Selection of

AIRPORT NOISE ANALYSIS METHOD

and

EXPOSURE LIMITS

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Analysis Method and Exposure Limits

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Section 1. INTRODUCTION AND PROPOSALS

The Maryland Environmental Noise Act (Ch. 287-1974) requires that the Aviation Administration of the Maryland Department of Transportation:

- establish procedures for calculation of cumulative noise exposure values*, and
- adopt limits by July 1, 1975, for cumulative noise exposure** for residential land use and other categories of land use on the basis of their noise sensitivity.

In compliance with these requirements the Administration has selected a method for describing noise from the operation of airports and developed a schedule of limits for cumulative noise exposure.

This paper presents in Section 1 summaries of the Administration's proposed method and limits. In Section 2, the paper presents detailed discussions of the technical bases for the proposals. Section 3 is a discussion of the proposals of the Administration.

Proposals

1. Based on the data presented in Section 2, parts I and II of this report, the Administration proposes

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* "Cumulative Noise Exposure" means a calculated or measured value for the exposure to aircraft noise in a 24-hour period at a given location.

** "Limit for Cumulative Noise Exposure" means the maximum cumulative noise exposure for a given land use which is compatible with that land use.

that cumulative noise exposure be expressed in terms of the A-weighted outdoor day-night average sound level L_{dn}.

2. Based on the data presented in Section 2, parts III and IV of this report, the Administration proposes the following schedule of limits for aircraft noise for various land uses:

Table 0

PROPOSED LIMITS FOR CUMULATIVE NOISE EXPOSURE FOR AIRCRAFT NOISE

	LIMITS FOR CUMULATIVE NOISE EXPOSURE (Day-Night Average Sound Level in dB (re 20 Micronewtons/1 sq. meter))	
LAND USE	Effective 1 July 1975	Effective when U.S. Fleet Noise Level is reduced 5 dB below 1 July 1975 level
Residential-Single & Two-Family; Mobile homes	65	60
Residential-Multifamily; Dormitories	65	60
Schools, Hospitals, Rest homes, Homes for the Aged, Nursing homes	65	60
Libraries, Churches	65	60
Transient Lodging Hotels, Motels	70	65
Auditoriums, Concert Halls	65	60
Sports Arenas, Outdoor Spectator Sports	70	65

Playgrounds, Neighborhood Parks	70	65
Golf Courses, Riding Stables, Water Recreation, Cemetaries	75	70
Office Buildings, Personal, Business, Professional	75	70
Commercial (Retail), Movie Theaters, Restaurants)	75	70
Commercial (Wholesale, some Retail), Industry, Manufacturing, Utilities)	75	70
Manufacturing, Communications (Noise Sensitive)	70	65
Livestock Farming, Animal Breeding	75	70
Agriculture (except livestock) Mining, Fishing	75	70

NOTE: This table is a portion of Table XIII in Section 3. Section 3 presents the underlying rationale for the limits.

3. Based on the need to inform buyers and lessees of properties of the existence of Noise Zones*, the Administration proposes real property notice requirements:

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* "Noise Zone" means an area of land surrounding an airport within which the cumulative noise exposure value is equal to or greater than the lowest limit for cumulative noise exposure established by the Administrator.

a) All buyers or tennants signing deeds or leases for properties which are partially or wholly within a noise zone will acknowledge, by signing, a statement such as:

"I ________ acknowledge that this property is partially or wholly within a zone of airport noise for an existing or proposed airport and that the level of aircraft noise may exceed the noise limits established by the Maryland State Aviation Administration."

SECTION 2. BACKGROUND INFORMATION

I. A SUITABLE MEASURE OF ENVIRONMENTAL NOISE EXPOSURE

A. Introduction

The airport noise provisions of Maryland's Environmental Noise Act of 1974 are intended to protect airports against encroachment and to protect airport neighbors against excessive airport related noise. The Act limits new land uses to those that are compatible with the noise environment around an existing airport; and it also restricts the development of new airports in areas where the noise would adversely impact existing land uses.

Pursuant to this goal, the Act requires the State Aviation Administrator to adopt (with the endorsement of the Secretary of Transportation and the Secretary of Health and Mental Hygiene, and after a public hearing) a suitable method and limits of cumulative noise exposure.

The Act does not specify which acoustical measure should be used for expressing the noise limits. This matter is one of the questions to be resolved in discussions with the Secretaries named in the Act and through the public participation process. It is the purpose of this chapter to recommend a suitable measure for the purposes of the Act. Subsequent chapters will examine the various effects that noise can have on humans, and, based on the results of those studies, will present recommendations for numerical values of the noise limits compatible with different land uses.

B. Requirements for a Suitable Measure of Airport Noise

We are concerned here to select an acoustical measure suitable for assessing the impact of aircraft noise upon humans at different locations in communities near an airport. Such a measure should assess the effects both of average noise level and of exposure time, and the choice should be based on the following requirements: 1. The measure should correlate well with human responses regarding hearing loss, sleep and speech interference, and annoyance due to noise exposure. 2. The measure should be capable of assessing the accumulated effect of all kinds of noise during a long period. 3. The measure should be simple enough that it can be obtained by direct measurement without extensive instrumentation or elaborate analysis equipment. 4. The required measurement equipment, with standardized characteristics, should be commercially available. 5. The measure for airport noise should be closely related to measures currently used for rating noise from other sources. 6. The single measure of noise at a given location should be predictable, within an acceptable tolerance, from a knowledge of the physical events producing the noise.

The remainder of this section discusses how these requirements were considered in the selection of the measure to be used for evaluating environmental noise around an airport. It draws heavily upon the Aircraft/Airport Noise Study report [1] submitted to the U.S. Environmental Protection Agency by the Task Group charged with conducting the study, Henning von Gierke, Chairman.

C. Physical Attributes of Sound Affecting Human Response

The accumulated evidence of research on human response to sound indicates clearly that the magnitude of sound as a function of frequency and time is the basic determinant of human response to sound.

1. Magnitude

Sound is a pressure fluctuation in the air; the magnitude of the sound describes the physical sound in the air; loudness on the other hand, refers to how people judge the sound when they hear it. Magnitude is stated in terms of the amplitude of the pressure fluctuation. The range of magnitude between the faintest audible sound and the loudest sound the ear can withstand is so enormous (a ratio of about 1,000,000,000 to 1) that it would be very awkward to express sound pressure fluctuations directly in pressure units. Instead, this range is "compressed" by expressing the sound pressure on a logarithmic scale. Thus, sound is described in terms of the sound pressure level (SPL which is ten times the common logarithm of the squared ratio of the sound pressure in question to a (stated or understood) reference sound pressure, usually 20 micro-newtons per square meter):

$$SPL = 10 \log (p/20)^2 \qquad (1)$$

2. Frequency Distribution

The response of human beings to sound depends strongly on the frequency of the sound. In general, people are less sensitive to sounds of low frequency, such as 100 Hertz (Hz),* than to sounds at 1000 Hz; at high frequencies, such as 8000 (Hz), sensitivity also decreases. Two basic approaches to account for people's difference in response to different sound frequencies are (1) to segment the sound pressure spectrum into a series of contiguous frequency bands by means of electrical filters, so as to display the distribution of sound energy over the frequency range; or (2) to apply a frequency weighting to the overall spectrum in such a way that the sounds at various frequencies are weighted in much the same way as the human ear hears them.

In the first approach, a sound is segmented into sound pressure levels in 24 different frequency bands, which levels may then be used to calculate an estimate of the "loudness" or "noisiness" sensation which the sound would cause. This form of analysis is usually employed when detailed engineering studies of noise sources are required. It is much too complicated (i.e., expensive) for monitoring environmental noise exposure. To perform such analysis, especially for time varying sounds, would require a very complex set of equipment.

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* Hertz is the international standard unit of frequency, until recently called "cycles per second"; it refers to the number of pressure fluctuations per second in the sound wave.

A frequency-weighted sound pressure level, on the other hand, is a one-number measure of noise that can be obtained with simple equipment. Such a sound level with a designated frequency weighting is called simply "sound level". Although this approach would not be satisfactory for detailed analysis for engineering noise control, it provides a satisfactory description of noise from a human response viewpoint, with sufficient accuracy for community noise evaluations.

With respect to both simplicity and adequacy for characterizing human response, a frequency-weighted sound level should be used for the evaluation of community noise. Several frequency weightings have been proposed for general use in the assessment of response to noise, differing primarily in the way sounds at frequencies between 1000 and 4000 Hz are evaluated.

The A-weighting, standardized in current sound level meter specifications, has been widely used for transportation and community noise description [2]. For many noises, the A-weighted sound level has been found to correlate as well with human response as more complex measures, such as the calculated perceived noise level or the loudness derived from spectral analysis [3,4].

One drawback in the use of the A-weighted sound level is that psychoacoustic judgment data indicate that effects of tonal components are sometimes not adequately accounted for by a simple sound level.

Some current noise ratings attempt to correct for tonal components, but such corrections introduce considerable complication. For example, in the present aircraft noise certification procedures, "Noise Standards: Aircraft Type Certification," FAR Part 36, the presence of tones is identified by a complex frequency analysis procedure. If the tones protrude above the adjacent random noise spectrum, a penalty is applied that increases the value found by the direct calculation of perceived noise level alone.

After consideration of this problem, the EPA Task Group concluded that the existing presence of a tone penalty in aircraft certification procedures effectively encourages a manufacturer to minimize tones in the sound of aircraft. Thus, certification requirements will minimize the <u>need to consider</u> tones in an environmental noise measure, so long as tonal effects are properly considered under source certification.

3. Time Distribution

Most noise sources generate sound levels with recognizable temporal patterns. The level may be constant, as for a steady source, or it may vary with time, as with the noise produced at a given point on the ground during the passage of an aircraft in flight. Since people's response to noise is influenced by the duration of the noise, it is necessary to include some account of its time pattern in a suitable noise rating.

The most basic description of the time-varying nature of a noise signal observed at any location is the record of sound level as a function of time. The symbolic expression for a time varying sound level is $L_{(t)}$. Such a function might describe the pressure history at a fixed location for any one of a number of similar noise events. Alternately, $L_{(t)}$ might describe the fluctuating sound pressure level encountered by a single observer moving through various noise environments.

Where a number of successive or overlapping noisy events occur, it is useful to have a continuous record of sound level as a function of time. From such a record, a statistical distribution of sound level versus percent of the total observation period can be derived. When such a distribution is obtained, it is common practice to identify by subscripts the respective sound levels exceeded during specified percentages of the observation time. Thus L_{90} is the sound level exceeded 90 percent of the time; L_{50} is the median value, exceeded for half the time; L_{10} is the sound level exceeded for only 10 percent of the time.

D. Development of the Measure of Community Noise

The first step toward specifying a measure for cumulative exposure to environmental/community noise is to choose a measure that accounts for the varying sensitivity of the ear with frequency. Other factors that affect human response must be examined, also. The factors considered most relevant to the selection of a suitable noise measure are discussed in this section.

1. Frequency Weighting

A conclusion of the previous section is that a frequency weighted sound pressure level is the most reasonable choice for describing the magnitude of environmental noise. In order to use available instrumentation for direct measurement, the A-weighting is the only suitable choice.*

2. Average Sound Level

As noted above, the measure of magnitude of noise in the community, at a given instant and place, is the fluctuating A-weighted sound level, often called simply sound level or noise level. The durations of the various sounds must be taken into account in an appraisal of levels of cumulative noise exposure around airports. This is done by giving the <u>average</u> sound level during a stated time period. (Justification for the use of the average sound level is given in Appendix A of Reference 1.) This average sound level is sometimes called equivalent sound level. The symbol is L_{eq}.

The average (equivalent) sound level is the constant sound level which, in a given situation and time period, would convey the same sound energy as does the actual time-varying sound in the same period. Two sounds, one of which contains twice as much energy but lasts only half as long as the other, would be characterized by the same

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* All sound levels in this report are A-weighted sound pressure levels in decibels with reference to 20 micro-newtons per square meter.

average sound level; so would a sound with four times the energy lasting 1/4 as long, etc. This relation is often called the equal-energy rule.

Some specifically named average sound levels are:

1. Hourly (average) sound level, L_h,
2. Daytime (average) sound level, L_d,
3. Nighttime (average) sound level, L_n.

For the present purpose, day extends from 7:00 a.m. to 10:00 p.m. (0700-2200); night from 10:00 p.m. to 7:00 a.m. the next day (2200-0700).

3. Annual Average Sound Level

The repetitive cycle of events in most environments leads to the natural choice of a 24-hour day as the base period for evaluation of environmental noise. Most airport operations are quite stable in their day-to-day schedules. However, at some airports seasonal variations in schedules will change the frequency of aircraft operations during various months. Thus, in assessing the environmental effect of an airport, the daily average noise level, should be averaged over a period of one year.

4. Daytime/Nighttime Average Sound Level

It is important to account for the difference in response of people in residential areas to noises that occur during sleeping hours as compared to waking hours. During nighttime, exterior background noises generally drop in level below their daytime values. Further, the activity of most households decreases at night, lowering the internally generated noise levels. Thus, intrusive noise events usually become more noticeable at night, since the intrusion above the background noise is greater than for daytime.

Methods of accounting for these daytime/nighttime conditions have been developed in a number of noise assessment methods employed around the world [5]. In general, the method used is to apply a penalty to noise events occurring during nighttime hours, that is, to treat night-time noises as though they were several decibels noisier than they actually are. Two approaches to identifying time periods have been employed: one divides the 24-hour day into two periods, the waking and sleeping hours, while the other divides the 24-hours into three periods--day, evening, and night.

The penalties applied to the non-daytime periods differ slightly among the different countries, but most of them penalize night activities by (nominally) 10 dB; the evening penalty, if used, is (nominally) 5 dB.

An examination of the numerical effects of using two periods versus three periods per day shows that for any reasonable distribution of aircraft flight operations, the two-period day and the three-period day are essentially identical (that is, the 24-hour equivalent sound levels are equal within a few tenths of a decibel).

The previous considerations support a basic measure for quantifying average noise around airports, namely the A-weighted sound level, averaged over a 24-hour time period, with a 10 decibel penalty applied to nighttime sound levels.

The basic quantity described above is termed the "Day-Night Average Sound Level," or more briefly, "Day-Night Level." The unit for this quantity is the decibel, and the letter symbol for it is L_{dn}. Figure 1 shows typical values of L_{dn} for various types of environment, with corresponding subjective evaluations.

