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Assessing the economic impact of aircraft noise on communities

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ABSTRACT

ASSESSING THE ECONOMIC IMPACT OF AIRCRAFT NOISE ON COMMUNITIES

by
Ithan B. Zimmer

The impact of aircraft noise on communities is complex and multi-dimensional. This matter cannot be resolved without careful analysis of a complex array of related problems and issues including the environment, the economy, and quality-of-life concerns of people living in proximity to airports or aircraft routes. The effects of community noise are widespread and varied. Impacts can include sleep and speech interference, activity interference, general annoyance, and property value decrease. In order to improve public policy and provide a foundation for additional research, it is imperative to establish the extent of a problem. Dollars are often the least common denominator in distinguishing the magnitude of an impact. This research addresses this problem in terms of the cost of noise impact to an order-of-magnitude.

It is extremely difficult to measure and price accurately most of these impacts. However, this dissertation evaluates, in dollars, the cost of aircraft noise to communities and provides possible strategies to mitigate negative consequences of that noise. The economic effect on the community is derived from the impact of aircraft noise on residential real estate values and the reduction of student proficiency rates on standard assessment tests.

It is assumed that noise is an inconvenience to the community and a symptom of airport related issues that include not only the quality-of-life of citizens, but also the economic well-being of the community and region at-large. It must be recognized that

airports provide and facilitate economic growth and prosperity for a region. Directly and indirectly, the aircraft industry provides jobs, wages, and airport-related regional sales.

Presently, there are no universally accepted cost models and virtually all existing models assess real estate impact as the primary cost concern. The primary thesis goal is not to find a precise value for the cost of aircraft noise, but rather to establish a rationale for utilizing and quantifying criteria in order to assess the cost of noise to communities. This, in turn, may assist in developing public policy to address the expanded concerns related to aircraft noise.

ASSESSING THE ECONOMIC IMPACT OF AIRCRAFT NOISE ON COMMUNITIES

by
Ithan B. Zimmer

A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Environmental Engineering

Department of Civil and Environmental Engineering

January 2001

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This dissertation is dedicated to
my family and friends

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LIST OF ABBREVIATIONS AND SYMBOLS

A	annual amount
ANAMS	Aircraft Noise Abatement Monitoring System
ANOVA	oneway analysis of variance
CASA	Controller Automated Spacing Aid
d	number of day flight events
dB	decibels
dBA	decibels (A-weighted)
DC	detrimental condition
df	degrees of freedom
DFG	District Factor Group
DNL	Day-Night average sound Level (contour)
DOT	US Department of Transportation
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPNL	Effective Perceived Noise Level
EWR	Newark International Airport
F	F statistic
FAA	Federal Aviation Administration
FICAN	Federal Interagency Committee on Aviation Noise
ft	feet
GED	general equivalency diploma
GIS	Geographical Information System
GPS	Global Positioning System
H	hypothesis
i	interest rate
INM	Integrated Noise Model
ITWS	Integrated Terminal Weather System
JFK	John F. Kennedy International Airport
LAX	Los Angeles International Airport
lb	pounds
L	sound pressure level
L_{dn}	day-night average sound level
L_{eq}	equivalent sound level
LGA	LaGuardia Airport
Log	base 10 logarithm
μ	population mean
MS	mean squares
N, n	number, years, number of night flight events
NCES	National Center for Education Statistics
NJCAAN	New Jersey Coalition Against Aircraft Noise
NJCER	New Jersey Citizens for Environmental Research

LIST OF ABBREVIATIONS AND SYMBOLS
(continued)

NJDOE	New Jersey Department of Education
NJIT	New Jersey Institute of Technology
NLR	Noise Level Reduction
P	present value or present worth, population
p	pressure
Pa	pascals
PANYNJ	Port Authority of New York and New Jersey
PFC	Passenger Facility Charge
PNL	Perceived Noise Level
R	correlation coefficient
R^2	coefficient of determination
S	salary
s	sample standard deviation
SS	sum of the squares
SEL	sound exposure level
SENEL	single event noise exposure level
T	time interval
t	Student's t test statistic
WTP	willingness to pay
x	sample mean

CHAPTER 1

INTRODUCTION

1.1 The NJIT Study

In November 1997, New Jersey Governor Christine Todd Whitman asked the New Jersey Department of Treasury to identify a clear set of principles, tools, resources, and methodologies that could be used to evaluate all aspects of an airport routing plan that could be accepted as valid by the State and other entities. The New Jersey Institute of Technology (NJIT) was subsequently invited to assist with this assignment and produced a study, *Strategies to Evaluate Aircraft Routing Plans* (NJIT, 1999).

This report presented findings and recommendations on aircraft routing scenarios taking into account operational, environmental, and socioeconomic factors. The issues of aircraft routing and aircraft noise are complex and multi-dimensional. They cannot be resolved without considering an array of related problems and issues including the environment, the economy, and personal quality-of-life concerns of people living near airports or aircraft routes.

The NJIT study also revealed a lack of information pertaining to dollar cost assessment for aircraft noise. Studies concerning new routing scenarios quantified decreases or increases in aircraft noise levels, but were mute on the negative or positive economic effect these may have on the community at-large. The NJIT study team found that stakeholders resist placing a dollar value on noise impacts. Leigh Fisher Associates (1994) did not address real estate impacts. Citizens groups and their representatives are aware of the impact of aircraft noise on real estate values, but they also are reluctant to articulate the issue because of the difficulty of supporting such findings before the scrutiny of adversaries. Delineating aircraft noise impact in financial terms may lessen their position and decrease their chance for success with regard to their study. Paul Hamilton of the airport and aviation consulting firm Samis & Hamilton specializes in airport planning, environmental studies, and economic analysis. He confirms the reluctance of stakeholders to argue reductions in aircraft noise in terms of dollars saved as it is extremely difficult to defend the methodology and therefore may be counterproductive (meeting between Paul Hamilton and author, April 1998). Clearly, the need for this type of research is important to determining the impact of aircraft noise on communities and also forms the foundation and justification for this study.

1.2 Problem Statement

Aviation is a critical factor in international commerce and national economic growth. As discussed in Chapter 3, the annual fiscal impact of the entire aviation industry runs into the trillions. The total value of real estate in the geographic area that aircraft noise affects is in the trillions (NJIT, 1999). As cited in multiple references (EPA, 1974, 1978, Cohen, 1980, Kryter, 1994, Evans, 1998, *et al.*), noise is at least an annoyance and in many instances a negative impact on health and quality-of-life as well as real estate values. These quality-of-life and real estate value problems have led to citizen lawsuits against airport operators and compensation for damages to property values. An extensive search has been conducted using the legal software tool, Westlaw, to find the monetary damages or settlements, but no exact cumulative numbers are available. However, the Environmental Protection Agency (EPA, 1971) cites that any estimate of aggregate damages based on litigation would be an astronomical sum. Although reference figures vary widely, the dollar cost of the negative consequences of aircraft noise to the American people can be measured in the billions.

1.2.1 The Need for Establishing the Cost of Aircraft Noise Impacts

Few references account for the array of aspects of noise impact, such as health, annoyance, cost of delay, noise abatement program cost, and house depreciation. Virtually none put a dollar cost on the physiological and psychological effects. There are no known studies that attempt to tie together, in dollar figures, all impacts of aircraft noise. Dr. Gary Evans, Psychology Professor at Cornell University, a leading researcher in the psychological effects of aircraft noise on children, indicates that there is a great need to put a dollar figure on aircraft noise impact on people (discussion between Dr. Evans and author, February 2000). Leading researchers, industry, citizen groups, and consultants shy from placing dollar values on aircraft noise impact.

Although it may be virtually impossible to establish a state-of-the-art model accepted by all stakeholders, the academic environment is an appropriate arena where these issues can be studied effectively without bias. Funding for research and noise control and abatement cannot be realized without establishing the depth of the problem.

Making the public aware of the ill effects of noise is critical to the protection of public health and welfare. Impacts may be compared in terms of dollar cost. Money can be a surrogate common descriptor for dealing with differing adverse impacts. Therefore, the economic impact of noise deserves attention.

These dollar estimates are necessary for comparison with other budgetary items. Policy makers, legislators, and fiscal officers from local to national levels consider monetary impact in order to make final decisions. Legislation that restricts noise levels or that requires noise mitigation usually is quite costly to the entity generating the noise. Research that establishes the areas of impact and that places an approximate dollar value on those impacts facilitates the decision-making process.

In order to improve public policy and provide a foundation for continued research, it is imperative to establish the extent of a problem. Estimated costs are often the least common denominator in distinguishing the magnitude of an impact. This research addresses the problem in terms of the cost of noise impact to an order-of-magnitude.

Although it is extremely difficult to measure and price accurately environmental noise impacts, this dissertation estimates the cost of aircraft noise to communities and provide possible strategies to mitigate negative consequences of that noise. The economic effect upon the community in this thesis is derived from two factors: the impact of aircraft noise on real estate values and possible educational attainment attenuation based on student proficiency rates. These two factors can affect individuals over an entire lifetime. If these negative impacts affect a child or an individual over a lifetime, the serious economic consequences for the individual become serious factors for the community.

Noise is an inconvenience to the community. Aircraft noise also is a symptom of related issues that range from the quality-of-life of citizens to the economic well-being of the community and region at-large. It must be acknowledged that airports provide and facilitate economic growth and prosperity for a region. Directly and indirectly, the aircraft industry provides significant numbers of jobs, upper scale wages, and airport-related regional sales.

Presently, there are no universally accepted cost models and virtually all existing models assess real estate impact as the primary cost concern. The primary goal of this thesis is not to find a precise value for the cost of noise, but rather to establish a rationale for utilizing and quantifying criteria in order to assess the cost of noise to communities. This, in turn, may assist in developing public policy to address expanded concerns related to aircraft noise.

1.2.2 Objectives

The primary objective in this thesis is to define an approach to quantify the economic impact of aircraft noise in the New York/New Jersey metropolitan area based on noise impact on real estate values and student proficiency rates. The need for this research became apparent while conducting the NJIT study (1999). There is a potential for using the approaches developed here in decision-making by the Federal Aviation Administration (FAA), aircraft industry, State and local government, and the public. The national airspace redesign currently underway by the FAA could make significant use of this research.

Noise is an inconvenience to the community and a symptom of airport issues that include not only the quality-of-life of citizens, but also the economic well-being of the community at-large. Apart from finding a precise value for the cost of noise, the engineering perspective and methodology and its assumptions to establish the magnitude of the problem are the central goals.

The dissertation objectives may be summarized as follows:

1. Advance the state-of-the-art in environmental impact analysis and noise control engineering by continuing research in noise impact analysis and mitigation.
2. Develop a rationale to attempt to quantify the aircraft noise impact on real estate values and student proficiency rates in dollars.
3. Develop preliminary estimates of cost, based on available data, to the New Jersey community due to its proximity to Newark International Airport and its associated flight patterns.
4. Indicate the future studies and methods and accompanying data and information required in fine-tuning this model.
5. Recognize at the outset, the work is not an end in itself, but a foundation on which others can stand to ultimately use for future enhanced analysis.

1.2.3 Technical Approach

The concept is to produce an evaluative model or a framework that provides a reliable estimate of costs associated with aircraft noise. The model is procedural, taking into account the large-magnitude impacts of home depreciation and student proficiency rates. Real-world numbers are applied to establish the order-of-magnitude impact.

The study uses areas of noise impact analysis that have not been previously collected in any one report. Cross-analysis is critical due to the unique problems in the Newark area (i.e., congested airspace, population density, and the urban environment). This provides a model that could be used in addressing aircraft noise in other urban environments.

Statistical analysis and engineering economics (basic finance) are used in this approach. Software used includes the Integrated Noise Model (INM) data, Geographic Information System (GIS) data, and Microsoft Excel.

Economic theory provides concepts for studying noise in terms of supply and demand, with quiet as a product or noise as a pollutant. These concepts include indifference curves, externalities, and the law of diminishing returns. Using information from specific case studies, order-of-magnitude values may be found for the cost of aircraft noise for a given area.

Airport operations in the New York/New Jersey metropolitan area continue to increase (Louis Berger, 1998). Any dollar figures for noise impact calculated will certainly increase with airport growth if no action is taken to mitigate the problem. If the problems of noise impact can be formulated and possibly solved for the complex and congested New Jersey area, it is logical to consider they can be solved anywhere in the world.

This work crosses disciplines, not only within engineering, but also into economics, education, and politics. Researchers and professionals from all these areas will find something of interest.

CHAPTER 2

NOISE FUNDAMENTALS

The major issue that the general public normally has regarding aircraft operations is the potential for noise impact. In this section of the report, a definition of noise is provided as well as the various ways that sound levels can be measured. In addition, potential areas of public impact due to elevated sound levels are described. Lastly, various legislation and national noise policy issues are discussed.

2.1 Noise Issues, Related Impacts, and Definitions

Aircraft noise often is defined as unwanted sound. Aircraft noise originates from its engines and airframe, although the engines are the more significant source of the noise, especially at takeoff. The principal sources of jet engine noise are the fan, the compressor and turbine, and the exhaust. The significance of the sources varies with engine design and operating procedure, but exhaust usually produces the largest part of the noise. The primary sources of airframe noise are from turbulent airflow past the undercarriage, leading and trailing edges of high-lift devices, aircraft cavities, and projections from the aircraft surface. In flight, the noises from these sources combine and therefore source origin is difficult to determine.

Noise level is defined in the same manner as sound level. Sound level is defined in terms of mean square sound pressure using the common (base 10) logarithm (log):

$$L = 10 \cdot \log\left(\frac{p_{rms}^2}{p_{ref}^2}\right) \tag{1}$$

where:

L is the sound level in decibels (dB)

p_{rms}^2 is the mean square sound pressure

p_{ref} is the reference pressure ($2 \cdot 10^{-5}$ Pa).

Human perception of sound varies according to frequency content. This effect can be accounted for by application of a weighting scheme for the sound frequencies. The use of A-weighting, measuring and predicting sound levels in A-weighted decibels (dBA), is the standard. Within the circuitry of the noise meter, the measured sound level is increased, decreased, or maintained (i.e., weighted) by a certain amount depending on the sound's frequency. The approximate frequency range of human hearing is 20 to 20,000 Hertz. A-weighting is based on typical human hearing of soft sounds. In general, it discounts low-frequency sounds. It may at times underestimate the effect of aircraft noise, partially due to the ability of longer waves to bend and penetrate walls and barriers. Consequently, A-weighting is not perfect. However, in most cases A-weighting correlates well enough with actual transportation noise impact and is almost universally accepted. A-weighted decibels are used in all noise metrics within this study.

Other frequency weighting schemes exist, but are not widely used. For some, it may be difficult to find measuring devices that support them. The greatest difficulty in using a frequency weighting scheme other than A is that those measurements may not be compared to anything other than measurements in the same weighting scheme. The vast majority of studies and sound measurements are performed with A-weighted decibels. Measurements may only be compared within the same frequency weighting scheme.

