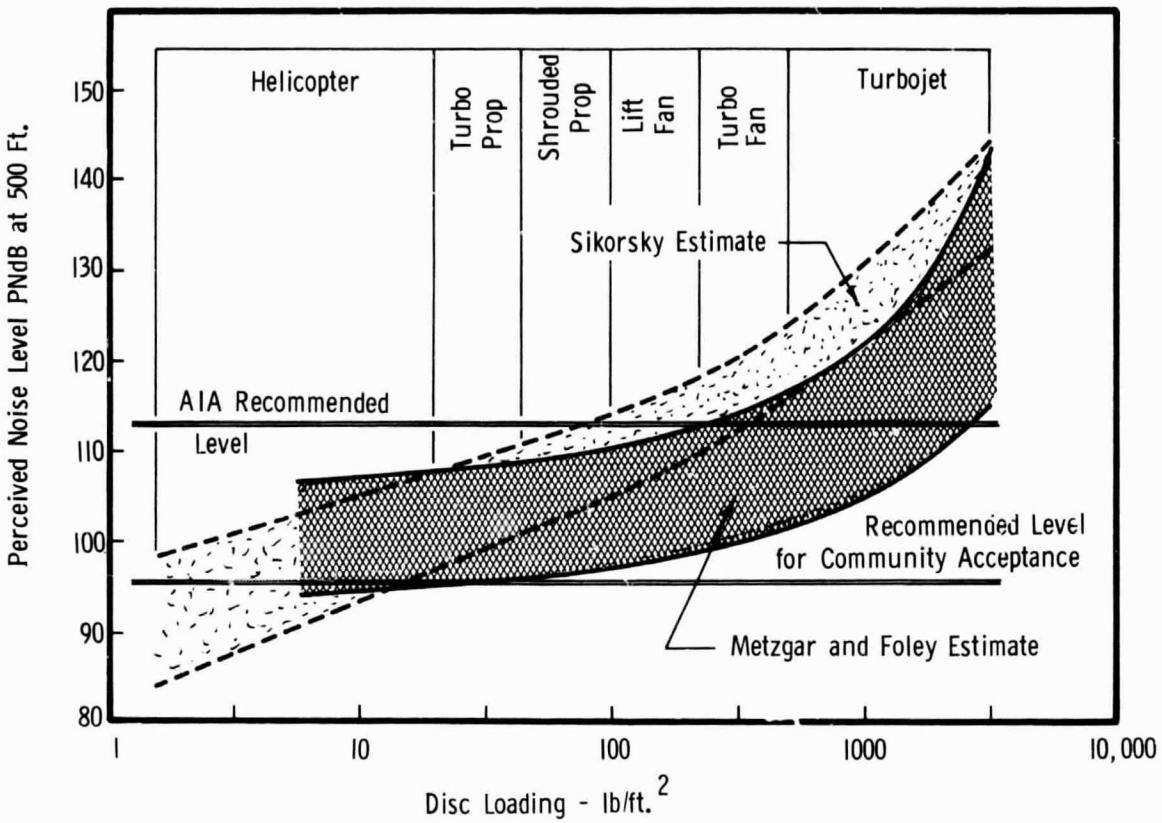
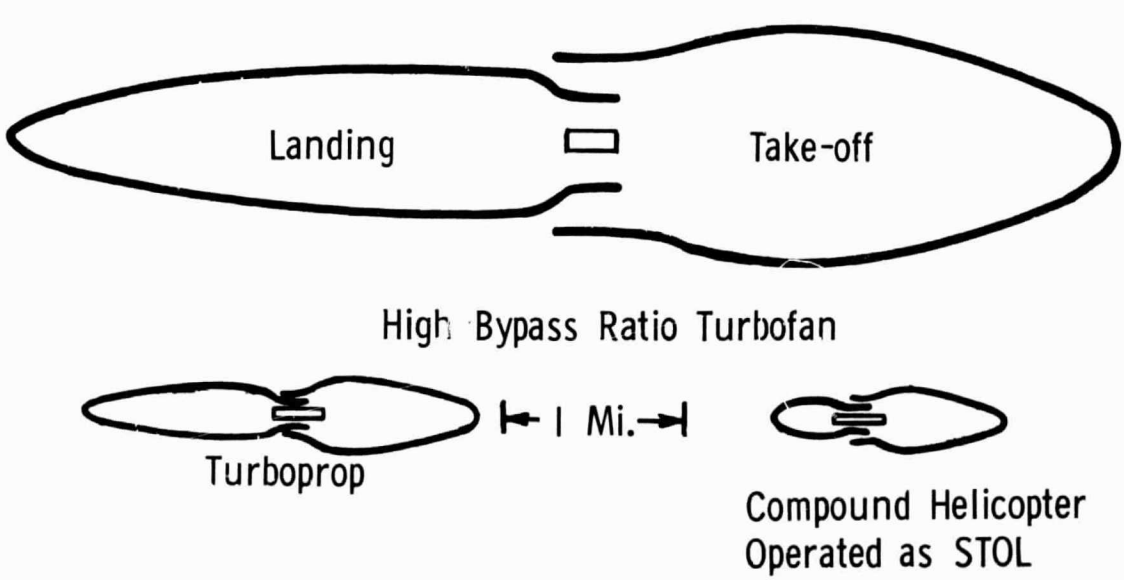
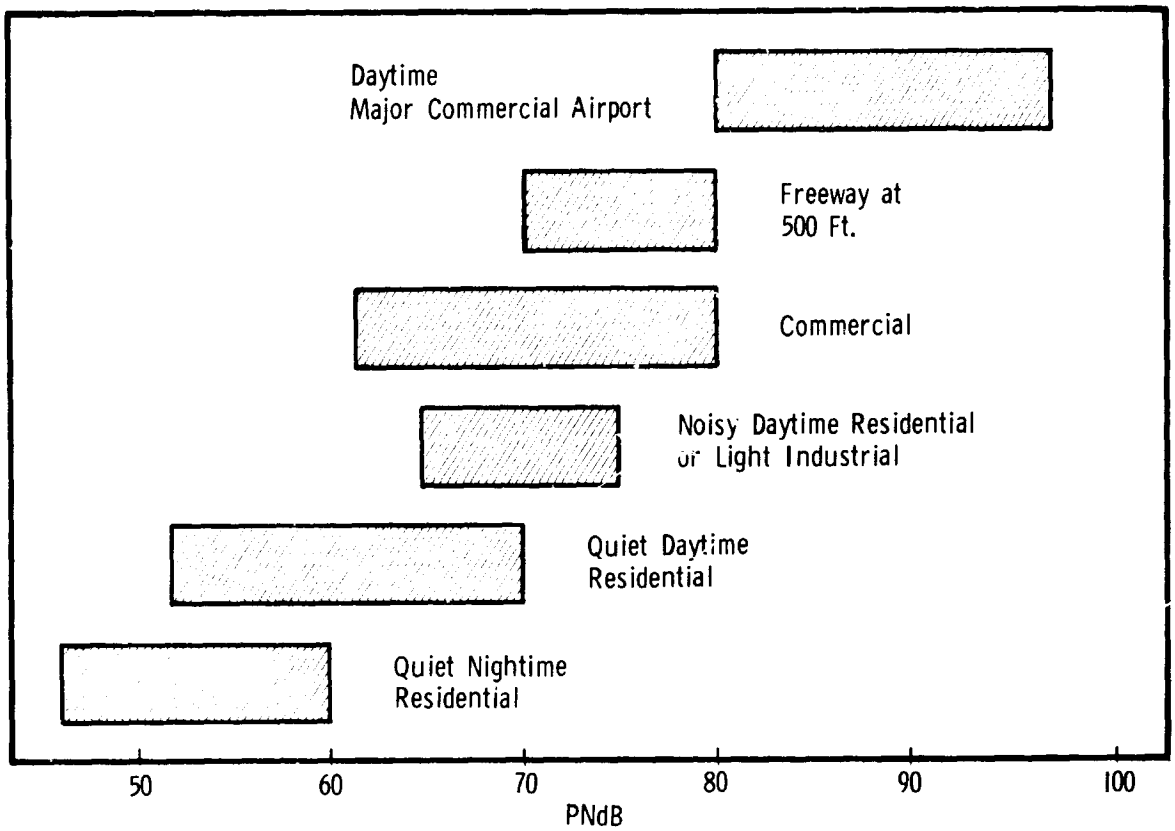


Figure 5.22. Noise Levels of Proposed 150 Passenger V/STOL Aircraft.



Source: Metzgar and Foley, **STOL Aircraft Noise.**

Figure 5.23. 95 PNdB Contours for Proposed 150 Passenger STOL Aircraft.



Source: Metzgar and Foley, **STOL Aircraft Noise.**

Figure 5.24. V/STOLport Background Noise Levels.

An additional noise intrusion on the community will be the overflights of the V/STOL aircraft during cruising flight. The more numerous flight paths, lower cruise altitudes and higher cruise power levels will diffuse low level sound. A recent study [17] presents a very graphic and perhaps overly pessimistic prediction of noise levels to be expected in the Los Angeles Basin due to overflights.

The number of operations at a V/STOL port will affect the annoyance in the surrounding community. From a noise viewpoint, the most optimistic forecast can be considered the worst case for flight frequencies. The following table shows the expected daily flights for typical suburban and urban ports.

1975	1985			
	STOL	VTOL	STOL	VTOL
Manhattan	130	524	420	2,096
Hartford	78	138	312	552
Levittown	46	0	184	30

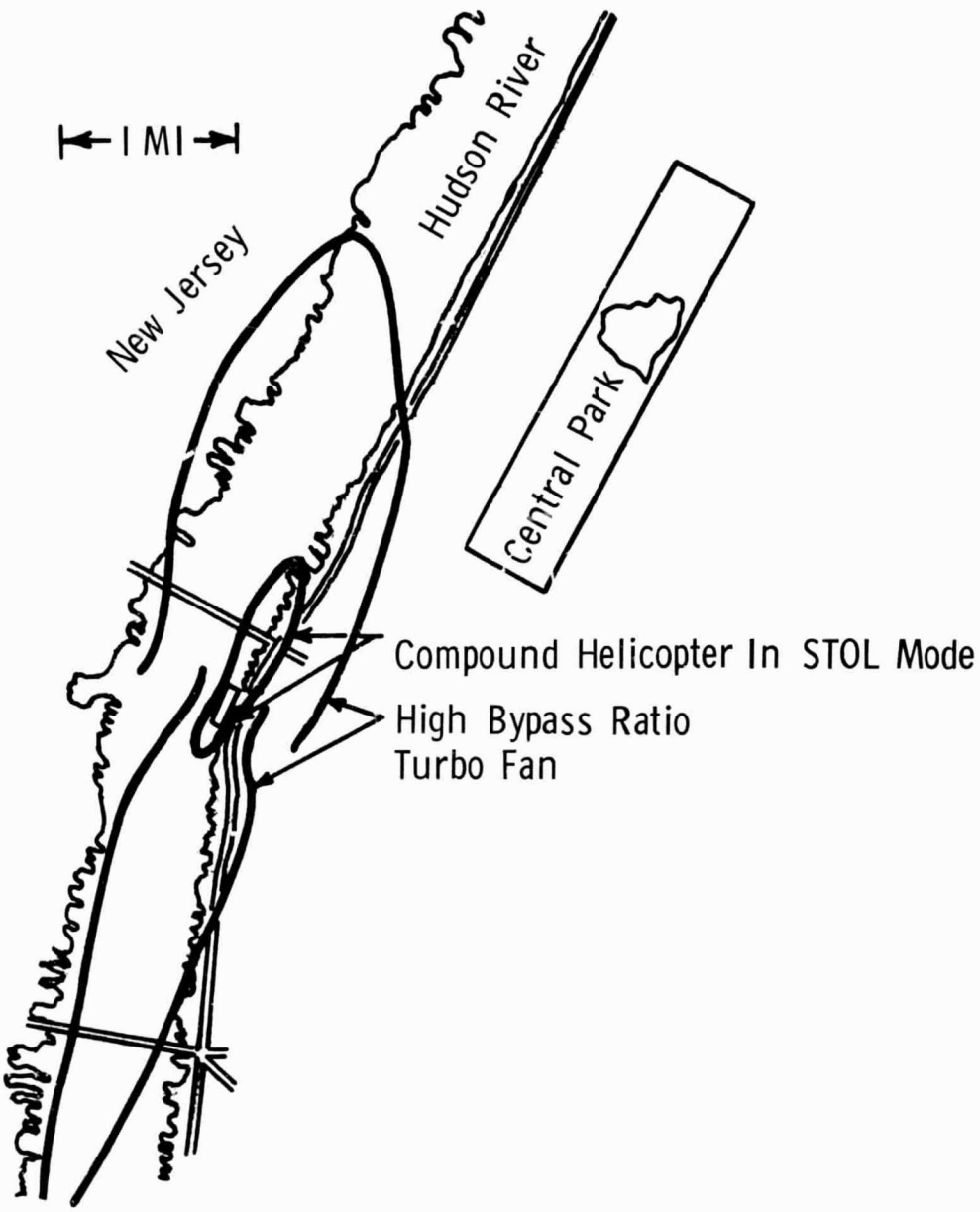
Of the extensive studies of V/STOL service in the Northeast Corridor, the CAB Initial Decision [97] and the Northeast Corridor Transportation Projects Report [82] are the most recent and most optimistic.

The NEF contours display readily the effect of flight frequencies on community annoyance. Figure 5.27 illustrates the growth in area enclosed by a NEF 30 contour line for a typical suburban V/STOL port.

V/STOL flights will introduce a new source of urban noise pollution, and the planner contemplating V/STOL ports should determine the acceptability based upon the highest capacity forecast for the port.

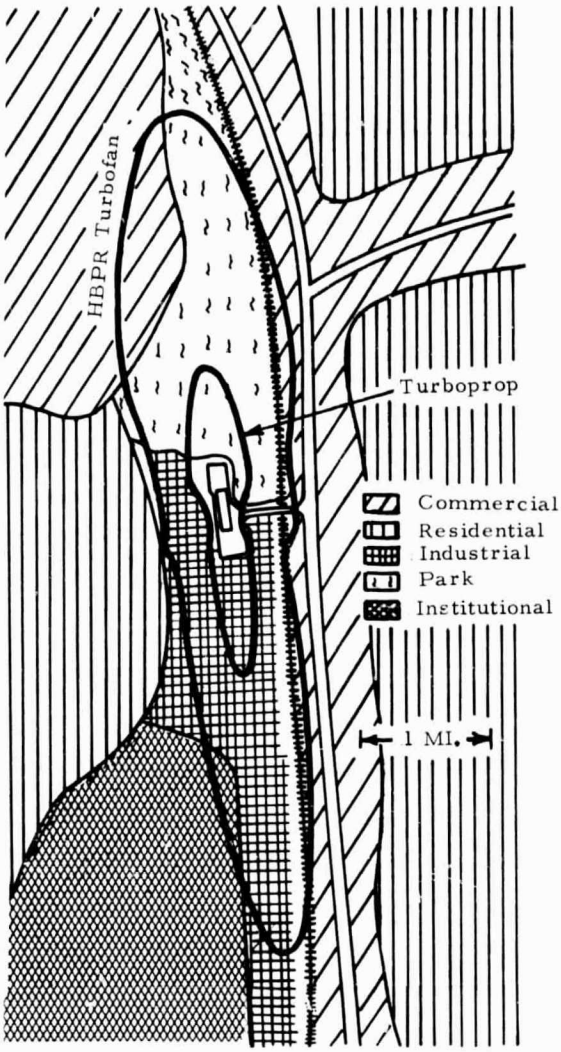
Progress Report on SST

The FAA intends to prohibit (except under special conditions) sonic booms over the continental United States by any civilian aircraft. Thus, the impact of the SST (Figure 5.28) on society will apparently result from landing and takeoff (since 30,000 to 40,000 feet high in subsonic flight the



Source: Metzgar and Foley, **STOL Aircraft Noise.**

Figure 5.25. 95 PNdB Contours of 150 Passenger STOL Aircraft for Proposed New York City West Side STOLport.



Source: Metzgar and Foley, **STOL Aircraft Noise.**

Figure 5.26. 95 PNdB Contours Around a Suburban STOLport for Proposed 150 Passenger Aircraft.

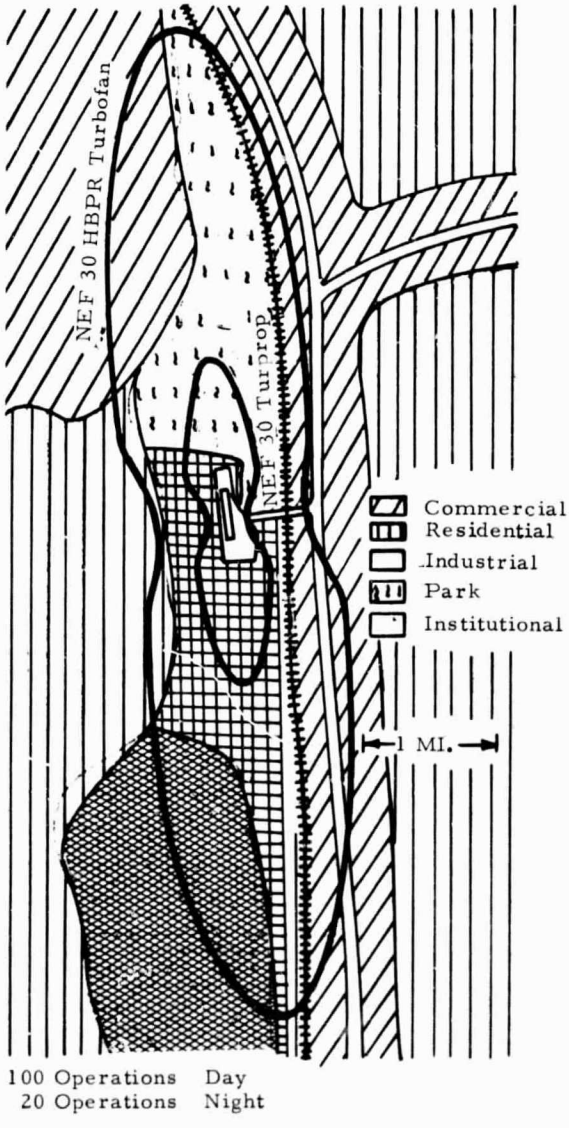
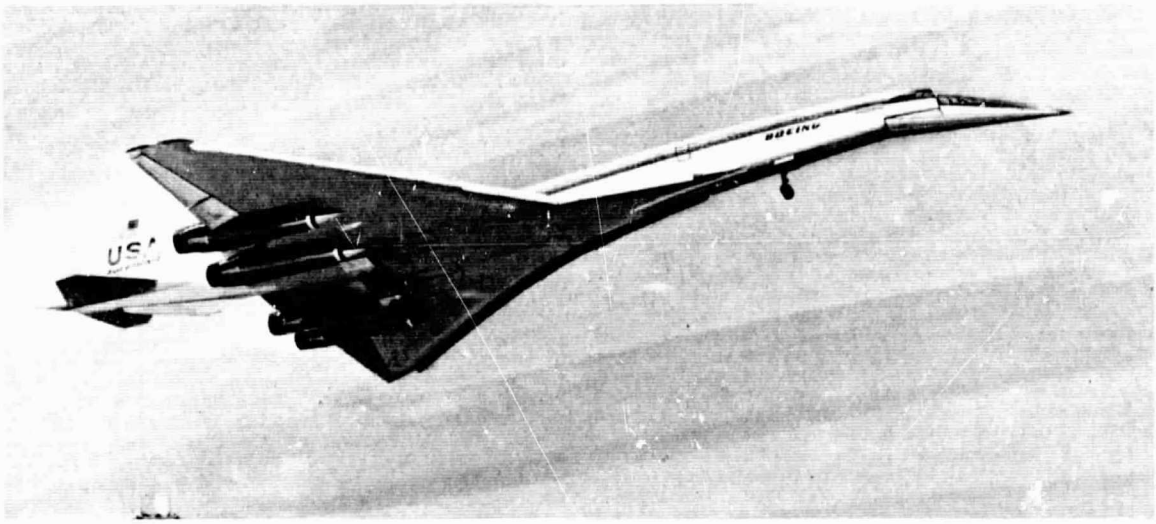


Figure 5.27. NEF 30 Contours for Proposed 150 Passenger STOL Aircraft in Suburban Environment.



Source: Boeing Company

Figure 5.28. Artist's Conception of the Boeing SST.

plane, due to natural attenuation, will not be heard by a listener on the ground.)

Figure 5.3 illustrates the noise levels associated with SST's and current subsonic jets at the three (3) noise certification measuring points. Figure 5.29 shows a 108 PNdB noise contour for the SST with prototype engines and with noise suppressed engines [4] which are technically feasible 6-8 years hence, superimposed on Logan International Airport. The major noise problem area associated with the SST is on the sideline where for over 1 n.m. and approximately 4.5 n.m. parallel to the runway the PNdB is in excess of 100. With noise suppression features installed, Boeing hopes to be able to match the FAA noise standards applied to new subsonic aircraft on approach and take-off.

Noise suppression plans which Boeing and General Electric are presently working on require that the suppressor design be integrated into the engine and installed on the airplane pod without introducing excessive range-payload economic penalties. Whether they can achieve a noise reduction with those criteria remains to be seen. Early suppressor designs would add weights of 14,000 to 25,000 pounds which would reduce range by 280 to 575 n.m. and passengers by 70 to 125.

While the FAA proposes to prohibit civil aircraft from producing a sonic boom over the continental United States, there are pressures to contravene this proposal. Consequently, the sonic boom generated by the US-SST must be considered. A sonic boom results whenever an aircraft exceeds the speed of sound. This boom is sensed on the ground as a sudden pressure increase to a peak overburden pressure followed in turn by a rapid pressure decrease back to atmospheric pressure and below. This overburden pressure, if plotted against time, is referred to as the boom signature.

The magnitude of the overburden pressure increases with aircraft weight and decreases with altitude. The SST will climb subsonic to 30,000 to 40,000 feet at which time it will be approximately 200 miles into its flight. It will then undergo transonic acceleration causing what is termed as an "acceleration superboom" with an associated overpressure of approximately 3 pounds per square foot. The cruise portion of the flight at Mach 2.7 will create a peak overpressure of 2.0 pounds per square foot. These overpressures are nominal or average pressures and may be increased or decreased in magnitude, by atmospheric conditions, ground reverberation and aircraft operations.

In summary, even with the sonic boom deleted as a problem, the sideline noise associated with take-off may result in the aircraft being banned at many airports—and certainly in Boston.

Future Ground and Water Vehicles

Several new modes or combined new and old modes of inter city ground transportation have been proposed, including air cushion and terrafoil vehicles, hydrofoils, Dial-a-bus Systems, high speed rapid transit, single high speed multiple passenger vehicles systems, Gravity Vacuum Trains (GVT), and guideway personal transit systems. Most of these systems could be built utilizing today's technology. The question is whether any **should** be built since the realization of a system would take several years and no guarantee could be given that a given system

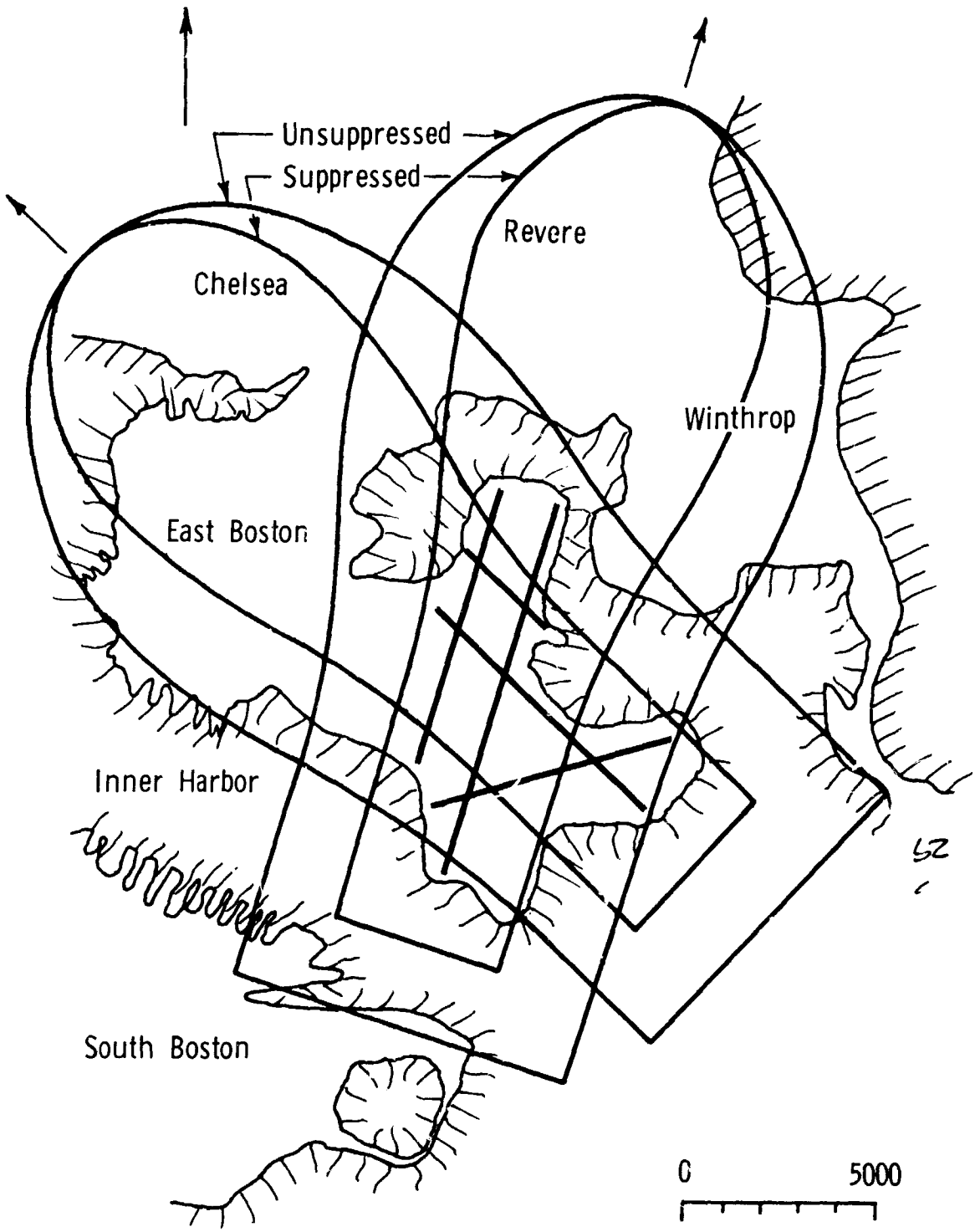


Figure 5.29. Logan International Airport 10B EPNdB Countours for SST with and without Suppression.

would satisfy the need (**i.e.**, be accepted by the riding public).

Some authors suggest a gradualistic approach to upgrade and optimize systems by adding new roadways and vehicles, and improving schedules. One study indicates that such an approach ". . . could not meet the future transportation needs of the cities, whereas innovations already in sight promise to do so." [52], [108]

To increase the present average speed in U.S. subways (i.e., 20 mph) a system of "personal transit" vehicles which travel on an automatic network of tracks ("guideways") has been proposed [52], [112], [36] (Figures 5.30 and 5.31). A modification of this system accepts automobiles that are either specially equipped (to travel on an electronically controlled guideway) or can be carried on flatbed guideway vehicles (Figure 5.32). This dual-mode use of the system would make its extension to the suburbs financially possible.

Alternatively, suburban personal transit service would be possible if travelers were transported to and from a guideway station by a "Dial-A-Bus." [112] In this mode, the traveler calls in his request for service to a certain destination, **e.g.**, a guideway station. An 8 to 20-passenger vehicle is optimally dispatched by computer to his **home**, offering door-to-door service. Although the performance of the Dial-a-bus system is still unproven, it offers promise of increasing the effective capacity of existing vehicular arteries by providing the flexibility necessary to make a daily traveler leave his car at home. The attractiveness of this scheme is further enhanced by the low fares (approximately equal to those now charged on regular buses) which are considered possible due to ride-sharing (**i.e.**, making several stops along the way—something taxis are usually prohibited from doing). Low cost and door-to-door service also mean that more off-peak hour travelers will use the system instead of their automobiles.

In small and medium size urban areas, the dial-a-bus system could provide public transportation without a system of personal transit by acting as a feeder system to existing fixed route buses or trains. It may even be possible to use the Dial-a-bus system for all transportation needs in some small cities. [18]

A computer simulation of a dual mode guideway indicated [52], [108] that it would attract 38 percent of the total travelers using public conveyances in 1975 as compared to only 23 precent of the total if no change were made. Since the dual mode guideway removed a sizeable fraction of the travelers from the existing arteries, the average automobile speed was also increased.

