AN ASSESSMENT OF THE NOISE IMPACT ASPECTS OF AIRCRAFT AND AIRPORT COMPATIBILITY

Kenneth McK. Eldred, Ken Eldred Engineering, Concord, Massachusetts

Abstract

This paper briefly describes the quantitative measures of noise appropriate to airports, the response of people to noise outside their homes, and land use criteria. It then presents a summary of the estimated current and future noise impact from airport operations, and an assessment of the potential for reducing their impact through airport noise control programs.

Introduction

In the late 1960's the Civil Aviation Research and Development (CARD) study (1) found aircraft noise in the vicinity of airports to be a major impediment to the development of airports and the growth of the civil aviation system. Subsequent events have proved this finding to be correct. Law suits, environmental impact statements, and state and local attempts to regulate airports, brought the development of existing airports to a crawl - and the development of new major airports practically to a complete halt.

Today, over a decade later, noise is still a major impediment to airport development, and it may continue to be an impediment for the next twenty years. Yet there is now some light at the end of the tunnel. The retirement of older noisier aircraft with their replacement by new quieter aircraft is underway. This accomplishment is the result of government and industry research and development since the late 1950's; Federal Aviation Administration (FAA) certification for noise beginning in 1969; and the design and production of new, quieter aircraft beginning in the early 1970's. We must not be lulled into believing that these achievements are sufficient to solve completely the nation's airport/aircraft noise problem in the very near future. They will not. But, they will bring sufficient improvement to offer the hope that the civil aviation system will gain some credibility with airport neighbors. And, hopefully, the system will have the wisdom to build on its new credibility to establish better working relationships among airports, their users and their neighbors.

Noise Descriptions and Their Application to Aircraft/Airport Noise

Magnitude and Frequency Weighting

A person's ability to perceive a specific sound depends upon its magnitude and character, as differentiated from the magnitudes and characters of other competing sounds in the environment. The magnitude of sound is generally described as its level, which is proportional to the logarithm of the mean square of the sound pressure fluctuations at a measuring microphone. The unit of magnitude is the decibel (dB).

There are many subjective attributes which can be used to describe the character of a sound. The most important have to do with its frequency content and its temporal pattern. Frequency spectrum content may be described in terms such as high pitched hiss, low rumble, tonal, broadband, etc. People hear sound at frequencies between 500 and 5000 hertz better than they hear sounds at lower or higher frequencies. Therefore, to measure the magnitude of sound in a way that is proportional to its perceived magnitude, it is necessary to weight the low and high frequency sounds so that they contribute less to the measured magnitude than do sounds at the middle frequencies that are heard more readily. The frequency weighting most commonly used for this purpose is the A-weighting which rolls off the low and high frequency sounds in much the same manner as can base and treble controls on a hi fi set.

The zero decibel value on the A-weighted sound level scale (sound level for short) is the reference pressure of 20 micro pascals (micro-newtons per square meter). This value was selected because it approximated the smallest sound pressure that could be detected by a human. The average sound level of a whisper at a one meter distance from the person who is whispering is 40 dB; the sound level of a normal voice at a one meter distance is 57 dB; a shout one meter away is 85 dB.

A more complex and more accurate frequency weighting to account for human perception is the perceived noise level. This scale was developed during a decade of research into aircraft sounds. It, together with a correction penalty for pure tones, is the magnitude scale used in measuring aircraft noise for certification. For a typical aircraft sound the value of the tone-corrected perceived noise level is typically 12-16 dB greater than that of the A-weighted sound level.

Time Variation of Sound Level

The temporal patterns of the A-weighted sound level are most easily observed on a continuous graphic level recording, such as the two eight-minute samples illustrated in Figure 1. One of the most striking features of these temporal patterns is that the sound level varies with time over a range of 33 dB, which is a ratio of 2000 to 1 in sound energy.

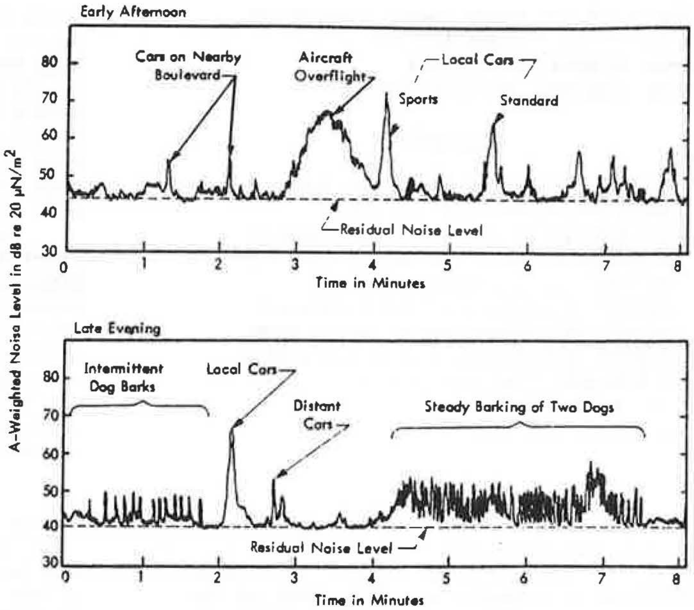
In these examples the sound seems to be characterized by a fairly steady state lower level, called the residual level, upon which is superimposed short term increases in sound level associated with various discrete (individual) single events. These single event sounds may be partially defined by their magnitudes or maximum sound levels. But they may also be characterized by their time patterns. The sound level of the aircraft in the example is greater than the residual sound level for approximately 80 seconds, whereas the sound levels from the cars are greater than the residual for much shorter durations ranging from about 5 to 20 seconds. Clearly, if the sound associated with one or more of these single events were of sufficient magnitude to intrude on a person's activities, the duration of the single event might be expected to effect the degree of intrusion, and of annoyance.

Experiments have demonstrated these effects and shown that the proper measure of the sound associated with a single event is to add all the sound energy together throughout the duration of the event. The quantity which expresses the total sound associated with a single event is sound exposure level (SEL) when the instantaneous magnitude of the sound is the A-weighted sound level. The analogous quantity, when tone-corrected perceived noise level is used as the measure of the instantaneous magnitude of the sound, is the effective perceived noise level (EPNL). EPNL is the primary quantity used for noise certification of aircraft under FAA regulations in FAR Part 36. (4) EPNL values are typically 2-6 dB greater than SEL values for aircraft sounds.

Duration and Number of Events

The large variation in sound level seen in the two samples of Figure 1 make it difficult to find any single number to characterize the amount of noise

Figure 1. Two samples of outdoor noise in front yard in Pacific Palisades (2), (3), with microphone 20 feet from the street curbing.



in either sample. One could identify the maximum and residual sound levels but this would leave out the important factor of the duration of the sound at levels between the maximum and residual levels. One could also describe the statistical properties of the sound in terms of the time above each of several levels selected to be at convenient intervals. But this would lead toward the use of many numbers to describe a noise rather than toward the use of a single number.

One solution to this problem is to determine the level of a steady-state sound which has the same A-weighted mean square sound pressure as does the actual time varying sound. This quantity is termed the Equivalent Sound Level (L_{eq}). Its principal virtue, besides providing a single number description of a complex time history of sound levels, is that its magnitude correlates well with the effects of sound on people. (5) This correlation extends over a wide variation in types of sound levels and time patterns, and effects, which range from speech interference to risk of hearing loss. L_{eq} is also the basis for the day-night sound level which is most often used to describe the outdoor noise environment.

