# Graphical Method for Airport Noise Impact Analysis

by
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# Abstract

The impact of airport noise on neighboring communities is an important consideration in the planning and operation of airports. When the Day-Night weighted average noise level exceeds the EPA's noise limit for residential land use of 65 DNL, a legal taking of the property owners ability to use and enjoy the property has occurred, and the property owner is entitled to compensation. Monetary compensation to property owners takes the form of buyouts or easements. Airports also attempt to mitigate the noise impact by offering homeowners in the 65-75 DNL contour soundproofing and implementing noise abatement (mitigating) procedures. The decision to provide monetary compensation or noise mitigation is based on the noise levels predicted by computer models for different procedures and levels of operation.

The large amount of data required to determine the noise impact makes graphical representation the only feasible method of data presentation. This thesis present a graphical decision aid that refines the present methods of graphical modeling by adding the effects of operational variation and adjusting the presentation method to allow for easier interpretation. The current method of modeling limits the considered data to scheduled flights proceeding along precisely defined routes. There is no allowance for unscheduled flights or deviations from the official flight path. The inclusion of other flight data tests the robustness of the idealized flight path analysis in a real world situation. Adding unscheduled, but documented flights to the model is easily done for an airport which charges landing fees or otherwise documents operations. The graphical decision aid allows the incorporation of flight variation. In the presentation, the viewers attention is focused on the populated areas impacted by the noise. The superposition of a color noise impact on a black-and-white map provides a natural frame of reference for the community as well as the airport operators.

Use of the graphical decision aid was evaluated in a case study comparing two departure procedures from runway 27 at Logan Airport in Boston, Massachusetts. Results of the case study indicate that the predicted noise benefit of a new procedure implemented to reduce the noise impact, were not achieved when operational variations were considered. The resulting noise impact numbers show that idealized DNL contours are limited in their application to simplify scenarios which include operational variations.

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# Chapter 1

# Introduction

Airplanes transport people and goods rapidly and economically over large distances. However, no progress is without its consequences. Airplane engines produce deafening sound levels at close proximity and disturbing noise levels for miles near take-off and landing sites. A high volume of aircraft traffic can make living near an airport difficult because the noise from airport operations interferes with community life.

The noise from an airport includes aircraft takeoffs and landings as well as aircraft taxiing, engine testing, and the sounds associated with cargo transport businesses located at or near the airports. In addition, airports also change the surface transportation patterns. The increased ground traffic, passenger and cargo, to and from the airport often overburdens the existing roads and highways, increasing the noise in the neighborhood. In Boston for example, the $11.6 billion Ted Williams Harbor Tunnel and Central Artery Expansion, locally known as the Big Dig, includes a tunnel, the latest of ongoing attempts to alleviate the surface traffic congestion into and out of Logan International Airport (estimated cost as of August 1997).

The seriousness of the airport related noise problem is determined by the number of people living near the airport. One solution is to build airports away from the communities they serve, but a remotely located airport defeats some of the purpose of using air transport. An ideal social solution would be reached if the all the people impacted by the noise had chosen to live there despite the noise because of other advantages offered by the location, such as cost or proximity to work. However, the rate of increase of airport related noise has exceeded the rate of housing turnover, especially in areas pre-dominated by

homeownership. Airport noise can increase from one day to the next due to a procedural change, while even in a rental market, a turnover rate of about six months can be expected.

Today noise considerations are handled through negotiations between the airport authorities and the community. Often however, the negotiations reach an impasse because the community wants the noise impact reduced over every house, and the airport authority cannot convey to the community the technical problems involved in reducing the noise impact at every location at which an aircraft overflight might become bothersome. The problem the airport operators are trying to convey is a combination of the infeasibility of providing relief to every one and the inability of air traffic control to precisely control the trajectory of each aircraft. At most airports, the only available data are aggregate noise contours based on the scheduled flights using the proscribed flight paths. The community can see in its daily life that the airplanes do not adhere strictly to the proscribed times or flight paths. Such an inconsistency undermines the confidence of the community in the airport data. What is often missing in these discussions is a compelling method to present data about aircraft flight paths and noise profiles for both the nominal case and several alternate examples that community members might question.

Data required to convey the airport's story comprises a tremendous list. Not only does the community want to see the nominal fair weather flight path, but they also expect to see variations due to weather, navigational error, and emergency situations. In additional to the flight path, the community would like to visualize the noise impact associated with the different flights. These requirements can only be met with some knowledge of the actual flight operations, the typical variation in aircraft trajectory and a measurement of aircraft noise at ground level. Additionally, the community would like to learn of the effect of proposed procedural changes prior to approval of the change. A tool that could portray this type of flight data would be useful to airport administrators.

Federal regulations grant those harmed by airport related noise the legal right to seek compensation from the airport operator. The EPA has determined that 65 DNL (described in Chapter 3) represents the maximum acceptable average outdoor sound level, and Federal Aviation Regulation (FAR) Part 150 uses this limit as the outdoor threshold noise level for compensation. Since it is in the interest of both community members and airport operators to know the location of this critical noise contour, a tool capable of presenting this information is required.

To find an analysis tool that is widely usable, theoretically accurate, and reproducible, the FAA has determined that a computational modeling method is the most appropriate. The model for determining the noise impact contours chosen by the FAA is the Integrated Noise Model (INM), which is now in its fifth version. A noise model must take information about the operations and fleet mix at an airport, and generate noise contours to be superimposed on population maps. The resulting noise contours must be believable to the airport operator, the FAA, and the local community. The newest INM system can use a number of inputs including information about the actual flight paths and the number of go-arounds. Unfortunately this information is only available at a limited number of airports. At most airports, the current INM inputs are dependent on the OAG listed flights. However, at airports where noise monitoring has been instituted, discrepancies have been discovered between OAG listed flights and actual operations. This can be significant when the omitted operation is a cargo aircraft landing at 3 a.m. While the computer modeling programs can provide a picture of the noise contours, they have their limitations and inconsistencies.

One limitation in the use of INM as the sole planning tool is that the INM system only shows the entire picture. It cannot relate specific operations to their respective noise impacts. The inputs are sufficiently complex that a simple relationship between a proce-

dural change and its effect on the noise contours is obscured. Additional planning tools would provide additional information about the robustness of the INM assumptions. Such a set of tools would illustrate the effect of variations in flight procedures, operational frequency, and population.

The purpose of this thesis is to show a method of graphically representing the legal metrics for airport noise impact and to suggest ways in which such a representation fosters better understanding of the problem for the community and the airport operator. The graphical decision aid provides a tool which is easily interpreted by all the participants in the decision making process. In addition, it provides a clear comparison among the different possible solutions. The initial problem of gathering accurate data for input into the model is addressed. The first step is to use the actual number of flight operations and their times. The difficulty increases with the next step, representing the effect of flight path deviations. Most airports do not have data on flight deviations so some approximations must be made based on patterns at other airports. Data presentation is also important. Noise over an inhabited area is of greater interest to planners than noise over the open ocean. A useful airport-planning tool will illustrate the noise impact as it affects neighboring communities. A tool to be used in conjunction with INM should show the link between the flight procedures and the community noise impact. By using the same metric, DNL, as the FAA, communities and the planner can identify present and future noise mitigation requirements. The model must also adapt to include other metrics that might be adopted locally or nationally in the future. The noise footprint will be shown only where it affects those areas of interest to the planners. Presently, such a metric will concentrate on densely populated regions and sensitive sites; the metric could be easily modified to take into account other factors such as nesting sites for endangered species. The focus of the graphical model then, is on the affect of noise on populations rather than just an outline of the

noise on the ground. Chapter two provides a brief overview of airport operations, airport expansion, and several types of noise mitigation programs developed as a result of increasing air traffic. Local discussion about noise mitigation programs are found wherever a major airport is near a populated area, in the US and overseas. A basis for noise measurement, aspects of human perception of noise and some dangers associated with loud noise are introduced in chapter three. Additionally, chapter three includes a discussion of aircraft noise, and how the noise levels also affect such mundane things as property values. Chapter four provides background on the effective representation of data as well as how the graphical representation of data can be used as a decision making tool. Chapter five explains how the community noise impact model is constructed, giving detailed comparisons between the community noise impact model and single event noise models. The noise aggregation program demonstrates how aircraft procedures can be transformed into a snapshot of community noise impact. Chapter six presents a case study of departures from Boston's Logan Airport in order to illustrates the possible utility of such a graphic decision aid in an actual policy situation. This application shows how a full range of modeling tools provides in depth information about the impact of a procedural change on the community noise impact. In conclusion, the final chapter describes how this noise addition meets present and future needs in noise models as well as noise mitigation protocols.

# Chapter 2

# Background

## 2.1 Noisy Aircraft and Communities

Although significant reductions in source noise have been achieved through the development and implementation of higher bypass engines, the dramatic increases in aircraft operations has been accompanied by increases in citizen complaints, and corresponding legal activity. The response of the federal government to these complaints and legal actions has been a series of federal guidelines covering noise and the airport operator response.

The new political and economic climate containing a mix of regulations, lawsuits, and citizen complaints has lead to the development of a multitude of noise mitigation programs. Given the rapid increase in the number of noise mitigation programs, it appears that airport authorities have determined that the cost of mitigating noise from increased aircraft operations is less than the associated benefits. For airport expansion to continue, this relationship must continue to hold.

## 2.2 Airport Operations

Airports have a wide variety of runway configurations based on environmental and operational considerations. Aircraft gain an operational advantage by flying into a head wind on take off and landing. Side gusts, on the other hand, present a more dangerous weather condition. Thus, runway headings are determined by the most common wind directions. Many airports consist of one set of intersecting runways as depicted in Figure 2.1(b). The two runways provide for single runway operation taking into consideration any seasonal variation. For example, airports on the east coast of the United States tend to

have one wind direction which predominates in the spring and summer, but have a different wind orientation in the fall and winter. This requires one set of intersecting runways for even the smallest airports. On the other hand, for the parts of California wedged between the mountain and the sea, the diurnal effects of the ocean and the desert can be stronger than any seasonal variation, making one set of parallel runways acceptable for a smaller airport as shown in Figure 2.1(a). Larger airports seeking to increase capacity might add additional runways as demonstrated in Figure 2.1(c) and (d).

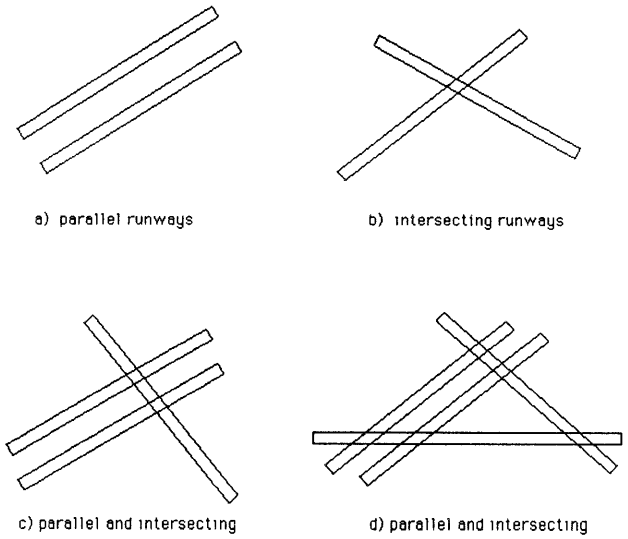


**Figure 2.1:** Airport runway configurations use (a) parallel or (c) intersecting runways based on wind conditions throughout the year. The addition of (c,d) more runways increases airport operations.

Multiple runways increase the capacity of an airport and are used in a variety of ways. With multiple runways, one can be used for landings while the other is for take off's. At airports with a mix in large and small aircraft, one runway can be used for larger aircraft while the other is for smaller aircraft. At airports with parallel runways adequately far apart using an advanced air traffic control system, the parallel runways can be used for simultaneous operations, greatly increasing the capacity of the airport.

## 2.3 Airport Expansion

Many US airports have out of abandoned military airfields. The bulk of the conversion happened in the 1940's and 1950's, but the trend still continues today. For example, Orlando International Airport was a small military air base during the 1920's that grew into a major international civilian airport and commercial transportation center. Currently, the legal battles have begun over El Toro Marine Air Station in California. With the good California weather making airports popular with general aviation, there is a move to turn the El Toro Air Station into a commercial airport. Additionally, with a well developed commuter jet network on the West Coast, it can be expected that the intersecting runways of the proposed El Toro airport will experience significant growth. According to opponents of the project, the safest, and therefore most commonly used takeoff trajectory extends directly over the more populated parts of this community. For the nearby residents, the difference between an occasional flight from an almost abandoned military airfield and the traffic at a bustling commercial center is staggering. A military airfield of declining importance might have zero to ten flights a day while a mid-size commercial center has several hundred flights.

The conversion process from military to commercial is an example of the intersection of local and national issues that are prevalent in air transport policy. The local community is given one chance to approve or disapprove an approximate plan for an airport. Once the airport is approved, the local control over the project diminishes. The FAA, in its role as the guardian of air safety and promoter of air commerce, controls many aspects of the operation of the airport, including all aircraft movement. Airports are generally funded in part by regional tax contributions, but local communities have limited jurisdiction over how the airport is operated. Only when these local funds are needed for airport expansion does the neighboring citizenry have any further input. The FAA has a mixed record in

accommodating local preferences with regard to airport operations. The FAA will consider local input to move traffic patterns, but will not support any measures that would decrease effective airport capacity.

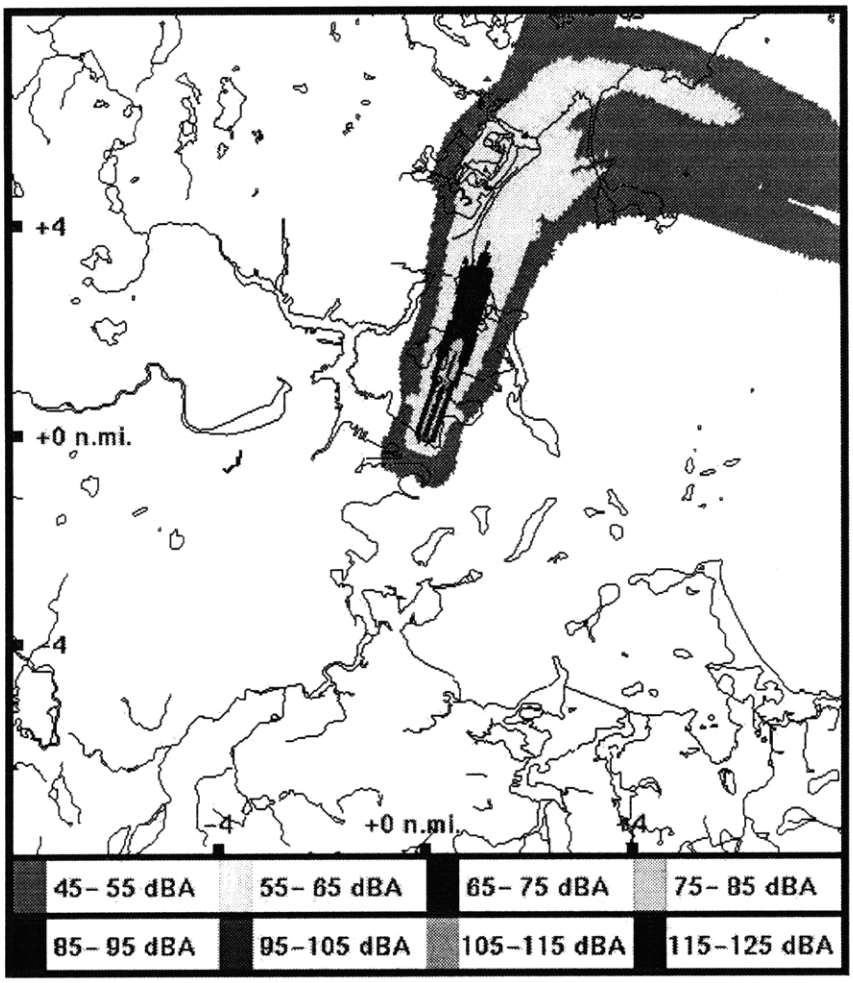


**Figure 2.2:** Sample Noise Footprint Accounting for Operational Variation

Air transport is not perfectly safe, so airport designers prefer to place airports such that take offs and landings occur mostly over unpopulated areas. These areas include the highly desirable coastal shoreline, farmland, industrial areas, and open spaces. In the time since the airports were built, not only has the total population of these areas grown, but the population density has increased as well. Because airplane noise is not a continual distur-

bance, it is often underestimated by persons looking to purchase a home. Figure 2.2 shows the simulated noise impact from just a single runway. This is a frequently used runway at a major airport with a pair of parallel runways and a third single runway. Much of the flight path and corresponding noise impact is over water, yet the increased number of persons living under the remainder of the flight path has increased the likelihood that the affected community will seek compensation for the detrimental noise levels. This has been realized, resulting in a noise mitigation program at this airport.

With the explosion of air traffic in the 1980's, the noise impact on local communities has increased substantially. Communities that had previously largely ignored their aviation neighbors noticed the noise and began to take civic action against the intrusion of aircraft noise into their daily lives. Aircraft expansion initiatives faced increasing local opposition. In the late 1980's, when federal building funds decreased, local communities used their vote against funding these expansions to block physical expansion of their local airport's runway systems. However, the FAA still has sole control over the operations at an airport, and the development of better air traffic control (ATC) systems permits a greater number of operations with the same runway system. Therefore, even communities which vote down physical expansion of their airport are faced with a greater number of aircraft operations.