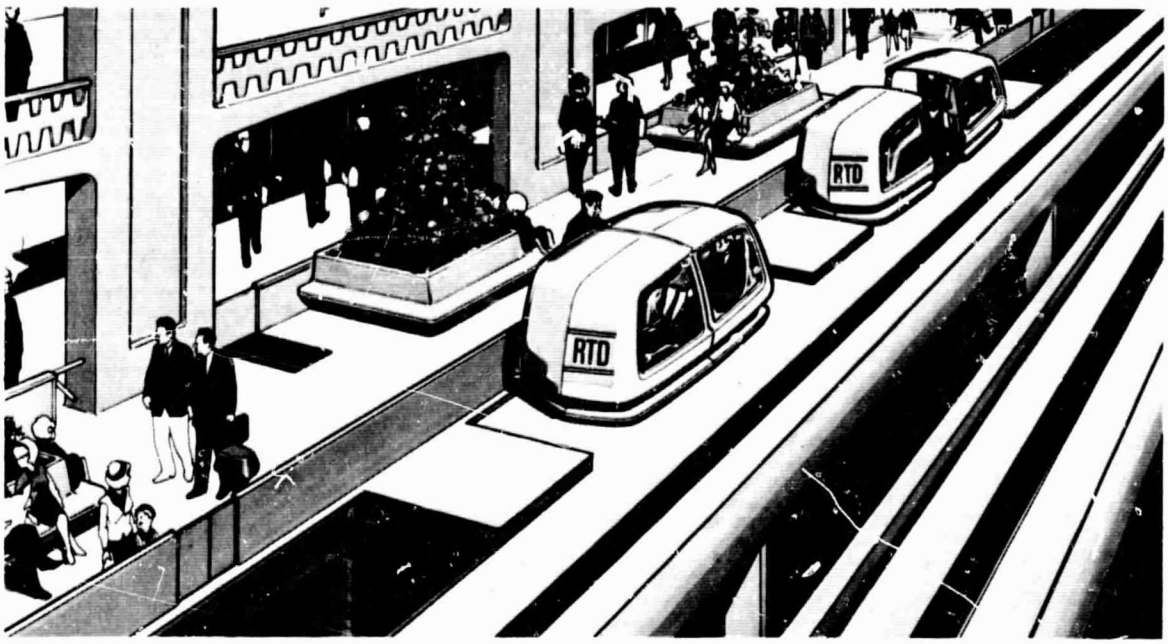
Another proposal suggests that the **existing** railroad right-of-way be improved to carry single electrically-propelled rubber-tired passenger or freight cars at 200 mph over distances up to 500 miles. [18] About 24,000 passenger cars (each holding up to 75 people) are estimated to handle 170 billion passenger miles per year. In addition, 18,000 freight cars (again single units would be used) would handle 400 billion ton-miles of high value freight and 760 billion ton-miles of commodity freight.

As noted elsewhere the use of rubber tires is not presently feasible because of the high noise levels and frequent replacement. Another problem is that rush hour operations require cars to run one second apart, ". . . the present time separation of cars on a freeway," to handle 250,000 passengers per hour. This is totally beyond the present technology associated with moving people through transportation terminals (to put this number in proper perspective, note that modern airports have difficulty handling less than 10 percent of this total per day).

While a great deal of work has been done on the development of large **air cushion vehicles** (ACV) (Figure 5.33) which can travel over land or water without the benefit of a road or track, these do not, at this time, appear to be feasible because the noise created by the lift and propulsion systems would be intolerably high (see next section). A proposed modification of the ACV for overwater application would provide the primary propulsion by water screws. [57] It is claimed that such a water craft traveling at 35 knots would be ". . . little noisier than a conventional ferry boat of comparable size." Tracked air cushion vehicles have also been proposed.

A safer device but more costly to install and less flexible in use, the "Terrafoil," [55] uses a wing plus the body to provide aerodynamic lift at high speeds (300-400 mph) within a partially enclosed guide. (Wheels are used for speeds below 80 mph.) The vehicle still has lift at high speeds even if power is lost and so can safely and slowly descend. Also, the guideway clearance for a terrafoil is much larger than for air cushion devices (**i.e.**, 1 foot versus 1 inch). Studies have shown that stability goes up with speed (it goes down for an air cushion vehicle) and that only about one-half of the power of the air cushion vehicle is required at high speeds. The major disadvantage of this system, in addition to guideway cost, is that an aircraft type propulsion system is probably required and hence noise would be a problem.

A mode of high-speed water transportation which is currently in its infancy is the hydrofoil. [115] (Figure 5.34) Thirty, 75, and 125-passenger models are currently available. The newest hydrofoil route operates on New York's East River and carries Wall Street brokers and bankers to and from their jobs. The major problem with this type of vehicle is that an obstacle can easily damage or break off a fin. (A submerged log has actually done this.) Such a situation would cause the hull to strike the water thereby producing a rapid deceleration due to the

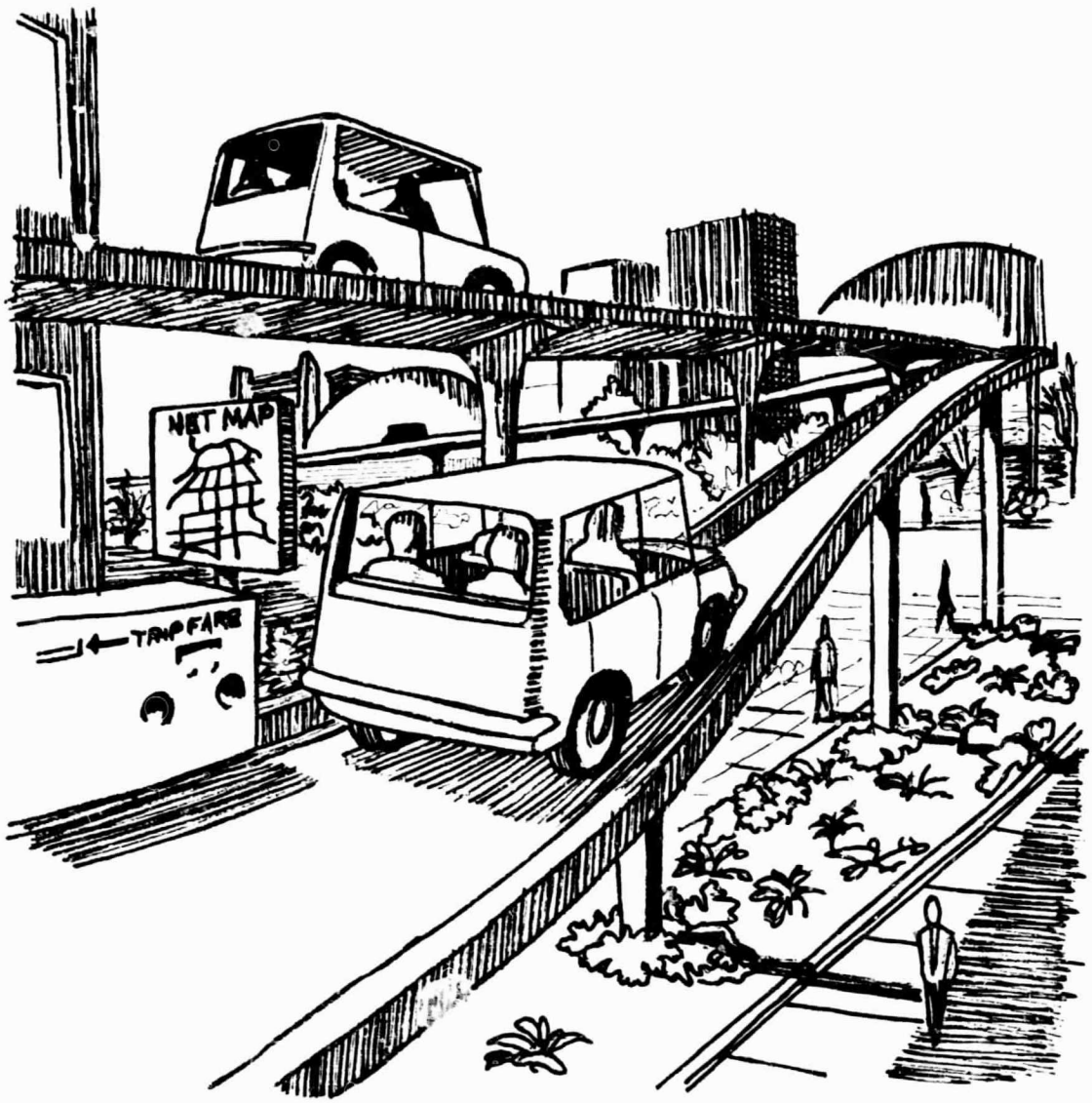


Source: Transportation Technology Inc.

Figure 5.30. A system of personal transit vehicles will allow the traveler to board a station (located off the main track and perhaps within a department store) after having indicated his final destination to a computerized routing system. Average point-to-point speeds of up to 80 mph (depending upon station separation) are considered feasible.

Source: Transportation Technology Inc.

Figure 5.31. An automatically controlled six-passenger personal transit vehicle which is propelled by a Linear Induction Motor and supported on an air cushion, 12 and 20-passenger models are also planned.



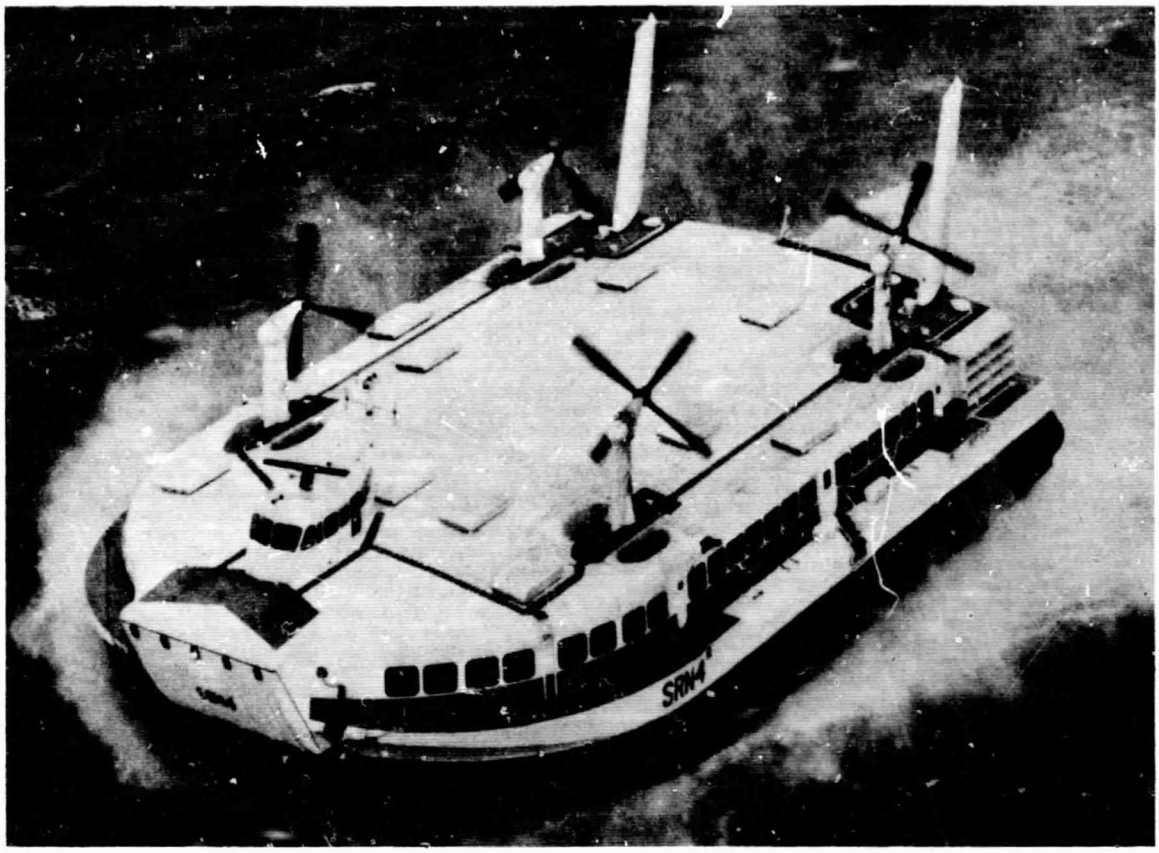
Source: "Future Urban Transportation Systems: Descriptions, Evaluation, and Programs," S.R.I., March 1968.

Figure 5.32. Specially equipped automobiles which can use either an electronically controlled guideway or an existing street or freeway will offer the traveler flexibility, convenience, and safety.

sudden increase in drag. Injuries to passengers not wearing safety belts might occur.

Research indicates that hydrofoils in excess of 2000 tons (as would be needed on a deep-sea route, for example) would not be practical since the weight of the larger foils which would be required increases faster than their lifting power.

High-speed rail rapid-transit systems, although relatively inflexible (due to a fixed right of way) have been attracting a great deal of attention in the last few years. The Penn-Central Metroliner has operated between New York City and Washington, D.C. for over two years and has been enthusiastically received by the riding public. (Figure 5.36) The first truly modern, commuter-type line in the U.S. began operation in early 1969 between Philadelphia and Lindenvold, New Jersey. Believing that comfort and reliability will attract passengers, the computerized line



Source: Bell Aerosystems Company

Figure 5.33. Riding 10 feet off the surface, British Hovercraft Corporation's 165-ton SRN-4 ACV today carries as many as 30 cars and 245 passengers at a time across the English Channel. The ACV completes the trip in 30 minutes, as compared with the 90 minutes required to make the same journey by ship. Its four top-mounted drive propellers are 19 feet in diameter. It is 130 feet long and 78 feet wide.

provides seats for 90 percent of its passengers and in its first year and one half of operation has had an on-time record of better than 95 percent at average speeds of 45 mph. [87] It is, therefore, not difficult to understand why there has been a steady increase in the number of people using the line. An added benefit of the line has been the reduction in the number of cars crossing the Benjamin Franklin Bridge over the Delaware River (the same bridge that is used by the line). Therefore, the effective capacity of the bridge has been increased (over the short term, at least).

The Bay Area Rapid Transit (BART) system, scheduled to begin operation in San Francisco in 1971, will incorporate many of the same computer and passenger-handling techniques used on the Lindenwold line. The success of these two lines should provide the impetus for building high-speed commuter systems in other parts of the country.

A system of high-speed rail (perhaps combined with a Dial-a-bus system) may be one of the few practical ways (from a political, economic, and technological standpoint) to meet the demands of the intra-megalopolis trip of less than 250 miles. This is especially true if the problems of air and ground traffic congestion are not solved and if the noise level of V/STOL aircraft cannot be reduced.

A final proposal is the Gravity Vacuum Train (GVT). [38] Capable of speeds of up to 245 mph (this is for a 10-mile distance between stations; higher speeds are possible for larger inter-station distances but at the expense of deeper tunnels), this underground system uses very little power (compared to conventional subways), generates little air pollution because the trains are propelled and stopped by gravitational and pneumatic effects, and can be made to operate very quietly (see next section). The major problem with this mode is economic; i.e., the trains

Source: U. S. Hydrofoils Company, Inc.

Figure 5.34. When in motion, wing-like fins of the hydrofoil protrude down into the water and provide lift and stability (even in choppy water) in much the same way as an aircraft wing. In normal operation, the hydrofoil's hull is completely out of the water and efficient operation at high speeds is possible because of the large reduction in drag which results. Speeds of 30-70 mph have been attained so far and it is expected that passenger carrying vehicles traveling in excess of 100 mph and freighters traveling around 300 mph are feasible.

must operate entirely within a tunnel, the cost of which is prohibitive with present-day tunneling procedures.

Future Modes: Noise

The noise produced by the vehicles mentioned in the previous section will come from the propulsion units, rubber tires, steel wheels, air cushions, and air turbulence.

Electric motors, steam engines, and gas turbines are promising replacements for the internal combustion (I.C.) engine. Measurements indicate that rotary electric motors rated below 300 hp would have a noise level of 75.9 PNdB at 100 feet. [34] Linear motors having the same horsepower rating would produce noise below this level. [34]

A major breakthrough in self-contained power supplies is required if rotary electric motors are to be used in the personal transit vehicle of the future. Presently fuel cells use relatively scarce and expensive fuels and are themselves expensive to produce. [112] Lead acid batteries are too heavy, and in fact, if all the automobiles in existence today were powered by storage batteries, the recharge demand would be close to the entire electrical power consumption in the U.S. (1530 billion kw hrs).

The Hybrid Engine is a technological compromise between the poor performance characteristics of an electric motor (i.e., short range between battery charges when the vehicle is operated at highway speeds) and the large emission of air pollutants associated with the I.C. engine. The hybrid would consist of a small gasoline engine, operating at a constant speed (so as to reduce the large amount of air pollution emitted during acceleration), used to charge a battery and an electric motor to drive the vehicle.

The gas turbine engine, considerably advanced in the aerospace industry, has received a great deal of attention recently. All performance characteristics (of engines of less than 300 hp) including air pollution (although it is not certain that the gas turbine will be able to meet standards currently being considered for oxides and nitrogen emission) and noise pollution

(assuming appropriate acoustical treatment of the inlet and exhaust) seem favorable. However, its relatively high unit cost presently makes it economically feasible only for use in high mileage vehicles (**e.g.,** buses and trucks) although Chrysler has tested 130 hp turbine-powered automobiles.

Problems associated with the earliest steam engines such as large water consumption and boiler explosions have long since been eliminated. Apparently only factors such as warm-up time (less than 1 minute) and the enormous investments associated with the I.C. engine and its components prevent promotion and acceptance of steam engines. They have excellent low-speed-torque characteristics and hence a small engine (**i.e.,** fewer horsepower) is required to give the same I.C. engine performance.

Personal transit vehicles will probably travel on either an air cushion or pneumatic tires and be electrically propelled either by a standard or a linear induction motor. Noise from the interaction of the tires with the guideway will produce squeal, hum, squelch, rumble, and thump. [34] Another source of noise will be the sliding from an electrical shoe (contact) on a "third rail." A comparison of the work of Cohen [30] and Kryter [64] with that of Dietrich **et al.** [34] reveals that tire noise would be the dominant source for a personal transit vehicle travelling at 50-60 mph. It is estimated that the overal noise level would be about 70 PNdB, 100 feet from the guideway. For the air-cushion personal transit vehicle, it is claimed that the noise level is "below the ambient." [25]

The rubber-tired Dial-a-bus vehicle will have noise characteristics similar to those of a standard bus or truck (operating at highway speeds). Thus, it is expected that at 100 feet the noise level will be approximately 95 PNdB. [30], [64]

The single, high-speed passenger and freight cars which are expected to run on rubber tires at 200 mph [18] are not currently feasible for two major reasons—pneumatic tires run at such speeds need to be replaced frequently and at 200 mph would represent

Source: Penn Central Company

Figure 5.35. The Metroliner provides a level of luxury comparable to that of an airplane. The non-stop train makes the center city-to-center city run between New York City and Washington D.C. in 2½ hours. (Better than airplane when all travel and waiting times are included.) In the future, this time may be reduced by as much as 33% if the design speed of 160 mph is ever attained (current maximum speed is 120 mph. This limitation is because existing grades and tracks are used.).

Source: United Aircraft Corporation

Figure 5.36. The Turbo-Train, capable of speeds of up to 160 mph, uses powerful, lightweight gas turbine engines but can also run on electric power. The combination of a pendulous suspension system (which banks the cars into the curve), and lightweight cars having a low center of gravity will permit 30-40% higher speeds than are now possible on runs which have many curves (e.g., New York to Boston).

a source of intense sound. At 150 mph the noise level is estimated as 128 PNdB at one foot and still over 100 PNdB at 100 feet. While it is concluded that rubber-tired vehicles would not be practical at present, there is no reason why the system could not be implemented with steel wheels.

The noise from high-speed rapid transit vehicles which roll on steel wheels has several sources, [34] most of the reviewed in an earlier section on present rail travel. Perhaps a special problem of high-speed rail transit is air turbulence, but this can be reduced by aerodynamic design, as on the Tokaido (Tokyo to Osaka) line.

The noise produced by a high speed rail vehicle taking all these mechanisms into account has been estimated to be 95 PNdB at 100 feet. [39] In addition, measurements by the DOT on the experimental Turbo Train (Figure 5.36) indicate that the overall noise level (Turbine noise dominating at 100-125 mph) is 112.5 PNdB. [116]

The Gravity Vacuum train will also operate on steel wheels. However, noise due to the flat spots on the wheels will probably be a minor problem because they are not used in the propulsion and braking operations of the systems. Since compressed air is only allowed to enter the tunnel at the beginning (for propulsion) of a trip, noise levels during travel will probably be well below 95 PNdB (no actual numbers are currently available). Also noise carried to the outside should be minimal (assuming acoustic treatment of air intake and exhaust vents) since stations will generally be at least 40 feet below the surface and tunnels will be even lower (the depth below the surface depends on stage lengths).

Air cushion vehicles which are propelled by prop or purejets have the following noise sources: [34]

1. The air compressor.
2. The passage of air between the vehicle and the guideway pads.
3. The free discharge of air into the surroundings.
4. The propulsion system.

The estimated overall (from all sources) noise level produced by one type of track ACV is 107 PNdB at 100 feet and 94 PNdB at 500 feet. [39] Another study reveals that the noise level produced by an SRN2 Hovercraft is about 127 PNdB at 50 feet. [27] In both cases, the noise is attributable to the propulsion system.

Modal Split as a Noise Abatement Procedure.

The fact that some modes of transportation are quieter than others suggests that some degree of noise abatement can be achieved by increasing travel by the less noisy modes.

Some of the many factors that influence the choice of modes are purpose, services offered, safety, distance, time required, cost, convenience, reliability, comfort, efficiency, availability and personal preference. These could be modified either to encourage or discourage the choice of a given mode and therefore influence the modal split. It would be presumptuous in a free society to assume optimal modal split based on noise alone, but noise considerations should influence modal choices.

To achieve a noise-optimal modal split requires an evaluation and comparison of the noise effects of the various modes of transportation on people. But can the effect of high-level aircraft noise on a few people near the airports at each end of a flight be compared with the effect of the somewhat lower level noise of a passenger train on many people along the line from point of departure to destination? Furthermore, a noise-optimized modal split for one community may be far from noise-optimal in another community due to different orientation and quality of transportation facilities. Since personal responses to sound are so complicated and unpredictable, it is difficult to arrive at a rigorous method of optimizing a transportation system with respect to noise.

Factors which should enter into the noise optimization procedure are

1. Relative noise levels of the individual modal noise at a given distance.
2. Duration of noise and frequency of occurrences.
3. Sensitivity of modal noise to increased traffic.
4. Relative separation of the noise-producing elements of the different modes.
5. Number of people exposed to noise by the different modes.
6. Community sensitivity to noise from the modes.

While the above factors must clearly be considered in a modal split to minimize noise, it is certainly not apparent just how each should be weighted. It is possible, however, to arrive at some guidelines for making the necessary decisions in a manner analogous to that of setting values of perceived noisiness. As a suggestion, let a representative group of people who are knowledgeable in the area of transportation noise and urban planning rate the modes for desirability on the basis of each of the factors mentioned above using a rating of 0-10 (10 indicating maximum desirability and 0 minimum desirability). This process should be repeated for each of the modal splits to be considered. (If a true optimization is to be achieved, many different modal splits, all of which fulfill the need, would have to be considered.) Next assign importance weightings to each of the factors previously considered wtih a high weighting indicating maximum importance.

An index number related to the desirability of incrementally increasing a given mode, **i.e.,** a new modal split, can be obtained by multiplying the desirability rating of that factor by the corresponding importance weighting and finding the sum of all numbers thus obtained. A comaprison of the **incremental desirability indices** for the modes can give direction for modifying the modal split for noise reduction. Here the smallest incremental desirability index would indicate the least desirable mode.

The sum of the incremental desirability indices gives an **aggregate desirability index** which can be compared with similar indices from other modal splits to determine the noise optimum split. The best modal split with regard to the factors considered would be the one with the largest aggregate desirability index. An illustrative example of the method is given in Appendix H.

This method of choosing a modal split could be modified to include other pertinent factors which are not noise-related such as feasibility, cost, demand, and convenience in order to avoid obtaining an obviously unrealistic solution. The method uses firm data when it is available and also allows consideration of those factors which cannot be easily quantified. A preliminary solution by this method could be investigated more conventionally to test the validity of the desirability and importance tables which could be modified by an iterative process until a workable solution is obtained. The desirability and importance ratings could then be used to optimize modal splits for other situations by modification of only those ratings which do not fit the new situation.

After the optimum noise modal split has been determined, the next problem is how to achieve it. Solutions to this problem must consider the factors influencing the user's choice of mode. Among the factors previously enumerated only the following will be considered variable for the purpose of modifying the modal split: (1) Services offered, (2) Time required for a given trip, (3) Cost, (4) Convenience, (5) Reliability, (6) Comfort, (7) Efficiency, (8) Availability, (9) Personal Preference. It is assumed that the choice of modes is most directly influenced by the time required for a given trip, cost and availability.

The next question is who will attempt to control the modal split. In a sense, each of the corporations involved in transportation is attempting to influence the modal split in its favor whenever it

improves its performance. Since no single corporation controls all of the modes, it will be assumed that the modal split would have to be controlled by governmental regulation. The three factors just mentioned can be influenced by a number of different means. An attempt to influence the modal split has been made in some areas by the introduction of high-speed rail transportation in an attempt to divert some of the short-haul passenger air traffic. Governmental agencies could influence the modal split by supporting improvements in speed and reliability of existing modes which are desirable from a noise standpoint. The cost of transportation by a noisy mode could be raised either by direct taxation or by placing and enforcing noise restrictions on those modes. Thus, some travel might be shifted away from that mode while at the same time providing incentive for noise reduction.

Partial control of availability, a direct influence on modal split, may be achieved by curfews on given modes during certain hours and restriction of certain types of vehicles from given areas. New modes to draw traffic away from the undesirable existing modes would also influence modal splits.

The total passenger demand supplied by each of the modes considered in a computerized model for the Northeast Corridor is shown in Table 5.4. The existing modes (automobile, air, and bus) were included in each run with various combinations of rail modes and the vertical takeoff and landing mode for aircraft (VTOL). The three rail modes considered were high speed rail over existing tracks (HSRA), high speed rail with new tracks in certain areas (HSRC), and tracked air cushion vehicles (TACV).

The computer results indicated that in the NEC the automobile would be dominant and a maximum variation of only about 3 percent could be made in automobile travel by any of the modal combinations considered. Bus transportation also seemed to be relatively insensitive to the addition of new modes. Conventional air transportation could be varied by about 25 percent by the modal combinations considered.

If one assumes that the worst noise problem is produced by air traffic, it would be logical to choose an optimization method based on minimizing conventional air traffic in and near metropolitan areas. Assuming that noise from both VTOL aircraft and from rail traffic will be held to levels comparable to motor vehicular traffic, the modal splits of Runs 107, 108, 109 in Table 5.4 would be about the same with regard to noise level.

FREIGHT MODAL SPLIT

Consideration must be given to manipulating the freight modes to improve the over-all noise situation. Excluding comfort and personal preference of passengers, the factors influencing passenger modes are also important in the case of freight transportation. The five principal freight modes rated in order of decreasing annoyance are as follows: air, motor truck, rail, inland waterways, and pipeline. It has been shown that the public is relatively insensitive to railroad noise as compared to the noise of air and motor truck modes. The most obvious reasons for this is that there has been almost no new rail lines and thus there has been time for the population to adjust to the presence of railroads in certain areas. This has not been the case with airports and highways which have undergone tremendous expansion coinciding with encroachment of residential areas on the land bordering transportation facilities and vice-versa.

It has been mentioned that the modal split can be influenced by improving the performance of the desired modes with regards to the factors influencing the modal choice. The most versatile freight mode is the motor truck and the second most versatile is the railroad. Inland waterways are restricted becasue of lack of existing navigable waterways between many points, and pipelines are extremely limited as to the types of goods they can transport. Thus it could not be expected that these modes would significantly increase their share of the freight traffic in the near

Total Annual Passenger Demand in Thousands [3]							
RUN	AUTO	AIR	BUS	VTOL	HSRA	HSRC	TACV
102	1753	60.5	71.0	0	0	0	0
103	1744	57.6	69.7	0	55.8	0	0
104	1742	56.8	69.3	0	0	72.1	0
105	1740	55.3	69.0	0	0	0	84.6
106	1710	45.9	64.3	68.3	0	0	0
107	1707	45.2	64.0	67.5	47.7	0	0
108	1706	44.8	64.0	67.3	0	61.9	0
109	1706	45.2	63.9	67.2	0	0	72.8

Table 5.4

future. The choice is one between rail and motor trucks to handle a large part of the total freight traffic.

One of the most promising developments in rail freight transportation has been the introduction of "piggy back" service and containerized freight. Piggy back service involves the transportation of loaded trailers such as are pulled by tractor-trailer trucks on flat cars. Containerization uses standardized containers resembling a truck-trailer without wheels. The principal advantage of such service is that it is a step toward an integrated freight transportation system combining the best features of the two modes. This system is advantageous from a noise point of view because it removes some of the trucks from the highways. Between 1958 and 1969 piggyback car loadings have continued to increase while the total railroad revenue car loadings have decreased slightly.

Containerization in the U.S. has been developed almost exclusively by ship lines. Railroads have failed to seize the opportunity partly because of financial and rate-making restrictions which discourage them from innovating. Containerization can use automated methods while at the same time connecting sea lanes with inland cities.

Other recent improvements in rail transportation which should be exploited to the fullest and expanded are the use of tri-level vehicle carriers for transporting new automobiles, the high-density box car and the unitrain concept. Each of these developments can have a part in reducing transportation noise by diverting freight traffic to the railroads.

When changes are made in a transportation system by influencing the modal split or by introduction of new modes it is necessary to give careful consideration to adequate interfacing between the modes so that new problems will not be caused by what seemed to be a solution to the old problem. Thus new transportation hubs must be carefully planned to avoid congestion, air pollution, and noise pollution. Technology is available for railroads to improve their services greatly both in the freight and passenger business, and while noise is not the most important reason for doing this, it gives one more reason. There is a great need for a truly integrated transportation system which can utilize all modes in an optimized manner, producing cooperation and interfacing between modes rather than competition.

In summary, considerable improvement can be made in the transportation noise problem by manipulation of the modal split. Fortunately such manipulation or optimization is compatible with improving other problems such as air pollution and the economic problems of the railroads. There is a need for the railroads to recapture more of the business they have lost to other modes. If this were done a significant improvement would be noticed in the transportation noise problem.

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Chapter VI

Legal

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Introduction

Where should responsibility for transportation noise abatement be located? From the data presented in the preceding chapter it could be argued that because technology created the noise problem it should shoulder the responsibility of correction. Moreover, the technological capability is available but abatement has not been given sufficient priority. Engineers who design and manufacturers who produce transportation vehicles and equipment cannot be expected to concern themselves too much with noise abatement at the source unless public pressure is brought to bear, however. This also holds true for transportation companies and their concern for operational noise or for proposals to separate or insulate the noise receivers from the noise sources. Public pressure may be exerted in numerous ways.