The day-night sound level (L_{dn}) is defined as the A-weighted equivalent sound level for a 24 hour period with a +10 dB weighting (or penalty) applied to equivalent sound levels occurring in the nighttime hours between 10 P.M. and 7 A.M. The nighttime penalty acts to increase the apparent levels at nighttime by 10 dB. Hence, an environment that has a steady daytime L_{eq} of 60 dB and a nighttime L_{eq} of 50 dB, has a weighted nighttime level of 60 dB (50 + 10) dB and a day-night sound level of 60 dB. The day-night sound level was developed by the Environmental Protection Agency as the principal descriptor for outdoor noise in the community (5). It has subsequently been adopted by the Department of Defense, Department of Housing and Urban Development (6), and by the FAA for airports in its regulations in FAR Part 150.

The analogous quantity to L_{dn} in the perceived noise level system is the Noise Exposure Forecast (NEF). This quantity uses a 12 dB nighttime weighting rather than a ten dB weighting. The numerical value of NEF is generally approximately 35 dB less than that of L_{dn}.

Figure 2 gives an example of annual average day-night sound level contours around Logan International Airport The L_{dn} 65 and 75 dB contours are depicted with heavy lines. The relative size and shape of these contours is a function of the relative utilization of the six runway ends for takeoffs and landings. Also illustrated in the figure are typical values of sound exposure level (SEL). These values range between about 90 and 96 dB on the L_{dn} 65 dB contour. This variation in the value of SEL on a given L_{dn} contour reflects the variation in the relative number and type of operations on the various runways since:

$$L_{dn} = \overline{SEL} + \log N_e - 49.4 \text{ in dB}$$

where $\overline{SEL}$ is the mix average sound exposure level at a given location

and N_e is the effective number of operations (either takeoffs or landings) equaling the number of daytime operations plus ten times the number of nighttime operations

Response of People to Noise

Many of the effects of noise on individuals are highly dependent on specific situations and not readily generalized. However, three primary direct effects - activity interference, annoyance and hearing loss - have been studied extensively, and their statistical relationships to noise provide the primary quantitative basis for noise evaluation and control. These quantitative relationships are summarized by EPA in its Levels Documents (5), and have been extended in the area of environmental assessment by the National Research Council, in its guidelines for assessment of the environmental impact of noise (9). The two effects applicable to airport noise, activity interference and annoyance, are summarized in the following.

Activity Interference

Social surveys have developed information on activity disturbance from environmental noise. In the late

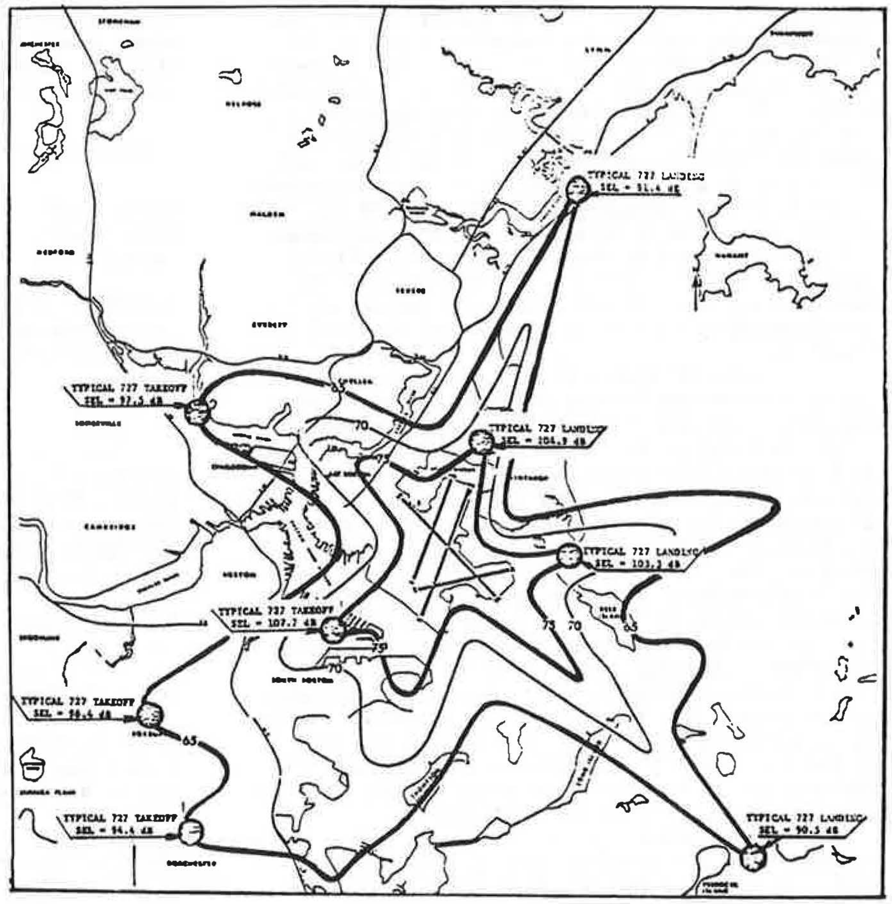


Figure 2. Example of cumulative noise contour from airport operations.

1960's, a survey (10) of over 4000 persons who were exposed to airport/aircraft noise revealed that the activity interference most often cited as extremely disturbing involved speech listening. (Table 1)

Table 1. Rank order of activities by percent extremely disturbed* by interference of aircraft noise (10).

	Percent
TV/Radio reception	20.6
Conversation	14.5
Telephone	13.8
Relaxing outside	12.5
Relaxing inside	10.7
Listening to records/tapes	9.1
Sleeping	7.7
Reading	6.3
Eating	3.5

*Percent scoring 4 or 5 on a 1-5 scale.

The first three of the activities in Table 1 involve speech communication. Here, the degree of interference is readily quantified in terms of sound level and listening situation. For the other six activities, the degree of interference often depends upon factors other than the magnitude and character of the noise, and these factors are not readily quantified. Note that criteria have not been established for noise levels which interfere with listening to music at home, although such criteria do exist for performing arts halls.

Interference with Speech Communications

Noise can interfere with speech communication in situations encountered at home, at work, in vehicles, and in other settings. Of chief concern to the majority of the exposed population is the effect of noise on face-to-face conversation indoors and outdoors, telephone use, and radio or television enjoyment. The extent to which noise affects speech communication depends on the location (whether indoors or outdoors), the magnitude of the noise, and the vocal effort of the talkers. It is possible to maintain communication over a wide range of intruding noise if the voice level is raised, but there is an upper limit above which no speech communication is possible. As the magnitude of noise is brought below this limit, the quality of communication steadily improves until a lower limit is reached where no interference can be detected.

The chief effect of intruding noise on speech is to mask the speech sounds and thus reduce intelligibility. The important contributions to intelligibility in speech sound cover a range in frequency from about 200 to 6000 Hz, and at each frequency speech has a dynamic range in level of about 30 dB. The intelligibility of speech will be nearly perfect if all these contributions are available to a listener for his understanding. But when noise masks, or covers up, some of these contributions, the intelligibility deteriorates. The amount of this deterioration depends on the noise level, the speech level and the degree to which the noise frequencies coincide with the important speech frequencies.