For comparative purposes, Table 1 lists some common sounds and their associated, typical A-weighted decibel levels. Even though the range of sound levels for the given qualitative description varies greatly, Table 1 (based on U.S. Department of Housing and Urban Development, 1972) provides an excellent comparison tool for understanding decibels. Loudness is a person's judgement, and therefore opinion, of the intensity of a sound. Although subjective, generally, over the majority of the loudness range and the range of sound regarding community noise, a 10 dB increase in sound pressure corresponds to approximately a doubling of loudness. Most people are unable to distinguish differences in sound pressure level of less than 3 dBA. This does not apply to the DNL metric.

Table 1 Common Sounds on the A-Weighted Decibel Scale

Sound	**Sound Level (dBA)**	**Approximate Relative Loudness**	**Relative Sound Energy**
Rock music, with amp	120	64	1,000,000
Thunder, snowmobile (operator)	110	32	100,000
Pneumatic hammer (operator)	100	16	10,000
Orchestral crescendo at 25 ft	90	8	1,000
Concrete mixer at 50 ft	80	4	100
Department store interior	70	2	10
Ordinary conversation at 3 ft	60	1	1
Urban residence	50	1/2	0.1
Average Office	40	1/4	0.01
Average bedroom	30	1/8	0.001
Quiet country residence	20	1/16	0.0001
Rustle of leaves	10	1/32	0.00001
Threshold of hearing	0	1/64	0.000001

2.1.1 Basic Noise Metrics

Noise energy is proportional to mean square pressure. To combine the noise contributions from several sources, start by converting noise levels to mean square pressure. The noise level due to n contributions is:

$$L_{combined} = 10 \cdot \log\left(10^{\frac{L_1}{10}} + 10^{\frac{L_2}{10}} + \cdots + 10^{\frac{L_n}{10}}\right) \tag{2}$$

where:

L_n represents contributions of individual sources in dB.

When two equal noise contributions occur simultaneously, the combined noise level is approximately 3 decibels higher than the level of a single contribution. That is, the argument of the logarithm is doubled and $10 \cdot \log(2) \cong 3$.

When noise levels vary with time, they are averaged into an equivalent noise level as follows:

$$L_{eq} = 10 \cdot \log\left[\left(\frac{1}{T}\right) \cdot \int_0^T 10^{\frac{L}{10}} dt\right] \tag{3}$$

where:

L_{eq} is the equivalent sound level, in dBA, the energy average of A-weighted sound over a given time interval

L is the time-varying noise (sound) level (dBA)

T is the averaging time interval.

Equivalent sound level is an appropriate metric for examining the impact of noise where sleep-interference is not a factor. It is mathematically defined as the average. Compared to a peak level, it is appropriate as a metric when information throughout a given time period is required. Peak or maximum levels usually do not reveal the sound exposure, especially if there are events occurring significantly above ambient levels. Note that noise events are not to be compared with averages.

Sound exposure level (SEL), also called single event noise exposure level (SENEL), is an energy-time integral used to represent an aircraft event. SEL predictions are based on representative noise measurements from aircraft events corrected for altitude, aircraft type, modifications (e.g., re-engining), and operation (takeoff or landing).

$$SEL = 10 \cdot \log\left[\int_0^T 10^{\frac{L}{10}} dt\right] \tag{4}$$

where:

L is the time-varying noise level, in dBA, due to the event

T is time in seconds

The time interval is measured between the initial and final times for which the sound level for the single event exceeds the background noise level. This measurement can most easily be performed with an integrating sound level meter. In order to measure a noise event, such as an aircraft flyover, the maximum sound pressure level should be at least 10 dB greater than background levels to ensure background noise does not contribute to the measured event.

2.1.2 Day-Night Sound Level

Day-night sound level (L_{dn} or DNL) is a descriptor that recognizes the added impact of nighttime noise. It is a 24 hour L_{eq} based on A-weighting with 10 dBA added between the hours of 10 p.m. to 7 a.m. DNL is an accepted descriptor of environmental noise when sleep-interference is a factor. In cases where sleep-interference is not a factor, it may be considered equivalent to L_{eq}. Community noise impact, including the impact on schools, is commonly described by DNL contours.

The strength of this descriptor is in comparative purposes as opposed to absolute noise level determination. One of the major difficulties in establishing any type of damage due to noise impact is that noise is usually transitory, especially in the case of aircraft noise. Unlike air or water contaminants that may be measured long after their source has stopped production, noise is fleeting. Additionally, the damage produced due to aircraft noise is difficult to measure. The community noise levels discussed in this research are generally below those that produce hearing damage. So, it is the comparative aspects of DNL that enhance measurement of the impacts discussed herein.

In 1981, the FAA formally adopted DNL as the single system for determining exposure of individuals to airport noise. All U.S. states, with the exception of California, use DNL. Incidentally, California uses the Community Noise Equivalent Level (CNEL) which is similar to DNL with a 5 dB penalty for evening noise between the hours of 7 p.m. and 10 p.m. The following characteristics make DNL an appropriate and accepted metric:

- It is a measurable quantity.
- It is relatively simple to understand, requiring no familiarity with acoustical theory.
- It provides a simple method to compare noise control methods (provided consistent input data and assumptions are made).

- It is the best measure available to identify quality-of-life impacts.
- By Federal interagency agreement, it is the best descriptor for all noise sources for land use compatibility planning.
- It is the only metric with a substantial body of scientific survey data on human reaction to noise.

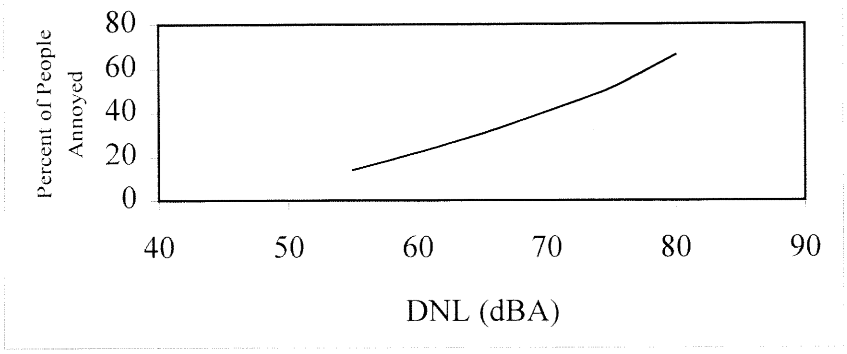
Table 2 describes subjective ratings of disturbance for various DNL contours. Generally, people experience significantly more disturbance as the aircraft noise level increases. Note there is still moderate to extreme disturbance reported below DNL55.

Table 2 Subjective Ratings of Aircraft Noise Disturbance in Different Contours (based on Kryter, 1994)

DNL Contour	**Percentage of people rating disturbance as:**			
	Not disturbing	**A little disturbing**	**Moderately disturbing**	**Very and Extremely disturbing**
< 55	15	38	38	9
55-60	50	35	35	10
60-65	10	10	53	27
65-70	17	17	39	27
70-75	14	14	18	54
75-80	0	0	50	50

A study at Heathrow Airport near London determined a relationship between the percentage of the population annoyed by community noise and noise exposure level in DNL. Figure 1 displays the results. The plot depicts a strong increasing linear correlation of people annoyed relative to day-night sound level.

Figure 1 Percentage of Population Annoyed (EPA, 1978)



There are limitations to the DNL descriptor that warrant attention. DNL contour calculations depend on the quality of the information used to construct them. These calculations are affected by the following conditions:

- Aircraft operational levels (e.g., number of operations, aircraft types, operation times, and actual flight tracks) are estimates only. When actual flight data is used, it usually covers only a number of days to weeks because of practical limitations in data analysis and possibly cost considerations. The activity may not be completely representative of all operations. Therefore, the overall study is only as good as the data is representative of typical operations.
- The noise profiles are averages. The noise signature of an aircraft varies depending upon many factors such as engine configuration, pilot's operational preferences, and environmental conditions.
- As A-weighted decibels are based on human response, human response to a given DNL level is subjective.

Although DNL is the most complete metric currently available, there are factors beyond the magnitude of the noise exposure that affect community reactions, such as:

- Duration and frequency of occurrence
- Time of year
- Time of day
- Background noise levels
- Familiarity with the noise source
- Presence of pure tones or impulse noise

Day-night sound level based on measured or predicted levels can be computed as follows:

1. Add 10 dBA to nighttime noise levels (measured or predicted between the hours of 10 p.m. and 7 a.m.).
2. Use unadjusted daytime noise levels (measured or predicted between the hours of 7 a.m. and 10 p.m.).
3. Compute DNL using the adjusted nighttime noise levels and the unadjusted daytime noise levels in Equation 3 for equivalent sound level (L_{eq}) with a twenty-four hour averaging time.

Aircraft noise predictions are based on the number of events and the accompanying SEL. Day-night sound level can be predicted from SEL values as follows:

1. For each event type compute:

$$E_i = SEL_i + 10 \cdot \log(d + 10 \cdot n) \tag{5}$$

where:

SEL_i is the SEL for that event type

d represents the number of events between 7 a.m. and 10 p.m. of a representative 24 hour period.

n represents the number of events between 10 p.m. and 7 a.m. of a representative 24 hour period.

2. Day-night sound level is then given by:

$$DNL = 10 \cdot \log\left(\sum_{i=1}^{N} 10^{\frac{E_i}{10}}\right) - 49.4 \qquad (6)$$

N is the number of different event types (different SELs).

Considering all advantages and disadvantages of DNL, it is the most complete metric available and sanctioned by the FAA. Therefore, DNL comprised of A-weighted decibels is the metric used throughout this report.

2.2 Physiological and Psychological Effects of Aircraft Noise

The physiological and psychological effects of noise vary widely among individuals. Response to noise is also strongly affected by the nature of the noise source. These effects that may include hearing, speech, and sleep impairment as well as blood pressure increases and children's learning impairments, are seldom studied in cost estimates of noise impact.

"Voluntary exposure" may be used to refer to sound or noise over which the recipient has complete control. Workplace noise exposure is semi-voluntary. Except for aircraft passengers and those employed in the aviation industry, aircraft noise exposure is involuntary. Voluntary exposure to sounds, workplace noise exposure, and involuntary noise exposure produce different psychological effects (Kryter, 1994).

The Environmental Protection Agency (1974) has identified a protective noise level limit on the basis of hearing loss due to long time exposure. The identified level is a 24 hours per day, 365 days per year equivalent sound level: $L_{eq} = 70$ dBA. This would protect 96 percent of the population from significant hearing loss. Exposure to higher levels could produce more than 5 dB of hearing loss at a frequency of 4000 Hertz in some of the population. With few exceptions, aircraft noise exposure makes a small or negligible contribution to hearing loss. Those with aircraft noise exposures that might exceed the protective noise level limit include individuals who reside or spend substantial amounts of time within day-night noise level contour DNL70. Aviation industry employees who work outdoors comprise a substantial portion of that group.

Sentence intelligibility (i.e., identifying words in context) in a typical living room, assuming a speaker using a normal voice level, and a listener with normal hearing may be related to noise level as follows:

Table 3 Sentence Intelligibility Indoors as a Function of Noise Level (Wilson, 1994)

Indoor sentence intelligibility (%)	80	95	99	100
Steady background noise level (dBA)	69	64	54	45

Intelligibility of individual words or numbers is less than 100 percent at a steady background noise level of 45 dBA. Sentence intelligibility is roughly 95 percent at a 3-meter speaker-to-listener distance outdoors with a steady background noise level of 45 dBA. A typical aircraft noise vs. time pattern consists of a series of noise events throughout the day and night. At DNL45, there will be many events with noise levels far exceeding 45 dBA in a typical aircraft noise vs. time history. Therefore, at DNL45, there will typically be many intervals of speech interference.

Sleep is crucial to health, and noise causes sleep interruption. Using information from the FAA (1977), one can estimate the percentage of residents disturbed as a function of aircraft-generated noise exposure. At DNL65, the approximate percentage of residents subject to sleep interference is:

- 46% startled
- 44% awakened
- 27% have rest or relaxation disturbed
- 24% kept from going to sleep.

It is difficult to evaluate the exact effect of outdoor noise on sleep. Individuals vary widely in sleep habits, building attenuation varies, and aircraft noise patterns vary as well.

Cohen, *et al.* (1980) found that children in aircraft noise impacted areas had higher blood pressure and were more likely to fail on tasks than those in quieter neighborhoods do. The study focussed on four impacted schools and three quiet (control) schools. Their data provide testimony to the effects of aircraft noise on psychological adjustment and on physiological, non-auditory aspects of health. The research supports the concept that noise need not be loud to annoy and effects on hearing are only one possibility.

Powers (1993) cited research that compared abilities of children from schools in quiet neighborhoods with those from four neighborhoods near Los Angeles County Airport. The study found that children from schools near the airport had diminished reading skills, gave up more quickly, and failed more often to solve puzzles. The study concluded that children might learn to cope with noise by tuning it out. Then, children may begin to tune out all auditory stimuli. It is assumed that poor auditory processing leads to reading problems. The Federal Interagency Committee on Aviation Noise (FICAN) continues research on the effects of aircraft noise on school-age children.

Evans (1998) reported on a study of 217 rural 3rd and 4th Grade school children living near Munich. The group was assessed six months before and six and eighteen months after the opening of an airport. Roughly half of the group lived under a flightpath. Modest but significant increases in blood pressure were found in the noise-exposed group. Evans stated that the results of this study might predict greater likelihood of higher blood pressure throughout adulthood.

Many, if not all, of the above issues are neglected in cost analyses related to aircraft noise, primarily due to the difficulty in obtaining dollar values. These factors may, in the long run, produce greater costs to the community than real estate losses that are purely economical.

2.2.1 EPA Protective Level Based on Activity Interference and Annoyance

The "Levels Document" (EPA, 1974) identifies DNL $\leq$ 55 as the protective level for activity interference and annoyance outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places where quiet is a basis for use. EPA (1974) identifies DNL $\leq$ 45 as the protective level based on indoor activity interference and annoyance.

These levels are cited and used in a myriad of noise studies. However, it must be understood that the levels identified in the "Levels Document" are not regulatory goals. They are levels defined by a negotiated scientific consensus without concern for economic or technological feasibility. They are conservative, with an adequate margin of safety, and designed to protect public health and welfare.

2.2.2 DNL45 as a Descriptor of Community Impact Due to Aircraft Noise

Although the FAA considers DNL65 and higher to be the level of significant noise exposure, this dissertation research and the EPA recognize that at DNL45 and above, there will typically be a general reduction in quality-of-life. In addition, the Leigh Fisher Associates report (1994) commissioned by the Port Authority of New York and New Jersey (PANYNJ), uses DNL45 as its trigger value to assess impacts of aircraft routing on the community in their study.