Common Law Remedies and Judicial Action

As many airport operators have learned to their sorrow, noise has legal ramifications. One basis for compensation for damage or for granting an injunction is allowing a right of recovery based on common law, **i.e.,** the unwritten law or precedent established by courts in past decisions. Disturbing the peace of the community was considered actionable long before urbanization, industrialization, and mass transportation intensified the noise problem in our society. Of the two traditional types of relief awarded for injuries to property or person, monetary compensation for damages is normally the appropriate remedy at law; when money damages are inadequate, however, an injunction may be appropriate, especially when the wrong complained of is of a continuing nature. Yet courts are usually reluctant to grant an injunction which would cripple a properly-conducted business or terminate an activity of significant social utility. Consequently, the measure of relief is usually damages in the amount of decline in property market value or compensation for material injury to persons.

Practically all cases dealing with transportation noise have been based on complaints about airplane operations over or near private residences. Consequently, this analysis will focus mainly on aircraft noise, but the basic legal principles involved are applicable to all sources of transportation noise.

Noise suits have traditionally been based on theories of trespass, nuisance, constitutional taking, and damaging

Trespass

The trespass theory, assuming an unauthorized physical invasion of a property owner's airspace, is not considered obsolete for two main reasons. In 1946, *U.S.* v. *Causby* [58] held that the maxim of property ownership of the sky "has no place in the modern world." and that the airspace above the immediate reaches of the land is part of the public domain. [58]

This was confirmed by the Federal Aviation Act of 1958:

> There is hereby recognized and declared to exist in behalf of any citizen of the United States a public right of freedom of transit through the navigable airspace of the United States. "Navigable airspace" means airspace above the minimum altitudes of flight prescribed by regulations issued under this chapter, and shall include airspace needed to insure safety in takeoff and landing of aircraft. [19]

Nuisance

Nuisance suits are based on the established right to the use and enjoyment of property without substantial and unreasonable interference by others. [47] Once it is determined that a substantial and unreasonable interference exists, however, the court must weigh the plaintiff's interest in peace and quiet against the interests of the defendant and public in maintaining the activity. Because of the great burden of proving that the interests balance in the plaintiff's favor, nuisance suits are probably not the optimum theory of recovery for harmful noise. Private citizens cannot be relied upon to bring action against all offensive noise makers, and the great expense of proving that a remedy is warranted often makes litigation prohibitive. For example, obnoxious city noise is often a mixture of sounds from various unidentified sources, and it would be practically impossible to prove that a particular defendant is responsible for a certain noise source. Even if the proper defendants could be specified, it is an enormous burden to prove that private harm from the activity outweighs its public benefits. It is also very significant that a remedy for a private nuisance is available only when the complainant's enjoyment of **his own** property is impaired. Thus, on this theory of recovery, relief from much of today's harmful noise (e.g., employment noise, travel noise) would be impossible.

Many apparently legitimate nuisance cases are unsuccessfully litigated because of the doctrine of "legalized nuisance." As explained by Lyman M. Tondel, Jr., the concept is that

> . . . *where a public or quasi-public enterprise*, like a railroad, or a powerplant or gasworks, or a sewer system, or an irrigation system, or a throughway, or an airport, or the like, *is expressly authori-*

> *zed by legislation, nuisanc claims that arise out ot its proper operation are to be denied.* The theory is that even if the activity in question would, if privately conducted, constitute a nuisance, it has been legalized by the legislative body which, within consitutional limits, authorized the particular conduct on behalf of the public. [55]

Thus, because of the burden of proof required of the complainant and because of the doctrine of legalized nuisance, suits based strictly on nuisance theory have had very little success in the control of noise.

Constitutional Taking

This theory, on which most noise cases have relied in whole or part is better known as "inverse condemnation" or the "taking" theory. It is based on the principle that the Fifth and Fourteenth Amendments to the U.S. Constitution and similar provisions in most state constitutions require or imply that no private property shall be taken for public use without just compensation. [57]

The so-called "airport cases" are based on the constitutional "taking" concept originating in the 1922 Supreme Court decision of *Portsmouth Co.* v. *United States*. [45] In *Portsmouth*, the Navy had placed a coastal defense battery on a headland and had fired guns seaward over the claimant's land. The court held that the firing of the guns imposed a "servitude" on the plaintiff's land which amounted to a "taking" of a private property for public use for which the Fifth Amendment of the U.S. Constitution required just compensation. [57] The significance of *Portsmouth* is that it recognized the condemnation of an intangible property interest, an aerial easement, which had theretofore been considered noncompensible. (In law, condemnation is a seizure, by the government, of private property for public use. It is usually referred to simply as a "taking.") Whether the object passing over the complainant's land is an artillery projectile, as here, or an airplane (as in *Causby*) there is a physical invasion of the airspace above his land, to which he is considered to have a qualified ownership.

In *U.S.* v. *Causby*, a chicken farmer alleged that he had been bothered repeatedly by aircraft from a nearby military base. The noise and vibration of overflying aircraft for all practical purposes had destroyed the residential value of his land and its value as a commercial chicken farm. The Court, while recognizing the right of freedom in air transit, nevertheless held that the owner might recover damages for a taking by the government of the use of his air space resulting in destruction in whole or in part of the utility of his property. The underlying rationale was espoused by Mr. Justice Douglas:

> Flights over private land are not a taking unless they are so low and so frequent as to be a direct and immediate interference with the enjoyment and use of land . . . It is obvious that if the landowner is to have full enjoyment of the land, he must have exclusive control of the immediate reaches of the enveloping atmosphere . . . The landowner owns at least as much of the space above the ground as he can occupy or use in connection with the land. [58]

In *Griggs* v. *Allegheny County*, a similar physical invasion of the overhead airspace was ruled a taking where aircraft regularly passing on a glide path 11 feet above plaintiff's chimney made the property so undesirable and unbearable for residential use that the complainant was forced to move. [27]] (The *Griggs* case is cited frequently for its holding that the county, the promoter, owner, and lessor of the airport, was the one who took the air easement and was empowered to acquire private property for the use of the airport. The airport operator failed to buy a sufficient air easement over the Griggs property, and thus should be the one by whom compensation should be paid.)

Each of these cases involved a physical invasion displacing the property owner. The taking was not based on the existence of an objectionable noise. It was there and may have caused damage, but damage alone does not constitute a taking. By the Court's reasoning, the physical invasion of the airspace was an essential element in order to award compensation. It is significant, however, that in each of the two cases, the noise was found so extreme that the property was considered worthless for the use to which it has previously been put. From *Causby* and *Griggs*, then, a taking occurs when owners forfeit a physical part of their property for government use. The recovery is for the value of the property actually lost by the invasion plus any consequential damages to the property that has not been taken. However, neighbors whose property has not been physically invaded by the noise source have no right to recovery for damages due to the noise or any other accompanying nuisance.

This principle was confirmed in *Batten* v. *United States* [7] when the Tenth Circuit held that noise, smoke, and vibration from jet aircraft were not a taking of property because there was no physical invasion by direct overflight and there was no suggestion that the property was considered uninhabitable. *Leavel* v. *United States*, following *Batten*, held that there was no taking

> . . . although there was, indeed, a substantial interference with the use and enjoyment (of the property) . . . Although plaintiff's property was located in an area

> of major noise, there was no actual invasion of her property rights by overflights or otherwise, and any damages suffered by her are no more than a consequence of the operations of the Base. [38]

A "taking" not requiring proof of a physical invasion is suggested by *Richards* v. *Washington Terminal Co.* [48] In *Richards* the Court recognized the right to be free from interference with the reasonable use and enjoyment of private property. Richards was the owner of residential land very near the mouth of a railroad tunnel and adjacent to the tracks of a railroad which had the power of eminent domain (eminent domain is the power of the state to take private property for public use upon compensating the owner; see Fifth Amendment, U.S. Constitution). He claimed that although there had been no actual physical invasion of his property by the trains, his interest in its enjoyment had been partially destroyed, (or taken) and thus condemned by two of the railroad's activities: by dust, cinders, smoke, and vibrations coming onto his land at points at which it abutted the tracks, and by an **intense** blast of dust smoke, and cinders fanned from the mouth of the tunnel. The Court denied compensation for the first kind of harm since it was of the kind and degree suffered by all persons living the track, harm normally incident to the operation of a railroad. The second kind of barn, which was unique to Richard's property, the Court held amounted to a condemnation of his interest in enjoyment of the land. The Court defined this interest as the right to be free from "special and peculiar damage" of a kind not suffered generally by those affected by the public enterprise. (It should be noted that in the law of nuisance there is an established right to be free from "unreasonable" interference in the use and enjoyment of property; in the law of eminent domain, according to *Richards*, the right is to be free from "special and peculiar" interference, by which is meant something more severe than "unreasonable.")

Few cases have dealt with the loud noises made by trucks and cars moving on modern high-speed expressways, and all have unanimously held that there can be no recovery. Widely cited is a passage from the opinion in *Bennett* v. *Long Island RR*:

> The rumble of trains, the clanging of bells, the shriek of whistles, the blowing off of steam, the discordant squeak of wheels in going around the curves, the emission of smoke, soot and cinders, all of which accompany the operation of steam cars, are undoubtedly nuisances to the neighboring dwellings in the popular sense, but are regarded as protected by the legislative authority which created the corporation and legalized its corporate operations. Nor does the legal nature of such annoyances change as traffic increases them in volume and extent. [9]

In *Thornburg* v. *Port of Portland*, [54] however, the court decided that a "continuing and substantial interference with the use and enjoyment of property" due to aviation noises is a taking, and the issue of whether it is substantial enough to permit recovery is for the jury to decide. Since the accepted definition of a nuisance is "a **substantial** interference with the reasonable use and enjoyment of land," the *Thornburg* doctrine might make every nuisance compensible, though this hardly seems likely.

Constitutional Damaging

The theory of constitutional damaging is similar to that of a taking except that only damage to property need be proven, precluding the physical invasion sometimes held necessary for a taking. Complaints of constitutional damaging are usually based on state constitutions which contain "damaging" provisions similar to taking provisions. About half of the state constitutions contain these. *Martin* v. *Port of Seattle* [39] relied on the damaging provision of the Washington constitution and took a more liberal approach to the requirements for relief by holding that a compensible damaging may be shown regardless of whether the damages alleged are greater than "substantial." In its decision, the Washington Supreme Court ignored its own past railroad cases, among which there was precedent which rejected constitutional "damaging" claims for substantial property depreciation resulting from railroad fires. [15]

By present common law, an injunction will not be issued to restrain the government or a government-authorized entity from a noisy activity so long as the activity is sanctioned by law and is not being conducted negligently. A plaintiff's only remedy would be damages in the amount of his property depreciation or personal injury.

The common-law rule concerning noise is probably not too far advanced from *Richards*. noise alone from a government or government-authorized source does **not** constitute a taking, even in the face of a decline in value of the complainant's property. Possibly this doctrine may change with any future recognition that the "damaging" provisions in an increasing number of state constitutions would permit recovery by the nearby landowner in such a set of circumstances. But until this is established with the appropriate limitations on what types of damages are deemed compensible, it cannot be assumed that the *Richards* doctrine is obsolete.

If legitimate damages are apparent in the absence of any physical invasion, a good argument for recovery might be based on the *Thornburg* and *Martin* cases. But since these are recent state court

decisions, success of a complaint based on them is questionable. Obviously, neither of the two decisions is consistent with *Causby* and *Griggs* since recovery was allowed in the absence of physical invasion of the complainant's property. Similarly, the principle involved is irreconcilable with *Richards* since there was no evidence that the plaintiff's damages were "special and peculiar" and of a kind not suffered by neighboring landowners. Then too, the *Bennett* doctrine, which conflicted with each of the two decisions, was not mentioned by either court.

It is difficult to project the impact of these two cases. Possibly the two courts intended to make a separate rule for aviation but hesitated to admit it expressly because of fear of violating the due process clause of the Fourteenth Amendment. Maybe the courts intended to reverse all previous eminent domain law. Whatever their purpose, it will most likely remain undiscovered until tested by future litigation of similar causes of action. One thing is clear: *Thornburg* and *Martin* would provide an excellent framework for establishing a more liberal recovery scheme for transportation noise.

Legislative Authority to Abate Transportation Noise

While common law recovery may provide adequate relief in certain cases, its role in exerting public pressure is limited. It takes time and money to fight a case through the courts, and many people are uncertain of their rights or unwilling to test them in the courts. Frustration with the ineffectiveness of court action in so many cases may account for at least some of the anti-noise demonstrations that have taken place in the vicinity of airports.

Court action may be a very appropriate spur to legislation, however. For example, if public opinion demands further regulation of transportation noise but legislators refuse to act because of vigorous lobbying against it or because they are not convinced the problem is serious enough to require it, a number of court rulings or one important decision upholding complainants could accentuate the need for legislative action. By establishing the principle that people should have the right to enjoy a reasonably quiet environment as basic to the liberty guaranteed in the Fifth and Fourteenth Amendments, the courts might insure that future noise suits would be decided on the basis of a recognized principle of law, and not the present inconsistent, indirect, and often frustratingly prohibitive scheme requiring extensive proof of damage to property or health.

The word "liberty" has been greatly expanded already by judicial interpretation. *Griswold* v. *Connecticut* [28] demonstrates the process by which the Supreme Court may find a constitutional basis for unenumerated rights; the right or privacy, although not specified in the Constitution, was deemed a "peripheral" right which carried the same protection as those specifically listed. Having gone that far to protect the right to privacy, there seems to be no reason for the Supreme Court not to recognize the right to a reasonably quiet environment. The Ninth Amendment provision: "The enumeration in the Constitution of certain rights, shall not be construed to deny or disparage others retained by the people" has been increasingly used in recent Supreme Court cases to uphold rights the framers neglected to include in the Constitution.

Statutory law provides more definiteness and certainty than common law for the protection of personal rights. Moreover, both the Constitution of the United States and the state constitutions provide for a number of governmental powers which might be interpreted to protect people against noise. Also, the prospects for effective and comprehensive action in dealing with the problem are greatly enhanced, especially if this action is at the federal level where it can be used to benefit the whole nation.

National Power

The greatest potential for federal noise abatement legislation lies in the constitutional power of Congress, "to regulate commerce with foreign nations, and among the several states . . ." The Interstate Commerce Commission has exercised a wide range of powers over railroads, highway commercial carriers, pipelines, and inland waterways for many years, and the Department of Transportation recently has been authorized to exercise numerous powers relating to transportation noise abatement on the basis of this power. In addition, Congress has the power "to make all laws which shall be necessary and proper for carrying into execution the foregoing powers . . ." This "elastic" clause has shown remarkable versatility when coupled with other constitutional powers, to expand greatly the specifically delegated powers of Congress. For example, Congress has exercised the power to regulate intrastate commerce if such commerce materially "affects" interstate commerce. Other constitutional powers of Congress which might be used for abating transportation noise are its taxing and spending powers, its power to exercise exclusive legislation in the District of Columbia, territories, and property belonging to the United States, and its power to establish post offices and roads. As the Walsh-Healey Act demonstrates, Government contracts can also contain noise abatement provisions as conditions required of contractors, subcontractors, and suppliers.

All state constitutions, laws, and judicial decisions are subject to the "supreme law of the land" which Article Six describes as the United States Constitution, national laws made in pursuance of it,

and treaties made under the authority of the United States. The significance of this for noise abatement is that a federal statute, provided it was deemed to be within the constitutional powers of Congress, would pre-empt any conflicting subordinate legislation and would block any attempts of state or local governments to prevent noise abatement measures. Similarly, if a state or local government used its police power to abate transportation noise but in such a way that it interfered unduly with interstate commerce or was unreasonable, denied equality, or required national uniformity, it could be ruled unconstitutional whether or not federal legislation on the subject existed.

Recent Supreme Court decisions illustrate that it is not as opposed as it once was to Congress using its powers to accomplish purposes other than those traditionally associated with their exercise. Though Congress has no directly delegated powers to provide for the general welfare, safety, health, and morality of the people nor to "insure domestic tranquillity," there is no reason why it may not seek to accomplish those goals through the fullest use of the powers which it does have. Likewise, although the Bill of Rights is intended as a limitation on the powers of the national government and not an extension of its powers, Congress is not prevented from using its powers in a positive way to make those rights more meaningful in a society increasingly in need of protection against noise. So far, Congress has used its power to abate transportation noise very sparingly but might be encouraged to do more.

State and Local Power

State and local governments, in contrast to the national government, are not restricted to powers specifically delegated by the United States Constitution. The Tenth Amendment reads: "The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States, respectively, or the people." Within the limitations on the use of its reserved powers expressed in the Constitution (as interpreted by the Supreme Court), therefore, the states and the subdivisions of government responsible to them possess the power to abate transportation noise within their boundaries if they wish to do so. Examples of what they have done so far follow.

City and State Regulations Highway Noise Ordinances

Most states and large cities have based their highway noise legislation on the Uniform Vehicle Code published by the National Commission on Uniform Traffic Laws, Washington, D.C. The portion of the code related to noise is purely subjective and relates only to muffler noise. Enforcement depends on the judgment of the police. Because of this difficulty of interpretation, the code has been upheld in some court cases and declared unconstitutional in others. [26]

To counter the general ineffectiveness of the subjective code, a number of cities have introduced into their codes objective measures of vehicle noise requiring use of a sound-level meter. Results have been mixed. In some localities the objective noise limit was set too high. Columbus, Ohio, repealed its legislation when it proved unenforceable. The noise of a particular vehicle could not be isolated on a busy street. Milwaukee, Wisconsin, also repealed an objective noise ordinance which had been effective, but was declared unconstitutional on the grounds that it unfairly affected nonresidents passing through the city. On the state level, only New York and California have passed objective highway noise control laws, although many other states are considering them.

New York adopted its legislation in 1965. Noise is considered excessive if it exceeds 88 dB(A), plus a 2 dB(A) tolerance, measured 50 ±2 feet from the center of the traffic lane at a speed less than 35 mph. Enforcement of this law has proved difficult, for while the vagueness of the subjective law has been eliminated, new problems have arisen. For example, the statute can only be enforced near toll stations where traffic is moving slowly (less than 35 mph) and the vehicles are sufficiently separated that the noise measurement corresponds only to the vehicle in question. Officials consider the maximum noise levels too lenient, as the only violations have been by diesel trucks, most of these with defective mufflers. In a 3-year period following passage of the act, only 45 arrests were made after checking 9,569 vehicles. [34] There have been no cases contesting the constitutionality of the ordinance.

In 1969, California amended its vehicle code to prescribe maximum noise limits for motor vehicles at speeds greater and less than 35 mph. Different noise levels in dB(A) units are specified for several categories of vehicles to be measured 50 feet from the vehicle. The statute also specifies lower noise limits to be met after January 1, 1973. New model vehicles cannot be sold within the state until a randomly selected sample exhibits compliance with the law. In the first 6 months the law was in effect, about 500 citations were issued. To date the constitutionality of the law has not been questioned. California officials have found that they can easily discriminate the noise of one vehicle from another in the curb lane of interstate highways. Initial experience indicated that the noise limits for motorcycles had been set too high. In April 1970, a bill was introduced in the legislature to amend the highway noise law by lowering the levels

permitted for motorcycles and automobiles. [12] This bill was passed in August 1970.

The California legislation is the most advanced and comprehensive highway noise law in this country (Appendix F). Based on its apparent success, many other states are considering the adoption of similar legislation.

It appears that the states are the smallest governmental units that can enact uniform noise limits because of the complications arising from different noise limits in adjoining communities. However, if a state law is not "adequate" for a community, there may be demand for a stricter local law. For example, New York City has found that the state noise limits are "completely unrealistic for the city." In many parts of the city, buildings are only 60 feet apart and the permissible noise levels on the sidewalks are well above hearing conversation cirteria. [56] Writers of noise limit legislation, therefore, must be careful to consider the unique requirements of their area and not just indiscriminately utilize specifications used in other localities. [18] The enforcement of any objective noise standard depends on the capabilities and limitations of the measurement equipment and the personnel that operate it. To be effective, measurements must be made with accurate and calibrated equipment by personnel properly instructed on noise measurements.

Airport Noise Ordinances

In reaction to mounting airport noise levels and their increasing damage to persons and property, individuals, citizens groups, and local legislatures have taken steps to abate and even totally eliminate aircraft noise. People harassed by the increasing noise of bigger, faster aircraft and more numerous flights have made dramatic attempts to draw attention to their plight: Mothers in Los Angeles have wheeled baby carriages on runways, and citizens have even taken pot shots at overflying aircraft. In a more orderly and acceptable (though perhaps not less emotional) approach, others formed citizens' committees to create awareness of the magnitude of the noise problem and to make legislators cognizant of the need for intelligent and effective legislation and enforcement. As a result, municipalities in several states have enacted ordinances designed to suppress airport and aircraft noise. These ordinances and ensuing court battles emphasize the problem faced by persons interested.

In *Allegheny Airlines, Inc.* v. *Cedarhurst* [3] the village was denied the right to enforce its safety ordinance which prohibited overflight at an altitude of less than 1,000 feet on the grounds that it invaded and conflicted with an area of legislation which the U.S. had pre-empted.

Audubon Park, Kentucky (Ordinance 4, S1 (Series, 1967), November 20, 1967) passed an ordinance prohibiting flights or operation of any aircraft over the city at a height of less than 750 feet. A Federal district court in 1968 permanently enjoined its enforcement as unconstitutional on the grounds that it was an undue burden on interstate commerce, an invasion into an area pre-empted by Congress, and in direct conflict with federal legislation. [4]

American Airlines, Inc. v. *Town of Hempstead* [5] involved New York City's John F. Kennedy International Airport, one of the busiest airports in the nation. The district court concluded that Hempstead's ordinance (limiting aircraft noise levels) unconstitutionally burdened interstate commerce, and that it operated in an area requiring uniform legislation and already pre-empted by federal legislation. The court of appeals affirmed the district court's decision on the grounds of direct conflict with applicable federal regulations controlling the patterns and procedures of aircraft flying in and out of Kennedy Airport because "compliance with the noise ordinance would require alternations in the flight patterns and procedures established by federal regulations." [6] The Hempstead ordinance and its failure symbolize the difficulty in resolving the noise problem by local ordinances aimed at controlling commercial airline operations. Some courts have allowed the enforcement of local ordinances barring jets from airports at certain hours, but these cases are of limited value as they refer only to airports handling primarily corporate jets and thus do not interfere significantly with commercial jet operations.

One effective and encouraging example of noise abatement is that adopted by the Port of New York Authority which operates the John F. Kennedy International Airport. It considers itself in a landlord-tenant relationship with the airlines using the facilities and in this capacity has set certain "lease conditions" which the lessee airlines must meet. One such condition is a 112 PNdb maximum noise level for aircraft take-offs at certain specified distances from the borders of the airport. As operator of Kennedy airport, it enforces its own regulations which affect flight patterns and procedures at the airport. The Port Authority defends its regulation as an expression of the common-law right of property ownership and control which thus can co-exist with federal laws and regulations. In *Port of New York Authority* v. *Eastern Airlines, Inc.*, [44] the district court upheld the regulation. If the Port Authority's position is a valid one, local governments may not need to resort to "police power" to impose maximum noise limits; municipal airport departments may achieve the same end by setting appropriate conditions in the airport lease-contract. In fact, the recently adopted Part 36 of the Federal Aviation

Regulation which prescribes aircraft noise standards for subsonic transport and turbojet airplanes states that:

> Compliance with Part 36 is not to be construed as a federal determination that the aircraft is "acceptable" from a noise standpoint, in particular airport environments. Responsibility for determing the permissible noise levels for aircraft using an airport remains with the **proprietor** of that airport. The noise limits specified in Part 36 are the technologically practical and economically reasonable limits of aircraft noise reduction technology at the time of certification and are not intended to substitute federally determined noise levels for those more restrictive limits determined to be necessary by individual airport proprietors in response to the locally determined desire for quiet and the locally determined need for the benefits of air commerce. (emphasis added)

All the FAA does is certify aircraft noise limits which it feels are technologically practicable and economically reasonable for individual type aircraft construction standards. It does not attempt to regulate operation or the volume of aircraft using a given airport. (For airports which have enacted various noise abatement procedures, see Appendix J.)

Noise at night is more annoying than like noise during daytime hours. Therefore, various types of night curfews may also be an effective method of decreasing annoyance levels of an airport's immediate neighbors. It is the responsibility of planners and of airport management to weigh the costs associated with a curfew in considering this possibility.

Zoning and Land Use

Zoning as a community function is based on the premises that the community interest is greater than that of the individual and that a satisfactory procedure can be devised for making zoning decisions. Case law [60] has firmly established that it is within the police power of the state to create zoning for the improvement of public health, morals, safety, or general welfare. However, the local authorities may not enact zoning regulations which interfere with Federal regulations.

With the growing recognition that noise can be detrimental to man, greater efforts are being made to regulate noise exposure, but few existing zoning laws incorporate providions for noise control. Of those that do, most are unenforceable, containing certain vague phrases that defy quantifications; for example, "excessive and unnecessary noise."

Traditionally, land use zoning is a local function with related individual decisions varying widely. Noise generated by arterial highways, airports, and other transportation modes generally affect large land areas encompassing several local jurisdictions which have rarely enacted effective regional zoning because of local pressures and politics. [2] The interests of communities in a given area are not always consistent with each other or those of the noise-producing activity such as airports and surface transportation lines.

The failure of the existing zoning codes to contain the noise problem has produced suggestions for modifications. Increasingly, quantitative noise exposure limits are being incorporated into zoning codes. An example is a performance standard established in Orlando, Florida, [25] which sets maximum noise levels at the boundaries of commercial and industrial zones. This type of zoning should be extended to include residential areas. In addition, increasing efforts are being made to incorporate compatible land use near major noise areas. However, adoption of such criteria is beset by a multiplicity of vested interests. For each action proposed there is someone or some group that will suffer for the benefit of the majority. [11]

The greatest appeal for compatible land use exists at present and future sites where land has not yet been developed. Industries can be located near noisy arterial highways, farming can be planned near airports, and shopping centers can be a buffer between industrial locations and residential areas. The major problem facing land use zoning is the coordination and cooperation of the many local governmental units that may have jurisdiction over the area to be zoned. Implementation of comprehensive zoning becomes subject to many strong and diverse political pressures.

In a bold step, the State of Minnesota recently passed an Airport Zoning Act [42] placing all types of land use and development control measures in the hands of an area-wide metropolitan council. The zoning act specifically charged the council with estimating noise exposure near new airport sites and basing their land use criteria and guidelines on their determination of an acceptable perceived noise level for the activities involved. The council has the authority to enforce compliance by local governments in the airport development area to share the tax resources generated by area growth.

California is currently considering a comprehensive set of rules and regulations [16] to set noise standards for existing and future state airports. The proposed standards include measurement methods, acceptable noise levels, land uses deemed compatible in high noise areas, and methods for controlling and reducing noise. However, in its current form the proposal does not specifiy how conflicts between

several affected communities are to be resolved. In comparison with the Minnesota act, the California proposal is directed more to existing airports and to airport operators.

In densely populated or highly developed areas, zoning does not hold much promise as a tool to lessen the impact of noise exposure. There are several reasons for this. [52] Zoning re[illegible]ons do not apply retroactively and thus are inef[illegible]e in changing existing land use that may be adversely affected by noise exposure. Land use zoning could not be enacted without monetary reimbursement to land owners if the zoning is held to be a taking of property. Generally, reasonable zoning, [50] particularly near airports, has been upheld; however, in several cases the courts have ruled that airport zoning restrictions can constitute a taking of property which requires just compensation. These precedents could be used by airport operators and others to resist compatible land use zoning because the zoning may force the operator to buy out a large number of property owners. Moreover, the validity of such zoning has not yet been established through court litigation. The final problems are practical and political ones.

Zoning will not and cannot abate transportation noise, and several local governments, all protective of their zoning rights, may be involved in compatible land usage. Zoning for noise control and compatible land use may be very useful for rural or new transportation centers or routes in remote areas, but such zoning can provide only a small portion of the solution to the transportation noise problem in highly urban and suburban areas.

Proposed City and State Action

Transportation is the predominant noise source in most urban areas today. As noted above, the smallest governmental unit which could realistically and effectively enforce motor vehicle noise limits is the state, but state laws have had severe drawbacks: public awareness and lack of concern for the growing noise problem, inadequate research, poor monitoring systems, ineffective enforcement of regulations, and vague, subjective language. This is the result of insufficient coordination among the various code authorities which draft noise control legislation and the drafting of such legislation on the basis of misleading, erroneous, and inadequate information. [34]

In spite of the problems involved, cities and states cannot simply ignore noise pollution until higher governmental levels have acted or environmental casualties precipitate action. [10] Immediate steps must be taken. The noise could be regulated at its source by prohibiting sale or operation of vehicles which exceed certain maximum noise limits (as in California). This could be initially done by testing random samples of all new car models to be sold in the state to determine if they meet the noise criteria. Natural deterioration of vehicles and changes made on them by their owners will necessitate monitoring and inspection procedures to insure continued operation within the acceptable noise criteria. This could be achieved by such methods as the use of sound meters installed in police patrol cars and at stationary locations along highways. Police could then write citations in the same way they do for violation of any part of the motor vehicle code. Noise readings could be added as a regular part of random road inspections made in some states and as part of regular automobile inspections in others. A licensing or inspection agency of municipal governments might also check by random sampling whether vehicles, aircraft, and powered equipment meet environmental noise standards. Noise restrictions on equipment used in state and local highway construction and maintenance as well as state and public utility vehicles could also be useful. Another regulation attacking the problem at its source is airport regulation of the numbers and kinds of aircraft that can take off and land at given hours. (For airports that have done this, see Appendix J.)

A second method of control is to insure compatible land use in the noise-affected areas. This can be done by requiring that noise contours be developed for existing and proposed highways, and then prohibiting construction where existing noise sensitive areas are within unacceptable noise contours, and (where economically and practically feasible) prohibiting construction of housing, hospitals, etc., in areas in which such unacceptable noise levels already exist. Zoning should be examined closely for use in such noise-sensitive areas as school and hospital locations. States and Municipalities might also require that proposed airports buy available land around the airport sites which would be within certain unacceptable noise contours and direct that such land be used for noise compatible interests(**e.g.**, golf course, industry, etc.).