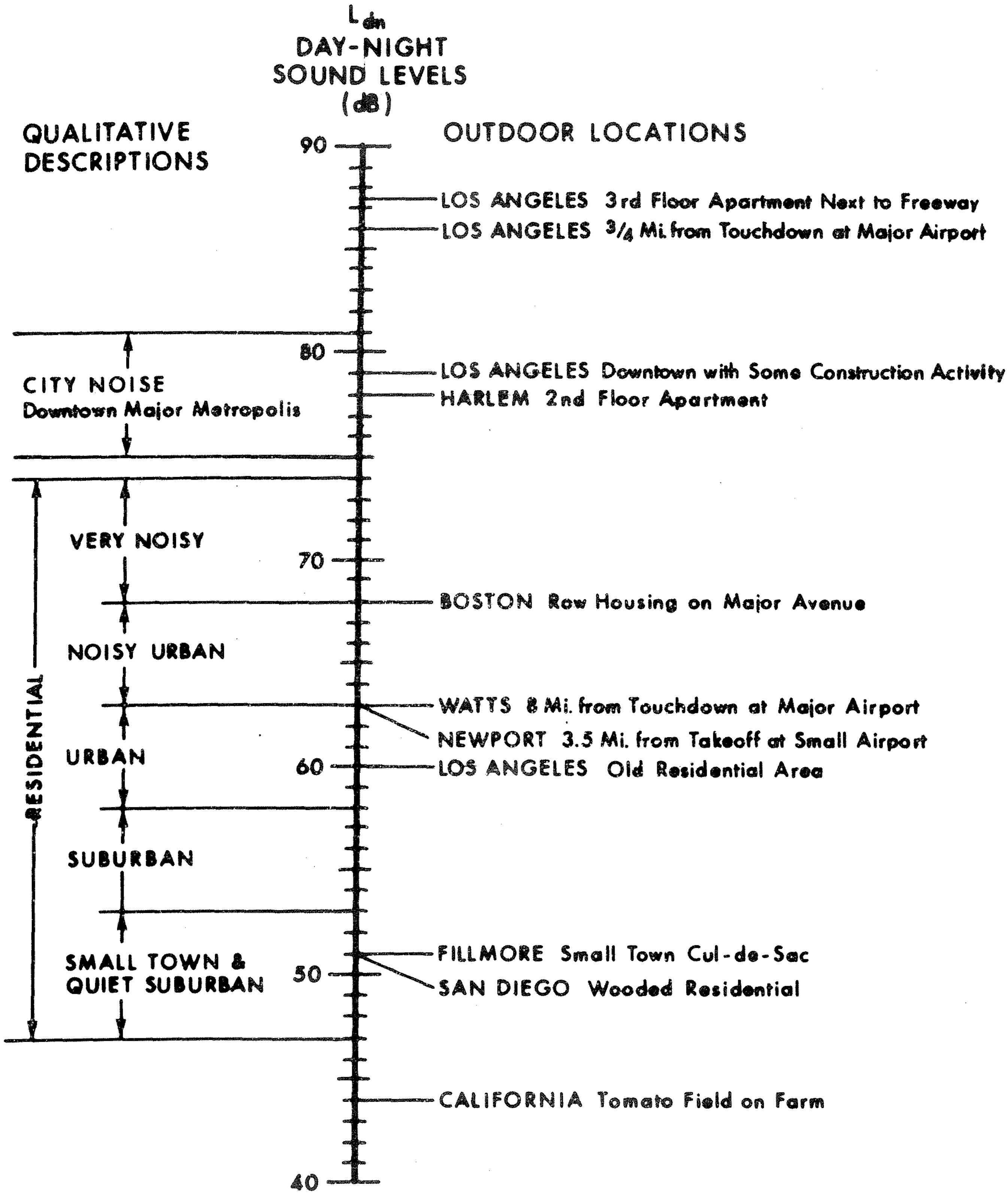

Figure 1. OUTDOOR DAY-NIGHT AVERAGE SOUND LEVEL IN dB (re 20 Micronewtons/ Sq. Meter) AT VARIOUS LOCATIONS

II. APPLICATION OF DAY-NIGHT SOUND LEVEL TO AIRPORT NOISE

Among the requirements for a suitable measure of cumulative noise exposure around an airport are the ability to measure it with available instrumentation and the ability to predict expected values from a knowledge of physical characteristics of the noise sources. These matters are discussed in this section.

A. Measurement of Day-Night Average Sound Level

The primary requirement in measuring average level is the ability to obtain an "energy average" of A-weighted sound level over the separate daytime and nighttime periods. These measurements may be performed with a variety of existing instrumentation, ranging from a standard sound level meter, used in conjunction with some sound level-history recorder such as a graphic level recorder, through meters that provide averaged noise levels periodically on an hourly basis, up to the more elaborate computerized monitoring systems now coming into use at some major airports.

The least sophisticated form of instrumentation, the combination of a sound level meter and a graphic level recorder, requires that the graphic recording of sound level as a function of time somehow be segmented into the various intervals in which the sound level lies. That is, using a series of discrete "windows," say 1 to 5 dB in width, the percentage of time that the sound level lies within each window is determined. This sound level/time distribution can be determined either manually or with so-called "statistical distribution analyzers" produced by various equipment manufacturers. The energy average of the sound level pattern during the observation period can then be computed from this level distribution.

The recently available exposure meters, or integrating sound level meters, perform this same function without the use of a level recorder. Most of these instruments provide hourly average sound levels which may then be appropriately combined to obtain the day-night average level, L_{dn}. Several manufacturers also offer instruments in such a form that the 24-hour value of L_{dn} may be obtained directly from the instrument, including the provision of the nighttime weighting function.

The advantage of the above devices is their portability. They are suited to surveys of relatively short duration, e.g., days to weeks. Where continuous monitoring is desired, e.g., on an annual basis, it is more convenient to utilize a permanent monitoring system with a number of fixed microphones, and to feed the sound signals through telephone lines to a central recording station. A small digital computer may be incorporated with the central system so that a variety of analyses can be made. Such quantities as maximum sound level per event, as well as hourly and daily average sound levels may be easily obtained from these systems.

Clearly, the choice of measurement capability depends on the time span of interest, the funds available, the regulatory requirements, and other matters unique to each situation. It should be observed, however, that the intent of the day-night sound level is to obtain a measure of the average sound level integrated over a long enough period of time to insure that variability in measurements due to weather, operational factors, traffic densities or seasonal effects are properly accounted for in the measurements.

B. Prediction of Day-Night Level for Airport Noise

In considering environmental noise in the vicinity of airports, it is important to be able to predict the noise environment for planning purposes. The measure chosen to describe environmental noise should also be readily adaptable to the various predictive methodologies that have been developed [6,7,8].

In the case of airports, the methods for predicting noise exposure combine the noise generating properties of various aircraft types with aircraft performance and operational procedures to yield contours of equal average sound level during a specified time period. Since the basic component of average sound level is an energy summation of sound exposure levels, the noise source descriptions for different aircraft can conveniently be presented in terms of the sound exposure level as a function of distance of closest approach of the aircraft during an event for different engine power settings, e.g., takeoff, approach, ground runup.

The sound exposure level at any point on the ground, for a single aircraft operation, can be obtained by first determining the distance of closest approach from the point of observation to the aircraft flight path, and then obtaining the sound exposure level from data for the individual aircraft type relating sound level and distance. The average noise level at each point of interest is obtained by adding logarithmically the sound exposure level contributions from all aircraft operations during the time interval of interest. (See Appendix A of Reference [1].

The prediction accuracy of any sound level model is no better than the accuracy of the operational input data. In planning efforts, the operational projections are not necessarily an accurate reflection of the eventual operations. Differences in flight paths for different aircraft, in climb performance as a function of weight, and in atmospheric conditions all contribute to differences between predicted and measured values of noise exposure level. These problems are common to all prediction methodologies, however, and are not functions of the noise level measure employed. The accuracy of average sound level predictions over a <u>projected</u> 24-hour operation, is within ± 5 dB of the measured values, irrespective of the noise level measure; the reason for the wide scatter range is that actual operations deviate from the projected operations. However, the accuracy of estimated 24-hour average noise levels for a set of known operational conditions compares within ± 1 dB of the measured values obtained for those operations [9].

The choice of the day-night average sound level, L_{dn}, as a measure of environmental noise was partly based on its relative ease of measurement. In the last analysis, measured values of day-night average sound level taken over a long enough period of time that a stable representation of annual daily average levels can be obtained, are preferable to predicted values. The simplicity of the measurement of day-night average sound level recommends it highly in this application.

C. Comparison of Day-Night Average Sound Level With Other Airport Noise Descriptors

A number of rating scales have been developed for airport noise analyses over the past 20 years [5]. The most prominent in the United States have been the Composite Noise Rating (CNR) and the Noise Exposure Forecast (NEF). The CNR has been used by FAA and the military services, while NEF has been used to some extent by FAA and DOT. More recently the Community Noise Equivalent Level (CNEL) has been developed for use in the California airport noise law [10]. A discussion of the comparisons between these ratings and L_{dn} is provided in Appendix A of Reference [1], and it is explained why an exact relationship between the ratings cannot be stated.

For comparison, however, the following relationships can be assumed, together with the estimated range of scatter:

$$L_{dn} \cong CNEL$$
$$L_{dn} \cong NEF + 35\ (\pm 3)$$
$$L_{dn} \cong CNR - 35\ (\pm 3)$$

A number of other ratings that have been developed internationally include the British Noise and Number Index (NNI), German Storindex ($\bar{Q}$), French Isopsophic Index (N), South African Noise Index (NI), International Civil Aviation Organization Weighted Equivalent Continuous Perceived Noise Level, WECPNL [5]. Each of these ratings accounts for the cumulative noise exposure in a very similar way, differing primarily in the technical details by which the noise exposure produced by individual aircraft flyovers is described. These measures are highly intercorrelated with NEF, CNR, CNEL, and thus with L_{dn}. Approximate conversions for these measure to L_{dn} can easily be derived, as they have been above for NEF and CNR (See Part of IV of this report).

D. The Effect on L_{dn} of Loud But Brief or Infrequent Noise Events

Sometimes the choice of L_{dn} as a measure of the impact of aircraft noise on a community is questioned on the basis that a measure based on an <u>average</u> noise level reckoned over a 24-hour period would be insensitive to the effect of very noisy events of short duration or infrequent occurence.

This objection has a certain amount of validity: just as the statement that the average depth of a river is 2 ft may conceal the existance of a pool deep enough to drown in, the restriction of noise exposure in a neighborhood to, say, an average noise level of 60 dBA may still permit quite loud and annoying noises if they are short enough in duration.

The EPA working group that recommended the adoption of L_{dn} was quite aware of this problem, but felt that the other advantages of this measure are so overwhelming that it should be adopted anyway. Here is what they said:

> "A practical simple measure of environmental noise cannot and need not take into account secondary effects. Neglecting secondary details in the measurement and control of environmental noise does not mean that these details are not important or that attention should not be paid to them through other control measures. For example, one-time noise events, high instantaneous peak values or objectionable discrete tones of individual sources must be seperately controlled by emission noise standards. Standards for cumulitive environmental noise exposure and emission/certification standards must complement each other. The emission or source standard can consider the details of the source characteristics and can employ methods of measurement, data analysis and interpretation appropriate for the charcteristics of the particular noise of for effective noise control engineering on this noise source. However, it is mandatory that all detailed source standards can be translated into one common noise measure. Exposure to all kinds of noise can then be added in this common measure of exposure to give a measure of total accumulated noise exposure."

But it is important not to exaggerate the limitations of average noise levels in dealing with infrequent loud noises. According to equation (A-7) in Appendix A of

Reference [1], for any neighborhood in which the background noise from all other noise sources is reasonably quiet (say, less than L_{dn}=60 dB), the contribution to the 24-hour L_{dn} from a single noisy flight is readily detectable. If the period during which the noise level is within 10 dB of the maximum level during the fly-by lasts 20 seconds, then the L_{dn} contribution of a single daytime operation is exactly 40 dB below that maximum fly-by level (30 dB below the maximum, if at night).

For example, suppose a neighborhood with background noise from all other sources amounting to L_{dn}=55 dB (EPA's identified level for residential neighborhoods). A single nighttime flyover with a maximum noise level of 85 dBA would raise L_{dn} to 58 dB; such a change is readily measured. If the maximum level were 95 dBA, L_{dn} would increase to 65 dB.

Turning the question around, legislation that restricts L_{dn} due to aircraft noise to values less than, say, 60 dB would forbid single night-time flight operations whose maximum noise level during fly-by exceeds 90 dBA (100 dBA in daytime). It would forbid <u>two</u> flights with maximum noise levels greater than 87 dB (night) or 97 dB (day), or ten flights with levels exceeding 80 dB (night), or 90 dB (day). If these noise intrusions still seem excessive, then the limit could be set at 55 or 50 dB. The point is not to select the limit level here, but to show that L_{dn} is not entirely insensitive to the rare noisy event.

III. CRITERIA OF ACCEPTABILITY FOR AIRPORT NOISE

A. Introduction

The relationship between the noise environment and the corresponding human response can be quantified by a single methodology for each site or noise-producing system, considered in terms of the effects on people in occupied places who are exposed to noise of a specified magnitude. This is not to say that all individuals have the same susceptibility to noise; indeed, they do not. Even different groups of people may vary in their response to noise, depending on previous exposure, age, socio-economic status, political cohesiveness and other social variables.

In the aggregate, however, even for residential locations the <u>average</u> response of groups of people is quite stably related to the cumulative noise exposure, as expressed in a measure such as L_{dn}. The response we are interested in is the <u>general</u> adverse reaction of people to noise. This response represents a combination of such factors as speech interference, sleep interference, desire for a tranquil environment, and the ability to use telephones, radio, TV satisfactorily. One measure of this response is the percentage of people in a population that would be expected to indicate high annoyance to noise of a specified level.

For schools, offices, and similar spaces where ease of speech communication or avoidance of the risk of hearing damage is of primary concern, the same averaging process can be used to estimate the potential response of people as a group, again ignoring individual variations from person to person.

In both instances, then, for residential and non-residential areas alike, we are interested in how the average response of people varies with their environmental noise exposure.

These considerations allow us to specify, for a variety of spaces or land uses, numerical values for site noise levels which, if they are not exceeded, would provide entirely acceptable acoustical environments. That is, if these values are not exceeded, we would expect zero impact on the community due to environmental noise.

Specific noise exposure criteria for land uses, or occupied spaces generally encountered in noise impact assessments, are listed in Section V. Note that these criteria are all specified as outdoor noise levels, even though the noise-sensitive activity in question is usually indoors. We have used the average noise reduction for typical building construction to translate from acceptable indoor environments to acceptable outdoor environments, since in any practical environmental noise regulation, it is only the outdoor noise levels that can be predicted and controlled.

A detailed discussion of the relationships between noise and human response is provided in several documents recently prepared by and for the U.S. Environmental Protection Agency (EPA). The different forms of response to noise, such as hearing damage, speech or other activity interference, and annoyance, are related to L_{eq} and L_{dn} in EPA's Criteria document [12], in EPA Levels document [11] and in the Task Group 3 report to EPA on the Aircraft/Airport Noise Study [1]. Substantially the same noise/response information is presented in all these documents; it represents the final summation of a comprehensive review of the field, and thus is the best source of up-to-date information on the effects of noise on people. We have relied heavily on this recently gathered body of scientific data in the preparation of the present report.

It is not the purpose of this section to recapitulate these data or past efforts, which are extensively documented in the literature [13,14,15,16], but rather to analyze how such data can be interpreted to arrive at maximum permissible average noise levels that define an acceptable cumulative environmental noise exposure. The analysis gives quantitative relationships between the average sound level to which the average individual in a population is exposed and the resulting effects.

The approach of this section will be first to present the quantitative relationship between cumulative noise exposure and the risk of health effects, primarily noise-induced permanent hearing loss. Similar relationships are derived between average sound levels and the percentage of individuals annoyed by aircraft noise, and between average sound levels and the percentage of time that speech communication will be interrupted. Annoyance due to noise and interference with speech communication cannot be identified at this time with direct disease-producing effects*, but must be interpreted as an interference of the noise environment with public health and welfare according to the intent of the Environmental Noise Act of 1974; certainly, according to the definition of health adopted by the World Health Organization, these noise effects on human activities and well-being would be included under health effects (See Section IV-E, below).

It must be kept in mind that the relationships between noise exposure and public health and welfare analyzed in this section are based on statistical probabilities rather than on individual cause-effect relationships. Therefore, the generalized relationships and the recommendation of

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* Recently, there has been a renewed interest in "generalized susceptibility" as a model for explaining the spread of human disease. It places the impact of urban noise in context with various other stresses whose cumulative effect is to upset the equilibrium by which an individual human holds off disease. Under this view, noise <u>in the urban context</u> may very well contribute significantly to the ills that some people have blamed on it.