In fact, in Table ES-3 of the Leigh Fisher report, of thirty-nine communities analyzed for existing and proposed DNL levels due to various routing scenarios, thirty-eight had existing DNL levels less than 65 dBA with the remaining community at DNL66. As such, if a DNL65 level was recognized to provide a reasonable quality-of-life from a noise perspective for impacted populations, the Leigh Fisher study would not have been needed. Indeed, the concerns of adverse noise impacts in many of the aforementioned thirty-eight communities would not be the on-going issue it is in the State of New Jersey.

Based upon the comments noted above, the DNL45 level is a reasonable estimator for beginning to address the impacts of noise exposure on the public with respect to real estate impact and student proficiency rate impact. This does not imply that the limits of aircraft noise as measured in the community should be 45 dBA as there are practical limits to noise mitigation and cost issues to consider. Additionally, it does not imply that there are no noise impacts below the DNL45 level. However, the ability to measure aircraft noise below that level with respect to community impacts would be difficult due to the multitude of everyday background noise and sounds that occur at that level. As such, this study uses DNL45 for determining "quiet" communities from an aircraft noise perspective in assessing impacts related to real estate and student proficiency rates.

2.3 National Noise Policy

The most significant policy implementation was phasing out older and noisier aircraft (called Stage 2) with the next fleet of quieter aircraft (called Stage 3). FAA gives a schedule for phaseout of Stage 2 aircraft via federal regulations, 14 CFR Part 91 and Part 161, which implement the Airport Noise and Capacity Act, PL101-508 (November 5, 1990). Part 91 required phaseout of Stage 2 aircraft greater than 75,000 lb takeoff weight in the 48 contiguous states by December 31, 1999. To the best extent of current knowledge, the transition from Stage 2 to Stage 3 was implemented on schedule. The appendix contains some of the differences in noise requirements between Stage 2 and Stage 3 aircraft. For brevity considerations, citing of sections of the Federal Register (14 CFR) are abbreviated by referring to the Part number.

Part 161 establishes a national program for reviewing airport noise and access restrictions. It ties the hands of airport operators, making such rules difficult if based on noise. This part applies to new rules promulgated after October 1, 1990. Except for specific exemptions, no new local direct or indirect noise or access restriction on Stage 3 aircraft may be implemented unless approved by the Secretary of Transportation or all aircraft operators at the airport. As of February 2000, no Part 161 program has been completed by any airport.

2.3.1 Responsibility for Noise

The US Department of Transportation (DOT) identifies aircraft noise impact mitigation as a shared responsibility. The Federal Aviation Administration views the role of each participant, with regard to noise control, roughly as follows:

Congress: Enacts laws related to aircraft operations and aircraft noise (e.g., the phaseout of Stage 2 aircraft in favor of quieter aircraft).

Federal Aviation Administration (FAA): Promulgates and enforces regulations related to safety, approves airport operator-proposed noise-abatement flight paths, sets standards.

Airport operators: Monitor noise levels, plan noise-abatement flight paths.

Air Carriers: Set flight schedules, meet noise standards by replacing aircraft, re-engining or fitting aircraft with Hushkits.

Local governments: Plan land use, develop master plans and zoning compatible with recommendations in FAA regulations Part 150 *Airport Noise Compatibility Planning.*

Residents impacted by aircraft noise: Understand noise issues and the steps that can be taken to minimize noise effects.

Prospective residents: Are cognizant of the effect noise may have on the quality-of-life.

2.3.2 Airport Noise Compatibility Planning

Land use must be considered when evaluating aircraft routing plans. FAA regulations 14 CFR Part 150 provides procedures for developing airport noise exposure maps and noise compatibility programs. Performance of a Part 150 can provide money for a community to sound treat homes and schools if they fall within zones of significant noise. The cost of sound insulation for a home is one form of the cost of aircraft noise.

It is not the intent of the FAA, through Part 150 studies, to encourage one noise abatement alternative over another, but to provide a planning and implementation approach to ensure that maximum noise abatement benefits are derived in a manner that does not place an undue burden on air commerce, is not discriminatory, and does not adversely affect the safe and efficient use of airspace (Wilson, 1994).

A general description of Part 150 is provided. Part 150 prescribes systems for:

- Measuring noise
- Determining exposure of individuals to noise
- Determining land use compatibility
- Providing technical assistance to airport operators

A noise compatibility program can:

- Promote planning

- Examine and analyze noise impact, costs and benefits associated with noise reduction, and actions to reduce incompatible uses
- Include public participation
- Include a noise abatement plan without unduly affecting national transportation
- Include implementable noise reduction techniques and land use controls

Program alternatives include:

- Land acquisition, air rights, easements, development rights
- Barriers, shielding, soundproofing of public buildings
- Preferential runway systems
- Flight procedures, flight track modification
- Restrictions based on aircraft noise characteristics
  - denial to classes not meeting Federal standards
  - capacity limitations based on noisiness of different types of aircraft
  - noise abatement takeoff or approach procedures approved as safe by the FAA
  - landing fees based on noise emission levels
- Landing fees based on time of arrival
- Partial or complete curfews.

If an airport operator submits a noise exposure map, the map must be revised when operations changes are significant. Such changes include an increase in day-night noise level of 1.5 dB or more that creates substantial new incompatible land uses or occurs within an already incompatible land use area. Persons who acquire land after publication of a noise exposure map are not generally entitled to recover damages with respect to airport noise. Exceptions include a significant change in:

- The type or frequency of aircraft operations
- Airport layout
- Flight patterns
- Nighttime operations.

Actual land use responsibility rests with local authorities. Zoning and other types of planning for compatible land use are most appropriate in undeveloped areas. Airport noise compatibility planning is difficult in developed regions such as those surrounding the three major PANYNJ airports.

The Part 150 program is voluntary. None of the three major New York/New Jersey airports have had a Part 150 performed. Per conversations with Ralph Tragale, Senior Community Relations Liaison with the PANYNJ, the reasoning for not performing the study is that it would not be cost effective for this area. Part 150 cannot improve the noise control programs already in place. Also, due to the zoning and land use around the airports, the Part 150 program would be of little use.

CHAPTER 3

ECONOMIC ISSUES RELATED TO AIRCRAFT OPERATIONS

3.1 Introduction

The existence and operation of Newark, JFK, and LaGuardia Airports in the New York/New Jersey metropolitan area is of major importance to the region's economic prosperity. As supported in Tables 4 and 5, directly and indirectly, the aircraft industry provides jobs, wages, and airport-related and regional sales. In addition, the personal income taxes resulting from employees of the aircraft industry enhance local, county, and state revenue.

In addition to the economic benefits, there are economic costs, which arise from the location and operation of the airports. These include direct and indirect subsidies to the airline industry in terms of tax-free bonds and New Jersey Economic Development Authority assistance, ratable loss not balanced by in-lieu-of rent and tax payments, and partial support of the FAA budget. Lastly, there is the potential impact of aircraft noise on property values, student proficiency rates as well as other physiological or psychological impacts.

Various budget information is cited in order to provide a clearer understanding of the aviation industry's financial picture at-large.

3.2 Benefits and Costs of the Airline Industry

The New York/New Jersey metropolitan region's major commercial airport system, consisting of John F. Kennedy International (JFK), Newark International (EWR), and LaGuardia (LGA) airports, is one of the world's premier air transportation centers. The airports promote regional, national, and global growth in travel and trade and are a significant driver of the region's economic vitality.

The economic benefits of the aviation industry for the three major PANYNJ airports are substantial. The following table illustrates these benefits. For Tables 4 and 5, the economic impact is based on 1994 levels of operation expressed in 1998 dollars and dollar amounts are in millions of 1998 dollars.

Table 4 Economic Impact of JFK, EWR, and LGA Airports (PANYNJ, 1998)

Impact	**Jobs**	**Wages**	**Sales**
Aviation Industry	232,630	$8,921	$27,465
Airport Construction	6,570	$275	$765
Visitors to the Region	141,070	$3,758	$11,643
Total Economic Impact	380,270	$12,955	$39,873

In short, the economic benefits of the three airports to the region help to drive the economy and must be considered when evaluating policy changes at these facilities. The following table contains similar information for EWR alone.

Table 5 Economic Impact of EWR Airport (PANYNJ, 1998)

Impact	**Jobs**	**Wages**	**Sales**
Aviation Industry	65,530	$2,489	$7,578
Airport Construction	1,360	$57	$161
Visitors to the Region	43,100	$1,134	$3,561
Total Economic Impact	109,990	$3,680	$11,300

The City of Newark has spent over $8.2 million on construction and development of Newark International Airport. The United States Government spent over $15.1 million prior to 1948. Through the end of 1998, the Port Authority has invested approximately $1.9 billion at the airport (PANYNJ, 1998).

3.2.1 Costs of Aircraft Operations

The assessment of costs associated with aircraft operations includes dollar expenditures, unrealized income and losses related to quality-of-life degradation. The following are examples of actual and virtual costs that may be examined in determining the cost of noise:

- Cost of aircraft modification (e.g., re-engine, hushkit)
- Cost of ground facility noise abatement (e.g., noise monitors, airport noise barriers)
- Passenger Facility Charges
- Actual construction expenditures to limit intrusive aircraft noise in homes and other buildings
- Delay costs (e.g., routing changes, holding patterns)
- Estimated effect on property values in noise-impacted areas
- Quality-of-life issues
- Public health.

3.2.2 Delay Costs

New York/New Jersey airspace has been identified as the most congested in the world. Newark Airport has been ranked as number one in the nation for flight delays. If airspace was infinite, and if there were no restrictions on flightpath due to noise considerations and other air traffic, then costs would presumably be minimized. If minimum cost cannot be realized, the carrier incurs a virtual cost, the difference between the income under ideal conditions and the income under actual conditions.

Travel time is a major factor in selection of a mode of travel. Newark Airport is consistently rated nationally as number one, "worst in the nation," for flight delays. Additionally, EWR consistently has the greatest percentage of flight delays of the three major PANYNJ airports. The PANYNJ continues to research the reasons for these delays. It is a critical subject of the FAA airspace redesign and will be addressed in future aircraft routing plans.

Passengers generally consider overall travel time in selecting their airport. Newark Airport has easy access by auto and bus and will have a direct rail connection in 2001. This surface transportation advantage over the other two major area airports offsets, to an extent, the higher rate of flight delays.

There exists controversy among professionals regarding the effect aircraft delays have on noise contours. An aircraft delay can affect the contour by being pushed into the night hours (past 10 p.m.) and receiving a 10 dB penalty in terms of DNL. Similarly, if the airport attempts to have aircraft depart earlier, say before 7 a.m., in order to lessen the morning rush hour load, there would be the same 10 dB penalty. Also, as aircraft arrive, if they are unable to land immediately, they are placed in a holding pattern. This pattern will increase noise over the designated holding pattern area.

3.3 Chapter Summary

There are economic benefits and costs associated with the siting of airports and related aircraft operations. The purpose of this chapter is to indicate some of the factors that contribute to the benefits and costs related to air traffic, and to provide quantitative estimates. The incredible magnitude of wages and number of jobs that an airport creates cannot be understated. This is one reason why people may fear the dollar costing of impacts. It is difficult to oppose such a large entity as an airport.

Significant findings noted in this chapter are listed below:

- PANYNJ airports have a significant impact on employment and economic activity in the Northern New Jersey - New York City region. Approximately 32.6 million passengers flew into or out of Newark Airport in 1998, an increase of 5.4 percent over the previous year, making EWR the eighth busiest airport in the country (PANYNJ, 1998).
- Runway space, ground facility limitations, and regional airspace congestion limit potential growth at EWR.
- Proximity to transportation facilities is an important consideration when selecting a home or business site. Those near flightpaths may be severely impacted by aircraft noise.
- The general public, air carriers, airport operators, and regulatory agencies, have a major stake in aircraft routing decisions.

CHAPTER 4

MODELING THE EFFECT OF AIRCRAFT NOISE ON PROPERTY VALUES

4.1 Summaries of Pertinent Literature

The following synopses of studies are provided to recognize the previous work with respect to aircraft noise and property values and to establish that there is a relationship between them. It provides the foundation for addressing the impact.

Although current research is cited throughout this report, many exceptional references on the cost of noise, as well as the subject of noise control are from the 1970s. Although not recent, these references are still used in the scientific community and still carry the validity that they did over twenty years ago. The early 1970s saw a great deal of legislation in noise as well as the entire environmental community. Therefore, much of the work in noise was published or revised shortly thereafter.

4.1.1 Walters (1975) and Kryter (1994)

They provide (as does Bugliarello, *et al.*) a review of what is arguably the most complete study of home depreciation due to noise ever undertaken. The study examined records of sales and appraisals and conducted surveys of panels of real estate experts. This British study, known as the Roskill Commission, provides depreciation percentages for three levels of housing values around Heathrow and Gatwick airports. Table 6 summarizes this information.

Table 6 Estimated Percent Depreciation in Housing Values (Kryter, 1994)

Location	**Housing Price Range**	**Percent Depreciation**		
		DNL68	**DNL75**	**DNL83**
Around Heathrow Airport	Low	0	2.9	5.0
	Medium	2.6	6.3	10.5
	High	3.3	13.3	22.5
Around Gatwick Airport	Low	4.5	10.3	15*
	Medium	9.4	16.5	22*
	High	16.4	29.0	39*
Average	Low	2.2	6.6	10.0
	Medium	6.0	11.4	14.0
	High	10.0	21.2	31.0

* Extrapolation

For instance, the percent depreciation for a medium priced house around Heathrow at DNL75 is 6.3%. DNL, synonymous with L_{dn} and defined earlier, is essentially the average noise level over twenty-four hours with a 10 dB penalty for events between 10 p.m. and 7 a.m. Generally, home depreciation due to noise increased with housing price range and increased with DNL contour (i.e., the more expensive the home and the noisier the area, the greater the depreciation).

It is interesting to note that although the spread of the quietest and noisiest group is 15 dBA, the quietest group is above DNL65. Within the groups, there are only 7 dB and 8 dB of separation. All three of the communities are within noise contours that, by today's standards, are unacceptable in the United States. While this alone should not affect the validity of the values obtained, it would be interesting to examine a community in relative quiet, say less than DNL55. Also, as this study was conducted in the early 1970s, noise control and use of noise mitigation guidelines and standards were not practiced widely. The need for new and improved studies is apparent.

The Roskill Commission (Kryter) estimated linear rates of depreciation for three price ranges of houses (1% per L_{dn} for high priced houses and 0.75% per L_{dn} for medium and low-cost houses).

Walters continues with an in-depth analysis based primarily on economic theory. The challenge of isolating phenomena in an experiment and fitting that information to a theory is readily apparent concerning the cost of noise. There is no simple answer to the relationship between noise and housing values. However, through the investigations noted above, the issue of the effect of aircraft noise on housing values is real and has been quantified in approximate dollar terms.