Almost all expanding airports have made financial concessions to their neighbors. Most major US airports are owned and operated by a nearby community (at this time the Hollywood-Burbank Airport is the only significant exception). While the FAA often appears as a remote government agency, airport operators must interact directly with local the community. Usually, only a minority of the owning community is impacted by the noise; the entire community can be up to thirty miles away from the airport, or be so large that the affected community is only a small fraction of the citizens. Despite community

ownership, airport operators frequently do not have a high degree of direct responsibility to those neighborhoods near the airport. Still, numerous noise mitigation programs have been initiated in the United States as well as overseas.

## 2.4 Noise Mitigation Programs

Noise mitigation programs are present at a wide variety of different airports, from major international centers like Logan Airport to small general aviation airports like Palo Alto. The term noise mitigation covers a wide range of efforts by the airport operator to lower the noise impact on the local communities. Measures include soundproofing, altered arrival and departure flight paths, aviation easements and property buyouts. Two approaches are found among the noise abatement programs. The first is to relocate residents affected by the noise. The second is to make people more comfortable where they live. Most noise mitigation programs use a combination of the two approaches as described more fully below.

Relocation is necessary in some areas directly adjacent to or underneath the flight path. The decision to purchase homes or relocate residents depends on the number of homes involved, the level of noise at the residence, and the condition of the homes. Noise levels above 85 DNL are extremely loud and can cause physiological damage. The EPA has determined that these noise levels are too high for any residential land use and guidelines require that the affected properties be converted to industrial or agricultural uses.

Below 85 DNL and above 65 DNL, noise mitigation programs make an effort to improve the quality of life of those inhabitants unable or unwilling to move. These programs include physically quieting a living space through a sound proofing program, implementing noise abatement procedures for aircraft using the airport and offering financial incentives. Direct financial methods, like aviation easements, do not actually reduce

the noise but provide for legal compensation of the affected community. Because of their high cost, the soundproofing programs are found at major airports, while smaller airports mitigate noise using VFR noise abatement flight paths. Most of these noise abatement programs originate locally, but are administered under federal regulations. The Logan Airport noise mitigation program pre-dates the federal regulations covered under FAR part 150, and as a consequence is one of the few noise abatement programs not regulated under FAR part 150. The noise mitigation programs are based on the needs of the local community as identified to the FAA and local airport operators.

Once an area has been designated to receive noise mitigation, other complications arise. Choices of which areas or which buildings to alleviate first often are political motivated. Ideally, the first houses to receive mitigation would be in high DNL contours under any set of flight procedures. Airport operators might not want to focus on a certain area, however, in anticipation of flight procedure changes or other effects that would reduce the noise in that area, thus protecting meager dollars. Once a house has been sound proofed, the airport operator cannot just remove the insulation or recoup his expense, even if flight procedures change and the house is no longer in a designated noise mitigation area. Else, the airport operator will have needlessly paid for abatement before any penalties, legal or political are incurred. Since the operator cannot directly control flight procedures, but must work through the FAA, anticipated procedural changes can be delayed; it may be in the interest of the operator then, to delay offering compensation.

Communities on the other hand, want their compensation quickly and in proportion to their damage. However, they often view the noise mitigation programs as arbitrary. Near the 65 DNL contour, it is possible for one house to be eligible for soundproofing, but the house 10 feet away to be outside the of contour and ineligible for any compensation. Compensation programs vary and take time to reach all affected. Even under ideal regulatory

circumstances, sound mitigation takes time. The DNL contours must be determined in a reproducible manner to have any legal legitimacy. Construction and buyback programs have limited funding each year, and progress only so fast once funded.

The costs of the different noise mitigation programs varies, as does the organization required to pay for the program. Flight path alterations can be accomplished at a minimum expense to the airport unless the measures result in a decrease in the number of operations. Any incidental costs, namely higher fuel consumption when the noise abatement procedure forces a longer approach or landing pattern, are born by the airline or aircraft operator. The cost of any community compensation program varies based on local property values and construction costs. Community compensation can also include other benefits, such as an improved public park, a sports facility or increased funding for schools. Such additional factors are difficult to account for and are considered on a case by case basis. Nationwide, the expense of a soundproofing program averages about $25,000 per residence between the 65 and 75 DNL contours, including administrative costs [Favorito]. These numbers are averages for major metropolitan areas, were presently the greatest community activity is found.

Two distinctly different noise mitigation programs are described below to provide examples of the scope and cost of such programs. One is in a large metropolitan area. The other is at a somewhat smaller major international airport attempting to expand its runway system. Noise mitigation programs were institutionalized nationally by the time the second program began. In spite of the differences at inception, the airports' noise mitigation programs are quite similar.

### **2.4.1** Logan Airport

Located in the heart of Boston Harbor, Logan Airport is one of a very small number of major airports which are inside the cities they serve. This is a double edged sword. On the

positive side, the flow of goods to and from the airport is faster and shorter, saving time and infrastructure. On the negative side, there is significant noise impact on densely populated areas. This increases community response to the noise, resulting in higher noise mitigation costs.

Responding to the increased noise of the expanding air traffic load in the 1970s coupled with new runway configurations and operations, several local communities banded together to complain. After a series of court challenges and community meetings, the operators of Logan airport, largely the city of Boston, began a noise monitoring and mitigation program. Logan has been monitoring the effect of airport noise on the local community since the 1970's using a series of microphones scattered throughout the Boston metropolitan area. As air traffic increased, the beginnings of a noise program were instituted. Houses at the ends of runways were relocated or demolished. Schools were soundproofed. A residential soundproofing program was added, and all houses within the 65 DNL contour became eligible for window and/or door replacement and to have one room designated as a quiet spot.

*Organization of the Program*

The program is directed by the Noise Abatement Office and is divided into two parts: noise monitoring and community soundproofing. The noise monitoring program is responsible for DNL contour determination. Community soundproofing is responsible for community outreach and construction of noise reducing building modifications. The two parts provide the Boston community with local technical expertise as well as local procedures for obtaining noise mitigation.

*Noise Monitoring*

The noise monitoring program is responsible for the technical side of noise mitigation, sound measurement and DNL contour determination. Twenty nine microphones are

located throughout the Boston area to measure noise events from the two airports controlled by MASSPORT, Logan Airport and Hanscom Field. While noise measurement can monitor airplane overflights, other noise sources such as barking dogs and delivery trucks are also detected. This introduces difficulty in measuring DNL contours due to aircraft noise. Screening these sounds out requires a sophisticated system which can identify and verify aircraft noises. Such a noise monitoring system is expensive, and can only be implemented by the largest airports, like Logan.

The noise monitoring group is also responsible for maintaining the noise complaint phone line. Complaints can be investigated using the recorded events. Comparison with radar data from the FAA for the same time period leads to the identification of the type of aircraft and in many cases the carrier and flight number. The noise monitoring program is being expanded to include additional microphones, as well as more sophisticated processing equipment.

*Soundproofing*

The residential soundproofing program at Logan began in 1985. Since then, the Soundproofing program has completed 2,066 houses (comprising 3,809 dwelling units) at a total cost of $60 million through the end of 1996 [Favorito]. The houses completed were single and multi-family dwellings of no more than three units [Favorito]. Future construction will include larger dwellings with upwards of twenty units for an estimated list of 1,266 houses with 3,144 units [Favorito]. The program has a yearly obligation to the city of 400 houses or 760 dwelling units; the projections for 1997 are 365 houses with 806 dwelling units [Favorito]. The average costs are approximately $4000 for the design and an average of $25-29,000 for construction per house, averaging $13-15,000 per dwelling unit [Favorito]. Construction costs have decreased, with present costs at the low end of the

range [Favorito]. The funding has been administered through a grant program, which is presently in Grant V [Favorito].

The community soundproofing project historically depended on federal funds. Historically, 80% of the funding came from the Airport Improvement Program (AIP), with the balance from Massport operating fees, including landing fees. Future funding sources are not yet determined, but are expected to be a mix of AIP and passenger facility fees (PFC) [Favorito].With decreasing federal funding, local funding, in the form of airport taxes as well as general city taxes are expected to make up the shortfall. The programs are bound by federal regulations as well as agreements between the communities and the airport operators. Despite the changes in the federal oversight for noise mitigation programs, Massport is committed to continuing the community soundproofing program at Logan Airport.

### **2.4.2** Seattle- Tacoma International Airport

Sea-Tac is a major international airport located between Seattle and Tacoma in Washington State. Sea-Tac is a major international transportation hub and has several thousand flights per day on its two runways. The Noise Remedy Program at Sea-Tac, initiated in 1975 and updated in 1985, makes use of the FAR Part 150 guidelines.

Unlike the program at Logan, which concentrated on schools, the Sea-Tac program began with private residences. In 1975, the Port of Seattle began a land acquisition program which identified 1008 parcels to be purchased under a Part 150 Plan [NRP12/31 1]. In 1985, the Part 150 Plan was filed, which included the land acquisition as well as a noise abatement program with various noise mitigation measures [NRP12/31 1]. The measures proposed included the purchases of another 361 parcels within the 75 DNL contour, as well as offering sales assistance and insulation to homes between the 65 and 75 DNL contour [NRP12/31 1]. The noise abatement program is funded by airport user fees such as

ticket taxes, profit sharing, landing fees, or space rental [NRP12/31 1]. The land acquisition, sound proofing insulation, and transition assistance programs were paid 80% by the FAA via airline ticket taxes, but the decrease in federal funding has resulted in the burden being paid locally by taxes on homes [NRP12/31 1]. The acquisition part of the program included 1328 homes and 103 vacant lots at a total purchase cost of $119 million [NRP12/31 1].

As of December 31, 1996, $97 million had been spent on insulation and transition assistance [NRP12/31 1]. Of the about 10,000 homes eligible for insulation, 5,113 have been completed at an average cost of $17,000 each [NRP12/31 1]. At that time there were an additional 1,432 homes which had been accepted to the insulation program but were not insulated; an additional 1,139 applications were outstanding, and an estimated 2,300 eligible homes have not yet applied [NRP12/31 1]. The rate of completion of insulation is about 1200 homes per year; 100 new homes are accepted every month; and the current application rate is 50 homes per month [NRP12/31 2]. The Port expects the insulation of all eligible residences to be completed by 2000 [NRP12/31 2]. At the end of 1996, there were 541 homes in the design or construction process [NRP12/31 2]. About 14% of all homes accepted into the program have withdrawn because their owner sold the house, did not want construction work done at their home, thought the proposed insulation was inadequate, hesitated to sign the Aviation Easement, and other reasons [NRP12/31 2]. If all the eligible homes chose to participate, the expected cost of the entire residential insulation program would be $17,000 per house for 10,000 homes with a total cost of $170 million over less than 15 years.

The insulation of public buildings was approved by the FAA in 1994 and work has begun as a pilot project at an expected cost of $3.5 million [NRP12/31 2]. Three building have been completed, two churches costing $500,000 and $350,000, and a condominium

complex costing $1.1 million [NRP12/31 2]. A bid has been accepted for the insulation of a third church at $350,000; the insulation of a convalescent home is in the design stage [NRP12/31 2]. The Part 150 update will discuss the expansion of the pilot project to include all similar public buildings which meet the FAA criteria, with an expected cost greater than $50 million [NRP12/31 2]. The Port is working with the local public school district to begin a program that will insulate the public schools [NRP12/31 2]. Five community college classrooms have already been insulated at a cost of $1.3 million for the five rooms [NRP12/31 2]. The expected total cost of insulating the schools is $45 million with an additional $7.5 million on the community college [NRP12/31 2]. This would result in the Port of Seattle spending more than $100 million on the sound proofing of public buildings alone. With the uncertainty of federal funds, the cost will be born solely by the Port and local taxpayers.

The Transition Assistance and Special Purchase Option program sold 186 homes, with 51 in the appraisal or sales process, from the pool of 351 applications [NRP12/31 2]. Eight homes remain on the waiting list while18 homes were removed from the list for reasons including the sale of the home, the owner changing his mind to sell, and the appraised value of the home in dispute [NRP12/31 2].

The Sea-Tac program was able to take advantage of federal money available in the late 1980's for Part 150 noise abatement programs. However, with the cut backs in federal funds, future plans are not as certain.

## 2.5 International Programs

Aircraft noise is not limited to the United States. In regions of high population density such as Europe and Japan, the air transport industry did not develop as rapidly during the 1980's and is now experiencing explosive growth. The social question of noise has been

encountered by many of these countries regarding rail and highway transportation. Underdeveloped countries are more likely to see aircraft noise as part of the price for progress. Other countries are taking steps to avoid the sudden noise impact of aircraft on their populations.

### **2.5.1** New Zealand

In 1992, New Zealand joined the group of nations that have a comprehensive noise management standard. Such a standard outlines what priorities the nation or region will consider when mitigating aircraft noise. Mr. Philip Dickinson was part of the standard setting effort and outlined some of the challenges facing potential standard setting bodies. Disturbances by persons in control of aircraft are not new in New Zealand, the earliest authenticated aircraft noise complaint was lodged in New Zealand in 1903 against a Mr. Richard Pearse for disturbing the peace [Dickinson, 113]. In contrast to the United States, noise control in New Zealand is in the hands of the local authorities, who have the authority to decide how to regulate and enforce nationally mandated sound exposures [Dickinson, 116]. In attempting to further understand the technical aspect of noise, the dB system was replace by pascal-squared-seconds [Dickinson, 114]. Pascal-squared-seconds or "pasques" are arithmetic, unlike the logarithmic dB system. In New Zealand, as in the United States, the legal challenge facing such regulations is one of the final and most onerous hurdles faced by such far reaching regulations [Dickinson, 117].

**Table 2.1: A listing of noise monitoring, soundproofing and direct compensation of selected worldwide noise abatement programs**

| Location | Monitoring | Soundproofing | Compensation |
|---|---|---|---|
| ENGLAND | Noise mitigation programs are in place at Heathrow, Gatwick, and Manchester. Monitoring is very sporadic. | Limited soundproofing in place at these airports. The promised operational restrictions were not realized. | No direct compensation outside of mitigation methods. |
| NETHERLANDS | At the airport in Amsterdam, a noise monitoring system is in place. | Yes, but again, lagging the increased noise. | No direct compensation outside of mitigation methods. |
| RAMSTEIN, GERMANY | At the US Airforce base in Germany, noise mitigation procedures are in effect which restrict evening and night operations. | No | Included in the total community compensation package from the airforce |

### 2.5.2 Other Countries

Noise mitigation programs the world over face similar hurdles. How much compensation can be offered to the individuals suffering from the increased noise from the airports without excessively raising the price of air transport? The answer lies in balancing local interest with national concerns. Past a legal noise threshold, 65 DNL, the airport operator is required to compensate the property owners because such noise constitutes a legal taking. Because this line is not drawn on the streets, it changes on a daily basis. Many airport operators have set up community outreach programs to act as a buffer between the airport and the community. The aim of these programs is to hear community complaints and, if appropriate, acted upon them through mitigation programs. Mitigation programs vary

from a incentive programs to outright takings, with most using a combination of methods. Several programs are compared in Table 2.1. Smaller airports are better able to accommodate the concerns of neighboring citizens because the transportation structure of an entire region does not depend on their operation. The economic considerations of a major airport must be balanced against the value of quiet to the neighboring communities. Ideally airports would be surrounded by industrial and commercial structures which would not be disturbed by the noise. Such community planning may develop as airports, and spaceports in the future, continue to grow both in size and importance.

# Chapter 3

# Noise and People

## 3.1 Sound and Noise

As music sales attest, not every sound provokes the same level of outrage as jackhammers and low-flying airplanes. Volume and frequency content is the difference between music and aircraft noise. Volume is a measure of sound pressure, but the wide range of frequencies also factor into how the sound is perceived. Sound measurement can be divided into two separate categories. The first is what the sound actually is, the second is how the sound is perceived. For the comparison of the different types of environmental noise, a single metric is necessary. Noise metrics attempt to take both factors into account when arriving at a single numeric indicator.

Noise of all forms is difficult to block as it penetrates well through solid objects. The best methods for reducing the impact of noise is to put the noise source far away from the sensitive population. This has been the goal of national and international noise abatement programs that incorporate noise abatement flight procedures. There are many ways of testing whether the noise has decreased after a new flight procedure is implemented. One way is to ask residents in the affected areas to evaluate noise levels after a new or modified flight procedure becomes effective. Although this technique allows one to determine whether a flight procedure change actually provides relief from the noise, it is slow. A faster way is to model the changes in the noise impact and to represent these different noise impacts in a form in which communities and airport planners could make decisions about acceptable levels of noise impact and to identify areas requiring additional noise mitigation or flight modification.

## 3.2 Description of Sound

### **3.2.1** Physical Characteristic

There are different ways of measuring sounds in the environment. Sound is a compression wave having both amplitude (or pressure) and frequency. Sound is normally measured logarithmically in decibels (dB), where each decibel corresponds to a certain pressure above a reference pressure. A 10 dB increase in volume is perceived as a doubling of the sound by the human ear, while a change of 3 dB is generally undetectable outside of laboratory conditions. Sound is subject to a number of identifying characteristics.

### **3.2.2** Sound in Everyday Life

The human ear can only withstand a biologically determined sound pressure before experiencing irreversible damage. Noises in everyday life range from 30 dB for a quiet space to 120 dB a few yards from a jet aircraft during take off, as depicted in Figure 3.1. Hearing damage generally begins at constant exposure to a noise level above 80 dB. Even at lower sound pressures, there are physical and psychological effects. When exposed to loud intermittent sounds even below that threshold, persons exhibit a measurable inability to concentrate on other tasks. The following metrics apply to all forms of sound, and have been used to analyze road noise, factory noise, rail noise, and rock concerts, as well as aircraft noise.