The traditional "infectious disease model, used for over a century to describe the probability of disease in a population and the progress of a disease in an individual, involves four steps: it supposes a <u>source</u> of each disease (that is, the presence of the germ in some part of the environment), the <u>transmission</u> of the disease to an individual by contact with the source, an <u>incubation period</u> during which the germ develops in the new host, and finally the <u>appearance of active symptoms</u> of the disease at the onset of manifest illness. [footnote continued on next page]

limit values are no assurance of whether or not the health of any particular individual is affected by the noise.

This model, essentially deterministic, fails to deal adequately with either chronic or mental disease. In addition, it offers no explanation of why, of the many people exposed to a source of disease, not all of them contract the disease; or why, among those who do develop it, the severity of its effects differ so greatly from one person to another.

According to the "generalized susceptibility" model, on the other hand, everybody is exposed to sources of diseases of all kinds that exist everywhere; but these diseases can be kept in a harmless state of latency by the homeostasis of the individual organism, unless his homeostatic equilibrium is upset by the cumulative effect of multiple stresses to the point where the active symptoms of disease appear. These stresses can be induced by a variety of stressors in the environment. Each person's susceptibility to disease, therefore, depends as much on the number and kinds of environmental stresses to which he is exposed, as on the "agents" of disease themselves [17].

The significance of these alternative models from the noise abatement point of view is this: under the mechanistic "infectious disease" model, the strategy for prevention of disease is to eliminate the source of disease or reduce the probability of contact, and to immunize against the contacts that could not be prevented. Under the "generalized susceptibility" model, the strategy would, in addition, seek to minimize the impact of all the stresses whose cumulative effect is to increase the probability of onset of actual illness. Thus, noise control techniques become a legitimate concern of public health authorities to the extent that they reduce the stress of noise exposure on the population.

B. Hearing Loss

There are two important considerations in evaluating environmental noise with respect to potential permanent hearing loss: the direct effect of environmental noise that is loud enough to cause hearing damage, and the indirect effect of environmental noise which, though not loud enough itself to cause damage, can still prevent recovery of the hearing mechanism from an occupational, recreational, or environmental noise overdose. The implications of these two considerations are examined in detail in Appendix B of Reference [1] and are summarized in the following paragraphs.

1. Direct Effect

The hearing threshold for an individual at a specific frequency is determined by measuring the level of the quietest sound that can be heard by the individual. The amount of hearing loss at any frequency is measured by the amount by which the hearing threshold has shifted upward from a previous value, or from the population norm.

Table I summarizes the relationship between daily noise exposure level and maximum noise induced permanent threshold shift for the most sensitive 10 percent of the population. The data assume 8 hours occupational noise exposure per day, repeated over a 40 year working lifetime. Usually, the threshold shift increases gradually over the 40 years of exposure; the term "maximum" refers to the greatest threshold shift occurring in this period, generally at the end.

The average of the permanent threshold shifts at frequencies of 500, 1000, and 2000 Hz, is used to define a "hearing handicap;" a person is considered to suffer a hearing handicap when his average puretone threshold for these three frequencies exceeds the International Standards Organization (ISO) audiometric zero by 25 dB or more [18]. The average threshold shift for these three frequencies is usually less than that at a frequency of 4000 Hz, where the greatest change in hearing threshold generally occurs for most types of noise. The data at 4000 Hz, therefore, provide a more sensitive indicator for the noise induced permanent threshold shift than data at lower frequencies.

Table I

MAXIMUM NOISE INDUCED PERMANENT THRESHOLD SHIFT IN DECIBELS, AT VARIOUS AUDIOMETRIC FREQUENCIES, FOR THE MOST SENSITIVE 10 PERCENT OF THE POPULATION, ASSUMING A 40-YEAR EXPOSURE FOR 8 HOURS PER DAY, AS A FUNCTION OF THE A-WEIGHTED AVERAGE SOUND LEVEL OF BROAD-BAND NOISE. (See Appendix B of Reference [1] for additional detail.)

	A-WEIGHTED AVERAGE SOUND LEVEL IN dB**			
Audiometric Frequencies (hz):	75	80	85*	90
Average Shift At 500, 1,000 and 2,000 Hz	1	1	4	7
Average Shift at 500, 1,000, 2,000 and 4,000 Hz	2	4	7	12
Shift at 4,000 Hz	6	11	19	28

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* Example: Of a large number of people exposed for 8 hours per day over a 40 year working lifetime to broad band noise with A-weighted average sound level of 85 dB, the most sensitive 10 percent of these people will exhibit, on the average, permanent threshold shifts as follows: at a frequency of 4000 Hz, the shift will be 19 dB; the average of the shifts at the frequencies 500, 1000, 2000, and 4000 Hz will be 7 dB; the average of the shifts at 500, 1000, and 2000 Hz will be 4 dB.

** Add 5 dB to the average sound level for intermittent noise such as that produced by aircraft operations.

Individual changes in hearing less than 5 dB are not generally considered noticeable or significant. For instance, repeated audiograms on the same individual will often show a 5 dB variability. Thus, the threshold of hearing damage for our purposes should be defined at the environmental noise level expected to cause a permanent threshold shift of 5 dB at 4000 Hz in the most sensitive 10 percent of the population. From Table I, this threshold level is seen to be an average A-weighted sound level slightly less than 75 dB for an 8 hour exposure to broad-band noise. For intermittent noises, such as that produced by aircraft or other moving vehicles, this threshold level may be increased by 5 dB to 80 dB, because of the opportunity for the ear to recover between noisy events.

2. Indirect Effects

Complete recovery from high levels of daily occupational or environmental noise requires a substantial period of "quiet" with the A-weighted sound level less than 65 dB (See Appendix B of Reference [1]). Assuming an outdoor-to-indoor noise level reduction of 15 dB, with windows partially open, the outdoor average sound level thus should not exceed 80 dB in order to assure that the indoor level does not exceed 65 dB.

3. Day-Night Average Noise Levels Low Enough to Prevent Hearing Loss

Values of day-night average sound levels consistent with the above two considerations are summarized in Table II. Based on the direct effect, the recommended upper limit of average sound level (80 dB for 8 hours outdoor exposure to intermittent noise) translates to maximum permissible outdoor values of L_{dn} between 80 and 86 dB, depending on the difference between the daytime and nighttime values of average sound level. The most probable maximum permissible value for L_{dn} in an actual environment would be 83 dB (See Appendix A of Reference [1], Fig. A-7).

Therefore, considering the direct effect only, an outdoor noise exposure of L_{dn}= 83 dB or less will produce no noticeable hearing change in 90 percent of the population who are outdoors as much as 8 hours per day on the average. This group is envisioned to include mostly young children and retired persons in warm climates, or certain occupational situations. Since the relationship between noise exposure and hearing in children has not been experimentally established, the criterion established for working adults must be used. The possibility that children might be more sensitive than adults to noise must be assessed when establishing what constitutes an adequate margin of safety. The general public who are <u>not</u> outdoors as much as 8 hours will, of course, be better protected from aircraft noise. Hearing loss from noise produced by occupational or recreational activities is not considered here, except to note that a noise dose of 75 dB for 8 hours would be insignificant (less than a 1 dB change in average sound level) when added to the current 90 dB (or proposed 85 dB) average sound level that is the limit for occupational exposure 8 hours per day [19].

Table II

SUMMARY OF THE PERMISSIBLE VALUES OF THE OUTDOOR DAY-NIGHT AVERAGE SOUND LEVEL IN DECIBELS FOR INTERMITTENT AIRCRAFT NOISE, UNDER TWO ALTERNATIVE CONSTRAINTS AND FOR THREE VALUES OF THE DIFFERENCE BETWEEN DAY AND NIGHT VALUES OF THE AVERAGE SOUND LEVEL.

Constraint:		Difference in Day and Night Values of Outdoor Average Sound Level		
		0	4*	10
Direct Effect Requirement	8 hours outdoors in daytime with L_{eq}=80 dB	86**	83**	80**
Indirect Effect Requirement	8 hours indoors at night with L_{eq}=65 dB indoors or 80 dB outdoors	86	87	90

* Most likely value in this range of L_{dn}.

** If outside noise is steady, e.g., not composed of a series of intermittent single event noises, such as produced by aircraft, these values should be reduced by 5 dB.

The day-night average sound level determined by the "indirect effect" requirement for an 8 hour period of "quiet" is the same (L_{dn} = 83 dB) as found for the direct effect, provided the 8 hours occur during daytime. However, if, as usual, the quiet period occurs at night, the values of L_{dn} are greater, ranging between 86 and 90 dB. Thus, the maximum permissible limits resulting from the direct effects of environmental noise are controlling if the "quiet" period occurs at night.

4. Summary of Hearing Damage Risk Criteria

In summary, the hearing damage criteria indicate that a day-night average sound level less than 83 dBA is required, to assure that at least 90 percent of the general population have no measurable loss of hearing ability over the 500 to 4000 Hz range of frequency.

Such cumulative effects of environmental noise would show up only after exposures exceeding 10 years. This means that hearing damage data on which to base criteria of acceptable noise exposure, or to modify the initial choice of criteria, accrue very slowly. Prudence demands a conservative approach to setting criteria in such a situation. Moreover, the 83 dB limit was derived under certain assumptions regarding life style and exposure that might lead to over-or underestimation of individual exposures. In view of the latter uncertainty, it is judged reasonable to recommend an L_{dn} of 80 dB as the maximum permissible yearly outdoor average sound level, to prevent adverse health effects on people's hearing.

C. Speech Communication and Its Importance

Speech communication has long been recognized as an important requirement of any human society. Interference with speech communication disrupts one of the chief specific distinctions of the human species, disturbs normal domestic activities, creates a less desirable living environment, and can sometimes, for those reasons, be a source of extreme annoyance.

Noise can disturb speech communication in a variety of situations encountered at work, in transportation vehicles, at home, etc. Of chief concern for the purposes of this report, however, is the effect of noise on speech communication at home, for face-to-face conversation indoors or outdoors, telephone use, and radio or television enjoyment.

The extent to which noise of the community affects speech communication around the home depends on the location (whether indoors or outdoors), the amount of noise attenuation provided by the exterior walls of the house (including windows and doors) and the vocal effort of the talkers. Certainly it is possible to maintain communication in the face of intruding noise if the voice level is raised; but in an acceptable noise environment one should not have to increase the voice level above a normal, comfortable effort in order to communicate easily.

1. Speech Interference Due to Noise

Research over a number of years since the late 1920's has made great progress in characterizing quantitatively the effects of noise on speech. A review of that work is contained in Refs.[13] and [20], and is summarized here.

The chief effect of intruding noise on speech is to mask the speech sounds and thus reduce intelligibility. The important contributants to intelligibility in speech sounds cover a range in frequency from about 200 to 6000 Hz, and at each frequency a dynamic level range of about 30 dB.

The intelligibility of speech will be nearly perfect if <u>all</u> these contributions are available to a listener for his understanding. To the extent that intruding noise masks out or covers up some of these contributions, the intelligibility deteriorates, more rapidly the higher the noise level, particularly if the noise frequencies coincide with the important speech frequencies.

It is no accident, from the evolutionary point of view, that the hearing of humans is most sensitive in the frequency range most important for understanding their speech. Therefore, it is not mere coincidence that the A-weighting, designed to imitate the frequency sensitivity of the human ear, should also be useful as a measure of the speech interference potential of intruding noise. A-weighting gives greatest weight to those components of the noise that lie in the frequency range where most of the speech information is compressed, and thus yields higher readings (A-weighted levels) for noises whose energy is concentrated in that frequency range.

a) Outdoor Speech Communication

For these reasons the results of rather complicated research studies can be easily simplified and summarized in terms of A-weighted sound levels as shown in Figure 2. This figure presents the distance between talker and listener for satisfactory conversations outdoors, in different steady background noise levels (A-weighted), for three degrees of vocal effort. This presentation depends on the fact that the voice level at the listener´s ear (outdoors) decreases at a predictable rate as the distance between him and the talker is increased. In a steady background noise from the community, there comes a point, as the talker and listener increase their separation, where the decreasing speech signal is first equalled and then masked by the noise.

The levels plotted in the figure do not permit perfect sentence intelligibility at the indicated distances; instead the sentence intelligibility at each distance is 95 percent, meaning that 95 percent of the key words in a group of sentences would be correctly understood. 95 percent speech intelligibility permits reliable communication because of the redundancy in normal conversation. That is,in normal conversations many unheard words can be inferred since they occur in a particular and often familiar context; often the vocabulary is restricted which further helps understanding. Therefore, 95 percent intelligibility is adequate for most situations.

Other factors, such as the talker´s enunciation, the familiarity of the listener with the language, and the listener´s motivation, also influence the intelligibility; but the plotted data are valid under average conditions.

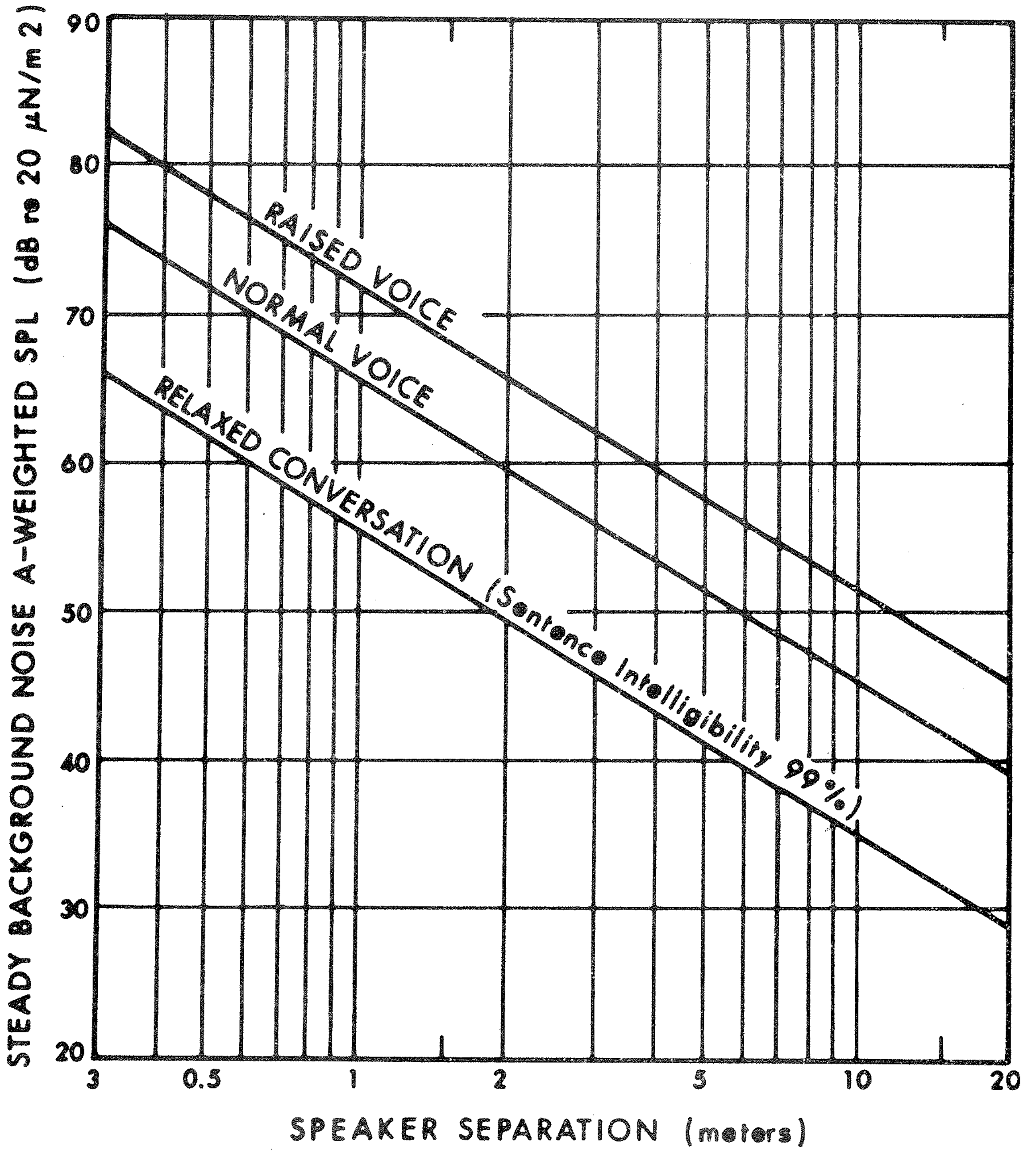


Figure 2. Maximum Distance Over Which Conversation is Considered to be Satisfactorily Intelligible (Sentence Intelligibility = 95% Except as Noted) for Different Background Levels

The data of Figure 2 are tabulated for convenience below:

Table III

STEADY A-WEIGHTED BACKGROUND NOISE LEVELS THAT ALLOW COMMUNICATION WITH 95% SENTENCE INTELLIGIBILITY OVER VARIOUS DISTANCES OUTDOORS FOR DIFFERENT VOICE LEVELS

VOICE LEVEL	COMMUNICATING DISTANCE (meters)						
	0.5	1	2	3	4	5	
Normal voice	72	66	60	56	54	52	dB
Raised voice	78	72	66	62	60	58	dB

If the levels in Figure 2 and Table III are exceeded, the talker and listener must either move closer together or expect reduced intelligibility. For example, suppose a conversation at a distance of 3 meters in a steady background noise of 56 dB using "normal voice" levels. If this background level were increased from 56 to 66 dB, the talkers would either have to move from 3 to 1 meter separation to maintain the same intelligibility, or alternately, to raise their voices well above "raised voice" effort. If they remain 3 meters apart without raising their voices, the intelligibility would drop from 95 to 65 percent (this last conclusion is not deducible from the figure).