Requirements for insulation of buildings which will be in areas of high noise exposure may be another effective tool. Hawaii, for example, has recently passed a bill [31] for acoustic noise control in schools in areas affected by noise.

Federal Noise Legislation

The Walsh-Healey Act, as amended May 20, 1969, provides Federal protection from harmful noise exposure to employees of Government prime contractors, subcontractors, and suppliers with Government contracts totaling $10,000 or more. Although primarily aimed to protect plant workers, the act is also applicable to transportation employees and thus

offers great potential for the abatement of a substantial segment of transportation noise.

The first federal law specifically directed toward transportation noise abatement was the Federal Aviation Act of 1958, [20] creating the Federal Aviation Authority (FAA) with power to issue "certificates of airworthiness' for aircraft and to pre e rules of air traffic relating to noise abatement. The FAA remains today the only Federal agency specifically authorized to make regulations regarding transportation noise abatement. The CAB is charged with "economic" regulation of air transportation and the FAA with "safety regulation."

Congressional hearings on noise abatement in 1962 and industry seminars by the President's Science Advisor in 1965 led to creation in 1966-67 of the Interagency Aircraft Noise Abatement Program (IANAP). In the same year, the FAA placed noise limits on airplane take-offs, adopted noise reduction flight procedures, and adopted a preferential runway system at Kennedy International Airport. [35] The IANAP implemented a program to provide policy guidance, to advise industry, and to promote interagency cooperation and coordination. In 1966 the new Department of Transportation [17] into which a number of functions and agencies (including FAA) had been consolidated was charged with promoting and undertaking research and development relating to transportation, including noise abatement, with particular attention to aircraft noise; consequently, an Office of Noise Abatement was established. Creation of the new department placed all major forms of U.S. transportation in one organization with the potential of regulating the noise of all modes. However, the concept of comprehensive transportation noise abatement as a national policy is apparently still too new to gain much acceptance.

On July 21, 1968, Public Law 90-411 empowered the FAA to regulate aircraft noise and sonic boom. The Administrator of FAA, in consultation with the Secretary of Transportation, is directed to prescribe and amend standards for measuring aircraft noise and sonic boom, and apply such standards, rules, and regulations in the issuance, amendment, modification, suspension, or revocation of any certificate authorized by Title VI of the Federal Aviation Act of 1958. Accordingly, Part 36 of the Federal Aviation Regulation went into effect December 1, 1969, [23] prescribing aircraft noise standards for subsonic transport type airplanes and for subsonic turbojet powered airplanes regardless of category. Effective Perceived Noise Level units are used for evaluating aircraft noise at three points of measurement along the flight path. The new regulations use a sliding scale based on the size of the airplane and set the maximum allowable noise volume for the three points of measurement. (These are discussed in more detail in Chapter V.)

Individual airport proprietors may lower the noise levels below those prescribed, but this is unlikely, and the FAA standards prevail because these are assumed to be as low as is economically reasonable, technologically practicable, consistent with the highest degree of safety, and appropriate for the type of aircraft to which they apply.

The Civil Aeronautics Board can control the volume (and indirectly the noise) of air traffic by its authorizations of air routes, but it has not yet considered environmental impact pertinent to such determinations. DOT has expressed to the Board its disagreement with this view, arguing that noise and air pollution are important factors to weigh in determining whether to authorize air service. At the same time, however, the DOT believes its own role in noise abatement should be solely in its initial aircraft certification authority and not in its power to establish safe flight procedures.

Another proposed FAA rule would amend Part 91 of the Federal Aviation Regulations to protect the public from civil aircraft sonic boom in accordance with the requirements of section 611 of the Federal Aviation Act of 1958. The National Environmental Policy Act of 1969 [43] is cited as supporting control of civil aircraft sonic boom.

Sonic Boom

Since the FAA has termed commercial SST flight over U.S. land masses at speeds producing sonic booms economically and technologically "unnecessary," it is perhaps superfluous to discuss liability for such commercial flights. It is presently suggested that if a commercial or private flight over the United States were to create a sonic boom, the airline would be held strictly liable (i.e., claimants would not need to prove negligence) for damages to persons or property caused by the boom. [46], [33]

Most sonic boom damages to date have been caused by military or experimental aircraft (commercial SST flights will not begin until 1971-1974), and have therefore fallen under the Federal Tort Claims Act. Strict liability is excluded as a theory of recovery under the act, as are damages which are the result of the performance of discretionary functions by the Government.

Recent decisions have held that the Federal Tort Claims Act's exclusion for "discretionary acts" applies to the creation of sonic booms by United States pilots and will therefore block recoveries for sonic boom damages on the bases of sovereign immunity. [32], [37], [49] In another decision, [59] the Government waived the discretionary function defense and expressly acknowledged the purpose of the test flights to have been "to measure structural response to sonic booms as well as to determine the normal reaction to ground population over a signific-

ant period of time to sonic boom pressures . . ." The court allowed recovery for the resulting damages, the decision apparently turning on the elements of causation and intention.

Suits by private citizens against the Government for sonic boom damage may be an immediate answer to the problem of a few individuals already injured. But in the long run, the greater threat is the possibility that in spite of the proposed FAA rule, [13] the SST may eventually fly at supersonic speeds over the continental United States. The types of damage that may occur include broken windows, injuries from flying glass, plaster cracks in houses, leaks in roofs, injuries resulting from sonic boom-caused startle reactions, and breakage of household goods shaken off shelves. Some inadequacies of the present laws are:

> (a) a plaintiff seeking compensation must prove that the sound (the sonic boom) infact caused the damages. That causal relation will be difficult to prove, both because of conflict among the experts about damage and because the plaintiff may not be able to identify the specific airline involved. He will have to get access to the records of the airlines of the Civil Aeronautics Board, not an easy task; even if successful, he will still have to pinpoint the cause-and-effect relationship between noise and damage. (b) it is not likely that insurance companies will readily pay off on "all risk" or "aircraft damage" clauses for claims for sonic boom damage. (c) unusual theories of recovery—negligence, *res ipsa loquitur*, trespass, strict liability, and the like—simply do not seem adequate to the problem. The net conclusion must be that present law is inadequate. [41]

A possible means of alleviating the financial burden on land owners by allowing reasonable recovery for damages might be to establish an entity by Federal **statute** that would be liable for all boom damage. All airlines that operate SST's would be required to contribute to the entity in accordance with a formula measuring boom damage risk. (For example, contributions in proportion to the number of an operator's SST flights, the population under its average flight carpet, and normal overpressure of its particular plane type at cruising speed and attitude.) [8]

Proposed National Legislation

It may be that much of the regulation of transportation noise should be done by state or local rather than the Federal government because Federal regulation might be too expensive and too difficult to implement. However, a centrally coordinated and comprehensive attack on the problem would be superior to the irregular pattern of state action that might be expected. The Federal government can provide model noise level requirements for Government contractors, for geographical areas in which it has exclusive jurisdiction, and for interstate commerce.

As transportation noise increases, an effective and systemized approach would be action on the federal level, through an agency which could coordinate national, state, and local work by encouraging research into the technology of noise abatement, setting acceptable noise guidelines for automobile manufacturers (as it now does with safety regulations requiring head rests, seat belts, padded dash boards, etc.), determining guidelines for acceptable noise levels on highways and for individual motor vehicles, and encouraging effective monitoring and enforcement of state laws made within the parameters of the federal regulations and standards.

President Nixon has recently proposed an anti-pollution agency, the "Environmental Protective Agency" (EPA), which will be concerned with water pollution, solid waste management, pesticide regulation, and radiation standards; an an ocean-and-atmosphere administration, "National Oceanic and Atmospheric Administration" (NOAA), which would lead research and development of National programs affecting the oceans and atmosphere. Under the President's plan, the two agencies would work in conjunction with the Presidential Council on Environmental Quality, created under the National Environmental Policy Act of 1969, [43] which will continue to coordinate Federal environmental policy and advise the President regarding protection and enhancement of the quality of the Nation's environment.

Executive Order 11514, "Protection and Enhancement of Environmental Quality," states that the Council shall among other things: promote the development of monitoring systems, assess environmental conditions, determine the effectiveness of programs for protecting and enhancing environmental quality, and foster investigations, studies, surveys, research, and analyses relating to environmental quality and the impact of technology. The act also prescribes that all agencies of the Federal government shall "include in every recommendation or report on proposals for legislation and other Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on . . . the environmental impact of the proposed action." This council would be in a position to recommend rules and regulations concerning acceptable and technologically practicable maximum noise levels (working in conjunction with other Federal agencies) and could also aid states in investigations for noise control through better highway and

airport planning and better airplane and motor vehicle technology.

However, major responsibility for control of all transportation noise should be centralized under the auspices of an independent agency whose major concern is the total environment, removed from existing bodies which are vulnerable to conflicting priorities and from scattered groups proposing impractical, incompatible, and ineffective solutions. It should be vested by Congress with rule making and adjudicative authority to control environmental pollution. This agency could evolve from the President's proposed Environmental Protection Agency. It would coordinate research and formulate uniform Federal laws for manufacturers, industry, and the general public.

Conclusion

Clearly, there are potential constitutional grounds for the control and abatement of transportation noise at all government levels. A Federal legislative scheme, however, would provide uniformity and coordination not present in a local state-by-state approach. Yet as past history has shown, oftentimes Congress is lethargic in legislating to control environmental problems, and consequently, much money and many valuable resources are wasted. Widespread noise abatement legislation and litigation on the state and local levels would hasten Congressional response. **Now** is the time to petition legislators to provide effective control for the ever-worsening transportation noise problem.

MUNICIPAL NOISE ABATEMENT SCHEME
CENTERS OF GREATEST NOISE ABATEMENT POTENTIAL

PRIMARY SOURCES OF EXTERIOR NOISE POLLUTION	MUNICIPAL DEPARTMENTS									OTHER
	Airport	Building	City Planning	Health	Licensing	Police	Traffic	Municipal Legislature	State Division of Highway	Federal Aviation Administration
GROUND VEHICLES		●	●	●	●	●	●	●	●	
Engine Noise				●	●	●	●	●	●	
Building Insulation		●		●				●		
Screening			●					●	●	
City Planning		●	●					●	●	
Land Use			●					●	●	
AIRPORT, AIRCRAFT, AIRWAYS	●	●	●	●	●	●	●	●		●
Airports	●	●	●	●		●	●	●		●
Airways	●		●	●		●		●		●
Engine Noise	●	●	●	●	●			●		●
Airline Location	●		●	●		●		●		●
Environmental Air Controller	●		●	●				●		●
Land Use	●		●	●				●		●
Insulation, Screening, Design	●	●	●					●		●

Adapted from:
Melville Branch et. al., Outdoor Noise and the Metropolitan Environment.

Figure 6.1. This chart may be used as a checklist of the proper municipal departments to select for abatement of various sources of noise pollution.

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Chapter VII

Recommendations For Noise Control

Transportation exists to serve individual travel needs and move vital goods and materials. As this report has shown, the demands placed on the United States transportation system will increase dramatically during the next fifteen years. But a paramount need, as people are becoming increasingly aware, is for a wholesome environment. Unfortunately, several forms of pollution, the by-products of modern technology, are degrading our environment. Our transportation system is a major contributor to ecological unbalance.

One of the most heinous by-products of transportation is noise. Virtually everyone in the United States has been bothered by transportation noise, and many have been quite adversely affected. Noise has been shown to contribute to hearing loss, speech interference, annoyance, stress, and sleep disturbance. There are indications that such noise is detrimental to the environment as well. As all pollutants are, in economic terms, external diseconomies or "social costs," all of society is made to pay the social costs of transportation noise pollution.

The need for mobility, economic growth, and national defense have motivated subsidies to develop the present transportation system. Now, society is demanding that the environment be given at least equal importance in national planning. Recognizing that health, happiness, and even survival are at stake, the public is demanding immediate action. A very significant response must be the reduction of transportation noise.

Summarizing conclusions reached earlier in this report, this chapter provides the information needed by state and local planners, as well as legislators, who choose to accept the challenge of reducing transportation noise pollution. Included are specific suggestions for noise criteria as well as recommendations and strategies for noise abatement through public awareness, legislation, community planning, and technology (see Figure 7.1).

Noise Criteria

The effects of noise on communities and on man's physiological and psychological processes were discussed in Chapter III. These effects suggest upper limits for noise exposure below which human functioning will not be impaired.

Table 7.1 shows maximum levels for continuous long-term noise exposure without adverse effects. Therefore, they establish optimum maximum noise limits for any noise-abatement design. Chapter III presents the hard data for these far from arbitrary exposure limits: the well-documented effects of noise on various aspects of human performance. Table 7.2 presents criteria for indoor and outdoor noise exposure in various community areas. Except for airports, the levels are for continuous, steady noise. If a continuous noise contains impulse noise or audible tones more than 10 percent of the time, maximum levels should be decreased by 5 dB(A).

Table 7.3 presents both recommended and typical existing levels for the various transportation modes and for construction equipment. Measurements should be made at 50 feet from all ground vehicles; or, in urban areas where these distances are impracticable, at 25 feet, with recommended limits increased by 2 dB(A). The background or ambient noise level must be at least 10 dB(A) below the vehicle noise level for measurements to be accurate. Each criterion must be similarly qualified for the duration, frequency, familiarity, and suddenness of the particular noise.

Some of the levels in Table 7.3 are well below similar ones in other reports which are based primarily on the capabilities of present technology. Future noise-abatement efforts, however, must consider all of the effects of noise on human factors in establishing ultimate goals. These goals should provide for long-range, step-by-step efforts to reduce noise from present to recommended levels, and to prevent new noise sources and increases in present ones. The criteria indicate what a safe noise environment should be in the hope for reasonable progress to make our lives less stressful.

Strategies For Noise Control and Abatement

Concerned and enlightened individuals and groups can effect significant reductions in current transportation noise levels. This voluntary cooperation to improve the environment, a cultural response to the noise problem, can be mobilized by education and cooperative information exchange. The following recommendations seek to contribute toward such goals.

Education

The public, manufacturers, and policy makers should be educated concerning noise as an annoyance, a health hazard, and, more generally, as an environmental pollutant. Although many people are annoyed by transportation noise, there is insufficient awareness that noise causes hearing loss, speech interference, stress, sleep disturbance, and may have adverse effects on job performance.

Industrial Efforts

Industry should be encouraged to publicize its positive efforts towards noise control and abatement, in the hope of generating similar efforts by other companies. Concern over pollution in general should

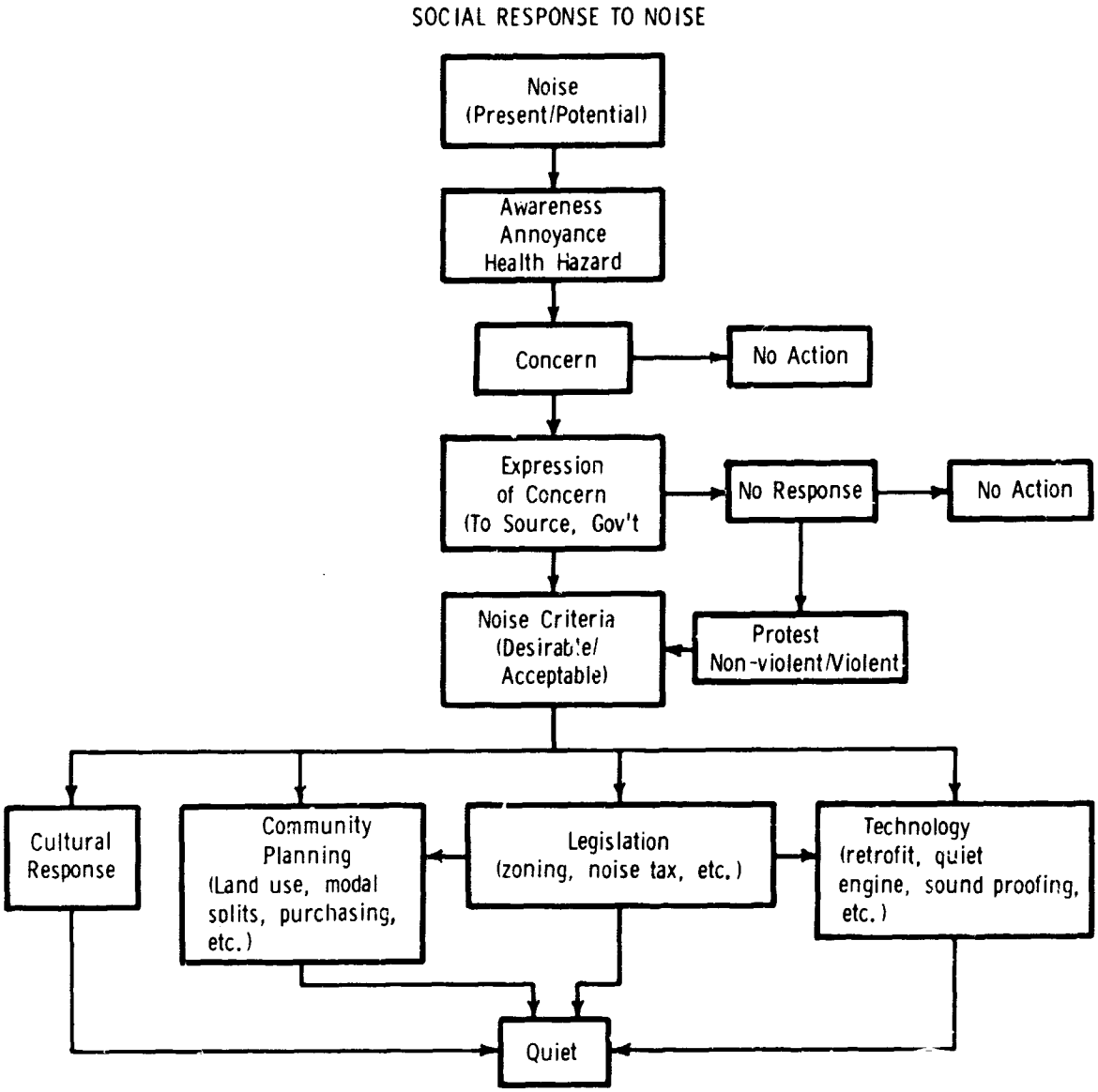

Figure 7.1.

Human Factor Noise Exposure Levels, dB(A)

Sleep Interference	Speech Interference	Body Stress Response	Hearing Loss
35[a]	50-55[b]	70-75	80

[a]Interference also depends on type and duration of noise and individual sensitivities.

[b]At a distance of 3 - 6 feet.

Table 7.1

Recommended Community Noise Criteria,[4] dB(A)

	Airports (at property line)		Industrial[b]		Commercial[b]		Urban Residential		Suburban Residential		Rural Residential		Noise Critical Areas		
													Hospitals		Churches
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day
OUTDOOR	80[a]	80[a]	65	55	60	50	50	45	45	40	40	30	40	35	40
INDOOR			80[c]	80[c]	50	50	45	35	45	35	40	30	40	35	50

[a]With current technology this limit probably can be met only by greatly expanding airport land areas.

[b]Levels specified to protect residents in and near this area.

[c]Maximum for unprotected ear. Value highly dependent on the particular industrial activity.

Table 7.2

Recommended Transportation Noise Criteria, [1, 2] dB(A)

	Typical Existing Levels	Recommended Noise Criteria	Measurement Location
Aircraft			
Subsonic and Supersonic	90-105	75	FAA Noise measuring sites.[1,2]
V STOL	——	80	500 feet from vehicle
Automobiles	85	75	50 ft. from vehicle centerline[a]
Motorcycles	95	75	50 ft. from vehicle centerline[a]
Commercial Trucks and Buses			
45 mph or less	88	75	50 ft. from vehicle centerline[a]
More than 45 mph	90	80	50 ft. from vehicle centerline[a]
Rapid Transit and Diesel Trains			
45 mph or less	85-95	70-75	50 ft. from vehicle centerline[a]
More than 45 mph	90-100	75-80	50 ft. from vehicle centerline[a]
Off-Highway Recreational Vehicles	85-90	75	50 ft. from vehicle centerline[c]
Construction Equipment	80-110	80	25 feet from equipment[c]
Vehicle Operators Compartment	80-95	70	Operating Compartment[c, d]
Vehicle Passenger Compartment	70-85	55	Passenger Compartment[c, d]

[a]Measured on open terrain with winds of 12 mph or less under any condition of grade, load, acceleration or deceleration.

[b]Steel wheel on steel track vehicles. The train length also affects the noise level.[1]

[c]Measured at manufacturer's maximum rated performance conditions.

[d]If the operator(s) and passengers occupy the same compartment, the passenger compartment criteria shall apply.

Table 7.3

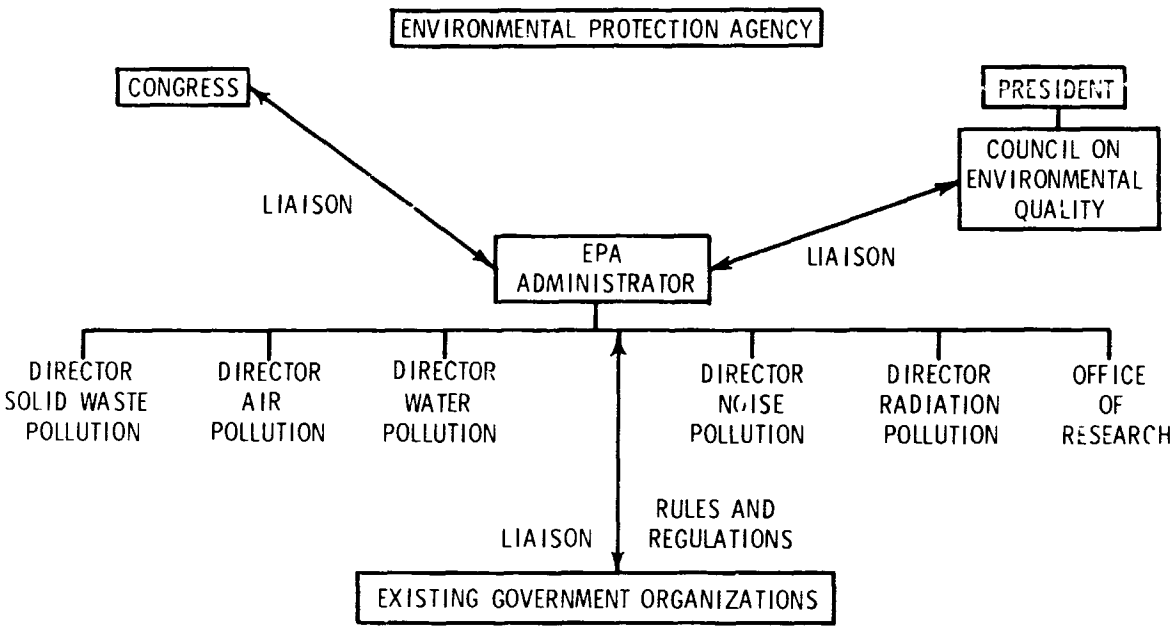

Figure 7.2.

transcend company lines. A coordinated effort by related industrial organizations could bring about widespread research efforts, expanded facilities and expertise, and elimination of duplication of effort.

Legislative, Organizational, and Planning Controls

Like many other community problems, transportation noise transcends governmental jurisdictional divisions. Obviously, the din of airplanes, trucks, automobiles, and trains does not disappear or change noticeably when these vehicles cross city, county, and state lines. It would appear, therefore, that the ideal solution to this jurisdictional problem would lie in the adoption and nation-wide acceptance of specified federal noise standards in order to provide uniformity and consistency for manufacturers, the transportation industry, and community planners alike. Although the goals of uniformity and consistency are important, they are not sufficient since often the nature and magnitude of the noise problem vary widely from one locality to the next. Moreover several of the noise abatement tools, such as zoning and building codes, are grounded in state and local jurisdictions, and it is extremely doubtful that communities will part with them in view of a lasting preference for "home rule." However, noise abatement legislation and controls must be applied at all levels of government with the hope that there will be significant coordination of these controls in the future.

Most of the following recommendations are independent of each other and are also independent of the political structure that exists in a particular area. The important element is that some authoritative person or group be charged with the responsibility of improving the quality of the environment for society.

Local, Regional, and State Organizational Controls

1. Pollution control administrators should be established at the local, regional, and state levels and should focus attention on environmental pollution, including noise pollution. The functions and duties ought to include: (a) collection of data on the sources, scope, and trends of environmental pollution, (b) submission of reports concerning the nature and causes of specific environmental problems to appropriate state and/or local officials; (c) submission of specific legislative, administrative, and operational recommendations for reducing and eliminating pollution; (d) promotion and publication of the continuing need for a pollution-free environment.

2. At the local governmental level, the responsibility for environmental pollution control could be located in such places as the mayor's office, city manager's or administrator's office, city or county planning department or commission, and so on. Responsibilities specifically related to noise should include:

(a) defining the noise problem

(b) monitoring community noise levels and identifying chief sources

(c) investigating means and resources to reduce noise

(d) establishing acoustical criteria and standards both for the present and future

(e) policing noise pollution and recommending fines, cessation of operations, and other penalties for offenders

(f) publishing information on the noise levels in various areas of the community. Potential buyers or renters of real estate in noisy areas should be advised of noise levels by written statement in the escrow, purchase, deed, or lease agreement.

3. Since the problem of noise is geographically pervasive, the coordination of the regional problems common to communities in close proximity is a necessity. The interaction of regional and interregional groups would lead to more uniform noise standards and abatement techniques.

Federal Organizational Controls

1. The recently proposed Presidential Environmental Protection Agency should be modified to become a completely independent establishment with regulatory and adjudicatory power to control environmental pollution, including noise pollution (see Figure 7.2).

The EPA would work closely in conjunction with existing federal organizations (such as the DOT) and would direct and coordinate pollution research and be responsible for the enactment of federal regulations to enhance the quality of the environment.

The EPA would also delegate responsibility to the appropriate state and federal organizations for enforcement and monitoring.

The personnel of the new agency should be appointed by the President and approved by the Senate for a term designed to make them less susceptible to political influence in their work. The result would be:

(a) a comprehensively coordinated attack on all environmental pollutants.

(b) a unique independence which would permit isolation from political pressure which might interfere with effective pollution control activities.

(c) a unique recognition as the ultimate pollution abatement authority for the nation.

2. The Council on Environmental Quality, formed under the National Environmental Policy Act of 1969, should include an intensive analysis and study of noise poilution as part of its function of investigating and advising on environmental problems, and should report on and disseminate its findings to the President and to the appropriate federal departments and agencies.

Land Use

1. Community planners should set criteria for the various land use categories. With available noise prediction techniques, they can determine compatible land use near existing or proposed transportation facilities. By controlling the land use near airports and highways and by controlling the location and/or the expansion of transportation facilities, communities can reduce the future discomfort of their populations, maintain land values in affected areas, and minimize complaints to city agencies.

The principal implementation tools of land use planning are zoning, "eminent domain," or negotiated easements. Land use planning is relatively inexpensive in undeveloped areas, but in developed areas is likely to be very expensive, and the soundproofing of structures may be necessary if land use tools are impractical. Soundproofing may also be expensive and may require government aid in the form of grants and loans.

2. Land use along high speed highways should be restricted to less noise sensitive uses such as warehouses, industrial developments, commercial buildings, etc.

3. Compatible land uses near airports are:

(a) activities involving few people.

(b) activities insensitive to additional noise.

(c) activities closely associated with the operation of the airport.

Purchasing Practices

As a matter of policy, all equipment and services purchased by the community should meet specified noise criteria. Local government purchasing power has a tremendous economic influence on producers and manufacturers. The injection of noise suppression requirements in supplier selection should result in new and improved products which would eventaully be introduced to the individual consumer because of mass production economies.

Licensing/Taxing

Specific maximum exterior noise level limits should be set for the sale and use of motor vehicles, aircraft, construction equipment, and other annoying noise sources. To enforce these restrictions, units must be designated for monitoring, testing, licensing, and enforcing the regulations. It should be stated that

liability for subsequent noise pollution belongs to one or more of the following:

(a) the manufacturer when he sells a product failing to meet prescribed standards.

(b) the user of products not meeting standards where the product is not sold locally.

(c) the user of products which exceed noise standards because the product has been altered since its manufacture or improperly maintained.

(d) the conductor of activities—rather than products—which exceed noise level limits.

Noise taxes could be imposed on noncomplying items.

Acoustical Insulation Requirements

Specified acoustical insulation requirements should be incorporated in building codes. These amended codes should apply to new and extensively renovated single and multiple-family dwellings and other structures within designated areas where the construction occurs after a specified date. In addition, acoustical treatment, if necessary, should be added to existing hospitals, schools, and other designated noise-sensitive structures.

So as not to pass the entire cost of acoustical insulation to building owners, government might ease the financial burden by perhaps removing such acoustical improvements from assessment for property taxes; or by offering reduced interest rates on FHA loans to those persons building acoustically treated structures, when the cost of the acoustical insulation exceeds a specified limit.

Transportation Systems Planning

1. Means for regulating traffic flow that can also produce, as a by-product, lower noise levels are:
   (a) lower speed limits.
   b) synchronized traffic light systems.
   (c) one-way streets.
   (d) traffic curfews in sensitive areas.
2. Truck routes in highly noise sensitive areas should be avoided as much as possible.
3. The transportation mix should be modified to reduce or isolate noise levels.
4. Noise should be an important parameter in the design and construction of new transportation systems or the modification of existing transportation systems.

Vehicle Inspection Requirements on Truck Mufflers

A satisfactory truck muffler should be required by law and included as a standard item in the vehicle inspection requirements for trucks. The state-of-the-art in truck muffling systems is sufficient to considerably reduce exhaust noise levels without any undue increase in truck costs.

Aircraft Certification

1. All SST aircraft, domestic and foreign, should meet current FAA noise certification levels for subsonic aircraft before being permitted to operate in U.S. airspace. This criterion should be established immediately.
2. The noise certification levels for V/STOL aircraft should be 95 PNdB at 500 feet. It would be a grave mistake to underestimate the resistance of the communities surrounding a proposed V/STOL port to higher noise levels.
3. The authority to set noise standards for aircraft should be placed in the newly formed Environmental Protection Agency, rather than the FAA.