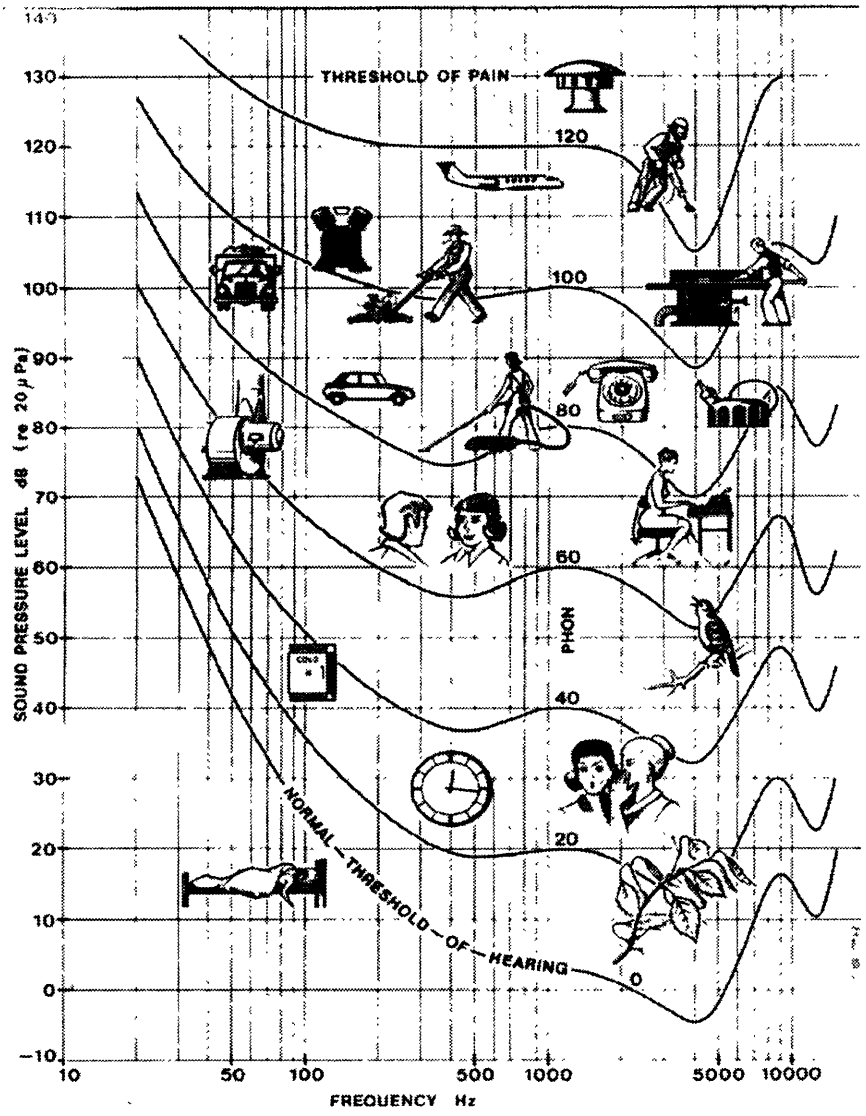


**Figure 3.1:** Typical sound pressure levels in dB and phons of common noise sources (Foreman 23).

### **3.2.3** Ways of Describing Noise Events

*Maximum Sound Pressure Level, Lmax*

As shown in Figure 3.2, Lmax is the maximum sound pressure level which is measured for a discrete noise. Lmax is a good measure for sudden sounds which can cause traumatic hearing damage, such as firearms and firecrackers.

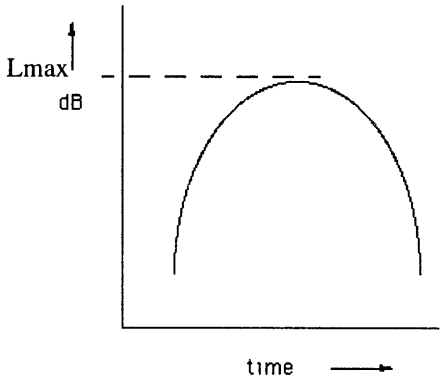


**Figure 3.2:** For a discrete noise event, Lmax is a measure of the maximum dB level of the sound.

*Time Above Threshold*

Time above threshold is the time over a pre-determined sound pressure level as shown in Figure 3.3. Such a measure is useful for determining the total impact of the sound. A common use of threshold measurement is for OSHA and EPA guidelines to prevent hearing damage due to exposure to high noise levels.

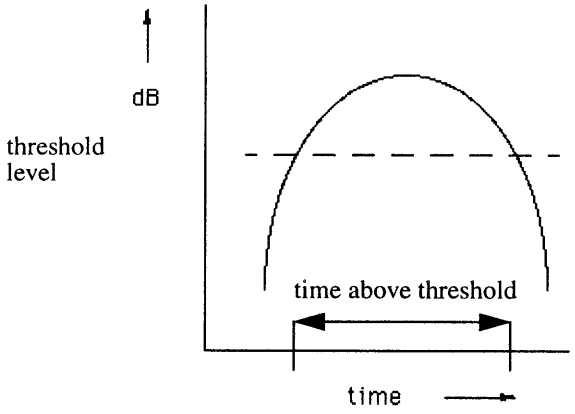


**Figure 3.3:** For a discrete noise event, the time above a certain threshold dB level can be used to gauge the noise event.

*Sound Exposure Level, SEL*

While Lmax and time above threshold are good measures of short, intermittent sound that can cause damage, they do not provide a means to compare the sounds to an equivalent prolonged sound. The SEL is the average sound pressure level of the sound averaged over the length of the sound. As shown in Figure 3.4, the SEL is an equivalent sound level to describe the sound.

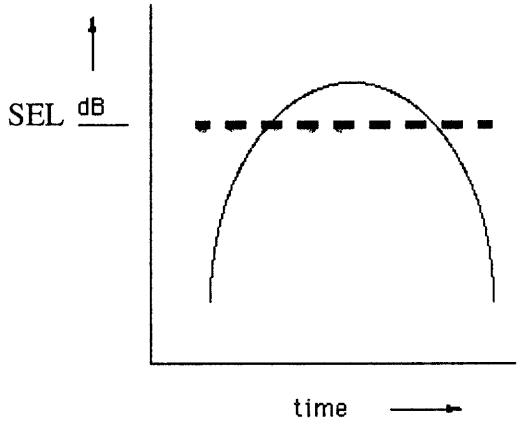


**Figure 3.4:** For a discrete noise event, the SEL is the equivalent average sound energy for the period of the sound.

*Day weighted, Leq*

SEL only measures the equivalent sound level of a single discrete sound. If the sound is repetitive, a comparison comprising many repetitions is necessary. For comparison, an average sound energy over a set period such as an hour or a day called the equivalent sound level, or Leq is used. Leq is an average of the repetitive sound over a set period as depicted in Figure 3.5

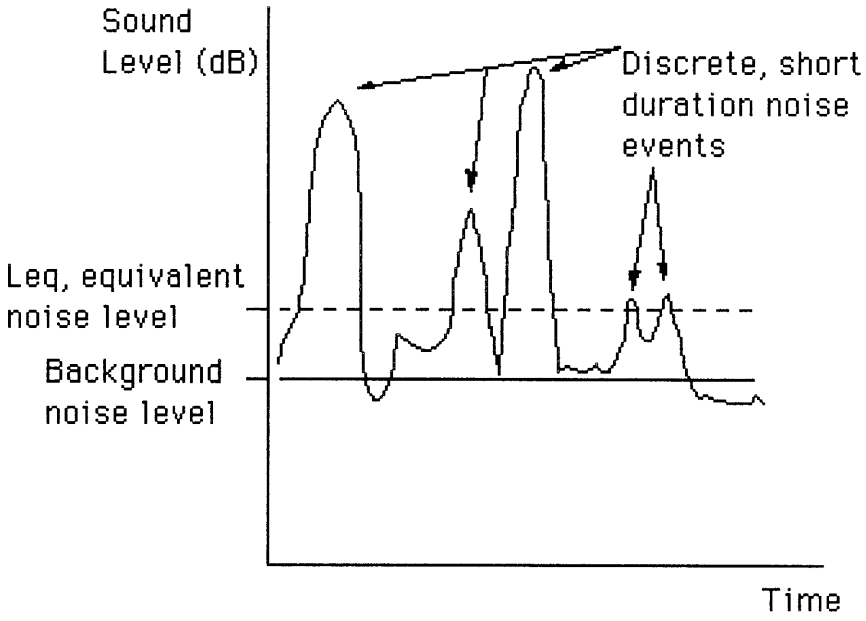


**Figure 3.5:** The equilibrium sound level, Leq, is an average sound level for discrete events that occur over a set period of time, typically over an hour or over a day.

*Day-night weighted, DNL*

DNL is also an equivalent sound level, except it imposes a night time penalty for sounds occurring during a set period of time. This is used to provide a larger weighting to aircraft operations that occur at might. Night is defined as 11pm to 7 am, and the penalty is 10 dB for EPA and FAA defined DNL. The EPA has determined that DNL is an appropriate measure for the noise impact of time variant as well steady noise events.

## 3.3 Human Perception of Noise

Sounds come in many different forms. There are pure tones, steady sounds, variable sounds. When measuring sound exposure, all these sounds must be summed in some meaningful way. Some sounds are hidden behind louder sounds, or masked. Some sounds

do not appear as loud as the sound pressure level might suggest. In short, sound indices also consider factors associated with the physical ability of the human ear to hear.

### 3.3.1 Perception of Noise

Some sounds can only be heard at certain times. At other times a competing sound will overwhelm, or mask the original sound. Masking of a sound occurs when a competing sound has a large amount of energy in the same bandwidth as the original sound [May 9]. A pure tone can be masked by a sound with a frequency within a critical bandwidth of the pure tone, based on the frequency of the tone. If the bandwidth is any wider, the tone again distinguished itself [May 9]. For a tone of 1000 Hz, the critical bandwidth is approximately 160 Hz. During the day in an urban setting, most sounds 55 dB or less are masked by other background sounds and do not contribute to the overall noise level.

In his book about sound and noise, May defines four important subjective responses to sound: loudness, noisiness, annoyance, and speech interference [May 5].

- Loudness is a measure of sound pressure level or volume.
- Noisiness measures the degree of inexorability of the sound when considered in isolation. This measure is independent of background, mindset of the listener or any other external factors [May 5]. The response to a recording of a passing streetcar measured in the laboratory would result in a measurement of noisiness.
- Annoyance considers the undesirability of the sound in an appropriate situation [May 5]. Annoyance considers the noisiness of the sound as well as other factors such as the duration, repetition and emotional content of the sound. For example, the response to streetcar noise as heard in an apartment adjacent to a busy street can be measured to obtain a measure of annoyance.

- Speech interference is important for determining at least one factor of how noise interferes with the ability of people to get on with their daily lives. Speech interference measures "whether or not a sound will interfere with one's speech perception" [May 6].

Sounds and environments can be evaluated by an index that measures speech comprehension under any noise conditions. An articulation index (AI) can be calculated using the 1/3 octave ban center frequency (Hz) and the sound pressure level (dB) [May 34]. Using curves constructed from the relative importance of different frequencies in speech intelligibility, the AI gives a measure of the effectiveness of verbal communication under such noise circumstances [May 35].

Loudness will accurately measure sound, but ignores the physiological bias of the human body for response to different frequencies. Noisiness, annoyance, and speech interference take into account how the sound is perceived. For a bureaucratically useful metric, these four effects must be combined into a single metric. To be useful in public policy, the metric must be based upon an objective and yet simple to determine measure. This criterion eliminates noisiness or annoyance. Speech interference is also a subjective measure, for the AI is different for native speakers and those just learning a language.

**3.3.2** The limits of the human ear

The human ear detects loudness as a combination of sound pressure and frequency. A good estimation of the sensitivity of the ear is that a change of 3 dB cannot be detected, and an increase of 10 dB is perceived as a doubling of the loudness. The human ear can perceive sound between 20 -20,000 Hz.Attempts to combine the sound pressure and frequency into a loudness measure for pure tones which mirrors the perception of the inner ear has resulted in a phon and sone scale [May 7].

### 3.3.3 Scales to accommodate human performance

At equal volume, the inner ear does not respond to all frequencies equally. The physical construction of the ear determines the response of the ear to different frequencies. To model this effect better, several different filters have been defined for different frequency and volume ranges. Figure 3.1 shows the response of the human ear to different common sounds. The phon contour mimics the loudness at which the human ear hears different frequencies. At 1000 Hz, the phon level is exactly the same as the sound pressure level. At other frequencies, a different sound pressure level is required to produce the same perceived volume. Mid and high pitch sounds are more annoying than low pitch tones.

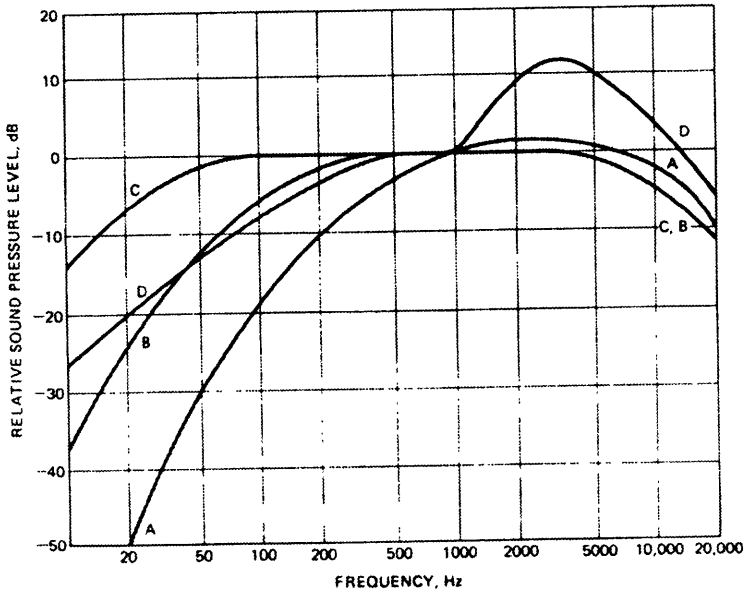


**Figure 3.6:** Graphical representation of the dBA, dBB and dBC weightings. [May 13]

Sound pressure levels of different weightings were created based on center frequency and bandwidth to allow for a single metric to represent broadband noise levels as heard by the human ear. Three response curves called A-weighting (dB(A) or dBA), B-weighting (dBB) and C-weighting (dBC) have been constructed for modeling the response of the

human ear to different sound levels. A-weighting applies a frequency dependent correction factor as shown in Figure 3.6 to mimic the relative sensitivities of the human ear for quiet sounds of about 40 phons. Experimental usage has shown that the dB(A) curve is applicable over all loudness regimes [May 13], so most countries us the dB(A) scale for aircraft noise. B-weighted is a similar scale for sounds at about70 phons, but is no longer used. C-weighting is for loud sounds of about 100 phons [May 12]. The dBC scale most nearly reflects the sound pressure level since it is a very flat weighting, and is still used in some cases to monitor aircraft noise, as shown in Figure 3.7

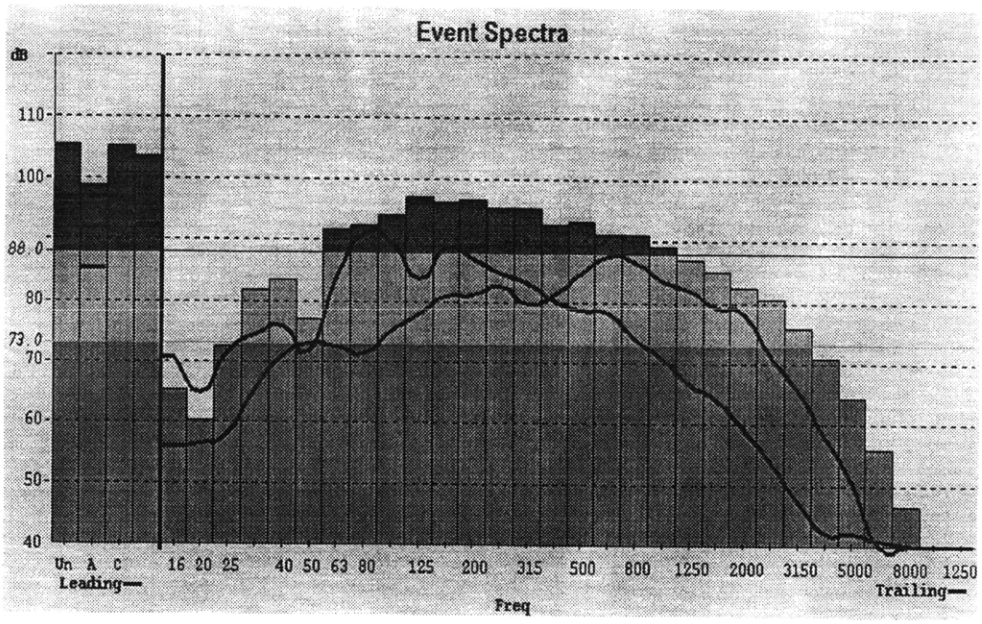


**Figure 3.7:** The noise spectrum of the measured noise from an aircraft overflight in a community neighboring an airport.with comparison of the dB(A) and dB(C) scales [MASSPORT Noise Monitoring System]

### 3.3.4 Physiological effects of noise

The environmental noise level is not just an annoyance. Exposure to loud noises causes a loss of hearing in individuals at levels as low as 80 dB. There are other dangers from environmental noise than just a deterioration of hearing, the most common effect. Constant exposure at lower levels can also have affects on other organs and bodily functions. The next most common is disturbed sleep. Older people are more affected by noise during sleep that younger people. Loud noises and sudden noises are more disturbing than background noise. Sudden and unpredictable noises during the day affect concentration and aggravate stress responses like increasing blood pressure. There are many factors that vary from person to person affecting the annoyance characteristic of noise.