In choosing suitable limits on environmental noise to permit comfortable speech, it appears reasonable to limit outdoor noise levels so as to permit reliable speech communication with normal voice up to two meters separation between talker and listener. The choice of two meters for the communicating distance is considered reasonable for typical outside communication requirements in urban areas. To achieve this goal, the average sound level should be no greater than 60 dB, according to Table III.

It is shown in Appendix C of Reference [1] that matters are changed only slightly if these criteria are interpreted as average noise levels for fluctuating noises, such as aircraft or traffic noise. In fact, the average noise level is a conservative measure of noise for protection of speech communications; the maximum permissible average sound level chosen to protect speech communication causes somewhat less speech interference when the noise fluctuates than when it is steady.

b) Indoor Speech Communication

The research results concerning the masking of speech sound out-of-doors are not valid indoors, because they depend on a predictable decrease of speech sound with increasing distance between talkers; the predictable relation is upset indoors because of reflections from the walls and other boundaries of the room.

Fortunately, however, there are well-known criteria of long-standing for acceptable noise levels indoors, appropriate to various indoor activities. These are tabulated in terms of A-weighted sound levels in Table IV.

Note that the range of recommended A-levels for indoor spaces typical of dwellings (items 6-8) is from 34 to 47 dB, but for spaces used primarily during the day where speech communications are important (items 7 and 8), the emphasis is on levels between 38 and 47 dB. A typical recommended level from the upper half of this latter range is 45dB. This level will allow relaxed, face-to-face conversation with essentially 100% sentence intelligibility for all locations of talker and listener in a typical room in a dwelling.

Assuming 15 dB attenuation through a partially opened window, the steady <u>outdoor</u> noise level could reach 60 dB without exceeding the indoor noise criterion of 45 dB for residences. With lower outdoor levels, the interior noise environment would shift toward the more favorable end of the recommended range listed for items 6 to 8 in Table IV, leading to improved speech communications conditions.

Table IV

ACCEPTABLE NOISE LEVELS INDOORS, APPROPRIATE TO VARIOUS INDOOR ACTIVITIES

Type of space(and acoustical requirements)	Appropriate L_A,dB
1. Concert halls, opera houses, and recital halls (for listening to faint musical sounds)	21 to 30
2. Broadcast and recording studios (distant microphone pickup used)	21 to 30
3. Large auditoriums, large drama theaters, and churches (for execellent listening conditions)	Not to exceed 30
4. Broadcast, television, and recording studios (close microphone pickup only)	Not to exceed 34
5. Small auditoriums, small theaters, small churches, music reherasal rooms, large meeting and conference rooms (for good listening), or executive offices and conference rooms for 50 people (no amplification)	Not to exceed 42
6. Bedrooms, sleeping quarters, hospitals, residences, apartments, hotels, motels, etc. (for sleeping, resting, relaxing)	34 to 47
7. Private or semiprivate offices, small conference rooms, classrooms, libraries, etc. (for good listening conditions)	38 to 47
8. Living rooms and similar spaces in dwellings (for conversing or listening to radio and TV)	38 to 47
9. Large offices, reception areas, retail shops and stores, cafeterias, restaurants, etc. (for moderately good listening conditions)	42 to 52
10. Lobbies, laboratory work spaces, drafting and engineering rooms, general secretarial areas (for fair listening conditions)	47 to 56
11. Light maintenance shops, office and computer equipment rooms, kitchens, and laundries (for moderately fair listening conditions)	52 to 61

12. Shops, garages, power-plant control rooms, etc. (for just acceptable speech and telephone communication). Levels above PNC-60 are not recommended for any office or communication situation — 56 to 66

13. For work spaces where speech or telephone communication is not required, but where there must be no risk of hearing damage — 66 to 80

2. Effect of Non Steady Noise

The data in Figure 2 are based on tests involving steady, continuous noise, for which case the noise level is equal to the average sound level. It might be questioned whether these results would apply to fluctuating noises. For example, when intermittent noise intrusions, such as those from aircraft flyovers are superimposed on a steady noise background, the average sound level is greater than the level of the background alone. If the sound levels of Figure 2 (and of Table III) are interpreted as <u>average</u> sound levels, it is evident that these values could be slightly increased (by an amount depending on the statistics of the noise), because most of the time......that is, except during the flyovers......the interfering noise level is actually lower than the average sound level.

The amount of this difference has been calculated for urban noise and aircraft noise statistics.

Table V

MAXIMUM PERMISSIBLE AVERAGE SOUND LEVELS THAT PERMIT 95 PERCENT SENTENCE INTELLIGIBILITY AT A DISTANCE OF 2 METERS, USING NORMAL VOICE EFFORT

Noise Type	L_{eq} in decibels
Steady	60
Urban Community noise	60+
Aircraft Noise	65

The results, shown in Table V, demonstrate that for 95 percent sentence intelligibility, normal voice effort and 2 meter separation between talker and listener, the value of the average sound level associated with continuous noise is less than the value for an environmental noise whose magnitude varies with time. It is concluded that, for a fixed value of the average sound level, minimum intelligibility is associated with continuous noise. Almost all time-varying environmental noises with the same average sound level would lead to better intelligibility. Alternatively, for a fixed value of the average sound level, the percentage of interference with speech (defined as 10 minus the percentage sentence intelligibility) is greater for steady noise than for almost all environmental noise whose magnitude varies with time.

D. ANNOYANCE

The word annoyance as used in this report as a general term for reported adverse responses of people to environmental noise. In this context, not the laboratory noisiness/annoyance studies but the studies of annoyance which are largely based on the results of sociological surveys have been considered. Such surveys have been conducted among residents in the vicinity of airports of a numbers of countries including the United States [22,23,24,25,26].

The results of these surveys are generally related to the percentage of respondents expressing differing degrees of disturbance or dissatisfaction due to the noisiness of their environments. Some of the surveys go into a complex procedure to construct a scale of annoyance, some report responses to the direct question of "how annoying is the noise". Each social survey is related to some kind of measurement of the noise levels (mostly from aircraft operations) to which the survey respondents are exposed. Correlation between annoyance and noise levels can then be obtained.

The results of the social surveys show that individual responses vary widely for the same noise level. Borsky [21], has shown that these variances are reduced substantially when groups of individuals having similar attitudes about "fear" of aircraft crashes and "misfeasance" of authorities are considered. Moreover, by averaging responses over entire surveys, almost identical functional relationships between human response and noise levels are obtained for the whole surveyed population as for the groups of individuals having <u>neutral</u> attitudinal responses.

In deriving a generalized relationship between reported annoyance and day-night average sound level it seems reasonable to use the average overall group responses, recognizing that individuals may vary considerably, both positively and negatively compared to the average, depending upon their particular attitudinal biases.

The relationship between the percentage of respondents who were "highly annoyed" and the day-night average sound level is shown in Figure 3, for the combined results of the first London survey [22], the Tracor study[24] and the second Heathrow survey [23]. These results, based on nearly 2,000 respondents in the first London survey and more than 7,500 respondents in the combined surveys, show an essentially identical relationship between the percent of people highly annoyed and the average sound level. The results are in complete agreement with the conclusions of a recent analysis of British, French, and Dutch survey results, conducted by the Organization for Economic Co-Operation and Development (OECD) [27].

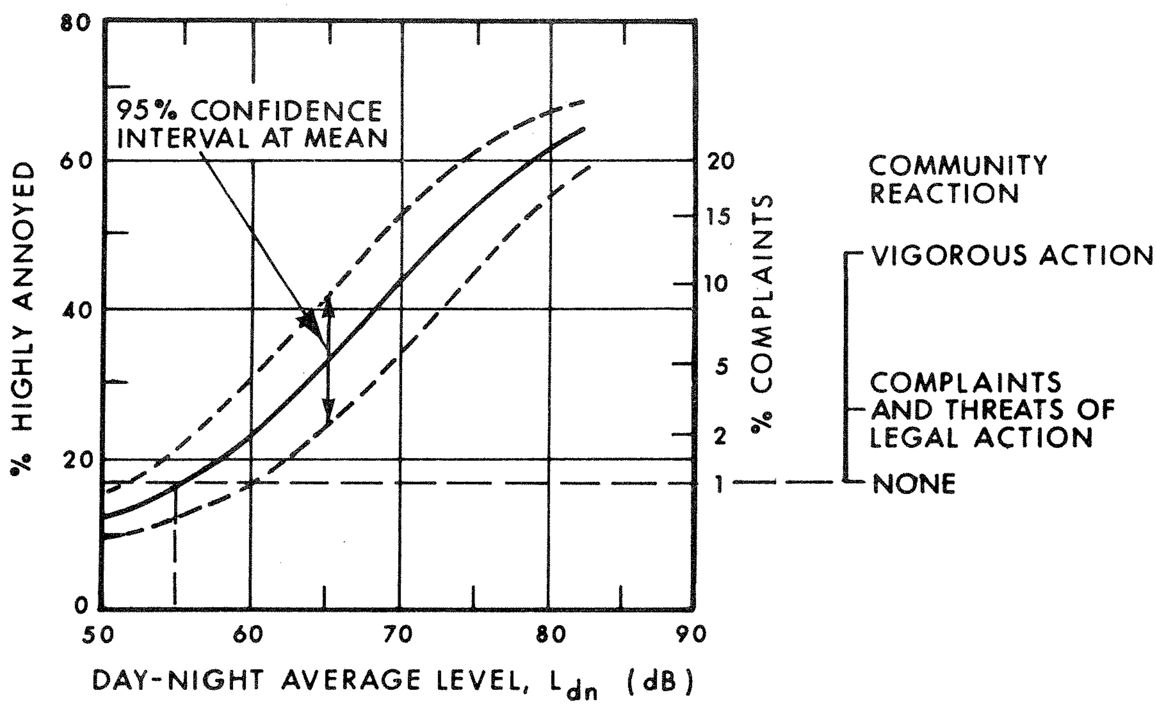


Figure 3. Intercomparison of Various Measures of Individual and Community Reactions as A Function of the Day-Night Average Noise Level, L_{dn} in Decibels.

As a final comparison, a scale showing differing degrees of overt community response is shown at the far right on Figure 3. This scale represents responses to a variety of noises, not only aircraft, based on the 55-case study[23] described in Appendix D of Ref. 1. On the average, adverse community reaction to noise becomes of serious concern at values of L_{dn} over 60 dB. However, it should be noted that, while no overt community response, in the average case, would be expected for L_{dn} of 55, about 18% of the people would still be highly annoyed. The crucial words here are "in the average case"; note from Figure 3 that the 95% confidence limits for this statistical comparison span a range of almost 10 decibels in L_{dn}. In more sensitive communities than the average , it could require L_{dn} as low as 50 to prevent overt community response, and there would still be the substantial remainder of highly annoyed people.

Individual annoyance and complaint data are summarized in Table VI. The percentage of complaints varies from 2 to 22% over the L_{dn} range of 60-80 dB, an average rate of increase of 1% per dB. In this same range of noise levels, the <u>rate of increase</u> in the percentage of people who are highly annoyed increases from 23% to 62%, an average rate of 2% per dB. However, for values of L_{dn} less than 60 dB, the rate of increase in the percentage of people highly annoyed increases at a lower rate, an average of 1% per dB, signifying that quite low values of L_{dn} would be required to eliminate the highly annoyed response completely.

Table VI

PERCENTAGES OF THE POPULATION NEAR THE AIRPORT IN AN AVERAGE COMMUNITY WHO ARE HIGHLY ANNOYED AND WHO LODGE COMPLAINTS ABOUT NOISE , FOR VARIOUS VALUES OF THE DAY-NIGHT AVERAGE SOUND LEVEL OF AIRCRAFT NOISE (from Figure 3).

Outdoor Day-Night Average Noise Level in dB	Percentage Highly Annoyed	Percentage Complainants
50	13	less than 1
55	17	1
60	23	2
65	33	5
70	44	10
75	54	15
80	62	over 20

A number of official statements of the effects of various noise levels on people's activities have been drawn from survey results such as those given above. These statements are examined and criticized in Section IV. Further details of several recent surveys are also discussed in detail in that Section.

E. GENERAL HEALTH EFFECTS OF NOISE

Although there is the possibility that noise of high level or extreme fluctuations may contribute indirectly to the incidence of non-auditory diseases, no conclusive evidence to support this possibility has been documented. Most experts agree that there is no well-established effect of noise on health (in the more restricted sense, i.e., the absence of disease) besides noise-induced hearing loss. A recent critical review of this subject [13] came to the conclusion "if noise control sufficient to protect persons from ear damage and hearing loss were instituted, then it is highly unlikely that the noises of lower level and duration resulting from this effort could directly induce non-auditory disease." (But see the footnote on pages 28 and 29).

On the other hand, Figure 4 shows the percentages of people who consult their doctors, who use ear protection, and who use sleeping pills to avoid sleep disturbance by aircraft noise, as revealed in a 1973 Swiss survey [28], as a function of the NNI rating for the noise to which they were exposed. Equivalent values of L_{dn} are also shown. All of these effects increase sharply with increasing aircraft noise level, and all have at least some implications concerning health...... particularly the increased diet of sleeping pills!