4.1.2 Bugliarello, *et al.* (1976)

This text thoroughly examines the Roskill Commission report as a case study as well as making their own estimates for noise costs under various situations. The valuation of noise is indirect. The price is realized from a subjective method whereby people determine their preference for airport access to extra cost (i.e., inexpensive houses vs. extra noise). The evaluation of the social cost of noise is evaluated considering noise as a product (or perhaps quiet as the product).

The effect of noise on economic efficiency, the cost of aircraft noise, and that of surface transportation noise are evaluated for dollar figures that are uncertain and extremely high (billions), and perhaps even under-estimated.

4.1.3 Herzing (1991)

The costs of airport noise are enumerated at the New Munich Airport with actual figures, in 1991 U.S. dollars.

The German Act Against Aircraft Noise provides funding for the sound treatment of homes within the L_{eq}75 contour (within a noise contour indicates noise levels at or above the given level). L_{eq}, defined earlier, is the average sound level over a given time period. As a contour, the time period is twenty-four hours. This cost the Munich Airport Authority approximately $3.7 million at the Riem airport. The L_{eq}75 contour will contain airport property, but there will be sound treatment beyond this contour. The new airports will sound treat to L_{eq}55. This German study makes use of day and night zones, which is not common in the United States. Herzing provides no explanation as to why there are separate zones for day and night. The reader is left to assume that they are mandated by the Act. The daytime zone is 67 square kilometers and uses the living room as the test area. The nighttime zone is 160 square kilometers and uses the bedroom as the test area. Members of both zones may apply for soundproofed ventilators for these rooms when windows are closed. These measures will cost an estimated $109.8 million.

There may be compensation available for deterioration in real estate values. This would pertain to areas close to the airport where the outdoors is affected adversely. The study neglects to provide a figure for this compensation.

Herzing reaffirms the point that not all measures against aircraft noise can be put in monetary terms.

4.1.4 Booz-Allen & Hamilton (1994)

According to this FAA commissioned study, *The Effect of Airport Noise on Housing Values: A Summary Report,* the effect of aircraft noise on housing values was 1.33 percent per decibel of quiet. This factor is based on a study of two moderately priced (as opposed to low priced), paired neighborhoods north of Los Angeles International Airport (LAX). The study found the price to noise relationship greatest in moderately priced and expensive neighborhoods. The aircraft noise differed by approximately 14 dB in the two neighborhoods in the study. The analysis made use of multiple linear regression to account for changes in various aspects of home prices. The 1.33% per dB is used in the order-of-magnitude estimate covered later in this chapter. It is estimated that most New Jersey and New York communities will experience noise exposure changes smaller than 14 dB due to routing changes.

4.1.5 Feitelson, *et al.* (1996)

The authors examine the effects of aircraft noise following airport expansion on the willingness to pay (WTP) for residences using a contingent valuation approach. They estimate WTP for a standard residence by systematically changing the noise settings of that location. Their results demonstrate that the compensation programs in place are inadequate and do not fully compensate for the losses due to higher noise exposure.

Further, it is determined that valuations should analyze noise as a multi-attribute externality as opposed to a single composite measure. A threshold exists beyond which a resident will not pay to live there due to the disturbance. This threshold will vary from resident to resident and residence to residence. They assert that this "kinked structure" helps explain the higher noise premiums obtained in contingent valuation method studies relative to hedonic price estimates.

4.1.6 Helmuth, *et al.* (1997)

Sea-Tac Airport (1997) found an assessed value depression of 10.1 percent near the Seattle-Tacoma (Washington) Airport. The value of a house and lot increases approximately 3.4 percent per quarter mile from the approach or departure flight track as far as the property is affected by that track. The study implemented a linear regression model.

The parameters were estimated from assessor's data on ten census tracts in the immediate vicinity of the airport. The study did isolate noise as an important variable for property values.

4.1.7 Bell (1997)

This report gives 10 standard classifications of detrimental conditions (DC's). Airport proximity is a ClassV DC - an imposed condition, an act or forced event that affects value, usually long-term or permanent. Bell reports 15.1 to 42.6 percent (27.4% average) diminution of value due to airport proximity. Bell also studied the rental rates per square foot of office buildings. He found the LAX (i.e., in proximity to the airport) office market rates 19.1 to 43.3 percent lower than surrounding markets (and vacancy rates higher).

4.1.8 Indifference Analysis

Studies that involve the impact of aircraft noise on home pricing often compare that noise to other factors. Samuelson and Nordhaus (1998) describe the modern theory of indifference analysis regarding consumer behavior. This concept is helpful in understanding how these factors interact in establishing the price of a home. The analysis is applied to treatment of the various factors involved in home pricing as goods or commodities. In short, the consumer is willing to give up some of one of the goods in order to get more of another at some given set of prices.

4.1.8.1 Factors Involved in Home Pricing

Many variables in addition to the quality of home construction, the size of the lot, the characteristics of the house (e.g., number, of rooms, garage, and pool) and the initial cost of the improvements affect real estate values. Additionally, there are neighborhood characteristics that influence homebuyers. The National Board of Realtors recommends the following traits to consider (Booz-Allen & Hamilton, 1994). These factors are implemented in the development of the 1.33% per dB value used in the later analysis.

- Property taxes
- Crime rate
- Quality of neighboring residential units
- Racial/ethnic/social characteristics
- Local traffic conditions/congestion

- Nearness to commercial and shopping centers
- Quality of local schools
- Quality of municipal services
- Access to public transportation
- Commuting distance
- Quality and proximity of recreational facilities.

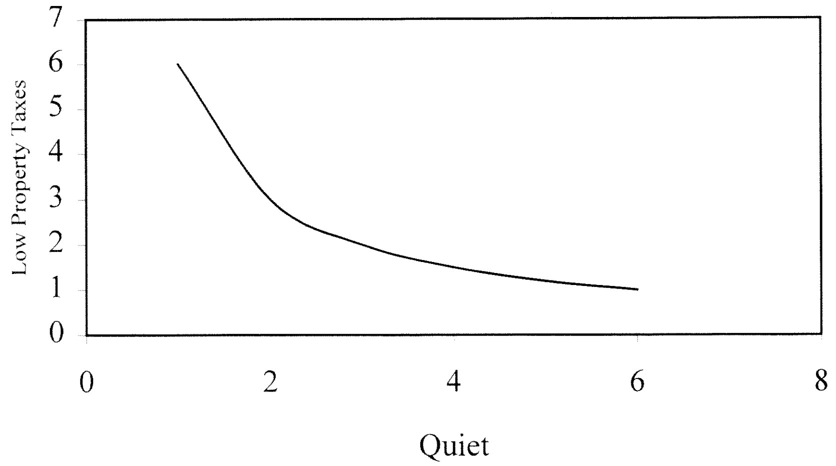
Intrusive noise, from all sources, is another important factor. This analysis treats quiet as a positive factor in home pricing determination.

4.1.8.2 Indifference Curves

The home buyer compares the above factors, including quiet, in choosing their house. Two of the factors, say low property taxes and quiet, are compared for some given price of the home, *ceteris paribus* (other things being equal). The consumer may prefer one of the factors to the other, or be indifferent between the two. If the consumer is indifferent between these two goods, there will be some combination of units of each of the goods that are equally preferable. For instance, the choices to which the consumer is indifferent may be a quiet neighborhood with higher taxes, or a louder neighborhood with lower taxes, or somewhere in the middle.

Figure 2 shows a plot of these options with hypothetical/relative units of the goods. Moving along the x-axis from left to right denotes more units of quiet. Moving up the y-axis implies lower property taxes. Any point along the curve represents a combination of quiet and low property taxes for which the consumer is indifferent. Getting more of one good compensates for giving up some of the other good.

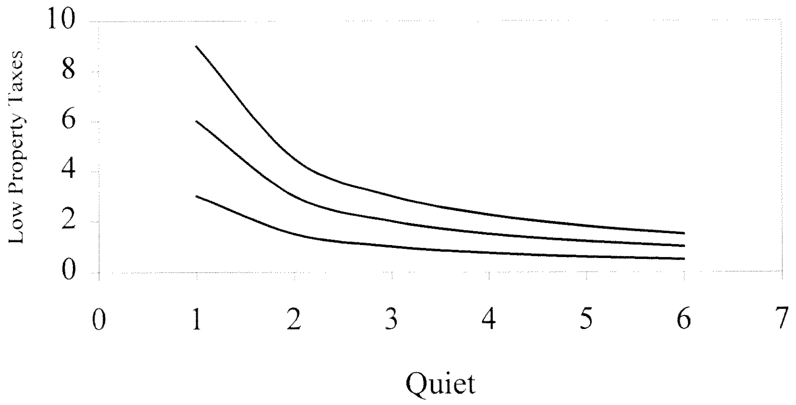
Figure 2 Indifference Curve



The curve is convex to the origin, similar to y = 1/x. As it is generally assumed that all the factors have some merit, increasing the preference for one will diminish the other, but not entirely. This explains the asymptotic nature of the curve in that the absolute value of the slope of the curve diminishes moving from left to right. The curve illustrates a property of economics that often holds true in reality, the marginal rate of substitution between goods and services. The property states that the scarcer the good, the greater its relative substitution value. One would be willing to trade off more of one plentiful good to get relatively fewer units of the scarcer good.

The slope of the curve is a measure of the relative marginal utility. This is a measure of what the consumer is willing to exchange, or substitute, between the two goods. Any of the noted factors in home buying may be viewed in this manner. The typical shape of the curve, convex to the origin, in Figure 2 conforms to the marginal rate of substitution between goods and services concept. However, the actual slopes of the curve will differ between consumers and between goods and services. Additionally, it should be noted as the curve itself moves away from the origin, higher levels of satisfaction are represented. In other words, there are increased quantities of both commodities. Figure 3 displays a family of indifference curves.

Figure 3 Family of Indifference Curves



Movement along any one of the single curves represents a constant level of satisfaction between the two goods. Movement to a higher curve (crossing successive indifference curves up and to the right) represents an increase in satisfaction from receiving an increase in both goods. This is analogous to the lines on a topographical map of a mountain or landscape. Along any one curve, the elevation is the same. Crossing to a higher line moves one to a higher elevation.

Aircraft noise, or levels of quiet, can be analyzed with this method. If considered a factor in home pricing, the consumer desires some level of quiet as compared to the other goods or services. As the price one is willing to pay for a home increases, the level of quiet attainable increases as compared to the other factors. The representative indifference curve moves outward from the origin. The shape and slope may change as consumer preferences change with an increase in wealth. However, the curve remains convex to the origin in accordance with the marginal rate of substitution between goods and services.

4.1.9 Summary of Pertinent Literature

In spite of the relative sophistication of the above analyses, the attempt to measure aircraft noise cost is challenging, and laden with problems. These problems include assumptions based on the opinions of people and the validity of noise costs being reflected in housing values. Techniques that are based on surveys, questionnaires, and imaginary situations are always subjective and therefore suspect. Also, noise-cost models based on property values usually demonstrate that the more expensive the house, the greater the noise burden. Are low-income people less disturbed by noise than their rich counterparts?

The references cited above can be summed up as follows with regard to real estate impact:

- In general, real estate values decrease as noise increases.
- There is less depreciation as the value of the home decreases.
- The more affluent the neighborhood, the greater the depreciation.

- The general approach is to delineate all aspects of home pricing including noise levels, and hold all but noise level constant. The theory is that the change in the price of the home would be directly proportional to that noise level change.
- Various methodologies in assessing real estate values were undertaken in the studies with no universally accepted method.

Data available on noise cost are inadequate for economic analysis, as are that for most externalities. Samuelson and Nordhaus (1998) define an externality as an activity that affects others for better or worse, without those others paying or being compensated for the activity. More specifically, an external diseconomy is a situation in which production or consumption imposes uncompensated costs on other parties. Aircraft noise is an external diseconomy, with no market and no price. Therefore, substitute methods are used to establish costs as well as the benefits of aircraft noise abatement.

Government regulation is in place to curb aircraft noise to an extent. If the environment was unregulated, industry would only provide enough pollution abatement as they saw to provide an equal amount of private benefit. It is unlikely that industry would account for the impact on the community (higher levels of aircraft noise, smaller levels of noise mitigation). In economic terms, an unregulated market economy, such as the airline industry, will generate levels of an externality, such as noise, at which the marginal private benefit of abatement equals the marginal private costs of abatement. Efficiency requires that marginal social benefit equals marginal social abatement cost (Samuelson and Nordhaus, 1998).

4.2 Procedure for Establishing the Effect of Aircraft Noise on Property Values

The following procedure is based on objective data available to the public, namely noise contours due to aircraft using Newark Airport, populations, and residential real estate values. Aircraft noise impact on industrial property is not considered in this analysis.

The determination of the effect of aircraft noise on property values may be based on meta-analysis of previous studies, or a new study of market data (actual sales data). Value changes should be corrected for general value changes that are independent of noise exposure. Analysis should be based on dramatic rather than subtle impact differences. This recommendation refers only to the design of a study; it does not imply that small noise level changes have no significance. A linear relationship (constant loss rate) may be assumed unless the data indicate a more complicated relationship. This type of analysis is performed as follows:

- Collect data on the effect of aircraft noise on property values. Preferably, this data may be placed in the form of percent property value loss per decibel.
- Calculate noise impact as a potential increase in value per decibel of quiet or loss in value per decibel of noise impact. Ignore levels below DNL45.
- Model typical aircraft operations at the time of the study.
- Plot day-night noise level contours, beginning with the DNL45 contour and continuing through the highest levels where people reside, perhaps to the airport.
- Determine the population in each DNL contour band.
- Estimate property values on a per capita basis.

- Estimate the total aircraft noise impact on property values for each DNL contour band. Base this impact on the average DNL in the contour band minus the baseline value of 45 dB.
- Add these values to obtain the total aircraft noise impact in dollars.
- Express the aircraft noise impact on an annual basis by amortizing the total impact, using reasonable interest rates and a selected recovery period. As an alternative, the annual interest rate may be applied to the total dollar loss without amortization.
- Repeat for aircraft operations with proposed route changes.
- Where applicable, adjust data for predicted changes in air traffic and aircraft type.

4.2.1 Basic Assumptions

This procedure uses the following assumptions in establishing an estimate of the effect of aircraft noise on communities. While all the assumptions may not be wholly accurate, they provide sufficient precision in making an "order-of-magnitude" estimate.

- Aircraft noise has a negative impact on real estate values.
- Over the noise ranges considered, there exists a positive correlation between the negative impacts of aircraft noise and DNL.
- Populations are uniformly distributed throughout the municipality and county and within a DNL contour.
- The population is homogeneous. For instance, all people have similar sensitivities to aircraft noise or at least those with various sensitivities are uniformly distributed.

- Real estate values within a municipality are uniformly distributed.
- There is a constant real estate loss rate (linear relationship) due to aircraft noise.