Aircraft Operations

1. The proposed rule (14 CFR Part 91) prohibiting the operation of any civil aircraft at a speed that would cause a sonic boom to reach any part of the United States, except the surface of the territorial waters, should be enacted at once.
2. Aircraft and airport operational procedures, such as preferred runways, reduced thrust take-offs, and over-water flight patterns, should be required by airport operators whenever possible.
3. If the two-segment aircraft approach path proves to be safe, it should be used at those airports where it will be advantageous.
4. The reduction of high nighttime ground run-ups of aircraft engines can and should be reduced to an absolute minimum at all airports.
5. An environmental air traffic controller might be appointed by the airport operator to work in conjunction with the FAA to maintain prescribed noise level limits, and to institute other airport-related noise abatement procedures.

Noise Abatement Technology and Research

Technology can contribute greatly toward the goal of a quieter community. Engineers must include noise as a design parameter.

Noise levels near airports, as interpreted by Noise Exposure Forecasts, are more sensitive to the noise levels of individual aircraft than to the number of takeoffs and landings. The ultimate solution to the aircraft noise problem thus lies with quieter aircraft, i.e., quieter engines. Without such engines, it is expected that the noise problem at small and medium size airports will become substantially worse during the next 15 years, while the combination of new, quieter aircraft and saturation conditions will prevent noise levels at most large airports from becoming appreciably worse.

The new generation of jumbo jets—the B-747, DC-10, and L-1011—will be quieter than current commercial aircraft and will meet FAA noise certification levels.

Retrofit Program

For current turbofan aircraft, the question essentially boils down to whether a noise reduction level of 15 EPNdB on approach and a weight penalty of 3140 pounds is worth $1 million. If the interested parties make a go-ahead decision on retrofit, the federal government should provide low interest loans to the involved airlines, which should make a fare increase to pay for the cost.

Quiet Engine Program

The federal government through NASA should accelerate its efforts in quiet engine research so that new aircraft can be equipped with these engines. However, the cost of re-engining current 4-engine aircraft, once the quiet engine is available, may not be feasible due to an estimated cost of $6 million per plane.

V/STOL Aircraft Research

A major research effort should be instituted to develop a quiet and economically feasible V/STOL aircraft. A V/STOL aircraft (with perhaps a 150-passenger capacity) should be developed by NASA to insure that acceptable noise levels can be attained. An engine noise limit of 95 PNdB at 500 feet in all directions should be used.

SST Suppressor Research

The pure jet engines for the SST generate such high noise levels that everyone concerned agrees that suppression is mandatory. General Electric has designed a movable center body which chokes the inlet, effectively blocking high frequency compressor sounds. Jet noise suppression, therefore, remains the largest unsolved noise problem. It is not at all clear at this time whether suppressors can reduce sideline noise to acceptable levels without imposing excessive weight or range penalties on the aircraft.

Sonic Boom Research

Considerable research has gone into determining the overpressures and signatures of sonic booms produced by several types of aircraft and the reaction of people to them. NASA has perhaps led the way, however, in seeking methods by which to minimize the boom's undesirable features. This is evidenced by their 1967 and 1968 conferences on sonic boom research [8], [9], [10] as well as many of their own research efforts. The boom generation characteristics of the US-SST as well as the Concorde and TU-144 are now fixed at overpressures of 2.0 to 2.1 PSF and no research is being conducted on ways to alleviate their boom. Research for minimizing boom levels in future SST's is currently considering airframe shape and the use of heat or force fields around the aircraft. The lowest value of overpressure that is obtainable considering aircraft shape alone varies between 1.0 and 1.5 PSF which is still an unacceptable level. This research is continuing, but it is doubtful that it will produce an acceptable boom level at the same time it will yield an economically practicable commercial aircraft. The application of a force or heat field to the zone around and 2-3 aircraft lengths in front of and behind the aircraft creates what is termed a "phantom body" which moves through the air with the aircraft without creating a boom. This technique has been considered theoretically feasible but would require enormous power expenditures. This procedure might, if the power problems are solved, reduce overburden pressures to approximately .1 PSF with rise times of .1 second with no sonic boom.

Tire Research

As indicated in Figure 5.9 and Figure 5.11, tire noise is the largest single source of noise generated by trucks, automobiles and buses at speeds over 50 mph. Tire research conducted in the past by manufacturers and government has concentrated on safety, durability, traction, and skid resistance with

little concern for noise generation characteristics. Recent noise measurements made on passing trucks have shown that differences in tire tread design coupled with tire wear yield up to a 15 dB(A) spread in sound level. The SAE has two committees working on developing a meaningful test procedure which will identify noisy tread and retread types with the end motive being a noise specification for tires. The National Bureau of Standards and Department of Transportation are currently conducting truck tire noise tests at Wallops Island to provide a data base that could be used in identifying the physical characteristics of tires and of tire/pavement interaction which produce noise.

The results of this research will yield a better understanding of tire noise, and this knowledge will result in a quieter tire, both for automobiles and trucks, in the period 1970-1985.

Muffler Research

Automobile exhaust mufflers in current usage bring the full throttle exhaust noise level down to the 86 dB(A) level at 50 feet. An estimated further reduction of 4 dB(A) would double the size and cost of the muffler. Air pollution control devices currently being installed will contribute to a noise reduction as a by-product.

The two-cycle gasoline engines used in such sport vehicles such as motorcycles and snowmobiles (as well as in lawn mowers and chain saws), require a great deal of muffling to bring them down to acceptable levels. There is or has been until recently, a direct conflict between the power output of such an engine and the back pressure a muffler imposes on the engine. With new "tuned" mufflers, however, the two-cycle engines can be reduced to 82-86 dB(A) at 50 feet with little power loss. An extension of this technology can bring the noise levels down to 78 dB(A) at little additional cost. Reductions below this level will require increases in muffler volume usually not available in sport vehicles using the two-cycle engine. For most devices utilizing two-cycle engines, other noise sources such as chain drives and track drives begin to predominate when the exhaust noise level is reduced to the 80 dB(A) level. To reduce overall noise levels further requires attention to the entire vehicle.

Current truck muffling technology can at minimal cost bring the exhaust noise level below that due to other sources such as tires and engine radiation.

There has been considerable interest in the use of gas turbine engines for trucks and heavy construction equipment. The inlet and exhaust noise emitted by turboshaft engines must be treated by methods developed for helicopters and aircraft. The great effort being expended in the aircraft area should have direct applications. The noise frequency spectrum of a turbine exhaust is much higher than reciprocating engines, which makes it amenable to attenuation through acoustic ducting treatment.

Railway Research

A reduction in wheel-rail noise of 8 dB is attainable if continuously welded rail is used instead of riveted or bolted joints. A further reduction of 10 dB can be achieved if the wheel and track are ground regularly to remove minor irregularities. There are only possible economic reasons why both of these procedures could not be implemented by the U.S. railroad companies as on the Japanese Tokaido line. On high speed passenger lines, welded rail joints are necessary for safety and riding comfort as well as for community noise reductions. The prime research design need is for an automatic machine which could align tracks and grind track imperfections in a single pass. Machines which can grind wheels are currently available.

Research on reducing train whistle noise should continue. The latest in muffler technology should be applied to muffling diesel and diesel-electric locomotives.

Soundproofing Technology

Architects today have the required materials and technical know-how to effectively soundproof new or existing buildings. The cost of attenuation increases as the desired sound level decreases, and is higher for existing buildings than it would be for new construction. In a recent Los Angeles pilot program [5] the cost to achieve 25-45 dB(A) attenuations ranged between $3,410 to $12,600 per dwelling. This cost coupled with an inhibition on the enjoyment of yard space usually associated with single-family dwellings makes soundproofing at best a marginal solution to the noise problem.

Future Direction of NASA Research

NASA should place an increased proportion of its efforts in the areas of noise abatement, V/STOL aircraft, and general aviation.

Epilogue

> If we apply the cost-benefit analysis scheme to the reduction of noise or any other pollution mechanism, we must decide on a whole series of environmental quality levels of increasing freedom from pollution that we can use for goals in a step-by-step program. Then we must decide whose benefit is pre-eminent. Usually the public comes out on the short end . . .
>
> If we value human life and the quality of life as we have come to expect it then we must choose conservative threshold limit values and protect the public even if the cost is higher than the cold hard facts that cost-benefit analysis might indicate. The quality of life is a concept that is difficult to justify in terms of profit and loss statements and the responsibilities of directors to stockholders in its narrowest sense. Yet, the stockholders and directors too are among the citizens whose lives are at stake. It is time to stop the blind application of economic justification for all kinds of pollution and in particular noise. The stresses on humans from the total environmental exposure in daily life are unknown, and lack of "factual" proof is no cause for lowering the standards. (Lewis G. Goodfriend, *Sound and Vibration*, April 1970)

Whatever "crystal ball" one uses in forecasting America's transportation needs, modes, and noise problems, there is always the temptation to be either overly optimistic or overly pessimistic. It is easy to conclude that in "the world of the future" man's general welfare will be greatly enhanced through continuing progress in satisfying his transportation nees. It is just as easy to conclude that, in the eagerness of an affluent society to get wherever it collectively wants to go as rapidly as possible, other values will be completely ignored or be given insufficient priority so that man will eventually destroy himself through the very technological ingenuity which some supposed would bring Utopia.

It is improbable that in the near future we will succeed in making **all** modes of transportation so quiet in their operation that nobody will be annoyed. However, society should not and need not tolerate transportation noise levels which interfere with the quest for the "good life" simply because it is economically unattractive to take the necessary abatement procedures. What is important is that society be shown this, and the authors feel that this report does just that.

> When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man . . . That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics . . .
>
> The economic approach to conservation is important: Don't reward but punish the destroyers. But this requires a philosophical and even ethical change toward the land and property ownership by a much larger proportion of the American people. (*New York Times*, August 11, 1970.)

Perhaps if it does no more, this report will be instrumental in helping to create a concerned public interest in transportation noise abatement that will grow strong enough to become an effective force before it is too late for either preventive or remedial action.

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Appendices

A. List of Participants and Secretarial Staff, NASA-ASEE Engineering Systems Design Program, 1970.

B. Acknowledgements.

C. Visiting Lecturers and Consultants.

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E. Chronology of Landmark Decisions and Major Noise Control Actions.

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APPENDIX A
FACULTY FELLOWS AND ASSOCIATES
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Ullman, K. B.	Office of High Speed Ground Transportation, DOT, Washington, D.C.
Vigrass, J. W.	Port Authority Transit Corporation of Pennsylvania and New Jersey
Wagner, Wayne	Donaldson Company, Inc., Minneapolis, Minnesota
Webster, Pat	Office of Systems Requirements, Plans, and Information, DOT, Washington, D.C.
Weihmiller, H.E.	Consultant to Highway Research Board, National Academy of Sciences, Washington, D.C.
Wiggers, George	Office of Systems Requirements, Plans, and Information, DOT, Washington, D.C.
Williams, W. L.	Highway Research Board, National Academy of Sciences, Washington, D.C.
Winzer, George	Office of Research and Technology, HUD, Washington, D.C.
Yost, N. C.	Deputy Attorney General, State of California

APPENDIX C

Visiting Lecturers and Consultants

Date	Visitor	Subject
June 9, 1970	Mr. Charles R. Foster Director Office of Noise Abatement, Department of Transportation	An Overview of the Transportation Noise Problem
June 10, 1970	Mr. Robert L. Paullin, Chief Regulations and Standards Division, Office of Noise Abatement Department of Transportation	Transportation Noise Regulations and Analytical Developments
June 11, 1970	Dr. Carl F. Zorowski, North Carolina State University	The Form and Function of Engineering Design
June 15, 1970	Mr. Harry Close, Chief Research Division, Office of Noise Abatement, Department of Transportation	Basic and Applied Research As Applied to Transportation Noise
June 16, 1970	Dr. Erich K. Bender, Deputy Manager, Applied Physics Department, Bolt, Beranek and Newman	Subway and Train Noise
June 17, 1970	Dr. Thomas Levere North Carolina State University	Noise and Sleep
June 18, 1970	Dr. Rolin F. Barrett North Carolina State University	Past, Present, and Future Transportation Systems
June 23, 1970	Mr. John M. Swihart, Chief Engineer Supersonic Transport Division, Boeing Aircraft Company	The Impact of the SST on Society
June 25, 1970	Dr. Alexander Cohen, Chief National Noise Study, Occupational Health Program, Dept. of Health, Education and Welfare	Environmental Noise and Human Effects
June 29, 1970	Dr. Gordon Stevenson Bingham, Dana and Gould Boston, Massachusetts	The Response of Local Governments and Courts to Aviation Noise Protest
July 2, 1970	Dave Klein Director of Fleet Planning Eastern Air Lines	The Impact of STOL Operations in the NE Corridor
July 7, 1970	Merrick Hellyar, Supervisor Commercial Operations Analysis Sikorsky Aircraft	The Use of Large Helicopters in Meeting Transportation Needs
July 8, 1970	Mr. John Powers, Director Aircraft Noise Abatement Federal Aviation Administration, Department of Transportation	FAA Noise Abatement
July 20, 1970	Mr. Dan Flynn Applied Acoustics National Bureau of Standards	The Role of the National Bureau of Standards in Noise Abatement
July 20, 1970	Mrs. Elizabeth Cuadra Wyle Laboratories	Transportation Noise and the Urban Environment
July 22, 1970	Peter A. Franken Divisional Vice President Bolt, Beranek and Newman	Airports and Community Planning
July 30, 1970	Mr. Thomas L. Coleman Office of Assistant Director Langley Research Center	Goals in Aeronautical Transportation Research

August 3, 1970	Mr. James T. Pyle, Director Aviation Development Council	Aircraft Noise and Community Reaction
August 5, 1970	Lt. Colonel Hal Davis, U.S. Air Force Office of Information, Hdqtrs MAC, Scott AFB	C-5 Capabilities and Use
August 5, 1970	Major C.E. Hollingsworth and Major V.G. Ramage, U.S. Air Force, Detachment 5, Hdqtrs MAC, Charleston AFB	C-5 Briefing

APPENDIX D

Group Organization and Leaders

The study activity was organized through selection of group leaders and delineation of subgroup and individual responsibility during the different phases of the program.

Group Assignments for Preliminary Needs Analysis

Initially the group was organized into two teams for preliminary study and survey of changing transportation needs. Tentative forecasts of demand for 1970-1985 were made. Team 1 was to pay specific attention to surface and subsurface transportation. Team 2 concentrated on airborne transportation.

Team 1	Team 2
Kenneth E. Case, Team Leader	Gerard G. Ventre, Team Leader
James J. Brady	Albert G. Bennett
Thomas B. Chorey	David O. Dickerson
George W. Goldman	Francis E. Griggs
Mansell H. Hopkins	Eugene W. Hurn
Allan E. Hribar	Richard D. Klafter
Chester E. Jarvis	Diane Lynch
Paul J. Jensen	Peter J. Milulka
Harvey B. Karp	Richard J. Tersine
Wilbur J. Marner	Arthur D. Yaghjian
Paul E. Russell	

Group Assignments for In-depth Study

Following two weeks of study, interim reports were prepared by each member and submitted to his team leader. The group was then reorganized to permit in-depth study on specific areas with assignments as follows:

Needs Analysis Group—This group was to further identify transportation needs and to refine estimates.

Chester E. Jarvis, Chairman	Eugene W. Hurn
James J. Brady	Richard D. Klafter
David O. Dickerson	Paul E. Russell
Mansell H. Hopkins	Richard J. Tersine

Effects Analysis Group—This group was to study the effects of noise upon the environment with particular attention on the effects of noise on human beings.

Allan Hribar, Chairman	Harvey B. Karp
Paul J. Jensen	Peter J. Mikulka

Legal Analysis Group—This group was to search court proceedings as well as legislation to determine what judicial and legislative activity had arisen as a result of noise.

Diane Lynch, Chairman	Allan Hribar
Tom Chorey	Chester E. Jarvis

Modes Analysis Group—This group centered its attention on transportation modal splits and the overall effect on noise levels of different modal splits.

Frank Griggs, Chairman	Richard D. Klafter
Albert G. Bennett	Paul J. Jensen
James J. Brady	Wilbur J. Marner
George W. Goldman	Paul E. Russell
Mansell H. Hopkins	Richard J. Tersine
Arthur D. Yaghjian	

Editorial Committee

David O. Dickerson, Chairman	Franklin D. Hart
J. Darrell Gibson	Chester E. Jarvis

Synthesis and Coordinating Committee

Kenneth E. Case for Modes and Effects Analysis; Gerard G. Ventre for Needs and Legal Analysis;
J. Darrell Gibson — Franklin D. Hart

Finalizing the Report

The last two weeks were spent finalizing the report and preparing specific recommendations for noise abatement and control. Again specific areas of responsibility were delineated as follows:

Preparation of Noise Criteria

Harvey B. Karp	Paul J. Jensen
Mansell H. Hopkins	Peter J. Mikulka
Allan E. Hribar	Paul E. Russell

Develop Strategy for Meeting Criteria

For developing public awareness: Harvey B. Karp and Paul E. Russell.

For community Planning: Mansell H. Hopkins, Paul J. Jensin, and Richard J. Tersine.

For legal and political strategy: James J. Brady, Thomas B. Chorey, and Diane Lynch.

For noise abatement technology: Albert G. Bennett, Francis E. Griggs, and Wilbur J. Marner.

Illustrations Committee

George W. Goldman — Peter J. Milulka
Paul E. Russell

Appendices Committee

Eugene W. Hurn — Richard D. Klafter
Arthur D. Yaghjian

During this final phase, the Editorial Committee and the Synthesis and Coordinating Committee continued devoting full-time effort to their primary tasks.

Figure D-1 graphically portrays the organization of effort and time schedules established for the study. The width of the horizontal bars represents the proportionate amount of manpower devoted to each of the separate phases of the study and the length of the bars indicates the time spent on each phase.

DESIGN STUDY TASK FLOW CHART

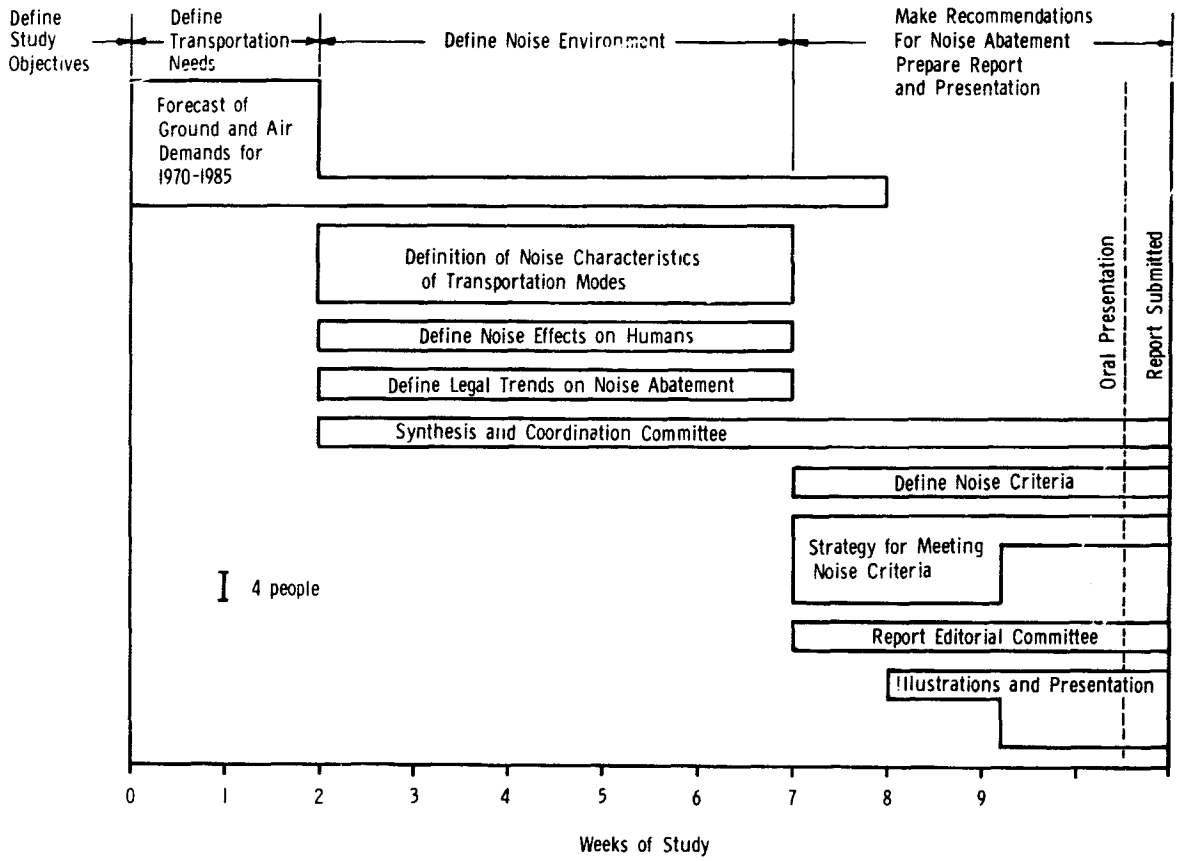

Figure D-1

APPENDIX E

CHRONOLOGY OF LANDMARK DECISION AND MAJOR NOISE CONTROL ACTIONS

1946	*United States* vs. *Causby*, (320 U.S. 256), in which the court held that under certain conditons flights of military aircraft over a landowner's land would be a taking of their property which required just compensation.
1952	United States Air Force organized Noise and Vibration Control Program.
1952.	Armed Forces National Research Council Committee on Hearing and Bio. Acoustics (CHABA) organized.
1955	*Allegheny Airlines, et. al, Port of New York Authority et al.*, vs. *Village of Cedarhurst*, (132 F. Supo. 871), in which a village was unsuccessful in its attempt to prohibit aircraft flight within its boundaries at altitudes of less than 1,000 feet.
July 1959	Los Angeles Sound Abatement Coordinating Committee (LASACC) formed by the Los Angeles Department of Airports in conjunction with all airline tenants operating jet aircraft at Los Angeles International Airport.
1960	Society of Automotive Engineer Committee A-21 formed to study aircraft noise and to recommend methodology in assessing and reporting aircraft exterior noise.
1962	*Thornburg* v. *Port of Portland*, (376 P. 2d100), Court decided that a continuing and substantial interference with the use and enjoyment of property due to aviation noises is a taking which might require compensation.
1962	*Batten* v. *United States*, (306 F 2d 580), Tenth Circuit held that noise, smoke, and vibration from jet aircraft were not a taking of property because there was no physical invasion by direct overflight and there was no suggestion that the property was considered uninhabitable.
1962	*Griggs* vs. *Allegheny Country Airport*, (369 U.S. 84), decision holding airport owner-operator liable for damages resulting from aircraft noise.
1964	*Martin* vs. *Port of Seattle*, (391 p 2d 540), allowed recovery for noise damage from flights which were not directly overhead.
July 1965	State of New York enacted a State Highway Anti-Noise Statute to become effective October 1, 1965. This legislature provided a measurable noise limit which could be enforced against motor vehicles creating excessive or unusual noise.
October 1965	The Office of Science and Technology, Executive Office of the President, after consultation with NASA, the FAA, and the National Aircraft Noise Abatement Council, sponsored a symposium on aircraft noise problem.
February 1966	An informal Task Force representing Government and industry was established to recommend the most desirable concept of a noise certification rule for subsonic aircraft.
March 1966	The President in his transportation message directed that a concerted effort be made by the Federal Government to combat the growing problem of jet aircraft noise near airports.
March 1966	Ad Hoc Jet Aircraft Noise Panel submits its report *Alleviation of Jet Aircraft Noise Near Airports*, to the Office of Science and Technology.
April 1966	Congressman Kupferman introduced in the House of Representatives the first bill to deal comprehensively with the general problem of noise.
1966	*American Airlines, Inc., et al.*, vs. *Town of Hempstead, et al.*, (272 F. Supp. 226), decision striking down as unconstitutional an ordinance passed by the Town of Hempstead which forbade operation of a mechanism or device (including airplanes) which created noise in excess of limits which were technologically impracticable.
September 1966	FAA prepared a series of drafts of aircraft noise certification concepts. These drafts were submitted to industry and were refined in the light of industry comments.
November 1966	London Conference attended by representatives of 26 countries and 11 international organizations concerned with aircraft noise. The conference document, *"Aircraft Noise—Report of an International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft"*, endorsed the viewpoint that the certification of aircraft for noise be considered as one critical step in the alleviation of the aircraft noise problem.
January 1967	Congressman Kupferman's bill reintroduced in the 90th Congress, 1st Session, as H.R. 2819. The bill would establish an Office of Noise Control within the Office of the Surgeon General under the Department of Health, Education, and Welfare. The legislation would also provide grants in aid for state and local governments to research ways and means of control, prevention, and abatement of noise.
August 1967	Neil H. Anderson, Executive Vice-President of the New York Board of Trade, appointed Chairman of a committee directed to study the problem and produce ". . . some noise rulings which will bring quieter trucks, tires, mufflers into everyday use."

February 1968	Society of Automotive Engineers Committee R-6 formed to study and develop aircraft fly-over noise rating scale.
July 1968	Aircraft manufacturing industry reacts to the use of the concept of Effective Perceived Noise Level in units of EPNdB as the evaluation of subjective response and the use of three points of measurements (approach, takeoff, and sideline). Recommended adoption of the concept of maximum instantaneous perceived noise levels in units of PNdB as the measure of subjective response.
July 1968	*Public Law 90-411. Federal Aviation Act of 1958* amended by H.R. 3400 adding Section 611 which required the FAA to establish and enforce regulations to control aircraft noise. FAA given power to withhold or revoke certification of an airplane which is too noisy by its standards.
1968	The State of California created the State Environmental Study Council to examine, in depth, state policies affecting environmental quality. It is to determine whether existing approaches are adequate, to identify unmet or inadequately met needs, to iden ify undesirable overlaps and conflicts in jurisdiction, and develop long-range environmental quality goals and recommendations. The Council will consider land use, air quality, noise abatement, and water resources in its study.
1969	The State of Minnesota enacted a law to place zoning authority in the vicinity of new airports in the hands of an areawide metropolitan council. The council was given broad authority to develop and enforce compatible land use criteria for noise-affected regions near airports.
January 1969	FAA Notice of Proposed Rule Making and invitation to interested persons to participate in the making of the proposed rule by submitting data, views, arguments, etc., as they may desire.
April 1969	Senator Tydings introduced Senate Bill 1818 entitled Environmental Quality Act of 1969 establishing within the Executive Office of the President an Office of Environmental Quality.
May 1969	Walsh-Healey Health and Safety Regulations establishing new standards for industrial noise promulgated to become effective May 20, 1969.
May 1969	President Nixon announced the establishment by Executive Order of the Environmental Quality Council and the Citizens Advisory Committee on Environmental Quality.
August 1969	State of California enacts anti-highway-noise legislation prohibiting noise levels in excess of 82 dB(A) for passenger cars and 92 dB(A) for trucks and buses.
October 1969	First Meeting of Sonic Boom Panel, International Civil Aviation Organization, Montreal, Canada, for the purpose of (1) developing an internationally acceptable method of describing and measuring sonic boom and (2) developing formula and/or models for determining the effects of sonic boom on humans, property, animal kingdom and terrain.
December 1969	As authorized by Public Law 90-411, FAA regulations amended by Part 36 to set standards for noise levels of future subsonic aircraft.
November 25 - 17 December 1969	Special Meeting of the International Civil Aviation Organization on Aircraft Noise in the Vicinity of Airdromes, Montreal, Quebec, Canada.
February 1970	At the request in a letter signed by 47 Congressmen on 12 January 1970, the FAA reports on activities regarding the abatement and control of aircraft noise.
April 1970	California Department of Aeronautics submits Report to the Legislature on Proposed Noise Standards for California Airports.
April 1970	FAA proposed rule which in effect prohibits the operation of civil aircraft over U.S. land masses at sonic boom producing speeds.
July 1970	President Nixon proposed the creation of an Environmental Protection Agency (EPA) and a National Oceanic and Atmospheric Administration (NOAA).

APPENDIX F

The text of the legislation enacted by the State of California prohibiting noise levels in excess of 82 dB(A) for passenger cars and 92 dB(A) for trucks and buses is included for information and guidance of other governing bodies interested in anti-noise legislation. Also included is the legislation lowering some of these limits, enacted in August 1970.

Pursuant to Article 21669.3 of that legislation, the California Department of Aeronautics submitted a comprehensive report to the legislature on April 1, 1970, proposing noise standards for California airports. The proposed regulations are "designed to cause the airport proprietor, aircraft operator, local governments, pilots, and the department [Department of Aeronautics] to work cooperatively to diminish noise." Single event noise limits are imposed and noise impact areas are controlled by establishing impact boundaries which are to be validated by measurement. Of interest also is the provision for establishing and validating noise impact boundaries for existing airports. Unless the California Legislature enacts otherwise, the proposal becomes effective January 1, 1971. To date, no exceptions to the proposal have been made.

Due to its length, the report is not reproduced here. It, too, would be of interest to those who seek to reduce and control noise by legislation. The report is entitled "Report to the Legislature on Proposed Noise Standards for California Airports Pursuant to Public Utilities Code Section 21669." The report was submitted by the California Department of Aeronautics, Joseph R. Crotti, Director, and is dated April 1, 1970.

CHAPTER 1318

An act to amend Sections 23130 and 27160 of the Vehicle Code, relating to motor vehicles.

[Approved by Governor August 30, 1969. Filed with Secretary of State August 31, 1969.]

The people of the State of California do enact as follows:

Section 1. Section 23130 of the Vehicle Code is amended to read:

23130. (a) No person shall operate either a motor vehicle or combination of vehicles of a type subject to registration at any time or under any condition of grade, load, acceleration or deceleration in such a manner as to exceed the following noise limit for the category of motor vehicle based on a distance of 50 feet from the center of the lane of travel within the speed limits specified in this section:

	Speed Limit of 35 mph or less	Speed Limit of more than 35 mph
(1) Any motor vehicle with a manufacturer's gross vehicle weight rating of 6,000 pounds or more, any combination of vehicles towed by such motor vehicle, and any motorcycle other than a motor-driven cycle:		
(A) Before January 1, 1973	88 dbA	90 dbA
(B) On and after January 1, 1973	86 dbA	90 dbA
(2) Any other motor vehicle and any combination of vehicles towed by such motor vehicle	82 dbA	86 dbA

(b) The department shall adopt regulations establishing the test procedures and instrumentation to be utilized.