## 3.4 Aircraft Sound

Aircraft noise, a form of traffic noise, co-exists with all the other sounds of daily life. The noise is continually emitted by the aircraft, but is perceived differently on the ground. The relative loudness of these sources depends on the aircraft operation, size, weight, and age. Aircraft can be divided into noise classes or stages based on the loudness of the noise. The sound profile of an aircraft to an observer along the flight path is similar to that of a passing car or train, as it has a haystack shaped profile as shown in Figure 3.8. This noise can be measured directly or simulated using computer modeling. This, however, only provides a measure of noisiness or the laboratory measure of noise. Complaint surveys and noise complaint hotline remain the primary methods used today to determine the level of annoyance, or community aggravation.

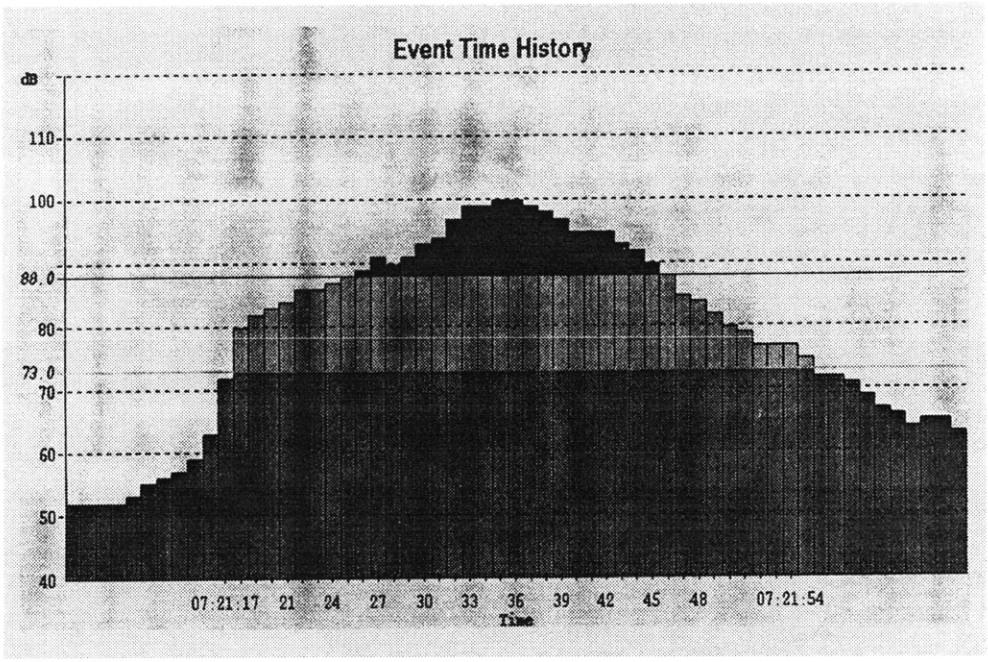


**Figure 3.8:** The haystack shaped profile of an aircraft overflight that might be measured in a residential neighborhood close to an airport. [MASSPORT Noise Monitoring System]

The source of aircraft noise can be attributed to either of two sources, engines or airframe. Engine noise is caused by high velocity, high vorticity flow impacting on stationary and rotating engine components and mixing with the slower moving airstream resulting in discontinuous velocity profiles, or mixing noise. The introduction of higher bypass ratio engines allows for significant mixing and slowing of this high velocity flow to occur within the engine casing, reducing the emitted noise substantially. Yet, the highest demands on aircraft engines are at take off and landing, resulting in the unfortunate coincidence that aircraft are noisiest when the aircraft is closest to the ground. Engine noise dominates during take off. Airframe noise is caused by the disturbance of the air as the aircraft moves through it. The air disturbance depends on the weight and shape of the aircraft, and increases in high lift configurations, such as the full flap landing configuration.

The disturbance is further enlarged by the vibration of older airframes during acceleration or deceleration. Thus, airframe noise is loudest on approach, and is comparable to or louder than engine noise on landing for modern high bypass ratio engines. Many noise calculations expected the engine noise to dominate, and so maximum noise calculation schemes are based on that assumption. In an attempt to provide guidance for airports trying to lower their noise impact, the FAA introduced a categorization scheme which classifies the aircraft into stages based primarily their size, weight, and number of engines.

Civilian jet aircraft are categorized into one of three noise classifications, or stages. The stages are defined as a combination of airframe and engine. Within a class of aircraft, Stage 1 aircraft are the loudest, and Stage 3 the quietest. The stages are determined by factors such as gross weight, take-off weight, and number of engines. Military aircraft are not required to meet any noise criteria unless specified in the individual design contract. Stage 1 aircraft have been banned from most civilian airports in the United States, with Stage 2 aircraft normally limited to day-time operations. A sample of different aircraft and their stage classification can be found in Table 3.1. Notice than some airframes can be in multiple stages, depending on age and engine type. In general, newer aircraft and engines are quieter than older ones. Since the certification process also allows heavier aircraft to be louder, Stage 3 aircraft are not always quieter than Stage 2 aircraft. Safety concerns always predominate in air traffic control, resulting in occasional Stage 2 night landings and Stage 1 landings at restrictive airports. For example, the Concorde, a Stage 1 aircraft, makes an occasional emergency landing at Logan Airport.

**Table 3.1: Airframe types listed in their applicable aircraft stages. Some airframes are listed in more than one stage due to improvements of some models to provide for quieter operation. [OAG Guide]**

| Stage 1 | Stage 2 | Stage 3 |
|---|---|---|
| Concorde | 747 | 747 |
| 737 | 737 | MD80 |
| 727 | 727 | Airbus |
| | Airbus | |

*Duration*

The noise profile of an aircraft has a haystack shape with a doppler shift. For an aircraft two miles from the airport, the time above 75 dB threshold is about thirty seconds. The interval between events is two to ten minutes for an active runway. In the daytime, a normal noticeable duration is about 30 seconds for an aircraft within 5 miles of the airport. Figure 3.8 shows a typical time profile at a single point of an overflight in a residential area of Boston. For sites closer to an airport, aircraft warm up and taxi noise is also heard and can significantly increase the noise impact.

*Distribution*

Aircraft noise is a by-product of aircraft operation. The frequency and spacing of the aircraft noise events depends on the location of the observation site, as well as the operational schedule of the airport. The noise is distributed over a wide band centering on the aircraft flight path. As discussed in Chapter Two, a commercial airport can have multiple runway configurations. The minimum is a single runway which is used for arrivals and departures. More common is a dual runway system. The operating runway depends on

wind direction. The location of the flight path to and from the runway depends on the safest approach for the desired number of aircraft as they arrive from various locations. Beyond the physical limitations of the aircraft, weather is the main safety concern for flight path determination. The flight path of the aircraft determines the location of the noise impact.

Noise contours for an airport are typically averaged over an entire year of operation. The contours are determined by the type of aircraft and the number events on a particular runway each year. Results, reported as DNL contours, are used in the United States and many European countries. These contours can then be used to determine regions requiring noise mitigation action. Figure 3.9 shows a sample noise contour map for an imaginary busy international airport.

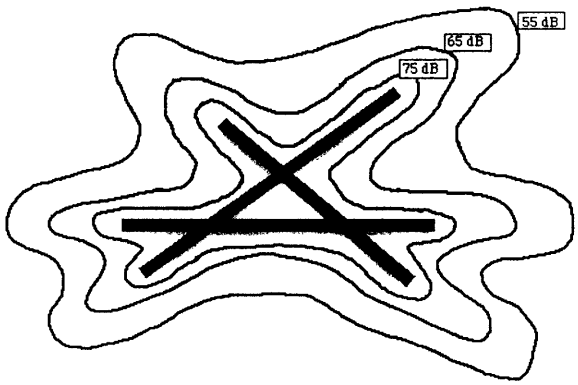


**Figure 3.9:** A typical noise contour for an entire airport

The other variations ignored in traditional estimation methods are atmospheric and surface effects. The noise heard by an observer on the ground is more important than the actual noise emitted from the aircraft. Atmospheric conditions can make a 10 dB difference in the transmitted sound. Surface conditions will also affect the distance traveled by the noise. Sound can be absorbed by uneven or soft surfaces such as forests, whereas it

travels great distances over flat surfaces like the open ocean. All of these factors change the sound before the issue of other background noise is even considered.

Airports determine noise impact around the airfield using computer simulation programs and direct measurement. At the present time and for some time into the foreseeable future, the best prediction of noise at sites near an airport will be computer simulated. The FAA has accepted that such a simulation is an acceptable way of estimating the noise impact. Direct measurements have further strengthened computer models by providing a means of calibration. However, legal compensation is based on the actual noise at the site, not a controlled laboratory set up or a computer model. While it is possible to measure the sound at sites near an airport, there are still problems with using direct measurements. One problem is separating background noise from the aircraft noise. Other problems exist even if the background noise could be completely filtered out. Looten reported difficulties with measurements at Geneva airport. At this time, the most widely accepted noise "measurements" come from computer models. For small and medium airports, the calculated noise level will continue to be the primary source of noise data, while larger airports, as is the case with Logan, might complement the computer model with direct measurements.

A. Looten conducted several tests at Geneva airport to determine what possible inaccuracies would hamper noise measurement at airports. Four important effects were identified as possibly leading to problems with the measured numbers [Looten, 125]. First, microphone height and, second, the nearby ground surface must be carefully controlled to place the microphone in free field. Third, grazing incidence changes the measurements by 3-5 dB for the frequency spectrum emitted by aircraft engines [Looten, 128]. Fourth, a mismatch between response time and calculation interval leads to mismatched results. For example, combining a slow response to a short Leq calculation can make a difference of 1-2 dB [Looten, 128-129]. In general, the data that can be collected is quite accurate, how-

ever, the prevalence of inappropriate averaging of noise data over long periods of time, and the insufficiency of measurement leads to small inaccuracies [Looten, 130]. These small inaccuracies can make a difference in the lives of people close to boundaries because the social policies are determined around these numbers [Looten, 130]. The important policy issue is not just the loudness of the noise, but how it is perceived. Further studies continue to reevaluate the appropriateness of the noise metrics for evaluating the noise impact on residential communities.

The effect of airport noise depends on many factors. An important factor is the level of noise caused by airport operations. A more important factor is how that noise is perceived. High noise levels over abandoned industrial areas or major highways cause little community upset. When aircraft are routed over previously quiet residential areas, the reaction changes. Not only are the neighboring inhabitants bothered by the noise, but their property values decline as the noise level increases. This decline happens well before the US legal limit, where the airport must mitigate the sound for the homeowner. To compensate for this, some areas of the country are requiring disclosure statements with home sales in areas with noise exposures down to 55 DNL. While this is being challenged in court, such regulations are clearly in the future. The characteristic of the noise is also important. One loud 30 second jet overflight may not equate to a quieter helicopter circling overhead for the better part of an hour. Additionally, the perception of annoyance may change among individuals.

Ranging in size from the small corporate jet to a jumbo 747, the jet aircraft is considered the primary cause of noise at commercial airports. As a consequence, most noise studies focus on the noise from jet aircraft. The Air Force, which operates a wider variety of jets than most commercial carriers, has commissioned numerous studies to review the appropriateness of the noise metrics in use, particularly the modeled DNL. To measure the

environmental impact, they look at DNL and created a logistic curve that translates the modeled DNL into a percentage of the population that is highly annoyed [Finegold Community Annoyance 26]. The analysis is based on the Schultz curve which shows that aircraft noise is comparable to general transportation noise, and uses a quadratic fit to establish the shape of the population annoyance curve to 400 social survey data points [Finegold Community Annoyance 25-27]. The night time penalty of 10 dB appears to only be robust for a small number of operations, and the study concluded that there was not enough information for extrapolating to many noise events (small or many not defined in paper) [Finegold Community Annoyance 29]. For a scenario with a large number of daytime operations and only a few night operations, DNL has been determined to be representative measure of community annoyance [Finegold Community Annoyance 25].

Aircraft noise perception depends on factor such as weather, background noise, time of day and location of the listener. Stormy weather limits aircraft operations and provides a higher background noise level, potentially masking aircraft noise. Other background noise sources, such as factories and automobiles can mask aircraft noise. These noise sources tend to decrease at night, which is also the time of greatest sensitivity. Noise at night interferes with sleep, a function which requires a low constant noise level. For indoor measurements, the sound experiences an attenuation of 10-30 dB. The amount of attenuation depends on the condition of the structure. In general, older houses mitigate the sound less due to loose windows and doors, and lower insulation levels. Additionally, reported complaints are higher in the summer than in the winter for temperate climates since windows are likely to be open.

### 3.4.1 Relevant Federal Guidelines

A typical airplane overflight near an airport renders outdoor conversation unintelligible for the duration of the overflight. Even factoring in damping from being inside a building, the level of communication possible during an overflight is only marginal for the thousands of persons in the United States who live near airports. The EPA considers an Leq of 65 dB (A) for outdoors, and an Leq of 45 dB(A) for indoors acceptable for speech [May 37].

HUD and the EPA have both set guidelines for the maximum noise exposure applicable for different activities. Schools, hospitals, and elder care are considered sensitive locations where excessive noise interferes with their operations. Residential noise levels, while higher, are expected to be low enough to allow sleep and other daily activities. Industrial noise exposure is usually the highest. Because of noise characteristics like masking, industrial areas are ideal for airplane flyovers. The use of green areas for airport flyovers is more controversial, although it might reduce the noise impact on residences. The purpose of green areas in an urban setting is to allow city dwellers a little bit of country. Since aircraft noise is more noticeable when one is outdoors, excessive aircraft noise can diminish the value of the green space.

The decision to expose large numbers of people to undesirable levels of noise is similar to other forms of pollution and is not limited to aircraft noise. The EPA and the FAA recognize levels above which the cost of the noise exposure is too high to continue a normal existence. Factory noise is covered by a number of regulating bodies, including the Occupational Safety and Health Administration and the EPA. Factory noise is usually contained to those who work at the factory or live very nearby. Aircraft noise is unique in that it has a broad impact; a single aircraft can disturb thousands of people, even some many miles away. Aircraft noise affects not just the individual or small locus of persons, but

entire communities. For example, in Boston, the 45 DNL contour includes hundreds of thousands of people.

## 3.5 Community Perception of Aircraft Noise

Aircraft noise is a 30 second noise event followed by a minute or two of normal background noise. The noise modeling for the purposes of government policy, averages that sound over an entire 24 hour day spread out over a 365 day year. But this is not how people perceive the aircraft noise. There is debate among experts on what type of noise disturbs people more, frequent load events or several isolated, very loud events. What is certain is that the effect of aircraft noise on a community is an increased number of complaints and a lowering of housing values. Additional studies have attempted to identify specific community groups that are more active in noise mitigation efforts.

### **3.5.1** Complaints

Since aircraft noise affects the general populace, public policy makers must assumed that all people have the same perception of aircraft noise for the purpose of constructing a usable metric. However, the issue will receive more attention as the level of community activism increases. Thus, the level of compensation and mitigation is linked to the level of community activism for instituting such options. Still an airport operator might expect certain people to complain more readily. Several studies have attempted to identify correlations between various indicators and noise complaints.

Noise level is clearly a factor in the level of complaints that can be expected, making a noise metric an important metric. The EPA has made estimates of the type of community response that can be expected for a given DNL level. [EPA 550/9-74-004 May 31]. Figure 3.10 shows the EPA's estimation of how the propensity to complain rises with increasing DNL. There are corrections which are used to take into account season, land

use, community attitudes, and type of noise [May 30]. When compared to complaints from areas with aircraft noise levels of this magnitude, the correlation is good. For example, at environmental noise levels greater than 60 DNL, a noise making entity can expect a significant number of complaints.

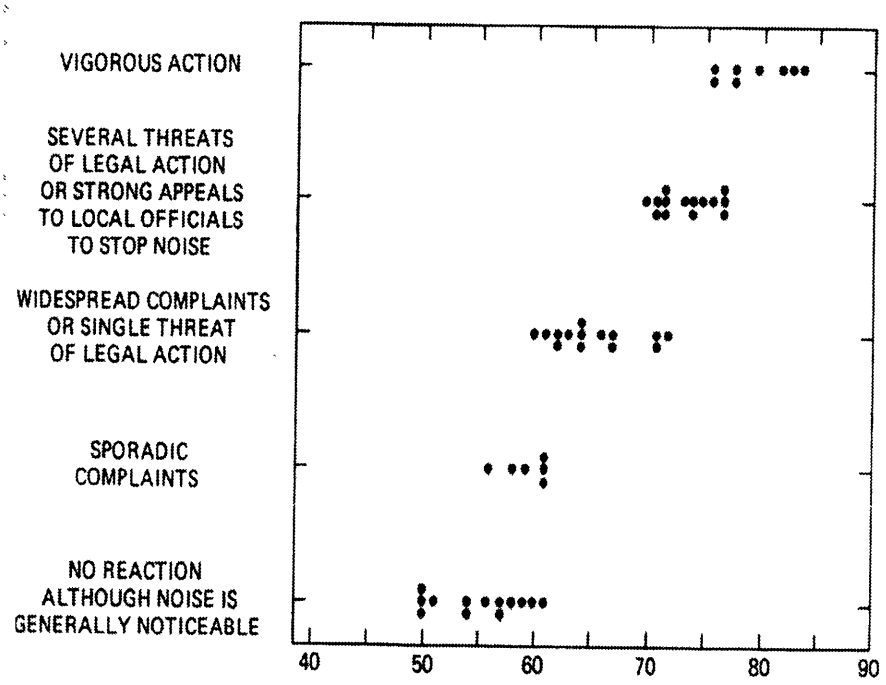


**Figure 3.10:** EPA estimated correlation between percentage of complaintants and DNL. [EPA 550/9-74-004 May 31].

Gillen and Levesque analyzed the complaint record from the Pearson International Airport, Canada, from 1987 through the first ten months of 1989. The purpose of the study was to demonstrate a correlation between socio-economic indicators and the propensity to lodge a complaint. If such a correlation could be found, the study would test if the correlation could predict the time and nature of complaints, including information on the complainants address. The total number of complaints were as follows: 1992 complaints in 1987; 3285 complaints in 1988; and 2456 complaints for the beginning of 1989 [Gillen Airport Noise Complaints 49]. A yearly average of 79% of the complaints were distrib-

uted among the 1816 census units of the study [Gillen Airport Noise Complaints 49]. Census data from the 1986 Census was used to estimate the socio-economic distribution and life-style of the census units [Gillen Airport Noise Complaints 51]. Gillen and Levesque hypothesized that the level of complaints from a community would depend on the noise level, but also on a number of socio-economic factors [Gillen Airport Noise Complaints 49]. The measure of cumulative noise used in Canada is the Noise Exposure Forecast (NEF). NEF measures cumulative noise and is about 10 to 15 units lower than the equivalent DNL. The range of NEF values in the study area was from zero to approximately 50 [Gillen Airport Noise Complaints 50]. Other factors which contributed to the propensity of complaints to originate from a neighborhood which were considered included the age of average houses in the Census units, whether tenancy or homeownership predominated, resident turnover rate, and average income of neighborhood residents [Gillen Airport Noise Complaints 51]. The inputs into the analysis are summarized in Table 3.2.