The results of speech research can be used to determine the levels of noise that will produce varying degrees of masking as a function of vocal effort and the distance between talkers and listeners. Other factors, such as the talker's language, the listener's motivation, and of course, the sharpness of the listener's hearing also influence intelligibility. The effects of noise in masking normal conversational speech in a home indoor situation are shown in Figure 3. If the level of the noise does not exceed 45 dB, 100 percent speech intelligibility is often assumed possible. If the level of the noise is then increased to 65 dB, the sentence intelligibility is expected to drop to 95 percent. If the words in the speech are not so familiar as those contained in ordinary conversational sentences, the intelligibility will be less than that depicted in Figure 3.

The level of speech sounds decreases as the distance increases between a talker and a listener. However, in an indoor situation, the distance over which the level decreases is limited by the enhancement of the speech sounds by reflection from the various surfaces and objects in the room. At greater distances in the room between talker and listener, the listener is in the reverberant field where the level of the speech sounds is essentially constant. The relationships shown in Figure 3 apply in the reverberant field of a room in a typical home when the distance to the reverberant field is approximately one meter (1.1 yard). If a room has significantly more acoustic absorption than assumed, the distance to the reverberant field increases somewhat, and the intelligibility is slightly less than that shown. If the room has significantly less absorption, the distance to the reverberation field and the intelligibility is somewhat better than shown.

Outdoors, where the talker and listener are not surrounded by the sound-reflecting surfaces of a room, the level of the speech sounds continues to decrease with increasing distance between talker and listener. Table 2 presents the maximum noise levels allowable for marginal communication conversation at the indicated distances and voice levels.

Figure 3. Sentence intelligibility for normal voice as a function of the steady background sound level in a typical indoor home situation (9).

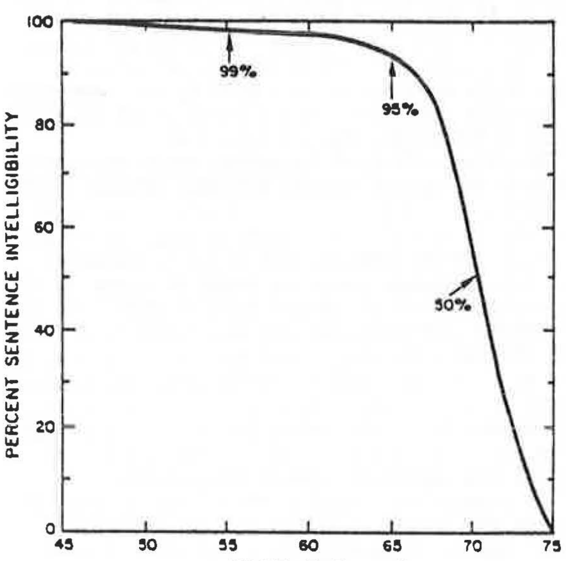


Table 2. Relationship between maximum A-weighted sound levels in dB which allow marginal communication (95 percent sentence intelligibility) over various distances outdoors* (11).

	Distance in Meters				
Voice level	0.5	1	2	3	5
Normal voice	72	66	60	56	52
Raised voice	78	72	66	62	58

*Subtract 20 dB to obtain levels for which no interference is expected (100 percent sentence intelligibility).

These maximum noise levels allowable for 95 percent sentence intelligibility are about 20 dB greater than the maximum noise levels allowable for 100 percent speech intelligibility, just as shown in Figure 3 for the indoor situation. However, outdoors, for a given noise level intelligibility may be improved by moving closer to decrease the distance between speakers, in addition to increasing the vocal effect.

For situations in which the magnitude of the noise fluctuates with time, the equivalent sound level may be substituted for the steady state sound level in either Figure 3 or Table 2. This substitution has been shown to be valid for real highway noises and other fluctuating noises. (12), (13)

Annoyance

The cumulative effect of activity interference by noise is often measured in terms of annoyance. Although other factors, such as attitude towards the noise source, may influence an individual's reaction to activity interferences, the percentage of people annoyed, or highly annoyed, in a given environmental situation provides a useful index of the severity of the situation. The relationships between noise and annoyance have been deduced from a series of social surveys and examination of community complaints and reactions to intruding noises.

The results of social surveys in several countries have been combined to give a general relationship between long-term average outdoor environmental noise in residential areas and the annoyance of the residence. (14) The surveys were associated with several types of noise situations, including noise resulting from urban traffic, highways, railroads, and airports. The results for 12 of the 19 surveys studied clustered closely around an average curve of all of the data, as shown in Figure 4. The results of the seven surveys that did not cluster as closely as those shown still had essentially the same average values.

The annoyance data are given in terms of the percentage of respondents who reported that they were highly annoyed by the noise. For this purpose, the people counted as "highly annoyed" are those whose response was in the top 27 to 29 percent of an annoyance scale ranging between "none" and "extreme," and for surveys where the scale steps were named, those who categorized themselves as "highly" or more than "highly" annoyed.

The results show that fewer than five percent of of the people are highly annoyed when the L_{dn} is less than 55 dB, and more than 37 percent of the people are highly annoyed when the L_{dn} is more than 75 dB. (14) These results are averages of many individuals, levels and situations. They appear to be useful in a statistical sense when applied to a large population over a range of situations. However, they may not give good predictions for an individual situation or for an individual person. For example, recent annoyance data at Burbank (15) shows much higher annoyance from aircraft noise than would be expected from the results in Figure 4.

For specific situations other factors must be considered, such as attitude toward the source of the noise, the relationship between the general background noise and that of the intruding noise, and the amount by which sound is attenuated from outside to inside (for example, windows typically open or closed). These factors have been partially evaluated in studies of community reaction. (2), (3) Their inclusion in the analysis may give significant improvement in specific situations.

Community Reactions

Analysis of the community reaction to a variety of types of intruding sounds demonstrates that the degree of reaction varying between "none" and "vigorous" is a function primarily of the relative level with and without the intruding noise. Corrections for other factors, such as prior experience, attitude, and the character of the noise, can improve the accuracy of this relationship. The principal corrections used for normalization were to add 5 dB to the level of the intruding noise if there was no prior experience with the noise, if it was of impulsive character, or if it contained prominent pure tones. A negative correction of 5 dB was applied to the level of the intruding noise if the noise occurred in winter only or the windows were always closed, or if the community had considerable prior exposure and a good relationship with the noise maker (see (3) for additional detail).

The results of applying these corrections to the intruding noises measured in 55 cases is shown in Figure 5. Approximately one-half of these cases involved steady state industrial and residential noises and the other one-half consisted of time varying transportation and industrial noises.

The non-reaction response in Figure 5 corresponds to normalized outdoor L_{dn} ranging between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value of 60 dB that characterizes the noise in a residential urban community (5) and that is the baseline category of normalizing the data. Thus, these data indicate that on the average no community reaction to an intruding noise should be expected when the normalized L_{dn} of the intruding noise is 5 or more dB less than the value of the L_{dn} existing in the absence of the intruding noise.

The data in Figure 5 indicate that widespread complaints may be expected when the normalized value of the outdoor L_{dn} of the intruding noise exceeds by 5 dB that L_{dn} existing without the intruding noise. Vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation in these data is 3.3 dB about their means and a tolerance band of ±5 dB envelopes approximately 90 percent of the data. When the data are not normalized, the correlation becomes much less, with the standard deviation increasing from 3.3 to 7.9 dB.

Land Use Criteria with Respect to Human Response

The Environmental Protection Agency (EPA) in its levels document (5) identified for residential areas L_{dn} of 55 dB as the "level...requisite to protect the public health and welfare with adequate margin of safety," the words in quotations representing its congressional mandate. (16) This level was derived by selecting 45 dB within a home as compatible with 100 percent speech intelligibility, adding 15 dB to account for the average noise reduction of a home with partially open windows, and subtracting 5 dB as a margin of safety to account for other effects. It should be noted that this identified level of 55 dB is not a regulation.