(c) This section applies to the total noise from a vehicle or combination of vehicles and shall not be construed as limiting or precluding the enforcement of any other provisions of this code relating to motor vehicle exhaust noise.

(d) For the purpose of this section, a motortruck, truck tractor, or bus that is not equipped with an identification plate or marking bearing the manufacturer's name and manufacturer's gross vehicle weight rating shall be considered as having a manufacturer's gross vehicle weight rating of 6,000 pounds or more if the unladen weight is more than 5,000 pounds.

(e) No person shall have a cause of action relating to the provisions of this section against a manufacturer of a vehicle or a component part thereof on a theory based upon breach of express or implied warranty unless it is alleged and proved that such manufacturer did not comply with noise limit standards of the Vehicle Code applicable to manufacturers and in effect at the time such vehicle or component part was first sold for purposes other than resale.

Sec. 2. Section 27160 of the Vehicle Code is amended to read:

27160. (a) No person shall sell or offer for sale a new motor vehicle which produces a maximum noise exceeding the following noise limit at a distance of 50 feet from the centerline of travel under test procedures established by the department:

(1) Any motorcycle manufactured before January 1, 1970 ..... 92 dbA
(2) Any motorcycle, other than a motor-driven cycle, manufactured on or after January 1, 1970, and before January 1, 1973 ..... 88 dbA
(3) Any motorcycle, other than a motor-driven cycle, manufactured on or after January 1, 1973 .. 86 dbA
(4) Any motor vehicle with a gross vehicle weight rating of 6,000 pounds or more manufactured on or after January 1, 1968, and before January 1, 1973 88 dbA
(5) Any motor vehicle with a gross vehicle weight rating of 6,000 pounds or more manufactured on or after January 1, 1973 ..... 86 dbA
(6) Any other motor vehicle manufactured on or after January 1, 1968, and before January 1, 1973 86 dbA
(7) Any other motor vehicle manufactured after January 1, 1973 ..... 84 dbA

(b) Test procedures for compliance with this section shall be established by the department, taking into consideration the test procedures of the Society of Automotive Engineers.

CHAPTER 1585

An act to add Sections 21669, 21669.1, 21669.2, 21669.3, and 21669.4 to the Public Utilities Code, relating to airports and making an appropriation therefor, and declaring the urgency thereof, to take effect immediately.

[Approved by Governor September 4, 1969. Filed with Secretary of State September 6, 1969.]

The people of the State of California do enact as follows:

Section 1. Section 21669 is added to the Public Utilities Code, to read:

21669. The department shall adopt noise standards governing the operation of aircraft and aircraft engines for

airports operating under a valid permit issued by the department to an extent not prohibited by federal law. The standards shall be based upon the level of noise acceptable to a reasonable person residing in the vicinity of the airport.

Sec. 2. Section 21669.1 is added to the Public Utilities Code, to read:

21669.1 There is hereby established an advisory committee to assist the department in the adoption of noise standards. The committee shall be composed of seven members appointed by the Governor as follows:

(a) Two members, one of whom shall be representative of homeowners concerned with aircraft noise.

(b) One member each from the Department of Public Health, the League of California Cities, the County Supervisors Association, the Department of Education, and the Air Transport Association.

The existence of the committee shall terminate on January 1, 1971.

Sec. 3. Section 21669.2 is added to the Public Utilities Code, to read:

21669.2. In its deliberations the department and the advisory committee shall be governed by the following guidelines:

(a) Statewide uniformity in standards of acceptable airport noise need not be required, and the maximum amount of local control and enforcement shall be permitted.

(b) Due consideration shall be given to the economic and technological feasibility of complying with the standards promulgated by the department.

Sec. 4. Section 21669.3 is assed to the Public Utilities Code, to read:

21669.3. The department shall submit a comprehensive report of the noise regulations adopted pursuant to Sections 21669, 21669.1 and 21669.2 to the Legislature on or prior to April 1, 1970, and the regulations shall go into effect on January 1, 1971 in the absence of legislative action adopting different standards.

Sec. 5. Section 21669.4 is added to the Public Utilities Code, to read:

21669.4. (a) The violation of the noise standards by any aircraft shall be deemed a misdemeanor and the operator thereof shall be punished by a fine of one thousand dollars ($1,000) for each infraction.

(b) It shall be the function of the county wherein an airport is situated to enforce the noise regulations established by the department. To this end, the operator of an airport shall furnish to the enforcement authority designated by the county the information required by the department's regulations to permit the efficient enforcement thereof.

(c) Penalties assessed for the violation of the noise regulations shall be used first to reimburse the General Fund for the amount of any money appropriated to carry out the purposes for which the noise regulations are established, and second be used in the enforcement of the noise regulations at participating airports.

Sec. 6. There is hereby appropriated from the General Fund in the State Treasury to the Airport Assistance Revolving Fund, as a loan, the sum of fifty thousand dollars ($50,000) to be used in carrying out the purposes of Sections 21669, 21669.1 and 21669.2 of the Public Utilities Code as added by this act, and to be repaid as follows:

(a) Any penalties assessed for the violation of noise regulations pursuant to this act shall first be used to reimburse the General Fund until such loan is repaid; and

(b) If legislation is enacted to impose a tax on aircraft jet fuel, the revenues from which are to be deposited in the Airport Assistance Revolving Fund, such revenues shall first be used to reimburse the General Fund until such loan is repaid.

(c) From any federal grants that may be obtained by the department for the purpose of promulgating the standards called for by his act.

CALIFORNIA LEGISLATURE—1970
REGULAR SESSION

ASSEMBLY BILL No. 2434

Introduced by Assemblymen Milias, Lanterman, Foran, and Beverly

April 3, 1970

REFERRED TO COMMITTEE ON TRANSPORTATION

An act to amend Section 23130 of the Vehicle Code, relating to motor vehicles.

The people of the State of California do enact as follows:

Section 1. Section 23130 of the Vehicle Code is amended to read:

23130. (a) No person shall operate either a motor vehicle or combination of vehicles of a type subject to registration at any time or under any condition of grade, load, acceleration or deceleration in such a manner as to exceed the following noise limit for the category of motor vehicle based on a distance of 50 feet from the center of the lane of travel within the speed limits specified in this section.

	Speed Limit of 35 mph or less	Speed Limit of more than 35 mph
(1) Any motor vehicle with a manufacturer's gross vehicle weight rating of 6,000 pounds or more, and any combination of vehicles towed by such motor vehicle:		
(A) Before January 1, 1973	88 dbA	90 dbA
(B) On and after January 1, 1973	86 dbA	90 dbA
(2) Any motorcycle other than a motor-driven cycle	82 dbA	86 dbA
(3) Any other motor vehicle and any combination of vehicles towed by such motor vehicle	76 dbA	82 dbA

(b) The department shall adopt regulations establishing the test procedures and instrumentation to be utilized.

(c) This section applies to the total noise from a vehicle or combination of vehicles and shall not be construed as limiting or precluding the enforcement of any other provisions of this code relating to motor vehicle exhaust noise.

(d) For the purpose of this section, a motortruck, truck tractor, or bus that is not equipped with an identification plate or marking bearing the manufacturer's name and manufacturer's gross vehicle weight rating shall be considered as having a manufacturer's gross vehicle weight rating of 6,000 pounds or more if the unladen weight is more than 5,000 pounds.

(e) No person shall have a cause of action relating to the provisions of this section against a manufacturer of a vehicle or a component part thereof on a theory based upon breach of express or implied warranty unless it is alleged and proved that such manufacturer did not comply with noise limit standards of the Vehicle Code applicable to manufacturers and in effect at the time such vehicle or component part was first sold for purposes other than resale.

APPENDIX G

ANALYTICAL MODEL FOR ESTIMATING AMBIENT NOISE LEVELS

Definition of Ambient Noise

According to U.S. Standard Acoustical Terminology, ambient noise is defined formally as ". . . the all encompassing noise associated with a given environment, being usually a composite of sounds from many sources far and near." [2*] A brief explanation of a procedure that could be used to measure ambient noise may clarify the formal definition.

Consider a continuously recording sound level meter, reading dB(A), placed outdoors at the center of every square acre (for example) of land in a typical standard metropolitan statistical area (SMSA). (Since ambient noise levels averaged over rural areas are negligible compared to the levels of transportation noise in metropolitan areas, attention will be confined to the latter.) After one year the time average noise levels in dB(A) are calculated for each meter. Furthermore, these time averages for each meter are averaged over the entire set of meters. The resulting number measures the average ambient noise level (as the term will be used here) in dB(A) for that particular SMSA and year.

Sound level meters reading dB(A) have been chosen because of their simplicity and the high correlation (Typically greater than .8) between dB(A) readings and judged loudness of traffic noise, which determines the ambient noise levels in most outdoor areas. [15], [20], [45] Of course, physical measurements alone are not entirely adequate for describing adverse reactions to noise. The general "personality" of the population exposed as well as the information carried by the noise represent other factors which may be important, [16] [43] but which will be ignored in the present discussion of ambient noise.

In brief, ambient noise is a steady-state noise level found by averaging metropolitan noise over large areas for extended periods of time.

Highway Vehicles Determine Ambient Noise Levels

Metropolitan noise sources can be separated into transportation noise, industrial noise, and noise associated with the assorted other activities of man. [119] Of the three major sources, transportation noise is the overwhelmingly predominant source of noise levels, annoyance, and complaints in metropolitan areas. [24]

Specifically, traffic noise is responsible for the ambient noise levels and the vast majority of disturbances in most metropolitan areas, even in areas that contain major airports. [119], [80], [24] Moreover, the noise levels near many industrial areas are determined by the traffic associated with the industrial activities.

Figure G-1 demonstrates that only cars, light trucks, and heavier trucks occur in great enough quantity and noise intensity to contribute appreciably to average ambient noise levels. The three types of vehicles have been considered separately in order to take into account the great differences in noise power produced by each mode.

The enormous number of cars on the road compensates for their comparatively low noise intensity. Conversely, heavier trucks occur in relatively small numbers, but their noise output is extremely high (14 times that of cars). Light trucks are situated somewhere between cars and heavier trucks with respect to both number and noise intensity.

The number of motorbuses is negligible even compared to the number of heavier trucks. The number of motorcycles is higher, but they also can be ignored for average ambient noise considerations since they are in use a much smaller fraction of time than cars and trucks. It is not intended to imply that as single vehicles or in localized areas, motorcycles or buses are not annoying. Simply averaged over area and time, the effect on ambient noise can be neglected.

Although the remainder of Appendix G is concerned with the derivation of ambient noise levels from estimated ensitites of cars, light trucks, and heavier trucks, the same procedure can be applied to any number and variety of highway vehicles.

Development of the Model

As a first step in determining time-area averaged ambient noise levels, consider each type of vehicle (e.g., cars) distributed uniformly as point sources separated by a dis-

Mode	Approximate No. in Use in 1967 (100) [13]	dB(A) Average drive-by noise level at 50 ft. at 25-35 mph [45], [53], [24], [8]
Cars	73,000,000	64 dB(A)
Light trucks (5-ton or less)	12,000,000	68 dB(A)
Heavier trucks (over 5 tons)	4,000,000	80 dB(A)
Motorbuses (excluding school buses)	50,000	78 dB(A)
Motorcycles	2,000,000	73 dB(A)

Figure G-1

*Reference numbers refer to sources in Chapter V Bibliography.

tance S, each emitting noise power P throughout the metropolitan area (Figure G-2). The separation distance S is related to the number of vehicles per unit area n like $S = 1/\sqrt{n}$. A uniform probability integration over a square of side S shows that the "random listener" will lie a distance of approximately $r_o = S/2 = \frac{1}{2}\sqrt{n}$ away from the nearest point source.

The idea is to calculate the noise level at the random listener by adding the contribution from each point source. The difficult summation can be converted into a more convenient integration by replacing the point sources with a continuous plane of Noise sources that begin at a radius r_o and extend to infinity as shown in Figure G-3.

The average power radiated per unit area P_a is simply made equal to the product of the number of vehicles per unit area n and the noise power P from each vehicle. Because of atmospheric absorption an area of radius greater than a few miles can be extended indefinitely without the introduction of appreciable change in ambient noise levels. [24]

Assuming each element of area radiates hemispherically, [19] the intensity I_o of noise at the origin O (random listener) can be found by integrating over concentric

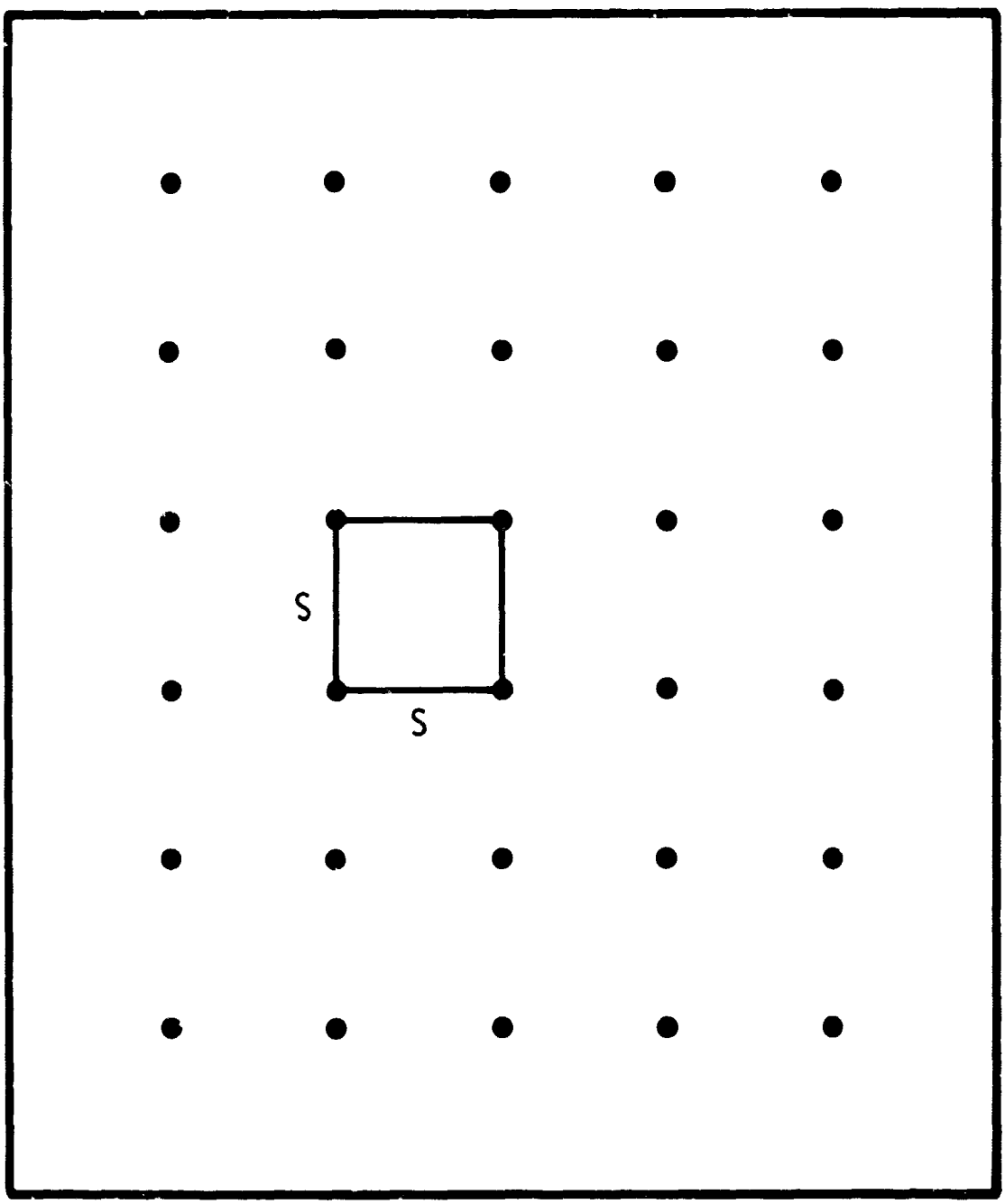

Figure G.2. Uniform distribution of point noise sources separated by a distance S.

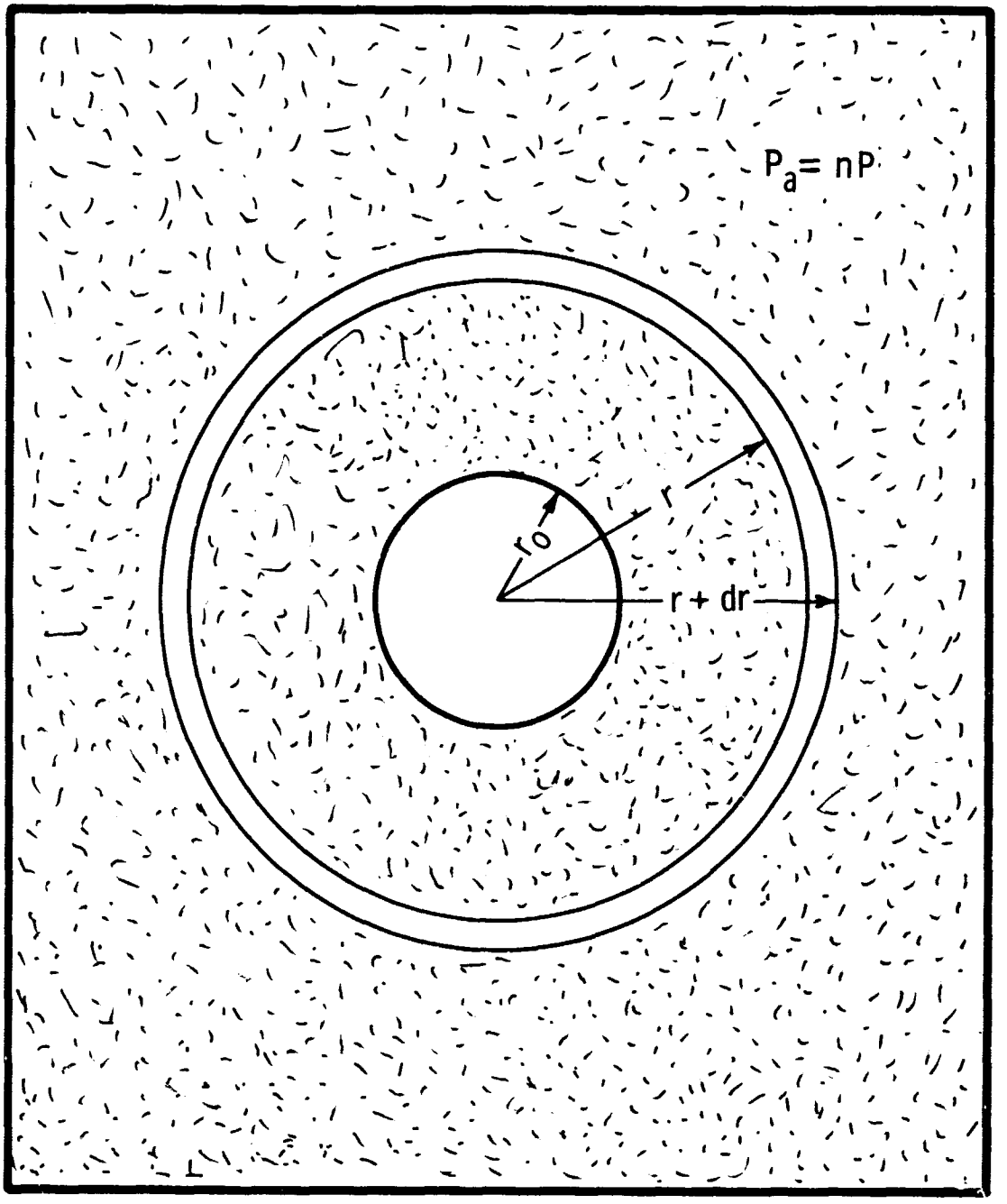

Figure G.3. Continuous distribution of sound power.

rings of metropolitan area to give

$$I_o = n\,P\int_{r_o}^{\infty}\frac{e^{-\alpha r}}{r^{\phi}}\,dr = nPE_1\ \frac{\alpha}{2\sqrt{n}}$$

where α is the atmospheric coefficient of air, and $E_1\ \frac{\alpha}{2\sqrt{n}}$ is a tabulated transcendental function [1] called the exponential integral of the first kind.

The noise intensity I_o can be converted to a decibel reading by dividing G.1 by the standard reference power P_o and then taking 10 times the logarithm of I/P_o, to yield

$$dB(A) = 10\ \log n + 10\ \log P/P_o + 10\ \log \frac{\alpha}{2\sqrt{n}}$$

The second term on the right hand side of G.2 can be related to the average drive-by noise level $dB_o(A)$, given in Figure G-1.

Specifically,

$$10\ \log P/P_o = dB_o(A) + 10\ \log 2\pi R^2$$

where R is the distance at which the $dB_o(A)$ level for each vehicle is measured.

Substituting G.3 into G.2 and substracting a decibel value $dB_s(A)$ to account for the reduction in noise caused by the shielding effect of structures yields

$$dB(A) = 10 \log n + \log E_1 \left(\frac{.1}{2\sqrt{n}}\right) + dB_o(A) - 26.5$$

where R has been replaced by 50 feet, α by .1 per mile, and $dB_s(A)$ by 10 decibels.

The value of .1 per mile was determined from the data reported by Beranek [9] on the minimum absorption coefficient of air in the 125 Hz range, the frequency range in which most cars and trucks emit the highest intensity of noise.

The $dB_s(A)$ reduction of 10 decibels has been chosen after the results of a report by Bolt Beranek and Newman [48] that indicates that attenuation due to structures will not exceed a maximum of 10 dB(A).

The ambient noise level from an arbitrary mix of highway vehicles can be found by substituting the average number per square mile, n, and the average noise level $dB_o(A)$ for each type of vehicle into G.4. The difficulty lies in calculating n, and in estimating the changes in n and $dB_o(A)$ through 1985. Fortunately, for cars, light trucks, and heavier trucks, n and $dB_o(A)$ can be related to other parameters which are tabulated in publications such as the Statistical Abstracts,

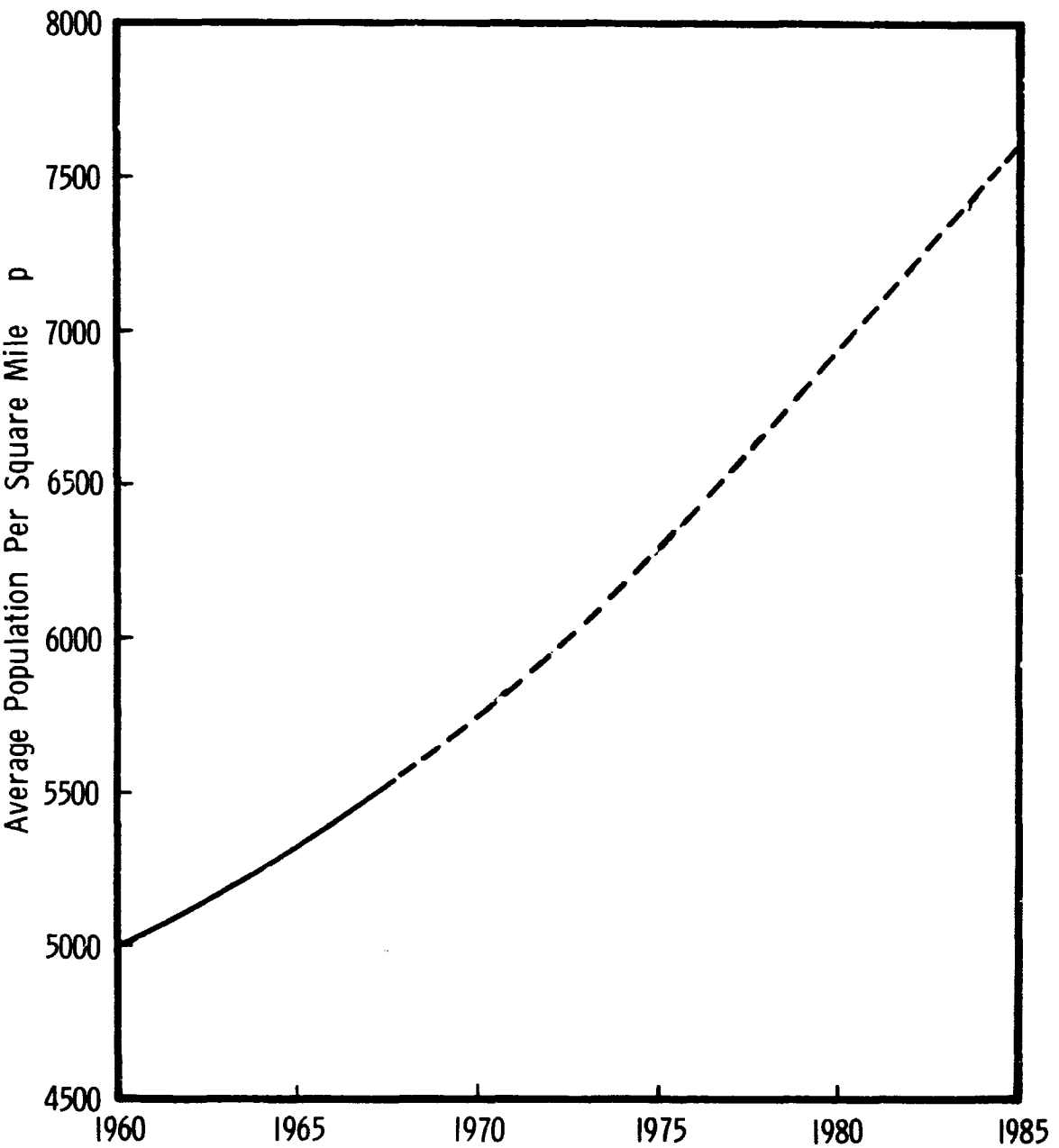

Figure G.4. Population based on Series A projections of the Bureau of Census (p = 5000 in 1960).

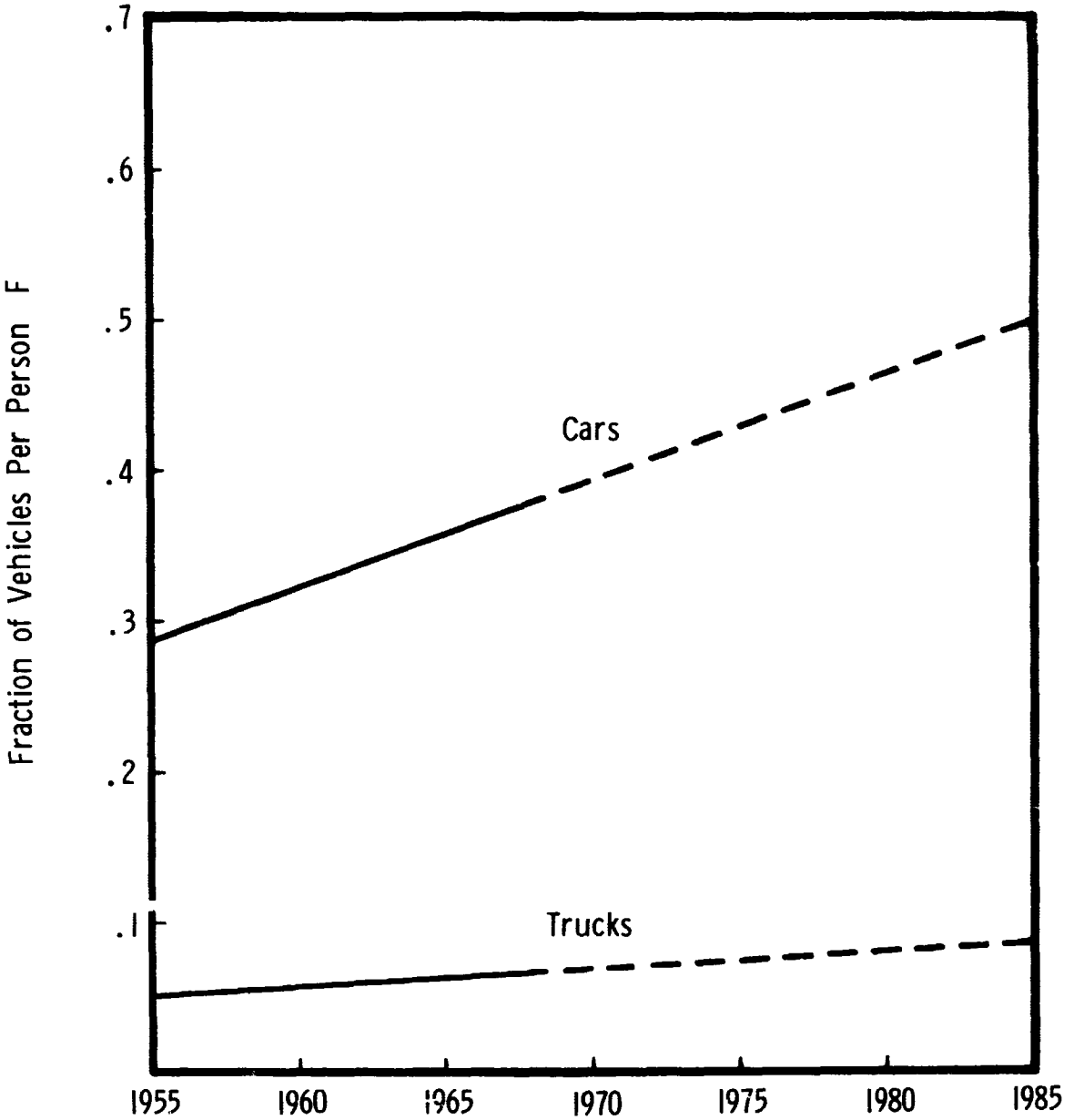

Figure G.5. Fraction of vehicles per person based on Statistical Abstracts.

[100] and which can be estimated by extrapolation to 1985.