**Table 3.2: Summary Statistics for Independent Variables [Gillen Airport Noise Complaints 52]**

| Variable | Mean | Standard Deviation | Maximum |
|---|---|---|---|
| Complaints per day (1987) | 0.7712 | 7.4296 | 235 |
| Complaints per night (1987) | 0.20091 | 1.13145 | 28 |
| Complaints per day (1988) | 0.99089 | 6.1588 | 170 |
| Complaints per night (1988) | 0.42288 | 1.7907 | 31 |
| Complaints per day (1989) | 0.78315 | 4.1007 | 92 |
| Complaints per night (1989) | 0.26636 | 1.2412 | 20 |
| Noise Exposure Forecast | 20.656 | 6.5386 | 50.092 |
| Day time arrivals | 2747 | 11856 | 64458 |
| Night arrivals | 199.86 | 858.95 | 4497 |
| Day departures | 9641.3 | 17454 | 87486 |
| Night departures | 2338.5 | 3125.1 | 7497 |
| Average house age | 20.813 | 12.365 | 56 |
| Standard deviation of house age | 1.14548 | 1.0358 | 14.459 |
| Population | 798.67 | 398.44 | 2060 |
| Tenancy | 0.41157 | 0.37963 | 1 |
| Average income | 41358 | 18204 | 230310 |
| Education | 0.53471 | 0.16314 | 0.973 |
| Mobility | 0.48951 | 0.24155 | 1 |

The study found the expected correlation between all of the factors except frequency, shown in Table 3.2. The method for estimating the frequency was based on the assumption that homes within a 60 degree arc, centered on the runway heading was assigned to the departure noise from that runway with no consideration for left or right turns [Gillen Airport Noise Complaints 50-51]. The study found that above a certain threshold, the increasing frequency of the aircraft events made little difference on the propensity of complaints to issue from a particular neighborhood, but the result might simply measure the location

and be a function of the NEF rather that actually showing frequency [Gillen Airport Noise Complaints 52].

The Gillen and Levesque study provides a quantitative validation for assumptions made about complaint patterns. The correlation of the noise level, the population, and the age of houses, assuming that renovation is not a common trend in the communities around the airport, to the number of complaints is well observed. However, the link to income and education is less sufficiently proven by correlation of complaints to a complaint line. Persons with higher incomes may be more likely to exercise other political avenues of expression, but might also be more aware of an airport complaint line. They are also more likely to be able to physically relocate if the noise is causing them undo duress, and be more likely to own their own home. A valuable result of the study is the discussion of how local political activism reflects the physical condition of the neighborhood as well as the demographics.

This study illustrates how non-noise factors have a significant effect on the community response. The policy questions which must be answered by each country and locality is to what extent should the airport authority takes responsibility for non-noise factors. For example, should the airport authority be responsible for upgrading all houses to the same noise standard, or just apply the same level of insulation to all houses, even though they will not all end up with the same indoor noise level. The primary result is that the actual noise and population are the main factors in complaint level. These are the primary factors taken into account by airport planning committees when planning compensation and mitigation programs.

### 3.5.2 Change in characteristics of the community, as defined by housing values

Aircraft noise is a characteristic of a neighborhood, like schools, roads, and the community swimming pool. A part of a home market value is determined by its location. A house in New York City has a different market value that an identical house in rural Florida. Similarly, a house near a mal-odorous chemical plant, or a high traffic superhighway will compare unfavorably to a house away from sound and odor sources. As might be expected, property owners near an airport or under the low altitude portions of a flight path generally suffer a decrease in housing value. Numerous studies of the affect of airport noise on housing prices in England and Canada were done in the 1980's and early 1990's. This study found that the propensity to complain correlates well with a decrease in the desirability of the residential location.

Alan Collins and Alec Evans studied the affect of aircraft noise on residential property values. They applied an artificial neural network for data processing and applied this method to from a previous study of residential property values around Manchester International Airport in England [Collins Residential Property 175]. They used the Noise Exposure Forecast for the aircraft noise index [Collins Residential Property 177]. They also found a statistically significant negative effect between aircraft overflight noise and the value of residential property.

Terrence Levesque performed a hedonic price analysis of the residential housing market around the Winnipeg International Airport, Canada, using the number of noise events over a predetermined threshold [Levesque Modeling the Effects 199]. The noise measure, Effective Perceived Noise Level or EPNL, measures the loudness as a function of sound pressure, duration, and the presence of pure tones [Levesque Modeling the Effects 200]. The study did enclose the entire 25 NEF contour [Levesque Modeling the Effects 203] which correlates to approximately 40 DNL. The study shows that adverse effects from

noise can be measured well below the 65 DNL threshold for legal compensation used in the United States.

The study used the market sales of houses from January 1985 to December 1986 [Levesque Modeling the Effects 203]. Single-detached housing comprised 99% of the sales, while only 59% to 76% of the housing in Winnipeg is single detached housing [Levesque Modeling the Effects 203]. The homes for sale were not representative by type of housing found, but were representative of the home typically for sale [Levesque Modeling the Effects 203]. The study found a decrease in market value at noise levels far lower than any legal limit requiring mitigation, American or Canadian.

Dean Uyeno, Stanley Hamilton, and Andrew Biggs expanded their analysis of the affect of aircraft noise to include multi-unit residential condominiums and vacant land surveyed during the period of 1987-88 [Uyeno Density of Residential Land Use 3]. They report similar decreases in property value as the noise impact rises. This shows that even transient populations who are less likely to be familiar with the aircraft flight paths and property consisting of unoccupied land, consider aircraft noise as a significant negative cost factor.

The measurement of noise and the effect of noise on people and communities is an important part of any noise monitoring and mitigation system. Despite the physical limitations of noise monitoring equipment good approximation methods can be devised which use extrapolated data to model the aircraft noise impact over a large region. Loud sudden noises upset children's and adults' ability to concentrate on anything but the most routine tasks. At higher noise intensity levels, permanent hearing damage can result. The federal government has decided that the areas impacted with noise levels above 65 DNL are unfit for residential usage. However, adverse effects as demonstrated by a drop in property values, can be present at lower noise impact levels. Since the negative effects of a poor com-

munity image can limit possible airport expansion, airport planners must also consider the unique aspects of airplane noise. When planning a community outreach program, it is important to recognize the impact of noise levels below the legal compensation limit, and how there noises are perceived by the community members.

# Chapter 4

# Graphical Representation

Given the ability of the human visual system to interpret visual images, it is a natural extension to use graphical representation, also called scientific visualization, as a decision making tool. The data may be represented graphically in many forms, but for use as a decision aid, the construction of the graphic should focus the attention of the viewer on the most important factors, but still allow the viewer to interpret the framework within which the solutions are realized. The graphical representation must include a metric that allows a comparison of the relative appropriateness of the possible solutions. An absolute metric is also possible if it is necessary to determine if certain wickets are met. Either type of metric allows a decision to be made from a variety of alternatives. The key function of the graphical representation is to be able to distinguish between the acceptable and the unacceptable, while highlighting optimal solutions. The interpretability and believability of the graphic is of primary importance in presentations, as in discussions between airport operators, airport owners, and the local communities.

Scientific visualization has been used for centuries to identify trends. Dr. Snow used a map with an identification of the houses of cholera deaths to pinpoint a contaminated water source in central London in September 1854 [Tufte 24]. Florence Nightingale showed the relationship between hospital hygiene and patient survival during the Crimean War. "Graphical summaries of data distributions are useful when it is either not feasible or not necessary to portray all the data" [Chamber 39]. However, it has been the advent of the computer which has made the large scale mapping of data sets timely and inexpensive. Only in the last ten years has the available computer power allowed the widespread application of scientific visualization. "Scientific visualization is concerned with exploring data

and information graphically" [Earnshaw 5]. The eye is one of the most discriminatory systems available for analysis. "An enormous amount of quantitative information can be conveyed by graphs; our eye-brain system can summarize vast amounts of information quickly and extract salient features, but it is also capable of focusing on detail." [Chamber 1].

"The success of visualization is mainly due to the soundness of the basic premise behind it; that is the basic idea of using computer generated pictures to gain information and understanding from data (geometry) and relationships (topology) [Nielson 97]. However, the available methodology guidelines remain weak [Robertson 58].

## 4.1 Preparing Data for Presentation

The first step of the process is to determine the goals or aims of the visualization. Robertson offers the following set of four questions to help determine which form of visualization is most effective: [Robertson 59]

1. What mental models most effectively carry various kinds of information?

2. Which definable and recognizable visual attributes of these models are most useful for conveying specific information either independently or in conjunction with other attributes?

3. How can we most effectively induce chosen mental models in the mind of an observer?

4. How can we provide guidance on choosing appropriate models and their attributes to a human or automated display designer?

Robertson calls the representation of the data on an easily recognized field, "natural scene paradigm." The addition of recognizable physical properties to this paradigm helps the

viewer feel comfortable with the representation and be able to understand the data representation [Robertson 60].

The aims of the interpretation are based on the type of data the graphic and the analysis will portray. The three listed types of interpretation are possible: [Robertson 61]

- single or point values
- gradients and features, local distribution
- global distributions, including trends and structures.

The appropriateness of the different types of interpretation depends on the question to be answered. In most questions, some understanding of all three levels is necessary. The inter-relationship between the data and the interpretation is dependent on presentation mechanics of the graphic.

On the mechanics of the graphics, Tufte, a widely quoted authority on the visual representation of data, states that [Tufte 13] "Graphical displays should:

- show the data
- induce the viewer to think about the substance of the graphic rather than about methodology, graphic design, graphic production technology, or something else
- avoid distorting what the data have to say
- present many numbers in a small space
- make large data sets coherent
- encourage the eye to compare different pieces of data
- reveal the data at several levels of detail, from a broad overview to the fine structure
- serve a reasonably clear purpose: description, exploration, tabulation, or decoration

• be closely integrated with the statistical and verbal descriptions of a data set".

Tufte also addresses very concretely the visual aspects of the graphic. This includes the background, the choice of color, the choice of typeface, and the actual representation of the data. The focus is on the message of the graphic. Tufte does not extol the virtues of misleading the reader. In fact, he campaigns vigorously against the deceptions prevalent in advertising graphics. This is a common theme of writers interested in maintaining public confidence in the graphical representation of data. "How to lie with statistics," is both a well-known book as well as a commonly accepted fact of literary and advertising life. Any graphic used for public consumption must establish a level of reliability by presenting the data in a format in which people can identify known relationships.

An appropriate graph for data analysis requires even greater scrutiny than a graph for data representation. When used for data analysis, a graphical representation must focus on the elements to be analyzed and provide a basis for comparing different solutions. "The graphical displays in this book are visual portrayals of quantitative information. Most fall into one of two categories, displaying either the data themselves or quantities derived from the data. Usually, the first type of display is used when we are exploring the data and are not fitting models, and the second in used to enhance numerical statistical analyses that are based on assumptions about relationships in the data" [Chambers 3]. In The Introductory Guide the Scientific Visualization, Earnshaw points out that, "the difference between scientific visualization and presentation graphics is that the latter is primarily concerned with the communication of information and results that are already understood. In scientific visualization we are seeking to understand the data" [Earnshaw 5]. "In using graphs for data analysis we need to recognize what kinds of perceived structures are attributable to the data and what kinds are artifacts of the display technique itself" [Chambers 317]. Chambers identifies five important considerations for the graphical representation of data:

iteration, matching goals and plots, true messages and artifacts, flexibility in the applications for the method, and interpretability. [Chambers 316-319].

Iteration is important because it allows the user to make changes to the scenario and to see the effect of these changes in the solution.

Matching goals and plots ensures that the display shows the results in such a way that the user is able to evaluate whether an individual scenario meets the user's goals. "The information on a plot should be relevant to the goals of the analysis. This means that choosing graphical methods we should match the capabilities of the methods to our needs in the context of each application" [Chambers 316].

True messages versus artifacts focuses on the accuracy of the representation. Artifacts are trends or relationships that are not present in the data, but appear out of the analysis method. An example of an artifact is when there is an apparent similarity, but no actual relationship. This can be a result of comparing inappropriate data sets, for example, a graph that relates sunspot activity to stock market performance, or a function of analyzing data sets which are too small to be of a statistical significance.

The flexibility in the applications for the method is important when devising a general data analysis method. While it is important to understand the limits of any methods used to analyze a given data set, it is also important to ensure that these limits do not restrict the usefulness of the method.

Interpretability is critical to the use of a graphic, which will not only be seen by its authors, but also by a wider audience. "When some interesting structure is seen in a plot, it is an advantage to be able to relate that structure back to the original data in a clear, direct, and meaningful way. Although this seems obvious, interpretability is at once one of the most important, difficult, and controversial issues "[Chambers 319].

The most common form of graphical data analysis today is the x-y plot common to every elementary science class. The most powerful tribute to the believability of graphics is that, despite all the powerful computer tools available to analyze data, no scientist would publish a paper or make a presentation without showing, in graphical form, the relationship between the data and any curve that represents the data. The scientists are convinced, and often correctly, that they can identify something that the computer missed. "The most extensive data maps, such as the cancer atlas and the count of the galaxies, place millions of bits of information on a single page before our eyes. No other methods for the display of statistical information is so powerful "[Tufte 26].

## 4.1 Specific Techniques for Presentation

The importance of graphical representation can be undermined by poor presentation methods. The first step is that the background does not overshadow the data, but provides a framework within which to analyze the data [Tufte]. But beyond this, there are only a limited number of openly available guidelines for graphical design methodology. Method guidelines are available in a number of forms, including software aids. One of these software aids, Visualization Tool Assistant (Vista) focuses on compositional design methodology based on research in graphical perception [Senay 37]. Senay and Ignatius pinpoint five categories of knowledge required for scientific data visualization: [Senay 37]

1. Data characteristics
2. visualization vocabulary
3. primitive visualization techniques
4. composition rule, and
5. visual perception rules.

While Senay and Ignatius do not expand on the all knowledge used by the Vista program, they explain how the five categories interact to arrive at a final presentation technique for a particular type of data. Data characteristics refer to how the data is organized, for example, nominal, ordinal, scalar, or tensor [Senay 37]. Visualization vocabulary is how the data in encoded, are the data units simple such as points, lines, areas, or volumes [Senay 38]. The data can also be compound, which would include positional data forms, as well as temporal data forms [Senay 38]. The three primitive visualization techniques supported by Vista include positional, temporal, and retinal [Senay 38]. Positional visualization shows how the marks vary within the image and data set, this includes maps and contour plots [Senay 38]. Temporal visualization is animation [Senay 38]. Retinal visualization is used to describe the shape of an object [Senay 38]. Senay and Ignatius identify five composition rules that can be applied to many visualization techniques [Senay 39].

Mark composition merges two or more data sets with one form of illustration, resulting in less data points than the sum of all the data sets being shown, but that each data point contains more information [Senay 39].

Composition of superimposition by superimposing one mark set over another, one data set must be a continuous contour to enable both data sets to be shown [Senay 39].

Composition by union simply plots both mark sets on the same axis, using different shapes or colors to differentiate the two data sets [Senay 40].

Composition by transparency combines two visualization techniques, the amount of each set that is visible depends on the transparency of the visualization technique used to show the top data set [Senay 40].

Composition by intersection highlights the intersection of multiple data sets, often only the intersection is shown and not the complete data sets, this minimizes an overly busy data set compilation [Senay 40].

Rules of visual perception are based on an extensive survey of knowledge of visual perception [Senay 40]. These heuristic rules are used by the software to fine tune the characteristics of the visualization techniques [Senay 40].

These composition rules apply three tests to each choice of presentation: [Senay 39]

1. The compatibility of component visualization techniques,
2. the visibility of each component upon composition, and
3. the distinguishability of components in the composite design.