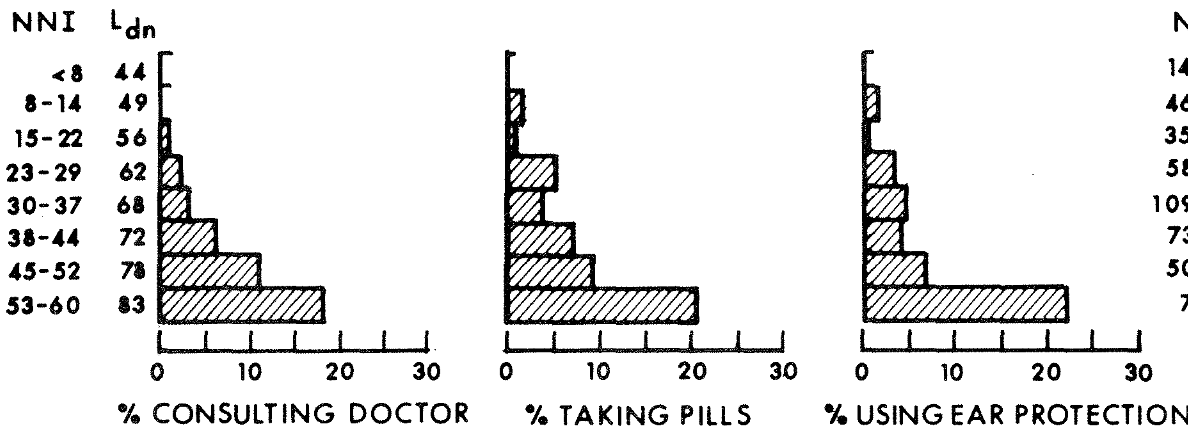


Figure 4. EFFECT OF AIRCRAFT NOISE ON USE OF EAR PROTECTION, CONSUMPTION OF SLEEPING PILLS AND CONSULTATION OF DOCTOR. 100% = NUMBER OF INTERVIEWED SUBJECTS IN EACH NOISE CATEGORY, DESIGNATED BY VALUE OF N.

F. SLEEP DISTURBANCE

Sleep disturbance due to noises is a potential indirect health effect of considerable concern, for it can certainly affect psychological well being, irritability and mood [13]. The awakening effect of noise depends on the characteristics of the individual person and the noise (such as time of night, age of individual, etc.). Noise limits for sleep interference cannot yet be so clearly established as for the risk of hearing loss or for speech interference. However, in quiet bedrooms sound levels below 30dB have ordinarily no arousal effects, while steady noise above 50 dB resulted in numerous complaints.

An outdoor day-night average sound level of 60 dB would provide average sound levels from exterior noise sources below 35 dB at night in an average bedroom with closed windows. The levels in a bedroom with open windows could, of course, be higher but it is reasonable to expect people who prefer to open their windows at night to be able to accommodate to slightly higher levels. While individual noise events might still be audible even in the presence of heating and air conditioning equipment, and might sometimes result in changes of sleep pattern, they would be considered for the most part as normal and acceptable by the large percentage of the US population living in an airport environment today. It does not appear that much would be gained by setting the goal for day-night average sound level lower than 60 dB, for this would not necessarily protect against occasional individual noise events whose duration is short but whose arousal/annoyance value is high.

The permissible day--night average sound level should not be set unrealistically low in an attempt to account for the effects of individual events of high intensity but low probability if they are not "cumulative" effects. It is recommended instead, that maximum sound levels during the night should be controlled through separate local noise ordinances, if desirable and necessary.

Experience has shown that, for typical traffic, airport and city noises, when the day/night difference in equivalent noise level is 10 dB or more, the daytime exposure is the main concern with respect to potential speech interference and annoyance. In these situations, a maximum permissible outdoor L_{dn} of 60 dB, will generally cause negligible speech interference or annoyance during daytime, in the average community, and will most likely cause no adverse effects on night-time sleep in normal people accustomed to the environment, even with windows partially open.

G. NATURAL INDOOR NOISE "FLOOR"

An important consideration in choosing criteria of acceptable environmental noise is the indoor noise level to be expected in residential areas irrespective of the outdoor noise environment. It clearly makes little sense to establish criteria for external noise sources that would cause levels indoors that are lower than the "self-noise"of residential living.

While few reported data are available on the variation of noise levels within homes accommadating a variety of different life styles, some limited information can be provided. The measured values shown in Table VII are considered representative of indoor average sound levels where external noise intrusion is not significant.

Table VII

NOISE LEVELS DUE TO TYPICAL INDOOR ACTIVITIES

Condition	L_{eq} (dB)
Typical people movement, no TV or radio	40 - 45
Speech at 10 feet, normal voice	55
TV listening level at 10 feet, no other activity	55 - 60
Stereo music	50 - 70

H. Noise Impact on Human Activities and Land-Use Compatibility (HUD)

Taking these results into account, the U.S. Department of Housing and Urban Development has prepared a chart outlining the impact of noise...for average conditions...on various human activities as shown in Figure 5. In addition, HUD presents a land use compatibility chart, shown in Figure 6 and Table VIII. For example, this chart suggests that residential land use for single and two-family homes or for mobile homes is satisfactory up to L_{dn}= 65 dB, with no special noise insulation requirements for new construction (designation A), and that the expected community response under these conditions would be that some noise complaints may occur, and noise may, occasionally, interfere with some activities (desigantion I). However, above L_{dn}= 62.5 dB, new construction should generally be avoided, etc. (designation B), and in such developed areas individuals may complain, perhaps vigorously, etc. (designation II).

For higher levels of noise exposure, the interpretations generally define a range of noise exposure in which new construction or development should not be undertaken unless an analysis of noise requirements is made and needed noise insulation features are included in the building design and site development. For more extreme noise exposure, many of the land uses are assigned an interpretation saying that new construction or development should not be undertaken at all.

As we shall see in Section IV, these recommendations are not particularly restrictive.

Low Impact: Activity can be performed with little or no interruption from aircraft noise, though noise may be noticeable above background levels.

Moderate impact: Activity can be performed but with some interference from aircraft noise due to level or frequency of interruptions.

Serious impact: Activity can be performed but only with difficulty in the aircraft noise environment due to level or frequency of interruptions.

Critical impact: Activity cannot be performed acceptably in the aircraft noise environment.

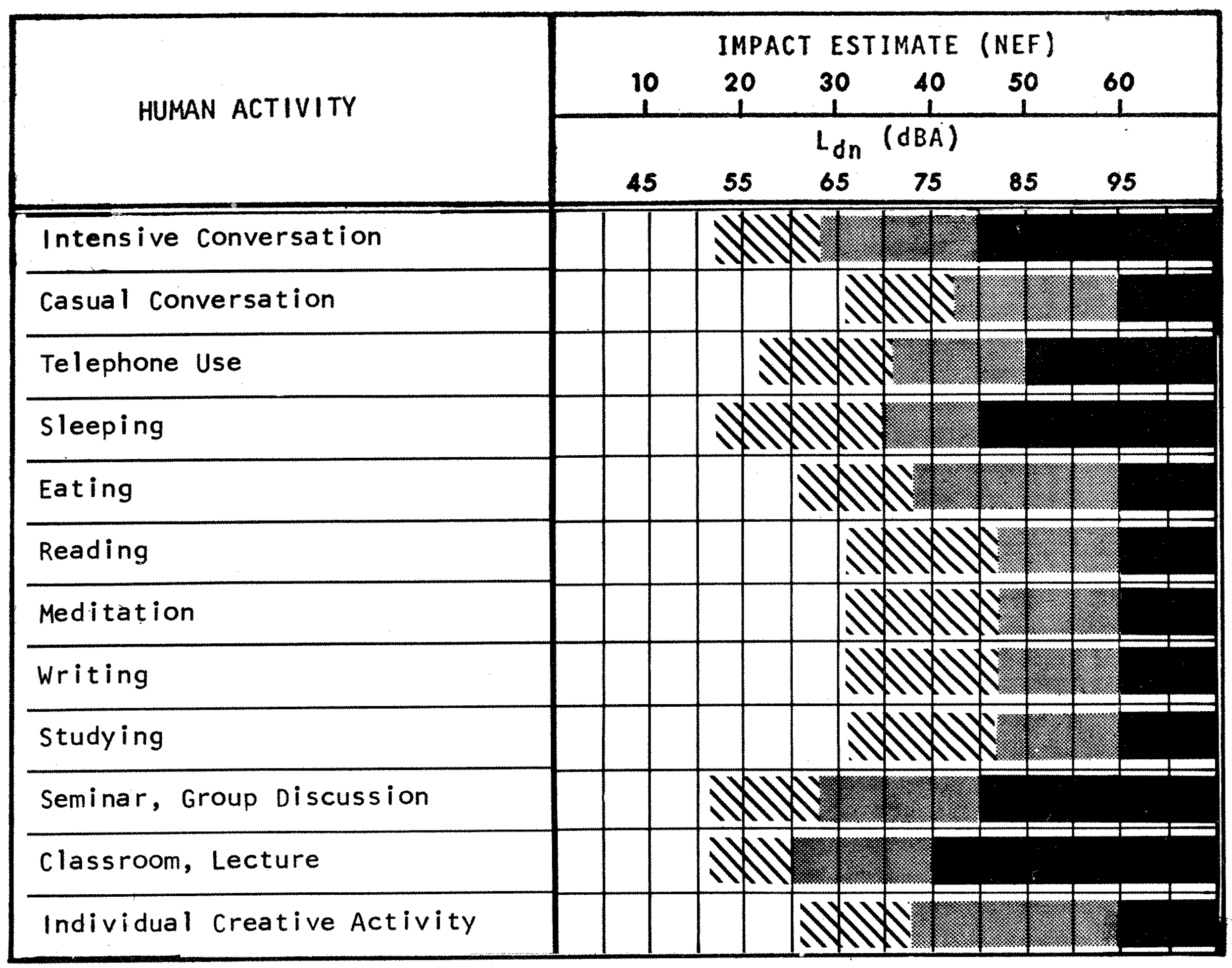
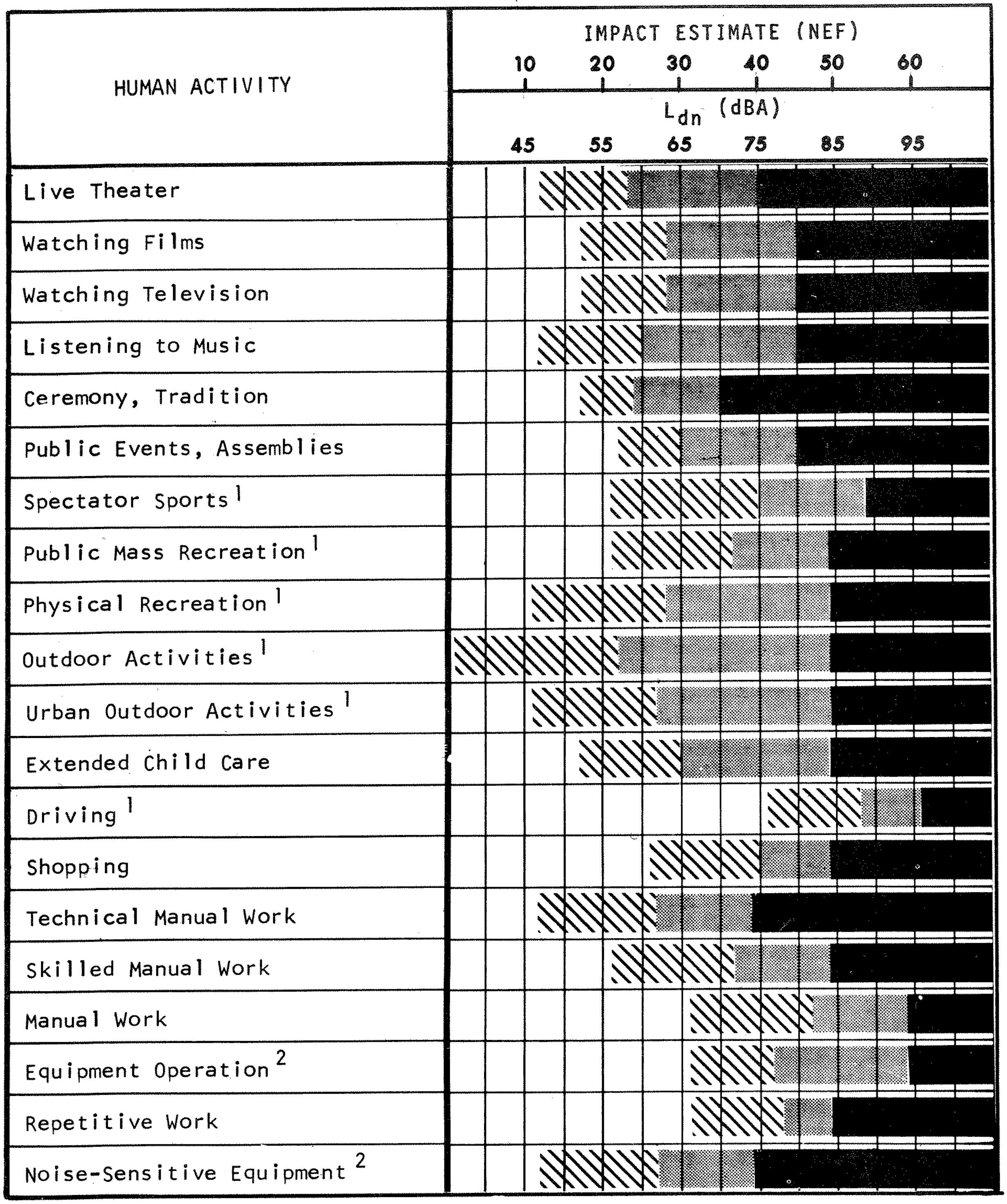


Figure 5. NOISE IMPACT ON HUMAN AVTIVITIES



[1] No allowance for structural insulation.

[2] Depends on characteristics of particular equipment.