The number of vehicles per square mile n can be approximated as

$$n = \frac{\rho F F_m M}{V Y},$$

where ρ is the average population density of the metropolitan area, F is the fraction of vehicles per person, F_m is the fraction of miles traveled in the metropolitan area, M is the average number of miles the vehicle travels per year, V is the average speed of the vehicle while in operation in the area, and Y is the time in one year.

The time in one year, Y = 8760 hours, is a trivial constant, and the speed V is assumed to continue constant through the years at 30 miles per hour for cars and 25 miles per hour for trucks. These values of speed are in accord with reported average suburban speeds. [51]

The parameters ρ, F, F_m, and M have been plotted to 1968 for cars, light trucks, and heavier trucks in Figures G-4 through G-7 and extrapolated to 1985. The extrapolations are quite conservative in that, except for the population density ρ, the curves are simply extended linearly under the assumption that recent past, and present trends in transportation will continue. The population density was assumed to grow as the series "A" population projections of the Bureau of Census. The population density in 1960 depends upon the metropolitan area under consideration. Figure G.4 assumes a population density of 5000 in 1960.

With the aid of equation G.5 and Figures G-4 through G-7, the number of cars, light trucks, and heavier trucks have been plotted to 1985 in Figure G-8 (assuming p = 5000 in 1960). The curve predicts an annual rise in vehicles per square mile of 6 percent, which is in good agreement with the annual increase in traffic volume of 7 percent for the Los Angeles region as reported by the California State Department of Highways. [17] The number of highway vehicles per square mile doubles every 10 to 15 years.

Finally, $dB_o(A)$, the noise level at 50 feet from each vehicle, must be estimated through 1985. As a first approximation, the average increase in noise emitted by each vehicle will be proportional to the increase in average horsepower per vehicle, [45] which has been plotted in Figure G-9. The increases shown in Figure G-9 correspond to a riser in average $dB_o(A)$ noise levels of .1 dB(A) per year. Substituting the numerical values obtained from Figures G-1, G-8, and G-9 into equation (G-4) results in the average ambient noise levels shown in Figures 5.11 and 5.12 of the main body of the text.

The effectiveness of specific noise control-abatement modifications, and changes in highway vehicle mix can be evaluated readily by inserting the new values of the relevant parameters into equation (G.4) and replotting the noise level curves of Figures 5.11 and 5.12.

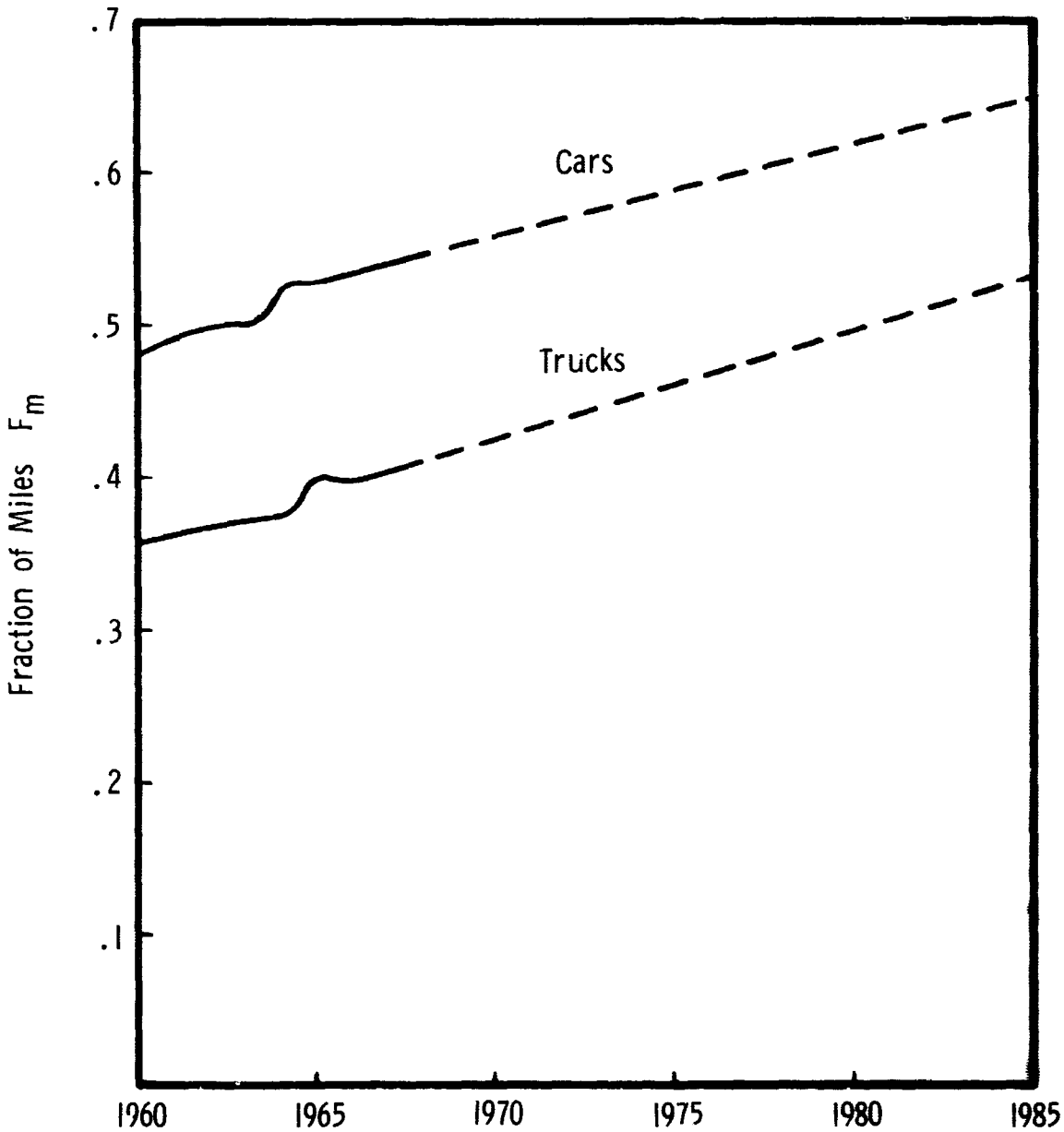

Figure G.6. Fraction of vehicle miles traveled in metropolitan areas based on Statistical Abstracts and the "1968 National Highway Needs Report" of the DOT.

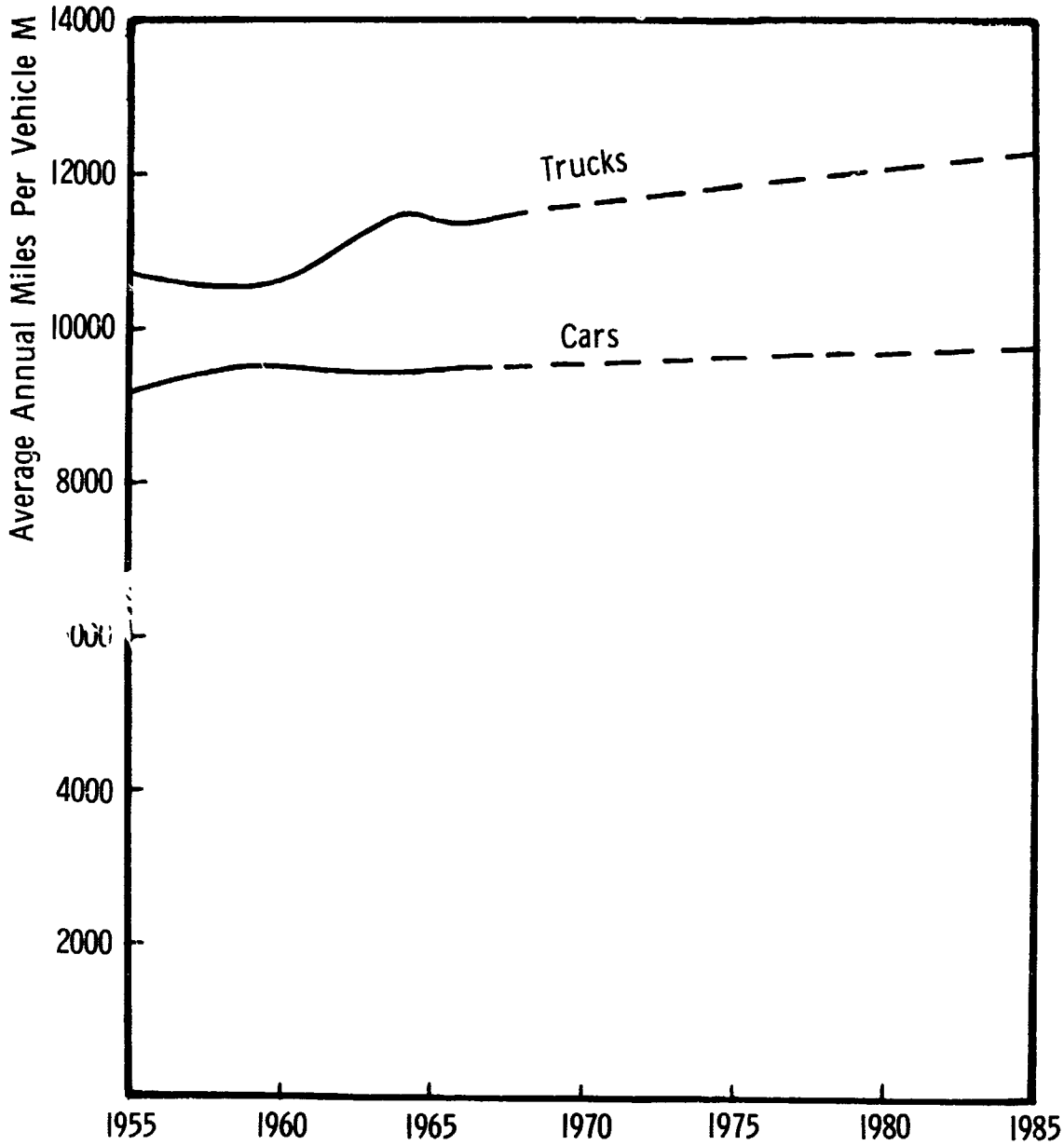

Figure G.7. Average miles per vehicle per year based on Statistical Abstracts and the "1968 National Highway Needs Report" of the DOT.

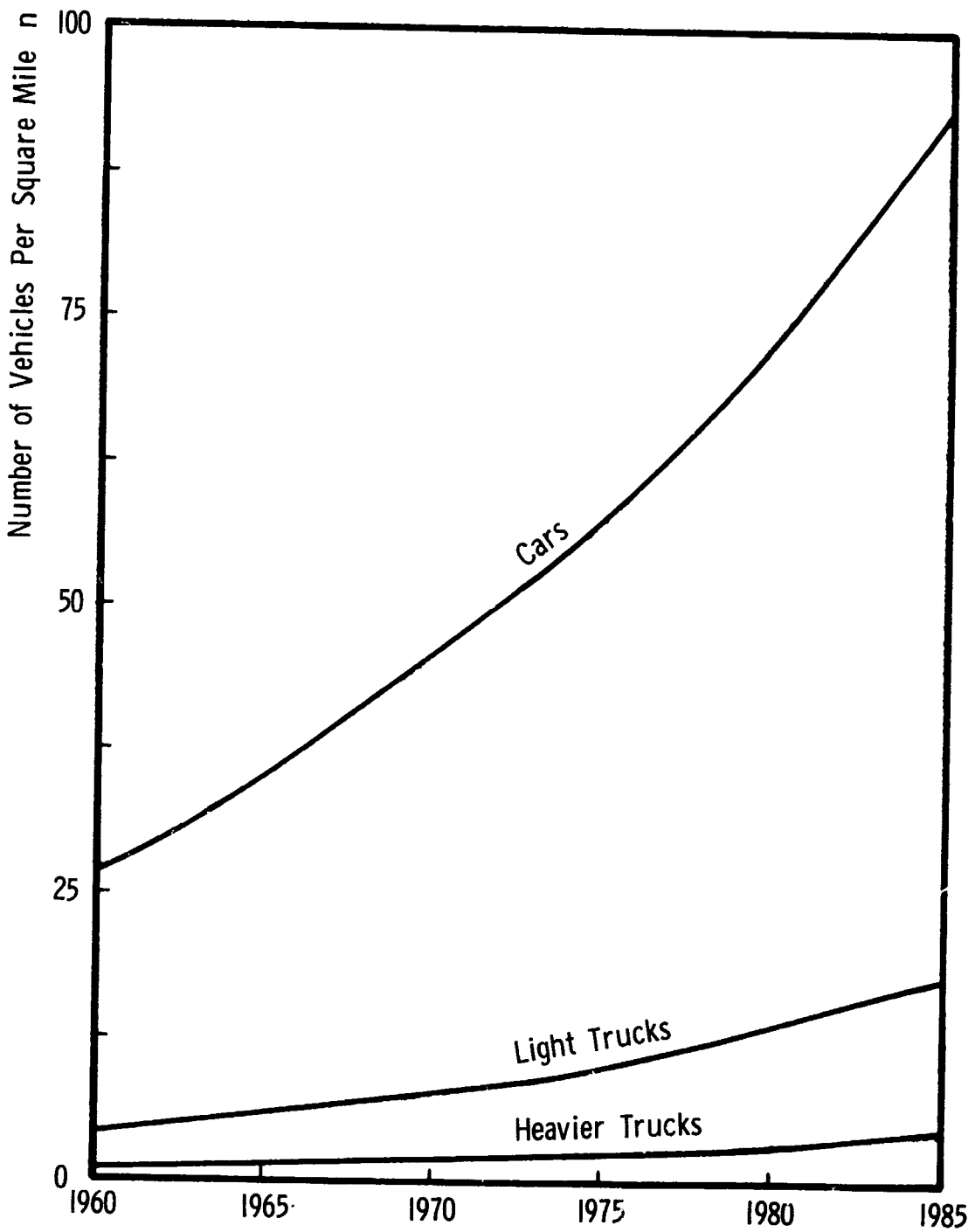

Figure G.8. Number of vehicles per square mile for a population density of 5000 in 1960.

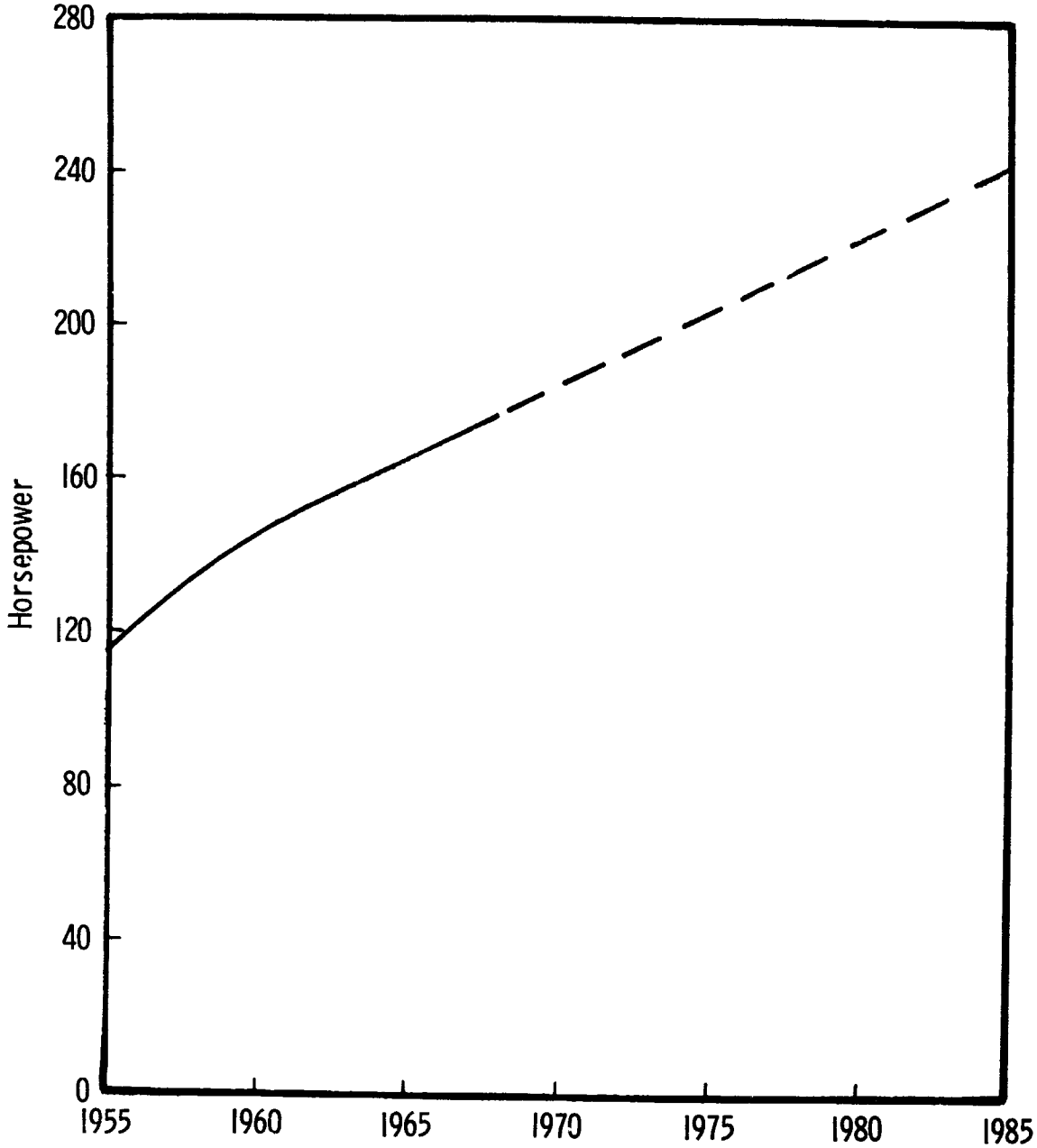

Figure G.9. Average horsepower per vehicle based on Statistical Abstracts.

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APPENDIX H

To illustrate the procedure for choosing a noise-optimal modal split as discussed in Chapter V, let it be assumed that a noise-optimal modal split is desired in which the following modes are to be considered:

Mode 1 Automobile
Mode 2 Train
Mode 3 Bus
Mode 4 Air

Let it also be assumed that the factors chosen for consideration in the noise optimization procedure are the following:

Factor 1. Relative noise levels of the individual modal noise at some average distance.
Factor 2. Duration of noise and frequency of occurrences.
Factor 3. Sensitivity of modal noise to increased traffic.
Factor 4. Relative dispersion of the noise-producing elements of the different modes.
Factor 5. Number of people exposed to noise by the different modes.
Factor 6. Community sensitivity to noise from the modes.

The modes are assigned desirability ratings relative to each of the above factors as shown in Table 1. The maximum rating of 10 indicates the maximum desirability and zero indicates the minimum.

Desirability Ratings for Modal Split 1, Relative to Factors 1-6

Factor	1	2	3	4	5	6
Auto rating	7	6	8	10	3	6
Train rating	2	4	10	8	2	10
Bus rating	3	4	9	9	2	8
Air rating	0	3	2	7	2	1

Table 1

Next, each factor is assigned an importance weighting relative to the other factors. In this example the importance weightings were restricted to integers between 0 and 10, but there is no reason a larger range of numbers could not be used.

The importance weightings assigned for this example are given in Table 2.

Importance Weightings of Factors 1-6

Factor	Importance Weighting
1	10
2	5
3	10
4	2
5	2
6	4

Table 2

The incremental desirability indices for the modes are calculated by multiplying the desirability ratings from Table 1 by the corresponding importance from Table 2 and adding the numbers obtained as follows:

Auto Incremental D. I. – 7x10 + 6x5 + 8x10 + 10x2 + 3x2 + 6x4 = 230
Train – 2x10 + 4x5 + 10x10 + 8x2 + 2x2 + 10x4 = 200
Bus – 3x10 + 4x55 + 9x10 + 9x2 + 2x2 + 8x4 = 194
Air – 0x10 + 3x5 + 2x10 + 7x2 + 2x2 + 1x4 = 57

The results of the incremental desirability calculations indicate that, for the modal split being considered, air traffic should be reduced, and auto, train, and bus traffic increased to effect an improvement in the noise problem.

The aggregate desirability index is the sum of the incremental desirability indices of the modes which have just been found. This index is

A.D.L. = 230 + 200 + 294 + 294 + 57 = 681

This number when compared with the aggregate desirability index of another modal split will indicate the relative desirability of the two splits from a noise standpoint.

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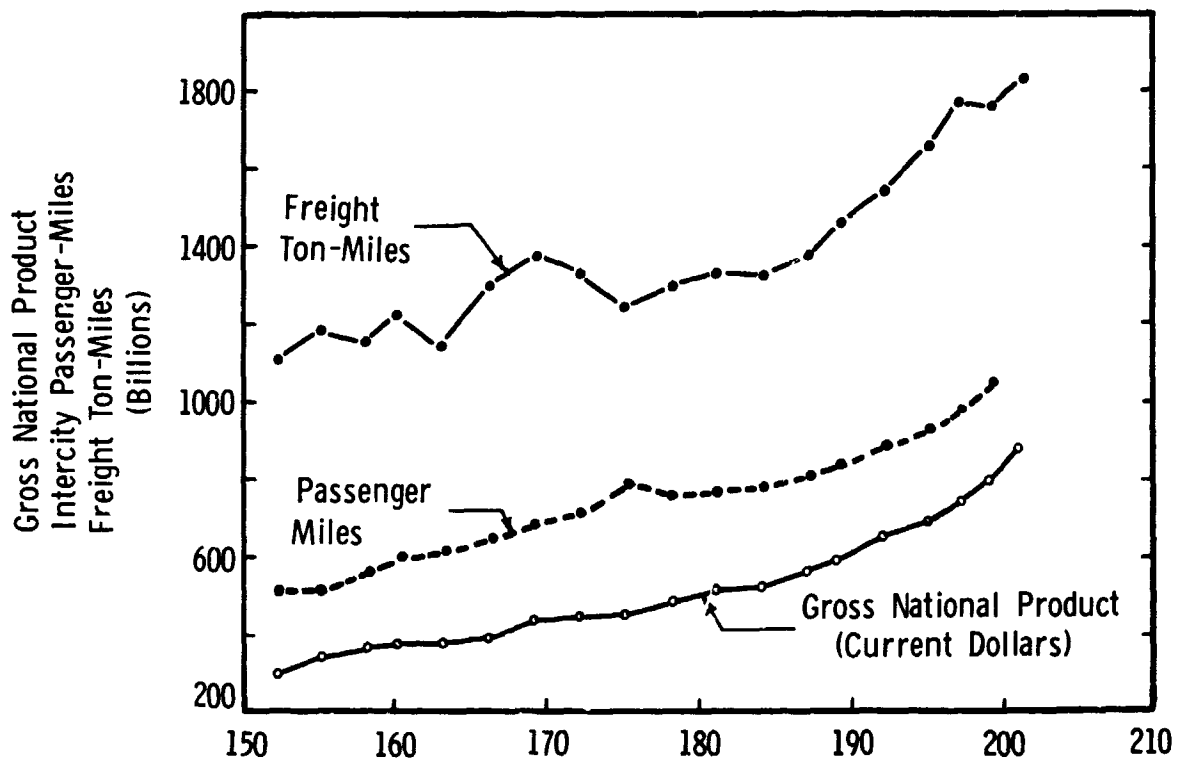
APPENDIX I



Gross National Product, Passenger-Miles, and Ton-Miles as Functions of Population

Figure I.1.

U. S. POPULATION, GROSS NATIONAL PRODUCT
INTERCITY PASSENGER-MILES AND FREIGHT TON-MILES
1950-1968

Year	U. S. Population (Millions)	Gross National Product (Billions)	Intercity Passenger-Miles (Billions)	Ton-Miles of Freight (Billions)
1950	152	285	509	1,094
1951	155	328	520	1,178
1952	158	346	558	1,144
1953	160	365	590	1,204
1954	163	363	607	1,123
1955	166	398	646	1,275
1956	169	419	680	1,355
1957	172	443	707	1,335
1958	175	447	749	1,215
1959	178	482	754	1,285
1960	181	504	773	1,314
1961	184	520	780	1,310
1962	187	560	806	1,371
1963	189	591	840	1,454
1964	192	632	882	1,540
1965	195	681	926	1,667
1966	197	740	967	1,763
1967	199	794	1,051	1,765
1968	201	866		1,834

Source: Department of Commerce, Bureau of Census, Statistical Abstract of the United States.

Table I.1.

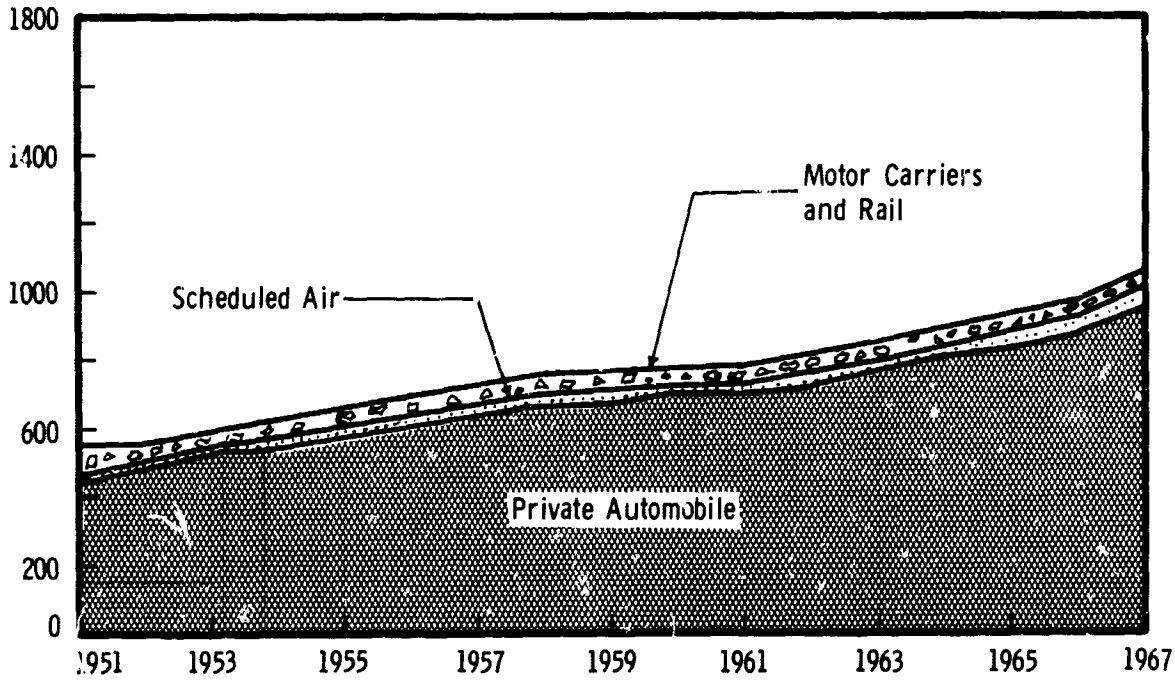


Figure I.2. Domestic Intercity Passenger Miles by Mode of Travel.

DOMESTIC INTERCITY PASSENGER-MILES BY MODE OF TRAVEL, 1951-1967
(BILLIONS)

Year	Common Carrier				Private Automobile	Total
	Scheduled Air	Line-Haul Rail	Motor Carriers	Total		
1951	10.5	29.8	22.3	62.6	457.8	520.4
1952	12.5	29.3	21.2	63.0	495.5	558.5
1953	14.7	26.9	19.6	61.2	529.2	590.4
1954	16.7	24.5	16.9	58.1	548.8	606.9
1955	19.7	23.8	16.6	60.1	585.8	645.8
1956	22.3	23.3	16.4	62.0	617.7	679.7
1957	25.3	21.1	16.4	62.8	644.8	707.6
1958	25.3	18.5	20.8	64.6	684.9	749.5
1959	29.2	17.5	20.4	67.1	687.4	754.5
1960	30.4	17.1	19.9	67.4	706.1	773.5
1961	30.9	16.2	19.7	66.8	713.6	780.4
1962	33.4	15.9	21.3	70.6	735.9	806.5
1963	38.3	14.4	21.9	74.6	765.9	840.5
1964	43.9	14.0	22.7	80.6	801.8	882.4
1965	51.6	13.3	23.3	88.2	838.1	926.3
1966	60.6	12.9	24.0	97.5	870.0	967.5
1967	75.5	10.9	25.0	111.4	940.0	1051.4

Source: 1951-1957, FAA, Statistical Handbook of Aviation, 1962;
1958-1967, FAA, Statistical Handbook of Aviation, 1967.

Table I.2.

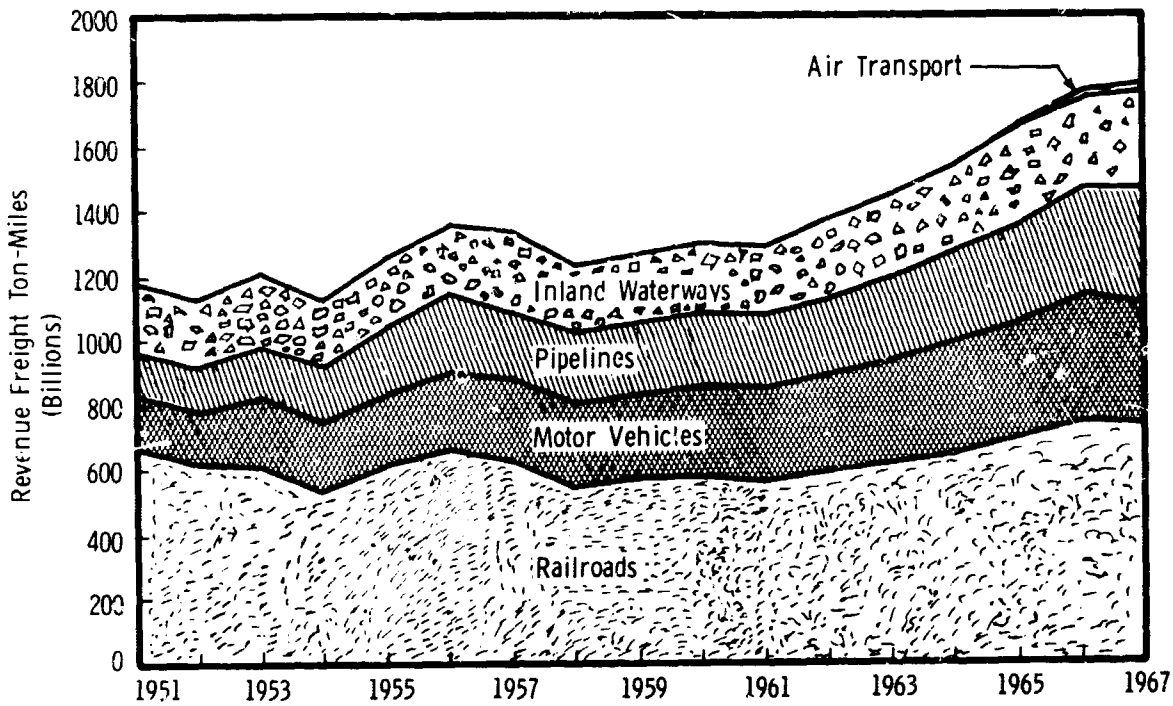


Figure I.3. Intercity Freight Traffic by Transportation Mode, 1951-1967.