Another important facet of graphical representation is the use of color. "Color is potentially one of the most effective coding methods, but also one of the most difficult to use correctly. We most often regard color as an excellent way to display quantitative differences (for example, when we want to plot four particularly overlapping clouds of points in a single scatter plot)" [Chambers 331]. Chambers is not the only researcher to raise concern about the overzealous use of color. While the use of "true" color uniformly enhances the understanding of the depiction, the use of false colors can confuse as well as aid comprehension [Levkowitz 20]. For example, the real world color of an object being depicted in 3D is generally clear, but the false colors on weather maps can emphasize uninteresting attributes simply by depicting them in brighter colors. Color can highlight characteristics of the data. The choice of color can create a virtual depth in a graphic, which is not present in the data by placing a bright color next to a more muted color. Another important consideration for the production of graphics, which will enjoy wide distribution, is the percentage of color-blindness in the population, about 8% of men and 2% of women [Levkowitz 22]. By selectively using color, it is possible to emphasis certain objects in a widespread display [Levkowitz 22]. For example, to focus attention on certain areas of a map, these parts of the map can be shown in color, while the background remains black and white or

gray scale [Levkowitz 22]. The rest of the map may be necessary to provide a frame of reference for the data.

There is little debate that a graphical representation can be superior to a verbal representation for diagrammatic problems, and most scientific problems are diagrammatic.

"In a *sentential* representation, the expressions form a sequence corresponding, on a one-to-one basis, to the sentences in a natural-language description of the problem. Each expression is a direct translation into a simple formal language of the corresponding natural language sentence.

In a *diagrammatic* representation, the expressions correspond, on a one-to-one basis, to the components of a diagram describing the problem. Each expression contains the information that is stored at one particular locus in the diagram, including information about relation with the adjacent loci" [Larkin 66].

The analysis of the noise footprint and its impact on the population uses cartography techniques. The noise can be compared to weather maps. Such forms of visualization are used to select features from the whole as well as observe topological relationships [Earnshaw 31]. "The visualization can then be used to plan for work to be done (e.g., by the service industries) in such a way as to minimize costs" [Earnshaw 32]. This planning for work is one of the necessary steps facing airports and communities who are planning a comprehensive noise abatement program. This modern application of cartography methods has changed the use of cartography from a simple representation of the landscape to a sophisticated data analysis system [Earnshaw 31]. Not just rivers and mountains can be represented on maps, but with the advent of census data, a population can also be modeled on a map [Earnshaw 31]. These maps also include pollution maps, which can be compared to air stream and power plant maps to track airborne pollutants. A modern application of the cartography technique is the application of a graphical analysis tool to analyze whether

people already in nuclear shelters in Zurich could be relocated if other emergencies arise, such as fire or flooding [Albert 139]. The problem stated in also appropriate for this type of graphical analysis because it has a defined set of starting parameters (the location of people in the shelters) and a well-defined goal (to move as many people as possible to other shelters by safe routes). To judge whether the existing system is adequate still needs at least one viewer and possibly some community discussion before an acceptable solution is achieved. The data representation in this case study was also a graphical map with organizational as well as geographical data, which the authors noted was well accepted by even the computer novices in the test group [Albert 140]. The noise abatement controversy is another ideal field for the application of scientific visualization techniques. The large data set and the necessity to disseminate the noise information to a wide audience make graphical representation an ideal format.

A graphical representation supports the decision making processes by showing large data sets in interpretable formats. The key issues in good scientific graphics are the selection of the data set and the selection of the display mechanics. The data sets must not only be accurate, but must completely describe the important variable in the problem. The selection of the display characteristics must again provide an accurate frame of reference, but also fit the data into package the eye can understand. The use of composition and color can support the ability of the visual system to distinguish patterns and possible solutions from the background. Then the most sophisticated sorting system available today, the human visual system, can be used to find solutions. The advantage of such a method in public policy questions is that almost everyone has access to such a system, allowing all parties to make independent interpretations. The mistrust of hidden calculations can be reduced, increasing communication between the parties.

# Chapter 5

# The Graphical Decision Aid

A graphical decision aid must provide a decision maker with the required information to make an informed decision. The presentation methods must provide just enough information for the viewer to make a complete decision, but not so much that the goal of the decision is lost. To design a graphical decision aid, two parameters must be determined. The first is the planned audience. The second is the type of decision to be made. After these parameters are established, the data sets necessary to render a complete and accurate graphical representation must be identified. The final step is to use all of this information to decide how to display the data.

The audience for the graphic is important in two ways. The first considerations are any preconceptions. Whether the audience is well-versed in the topic or rather new to the problem determined how much jargon-style symbolism is appropriate. The other consideration is how to present information for problems which are actually under the control of the viewers. For example, when the goal is adapting the flight paths to ease the noise impact, the model should not attempt to answer the question of whether the airport should be built at all. In the case of the airport noise debate, the audience members are airport operators, community members, federal oversight agencies. These groups bring different levels of expertise to the discussion. The community members understand the noise impact, but have widely differing levels of knowledge about how it is caused. The airport operator and federal oversight agencies are more likely to understand the causes of the noise, that the actual impact.

The solution which the noise impact committees around the country are struggling with is how to maintain and increase airport usage while limiting the negative impacts on

the communities. Since runway heading are fixed by weather and safety concerns and the noise from an individual aircraft is limited by a combination of available technology and federal statutes, the only area of influence available to these groups is the limited control over number of flights and their nominal flight path. Therefore, the problem to be solved by this graphical decision tool is what should the nominal flight paths to and from the airport runways be to minimize the community impact while not unduly restricting flight operations. The definitions of what constitute acceptable noise levels and undue flight restrictions must be left as open parameters to be determined by the local authority in conjunction with federal guidelines.

After determining the problem to be solved, the next step is to look at the information available. This is any information which allows viewers to make informed decisions about the possible effects of changing aircraft flight paths. This information can be directly measured or constructed hypothetically. The first necessary piece of information is what the noise is. This noise can be either simulated or measured. Included in this noise data set should also be some measurement or approximation of how the noise varies under real operating considerations. The second piece is where the noise is, a map or coordinate system provides this information. The next is where are the people, this is both a distance from the noise source and a location on the ground. Another important data set is how the noise is measured and aggregated, these legally endorsed methods are the basis for any decision making and compensation. Other pieces of available data might include the location of sensitive receptors, churches, schools, nursing homes, to name a few. The number of complaints and their origin might be used to indicate community annoyance. The number of lawsuits, the incidence of noise induced sleep disorders, are other possible data sets which might be appropriate in this analysis. The decision of which data sets to use depends on what Chambers describes as matching goals and plots [Chambers 316]. The

central issue is whether the user can determine from the plot information when an acceptable solution has been found.

Once the question has been determined, and all the available potentially relevant data has been found, the next step is to design the graphical decision making model. The four questions posed by Robertson for modeling guidelines can just as appropriately be applied here in an adapted format [Robertson 59]:

> 1. What mental model provides a comfortable framework for the viewer?
>
> 2. How does the viewer recognize the information and differentiate between the different forms?
>
> 3. How does the viewer identify patterns in the information?
>
> 4. How can the viewer know when an acceptable solution has been found?

Of the three primitive visualization techniques described by Senay and Ignatius, positional, temporal, and retinal, only positional is relevant. Noise has no physical dimensional characteristics, so retinal representation is inappropriate. The time animation techniques of temporal representation do not illustrate the aggregate noise impact which is the focus of this model. The positional representation of a map or contour diagram is the visualization technique which meets the needs of a noise aggregation model. The natural scene paradigm described by Robertson is in its simplest form a map. In the airport noise controversy, a map is the best background for data because it not only provides a comfortable framework for the viewer, but it provides all three of the interpretation possibilities. The point, feature, and global distribution of the noise data are all clearly displayed on a map. A community member can see how they are affected, how their neighborhood is affected, and how their exposure level compares with others. Other possible frameworks, such as a histogram with the number of people affected at each noise level provide neither

a comfortable framework or a complete set of interpretation possibilities. Once a framework has been determined, the next issue is how to present the remaining data on this frame.

To be able to determine which structures are true relationships in the data and which are artifacts of the display process is another one of Chambers' important considerations for scientific visualization. Each data set must be examined as to whether it contributes to the iteration towards a solution or clouds the problem. Upon examination, not all the data sets lists in the previous paragraph are relevant to the goal of minimizing the noise impact. While the number of complaints or noise related physical illnesses might be interesting for a public health study, Congress has determined that DNL shall be the basis for noise impact measurements, decisions, and compensation in the United States. DNL is based on the sound on the ground of aircraft weighted by the time of day. In the case of an airport, the noise impact is a function of the noise footprint of the airplane, the population distribution, and the time of day distribution of the flights. A related data set, the location of sensitive receptors might also be of importance to the audience because of the importance of these receptors to daily life and the higher cost of soundproofing these facilities. An appropriate graphical analysis method for determining the noise impact will examine these three data sets. It may be necessary to create these data sets by combining other available data sources. The map will be included to provide a framework within which to display the data, the noise footprint will the level of noise over populated areas, within the noise footprint, the contours will be clearly defined to show where the mandated compensation or notification cutoffs are in relation to important landmarks. These important landmarks can include population concentrations or sensitive receptors. The five composition rules of Senay and Ignatius result in at least five display possibilities which include all three of these data sets, with varying degrees of composition. If the map is taken to be the axis for

the noise, a single noise footprint which uses contour indicators to differentiate the different noise levels is an example of mark composition. If these noise footprints are combined into a DNL contour map, the composition is still mark composition, each point has a location and DNL. If sensitive receptors are added, mark composition has been combined with composition by union, since these marks are likely to be found in the same portions of the map, composition by transparency will also be used. A different mark type has been used to show the second data set (the location of the sensitive receptors) on the same axis (the map). A map where the noise footprint has been removed over unpopulated areas in an example of composition by intersection. When the sensitive receptors are added again, composition of transparency has been used. To determine which of these display methods best suits the problem at hand, it is necessary to re-examine the problem statement. The goal of the graphical analysis is to determine a nominal flight path which would mitigate the noise impact on the surrounding communities. Tufte admonishes that "Graphics should... make large data sets coherent [13]," and Chamber stresses the relevance of the information in the plot [316]. The choice of representation for the decision analysis depends on which data is relevant to the decision the viewer needs to make. Since the noise impact presently defined as none where there are no people, a method of composition to be applied to the data is the method of intersection. The DNL footprint will only be shown where it intersects with populated areas. Since the analysis hinges on how much noise is there, not just whether or not there is noise, it is important to show the level of noise impact at each location. This can be done using color or distinctive patterning. Distinctive patterns found in black and white computer illustrations from the 1970's and 1980's often suffer from a moiré effect. The combination of hatches and diagonals and squiggles fool the eye into seeing the page as moving, distracting from the information on the graph. Such effects are no longer acceptable as computer graphics have become more

capable. The use of false color, common in NASA illustration of the moon and planets, can also be distracting. Color can attract the eye and create visual relationships where there are none in the data. Color can be used to direct the eye to the important parts of the graphic. In this example, with the map as the background, the use of color to show the noise footprint, effectively draws the eye to the noise, but still allows all the reference information of the map to be used for viewer orientation. The use of distinct colors for the different DNL levels shows the differentiation between the legal rights and responsibilities of the differently affected communities. Sensitive receptors need to be shown in a color not related to any of the colors in the DNL contours and with a distinctive shape. The choice of the data sets, the choice of framework, composition, mark type, and color are used to create a graphical decision making tool which allows the viewer to determine whether a nominal flight path meets the noise impact restrictions of the community. The data sets are the flight path including its noise impact, the community composition and location, and the time distribution of the flights throughout the day.

The graphical representation resulting from this analysis is a map with a color contour depiction of the DNL contours over populated areas. Additional distinctive marks are used to indicate sensitive receptors. The DNL contours are red, blue, gray, green, and pink, where the sensitive receptors are indicated by yellow squares.

## 5.1 Modeling Process

The optimized representation was used to create a modeling process. The noise footprints were calculated using the NOISIM program from John Paul Clarke. This program also included rudimentary population data as well as accurate geographic data. The aggregation metrics use the NOISIM output to determine sound levels and duration for use in the DNL equations. To use a realistic number of operations, the operational numbers were

taken from the logs of Logan International Airport in Boston. The number of operations based on scheduled flights often underestimates the actual number of operations. Logan has the most sophisticated noise monitoring system in the country. They not only have records tabulated for actual flight operations, but they are able to track these operations flight paths and their corresponding noise profiles at noise monitoring sites. This information was used to determine the operational distribution of the flight paths. This important step is often left out of noise calculations, because of the difficulty obtaining or estimating this distribution.

The steps in the modeling process are:

1) Determine the flight path(s). Flight paths include any takeoffs, landings, taxiing, routine engine run ups or go-arounds, which might significantly affect the noise level over an affected area. This selection of noise sources is also subject to any federal, state, or local legislation which might limit it to a subset of this list. Whenever possible actual flight data should be taken, however, simulator data can also be used (and was used in conjunction with actual data for the samples).

2) Determine the flight path distribution. A measured data set is preferable, but it is possible to use simulator information or, in the simplest case, an approximation from other observations, to determine the most common deviations from nominal flight paths. Deviations are possibly caused by pilot propensity to take corners late or early, the effect of wind on actual heading, and small navigational errors.

3) Aggregate the flight paths according to distribution. This takes the NOISIM outputs for the different flight paths and aggregates them according to the proscribed DNL equations and the percentage of flights using that particular distribution.

4) Show the flight paths DNL footprint. To provide an intermediate check in the calculations, it is possible to show the entire aggregated DNL contour diagram.

5) Show the noise impact of the proposed flight path. Here the relative operational noise impact is shown for the selected nominal flight path. This will include the expected trajectory deviation during operational flights.

6) Iterate the flight paths until the committee is satisfied that the proposed flight path meets the needs of the airport as well as the surrounding communities.

The modeling processes result in a series of graphical images. These images show the noise impact of flight procedures on the local communities. The representation uses different composition techniques to visualize the data. The decision maker can take images and determine which of the flight paths minimizes the noise impact on the community, bringing the benefits of lower sound proofing costs as well as decreasing community aggravation. The black and white map with the color overlay of the noise impact provides a comfortable reference while focusing on the aircraft caused noise. Earnshaw points out that the use of such topographical representations is a way to save work and money while designing the best strategy to combat air and water-borne pollutants [31]. The application of these methods to the noise mitigation issue requires more sophisticated measurement data to construct meaningful graphs, but is also a natural application of scientific visualization.

# Chapter 6

# Case Study: Runway 27 at Logan International Airport

One of the most acrimonious confrontations over urban noise began with a change in the flight procedures for departures from runway 27 Logan Airport. During the 1970's, Logan Airport experienced a sharp increase in the demand for aircraft operations. In an attempt to handle the increased traffic without physically expanding the airport, the FAA instituted a number of operational changes. Better air traffic control equipment and procedures made it possible to include runway 27 departures in more runway use patterns. The takeoff procedure was modified to allow the use of runway 27 in conjunction with other runways to maximize the available capacity. The overall increase in the number of operations resulted in a several hundred percent increase in the usage of runway 27 alone. As depicted in Figure 6.1 runway 27 departures fly over the heart of South Boston. The left side of Figure 6.1 shows the location of Logan Airport in the greater Boston Area, the black line extending from the runway is the runway centerline for runway 27 departures. The right hand illustration in Figure 6.1 shows the layout of the runways for Logan Airport.

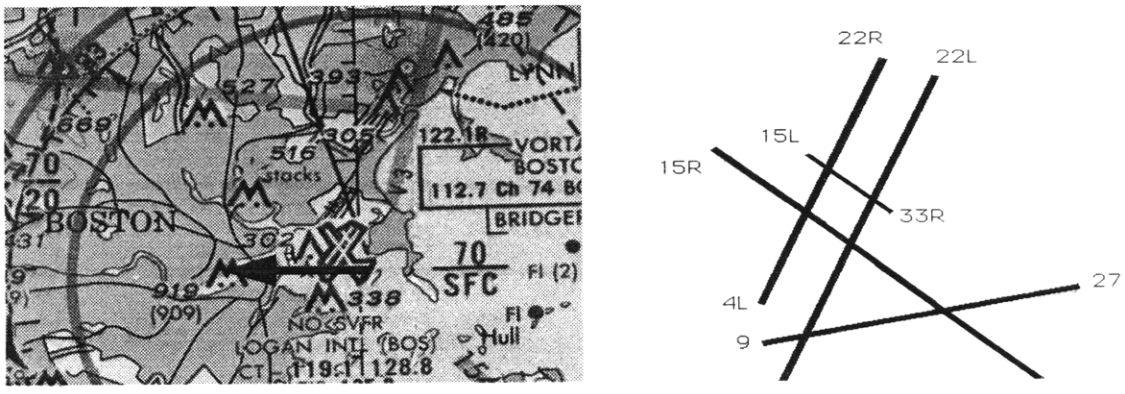


**Figure 6.1:** An overhead depiction of the runway layout at Boston's Logan International Airport shows that runway 27 departures fly right over the heart of South Boston.

## 6.1 Background

The community of South Boston reacted negatively to the unannounced change in Runway 27 departures. South Boston had been a quiet community. Without warning, the noise due to aircraft operations increased. They complained based on the lack of research done on the environmental effects of a major change in runway usage. In 1987, the Court in Massachusetts ruled that the FAA and MASSPORT had overstepped their jurisdiction to make unapproved changes in the flight procedures without doing an appropriate environmental impact study. The court decided that the procedural change had made a substantive difference in the environmental conditions in the South Boston communities neighboring Logan Airport.

The court ruling required that all possible measures be taken to reduce the noise without adversely impacting the capacity of the airport. Under court order, MASSPORT and the FAA conducted a new study, which attempted to mitigate the noise for the people of South Boston while maintaining the same operational capacity, given the physical limitations of the Boston skies. A committee was formed with representatives of the FAA, MASSPORT, and the community. In 1995, they agreed to a Record of Decision which kept the same runway configurations, but made a slight change in the departure procedures for runway 27 departures. The slight change in the takeoff procedure would try to direct the air traffic over more industrial land and other unpopulated areas.