4.2.2 An Order-of-Magnitude Estimate of the Effect of Aircraft Noise on Property Values in the New Jersey Study Area

An analysis was performed to estimate the effect of aircraft noise on property values in the New Jersey study area using the procedure noted above.

The analysis makes use of the most current real-world information available. The noise levels are based on the "existing procedures" measurements reported in Leigh Fisher Associates (1994). These procedures are still in use as of the year 2000. The only significant difference between these noise levels and present-day levels is the elimination of Stage 2 aircraft as of January 1, 2000. The populations are taken from the New Jersey Public Information Network 1996 estimates of resident population by municipality. The Geographic Information System (GIS) is used to determine municipality inclusion and, therefore, population inclusion within a noise contour. GIS Resource Data is from the New Jersey Department of Environmental Protection, Office of Information Resources Management. The real estate values are 1997 true values provided by the New Jersey Division of Taxation.

New Jersey's real property tax is a tax according to value. All real property is assessed according to the same standard except for qualified agricultural or horticultural land. True value is defined as what a willing, knowledgeable buyer would pay a willing, knowledgeable seller on the open market at a bona fide sale as of the statutory October 1 pretax year assessment date. The true value of all real estate within the DNL45 contour is approximately one-quarter trillion dollars. The total population living within this contour is approximately 3.9 million people (NJIT, 1999).

The analysis starts with communities within the DNL45 contour and subsequently makes estimates at the DNL55 and DNL65 values. The bottom line dollar loss is calculated by multiplying the following factors:

- Approximate average noise level within successive contours less 45 dB (initial, or baseline, noise contour)
- Aggregate Real Estate True Value per Capita for the particular noise contour
- 1.33% per dB loss in real estate value for moderately priced houses based on Booz-Allen & Hamilton (1994). (A more appropriate value, or series of values, derived from the Roskill Commission (see Table 6), or other study, based on the population affluence or other socioeconomic factors may be used).
- Approximate population within successive noise contours.

The dollar loss for the noise contours considered are totaled for final loss. This value is the one used in amortization based on a given interest rate and period of recovery. The following table provides the results of this analysis.

Table 7 Order-of-Magnitude Estimate of the Effect of Aircraft Noise on Property Values in the New Jersey Study Area

Range	**True Value per Capita**	**Population**	**Dollar Loss**
DNL 45-55	$62,000	2,500,000	$10.3 billion
DNL 55-65	$47,200	914,000	$8.6 billion
DNL >65	$43,200	450,000	$5.9 billion
Total		3,860,000	**$24.8 billion**

The formula for capital recovery converts a present value or present worth (P) to an annual amount (A) based on a given interest rate (i) and recovery period (n). Equation 7 illustrates capital recovery.

$$A = P \cdot \left[\frac{i \cdot (1+i)^n}{(1+i)^n - 1} \right] \tag{7}$$

The total dollar loss of \$24.8 billion amortized at 7 percent over 30 years is \$2.0 billion per year. This is the order-of-magnitude aircraft noise property value impact for New Jersey residents based on the data used. Table 8 depicts values for various interest rates and recovery periods using a present worth of \$24.8 billion.

Table 8 Annual Noise Impact for New Jersey Residents (\$Billions/year)

Yearly Interest Rate (i)	**Recovery Period (n, years)**				
	20	**25**	**30**	**35**	**40**
4%	1.8	1.6	1.4	1.3	1.3
5%	2.0	1.8	1.6	1.5	1.4
6%	2.2	1.9	1.8	1.7	1.6
7%	2.3	2.1	2.0	1.9	1.9
8%	2.5	2.3	2.2	2.1	2.1
9%	2.7	2.5	2.4	2.3	2.3
10%	2.9	2.7	2.6	2.6	2.5

As an alternative analysis, use the annual interest rate without amortization. Merely apply an appropriate interest rate to the present value and use that as the dollar impact per year. So, for the total dollar loss in Table 7, at 7 percent, the impact is 7% of \$24.8 billion or \$1.7 billion per year.

4.2.3 Example of Real Estate Impact Due to Aircraft Noise

The following hypothetical situation further clarifies the dollar impact of noise on housing values.

- An Impacted family owns a home valued at $200,000.
- A change of aircraft routing has approximately doubled the number of flights over the neighborhood of the Impacted family.
- As a result the day-night sound level (DNL) has increased by approximately 3 dB.
- If we use the results of a study of moderately priced housing, the Impacted family property value would decline by roughly 4 percent or $8,000 (4% is 1.33% per dB with a 3 dB change).
- Even if there is a general (e.g., statewide) inflation in real estate values, it is assumed that noise-impacted real estate would experience a smaller value increase. The difference is considered a "loss."
- The Impacted family decides to move to an otherwise equal house in an otherwise equal neighborhood that has not experienced an increase in noise impact.
- The Impacted family purchases a home from the Unimpacted family for $200,000.
- The Impacted family sells their previous home in the impacted neighborhood for $192,000.
- The Impacted family adds $8,000 to their 30-year mortgage.
- Their additional annual payment can be used as their annualized cost.

- An alternative annualizing procedure uses only the interest on \$8,000 of the mortgage debt, not counting amortization.
- Broker and moving costs are not considered in the above scenario.

4.3 Chapter Summary

Although air traffic changes from year to year, these contours remain essentially intact with only the move to a Stage 3 fleet significantly affecting the values. The Port Authority of New York and New Jersey anticipates a shrinking of noise levels due to the Stage 3 fleet (Louis Berger, 1998). In other words, there will be fewer people and less real estate within any given noise contour.

The calculated impact does not apply to current or future noise levels. However, the following observations are made:

- Close to four million New Jersey residents live in the study area. That is, they are impacted by aircraft noise at DNL45 or higher. Total real estate value in the study area is in the region of one-quarter trillion dollars.
- New Jersey residents are major stakeholders in any plan to reconfigure airspace (or decision not to reconfigure airspace).
- Subsequent studies should evaluate total aircraft noise impact, as well as changes in impact due to changes in traffic, routing, and aircraft type.
- Aircraft noise impact should be evaluated on a dollar basis, using best available modeling techniques.

- Aircraft noise has a negative impact on property values. Conversely, a reduction in aircraft noise would have a positive impact on property values. An order-of-magnitude estimate of the impact of aircraft noise on property values in the study area is two billion dollars per year.
- Aircraft noise impact should be compared with other costs and benefits, both on a total basis and on a per-ticket basis.

CHAPTER 5

MODELING THE EFFECT OF AIRCRAFT NOISE ON STUDENT PROFICIENCY

5.1 The Effect of Aircraft Noise on Children

The effect of aircraft noise on children is well documented. The following synopses of studies are provided to establish that there is a relationship between aircraft noise and children's health and learning. It provides the foundation for addressing the problem with respect to student proficiency.

5.1.1 Kryter (1994)

Kryter cites a mountain of research, over two hundred papers, concerning non-auditory system responses to sound and noise. A summary of the conclusions of the studies that address the effects of aircraft noise on children is provided below.

- Children living near airports had functional cardiovascular-system and nervous-system changes consisting of increased fatigue, blood pressure abnormalities, and cardiac insufficiency.
- Children are possibly somewhat more susceptible to increased blood pressure from environmental noise than adults.
- Multiple schools report activity interference from aircraft noise. This is attributed to the masking effects of noise on speech.
- Kryter cites Maser, *et al.* as an unpublished study involving the effect of aircraft noise on achievement test scores. Kryter was a co-author and, hence, had access to the work although unpublished. This study dealt with school grades 3-7 and 5-10, but in

only one school district, a narrow range of data to be sure. Therefore, there was no socioeconomic stratification, although city and school officials (possibly subjective) stated that the socioeconomic levels between noisy and quiet communities was similar. There was a division for aptitude levels. The results revealed no impact with respect to noise levels for the high-academic-aptitude students. However, there was an impact for middle- and low-academic-aptitude students.

5.1.2 Evans and Maxwell (1997)

Evans and Maxwell examined 1st and 2nd Grade students and found that those who were chronically exposed to aircraft noise had significant deficits in reading as determined by standardized tests. The children exposed to the chronic noise suffered from impaired speech perception.

5.1.3 Evans, *et al.* (1998)

The authors concluded that chronic exposure to aircraft noise increased psychophysiological stress (i.e., resting blood pressure and overnight epinephrine and norepinephrine). It depressed quality-of-life indicators over a two-year period with nine to eleven year-old children. Quality-of-life was measured using a standard index based on physical, psychological, social, and functional daily life aspects. This work demonstrates that aircraft noise significantly elevates stress in children at levels far less than the levels necessary to produce hearing impairment. These effects were detected in children who had no apparent hearing damage while living in the immediate vicinity of the airport. The aircraft noise level in the impacted communities was $L_{eq} = 62$, the level in the quiet communities was $L_{eq} = 55$. Additionally, the authors cite their research adds validity to previous results that revealed increased stress among adults working and children residing in chronically noisy environments.

5.1.4 Summary

Previous work involving school children has dealt with two sample groups, one impacted by noise and one not impacted relative to the other (control group). The groups center on students in relatively few schools or only one school in each group. It is arguable that using a larger population for the quiet and noisy groups, that is, multiple school districts, would decrease the chances for introducing error and produce a more statistically significant test. Generally, procedures for estimating subjective annoyance as well as measuring annoyance through a medium (proficiency passing rates), are intended for larger populations. Drawing conclusions from a small sample can produce questionable results. Considering even a few hundred students may seem a large population. If they are all from the same school, one may consider them a single data point. The procedure presented herein, uses a broad range of data from forty school districts containing thousands of students. However, the sample size is the number of school districts.

5.2 Procedure for Modeling the Impact of Aircraft Noise on Student Proficiency

As established in the previous section from other research, there is an effect on children from aircraft noise. Previous studies have focussed on relatively few schools and counted the number of students as sample size. The following procedure increases the sample size for the impacted and control groups with respect to school districts, and therefore students. Each piece of data, n, represents a school district as opposed to a student. The strength of the statistics increases as potential errors introduced by taking a single student's proficiency rates are canceled via the averaging process.

5.2.1 The Study Area and Noise Groups

The study area is Northern New Jersey. Newark International Airport (EWR) is the local airport. EWR consists of 2,027 acres in Essex and Union Counties between the New Jersey Turnpike and U.S. Routes 1 and 9 and I-78. It is approximately sixteen miles from midtown Manhattan.

The Leigh Fisher Associates report (1994), flight tracks for typical operations at EWR supplied by the Port Authority of New York and New Jersey, and the Geographic Information System (GIS) are used to determine municipality, and subsequently school district, inclusion within a given noise contour. Municipalities are divided into "quieter" (control) and "louder" (impacted) groups. It is important to maintain a significant difference between these two groups with respect to aircraft noise. The greater the difference, the more arguable the case that any eventual impacts may be attributed to aircraft noise. In this case, the average DNL for the quieter group is less than 45 dBA. Due to background noise and limitations in noise measuring techniques, an exact measure below this level attributable to aircraft noise is virtually impossible and would be questionable. As previously discussed, DNL45 may be seen as a baseline level in aircraft noise studies. The average DNL for the impacted group is approximately 60 dBA. The difference, conservatively estimated as 15 dBA, is significant by any standard.

Additionally, the DNL averages for the groups are on either side of DNL55, which the EPA (1974, 1978) recommends as the level to protect public health and welfare.

5.2.2 District Factor Groups

Once there is a significant number of municipalities that can be included in one of the two groups, they are divided into socioeconomic categories. Socioeconomic factors must be held constant in order to attribute any measured impact to aircraft noise. In New Jersey, school districts are categorized according to District Factor Groups (DFG). By using DFGs, school districts may be compared on an equal footing.

The following description, compiled from information from the New Jersey Department of Education (NJDOE), on District Factor Groups is provided. The DFG is an indicator of the socioeconomic status of citizens in each district and has been useful for the comparative reporting of test results from the State's testing programs. The groups are adjusted every ten years based on United States Census. There are seven indices used to group the districts:

- Percent of adult residents who failed to complete high school
- Percent of adult residents who attended college
- Occupational status of adult household members. The occupations are:
    - laborers
    - service workers (except private and protective)
    - farm workers
    - operatives and kindred workers

  - protective service workers
  - sales workers
  - clerical and kindred workers
  - craftsmen, foreman, and kindred workers
  - quasi-professionals
  - managers, officials, and proprietors
  - old and new professionals
- Population Density per square mile
- Income (median family income)
- Unemployment (percent of those in the work force who received some unemployment compensation)
- Poverty (percent of residents below the poverty level).

These variables are combined using a statistical technique called principal components analysis, which results in a single measure of socioeconomic status for each district. Districts are ranked according to their score on this measure and divided into eight groups based on the score interval in which their scores are located. There are eight DFGs based on the 1990 United States Census data. They range from A (lowest socioeconomic district) to J (highest socioeconomic district) and are termed: A, B, CD, DE, FG, GH, I, J. The groups consist of districts having factor scores within an interval of one tenth of the distance between the highest and lowest scores. The number of DFG categories may be adjusted based on new census data. There is nothing in particular with reference to the number eight other than it satisfied the requirement for ranges within a category for the data.

The number of districts includes all New Jersey public school districts (regardless of school configuration or grade levels served). The distribution for all of New Jersey is delineated in Table 9.

Table 9 DFG Distribution (NJDOE, 2000)

DFG	**Number of Districts**
A	35
B	78
CD	75
DE	100
FG	87
GH	78
I	105
J	15

The distribution is relatively uniform from group B through I. There are fewer districts at the two extremes, A and J.

Due to confounding factors as well as impacts other than aircraft noise (both positive and negative impacts) in the higher and lower socioeconomic groups, these groups are not included in the analysis. This is not to state that aircraft noise does not affect these groups. Furthermore, this is not to state that there should not be future investigations including these groups. However, there are other factors that cannot be accounted for with this analysis. For example, there is generally more noise from rail and surface traffic in the lower socioeconomic groups than would be typical. To state that an educational impact is due to aircraft noise would be incorrect. Similarly, in the wealthier districts, the increase in educational opportunity beyond the norm could more than offset any impact due to aircraft noise. Therefore, groups A, B, I, and J are neglected for this analysis.

The remaining four groups (CD, DE, FG, and GH) are combined into a "middle group." The reason for this mix is to ensure a statistically significant sample size. There are insufficient numbers of school districts for the impacted and control groups divided among the four middle groups. Results, either accepting or rejecting a hypothesis, would be suspect based on a small sample size. It is believed the socioeconomic factors in this middle group are held close enough for this analysis, within a reasonable margin of error, that aircraft noise may still be deemed the only significant difference between the groups.