EPA, in its strategy document, (17) first recommended immediate efforts to reduce noise exposure to a L_{dn} value of no more than 75 dB. This value is essentially consistent with the L_{dn}

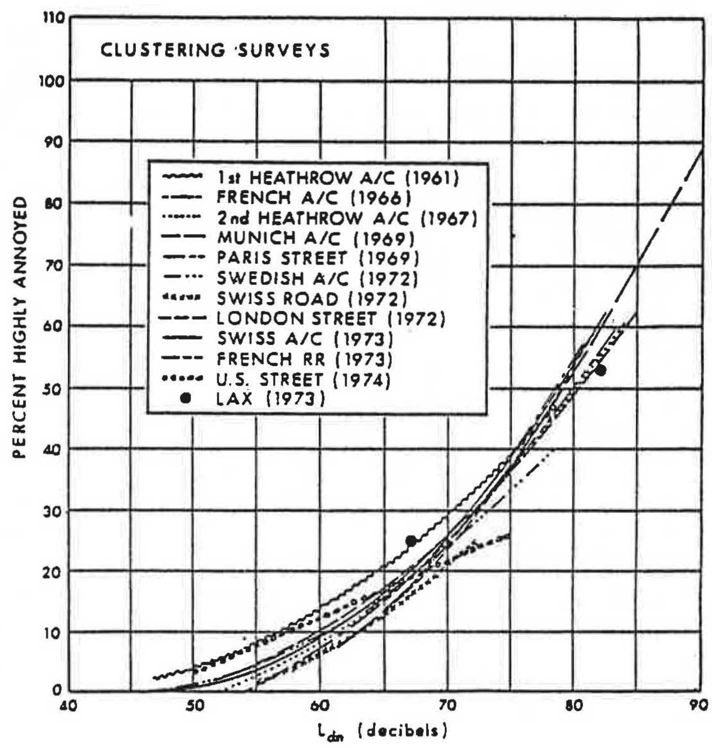
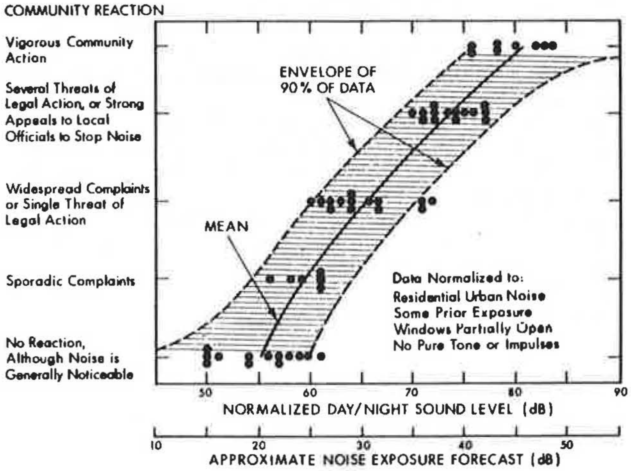


Figure 4. Summary of annoyance data from 12 to 19 surveys in which data show close agreement. (14)

Figure 5. Community reaction to intrusive noise of many types as a function of the normalized day/night sound level. (3)



previously identified (5) as a maximum level with respect to protection of hearing. Second, EPA recommended reduction of environmental noise levels to L_{dn} 65 dB or lower through vigorous regulatory and planning actions. Third, EPA recommended adoption of L_{dn} 55 dB as a goal to be considered "to the extent possible" in the planning of future programs.

An L_{dn} of 65 dB is the maximum level acceptable to HUD (6) for residential housing sites without special approvals. HUD also considers that noise levels above an L_{dn} of 75 dB are unacceptable for residential use. Similarly, the FAA (7) considers L_{dn} values of less than 65 dB to be normally compatible with all land uses and values of more than 75 dB to be normally incompatible with residential land use, even with increased noise reduction. More detailed sets of recommendations are contained in both of these regulations.

Estimate of Current and Future Noise Impact

Several studies have been conducted since 1970 to estimate the impact of the noise from airport operations on neighboring residents. The maximum value of the population estimated to reside in areas where the L_{dn} exceeded 65 dB (NEF 30) was variously estimated between 5.0 and 7.5 million people. (18), (19), (20), (21), (22), (23)

An estimate of the national variation of this noise exposure for the years 1960-2000 is given in Figure 6. (24) It shows a rapid increase of the population exposed to L_{dn} values greater than 65 dB from zero to 95 percent of its maximum value in the ten years following the introduction of the B707 turbojet airliner in 1948. The estimate shows little change in the early 1970's, a maximum of 100 percent in 1975 then a decline to 50 percent in 1985. It should be emphasized that these estimates are for the national fleet, not for specific airports. The noise impact at many of the large international airports peaked in the early 1970's and then began to decrease as wide-body jets replaced narrow-body four engined jets. However, the noise impact at other smaller airports with only JT8-D aircraft was still increasing in the late 1970's because of increased numbers of operations, and without a significant change in fleet mix.

It should be noted that the most perceptible decrease in population impact to be seen in Figure 6 is due to be completed in 1985 when the majority of the older noisier aircraft will be either retrofitted or retired. After that date, the estimated decrease in noise impact continues, but at a much slower rate, with the noise dominated by Stage 2 JT8-D powered aircraft, the B727-100-200, B737-100-200 and the DC9-10-50. If these aircraft were to be retired by the year 2000, the percentage of the maximum population exposed to airport noise in excess of an L_{dn} of 65 dB would be reduced from 37 percent to approximately 13 percent. However, even this 13 percent of 5-7.5 million would be 650 thousand to 1.0 million people. Without retirement of earlier JT8-D aircraft or other airport noise control programs, the number of people exposed to levels exceeding an L_{dn} of 65 dB are estimated to be 1.85-2.75 million in the year 2000.

Potential Noise Reduction 1982-2000

The total noise around an airport is usually displayed in contours of equal cumulative noise, such as those on Figure 2. The magnitude of the total noise impact at an airport is usually stated as either the area or the population as a function of contour noise level. For a specific airport the contour noise levels, sizes, shapes and populations encompassed are principally dependent on the seven factors listed in Table 3.

It has been shown (24) that these seven factors can be subdivided into two almost independent subsets that may be called 1) the aircraft noise characteristic, and 2) the airport noise impact potential (see Table 3). The airport noise characteristic contains the three factors that are most strongly correlated with the total noise output at an airport, or that of the national fleet. The airport noise impact potential contains the four factors that are most strongly correlated with the shapes of the noise contours and their spatial distribution with respect to population.

The magnitude of the noise impact potential at an airport may be expressed directly in terms of population versus related noise level or the combination of population versus area and area versus relative noise level. The relative noise level must be suitably chosen so that the absolute value of the noise at an airport may then be estimated using the aircraft noise characteristic. The aircraft noise characteristic at an airport may be represented by the L_{dn} calcuated in the airport fleet operations at a fixed distance from the aircraft and for a specified engine thrust.

For national estimates, the aircraft noise characteristic level can be obtained by estimating the L_{dn} (or NEF) at a selected distance for the fleet average daily operations and relating it to area. The best correlations between the estimated aircraft noise characteristic level and area have been found in one study to occur when the characteristic level was calculated for maximum climb thrust at a slant distance of 1000 feet. (21) The results for the national data base derived in this manner (24) are summarized in Figures 7 and 8.