FREIGHT REVENUE TON-MILES
BY MODE OF TRANSPORT, 1951-1968

Year	Railways	Motor Vehicles	Inland Waterways	Pipelines	Airways	Total
1951	655	188	182	152	.38	1,178
1952	623	195	168	158	.42	1,144
1953	614	217	202	170	.41	1,204
1954	557	213	174	179	.40	1,123
1955	631	223	217	203	.48	1,275
1956	656	249	220	230	.56	1,355
1957	626	254	232	223	.57	1,335
1958	559	256	189	211	.58	1,215
1959	582	279	197	227	.74	1,285
1960	579	285	220	229	.78	1,314
1961	570	296	210	233	.90	1,310
1962	600	309	223	238	1.29	1,371
1963	629	336	234	253	1.30	1,454
1964	666	356	250	266	1.50	1,540
1965	709	388	262	306	1.91	1,667
1966	751	412	265	333	2.25	1,763
1967	731	389	281	261	2.59	1,765
1968	757	396	287	391	2.90	1,834

Source: CAB, Handbook of Airline Statistics, 1969 Edition.

Table I.3.

NUMBER U.S. CARRIER FLEET ACTIVE AIRCRAFT
ON DECEMBER 31, BY AIRCRAFT TYPE

Year	Fixed Wing				Rotary Wing			Fleet Total
	Type Engine			Total	Type Engine		Total	
	Turbine		Piston		Turbine	Piston		
	Turbojet	Turboprop						
1957	-	59	1,909	1,967		26	26	1,993
1958	6	90	1,963	2,059		22	22	2,081
1959	84	213	1,530	1,829		23	23	1,850
1960	202	230	1,678	2,110	1	24	25	2,135
1961	319	261	1,505	2,085		19	19	2,104
1962	397	262	1,368	2,027	8	12	20	2,074
1963	432	267	1,360	2,059	12	8	20	2,079
1964	564	276	1,221	2,061	13	7	20	2,081
1965	725	312	1,067	2,104	15	6	21	2,125
1966	1,006	372	873	2,251	16	5	21	2,272
1967	1,344	444	642	2,430	17	5	22	2,452

Source: FAA, Statistical Handbook of Aviation.

Table I.4.

NUMBER OF POWERED GENERAL AVIATION
AIRCRAFT ON DECEMBER 31, BY TYPE OF AIRCRAFT

Year	Type of Aircraft					Total
	Single Engine		Multiengine	Turbinel	Rotary	
	1-3 Place	Over 3-Place	(Piston)	Jet	Wing	
1955	35,740	19,240	3,342		237	58,559
1956	35,358	22,805	4,183		283	62,629
1957	35,898	23,751	5,036		344	65,029
1958	35,522	26,170	5,416		439	67,547
1959	34,543	27,301	6,034		525	68,403
1960	33.472	34,829	7,243		634	76,178
1961	32,800	38,206	8,241	160	798	80,205
1962	32,341	41,120	8,973	213	967	83,614
1963	30,977	42,657	9,450	245	1,171	84,500
1964	30,367	45,777	10,338	306	1,306	88,094
1965	31,364	49,789	11,403	574	1,503	94,633
1966	35,681	52,940	12,671	915	1,622	103,829
1967	41,683	61,124	14,420	1,565	1,858	120,650
1968	44,271	64,259	15,542	1,962	2,149	129,000

Source: Speas Associates, The Magnitude and Economic Impact of General Aviation, 1968-1980. Aero House, Manhasset, N.Y.

Note ( ) indicates forecasts.

Table I.5.

AIRCRAFT OPERATIONS AT FAA-OPERATED
AIRPORT TRAFFIC CONTROL TOWERS BY TYPE OF AIRCRAFT
(MILLIONS)

Year	Type of Operations				Total		Total
	Itinerant			General Aviation (Local)	Air Carrier	General Aviation	
	Category		Total				
	Air Carrier	Gen. Aviation					
1958	6.8	7.7	14.5	5.8	6.8	13.5	20.3
1959	7.1	6.4	13.5	6.2	7.1	12.6	19.7
1960	6.9	8.7	15.6	5.8	6.9	14.5	21.4
1961	6.7	7.2	13.9	5.9	6.7	13.1	19.8
1962	6.7	10.2	16.9	6.8	6.7	17.0	23.7
1963	7.0	11.4	18.4	8.1	7.0	19.5	26.5
1964	7.2	12.7	19.9	9.8	7.2	22.5	29.7
1965	7.5	14.3	21.8	11.6	7.5	25.9	33.4
1966	7.9	17.5	25.4	15.1	7.9	32.6	40.5
1967	9.0	19.1	28.1	17.1	9.0	36.2	45.2
1968	9.9	21.3	31.2	19.0	9.9	40.3	50.2
1969	10.4	21.8	32.2	19.0	10.4	40.8	51.2

Source: Federal Aviation Administration, Air Traffic Activity and Statistical Handbook of Aviation.

Table I.6.

GENERAL AVIATION
HOURS AND MILES FLOWN BY TYPE OF FLYING
(HOURS IN THOUSANDS; MILES IN MILLIONS)

Year	Type of Flying										Total	
	Business		Commercial		Instructional		Personal		Other			
	Hours	Miles	Hours	Miles	Hours	Miles	Hours	Miles	Hours	Miles	Hours	Miles
1955	4,300	628	1,950	246	1,275	121	1,975	222			9,500	1,217
1956	4,600	672	2,000	247	1,500	158	2,100	238			10,200	1,315
1957	4,864	721	2,013	249	1,864	202	2,109	241	88	13	10,938	1,426
1958	5,699	847	2,365	299	2,150	232	2,365	282			12,579	1,660
1959	5,699	858	2,365	292	2,043	223	2,796	343			12,903	1,716
1960	5,699	881	2,365	299	1,828	194	3,172	387	57	8	13,121	1,769
1961	5,699	888	2,634	333	1,796	203	3,398	425	75	9	13,602	1,858
1962	5,431	935	3,051	367	2,385	256	3,489	388	144	20	14,500	1,966
1963	5,740	983	3,172	369	2,417	266	3,626	410	151	21	15,106	2,049
1964	5,823	1,047	3,305	393	2,675	284	3,777	436	158	22	15,738	2,172
1965	5,857	1,204	3,348	461	3,346	359	4,016	512	166	26	16,733	2,562
1966	7,057	1,536	3,555	516	5,674	646	4,540	606	197	32	21,023	3,336
1967	6,578	1,431	3,918	569	6,262	713	5,173	691	222	36	22,153	3,440

Source: FAA, Statistical Handbook of Aviation.

Table I.7

ITINERANT AIRCRAFT OPERATIONS AT FAA TRAFFIC CONTROL TOWERS BY SIZE OF HUB AND AIRCRAFT CATEGORY (THOUSANDS OF OPERATIONS)

Year	Hub Size								Grand Total
	Large Hub		Medium Hub		Small Hub		Non-Hub		
	Air Carrier	General Aviation	Air Carrier	General Aviation	Air Carrier	General Aviation	Air Carrier	General Aviation	
1958	3,493	2,444	1,781	2,239	1,267	2,268	229	757	14,478
1959	3,676	2,730	1,837	2,298	1,321	2,407	284	966	13,519
1960	3,681	2,937	1,599	2,150	1,326	2,699	280	896	15,568
1961	3,506	3,046	1,455	2,124	1,383	2,850	341	1,172	13,897
1962	3,494	3,250	1,411	2,238	1,422	2,979	410	1,686	16,890
1963	3,560	3,917	1,586	2,557	1,478	3,185	418	1,741	18.442
1964	3,638	4,447	1,664	2,885	1,436	3,402	442	1,950	19,864
1965	3,891	5,031	1,706	3,195	1,473	3,854	451	2,249	21,850
1966	4,259	6,308	1,649	3,442	1,502	4,560	487	3,204	25,411
1967	5,040	7,13[illegible]	1,795	3,635	1,674	4,953	507	3,352	28,087
1968	5,536	7,68[illegible]	2,189	4,453	1,694	5,177	530	4,023	31,287
1969	5,810	7,582	2,299	4,517	1,733	5,363	571	4,331	32,206

Source: FAA, Air Traffic Activity.

Table I.8.

HIGHWAY STATISTICS REGISTRATIONS, VEHICLE MILES, AND AVERAGE MILES PER VEHICLE FOR PASSENGER CARS, TRUCKS, AND BUSES

	1950	1955	1960	1965	1967	
Registrations (Thousands):						
Passenger Cars and Taxi	40,399	52,145	61,682	75,258	78,354	80,414
Trucks and Buses	8,823	10,544	12,187	15,100	15,839	16,517
Motorcycles	454	412	510	1,382	1,753	1,953
Vehicle Miles (Billions):						
Passenger Cars	364	487	588	711	751	779
Trucks and Combinations	91	111	127	172	174	182
Buses	4.1	4.5	4.4	4.8	4.9	5.0
Total Travel	459.1	602.5	719.4	887.8	929.9	996.0
Average Miles per Vehicle:						
Passenger Cars[a]	9,040	9,359	9,446	9,286	9,384	9,449
Trucks	10,776	10,697	10,583	11,587	11,207	11,204
Buses	20,910	17,658	16,004	15,215	15,012	14,766

[a]Includes Taxicabs and Motorcycles

Source: Department of Transportation, Federal Highway Administration, Annual Report as reported in Statistical Abstract, U.S. Census Bureau.

Table I.9.

Appendix J

Airports Utilizing Noise Abatement Procedures

A. APPROACH PROCEDURES:

Two-segment initial large angle descent maintaining maximum alt. with roundout to low angle to final approach	Montreal Toronto Fresno		
Maintain maximum or traffic pattern altitude until final approach (glide slope)	Ottawa Winnipeg Wash. Nat'l O'Hare Seattle/Tacoma	Kennedy Minn./St. Paul Louisville Miami Los Angeles	Orly Frankfurt Heathrow Zurich
Remain on glide slope until final approach	Bakersfield Newark		
Fly so as to avoid noise-sensitive areas	Calgary Tokyo		
Avoid excessively low approaches	Ft. Lauderdale		
Runway threshold extended/Displaced landing threshold	Kennedy Bakersfield Newark		
No procedure mentioned or no information available	Phoenix Tampa Tulsa Dulles	Denver (procedures for training flights only) San Francisco (present regulations being revised)	

B. TAKEOFF PROCEDURES:

Two-segment climbout with power cut-back at noise sensitive areas	Wash. Nat'l Frankfurt	Toronto Winnipeg	
Two-segment climbout with cut-back at specified altitude	Heathrow Orly	USSR Zurich	
Takeoff heading to specified altitude, no power cut-back mentioned	Fresno Los Angeles Seattle/Tacoma	Montreal Ottawa Andrews AFB	Miami O'Hare

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B. TAKEOFF PROCEDURES: (continued)

Takeoff heading specified to point of turn	Ft. Lauderdale Louisville Minn./St. Paul	Calgary Oslo Tokyo	Portland, Ore. Hickam AFB
Noise level specified at noise sensitive areas	Kennedy (112 PNdB)		
Runway heading to specified distance before turning	Logan Tampa	Phoenix	
No procedures specified or no information given	Dulles Okla. City Milwaukee	San Diego Atlanta	Bakersfield San Francisco (regulations being revised) Denver (training flights only)

C. TAKEOFF AND APPROACH ROUTE PROCEDURES:

Preferential Runways:				Avoidance of Populated Areas:
Logan Kennedy (nighttime only) O'Hare Miami Orly	Minn.-St. Paul Tampa Ft. Lauderdale Fresno Zurich	Denver Buffalo Bakersfield Louisville Oslo	Ottawa Montreal Toronto Winnipeg Tokyo	Los Angeles Phoenix Dulles Calgary Heathrow

D. LIMITATION OF OPERATIONS:

Night Movement Restrictions:	Number of Operations	Type of Aircraft
Kennedy 10 PM-7 AM Pref. Runws.		
Los Angeles 10 PM-7 AM Pref. Runws.		
O'Hare 11 PM-7 AM Pref. Runws.		

D. LIMITATION OF OPERATIONS: (continued)

Night Movement Restrictions:	Number of Operations	Type of Aircraft
Fort Lauderdale 10 PM-8:30 AM Pref. Runws.		Training flts. banned
Tulsa 10 PM-7 AM Pref. Runws.		
Miami IFR 7 PM-7 AM		
Washington National No jet ops. at night	Limited	No 4-engine jets
Minnesota/St. Paul Sched. reduced		Training flights diverted
Denver 10 PM-7 AM No trainers		Noise Abatement proc. for training flts. only
Ottawa 10 PM-8 AM No trainers		
Toronto 10 PM-7 AM No tech. or charter flts.		
Orly 10:15 PM-6 AM No jet takeoffs		Training flights banned
Heathrow 11 PM-6 AM Limited takeoffs	1 Apr.-31 Oct. ops. limited	
Frankfurt 9 PM-5 AM		
Zurich 9 PM-7 AM Runway 34 only		
Oslo No ...ght jets—diverted		
Tokyo Airport and Most Airports in the USSR Serving Jets Have Night Restrictions		

E. NONOPERATIONAL PROCEDURES

Airport Layout	Land Acquisition	Land-Use Planning	Public Relations	Building Insulation	Zoning	Area Renewal
Sacramento	Sacramento	Sacramento		Dallas		
	Dallas					
Ft. Lauderdale		Ft. Lauderdale				
			Buffalo			
Islip, L. I.	Islip, L. I.	Islip, L. I.				Islip, L. I.
		Denver			Denver	
	Oklahoma City	Oklahoma City			Oklahoma City	
		Seattle/Tacoma				
		San Francisco	San Francisco	San Francisco	San Francisco	
	Las Vegas	Las Vegas	Las Vegas		Las Vegas	
		Toledo				
		Salina, N. Y.			Salina, N. Y.	
		Bradley Field			Bradley Field	
	Ocean Side, Cal.	Ocean Side, Cal.			Ocean Side, Cal.	
		Atlanta				
		Ventura			Ventura	
Oakland						
Washington Nat'l	Washington Nat'l					
		Orange Co., Cal.			Orange Co., Cal.	
		El Paso, Tex.				
		Hayward, Cal.				
Minn./St. Paul		Minn./St. Paul			Minn./St. Paul	
	Louisville	Louisville				
Fresno	Fresno	Fresno	Fresno	Fresno	Fresno	
	Miami		Miami			Miami
	O'Hare (prop)	O'Hare (prop)			O'Hare	O'Hare (prop)
		Phoenix		Phoenix (prop)		
Toronto	Toronto	Toronto				
	Los Angeles	Los Angeles	Los Angeles	Los Angeles		Los Angeles
		Akron/Canton	Akron/Canton		Akron/Canton	
Raleigh/Durham		Raleigh/Durham	Raleigh/Durham		Raleigh/Durham	
		Milwaukee	Milwaukee		Milwaukee	
	Portland, Ore.					
		Midland, Tex.				
	Des Mc. , I.					Des Moines, I.
Dulles			Dulles			
		Kennedy (prop)	Kennedy	Kennedy		

E. NONOPERATIONAL PROCEDURES (continued)

Airport Layout	Land Acquisition	Land-Use Planning	Public Relations	Building Insulation	Zoning	Area Renewal
San Juan		Tampa Ontario, Cal.			Tampa Ontario, Cal.	
			Andrews AFB		Andrews AFB	
		Norton AFB			Norton AFB	Norton AFB
					El Toro MB	
			Hamilton AFB		Hamilton AFB	
	Nashville					
		St. Petersburg Cleveland				
New Orleans						
		Columbus Hartford, Conn. Manchester, N.H.				
	Memphis		Memphis			
		Long Beach, Cal. Lakeland, Fla.				
	Detroit (prop)	Detroit Frankfurt (F.G.)		Heathrow Tokyo	Detroit (prop) Tokyo Fed. Ger. U.S.S.R.	Detroit (prop)

F. MISCELLANEOUS PROCEDURES

AVIGATION EASEMENTS	TAX RELIEF	OTHER
Oklahoma City	Dallas	Carswell AFB[1] Walker AFB[1]
Las Vegas Ocean Side, Cal. Fresno Phoenix	Toronto Los Angeles	
Midland, Tex. Des Moines, I. Torrance AFB		

[1]Underground school construction within vicinity of AFB

From: Aircraft Noise and Airport Neighbors: A Study of Logan International Airport. Peter A. Franken, David Standley. Report No. DOT/HUD IANAP-70-1, March, 1970.

APPENDIX K
GLOSSARY

A-SCALE SOUND LEVEL dB(A): The A-scale sound level is a quantity, in **DECIBELS**, read from a standard **SOUND-LEVEL METER** that is switched to the weighting scale labeled "A." The A-scale discriminates against the lower **FREQUENCIES** according to a relationship approximating the auditory sensitivity of the human ear at moderate sound levels. The A-scale sound level measures **approximately** the relative "noisiness" or "annoyance" of many common sounds. See also **PERCEIVED NOISE LEVEL**.

ABSORPTION (of sound): The conversion of sound energy into heat energy reducing the reflection of sound by a structure.

ACOUSTICS: (a) The science of sound. (b) Those factors of a room or auditorium that determine its character with respect to the quality of the received sound.

AMBIENT NOISE: Ambient noise is the total of all **NOISE** in a system or situation, independent of the presence of the desired signal.

ATMOSPHERIC ABSORPTION COEFFICIENT: A measure of the exponential decay with distance of a sound wave traveling through air.

AUDIOMETER: An instrument for testing the sensitivity of hearing.

AUDITORY THRESHOLD: The minimally perceived loudness is the threshold of audibility and, unless otherwise specified, the term auditory threshold is usually synonymous with this. There is, however, a differential threshold of audibility which refers to the minimally perceived changes in loudness or pitch, according to which dimension is specified. In either case the threshold is not a sharp dividing line but rather a region of uncertainty, and the threshold is usually taken to be the point at which an appropriate repsonse occurs 50 percent of the time.

BAND CENTER FREQUENCY: The band center frequency is the designated mean **FREQUENCY** of a band of **NOISE** or other signal.

BEL: (a) A scale unit used in the comparison of the magnitudes of powers. The number of bels, expressing the relative magnitudes of two powers, is the logarithm to the base 10 of the radio of the powers. (b) The ratio of two measures of sound power expressed as a logarithm to the base 10. A decibel (dB) is one-tenth of a bel. Being a ratio, the bel has no dimensions. The sound-pressure level in decibels is equal to 20 $\log_{10}(p/p_0)$, where p is the sound-pressure level of a given sound and p_0 is an arbitrary sound-pressure level usually taken to be 0.0002 dynes/cm.

BUILDING CODE: Minimum standards of construction required to be met within the jurisdiction of the regulatory authority.

CONDEMNATION: The legal process by which the public acquires property and other rights for public use, through the exercise of the power of eminent domain.

CYCLE: The sequence of changes taking place during the period of a recurring variable quantity.

CYCLES PER SECOND (Hertz): A measure of the frequency of sound equal to the number of times that the sound wave is repeated at a given fixed point in 1 second.

DECIBEL: One-tenth of a bel (see **BEL**).

DOMESTIC OPERATIONS: In general, operations within the territory of the United States, including the domestic operations of the certificated trunk carriers and the local service, helicopter, intra-Alaska, intra-Hawaii, and domestic, all-cargo carriers.

EASEMENT: An acquired privilege or right of use or enjoyment, falling short of full ownership, which one person may have in the land of another.

EFFECTIVE SOUND PRESSURE (ROOT-MEAN-SQUARE SOUND PRESSURE): The effective sound pressure at a point is the root-mean-square value of the instantaneous sound pressure over a time interval at the point under consideration. In the case of periodic sound pressures, the interval must be an integral number of periods or an interval long enough compared to a period. In the case of non-periodic sound pressures, the interval should be long enough to make the value obtained essentially independent of small changes in the length of the interval. Note: the term "effective sound pressure" is frequently shortened to "sound pressure."

EMINENT DOMAIN: The sovereign power of government over property which enables the public to appropriate private property or rights therein for public use with or without the owner's consent, but with reasonable compensation to the owner.

FREQUENCY: The time rate of repetition of a periodic quantity. It is usually expressed in Hertz (cycles per second).

GENERAL AVIATION AIRCRAFT: All civil aircraft except those classified as air carriers. The term "air carrier" refers to aircraft operators certificated by the Federal Aviation Administration to transport by air, person, property, and mail.

HEARING LEVEL: Hearing threshold level. A measured threshold of hearing, expressed in decibels relative to a specified standard of normal hearing.

HEARING LOSS: The amount by which a person's hearing is worse then normal, resulting from some specific cause such as advancing age or noise exposure.

HOUSING CODE: Minimum standards dealing with the occupancy, minimum facilities, and maintenance of existing structures used as residences, required to be met within the jurisdiction of the regulatory authority.

INTENSITY: A measure of the amount of sound energy that flows through a unit area in a unit interval of time. It is usually measured by recording the pressure of the sound which can be related to intensity under special measurement conditions.

INVERSE-SQUARE LAW: The inverse-square law describes that acoustic situation where the mean-square **SOUND** pressure changes in inverse proportion to the square of the distance from the source. Under this condition the **SOUND-PRESSURE LEVEL** decreases **6 DECIBELS** with each doubling of distance from the source.

ITINERANT OPERATIONS: All aircraft arrivals and departures other than local operations. Local operations are operations by aircraft operating in the local traffic pattern within sight of the tower, by aircraft known to be

departing from or arriving from flight in local practice (within a 20-mile radius of the town), or by aircraft which execute simulated instrument approaches or low passes at the airport.

LARGE AIR TRAFFIC HUB: A community emplaning 1.00 percent or more of total emplaned passengers in scheduled service of the certificated route air carriers.

LEVEL: In acoustics, the level of a quantity is the logarithm of the ratio of that quantity to a reference quantity of the same kind. The base of the logarithm, the reference quantity, and the kind of level must be specified.

LOUDNESS: The psychological response made by an observer to the physical intensity of sound.

LOUDNESS CONTOUR: A curve that shows the related values of sound pressure levels and frequency required to produce a given loudness sensation for the typical listener.

LOUDNESS LEVEL: The loudness level of a sound is measured by the sound pressure level of a standard pure tone of specified frequency which is assessed by normal observers as being equally loud.

MEDIUM AIR TRAFFIC HUB: A community emplaning between 0.25 and 0.99 percent of the total emplaned passengers in scheduled service of the certified-route air carriers.

MICROBAR: A unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter. Note: the term "bar" properly denotes a pressure of 10^6 dynes per square centimeter. Unfortunately, the bar was once used to mean dyne per square centimeter, but this is no longer correct.

MODAL SPLIT: The division of traffic between the various transportation modes, usually expressed in percentages.

NOISE: Physically, noise is defined as a complex sound with little or no periodicity, but psychologically it is customarily defined as any annoying or unwanted sound.

NOISE RATING CURVES: An agreed set of empirical curves relating octave band sound pressure level to the center frequency of the octave bands, each of which is characterized by a "noise rating" (NR) which is numerically equal to the sound pressure level at the intersection with the ordiante at 1,000 Hz. The "noise rating" of a given noise is found by plotting the ocatve band spectrum on the same diagram and selecting the highest noise rating curve to which the spectrum is tangent.

OCCUPATIONAL DEAFNESS: The loss of hearing acuity resulting from prolonged exposure to high-intensity noises in an industrial situation.

OCTAVE BAND: An octave band is a FREQUENCY band with lower and upper cut-off frequencies having a ratio of 2.

OSCILLATION: The variation, usually with time, of the magnitude of a quantity with respect to a specified reference when the magnitude is alternately greater and smaller than the reference.

OVERPRESSURE: The difference between the pressure at a point at any instant and the ambient atmospheric pressure; positive when the pressure is greater than the ambient atmospheric pressure, negative when it is less.

PASSENGER ORIGINATIONS: The number of revenue passengers boarding aircraft at points of initial emplanement on reporting carrier's operation. The return portion of a round trip is counted separately as an initial origination. Passengers traveling on an intertime ticket are counted as an initial origination on each of the carriers in the journey.

PEAK OVERPRESSURE (P_{max}): The peak overpressure is the highest positive value of the overpressure.

PEAK VALUE: Of a varying quantity is a specific time interval. The maximum numerical value attained whether positive or negative.

PERCEIVED NOISE LEVEL: The perceived noise level of a sound is measured by the sound pressure level of a reference sound which is assessed by normal observers as being equally noisy. The reference sound consists of a band of random noise between one-third and one octave wide centered on 1,000 Hz.

PERIODIC QUANTITY: A specific quantity which recurs at regular intervals of time.

PERMANENT THRESHOLD SHIFT: The component of threshold shift which shows no progressive reduction with the passage of time when the apparent cause has been removed.

PITCH: The psychological response made by an observer to the physical frequency enabling sounds to be rated on a continum of higher or lower.

POWER LEVEL: Power level, in decibels, is 10 times the logarithm to the base 10 of the ratio of a given power to a reference power. The reference power must be indicated. (The reference power is usually taken as $1.0 \times 10^{-12}_{-12}$ watt.

PRESBYCUSIS: The loss of hearing acuity occuring as a normal result of the aging process.

PRESSURE SIGNATURE: The pressure signature is a curve giving the variation of the overpressure with time.

PURE TONE: A sound in which the sound pressure changes sinusoidally with time.

RISE TIME: The rise time of a shock is the time interval between the onset of the shock and its specified termination.

ROOT-MEAN-SQUARE VALUE: The square root of the mean value of the squares of the instantaneous values of a quantity. The RMS value is often called the **effective value**.

SIGNATURE INTERVAL: The time interval between the onset of the first shock and the onset of the last shock in the signature.

SINE WAVE: A wave form in which the characteristics can be represented by a graph of the sine of the angle to the size of the angle. In sound it is usually obtained by plotting the sound pressure changes as a function of time.

SMALL AIR TRAFFIC HUB: A community emplaning between 0.05 and 0.24 percent of the total emplaned passengers in scheduled service of the certified-route air carriers.

SOUND: A mechanical disturbance, propagated in an elastic medium, of such character as to be capable of exciting the sensation of hearing.

SOUND INSULATION: (a) Means taken to reduce the transmission of sound, usually by enclosure. (b) The property of a partition that opposes the transmission of sound from one side to the other.

SOUND LEVEL: A weighted value of the sound pressure level as determined by a sound level meter.

SOUND LEVEL METER: An instrument designed to measure a frequency weighted value of the sound pressure level. It consists of a microphone, amplifier, and indicating instrument having a declared performance in respect to directivity, frequency response, rectification characteristic, and ballistic response.

SOUND POWER: The total sound energy radiated from a source per unit time. The unit is the watt, symbol W.

SOUND POWER LEVEL: The sound power level of a source, in decibels, is equal to 10 times the logarithm to the base 10 of the ratio of the sound power of the source to some reference sound power which should be explicitly stated.

SOUND PRESSURE LEVEL: The sound pressure level of a sound, in decibels, is equal to 20 times the logarithm to the base 10 of the ratio of the RMS sound pressure to the reference sound pressure. In case of doubt, the reference sound pressure should be stated.

SOUND PROPAGATION: The wave process whereby sound energy is transferred from one part of a medium to another.

SOUND TRANSMISSION: The transfer of sound energy from one medium to another.

SOUND WAVE: A disturbance whereby energy is transmitted in a medium by virtue of the dynamical properties of the medium.

SONIC BOOM: The characteristic bang which occurs when an aircraft is exceeding the speed of sound. It results from the polarization of the shock waves produced in two waves which cause a large rise, a gradual fall, and a further large rise in the air pressure.

SPECTRUM: The spectrum of a sound wave is the description of its resolution into components, each of different FREQUENCY and (usually) different amplitude and phase.

SONIC BOOM CARPET: The sonic boom carpet is the area on the ground in which sonic booms are experienced from a particular supersonic flight.

SPEECH INTERFERENCE LEVEL (SIL): A measure of the degree to which noise interferes with speech (Alder-sey-Williams, 1960). It is usually obtained by taking the mean of the intensities in the 600 to 1,200 Hz, 1200 to 2400 Hz and 2400 to 4800 Hz frequency bands.

STANDARD METROPOLITAN STATISTICAL AREA (SMSA): An SMSA, defined by the Bureau of Census, is essentially a county or group of contiguous counties (towns and cities in New England) which contain at least one central city of 50,000 inhabitants or more, or "twin cities" with a combined population of at least 50,000.

SUPERBOOM: A sonic boom with larger overpressure than normal due to aircraft acceleration or maneuvers, special atmospheric conditions, and merging of two or more booms.

TEMPORARY THRESHOLD SHIFT: The component of threshold shift which shows progressive reduction with the passage of time when the apparent cause has been removed.

THRESHOLD SHIFT: A loss of hearing acuity resulting from exposure to sound.

TONE: (a) A sound giving a definite pitch sensation. (b) Sometimes, also, the physical stimulus giving rise to the sensation.

ZONING: The employment of the police power of the state to regulate the use of land, the height and bulk of buildings, the proportion of the lot that may be covered, and the density of population.

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