5.2.3 Average Proficiency Rates between Noise Groups

After the two groups have been formed, the proficiency tests are examined. In New Jersey, proficiency tests are administered in the 4th, 8th, and 11th Grades. The formal names for these tests are: Elementary School Proficiency Assessment, Grade 8 Proficiency Assessment, and High School Proficiency Test. The 4th and 8th Grade assessments place a student in one of three categories: partially proficient, proficient, or advanced proficient. The number reported in this study for the 4th and 8th Grade tests in this analysis is the total percentage of proficient and advanced proficient students. The 11th Grade test provides a percent passing. This is the percentage used for the 11th Grade tests in this analysis. The scores for the 1998-1999 academic year (the latest available) are used in all cases. For brevity sake, the above measurements of proficiency will be referred to as tests. Similarly, the numbers reported are termed proficiency rates.

The averages for the n pieces of data in the quieter and louder groups, $\bar{x}$, are calculated by:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{8}$$

and are compared for each grade level of exam. The results are tabulated in Table 10.

Table 10 Average Proficiency Rates for Quieter and Louder Groups

Test	**Quieter (%)**	**Louder (%)**
4th Grade	53.4	44.9
8th Grade	83.4	68.9
11th Grade	86.2	76.9

In each case, the quieter group had a higher proficiency rate than the louder group. The question is whether the difference is significant at some level of confidence. Is the average for the quieter population equal to that of the louder population? In other words, did the quieter group just happen to have higher scores than the louder group in this case when in actuality, there is no difference in proficiency rates between the two populations. This hypothesis is addressed with the student's t test for equality of means and the oneway analysis of variance.

5.3 Statistical Analysis of Proficiency Rate Difference

For each proficiency test in the two groups, a sample standard deviation, s, was calculated using:

$$s = \sqrt{\frac{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2}{n-1}} \tag{9}$$

The results are tabulated in Table 11.

Table 11 Statistical Metrics for Quieter and Louder Groups

	Quieter			Louder		
Test	**Average (x_1)**	**Standard Deviation (s_1)**	**Number (n_1)**	**Average (x_2)**	**Standard Deviation (s_2)**	**Number (n_2)**
4th Grade	53.4	15.7	21	44.9	12.4	19
8th Grade	83.4	10.1	14	68.9	11.6	19
11th Grade	86.2	1.7	5	76.9	7.8	17

The sample size decreases in some cases with 8th and 11th Grade exams. This is due to regional school systems and sparser populations in some areas. As students age, some school districts combine with others or there are simply less of the higher grades in a given school district. In the case of regional schools, the data is only used if the school districts contributing to that test are of the same district factor group.

5.3.1 Student's t test

The hypothesis, alluded to earlier, for the one-tailed Student's t test is:

H_0: $\mu_1 = \mu_2$

H_A: $\mu_1 > \mu_2$

The symbol μ represents the population mean of which sample means, $\bar{x}$, are taken. The null hypothesis (H_0) states the proficiency rates for the underlying populations that the two groups represent are the same. In other words, aircraft noise has no effect on proficiency tests. The alternative hypothesis (H_A) states that the quieter group, represented by population mean μ_1, is significantly higher in proficiency than the louder group, represented by population mean μ_2. The goal of this analysis is to be able to reject the null hypothesis, thus stating that aircraft noise negatively impacts proficiency rates.

The test statistic, t, is calculated as follows:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{10}$$

The number of degrees of freedom (df) are calculated using:

$$df = n_1 + n_2 - 2 \tag{11}$$

Statistical tables are used for the critical values of t for a given level of confidence. If the value of t calculated from the data is greater than the value for the given level of confidence, then there is a significant difference and the null hypothesis is rejected. The results are tabulated in Table 12.

Table 12 Student's t test Results

Test	**t**	**df**	**t 95%**	**t 99%**
4th Grade	1.909	38	1.687	2.430
8th Grade	3.825	31	1.696	2.454
11th Grade	4.561	20	1.725	2.528

The null hypothesis is rejected with a 95% level of confidence for the 4th Grade test since 1.909 is greater than 1.687, but less than 2.430. It is rejected with a 99% level of confidence for the 8th and 11th Grade tests, as both of the values for t are greater than the associated critical values for the 99% level of confidence. Therefore, the proficiency rates for the quieter communities are significantly higher than the proficiency rates for the louder communities.

In this case, the student's t test is implemented to compare two means. There is an assumption that the sampled population has a normal probability distribution. Proficiency rates for a large population are assumed to have a normal distribution. However, the distribution of the t statistic possesses nearly the same shape as the theoretical t distribution for populations that are not normal, but have a mound-shaped probability distribution (Mendenhall, 1979).

The student's t test also assumes the same variances for the two populations. The sample standard deviations noted above are somewhat different, but close. This is most likely due to the sample size being relatively small. Since the students are from the same underlying populations, it is assumed that the population variances are the same.

A stronger hypothesis test is the oneway analysis of variance. It is generally more difficult to reject the null hypothesis. Additionally, the variances of the two samples may differ.

5.3.2 Analysis of Variance, the Coefficient of Determination, and the Correlation Coefficient

This section uses the oneway analysis of variance (ANOVA) to determine if there is significant difference between the proficiency rates of the two groups. The coefficient of determination (R^2) and the correlation coefficient (R) are examined to reveal any connection between aircraft noise and proficiency rates. The relationship between F and R^2 is provided to further the analysis.

The hypothesis for the analysis is:

H_0: $\mu_1 = \mu_2$

H_A: $\mu_1 \neq \mu_2$

As with the Student's t test, the symbol μ represents the population mean of which sample means, $\bar{x}$, are taken. As before, the null hypothesis (H_0) states the proficiency rates for the underlying populations that the two groups represent are the same (aircraft noise has no effect on proficiency tests). The alternative hypothesis (H_A) states that the quieter group, represented by population mean μ_1, is significantly different in proficiency than the louder group, represented by population mean μ_2.

Since the average for the quieter group is greater than that for the louder group in each case, a rejection of the null hypothesis implies that the averages for the quieter group are greater than (not merely unequal to) that for the louder group. The goal of this analysis remains to be able to reject the null hypothesis, thus stating that aircraft noise negatively impacts proficiency rates.

The calculations for this analysis are more involved than that for the student's t test and require the introduction of a number of statistical metrics and the ANOVA table. The pooled average ($\overline{x_p}$) is defined as follows:

$$\overline{x_p} = \frac{\overline{x_1} \cdot n_1 + \overline{x_2} \cdot n_2}{n_1 + n_2} \tag{12}$$

The sum of the squares between (SS_{betw}) and the sum of the squares within (SS_{with}) are:

$$SS_{betw} = n_1 \cdot \left(\overline{x_1} - \overline{x_p}\right)^2 + n_2 \cdot \left(\overline{x_2} - \overline{x_p}\right)^2 \tag{13}$$

$$SS_{with} = (n_1 - 1) \cdot s_1^2 + (n_2 - 1) \cdot s_2^2 \tag{14}$$

The sum of the squares pooled (SS_{pool}) is:

$$SS_{pool} = SS_{betw} + SS_{with} \tag{15}$$

The pooled sum of the squares represents overall variability. The sum of the squares between groups is the variability explained by the model. The sum of the squares within the groups is the unexplained variability due to error or some other variable not accounted for in the model.

There are two types of degrees of freedom implemented for the ANOVA. The degrees of freedom between (df_{betw}) the groups are the number of groups less one. Since there are always two groups in this analysis (quieter group and louder group), this number will always be unity. The degrees of freedom within (df_{with}) the groups is the number in the pool ($n_p = n_1 + n_2$) less the number of groups (2), as was done with Equation 11.

The mean squares between (MS_{betw}) and within (MS_{with}) are calculated as:

$$MS_{betw} = \frac{SS_{betw}}{df_{betw}} \tag{16}$$

$$MS_{with} = \frac{SS_{with}}{df_{with}} \tag{17}$$

Finally, the F statistic may be calculated from the ratio of the mean squares between and the mean squares within:

$$F = \frac{MS_{betw}}{MS_{with}} \tag{18}$$

Statistical tables are used for the critical values of F for a given level of confidence. If the value of F calculated from the data is greater than the value for the given level of confidence, then there is a significant difference and the null hypothesis is rejected.

R^2, the coefficient of determination, is calculated as follows:

$$R^2 = \frac{SS_{betw}}{SS_{pool}} \tag{19}$$

R^2 has other names of interest, "the percent of explained variation" and "calibration factor for product of variation." R^2 and its square root, R, the correlation coefficient, are useful in determining the dependence between the data variable (proficiency rate) and the variable used to break up the groups (aircraft noise). There is a direct relationship between F and R^2:

$$F = \frac{R^2 \cdot (n_p - 2)}{1 - R^2} \tag{20}$$

Equation 20 is important in analyzing values of R^2 for F. High values of F (greater than a critical level) imply rejection of the null hypothesis, the goal in this analysis. By inspection, if the F values are acceptably high, that implies that R^2 is relatively high as well (directly proportional). As R^2 increases, the numerator increases and the denominator decreases ($0 \leq R^2 \leq 1$), meaning that F increases. Therefore, for acceptable values of F, R^2 is automatically determined. This means that the paradigm of low R^2 having no significance is, in fact, a misperception. Outside of purely physical law analysis, R^2 may take on any range of values and still have significant meaning. This issue will be addressed later with the calculated values of R^2 and R.

Applying the above equations to the data, the ANOVA table is developed. Tables 13, 14, and 15 exhibit the results for each of the grades.

Table 13 ANOVA for 4th Grade Test

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Squares**	**F**
Between	1	720.6938	720.6938	3.56
Within	38	7697.48	202.5653	
Pool	39	8418.1738		

The right critical value for a 90% level of confidence is 2.84, which is less than 3.56. Therefore, the null hypothesis is rejected with a 90% level of confidence. This means the proficiency rates for the quieter group are significantly different (higher) than that for the louder group with a 90% level of confidence for the 4th Grade test.

Table 14 ANOVA for 8th Grade Test

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Squares**	**F**
Between	1	1694.742	1694.742	14.02
Within	31	3748.21	120.91	
Pool	32	5442.952		

The right critical value for a 99% level of confidence is 7.53, which is less than 14.02. Therefore, the null hypothesis is rejected with a 99% level of confidence. This means the proficiency rates for the quieter group are significantly different (higher) than that for the louder group with a 99% level of confidence for the 8th Grade test.

Table 15 ANOVA for 11th Grade Test

Source	**Degrees of Freedom**	**Sum of Squares**	**Mean Squares**	**F**
Between	1	334.1659	334.1659	6.79
Within	20	985	49.25	
Pool	21	1319.1659		

The right critical value for a 95% level of confidence is 4.35, which is less than 6.79. Therefore, the null hypothesis is rejected with a 95% level of confidence. This means the proficiency rates for the quieter group are significantly different (higher) than that for the louder group with a 95% level of confidence for the 11th Grade test.

Table 16 lists the R^2 and R (in percent) for the above analyses.

Table 16 Coefficient of Determination and Correlation Coefficient for All Tests

Test	**R^2**	**R%**
4th Grade	0.0856	29.3
8th Grade	0.311	55.8
11th Grade	0.253	50.3

In a physical science or field such as engineering, R^2 and R values above 0.9 generally are considered a success. Often, values below 0.8 are dismissed for a variety of reasons, some of which are poor experiment design, too much error in the experiment, and rejection of the law being tested. However, there are branches of the scientific community, such as economics or psychology, where values below 0.5 are not only common, they are also significant. This occurs in analyses where there is multiple, sometimes hundreds of variables affecting a given phenomenon and for which the sample sizes are large. One description of R^2 is percent of explained variation. In a perfect model, with no error, the total of all the variations due to all independent variables should be unity. If a given model tests for just one of the variables for a given phenomenon, the others being held constant, R^2 will explain the variation in the phenomenon from that variable. Therefore, theoretically, any value of R^2 above zero could be significant. Also, R is a measure of linear correlation. There may be a far more complex relationship (non-linear) between the factors. In reality, confounding factors and error are always present. However, it would not be sensible to dismiss values of R^2 or R merely because they are not above a predetermined level.

The F values calculated revealed significance at a certain level of confidence. That can be viewed as a "green light" for using R^2 due to the direct relationship between them as described in Equation 20. The significant levels of F may be interpreted to mean that R^2 values are significant and high enough, within a certain level of confidence, to make decisions regarding the relationship between aircraft noise and proficiency rates.

Previously, it was noted that R represents the dependence between the proficiency rate and the aircraft noise. It may be used as a calibration factor between the two. Due to the amount of error that may be present in this analysis (discussed later), it would not be prudent to take the values for R as an exact, linear calibration factor between aircraft noise and student proficiency. For example, it may not be accurate to state that for the 11th Grade test, aircraft noise is responsible for 50.3 percent of the test score. There are many factors that affect one's test score in any situation (e.g., studying, health, and teaching quality). What this data does suggest is that aircraft noise is one of those factors for these proficiency tests. If aircraft noise is decreased significantly or eliminated entirely, it is likely that test scores will improve.

The 8th and 11th Grade R^2 and R values appear to be consistent with each other. The 4th Grade values are lower. These lower values are expected since the F value only produced a rejection of the null hypothesis at the 90% level of confidence. It may also mean that there are factors affecting that proficiency test that are not affecting the other two. It may also be noted that the actual proficiency rates for the 4th Grade test are lower than the other two. This may be attributable to the age (maturity) of the students. However, it must be noted that the 4th Grade test has received news press with regard to its difficulty (Mooney, 2000). It is suspected that the proficiency criterion was at too high a level for the 4th Grade students. However, the grading was consistent across the population. Therefore, the data is acceptable for this analysis. It may not be compared to rates for the 8th and 11th Grade tests. Therefore, in addition to the age of the students, it is likely that the difficulty of the test was a much more important factor than the environment (i.e., aircraft noise).

5.4 Economic Impact of Reduced Student Proficiency Rates

5.4.1 Annual Earnings of Young Adults by Educational Attainment

The importance of an education for the success of one's future can not be understated. While there have been and always will be those who are financially successful with little or no education, a high school and college education generally enhances earning capacity. The National Center for Education Statistics (NCES) provides hard numbers on the value of an education with regard to earning capacity. A salary can be based on many factors such as national or local economic conditions, supply of workers, employer's perceptions, worker's experience, and education.

Table 17 provides a ratio of median annual earnings of wage and salary workers ages 25-34 whose highest education level was grades 9-11, some college, and a bachelor's degree or higher to those with a high school diploma or general equivalency diploma (GED). It also differentiates with respect to sex. The values in the table represent the percentage difference in earnings relative to 1.0 for a high school diploma or GED. They are a measure of the earnings advantage of completing, or attending, college and the earnings disadvantage of not completing high school.