Figure 7 shows that the relative national population potentially impacted by aircraft noise is a smooth function of the noise contour area. Figure 8 shows that the estimate total area within L_{dn} 65 dB (NEF-30) is well correlated with the air carrier fleet total aircraft noise characteristic level (FTNCL). The FTNCL is calcualted by computing the takeoff sound exposure after cutback of thrust for

Figure 6. Estimated change in relative population residing within noise contours of NEF 30, 35 and 40 dB (equivalent to L_{dn} of 65, 70 and 75 dB respectively) for airport operations from 1955-2000 and constant 1970 population. (24)

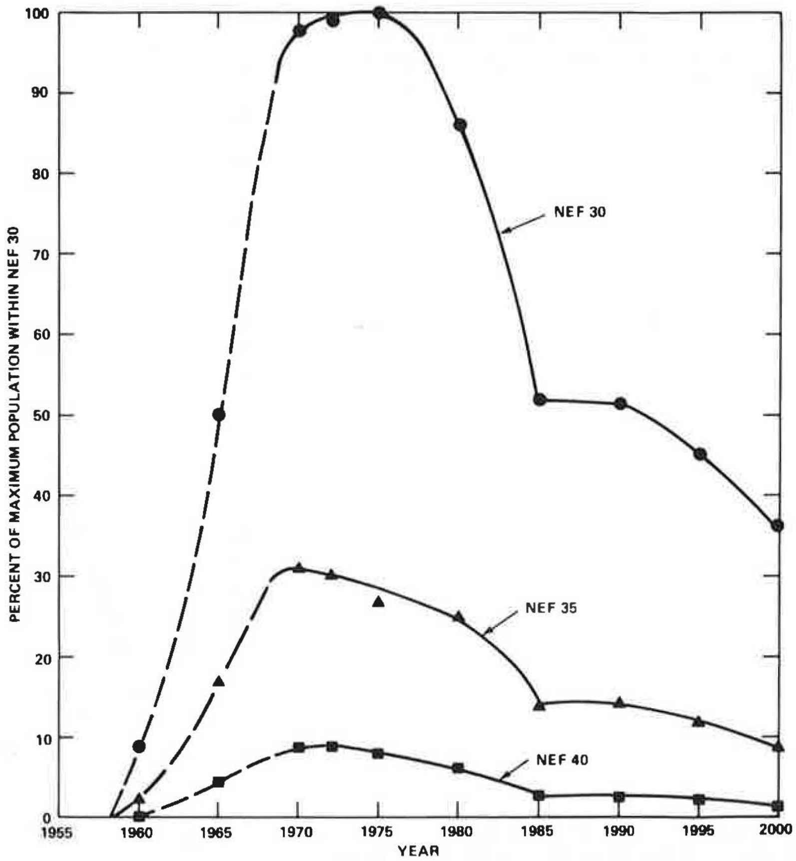


Table 3. Factors in airport noise impact.

a)	NOISE VS DISTANCE BY AIRCRAFT TYPE	AIRCRAFT NOISE CHARACTERISTIC
b)	NUMBER OF OPERATIONS BY AIRCRAFT TYPE	
c)	RATIO OF THE NUMBER OF DAYTIME TO NIGHTTIME OPERATIONS BY AIRCRAFT TYPE	
d)	FLIGHT PROCEDURES (THROTTLE AND FLAP MANAGEMENT) USED FOR LANDING AND TAKEOFF BY AIRCRAFT TYPE	AIPPORT NOISE IMPACT POTENTIAL
e)	STAGE LENGTHS (TAKEOFF AND LANDING WEIGHTS BY AIRCRAFT TYPE)	
f)	SPATIAL CONFIGURATION AND RELATIVE UTILIZATION OF THE FLIGHT TRACKS BY AIRCRAFT TYPE	
g)	SPATIAL DISTRIBUTION OF POPULATION	

each type of aircraft at a slant distance of 1000 feet times its average daily operations and summing over all aircraft types.

Figure 9 shows the estimated change in FTNCL for commercial operations in the U.S. from 1960 through 1995. Its value reached a maximum in 1975 of about 9 dB greater than its value in 1960. Its value in 1985 is about 2 dB less than in 1975, and in 1995 one dB lower than in 1985. However, if the JT8-D aircraft were retired by 1995 the FTNCL in that year would be about 8 dB less than its 1975 value, almost reducing it to its value in the early 1960's.

It should be noted that the national fleet average noise characteristic level has been steadily going down since 1960 at a rate of about 3.3 dB per decade. This rate of decrease should continue approximately to the year 2000-2005 when the fleet will become almost entirely composed of aircraft certificated for noise to the levels of the FAR Part 36 - Stage 3.

Goals for Source Reduction

Analysis of the relationships in Figures 7 and 8 indicates that to reduce the population exposed to an L_{dn} in excess of 65 dB to 0.3 percent to 1.0 percent of its maximum value requires a reduction of 16-19 dB below the 1975 value in the fleet average noise characteristic level (FANCL). This reduction would result in levels that are 6 to 9 dB below the levels for an all high bypass fleet. Similar analysis of single event data (25) indicates that to attain negligible population within a L_{dn} 65 dB at an average busy runway for a hypothetical 220,000 maximum gross weight fleet average aircraft requires levels that are 14-16 dB below the 1975 values and 9-10 dB below the Stage 3 levels. Satisfying these requirements would mean that the EPNL limit for takeoff would be about 85 EPN dB for a 220,000 pound max-gross weight aircraft.

This analysis shows that considerable additional source reduction would be required if source reduction were to be the only method of controlling airport noise. And even if a Stage 4 regulation with levels 10 dB below Stage 3 were a possibility, which it is not, at least today, one would not expect to realize

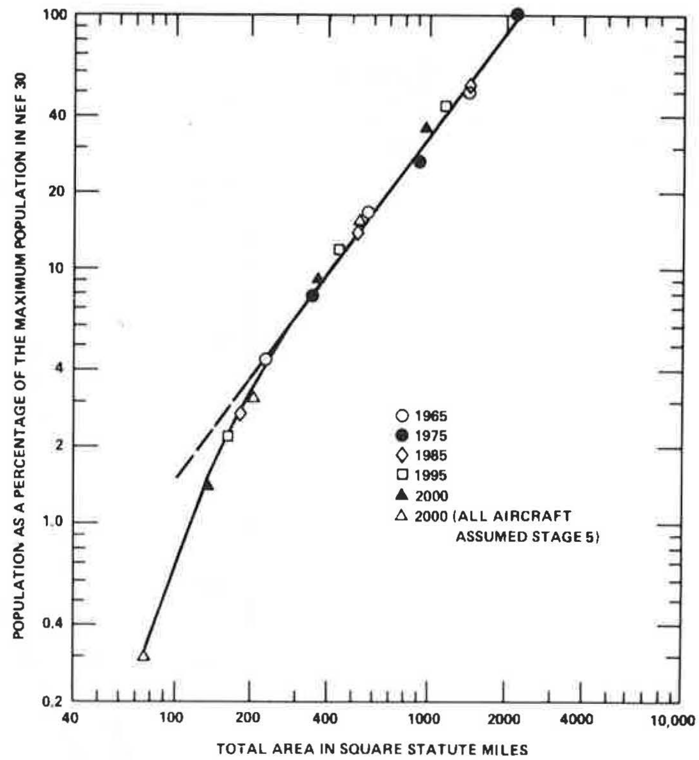


Figure 7. Relative population as a function of contour area. One hundred percent has been variously estimated to be between 5 and 7.5 million people. (24)