Figure 5. (cont.) NOISE IMPACT ON HUMAN ACTIVITIES

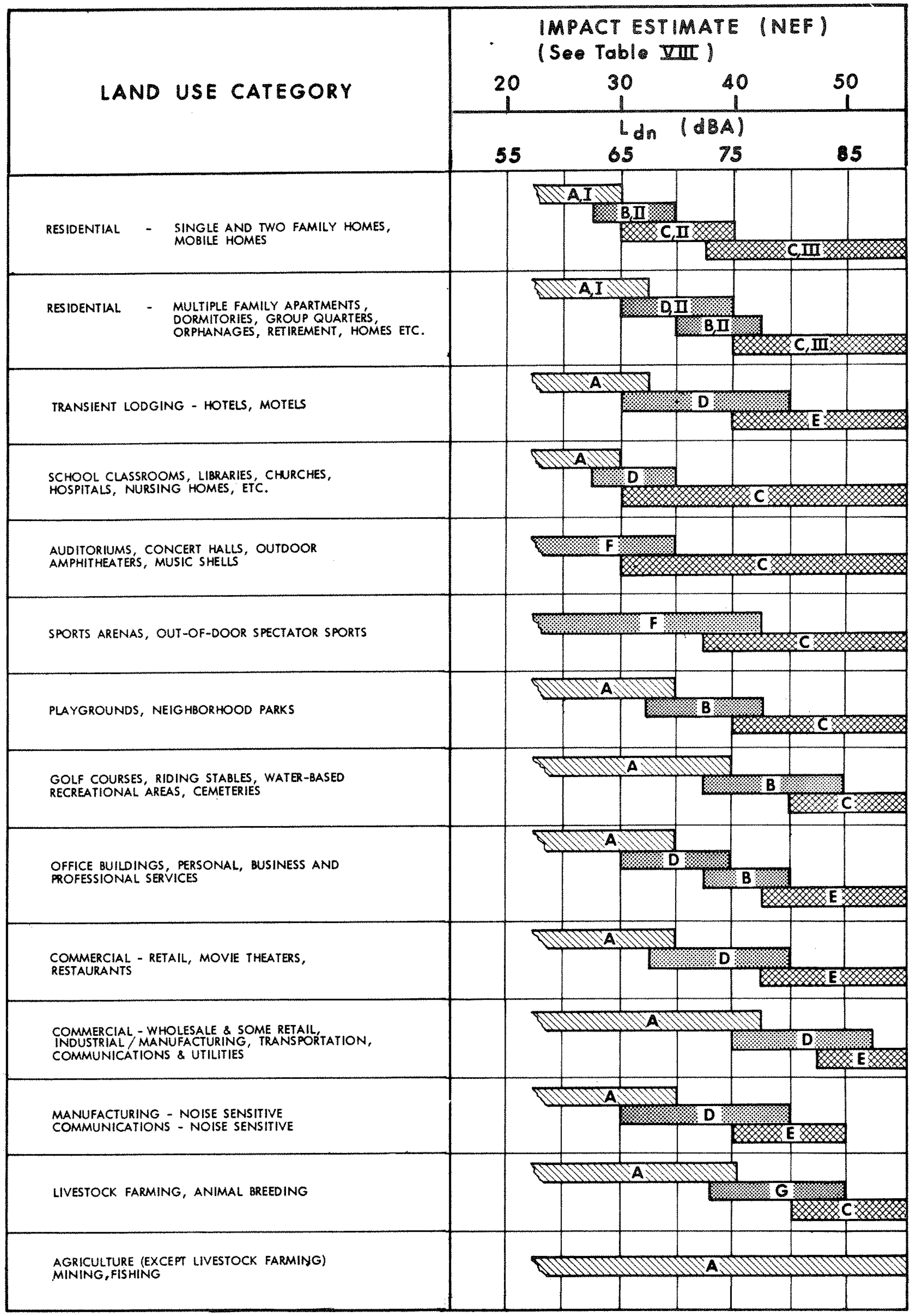


Figure 6. LAND-USE COMPATIBILITY CHART

Table VIII

NOISE COMPATIBILITY INTERPRETATIONS FOR USE WITH FIGURE 6

General Land Use Recommendations*

A. Satisfactory, with no special noise insulation requirements for new construction.

B. New construction or development should generally be avoided except as possible infill of already developed areas. In such cases, a detailed analysis of noise reduction requirements should be made, and needed noise insulation features should be included in the building design.

C. New construction or development should not be undertaken.

D. New construction or development should not be undertaken unless a detailed analysis of noise reduction requirements is made and needed noise insulation features included in the design.

E. New construction or development should not be undertaken unless directly related to airport-related activies or services. Conventional construction will generally be inadequate and special noise insulation features must be included. A detailed analysis of noise reduction requirements should be made and needed noise insulation features included in the construction or development.

F. A detailed analysis of the noise environment, considering noise from all urban and transportation sources should be made and needed noise insulation features and/or special requirements for the sound reinforcement systems should be included in the basic design.

G. New development should generally be avoided except as possible expansion of already developed areas.

Community Response Predictions**

I. Some noise complaints may occur, and noise may, occasionally, interfere with some activities.

II. In developed areas, individuals may complain, perhaps vigorously, and group action is possible.

III. In developed areas, repeated vigorous complaints and concerted group action might be expected.

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* Land use recommendations are based upon experience and judgement factors without regard to specific varitions in construction (such as air conditioning and building insulation) or in other physical contitions (such as terrain and the atmosphere). These features and others involving social, econimic, and political conditions must be considered in recommending individual use and density construction combinations in specific locations.

** Community response predictions are generalizations based upon experience resulting from the evolutionary development of various national and international noise exposure units, in particular, the Composite Noise Rating (CNR). For specific locations, considerations must also be given to the background noise levels and the social, economic, and political conditions that exist.

I. EPA's Identified Noise Levels

Basing their decisions on the same scientific data as HUD, EPA has identified levels of environmental noise "requisite to protect public health and welfare with an adequate margin of safety" as indicated in Table IX.

Table IX

YEARLY AVERAGE EQUIVALENT SOUND LEVELS IDENTIFIED AS REQUISITE TO PROTECT THE PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

	Measure	Indoor: Activity Interference	Indoor: Hearing Loss Consideration	Indoor: Protect Against Both Effects (b)	Outdoor: Activity Interference	Outdoor: Hearing Loss Consideration	Outdoor: Protect Against Both Effects (b)
Residential with outside space and Farm Residences	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Residential with no outside space	L_{dn}	45		45			
	$L_{eq(24)}$		70				
Commercial	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Inside Transportation	$L_{eq(24)}$	(a)	70	(a)			
Industrial	$L_{eq(24)}$(d)	(a)	70	70(c)	(a)	70	70(c)
Hospitals	L_{dn}	45		45	55		55
	$L_{eq(24)}$		70			70	
Educational	$L_{eq(24)}$	45		45	55		55
	$L_{eq(24)}$(d)		70			70	
Recreational areas	$L_{eq(24)}$	(a)	70	70(c)	(a)	70	70(c)
Farm Land and General Unpopulated Land	$L_{eq(24)}$				(a)	70	70(c)

Explanation of indentified level for hearing loss: The exposure period which results in hearing loss at the identified level is a period 40 years.

Code: a. Since different types of activities appear to be associated with different levels, identification of a maximum level for activity interference may be difficult except in those circumstances where speech communication is a critical activity.

b. Based on lowest level.

c. Based only on hearing loss.

d. An $L_{eq(8)}$ of 75 dB may be identified in these situations so long as the exposure over the remaining 16 hours per day is low enough to result in a negligible contribution to the 24-hour average, i.e., no greater than an L_{eq} of 60 dB.

IV. LIMITS FOR CUMULATIVE NOISE EXPOSURE

A. OFFICIAL STATEMENTS OF RELATIONSHIPS BETWEEN EXPOSURE AND CORRESPONDING HUMAN RESPONSE

Part III of this report has summarized scientific studies of the various effects that exposure to noise may have upon people. From time to time these results have been interpreted by various writers for the purpose of establishing maximum acceptable limits of community noise exposure in general, or compatible land use patterns based on noise exposure in the vicinity of airports, in particular. The notion of what constitutes an "acceptable" or "compatible" noise exposure, however, differs greatly according to the affiliation of the writer.

The airport operator's definition of the "noise problem", for example, has to do with whether or not he will be able to continue his airport operations in their present form. He is thus concerned that the noise criteria should not overstate the severity of aircraft noise impact, particularly if the criteria are incorporated into public policy statements [29]. National aviation authorities have interests similar to those of the airport operator; and those that have adopted standards of allowable aircraft noise have demonstrated strong sympathy with the views of airport operators in the past.

Figure 7 compares the officially adopted statements of the relationships between aircraft noise exposure and expected human response, or land-use recommendations, for France, Germany, the United Kingdom, the Netherlands, South

Africa, and the United States. A horizontal line across the page would connect noise ratings in the various countries that correspond to approximately equal exposure to aircraft noise. Despite the differences in the formulations of the several national noise ratings, there is close agreement in the statements of expected response for a given amount of noise exposure.

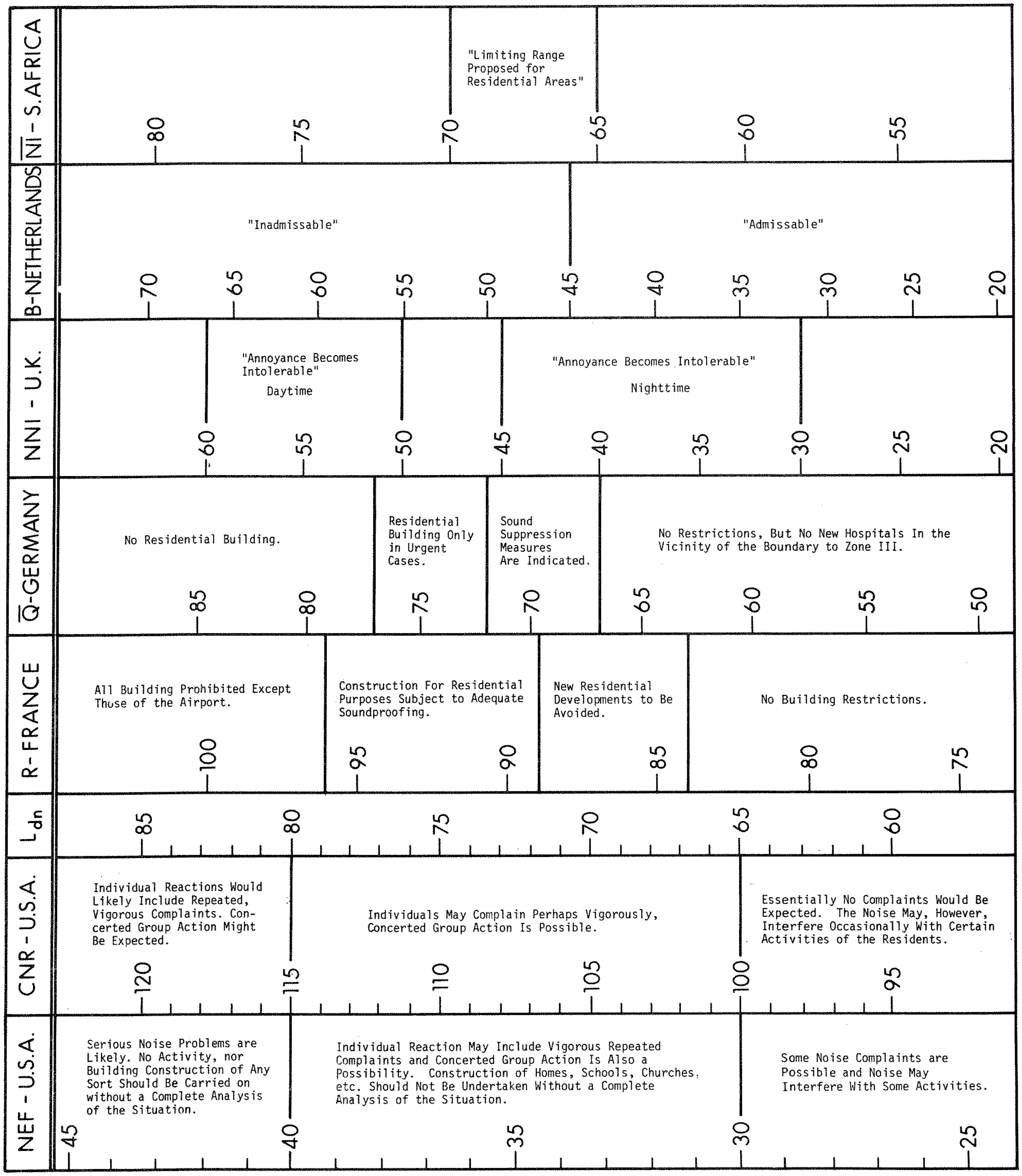

Figure 7. APPROXIMATE EQUIVALENCES BETWEEN NOISE EXPOSURE INDICES AND RESPONSE OR LAND-USE DESCRIPTIONS

1. Maximum Permissible Noise Exposure in Residential Areas in Various Countries

The British conclude that "the maximum acceptable aircraft noise exposure lies in the range from NNI 30 to 45 for night-time, and 50 to 60 NNI" for daytime, [37] since they "consider that exposure to aircraft noise reaches an unreasonable level in the range 50 to 60 NNI." [38] (50 to 60 NNI corresponds approximately to L_{dn}= 77 to 83 dB). Note that the "unreasonable level" of noise exposure is equated here to the "maximum acceptable" exposure for residences.

The French put no restrictions on residential construction for aircraft noise impact less than R 84; but if special sound insulation is provided, residential buildings are permitted in areas with noise exposure up to R 96. (R 84 to 96 corresponds to L_{dn}= 67 to 79.)

The Dutch authorities regard the maximum tolerable level of annoyance to be reached at a "total noise load" of B 45 (equivalent to L_{dn} of about 70).*

The German authorities define aircraft noise exposure zones such that no residential building is permitted for $\bar{Q}$ greater than 82; residential buildings are permitted where $\bar{Q}$ lies between 72 and 82, provided that appropriate sound

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* Because the $\bar{Q}$ and $\bar{NI}$ ratings take the time pattern explicitly into account, no exact equivalence exists in general between these ratings and L_{dn}; and because of the different dependence on number of operations, the same is true for the NNI and B ratings. The equivalences stated here are strictly valid only for a specific set of operations.

attenuation measures are included in the construction; no restrictions apply on residential building below $\bar{Q}$ = 72, but no hospitals, rest homes, homes for the aged, schools, churches or scientific institutions may be built near the $\bar{Q}$ = 72 boundary. ($\bar{Q}$ = 82 corresponds to L_{dn} = 77, $\bar{Q}$ = 72 to L_{dn} = 70.) (See footnote on previous page)

In South Africa it was concluded that the upper bound of noise exposure for residential development is between $\overline{NI}$ 65 and 70 (corresponding to L_{dn} = 70 to 75).(See footnote on previous page)

In the United States, two alternative ratings for aircraft noise are in widespread use by the armed forces and earlier by the FAA; the expected community responses for various values of these ratings are given at the left in Figure 7.* The range of CNR below 100 (equivalent to 30 NEF or L_{dn}=65) is regarded as acceptable for residential use without qualification; the range between CNR 100 and 115 (30 to 40 NEF, or L_{dn}= 65 to 80) is acceptable under special conditions. (The U.S. Department of Housing and Urban Development has made these special conditions clear, see below.)

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* No account is given here of the Aircraft Sound Description System (ASDS) introduced by the FAA, because it is not readily related to CNR and NEF, in terms of which correlations with human response have been studied. In fact, no claim has been made to relate ASDS to human responses, at all.

In summary, the comparison shown in Figure 7 (with the exception of the Dutch, who are more conservative) identify an upper boundary of acceptable noise exposure for residential use between CNR 110 and 118 (NEF 37 and 42, L_{dn}= 75 and 83). In areas where no restrictions on residential land use are imposed, the upper limit of noise exposure corresponds to a range from CNR 102 to 106 (NEF 31 to 34, L_{dn} = 67 to 71).

B. Establishment of Official Criteria

Such noise criteria, that identify limits of official acceptability for residential use in the CNR 100 (NEF 30, L_{dn}= 65) range, are not based on unqualified community acceptability. In each of the national scientific studies in which noise limits were developed, these levels of noise exposure showed up as "maximum tolerable" and were regarded as turning points above which annoyance increases very rapidly; but sizable portions of the populations were seriously disturbed at much lower levels. These maximum tolerable noise levels, however, were adopted by the authorities and treated as <u>acceptable</u> levels, such that special precautions and noise abatement measures are required <u>only for more severe exposure</u>. The situation is even more extreme in the U.S., since the criteria were based on overt action in terms of complaints or legal action. It is well known that serious public annoyance is prevalent long before official complaints are lodged (see Section IV-C-3-b below).

1. Case Histories From Which Original CNR Rating was Developed.

Let us look more carefully, then, at the results of the original studies. Table X summarizes the results of the case histories from which the original CNR rating was developed. In cases with CNR of 100 (L_{dn}=65) there were vigorous complaints and threats of legal injunction; management took steps to reduce the noise. In a case with L_{dn} of 70, there were threats of injunction. In case 1, with L_{dn} of 75, the municipal authorities had to shut the offending facility down. In cases where the L_{dn} was as low as 60, there were strong complaints and one township acted to try to prevent aircraft flyovers. Even with an L_{dn} of only 55, there were consistent complaints and acoustical consultants had to be called in for noise control.