Table 17 Ratio of Median Annual Earnings by Educational Attainment to 1.0 for a High School Diploma (NCES, 1999)

Year	**Grades 9-11**		**High School Diploma/GED**		**Some College**		**Bachelor's Degree or Higher**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**
1990	0.71	0.58	1.0	1.0	1.14	1.34	1.48	1.92
1991	0.64	0.64	1.0	1.0	1.14	1.32	1.53	1.90
1992	0.68	0.76	1.0	1.0	1.13	1.34	1.60	2.00
1993	0.67	0.59	1.0	1.0	1.12	1.31	1.57	1.99
1994	0.68	0.58	1.0	1.0	1.14	1.20	1.52	1.86
1995	0.74	0.62	1.0	1.0	1.11	1.28	1.52	1.91
1996	0.69	0.64	1.0	1.0	1.14	1.27	1.54	1.88

For example, the 0.69 in 1996 for males aged 25-34, who only completed some high school means that their earning capacity was 31 percent less than those who had a high school diploma were. Similarly, the 1.88 for females with a bachelor's degree or higher in 1996 means that their earning capacity was 88 percent greater than those who had a high school diploma. In 1992, women aged 25-34, who completed college made double that of the high school graduates.

For simplification purposes, Table 18 averages the above numbers. Years 1990-1996 and males and females are averaged for each educational attainment level.

Table 18 Averages of Earnings Capacity Ratios

Grades 9-11	High School Diploma/GED	Some College	Bachelor's Degree or Higher
0.66	1.00	1.21	1.73

Therefore, it can be stated loosely that relative to a person with only a high school diploma or GED, someone with a 9-11 grade education makes 34 percent less, someone with some college education makes 21 percent more, and someone with a bachelor's degree or higher makes 73 percent more. These figures are overwhelming. Even a small percentage of individuals that do not attain the next higher educational level, for some given reason, will contribute greatly to lost wages over a large population.

5.4.2 Student Proficiency Rates and Educational Attainment

There are no known studies available that directly relate the score on a proficiency assessment and eventual educational attainment. The issues regarding such a study are complex. Perhaps most importantly, should such a study be undertaken? For instance, poor scores early on in one's educational career could damage motivation for attaining a higher education.

Those issues aside, it is reasonable to assume that test scores are proportional in some respect to eventual educational attainment. This is often a basis for using any standardized test, or even grade point average, for admissions to private schools, colleges, and professions. Without defining an exact relationship between educational attainment level and a given proficiency test score, it is assumed that on average, over a large population, the relationship is proportional. Therefore, to some extent, higher proficiency test scores imply higher educational attainment. In fact, Table 17 supports this assertion in that salary is directly proportional to educational attainment.

For the 4th, 8th, and 11th Grade proficiency tests, the quieter group scored better than the louder group at a statistically significant level of confidence. Based on the assumption that proficiency rates are proportional to educational attainment, it is reasonable to state that on average, over a large population, the educational attainment of those living in the quieter areas could be higher than that of those living in the louder areas.

There are no known studies that make an assessment of the impact of aircraft noise on eventual educational attainment. However, based on:

- the significant decrease in proficiency rates in aircraft noise impacted areas,
- the assumption that proficiency rates are proportional to educational attainment, and
- the previous references cited concerning the physiological and psychological impacts of aircraft noise,

there is reason to consider that some measurable number of people will fail to attain the next highest level of education due to aircraft noise. It is premature to assign a general number of people or a percentage of a population that may fail to attain the next highest level of education due to aircraft noise. However, the relationship between the 11th Grade test and attainment of a high school diploma is of interest.

5.4.3 Example of the Economic Impact of Aircraft Noise Based on Salary

For illustrative purposes, examine the difference in proficiency rates for the 11th Grade test. The proficiency rate for the quieter group is 86.2%, that for the louder group is 76.9%.

In the absence of additional data, assume that the 11th Grade proficiency rates are directly proportional to the attainment of a high school diploma, at least to an "order-of-magnitude." The yearly salary differential between the quieter and louder groups may be realized by looking at salary differences based on a high school diploma vs. 9-11 grade education.

According to U.S. Census Bureau data, the average 1997 annual income for persons 18 years old and over by educational attainment was:

$21,660 per year for high school diploma or GED

$14,920 per year for 9-11 grade education (Mortenson, 2000).

What population is impacted by aircraft noise in this case? The study area remains the same, northern New Jersey with DNL45 or greater used in the real estate analysis in Chapter 4. The population of this area is approximately 3.9 million persons. Realistically, consider the population initially affected by the lack of a high school diploma, persons 18-24 years old. In New Jersey, approximately 8.4 percent of the population are within that age range (New Jersey Department of Labor, 1998). Therefore, the impacted study area population for this assessment is 8.4% of 3.9 million persons, or 327,600 persons.

For simplification purposes, assume the salaries for this age group are either based on a high school diploma or 9-11 grade education. In other words, all individuals in this population either have a high school diploma/GED or 9-11 grade education. Also assume all persons in this age group contribute to the labor force. The potential yearly salary for quieter and louder groups is calculated for the purpose of relative comparison (wage differential) as opposed to actual salary of the given group. Recalling the assumption that proficiency rates are proportional to educational attainment, estimate the relative salary by the following equation:

$$S = (S_{HS}) \cdot (P_T) \cdot (P_{HS}) + (S_{NHS}) \cdot (P_T) \cdot (P_{NHS}) \tag{21}$$

where:

S is the total relative salary in \$/year

S_{HS} is the average annual income per capita for high school diploma/GED

S_{NHS} is the average annual income per capita for a 9-11 grade education

P_T is the total population in the study area

P_{HS} is the relative percent of the population with a high school diploma/GED

P_{NHS} is the relative percent of the population with a 9-11 grade education

($P_{HS} + P_{NHS} = 100\%$).

Using the U.S Census Bureau salaries and total population values and substituting in the proficiency rates for the louder group (P_{HS} = 76.9%, P_{NHS} = 23.1%) into Equation 21, S = \$6.59 billion/year.

Similarly, assuming an equal population (for the purpose of relative comparison) for the quieter group and substituting in the proficiency rates for the quieter group (P_{HS} = 86.2%, P_{NHS} = 13.8%) into Equation 21, S = \$6.79 billion/year.

Interpreting these values as relative to each other, the difference is \$0.2 billion/year or \$200 million/year. This indicates approximately a 3 percent disadvantage in salary for the noise impacted, or louder group based on high school diploma vs. 9-11 grade education. It would be hasty to apply this same percentage to the next higher levels of educational attainment, but it is reasonable to consider that some impact exists at those educational levels as well.

The value of \$200 million per year may be taken further. In this study, one population lives in an area impacted by aircraft noise, DNL60 on average. The other population is relatively unaffected by aircraft noise, living at a DNL45 contour or less on average. Conservatively, the difference is an average of 15 dB. It is this difference in aircraft noise level that generated the difference in proficiency rates between the groups. Other factors were maintained as constant as possible, thus, only aircraft noise separates the groups. Recall the total population to consider in this example is 327,600 persons. Dividing the salary by the population in the impacted study area and by the noise level difference of 15 dB, the impact is approximately \$41/year/capita/dB. That is a salary reduction of \$41 per year per capita per average decibel of noise greater than DNL45. This impact, or a value similar to it, may be carried over a person's career in the labor force if no mitigating action is taken. Certainly, in the short term, as long as the reduction in educational attainment exists, the value may be applied over a set of years.

5.4.4 Example of Economic Impact of Aircraft Noise Based on Pupil Expenditure

An additional analysis considers the economic impact based on the investment of educational dollars on an affected student. It is assumed that the significant decrease in proficiency rate will affect educational attainment, for instance attainment of a high school diploma. If this is the case, it is arguable that the return on the investment for that student is less than it could have been if the student had graduated. As stated earlier, it is premature to assign some number of students or percentage of students that may fail to finish high school. However, it is reasonable to assume that there will be some number of students that fail to graduate.

The 1998-1999 State average for total cost per pupil in New Jersey was $9565 per pupil per year (NJDOE, 2000). The per pupil expenditure includes:

- tuition expenditures
- transportation
- lease purchase interest
- residential costs
- judgments against the district
- facilities/acquisition costs

- restricted expenses, less nonpublic services and adult schools, plus students sent out of the district.

Obviously, the cost may increase or decrease over the years.

The formula for equal series present worth converts an annual amount (A) to a present value or present worth (P) based on a given interest rate (i) and period (n). Equation 22 illustrates equal series present worth.

$$P = A \cdot \left[\frac{(1+i)^n - 1}{i \cdot (1+i)^n} \right] \tag{22}$$

Assuming $9565 is the cost per pupil for each of the thirteen years (n) of public education (K-12), the present value (P) of that annual payment (A) may be calculated for a given interest rate (i) using Equation 22. Table 19 displays this cost for various interest rates. Assuming an interest rate of 7 percent, the present value of the cost of educating a student in New Jersey is approximately $80,000. To clarify, at 7 percent interest a present amount of $80,000 is sufficient to make annual payments of $9565 for the next thirteen years, *ceteris paribus*.

Table 19 Present Value of a New Jersey Public School Education

Yearly Interest Rate (i)	**Present Value ($), 13 Years of School**
4%	95,500
5%	89,800
6%	84,700
7%	79,900
8%	75,600
9%	71,600
10%	67,900

A high school diploma is a primary goal of elementary and secondary school education. However, it is not the only goal or benefit of these thirteen years. To state that the $80,000 investment is squandered if the student does not earn a diploma is flawed. However, it is reasonable to state that the investment has not yielded its potential return. The value perceived as a loss in the investment multiplied by the number of students impacted is a loss in dollars for the taxpayer, for the State of New Jersey, and therefore for the community at-large.

5.5 Chapter Summary

This analysis demonstrates an impact of aircraft noise on student proficiency for the middle group. As noted earlier, the highest and lowest socioeconomic groups were neglected due to confounding factors. It is believed that impact is real in those communities as well, but is impractical to measure with this analysis. Similarly, other communities that are not as heavily populated are affected even though it is difficult to obtain a statistically significant population to measure an impact. The results of this analysis would be valid in those areas as well.

From an economic standpoint, the two examples demonstrate techniques to assess aircraft noise impact in dollar terms. The following observations are made:

- Students in New Jersey are adversely affected by aircraft noise.
- Future educational attainment and earning capacity are impacted. It is plausible that the overall salary impact is on the order of 3 percent.
- The investment the State of New Jersey and its citizens make in educating students may be impacted by aircraft noise.

CHAPTER 6

NOISE MITIGATION TECHNIQUES

In general, there are three methods of reducing noise: at the source, transmission path interruption, and protecting the receiver. Often, the three are combined in some fashion to produce the desired noise level reduction. This chapter first suggests mitigation based on traditional methods of protecting the receiver of the noise and controlling noise at the source. These methods are followed by those established in the NJIT study (1999) which provides a wealth of content that directly relates to the issues of community aircraft noise impact.

6.1 Sound Treatment of the Receiver

One obvious method of noise mitigation is sound treatment or sound insulation of schools and homes. In some locations, noise levels cannot be reduced by routing changes or other means. Aircraft noise studies should identify such communities with the greatest noise impact and evaluate the feasibility of sound treatment to reduce aircraft noise intrusion.

It is noted that treatment of buildings to reduce intrusive noise offers only partial relief for the following reasons:

- Building treatment has no effect on outdoor noise exposure.
- When windows are open, the open-window sound transmission path dominates. In this case, building treatment has negligible effect.

- If windows are kept closed, mechanical ventilation systems are required. These systems must be operated for longer periods in noise-impacted areas (with potential adverse environmental effect). Mechanical ventilation systems used in building sound treatment are designed to have a negligible effect on the noise environment.

Murphy (1996) describes a residential sound insulation pilot program involving four homes impacted by the Sarasota-Bradenton International Airport. Day-night sound levels were in the range $65 \leq \text{DNL} \leq 75$. Simultaneous interior and exterior sound exposure levels (SEL) were measured with digital integrating sound level meters. Measurements were taken in various rooms for numerous flights. Noise level reduction (NLR) was based on the difference between exterior and interior SEL's. This procedure eliminates the need for time-consuming measurement of interior and exterior day-night sound levels at each site.

Exterior sound exposure levels were in the range $103 \text{ dB} < \text{SEL} < 110 \text{ dB}$. Before modification, the dwelling-average noise level reductions were in the range $20 \text{ dB} < \text{NLR} < 24 \text{ dB}$. Principal modifications to the dwellings included replacement of windows, replacement and/or addition of doors, and heating-ventilating-air conditioning modifications. Costs per dwelling ranged from approximately $8000 to $18,000. After modification, the dwelling-average noise level reductions were in the range of $28 \text{ dB} < \text{NLR} < 36 \text{ dB}$. In individual buildings, the increase in noise level reduction ranged from 7 to 12 dB.

The study cataloged 1200 dwellings between the DNL65 and DNL75 contours. Cost was considered in the final selection for the pilot program; thus, costs would be higher if more dwelling types were represented. In addition, adjustments would need to be made if the study results are applied to the New York/New Jersey metropolitan area. Differences in building types and construction costs and annual changes in construction costs should be considered.

A more direct attack on lessening the impact on students is to sound treat schools. Frank (2000) reviews the Port Authority of New York and New Jersey's program for sound treating schools. The following information summarizes this reference.

The Port Authority is considering requests from schools not automatically eligible for sound treatment for the program. The last school sound treatments to be funded by the FAA are underway. The exact implementation of the sound treatment program varies from school to school depending on configuration. It costs more than one million dollars to complete each school. Federal Airport Improvement Program grants cover around 80 percent of the cost, the Port Authority pays the remainder. The Port Authority uses flight fees charged to the airlines to recover the payments. The program usually includes installing sound treated windows, ceilings, and doors, as well as mechanical ventilation.

The schools that received funding lie within the DNL65 contour (i.e., ≥ DNL65). There presently is no funding to treat schools that lie outside of this area. The need for sound treatment of schools outside the DNL65 contour is supported by this research. While there is little argument that the schools in the most impacted areas should receive funding priority, there must be programs at some level to assist all other schools in this endeavor.

Sound treatment of all schools impacted by aircraft noise above DNL45 would be a noble pursuit. However, the financing of this type of program is a considerable concern. The other major concern is that sound treatment of a building does not protect an individual from the noise when outside. It is arguable that a student's performance is affected by many factors, only some of which are while they are in the classroom. Since there are aircraft noise impacts while the student is outside or while they are in an untreated home, their ability to learn may be impeded.

There are funding programs for sound treatment of homes within the DNL65 contour. However, the large number of homes that may require sound treatment beyond that contour make it impractical to serve the entire community's needs. The case for control of noise at the source is enhanced by the impracticality of mitigating the problem via protection of the receiver.

6.2 Noise Control at the Source

Source control normally is considered the most effective method of noise control. Source control can involve replacing noisier Stage 2 aircraft with new Stage 3 aircraft, re-engining, or hushkitting. Changes from Stage 1 (essentially uncertified for noise) to Stage 2 high-bypass-ratio engines increased efficiency, as well as reducing noise. The change produced a dollar benefit for the airlines.