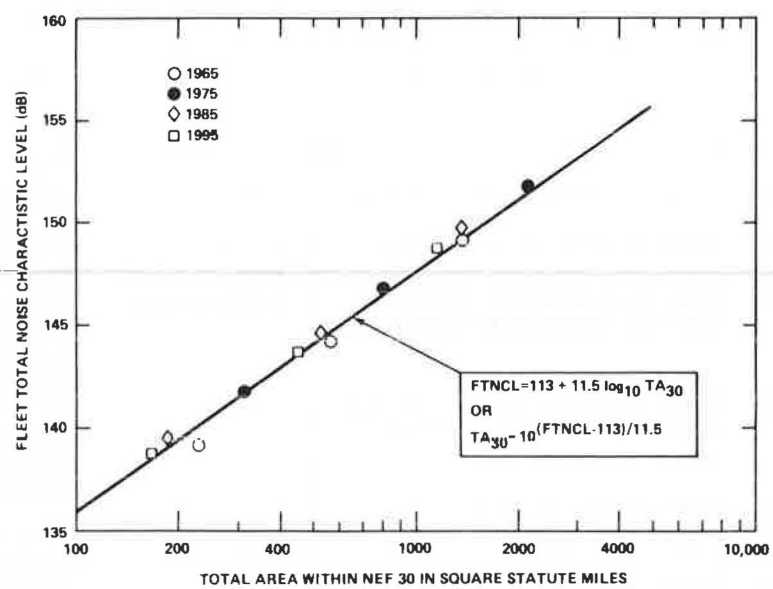


Figure 8. Estimated relationship between total contour area within NEF 30 (TA_{30}) (almost the same as L_{dn} 65 dB) and the air carrier fleet total characteristic noise level (FTNCL) for the national civil airport system. (24)

a Stage 4 fleet before the year 2015 to 2020. Thus, even under the most optimistic scenarios it is clear that additional source reduction beyond Stage 3 cannot be counted on for added potential airport noise reduction in the near term. Therefore, additional near term noise reduction must be found when possible at the airports where it is required. (26) (28) This airport specific approach, coupled with continued vigilance towards reducing certification levels by as much and as soon as technologically practical and economically feasible, should speed the long term solution to the airport noise problem.

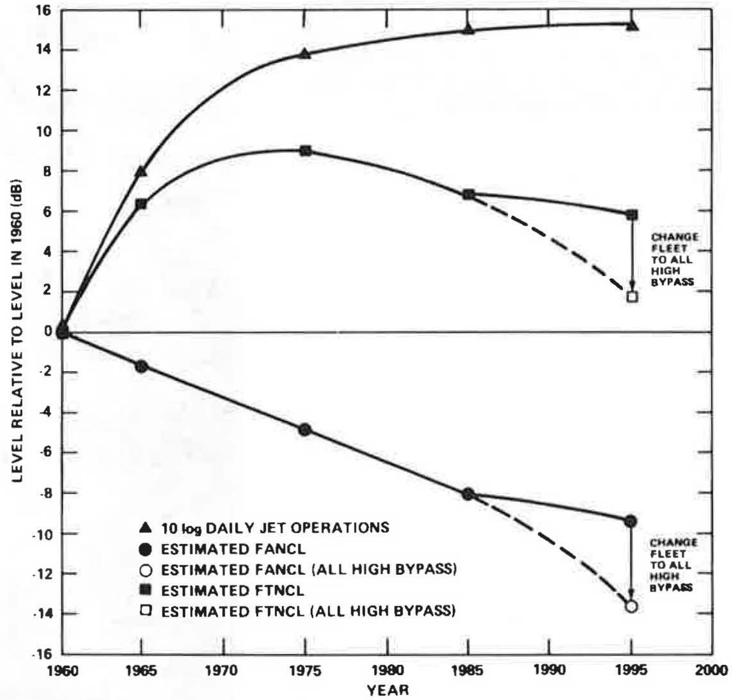
Noise Control Options at Specific Airports

The significant factors for the noise at any specific airport were summarized in Table 3. Each has potential use for noise control. However, as will be seen in the following brief analyses there may be significant economic and other conseuqences associated with achieving noise reduction by use of some of these factors.

a. Maximum Noise level Restrictions in the Community

The basic noise versus distance by aircraft type as used here is considered to be fundamental to the design - and thus controlled through the FAA certification process. However, an airport can

Figure 9. Relative change in fleet average noise characteristic level (FANCL), ten log average daily air carrier operations and fleet total noise characteristic level from 1960 to 1995. (24)



establish limits on the maximum levels of noise at stated positions or distances, which could be set to prohibit the use of the airport by noisier aircraft. These limits may be set by time of day, e.g., nighttime limits are often lower than are daytime limits.

There is considerable controversy over how these limits are to be applied: 1) to assure that they are non-discriminatory, and 2) over how much curtailment of operations through progressively more restrictive noise limits is permissible before it is considered to interfere with interstate commerce. Finally, direct economic costs and inditect costs resulting from a decrease in availability of transportation service, may become a significant factor depending upon the fleet mix at a specific airport, and the proportion (and function) of the fleet affected by the limit.

b. Restrictions of Number of Operations by Aircraft Type

Limiting the number of operations by aircraft type is very difficult under current legal constraints, except for curtailing operations of the noisiest or largest aircraft by an appropriate non-discriminatory regulation (see a. above). In some situations the airport fleet may contain only one type of aircraft, or its noise may be dominated by a significatn number of operations by one type of aircraft. If it is impracticable to consider eliminating service from that type of aircraft,then some noise reduction could be obtained by reducing the numbers of its operations. There usually are at least two problems with this approach. First, limiting operations is not very cost effective, i.e., a 1 dB improvement requires a 21 percent reduction in operations and a 3 dB improvement requires a 50 percent reduction in operations. Second, with deregulation, there are considerable legal hurdles to overcome in endeavoring to find a practicable and legal scheme for controlling the numbers of operations.

c. Restrictions of Nighttime Operations

The nighttime noise penalty of 10 dB in the day-night sound level descriptor means that the noise from one nighttime operation is counted the same as is the noise from ten daytime operations of similar character. Thus, for airports which have nighttime operations (10 P.M. to 7 A.M.), their reduction often appears to have considerable potential to reduce noise impact. Often, considerable progress may be achieved through working with the airport's user-operators to eliminate nighttime flights that have only marginal benefit, rescheduling other operations and providing quieter aircraft for nighttime. This latter result can be achieved for all nighttime operations by a nighttime noise limit (see a. above).