Like Logan, many airports continue to experience difficult community relations. Modeling tools, such as NOISIM, can help airports and communities discuss and view pending changes to airport operations. The following presentation compares the old and the new flight procedure for Logan's Runway 27, and illustrates the benefit of graphical presenta-

tion in the decision making process. Several assumptions or limitations were made to simplify the presentation, since the purpose is to display the virtue of the program, and not reopen the controversy surrounding runway 27. With this goal in mind, the scope of variables was limited to capture the effect of the changed flight procedures, but not necessarily the value of the change.

Runway 27 was chosen for many reasons. First, due to the long, public nature of the controversy, there was a wide range of data available about this case. MASSPORT maintains a database of flight path deviations and local sensitive receptors. Second, the problem is limited by the fact that runway 27 is only used for departures. Third, the case provides two separate scenarios to evaluate, allowing for a comparison of a procedural change. The runway 27 controversy provides a simple, relevant case study, but still shows the salient features of the improved NOISIM program.

## 6.2 Case Parameters

The purpose of this case study was to illustrate that good graphical representation can aid the decision making process. The flight paths used in this case study are approximations of the flight paths for the Runway 27 controversy. The actual operational flight paths depend on many factors that would add little value to this presentation. For simplification, factors such as weather conditions, pilot experience, and the amount of air traffic at flight time that would normally affect the departure routes have been kept constant. Other situations such as aborted take offs or emergency go-arounds were not considered. The approximations also avoid conflict with any ongoing negotiations among Logan Airport operators, the FAA, and community representatives. Two "ideal" flight paths were used to conduct this study. Deviations from these "ideal" flight paths were analyzed to approximate actual flight conditions in order to demonstrate the value of the NOISIM program.

Figure 6.2 shows the old and the new flight procedure as defined for this case study. In September 1996, a new departure procedure for runway 27 as detailed in the Final Record of Decision was implemented. The change in the procedure is small, a half nautical mile change in the turn point with an additional 10 degree change in heading. For this study, the half nautical mile was omitted and only the 10 degree variation was considered.

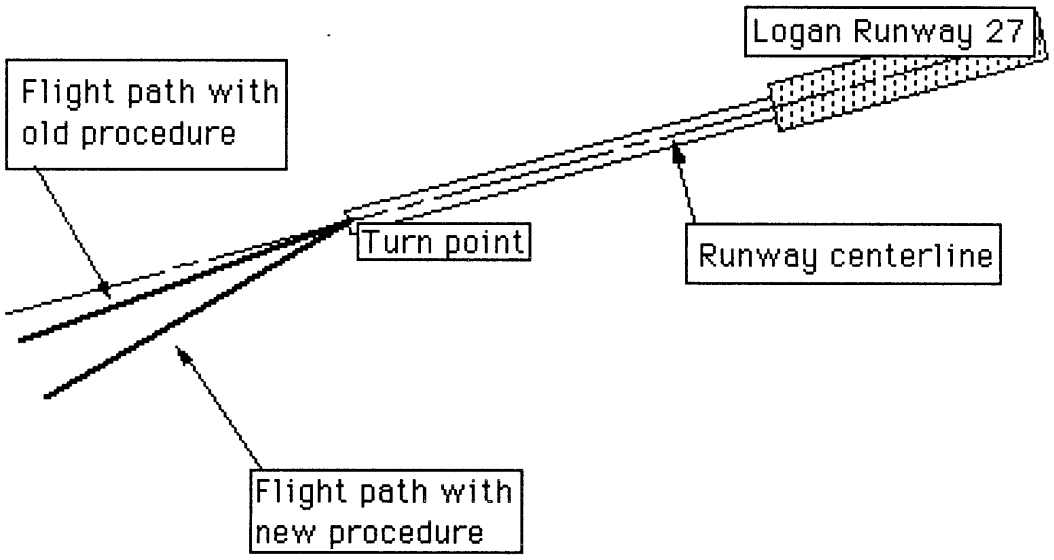


**Figure 6.2:** Old and new flight procedures for Runway 27 departures

DNL contours (with and without operational variations) and noise impact are presented for both the old and new procedures. The DNL contours without operational variations provide no new analytic capacity beyond what is already widely available. The DNL contours with operational variations provide a more accurate representation of the actual DNL contours. The noise impact is a graphical representation of the DNL contours over populated areas. Such a graphical decision tool provides an accurate and easily interpreted representation of how the noise from the aircraft procedure impacts local communities. Noise impact pictures are valuable to airport and community planners when evaluating different procedures.

The graphical results have been reproduced in grey scale while the program uses color graphics. The screen displays have a white map on a black background with a color overlay of the noise footprint or impact, and a brightly colored dot to indicate the location of a sensitive receptor. The sensitive receptors, as shown in the color graphical aid, have been excluded because they could not be clearly duplicated in the reversed grey scale version. The number of people in the 45-55 DNL, 55-65 DNL, and 65+ DNL contours were calculated with and without considering operational variations. Despite the simple graphics, the representation of the noise impact makes it easier to interpret which part of the noise footprint actually impacts people.

Population results reported as part of the case study depend on the population distribution used in the analysis program. The greater Boston area includes two counties. For this case study, population data for each county was evenly distributed over all the census blocks used to determine the population concentrations. This level of resolution introduces a substantial margin of error in the population counts, but can easily be corrected by using the more accurate population counts based on the individual census blocks. Again, the salient features of the NOISIM program are demonstrated while maintaining simplicity.

## 6.3 Results

The results of the analysis show that operational variations have a significant effect on the shape and location of the DNL contours. The graphical representation shows how the shape and size changes, while a numerical analysis of the impacted region quantifies the difference.

### **6.3.1** DNL Contours Assuming Ideal Flight Paths

The first refinement in the graphical decision aid combines the single event noise contours to produce a DNL contour. The average numbers used were based on data collected

by MASSPORT. Since DNL contours represent the legal metric by which the noise impact is measured, all discussions which involve the legal obligations of the airports to compensate communities for their decrease in quality of life must use DNL contours to measure the impact. The accuracy of the DNL contour is dependent on the data available for the analysis. The DNL contour requires not just the optimal flight path, but the number of operations using the flight path broken down between day and night time flights. Most airport still use the scheduled OAG flights for the distribution of operations, thus introducing error into the DNL calculations. Any airport which charges landing fees could easily base this analysis on the actual number of operations. It could reasonably be expected that airports will use the actual number of operations in future DNL calculations. The DNL contour subroutine can use either source as an input, including excessively noisy events such as go-arounds if the flight paths can be modeled.

The DNL contours produced assuming that all aircraft follow the "ideal" flight paths are shown for the old procedure in Figure 6.3 and for the new procedure in Figure 6.4.

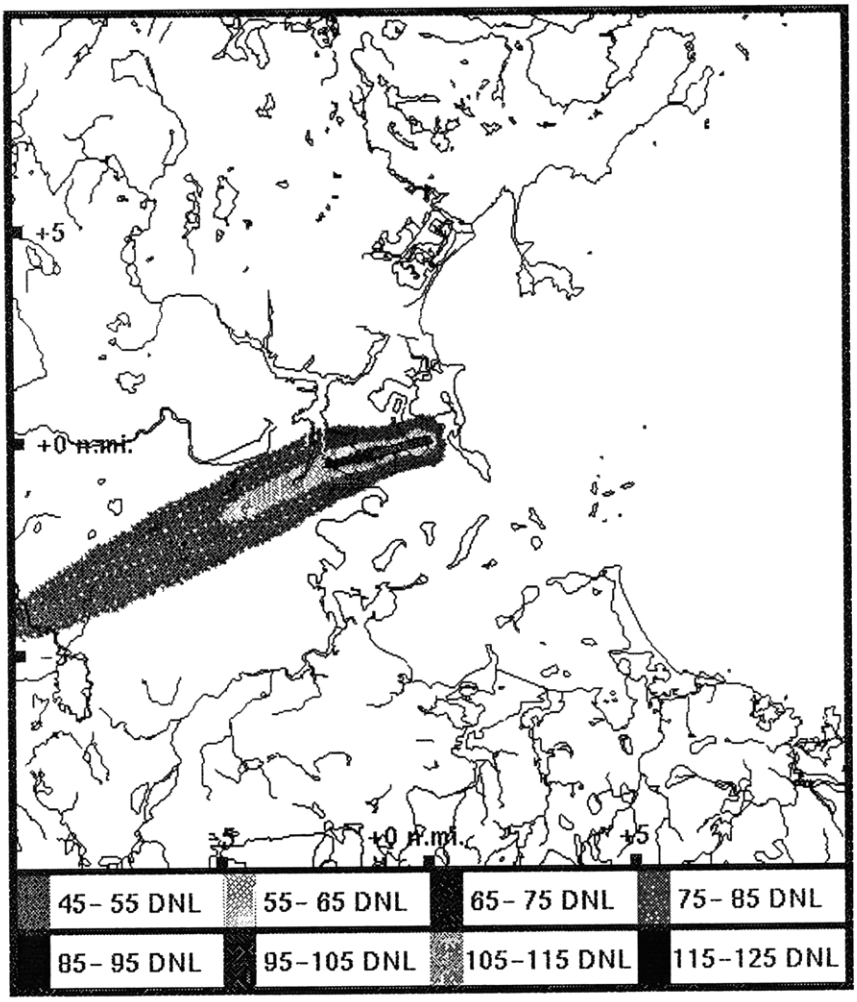


**Figure 6.3:** The DNL contour of Runway 27 departures using the old procedure.

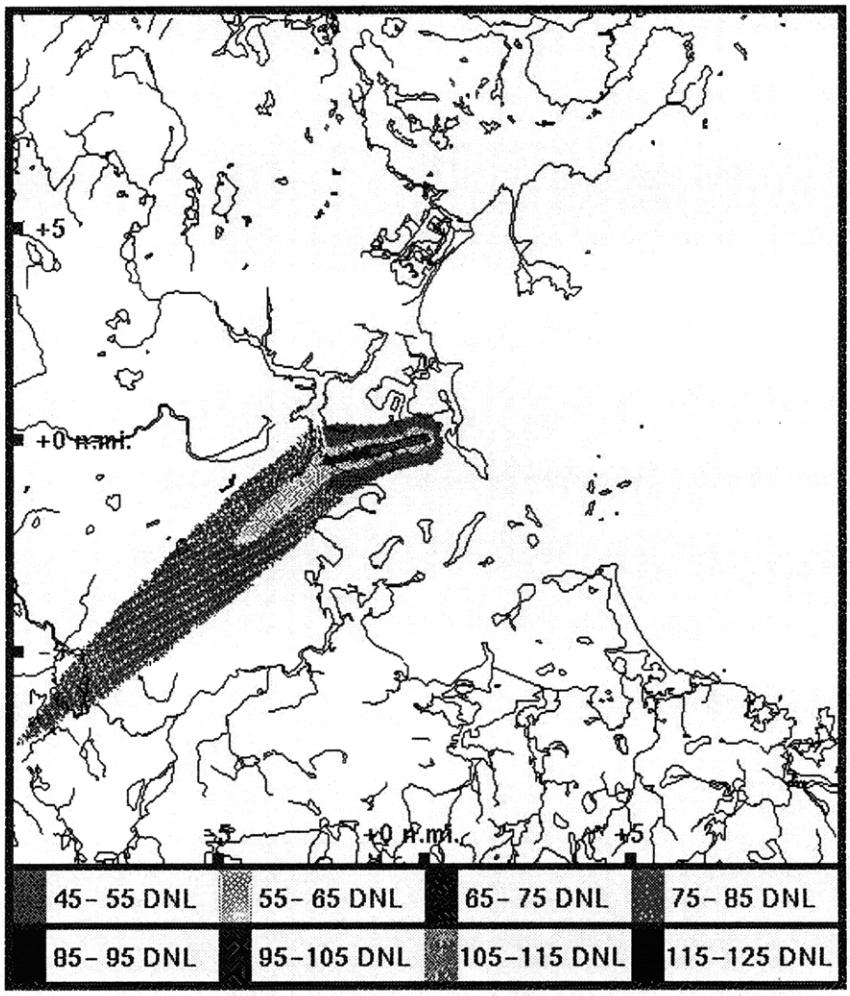


**Figure 6.4:** The new Runway 27 flight procedure adjusted to the DNL contour

The differences between the old procedure in Figure 6.3 and the new procedure in Figure 6.4 are shown in Table 6.1. As the table shows the population impacted by noise greater that 55 DNL decreases when the new procedure is implemented. Although many people are impacted by 45-55 DNL noise, 55 DNL is normal urban noise, and the effect of one additional noise source at 55 DNL is negligible.

**Table 6.1: Noise Impact of Idealized Flight Procedures**

| | 45-55 DNL | 55-65 DNL |
|---|---|---|
| Old | 52,692 | 6,411 |
| New | 102,133 | 5,263 |

### 6.3.2 DNL Contours with Operational Variations

A noise aggregation scheme was developed to show the effects of flight path deviations. Navigational inaccuracies and crosswinds cause pilots following the approved departure plan to deviate slightly from the ideal track. In the aggregation, four discrete deviations plus the ideal flight path were used, with the percentage of flights following each deviation based on data recorded by MASSPORT. Using a set number of discrete deviations mirrors the way that MASSPORT reports and evaluates compliance with the departure flight rules.The noise monitoring program at Logan has separated the flight variation data into five different average flight paths each with their own percentage occurrence. This spread was used to model both the old and the new flight path variation. The result is a hand-like profile for the DNL contours with operational variation. This hand-like profile could be expected to smear into a shorter fan shape if the noise aggregation captured all flights on the actual flight profile. Increasingly sophisticated data collection and analysis methods make such a task a distinct possibility in the future.

Figure 6.5 shows the DNL contours with flight path variations under the old flight procedure. Figure 6.6 shows the DNL contours with flight path variations following the new flight procedure. While these are still visible differences between the two impact contours, the difference has decreased. Even at 4 nautical miles from the runway centerline, there

appears to be some overlap in the affected areas. With this additional piece of information, the difference between small procedural changes becomes more difficult to see when the viewer must mentally filter out water and industrial areas to determine the actual noise impact. The broad footprint is more difficult to evaluate if the viewer is depending on personal knowledge of the area.

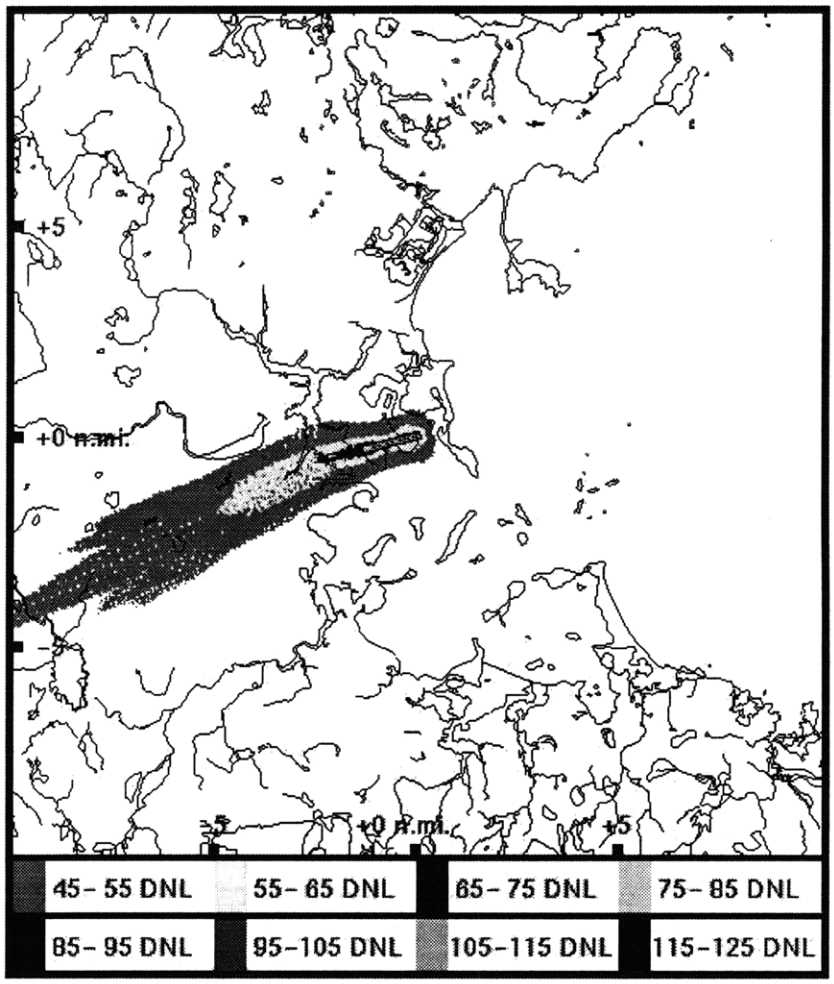


**Figure 6.5:** The DNL contour for departures from Runway 27 using the old procedure. The actual departure path varies from the nominal departure path for some airplanes.

While the ability to track the actual flight operations is not widespread at airports nationally, Logan Airport's noise monitoring division, in cooperation with the FAA, has

developed the ability to monitor individual flights and correlate their flight path with that measured at the monitoring sites. At most airports where this ability is unavailable, one must use an approximated data set for the noise calculations. This poor data availability makes it unlikely that operational variations in individual procedures will be used for the calculation of legally valid metrics in the near future.