Table X

SUMMARY OF CASE HISTORIES OF RESPONSES TO NOISE IN RESIDENTIAL AREAS FROM Rosenblith and Stevens

No.	Description of Facility and Noise	CNR*	L_{dn}**	Predicted Average Response	Actual Response
1	Large wind tunnel in mid-west	110	75	Vigorous legal action	Municipal authorities forced facility to shut down.
2	Large wind tunnel in mid-west	100	65	Threats of legal action	Vigorous telephone complaints and injuction threats. Management took immediate steps to lessen noise.
3	Exhaust for air pumps, factory in industrial area	95	60	Strong complaints	Lodging house owner entered complaints with client and with local Dept. of Health
4	Engine run ups aircraft mfg. plant	80	45	Less than mild annoyance	No complaints reported by management. Operations restricted to day time only.
5	Airport ground run ups	95	60	Strong complaints	Complaints by civic organizations, individual telephone calls and letters of complaints.
6	Aircraft in flight near airport	95	60	Strong complaints	Vigorous complaints by letter and telephone. One town attempted to prevent passage of aircraft.
7	Aircraft engine mfg. plant test cells	85	50	Mild annoyance	No complaints reported for daytime operation; a few for

					operation after 11 p.m.
8	Loading platform with trucks,men shouting, etc.	100	65	Threats of legal action	Vigorous complaints to management. Acoustical consultant called in by firm.
9	Transformer noise in very quiet res. area	105	70	Between threats of legal action and vigorous legal action	Injunction threats
10	Large fan at power company; single freq. components	90	55	Strong complaints	Residents complained consistently, consultants called in to advise on noise control.
11	Weapons range, intermittent firing, 3-sec bursts several times per day	100	65	Threats of legal action	Vigorous complaints from nearby residents for winter operation.

* Estimated on basis of "level rank" band spectral measures as given in orginal reference.

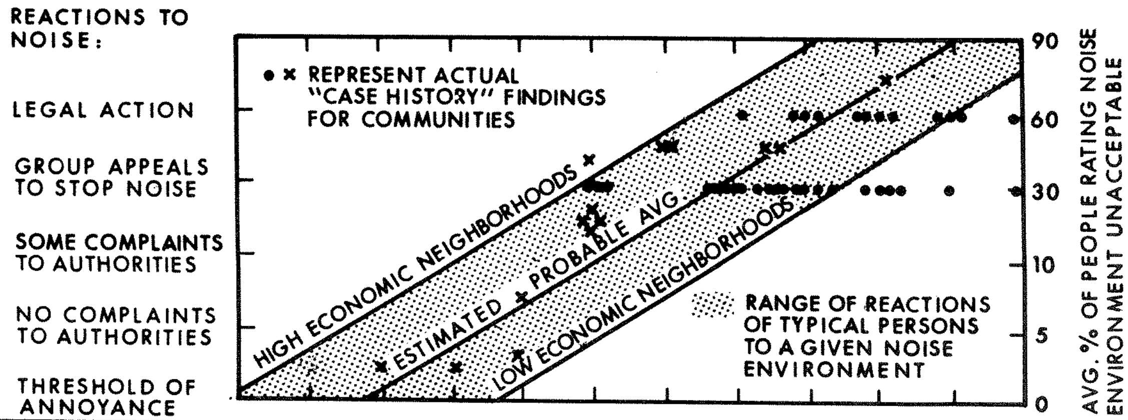
** Estimated on basis that $L_{dn} \simeq$ CNR-35

2. Summary of Subsequent Case Histories

Figure 8 presents further data on the observed responses of communities in a number of other case histories. For CNR of 100 (L_{dn}=65), the range of actual responses lay between "Some complaints to authorities" and "Legal action"; the most common response at L_{dn}=65 was "Group appeals to stop noise." Between 30 and 70% of the people rated the noise environment as unacceptable.

3. Criticism from Scientists

According to Galloway, "There is a growing sentiment among some social scientists that community attitude [to aircraft noise] is under-estimated by the present criteria."--[29]



NOISE ENVIRONMENT OF ANY SPECTRAL OR TEMPORAL NATURE		L_{dn}	30	35	40	45	50	55	60	65	70	75	80	85
		CNR	65	70	75	80	85	90	95	100	105	110	115	120
		NEF	-35	-30	-25	-20	-15	-10	-5	0	5	10	15	20
NOISE OF ANY SPECTRUM PRESENT CONTINUOUSLY DURING THE HOURS OF	7 AM - 10 PM	EPNL	77	82	87	92	97	102	107	112	117	122	127	132
		MAX PNdB, dB(D′), dB(A′)	40	45	50	55	60	65	70	75	80	85	90	95
	10 PM - 7 AM	EPNL	65	70	75	80	85	90	95	100	105	110	115	120
		MAX PNdB, dB(D′), dB(A′)	30	35	40	45	50	55	60	65	70	75	80	85

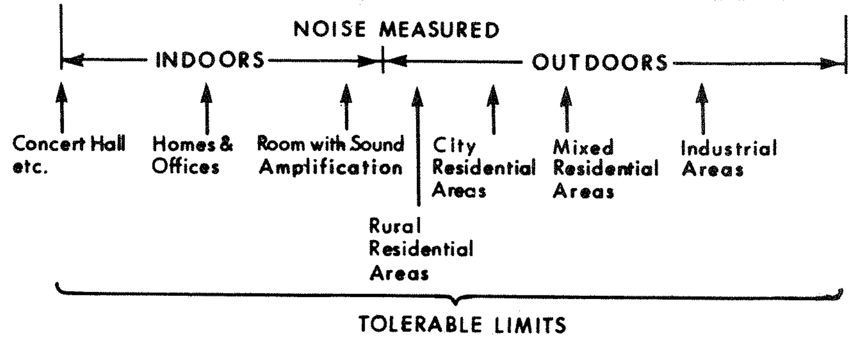


Figure 8. RELATION BETWEEN A HABITUAL COMPOSITE NOISE RATING AND: (a) COMMUNITY REACTIONS TO NOISE (left-hand ordinate);(b) ATTITUDES OF INDIVIDUALS OF THE UNACCEPTABILITY OF THE NOISE (right-hand ordinate). PARAMETERS ARE ECONOMIC STATUS OF NEIGHBORHOODS. dB(D′) minus 6 = dB(D); dB(A′) minus 13 = dB(A). Adapted from figure 238 from Kryter [30].

This is something of an understatement in itself, since he cites in support the recent book of Kryter [30], whose section entitled "CNR (and NEF) Tolerable Limits of Exposure to Aircraft Noise" is quoted below.

"Attention is invited to the following chart which is incorporated in the airport planning guide developed in the United States. This chart proposes that three zones be identified from CNRs as measured or predicted for given neighborhoods.

Zone I: $CNR<100^*$. Essentially no complaints would be expected. The noise may, however, interfere occasionally with certain activities of the residents.

Zone II: $100 \leq CNR \leq 115$. Individuals may complain perhaps vigorously. Concerted group action is possible.

Zone III: $CNR>115$. Individual reactions would likely include repeated, vigorous complaints. Concerted group action might be expected.

"The above zones, particularly Zone I, would appear to greatly underestimate typical behavior of people exposed to noise as shown in Figure 8 and Table X.

"...

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* Zone boundary designations in terms of L_{dn} are as follows: Zone 1: $L_{dn}<65$; Zone II: $65 \leq L_{dn} \leq 80$; Zone III: $L_{dn}>80$.

"The originators of the above zone chart did not necessarily intend the zones to be used as "criteria"[**]. Nevertheless civil and legal agencies are likely to make decisions in terms of these zones, and as a result ... the highest noise level exposure of a zone becomes, in fact, the tolerable limit to be allowed for noise control codes or regulations. We would submit that the weight of the sociological, psychological and political evidence is that in typical residential communities an appreciable percentage (approximately 10%, see Fig. [8]) of the people will complain, or feel like complaining, vigorously when the CNR reaches 90 and that legal and other group actions against the noise will start with CNRs of 90 and be nearly universal with CNRs above 100, unless suppressed because of strong economic or political forces, or sparseness of people exposed. Further, when some percentage of the people, such as 10% , feel the noise is unacceptable, the remaining 90% will dislike the noise or be neutral towards it. It would appear that the zoning given in the subject planning guide is based primarily on what are descriptors of the behavior in low economic or depressed areas and not that in the average or higher economic residential areas.

"A new land use compatibility chart was recently prepared [1967] under the auspices of the Federal Aviation Administration, for use with aircraft noise, as shown in Table [XI]. "Table [XI] appears to be more realistic than the earlier airport planning guide, but the suggestion of a

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** Both Galloway and Kryter are using the word "criteria" here with the meaning of "limits".

real compatibility of a CNR of 90 to 100 [L_{dn} fo 55 to 65] with residential dwellings is not consistent with the experience of average and better than average residential areas."

TABLE XI

LAND USE COMPATIBILITY CHART FOR AIRCRAFT NOISE (TAKEOFF AND LANDING).

					LAND USE COMPATIBILITY								
Noise Sensitivity Zone	L_{dn}	CNR	NEF	NEF	Residential	Commercial	Hotel, Motel	Offices, Public Bldgs.	Schools, Hospitals, Churches	Theaters, Auditoriums	Outdoor Amphi-Theaters, Theaters	Outdoor Recreational (Non-Spectator)	Industrial
I	< 55	< 90	< -10	Approx < 24	yes	yes	yes	yes	yes	Note (A)	Note (A)	yes	yes
II	55 - 65	90-100	-10-0	24-34	yes	yes	yes	yes	Note (C)	Note (C)	no	yes	yes
III	65-80	100-115	0 - 15	34-49	Note (B)	yes	Note (C)	Note (C)	no	no	no	yes	yes
IV	> 80	> 115	> 15	49	no	Note (C)	no	no	no	no	no	yes	Note (C)

Note (A) - A detailed noise analysis by qualified personnel should be undertaken for all indoor or outdoor music auditoriums and all outdoor theaters.

(b) - Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible. New single dwelling construction should generally be avoided. For high density dwellings (apartments) construction, Note (C) will apply.

(C) - Avoid construction unless a detailed analysis of noise reduction requirements is made and needed noise control features are included in building design.

C. Recent Studies of Correlation Between Noise Ratings and Community Response.

Galloway himself has recently (in 1974) examined the results of some very recent research to determine the correlation of noise ratings with community annoyance [29]; relevant portions of that analysis are summarized in this section.

Since the preparation of Figure 7, several studies of community response and annoyance have become available. Two of these studies were conducted under HUD's Metropolitan Aircraft Noise Abatement Policy (MANAP) studies in the vicinity of Chicago's O'Hare Airport [31] and at Windsor Lock's Bradley airport [32]. A major investigation of noise and annoyance around seven airports was conducted under NASA sponsorship by Tracor Inc.[24], and a second survey around London's Heathrow airport was reported [23]. In the following discussion, pertinent findings that help assess the relationship between noise exposure rating methods and community response are summarized.

1. O'Hare Study[31]

As part of its work under the MANAP program the Northeastern Illinois Planning Commission made an analysis of complaint records kept by FAA between 1965 and 1969 (a small fraction of the complaints received by local authorities) on noise from aircraft operations. This analysis was made in terms of the NEF contours derived for O'Hare's aircraft operations by FAA. Their conclusions were:

a) Complaints received from May to September were three to four times as high as those received during other months.

b) Complaints received from daytime operations were 50% higher than those from night. However, daytime operations were almost six times as numerous as night-time operations.

c) The rate of complaints from inside the NEF 40 contour was five times the rate from the area between NEF 30 and NEF 40, although 40% of the total number of complaints originated in this latter region because of its much larger area.

d) About one-third (34.7%) of the complaints originated outside the NEF 30 contour. These complaints, however, closely followed flight path dispersions.

2. Bradley Study[32]

Another study under the MANAP program conducted by the Capitol Region Planning Agency in the vicinity of Bradley International Airport is particularly revealing. As part of this program, a questionnaire survey was conducted to obtain 790 residents' attitudes about aircraft noise. A sampling distribution was used to cover residents in NEF zones of 25 and higher, plus control areas which were outside the NEF 25 contours but still relatively close to the airport.

Pertinent conclusions from this survey are:

a) For respondents living in areas having NEF values of 35 and higher, the response to a series of questions revealed:

Aircraft noise is:

not a nuisance	4%
a minor nuisance--can be accommodated	36%
a major nuisance--unpleasant to serious	50%
a pressing disruption--unlivable	10%

Fear of an aircraft crash is not of concern to 71% while 17% have lodged complaints; 65% said noise was annoying often or constantly.

51% said noise stops conversation often or constantly, but only 29% said it disrupts sleep.

b) The percentage of responses indicating that aircraft noise was often or constantly annoying, by noise exposure zone, was:

NEF	40	35	30	25	Control (NEF <25)
L_{dn}	80	72	65	57	<57
%	83	59	42	26	22

3. Tracor Study[24]

An intensive, three-year study of noise exposure and annoyance due to aircraft noise was completed in 1971 by Tracor under NASA sponsorship. This program surveyed communities around the major airports in Boston, Chicago, Dallas, Denver, Los Angeles, Miami, and New York. A total of 8207 interviews were obtained, and noise exposure data at the interview areas was obtained from the analysis of more than 10,000 aircraft flyovers.

Among the general conclusions from this program were:

i) CNR, NNI, and NEF are essentially interchangeable in predicting annoyance.

ii) General estimation of annoyance from measured noise exposure alone leads to correlation coefficients of the order of 0.4 to 0.5; the addition to the rating of attitudinal variables predicts individual annoyance with a correlation coefficient up to 0.8. These additional factors are also intercorrelated with noise exposure in most instances.

iii) A significant reduction of annoyance requires a CNR of 93 (L_{dn} of 58) or less; above 107 CNR (L_{dn}=72) annoyance increases steadily ; above 115 CNR (L_{dn}=80) noise exposure is associated with increased complaint.

iv) The number of highly annoyed households in a community can, within certain limits, be predicted from the number of complainants.

(a) Percent Highly Annoyed vs CNR

Borsky[21] has reviewed the Tracor data and presents population percentages annoyed as a function of noise level, fear, and misfeasance. On the basis of this analysis, one can derive regression equations that show the percentage of people who are highly annoyed in a population exposed to a given CNR; slightly different equations result for people with different attitudes toward aircraft in general. For "typical" attitudes, the equation is

$$\%\text{Highly Annoyed} = 2.28L_{dn} - 122 \qquad (2)$$

which predicts that in a population exposed to aircraft noise with an L_{dn} rating of 65, 26% would be highly annoyed; for L_{dn} = 55, only 3.4% would be highly annoyed. A 10 dB reduction in noise level would result in a 23% decrease in the percent of highly annoyed people in a population. This equation predicts "zero % highly annoyed" for L_{dn} = 53.

(b) Percent Highly Annoyed vs. Percent Complaining

The Tracor data also permit an examination of the relation between annoyance and actual complaints. This analysis results in the following equation,

$$\%\text{Highly Annoyed} = 12.3\sqrt{\%\text{Complaints}} + 4.3 \qquad (3)$$

which predicts that with no complaints at all there will still be some people highly annoyed. When there are only 9% of a population actually complaining, there are about 41% highly annoyed; with 100% of the population highly annoyed, only 61% would be expected to complain. Note that it is the number of different individuals lodging complaints not the number of complaints, that is counted here.

4. London Study - 1967 [23]

One of the most extensive social surveys of response to aircraft noise was performed around London's Heathrow airport in 1961. This survey led directly to the NNI rating procedure now in use in England. The rapid increase in jet aircraft traffic after 1961 and the introduction of the turbo-fan engine have produced major changes in noise exposure around Heathrow. In order to assess the changes in both the noise exposure and the community response to these changes, a combined noise measurement program and social survey were made in 1967; the results first became publicly available in 1971.