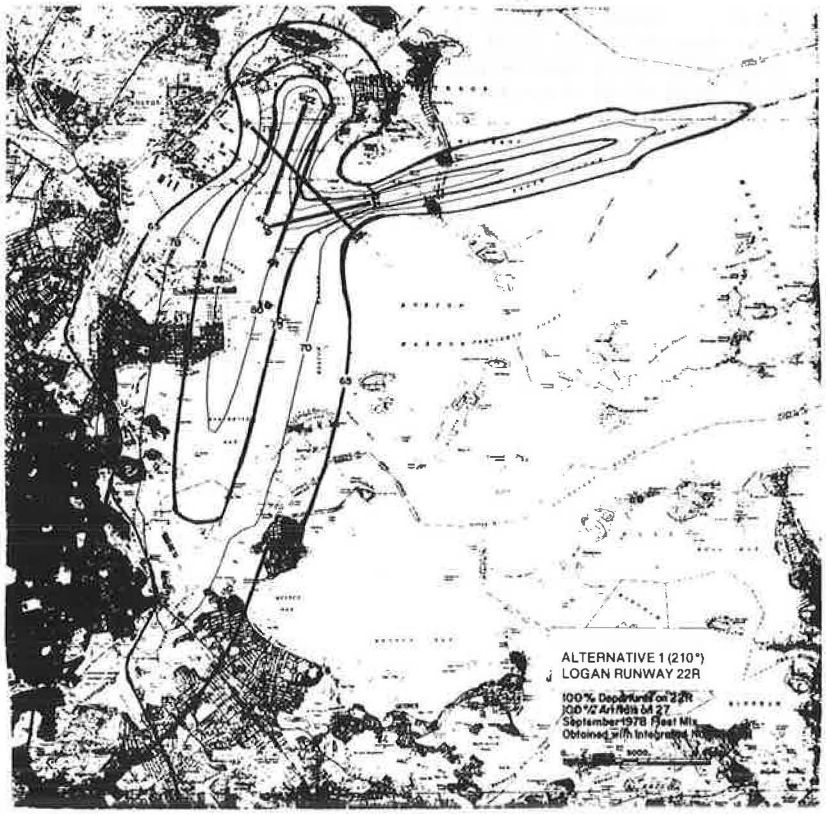
A total curfew on nighttime operations exists at several airports in this country and abroad. However, the ability of an airport proprietor to establish a curfew may be severely restricted by various legal challenges, and may result in a significant loss of transportation service. Also, once a curfew is established it may prove difficult to remove at some future date when aircraft are quieter. Finally, it should be recognized that once the nighttime operations become less than 2.6 percent of the total day operations their elimination would result in less than a one dB reduction in L_{dn}. And if nighttime operations are one one percent of the total day operations, their elimination would result in a reduction of only o.4 dB in L_{dn}.

d. Noise Abatement Flight Procedures for Takeoff and Landing

There exist potential noise reductions to be obtained from the use of improved throttle and aircraft configuration techniques for both landing (29) (30) and takeoff. (25) (31) If these procedures could be tailored to specific airport requirements, the gains could even be greater. However, there is considerable controversy over the notion of changing cockpit management procedures from airport to airport, particularly with respect to pilot workload and safety implications.

An analysis (25) of takeoff procedure for several types of aircraft generally supports the procedures suggested in FAA AC91-53 (31) for national uniform application. Additionally, it recommends that JT8-D powered aircraft B727, B737 and DC9 use the maximum cutback suggested in FAA AC91-53, rather

Figure 10. Example of contours of day-night sound level for 100 percent operations arriving on Runway 27 and departing on Runway 22R at Logan International Airport for 1978 operations (27).



than the minimum. For application to specific airports it concludes:

1. For all aircraft with high and intermediate values of noise reduction with thrust cutback; i.e., B727, B737, DC9, DC10 and L1011:
   a) If the populated area is close to the airport, attain the maximum altitude before reaching the populated area, then initiate maximum cutback, and subsequently resume climb thrust either after passing the populated area or when attaining an altitude where the noise on the ground is estimated to be less than a pre-selected value.
   b) If the populated area is far enough from the airport to allow completion of partial or complete cleanup before reaching the populated area, initiate acceleration and cleanup at the lowest safe altitude, then initiate maximum cutback at the beginning of the populated area, and subsequently resume climb thrust as above.
2. For aircraft with low climbout performance and with low values of noise reduction with thrust cutback, i.e., B707, DC8 and B747, attain the maximum altitude before reaching the populated area, then initiate minimum thrust cutback and proceed to cleanup and continue to climb.

c. Stage Length Restrictions

The weight of an aircraft has a significant effect on its potential noise impact during takeoff or landing operations. Thus, restricting the maximum distance (Stage length) to be served from a specific airport may have the collateral effect of minimizing some of the heaviest takeoff weights at the airport. Such restrictions exist at some airports and may be particularly appropriate and legally defensible at airports which are located in close proximity to a larger and less restricted airport. The effectiveness of such restrictions would depend upon their nature, the practices of the user-operators in terms of aircraft weight (e.g., ferrying fuel on certain routes), typical payloads, destination and fleet mix and other factors. The cost of such restrictions would be highly dependent on the specific situations.

f. Optimized Use of Airport Spatial Configuration and Aircraft Ground Tracks

In developing noise reduction alternatives for a specific airport one of the first factors to examine is the location of its flight tracks with respect to land use. It is desirable that these tracks be located to make maximum use of compatible land uses such as water, industrial, commercial and agricultural. Where opportunities exist for changing flight tracks to reduce their noise impact potential, they should be carefully studied with respect to noise benefits, local air space management, fuel cost, time cost and other factors.

The Logan Runway 22R departure study (27) is one of the more detailed studies of flight track alternatives. Figure 10 illustrates the L_{dn} contours for a day on which all aircraft were assumed to arrive on runway 27 and depart on runway 22R. The contours are for the 210° departure, one of six alternative tracks in the study. The population living in areas where the L_{dn} (maximum day) exceeded various values for each of the alternatives is summarized in Table 4. It is clear that there is a large variation in population impact amongst the alternatives and that the alternative 6, which ultimately was chosen, represented a significant reduction in population impact relative to alternative 1, the base case.

Table 4. Estimated number of people living in areas to the south of Logan Airport where the noise from departures exceeds certain day-night sound levels for alternative departure procedures from runway 22R and arrivals on runway 27. (All aircraft are assumed to use these two runways for an entire 24-hour day).

	ALTERNATIVES					
	1	2	3	4	5	6
DAY-NIGHT SOUND LEVEL (L_{dn}) EXCEEDED (dB)[1]	210°	180° Right	180° Left	160° Radial	195° to 220° Radial	100° Heading
65	91,300	36,600	9,700	4,800	66,500	2,800
70	22,400	600[2]	2,700[2]	700[3]	10,400	1,900[3]
75	7,900	0	0	0	600	0
80	3,300	0	0	0	0	0

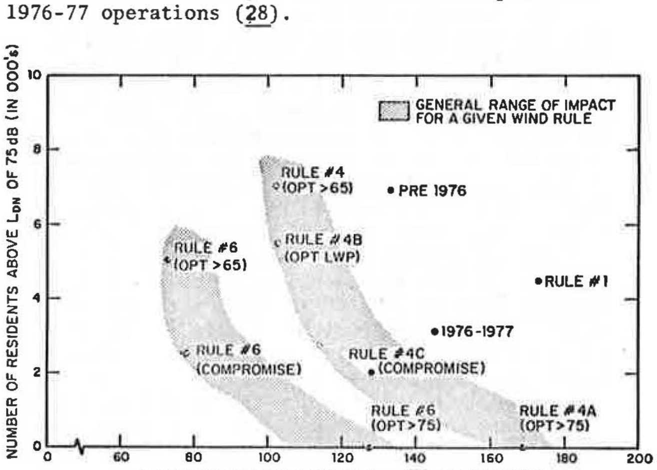
Notes

1 These levels should be reduced by approximately 5 dB to relate to yearly average exposure.

2 These population counts for 180° right and 180° left should be equal since the two procedures are identical until outside the L_{dn}70 contour. The difference arises from the fact that the radar traces from which flight tracks were modeled differed slightly on 2 days that the procedures were tested.