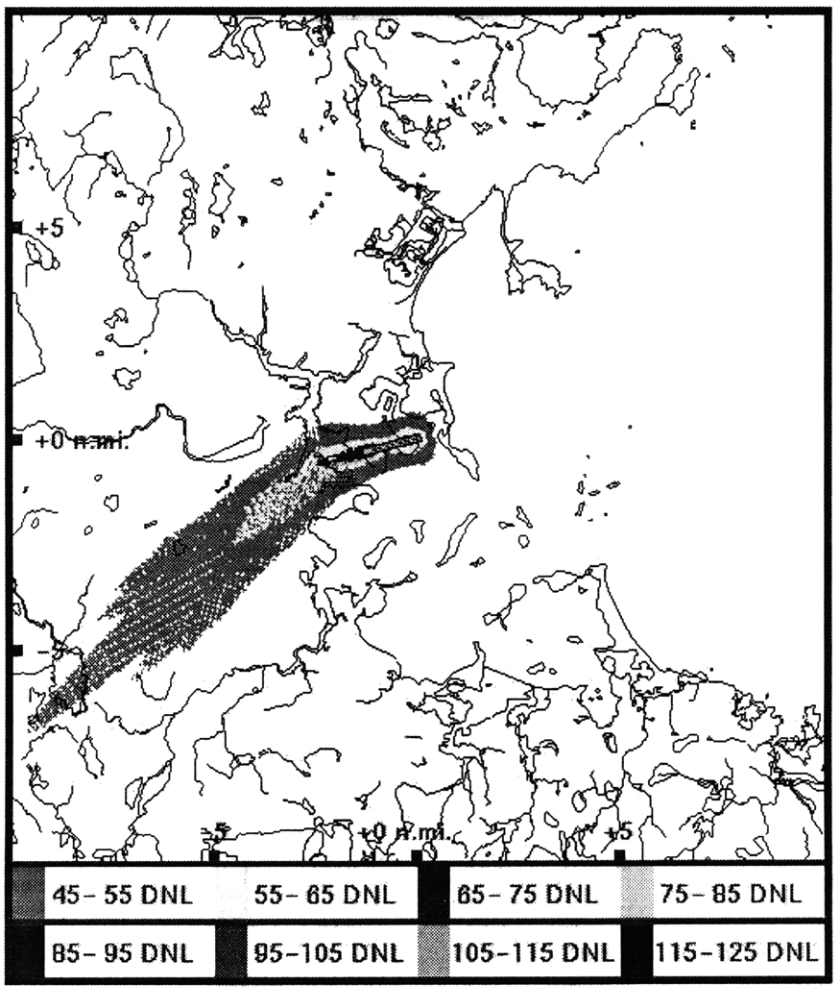


**Figure 6.6:** The DNL contour with variations in flight path for Runway 27 departures using the new flight procedures.

The number of people affected by the flight noise increases as the spread of aircraft deviation from the "ideal" flight path increases. As expected, the area under each contour

grows with operational deviations. While some people might suggest that the number of people in the loudest zone of impact would decrease, the opposite is found to be the case for the simple scenario. The population affected by the actual operational deviation is listed in Table 6.2. The percent change in affected people depends on the geographical distribution of the population under the DNL contours. These are actual numbers under the runway 27 departure, which include populated and unpopulated areas.

When the affected population is examined for the new and old procedure assuming operational variation, the analysis indicates that there is no benefit to implementing the new procedure. Table 6.2 shows the noise impact for the old and new procedures with operational variation.

**Table 6.2: Noise impact considering operational variation.**

| Flight Procedure | Population in the 45 DNL contour | Population in the 55 DNL contour |
|---|---|---|
| Old, with variation | 59,832 | 6,608 |
| New, with variation | 104,871 | 6,767 |

### **6.3.3** Effect of Operational Variation on Affected Population

The idealized DNL contours predict that less people are affected by the new procedure than the old. The inclusion of operational variations however, shows that the expected benefits are at best negligible. The percentage change due to operational variation are shown in Table 6.3. The comparison between the old and the new procedure without operational variation favors the new procedure for louder contours above 55 DNL as shown in Table 6.1. When operational consideration is considered, the value of the change is less certain, as shown in Table 6.4.

**Table 6.3: Change in noise impacted population due to operational variation**

| Procedure | 45-55 DNL | Percentage Change | 55-65 DNL | Percentage Change |
|---|---|---|---|---|
| Old, no variation | 52,692 | +13.5% | 6,411 | +3.1% |
| Old, with variation | 59,832 | | 6,608 | |
| New, no variation | 102,133 | +2.7% | 5,263 | +28.6% |
| New, with variation | 104,871 | | 6,767 | |

**Table 6.4: Change in analysis result due to operational variation**

| Procedure | 45-55 DNL Percentage Change | 55-65 DNL Percentage Change |
|---|---|---|
| Old, no variation | +94% | -8.15% |
| New, no variation | | |
| Old, with variation | +75% | +1.02% |
| New, with variation | | |

When operational variations are taken into account, the number of affected persons actually increases for the 55-65 DNL contours as well as the 45-55 DNL contours as shown numerically in Table 6.3. The procedural change only focused on those individuals in the 55 DNL contours and higher, with an emphasis on the individuals in the over 65 DNL contours. Based on the idealized DNL analysis, the new procedure would be a better choice. Once an accommodation for operation variation is considered, the benefit is no longer certain. This discrepancy is an indicator that further study is needed not only of the

procedure, but also of the analysis method. A robustness test is necessary While, the modified change does not exactly mirror the procedure outlined in the final decision of the committee, the case study does show that the method of analysis is not robust. The committee concentrated on decreasing the impact on those most severely affected, those in the 55 DNL contours and above. Like in this scenario, where both the change and the effects are small, even a small error compromises the robustness of the solution.

### **6.3.4** Noise Impact

The final change in the display format removed the contours from non-residential areas (industrial or unpopulated) so that only the noise impact on residential areas is displayed. Now, airport planners and communities can readily see the noise heard by each community. This feature prevents confusion between contours of noise produced and the noise impact, and conforms to the representation of the ideal graphical decision aid as described in Chapter Five.

Figure 6.7 shows the footprint over populated areas only for the old flight procedures. The black squares on the map represent only some sensitive receptors. Other sensitive receptors are not depicted due to the necessity to enlarge the sensitive receptor for grey scale representation. While the sensitive receptors here represent a hospital, a school and a nursing home, any feature deserving special consideration can be so marked. Therefore, airport planners and community leaders can identify particular features to avoid or to use as a reference point. The corresponding map for the new flight procedure is Figure 6.8 below. The effect of the large footprint is easier for the viewer to judge when the irrelevant data is eliminated. The larger populated area covered by the new procedure is clear when comparing Figure 6.8 with the old procedure in Figure 6.7. The lack of change in the 55-65 DNL contour from the old to the new procedure shows clearly that assuming opera-

tional variation, the decrease in noise achieved by implementing the new procedure is minimal at best.

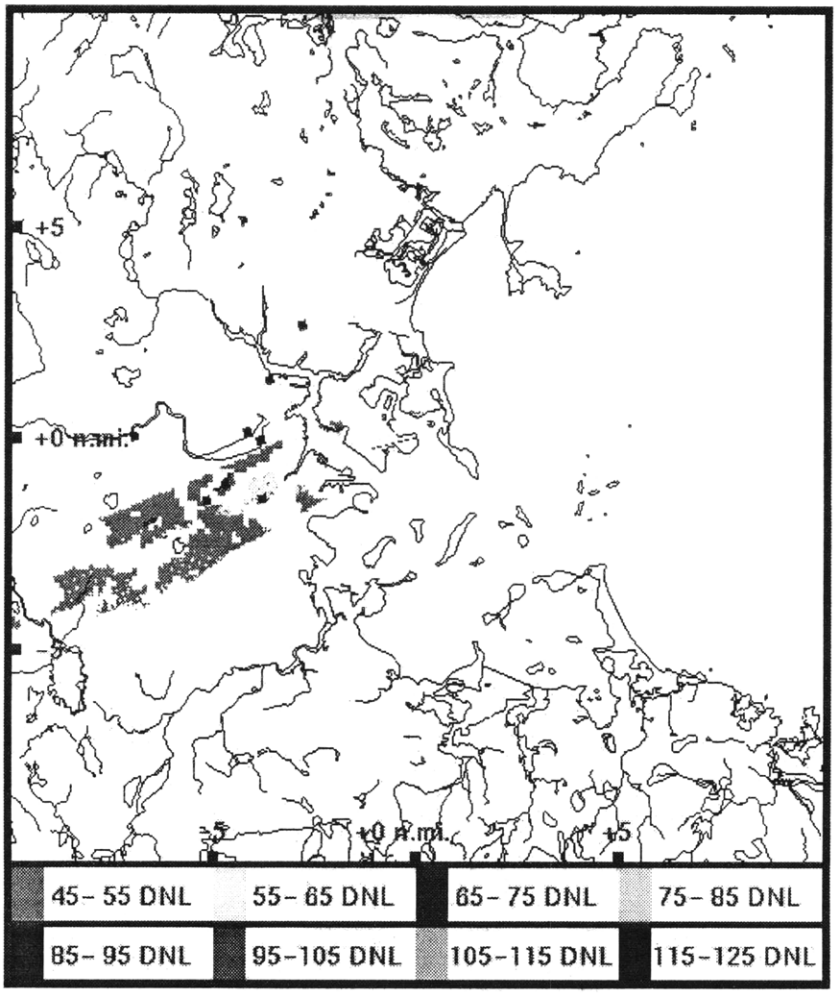


**Figure 6.7:** The noise impact on residential areas using the old flight procedure for Runway 27 departures.

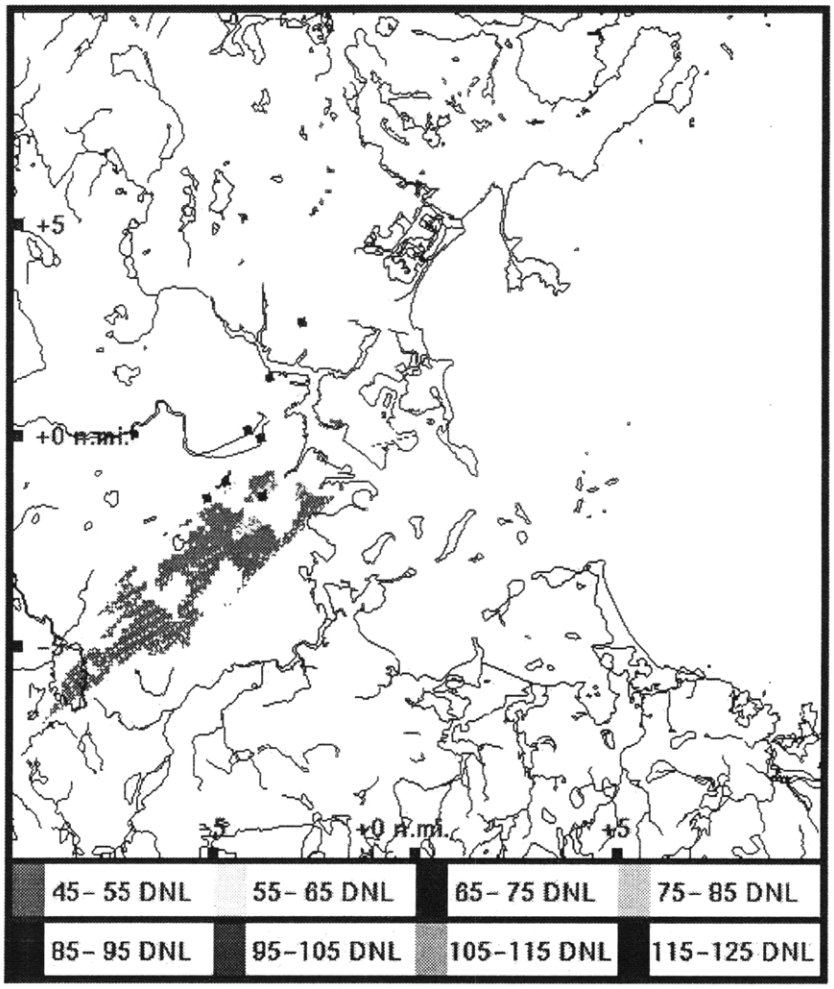


**Figure 6.8:** The noise impact on residential areas for Runway 27 departures using the new flight procedures increase the exposure to noise levels below 55 DNL, but decreases the exposure to levels above 55 DNL.

## 6.4 Policy Implications

The increased noise impact is partially due to the use of an approximation of the new procedure, resulting in a greater noise impact than the actual Record of Decision. The increase in affected population between the new procedure and the old procedure does not accurately compare the actual new runway 27 departure to the old runway 27 departure. The purpose is to show two related procedures and the effect of operational variations has

on the noise impact. It also demonstrated how a well designed graphical decision aid can communicate this effect to airport planners and community members alike.

With regard to the sensitive receptors, the new procedure affects a greater number of sensitive receptors when the idealized procedure is followed, but the difference disappears when the operational variation is considered. The actual procedural change has yielded similar results. In addition, the Final Decision analysis does find a few hundred people in the 65+ DNL contour while this case study did not. A difference of few hundred people are well within the error range of this case study based on the broad approximations. The community and airport operator must make a number trade-offs and the noise impact module allows these comparisons to be made by presenting the information in a graphical format which present the options.

If the research indicating that adverse affects are manifested in a community with a noise impact well below the legal limit proves to be accurate, a decision to ignore the effects for DNL contours below 55 DNL might subject more communities to such effects. The only possibility in such a situation is a change in a fundamental way the way in which noise impact compensation is calculated. Such a change is not within the scope of a local negotiating committee. The 65+ DNL contours are important because they define the legal limit, while the 55-65 DNL contours are relevant because they indicate how the noise impact would change with an increase in operational tempo. The 45-55 DNL contour represents the area in which a majority of the community members live as shown in Table 6.1 and Table 6.2; it is important that their noise impact be represented to grant legitimacy to the noise impact graphics.However, day averaged noise levels below 45 DNL are quieter than any found in a busy city or small town, making a separate calculation of aircraft noise in this range misleading.

Using a modified runway 27 departure procedure, the different graphical methods arrive at different solutions to the question whether the new procedure will lessen the noise impact on the communities neighboring Logan. The aggregation scheme which assumes perfect adherence to flight procedure clearly favors the new procedure. The aggregation scheme which takes into account variations in the flight procedure suggests that the change may not have a noise benefit to the communities. The graphical decision aid which focuses on showing the affected population clearly shows this lack of change in the 55-65 DNL contour size. This disparity in the outcomes indicates a lack of robustness in the idealized solutions. While there may be no alternatives at this time, community members and airport planners should be aware of potential problems.

The runway 27 controversy is not an isolated incident. The community pressure on airports in increasing. A graphical decision aid can incorporate very large data sets and render an interpretable graphic. The natural scene representation of a complex technical and legal issue allows a single graphic to bridge the gap between the airport operators who are eager to clarify the air traffic control limitations inherent in aircraft flight and the community, who are eager to show how they are disturbed. Like all models, this graphical representation is only as good as the data used to produce it. Therefore, until legal guidelines are established to legitimate data sets such as flight path dispersion, this type of tool can only be used as relative measure among a set of alternative solutions.

# Chapter 7

# Conclusion

The noise impact around a major international airport often exceeds 65 DNL, the EPA's noise limit for residential land use. When this occurs, a legal taking of the property owners ability to use and enjoy the property has occurred, and the property owner is entitled to compensation. Local guidelines for the type and level of compensation required are determined through negotiations between airport operators and the nearby communities. Like many public policy debates, the parties arrive at the table with different hopes and expectations, as well as widely differing levels of experience in the technical and social aspects of the problem. This difference in experience and frame of reference puts a greater onus on any decision aid to bridge the gap between the different parties. The large volume of data required to fully understand the impact of aircraft noise in a community makes anything but a graphical decision aid impractical.

A computer based graphical decision aid has been developed for use in noise negotiations. The current method of modeling is limited to the consideration of scheduled flights proceeding along precisely defined routes. There is no allowance for unscheduled flights or deviations from the official flight path. The graphical decision aid complements the existing computer modeling techniques in that it performs functions not previously available. The graphical decision aid uses as input either the output of a flight simulator or actual flight data. Multiple inputs can be used to account for different types of aircraft or different flight profiles. The possible outputs range from the noise profile of a single flight to an aggregate DNL contour taking into account flight path variation. The operator specifies the number of different flight profiles for the desired DNL contour.

The graphical decision aid presents a large data set using natural scene representation to permit viewing and understanding by a diverse audience. The superposition of a color noise impact on a black-and-white map provides a natural frame of reference for the community as well as the airport operators, and takes advantage of the most sophisticated analysis system, the human visual system. By combining flight path data with the geographical and population data, the graphical decision aid represents the noise impact of aircraft operations on the communities near the airport in a easily comprehensible format which is relevant to the decision at hand. The tool is versatile because it is able to display single flight path data, aggregate DNL contours, and community noise impact allows for the display of the relevant data, making it a believable graphic for the community.

Use of the tool was illustrated in a case study which evaluated two departure procedures from runway 27 at Logan Airport in Boston, Massachusetts. The results showed the unsuitability of the premise used by previous noise impact calculations that all aircraft perfectly follow the official procedure. This is clear to the resident whose home is many blocks from the published flight path yet routinely sees flights on either side of his/her home. Such operational error has a significant impact on the quality of life of persons living in the vicinity of the flight path. The other result is that the change in impact made possible by a small procedural change is minimal, but can reduce the noise at a specified location. The use of idealized flight paths for modeling noise impact does not result in a robust solution for modeling the noise effects on neighboring communities. Use of the graphical decision aid will allow planners to evaluate the effect of procedural changes on a case by case basis. By applying the graphical to real situations, it is possible to show the factors and future trends which need to be considered by airport and community planners.

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