The noise requirements of 14 CFR Part 36 for Stage 2 and Stage 3 aircraft include exacting test procedures and repeated tests to ensure statistical significance of results (see Appendix). In addition, the regulation provides for tradeoffs, where noise levels exceeded at one or two measuring points are offset by measurements at other points. The replacement of Stage 2 aircraft by Stage 3 as of January 1, 2000 represented a significant action in controlling aircraft noise.

Approximate hushkit cost per aircraft ranges from $1.2 million (for the DC9-10) to $3 million (for the 727-200). Re-engining 727-200's with Pratt & Whitney JT8D-217C or 219 engines to qualify for Stage 3 certification costs $8-10 million/aircraft, but yields an operating cost reduction, shorter takeoff field length, and extended range. These estimates are in 1991 dollars.

Talks of the next quieter stage of aircraft, sometimes called Stage 4, are underway, but extremely preliminary. Substantial quieting via engine design may be cost-prohibitive and practical limits of aerodynamic design will be at issue. Even assuming that the public, industry, and government come to an agreement on the technical details and schedule for implementation, it is unlikely that these aircraft will be in use within this decade. It took approximately ten years to complete the move from Stage 2 to Stage 3.

Source control not only includes producing improved engines and airframes with respect to noise generation, but also includes removal of the source itself. This takes many forms ranging from airport closure or aircraft retirement to changing flight paths, flight schedules, and flight arrival and departure profiles.

For this study area, citizens groups have suggested "ocean routing" which consists of routing schemes that make more use of the bodies of water to the east of Newark Airport. The New Jersey Coalition Against Aircraft Noise (NJCAAN), Inc. (1993) describes these procedures in a report prepared for the New Jersey Citizens for Environmental Research (NJCER), Inc. At the request of the Port Authority, Leigh

Fisher Associates (1994) studied the implications of ocean routing on the New Jersey and New York communities in the area. Regardless of this particular plan, a change in aircraft routing will control noise at the source. One significant problem is that, usually, there are new communities that are adversely affected by a new aircraft routing scenario. This is especially true in the New York/New Jersey area due to the population density and the presence of three major airports as well as a number of general aviation (smaller) airports.

6.3 FAA Airspace Reconfiguration

The FAA airspace reconfiguration is underway. This massive project's objective is to redesign the airspace over the entire United States. The project begins with the New York/New Jersey airspace. The redesign certainly will affect communities. However, Congressional funding for the redesign as well as planning ahead for funding for sensitive receptors, such as schools, should be made available.

It is anticipated that the redesign plan will optimize a number of factors. One of these factors is the reduction of environmental and community noise impact.

6.4 Mitigation Methods via Technology

Technological improvements have the potential to dramatically improve human and equipment performance. EWR requires improved air traffic control technology. This improved technology aids in noise mitigation by improving track precision. It facilitates aircraft maintaining their designated tracks, thus keeping noise away from sensitive receptors or away from areas designated as sensitive.

Improved weather systems, such as the Integrated Terminal Weather System (ITWS) in use at EWR, allows more efficient runway use and air traffic planning. The Global Positioning System (GPS) also plays a role in keeping aircraft on track and improving operational efficiency. GPS allows for closer spacing of aircraft, which in turn reduces airtime and noise. These improvements reduce delays and therefore reduce the amount of traffic that may be held over into evening and nighttime hours or placed into holding patterns. As discussed, people generally are more sensitive to noise at night and recall there is a 10 dB penalty for nighttime noise.

Advances in computer software and hardware make it possible to consider an array of different routing plans at a reasonable cost. Different flight routing plans for source control may be compared and contrasted with relative ease. There are a number of computer models available to facilitate routing plan design, and noise modeling.

There are other examples of technology advances that may reduce delays and therefore noise. The Controller Automated Spacing Aid (CASA) allows for simultaneous runway usage. In the case of EWR, Runways 11 and 22L may be used simultaneously. Also, the departure spacing program eliminates manual flight processing and significantly reduces departure delays during severe weather.

The Port Authority uses the Aircraft Noise Abatement Monitoring System (ANAMS) as a major part of its noise control program. The system:

- Automates compliance with PANYNJ departure noise limits
- Monitors airline adherence to prescribed noise abatement procedures
- Provides a flight track data base useful in facilitating response to complaints

The primary data sources for the system are radar data from the FAA and noise monitoring data from the microphone system. Using these synchronized data, ANAMS correlates flight tracks and noise events. The system receives weather data from the Automated Weather Display System. Output consists of graphical plots and numeric reports. With the combination of flight track data and noise monitoring, ANAMS facilitates the study of new noise procedure effectiveness.

An aggressive technology investment program can assure state-of-the-art equipment and systems for ground and air operations. Efficient operations mean decreases in flight time, which means less noise impact on the community.

6.5 Propeller and Jet Aircraft

Airport landing fees were designed to cover airport facility maintenance costs. Since larger aircraft had a larger impact on the facilities, such as runways, cost was allocated according to weight. There are current economic issues, such as airspace allocation and cost of delays, that exceed the traditional physical cost issues.

Departing propeller aircraft use slower speed than their jet aircraft counterparts. When the two operate on similar flight tracks, there is increased spacing between aircraft and different timing due to the slower propeller aircraft. A typical jet spends five minutes in the immediate airspace compared to an average of ten minutes for props. A typical commuter type propeller aircraft uses 50 percent more airfield resources than a jet. Optimistically, props require approximately 1.5 minutes to depart to roughly one minute for a jet. Runway efficiency declines.

Air resource design can include plans to more effectively schedule jet and propeller aircraft to as to minimize the air resource impact of the props.

6.6 Air Resources Research Center

The primary issues discussed in this research, real estate value impact and student proficiency rate impact, are complex. Also, they are not the only issues that require research. The issues that affect the community near airports and aircraft flight paths are interrelated and involve challenges regarding the environment, the economy, and quality-of-life. The complexity of the issues regarding Newark International Airport is compounded by the presence of other major airports and intermodal transportation within the region.

The intricacy of the aircraft routing problem and aircraft noise requires a review of a variety of other issues, such as:

- Safety
- Environmental protection
- Technology improvements
- Infrastructure improvements
- Military airspace requirements
- Capacity to meet increased future needs

Reliable and unbiased advice should be available to address these factors and provide solutions. The availability of a robust, unbiased, independent resource center would provide a positive and substantial step in this effort.

6.7 Chapter Summary

There is no single solution to resolve the problem of aircraft noise. The actions noted above have the potential not only to reduce aircraft noise, but also to improve operations, management, equipment, and the quality-of-life of airport neighbors.

Mitigation techniques require funding. Congressional and government funding is only one method. A noise mitigation fee on a per ticket basis would provide significant revenue to accelerate effective noise reduction strategies. Through this method, the cost is on the user of the service (the traveling public) as opposed to the community at-large. Controls must be in place to ensure that these fees are used only for noise mitigation purposes.

From an economic view, the law of diminishing returns applies. This law holds that there will be less and less output when adding additional doses of an input while holding other inputs fixed. The marginal product of each unit of input will decline as the amount of that input increases, holding all other inputs constant (Samuelson and Nordhaus, 1998). Realistically, this law is more of an observed regularity than a scientific law. Nevertheless, there is only so much that can be done to mitigate noise. Funding is important, but regardless of the magnitude of the funds, it is extremely difficult, if not impossible, to eliminate aircraft noise entirely.

CHAPTER 7

CONCLUSIONS

7.1 General

This research assessed the impact of aircraft noise on a New Jersey study area in terms of reductions in real estate values and student proficiency rates. The reduction in real estate values for the study area is approximately $2 billion per year. New Jersey residents are major stakeholders in plans to reconfigure airspace.

Student proficiency rates are significantly reduced because of aircraft noise. The overall salary impact for this loss in proficiency is on the order of 3 percent and may be estimated at $41 per year per capita per average decibel of noise greater than DNL45. Additionally, the return on investment of what the State of New Jersey and its citizens pay to educate their children is reduced.

Noise control and mitigation approaches include details of source control, receiver protection, technological innovations, airspace management, and continued research. Any level of noise control pursued must consider economic, political, and technological issues. Airports provide a crucial service to the community and drive the economy. The mitigation techniques discussed will reduce aircraft noise impact and therefore lessen the economic burden borne by the community. The financing of these techniques, whether by industry or at local, State, or Federal levels, must be given due thought.

The need for the procedures in this work is best expressed with the following concept from economic theory. In order to estimate costs for externalities such as aircraft noise, there are some environmental economists who commonly employ a technique called contingent valuation. In short, this technique involves asking people how much they would be willing to pay in a hypothetical situation to correct an environmental impact (Samuelson and Nordhaus, 1998). The methodology is controversial and suspect because people must place a dollar value on something they may never have experienced or do not understand. Additionally, since the people never have to pay real money, they are willing to pay extra theoretical dollars in the name of a worthy cause. Results vary by many orders of magnitude.

It is precisely this type of thought process that must be avoided. The focus of this dissertation was assessing the economic impact of an environmental impact, aircraft noise, using tangible figures. The challenge of isolating a variable such as noise in an analysis and determining an associated consequence is readily apparent. When factors in an environmental impact analysis, such as noise, are given an objective monetary value, they may be compared to each other. The values calculated herein are "order-of-magnitude," but they are as objective as possible and therefore carry more validity than opinions.

7.2 Assessment Enhancements and Suggestions for Further Study

7.2.1 Noise Levels

By far, the most significant issue in a study such as this is the accuracy of the noise level contours. They are estimates from the start, dynamic, and depend upon a host of factors. Any modeling enhancement to improve their precision is a benefit. When considering noise level differences between two populations, maintain as large a difference as practical between the groups. A variety of software packages are available for noise and airspace modeling. Modeling software is almost continuously updated. Consideration of the data input, assumptions, and rules for ground and airspace management are critical for the effectiveness of any these models (garbage in, garbage out).

Noise levels may be measured directly. This generally is labor intensive and expensive. The number, configuration, and quality of microphones limit measurements. Consequently, the area that may be covered for a set of measurements at any one time is restricted. Corrections for background noise and environmental conditions (weather-related) are of concern. However, the measurements made are real as opposed to modeled. If sufficient funding is available, large-scale state-of-the-art noise monitoring systems for a community or region are an exceptional analysis tool.

Accuracy of noise levels affects the validity of a regression analysis. With more precise noise levels for each municipality, the accompanying regression analysis will enhance any findings. This analysis had two noise groups, quieter and louder. Precise noise levels allow for more groups. For instance, establishing a group for every 3 to 5 decibels of difference in DNL contour is an excellent goal, but perhaps unrealistic. Three or more noise groups enhance statistical analysis and strengthen results.

Improvements and research in noise metrics are on-going. Until future metrics are validated by the appropriate agency, the day-night sound level is the best available in spite of the inherent deficiencies discussed earlier.

7.2.2 Other Factors

Any estimate of the effect of aircraft noise on real estate values, such as the 1.33 percent loss per decibel used in this research, requires scrutiny. Improvement of the accuracy of this number for various housing price ranges is valuable. The estimates for population, real estate values, and wages are as reliable as practical. Official values provided by the state or federal agency are appropriate.

In addition to student proficiency rates, the effects of aircraft noise on student attendance, faculty attendance, and mobility rate (students entering or leaving school during the academic year) are of interest. Initial research by the author found no apparent correlation. However, future research may delve into these areas, as there may be some relationship.

In order to appreciate fully the impact of aircraft noise on the community, all factors should be accounted for in monetary terms. Additional factors regarding physiological and psychological aspects of noise impact should be addressed and recognized as a cost factor. Subsequent economic impact models may then be developed.

When isolating noise as a factor, other factors must be held constant. It is difficult to hold all socioeconomic factors fixed. The district factor groups in this analysis are effective, but are updated with the U.S Census. Methods for maintaining their accuracy in the interim are warranted. Additional methods of holding factors constant and thereby minimizing the differences between the groups are of tremendous value.

The most important aspect of any procedural modification is maintaining objectivity.

7.3 A Final Note

The following citation dates from 1962. Interestingly, it holds as true today as it did almost forty years ago. No doubt it will hold true forty years hence. Sir E.B. Hill wrote, "All scientific work is incomplete-whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. …The day of precise quantitative measurement of health and welfare effects has not yet arrived. Until such measurement is possible, action must be based upon limited knowledge, guided by the principal of the enhancement of the quality of human life. …" (EPA, 1974).

APPENDIX

A.1 Stage 2 and Stage 3 Aircraft Requirements

A comparison of Stage 2 and Stage 3 noise levels are provided to demonstrate an example of the noise reduction realized by source control. These standards are set forth in 14 CFR Part 36, Noise Standards: *Aircraft Type and Airworthiness Certification.*

Noise measurement points are located as follows:

- Takeoff: 21,325 feet from the start of the takeoff roll on the extended centerline of the runway.
- Approach: 6562 feet from the threshold on the extended centerline of the runway.
- Sideline: On a line parallel to and 1476 feet from the extended centerline of the runway where the noise after lift-off is greatest. For an airplane powered by more than three turbojet engines, the distance is 0.35 nautical miles to show compliance with Stage 2 limits. One nautical mile is approximately 6076 feet or 1852 meters.

Some of the Stage 2 and 3 noise level limits are indicated below to illustrate the effect of aircraft weight, configuration, and design stage. Values are limits of effective perceived noise level (EPNL, measured in EPNdB). EPNL is a physical measure designed to estimate the effective "noisiness" or a single noise event. It is usually applied to aircraft flyovers. It is derived from instantaneous perceived noise level (PNL) values by applying corrections for pure tones and for the duration of the noise event.

A.1.1 Stage 2 Aircraft

- Takeoff: 108 EPNdB for maximum weights of 600,000 lb or more, reduced by 5 EPNdB per halving of weight down to 93 EPNdB for 75,000 lb or less.
- Sideline and approach: 108 EPNdB for maximum weights of 600,000 lb or more, reduced by 2 EPNdB per halving of weight down to 102 EPNdB for 75,000 lb or less.

A.1.2 Stage 3 Aircraft

- Takeoff: Airplanes with more than three engines: 106 EPNdB for maximum weights of 850,000 lb or more, reduced by 4 EPNdB per halving of weight down to 89 EPNdB for 44,673 lb or less. Three engines: 104 EPNdB for maximum weights of 850,000 lb or more, reduced by 4 EPNdB per halving of weight down to 89 EPNdB for 63,177 lb or less. One or two engines: 101 EPNdB for maximum weights of 850,000 lb or more, reduced by 4 EPNdB per halving of weight down to 89 EPNdB for 106,250 lb or less.
- Sideline: Regardless of number of engines: 103 EPNdB for maximum weights of 882,000 lb or more, reduced by 2.56 EPNdB per halving of weight down to 94 EPNdB for 77,200 lb or less.
- Approach: Regardless of number of engines: 105 EPNdB for maximum weights of 617,300 lb or more reduced by 2.33 EPNdB per halving of weight down to 98 EPNdB for 77,200 lb.

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