3 These figures should be equivalent. However, the contours for Alternative 6 include two population centroids that lie just outside the contours of Alternative 4.

Figure 11. Approximate number of residents in areas above L_{dn} 65 and 75 for various runway utilizations and wind rules at Logan International Airport with 1976-77 operations (28).



Once the flight tracks have been optimized at a specific airport, opportunities for reduction in population impact may exist by optimizing the relative utilization of these tracks. The potential for utilization of the tracks associated with each runway depend upon the wind and weather conditions, the capacity of each runway (or runway combinations) to meet demand, runway length, etc. In general, preferential runway assignments can only be made in weather conditions that meet the visibility, wind velocity and direction and runway conditions established by the FAA. (32)

Figure 11 illustrates the potential sound in a previous study (28) for varying population noise impact at Logan International Airport as a function of wind rule (safety criteria for preferential runway use). Rule 1 required that all operations utilize the runway most nearly aligned into the wind. Rule 4 was the then existing FAA order and Rule 6 was an FAA proposed revision. The current FAA order (32) is thought to be intermediate between Rules 4 and 6.

It is clear that, for Logan, there is a considerable ability to control runway utilization to minimize the number of people most heavily impacted (L_{dm} greater than 75 dB) at the expense of increasing the number of people where the L_{dn} is greater than 65 dB, or vice versa. The decision of which alternative utilization to chose for a given wind rule poses a difficult choice for the airport and the affected populace and their representatives. The reduction in noise impact for this example for Rule 4 was about equal to that which would result from a one dB reduction in aircraft source noise, and for Rule 6 a two dB reduction.

Obviously the potential for reduction in noise impact by optimizing flight tracks and runway utilization is highly variable amongst airports as it depends entirely on local geography and other local factors. It is not possible to generalize its potential to the national level with any degree of certainty.

g. Allowance for Spatial Distribution of Population

The spatial distribution of population is an independently variable factor although its importance stems from the relationships between the location of flight tracks and people. For airports located in the countryside where the population is very low, some form of control of land use development is essential to prevent future encroachment in noisy areas. For many years zoning has been advocated for this purpose, but it has been found in practice to be a fairly weak and unreliable tool. More success has been found through actual purchase of the land or of aviation easements to the land.

Where populations already exist in high noise areas, and where optimization studies show that meaningful noise reduction will not be possible for the foreseeable future, the remaining possibilities are land use conversion to more compatible useage or soundproofing.

Proposed Noise Reductions for the Next Twenty Years

The results of the various noise reduction techniques discussed above cannot be easily extrapolated to the nation because there are insufficient comparable studies to give good estimates of the national effect of measures at individual airports. However, it is useful to update the similar estimates made by this author in 1978, (26) recognizing that some of these estimates are more tenuous than others. The results are summarized in Table 5.

Table 5. Estimate of National Average Noise Reduction in Decibels of Various Air Carrier Aircraft/Airport Noise Reduction Options

Item	1975 fleet	1985 fleet after retrofit	2000-2005 fleet*
Basic aircraft noise	0	3	10
Improved landing procedures	0-1	0-1	0-1
Improved takeoff procedures	0-2	0-3	0-1
Airport optimization	0-5	0-5	0-5
Range of reduction	0-8	3-12	10-17
Average value of reduction	4	7.5	13.5
Effect of increased operations	0	-1	-2
Average net reduction	4	6.5	11.5
Percent of 1975 population** estimated within L_{dn} 65 dB			
Basic aircraft noise only	100%	50%	13%
Average net reduction	37%	16%	4%

*Assumed all high bypass
**No population growth is assumed, only that population that existed in 1975 is included.

Concluding Remarks

We are now in the first era of significantly perceptible airport noise reduction. The Stage 1 four-engined narrow-body aircraft are being phased out other Stage 1 aircraft are being retrofitted - and, new quieter Stage 3 aircraft are arriving in service.

The net result of these actions on a national basis is estimated by 1986 to be a 50 percent reduction in impact from its maximum reached in the mid-1970's. However, these benefits are expected to accrue primarily to those large airports that have had significant numbers of 707/DC8 aircraft. At other airports served by the smaller JT8-D powered aircraft - the increase in their operations is expected to negate part of the gains of retrofit.

Advantage should be taken of this transition to a new situation in which noise control is perceptible. The opportunity is available to convince noise impacted airport neighbors that the civil aviation system is trying to reduce noise, and is making progress. To the extent that this progress can be credibly demonstrated, there is now a unique opportunity to establish a more positive relationship between airports, their users, and their neighbors, bringing changes away from confrontation towards rational discussion, and to use this relationship to develop airport specific long range plans to attain minimum future noise impact consistent with community and industry economic and other constrants.

At airports with noise problems, continued consideration is needed on all aspects of noise control including:

- Optimized flight tracks to avoid population to the extent possible. This may mean new runways at some airports.
- Optimized runway preference to minimize total impact - include consideration of seasonal factors and time of day.
- Relevant noise abatement thrust and flight management procedures for landing and takeoff.
- Potential noise limits, noise charges and other methods to encourage use of quieter aircraft, particularly at night.
- Acquisition and redevelopment of some areas which have high noise impact (L_{dn} greater than 75 dB) both now and estimated to continue in the foreseeable future.
- Soundproofing of some residences in areas of significant noise impact (L_{dn} 65-75 dB) both now and estimated to continue in the future.

Full application of these techniques might be expected to reduce the population impacted to as little as one-third that impacted without their application, but there may be some airports where little reduction is practicable.

On a national level it must not be concluded that the national airport noise problem will be solved totally by the introduction of the Stage 3 airplane, although problems at many specific airports may be solved. Quieter aircraft are still needed to offset the adverse effects of increases in operations and to relax costly restrictions at specific airports that were required for noisy aircraft. There is a need to establish a national set of goals for future aircraft/noise certification that are compatible for existing airports. A rough estimate of that goal would be a future fleet average aircraft with an EPNL of 85 EPNdB for takeoff at 6500M from start of roll. This goal is about 12 dB below the current Stage 3 limits. The technical capability is available to make realistic studies that are required to develop the information that can be used to decide the tradeoffs amongst alternatives and arrive at a consensus goal. It should be used to reach a conclusion.

Second, technical studies should be undertaken to develop the R&D requirements to eventually attain the capability to design economically viable and productive aircraft to meet the consensus goal. These studies should look at both the aerodynamic and engine side of the problem - together. Special attention should be given to low speed lift/drag ratio, maximum lift, number of engines, thrust-weight ratio, higher noise reduction for thrust cutback, higher bypass ratio, optimum design of engine cycle for mission thrust requirements and improved acoustic treatment.

Finally it is important that the airport, airline and aircraft industries become comfortable with noise and bring it out on the table as just another factor to be considered, just as are items such as pavement thickness, gate clearance, and capacity. The aircraft industry and government made enormous progress in this area, as witness the noise reductions achieved in the new aircraft. They have progressed because they consider noise throughout the aircraft and engine design process, rather than attempting to deal with noise only after the design has been finalized. The rest of the civil aviation systems should be able to find a way to accomplish the same thing - to forget the concept of noise as "a nasty problem dreamed up by a group of zealots that is best hidden under a pile of sand," and begin to think of noise as just one more human engineering factor to be included in optimizing the initial design of airports and of the entire civil aviation system. A realistic and positive approach should lead to real progress.

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