Some of the conclusions arrived at in this study are of interest here. They include:

a) Middle class respondents tended to express higher annoyance for the same noise exposure than working class respondents.

b) Mean annoyance scores were almost identical in the two surveys. The point on the scale considered critical in terms of acceptability was the same in both surveys (between 3 and 4 on an annoyance scale which ranges from 0 to 5).

c) Assessments of acclimation to aircraft noise revealed that the majority of people acclimate at low noise levels, but this proportion drops markedly with increasing noise level. Further, at the higher noise levels, those living in the area longest tend to be more highly annoyed.

d) While not conclusive, there is some evidence that the higher the background level, the less people are annoyed by aircraft noise, e.g., the difference between signal level and background level is of some importance.

5. Generality of the Relationship Between Average Annoyance and Noise Exposure

The preceding section showed how the Tracor data could be used to derive an expression for the percent of a noise exposed population that would be highly annoyed as a function of the noise exposure. It is of interest to examine how well this relationship can be applied to the results of other surveys. Two such evaluations, conducted simultaneously in recent months, have been published.

In one study, a task group of the EPA Study of Aircraft/Airport noise reviewed the various U.S. and English survey results and showed that the relationship between percentages of population highly annoyed and noise exposure were essentially identical when compared on a common noise measure [1]. In the second study, Alexandre compared the results of the two English surveys, the Dutch survey, and two French surveys, one completed in 1972, to obtain a general relationship between annoyance and noise exposure for the aggregated results [33].

These two evaluations gave almost identical results and confirm the analysis of percent of population highly annoyed described above, within a few percent, for a specified noise exposure.

It is reasonable to conclude that the relationship between percentage of an exposed population highly annoyed and the magnitude of noise exposure produced by aircraft in flight is well established.

6. Summary Critique of Current Official Aircraft Noise Limits

On this basis, the L_{dn} = 65 value (30 NEF), which sets the boundary below which aircraft noise exposure is expected to be tolerated in the present criteria, corresponds to a population where approximately 26% of the people would be highly annoyed, but only about 3% would complain. The L_{dn} = 80 (40 NEF) value corresponds to about 60% highly annoyed in the population, with about 21% complainants.

Galloway concludes, in agreement with Kryter, that the statements associated with the present CNR-NEF criteria that purport to describe the response expected for various degrees of aircraft noise exposure are understatements [29].

It therefore seems obvious that the limits of Figure 7 are not adequate for aircraft noise abatement in the long run, since they are deliberately permissive. While they may be useful for the immediate purposes of halting the degradation of the noise environment, they are hardly suitable as goals for substantially improving it.

It is important not to misunderstand the nature of the criticism expressed here. The validity of the CNR and NEF and similar energy-based ratings for assessing the impact of aircraft noise is not in question, but rather the statements of human response that are associated with particular rating values.

The choice of acceptable noise limits can never be based only upon the relationship between noise exposure and the corresponding effects upon people. Considerations of economics and technical feasibility must also enter into the decision. Setting the balance between criteria for an acceptable noise environment, and the cost (in time and money) of achieving it, is the proper concern of government, not the scientist. Such planning involves complex social, political and economic decisions that can only be partially guided by technology.

The question is whether or not the evolution of the noise ratings has led to a mis-statement of the effects of aircraft noise on people that justifies a permissive attitude on the part of the rule-makers of the national aviation authorities.

D. U.S. Department of Housing and Urban Development (HUD) Noise Policy

The United States Department of Housing and Urban Development (HUD) is committed to an effort to "provide decent housing and a suitable living environment for all Americans." Its interests are thus not directly aligned with those of the aircraft industry and the military, with respect to assessing the impact of aircraft noise. Nevertheless, any official HUD policy is subject to review and criticism by the other Federal agencies, and would be influenced by the positions of these agencies.

HUD has recently (November 1972) reviewed aircraft noise criteria for a variety of land uses [34] (See Figure 6). The suitability of the CNR-NEF criteria was reaffirmed by HUD and their applicability was broadened to include all HUD programs, according to Policy Circular 1390.2 of August 1971. The interim noise standards associated with this policy provide for local approval of projects exposed to values of CNR less than 100 (NEF less than 30, L_{dn} less than 65); an environmental statement outlining noise control measures must be provided for projects in CNR regions of 100 to 115 (NEF 30 to 40, L_{dn} = 65 to 80), plus the concurrence of the Regional Administrator; and at higher noise exposure the approval of the U.S. Secretary of HUD is required for any exceptions -- and such exceptions are strongly discouraged. By comparison of these limits with the leftmost two columns of Figure 7, one can see that HUD has essentially adopted the noise limits previously established for the United States by the FAA. Moreover, HUD's noise policy, as stated above, is consistent with its land-use guidelines, described in Part III-H of this report. It may be that HUD's current position was actually based on a trust in the response descriptions described above (Parts IV A and B).

HUD is engaged at the present time in reviewing the adequacy of its noise policy and standards, in relation to its commitment to provide a suitable living environment for all Americans. In particular, the permissive interim standards for aircraft noise are expected to be closely scrutinized, and are subject to revision.

E. EPA´s Levels Document

The Noise Control Act of 1972 (Public Law 92-574) directed the U.S. Environmental Protection Agency (EPA) to publish "information on the levels of environmental noise, the attainment and maintenance of which in defined areas and under various conditions are requisite to protect the public health and welfare with an adequate margin of safety." Accordingly, after extensive study and discussion, EPA published its report, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," the so-called "Levels Document" [11].

We emphasize immediately that EPA´s Levels Document was published to present <u>information</u> as required by the Noise Control Act; the noise levels identified therein, and summarized here in Table XII, do NOT constitute EPA regulations or standards since they deliberately do not take into account cost or technical feasibility, or whether or not, in any particular situation, it would be desirable to undertake noise abatement activities that will undoubtedly interfere with other activities of value. Throughout the Document the words "identified level" are used to express the environmental noise levels whose attainment would "protect the public health and welfare with an adequate margin of safety." The words "goals" , "standards", or "recommended levels" are avoided as inappropriate, because neither Congress nor EPA has concluded that the identified levels <u>should</u> be adopted as limits or standards by states and localities. This is a decision that the Noise Control Act clearly leaves to the states and localities themselves.

Table XII

SUMMARY OF NOISE LEVELS INDENTIFIED AS REQUIRED TO PROTECT PUBLIC HEALTH AND WELFARE WITH AN ADEQUATE MARGIN OF SAFETY

Effect	Level	Area
Hearing Loss	$L_{eq(24)} \leq 70dB$	All areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55dB$	Outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq(24)} \leq 55dB$	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq(24)} \leq 45$ dB	Other indoor areas with human activities such as schools, etc.

<u>Explanation of Table XII:</u>

1. $L_{eq(24)}$ represents the sound energy averaged over a 24-hour period. L_{dn} represents the $L_{eq(24)}$ with a 10 dB nighttime weighting.

2. The hearing loss level identified here represents annual averages of the daily level over a period of forty years. (These are energy averages, not to be confused with arithmetic averages.)

The phrase "health and welfare" as used in the Levels Document means "complete physical, mental and social well-being and not merely the absence of disease and infirmity." (This is the definition adopted by the World Health Organization, in Geneva.) It also includes personal comfort and well-being and the absence of mental anguish and annoyance.

The concept of annoyance, however, raises a problem. From a legal standpoint, annoyance is not, in itself, a legitimate concept; it is the human response to some unwanted situation, whereas it would be the "situation" itself causing the annoyance that the law would be concerned with. For this reason, the common law has never recognized annoyance as being a compensable injury without an additional showing of interference with a recognized personal or property right. EPA's Levels Document, while acknowledging the importance of annoyance in motivating adverse public reaction to noise, bases its identified levels on actual interference with important human activities and on hearing loss.

F. Recommendations of EPA Task Group on Aircraft/Airport Noise

The Noise Control Act of 1972 also directed EPA to study the adequacy of current and planned regulatory action by the Federal Aviation Administration (FAA), undertaken in the exercise of FAA authority, to abate and control aircraft/airport noise. Among other actions, the governing provision required the EPA to study "the implications of identifying and achieving levels of cumulative noise exposure around airports."

In support of this requirement several task groups were formed, with a membership made up of representatives from other Federal agencies, state and local governments, environmental and consumer action groups, professional societies, pilots, air traffic controllers, airport proprietors, airlines, users of general aviation aircraft, and aircraft manufacturers.

Task group three was asked to

-- determine the merits and shortcomings of methods of characterizing the impact on the public health and welfare of the noise of present or proposed aircraft/airport operations;
-- select the most appopriate of such methods for adoption by the Federal Government, keeping in mind (1) the role of airport operators and owners and the rights of the public; (2) the costs of noise monitoring; (3) the implications of this choice for enforcement of regulations; and (4) the relationships to other measures for environmental source description and control;
-- determine the implications of issuing Federal regulations that establish a standard method for characterizing the noise from aircraft/airport operations, and of specifying maximum permissible noise levels for the protection of the health and welfare.

In addition to responding to the charges listed above, the report of the Task Group went one step further and recommended suitable limits for noise exposure, both for immediate and long-term application.

Although we have drawn heavily upon the study, recommendations and conclusions of that Task Group earlier in this report, it is their recommendations for suitable noise limits that hold the greatest interest for us in the present context:

"-- To protect the public health and welfare against the risk of any measurable permanent noise induced hearing loss, with adequate margin of safety, and to protect the public against completely unacceptable amounts of annoyance and speech interference, a yearly outdoor day-night average sound level of 80 decibels in residential areas should, as soon as possible, be promulgated as the permissible limit. Exceptions to this maximum permissible noise level must be based on zoning regulations and/or building codes that will assure a maximum average sound level (not day-night average!) of the occupants (allowing for a reasonable combination of indoor and outdoor exposures, based on the expected living styles of the community) not exceeding 75 dB.

"-- A yearly day-night average sound level of 60 dB <u>or below</u> should be the long-range limit of the EPA for environmental noise quality in residential areas with respect to health and welfare. For specific situations local authorities may prescribe lower noise levels, particularly for areas that have a quieter environment now, and for which there is no planned requirement in the public interest to allow noise levels to increase to the maximum permissible level. Exceptions to the outdoor $L_{dn} \leq 60$ may be based on zoning regulations, building codes and/or expected lifestyles, provided the indoor L_{dn} predicted to reach the individual ear from environmental (not produced by the individual) noise is less than 45 dB.

"-- The time schedule for implementation of the $L_{dn} \leq 60$ dB goal with respect to aircraft noise should be based on detailed economic and technological feasibility studies, and should agree with a similar schedule to reach this goal with respect to other noise sources, such as traffic noise. To achieve this goal, public understanding must be raised of the noise exposure problem, the proposed measure of noise exposure, the noise exposed zones and the permissible noise levels with respect to health and welfare." [Emphasis added].

It will be noticed that the noise levels in the Levels Document are lower than the limits proposed by the EPA Task Group on Aircraft/Airport noise; this is because the Levels Document includes the "adequate margin of safety" mandated by the Congress.

Another jurisdiction, such as a State or local government, might conclude, after weighing similar factors, that lower noise limits are desirable for its own situation; and it is free under the Noise Control Act to adopt regulations that are more restrictive than those recommended by EPA's Task Group or identified in the Levels Document. It would not be free to adopt regulations that are <u>less</u> restrictive than the Levels Document, if that document's levels became Federal standards.

G. The Problem of Socio-Economic Status

Present noise criteria for residential use were derived from a broad variety of communities and tend to average out the differences in social and economic conditions existing in many communities. In the past ten years, however, we have become increasingly aware of the effect of the socio-economic status (SES) of a community on its attitudes about noise. In a recent London survey of community response to aircraft noise, middle class people appeared to be more readily bothered by noise than working class people (See part IV-C-4).

In a recent U.S. study of annoyance due to traffic noise [35], it was found that among people who had not progressed beyond elementary school, the percentage of people annoyed was only 0.4 as great as the percentage of people not annoyed. In a group of people who had attended college, the percentage of annoyed people was 1.6 times that of non-annoyed people.

Families with annual income close to $5,000 were 0.7 as likely to express annoyance as the sample whole; those with $25,000 incomes were twice as likely to express annoyance as the sample whole.

Galloway was able to increase the correlation between annoyance and highway noise exposure from about 0.5 to 0.9 by weighting the response with SES considerations [36].

Notwithstanding the increasing evidence that expressed annoyance appears to increase with increasing SES, it does not appear prudent, in regulations, to make explicit adjustment for SES. It would be a difficult political position, indeed, to argue that people of high SES should have greater protection from noise exposure than those of lower SES. Nevertheless, planners should be aware that, within any specific community, any apparent differences in community response to a given noise exposure, as compared to present criteria, may be directly related to SES variables.

Section 3. THE NOISE PROPOSALS OF MARYLAND STATE AVIATION ADMINISTRATION

Proposal 1.

The Administration proposes that cumulative noise exposure be expressed in terms of the A-weighted outdoor day-night average sound level, L_{dn}.

The selection of L_{dn} is a logical outcome of the analysis presented in Section 2 , Parts I and II. The method meets fully the requirements of the Environmental Noise Act of 1974 and is consistent with proposals of the U.S. Environmental Protection Agency.

Proposal 2.

The Administration proposes the following schedule of limits for aircraft noise for various land uses.

Table XIII

PROPOSED LIMITS FOR CUMULATIVE NOISE EXPOSURE

LAND USE	LIMITS FOR CUMULATIVE NOISE EXPOSURE (Day-Night Average Sound Level in dB (re 20 Micronewtons/1 sq. meter)) Effective 1 July 1975	Effective when U.S. Fleet Noise Level is reduced 5 dB below 1 July 1975 level	Assumed Outdoor-Indoor Noise Reduction (dB)
Residential-Single & Two-Family; Mobile homes	65	60	15
Residential-Multi-family, Dormitories	65	60	15
Schools, Hospitals, Rest homes, Homes for the Aged, Nursing homes	65	60	15
Libraries, Churches	65	60	25
Transient Lodging, Hotels, Motels	70	65	15
Auditoriums, Concert Halls	65	60	35
Sports Arenas, Outdoor Spectator Sports	70	65	0
Playgrounds, Neighborhood Parks	70	65	0
Golf Courses, Riding Stables, Water Recreation, Cemetaries	75	70	0
Office Buildings, Personal; Business, Professional	75	70	25

Commercial, (Retail) Movie Theaters, Restaurants	75	70	25
Commercial, (Whole-sale, some retail) Industry, Manufac-turing, Utilities	75	70	15
Manufactoring, Commu nications (Noise sensitive)	70	65	25
Livestock Farming, Animal Breeding	75	70	0
Agriculture (except livestock), Mining, Fishing	75	70	0

Notes:

a. In preparing these limits for cumulative noise exposure the Administration had to resolve the same dilema that has beset aviation authorities who have had to set noise limits in the past, and whose choice of limits has been critically scrutinized in this report. It is unsupportable in terms of the Administrator's basic charter to set aircraft noise limits so low that the enforcement would forbid airports to operate at all, or would severely curtail their service to the public. The most effective way to control airport noise is to quiet the source, the aircraft. The Federal government, through the FAA, controls aircraft noise. A state may not institute aircraft noise source standards, but may set airport noise standards. Maryland may and does encourage source control's by the FAA, but the State must still wait for the FAA to act on such source controls.

The means of breaking through the dilemma is to recognize that the abatement of aircraft/airport noise must be the subject of long-range planning if it is to be effectual.

Limits should be set immediately that can be complied with now, by means of operational and other changes that are not intolerably restrictive of airport operations. The proposed limits, to be effective 1 July 1975, are consistent with existing national standards. To achieve levels consistent with EPA proposals the Administration will set a firm schedule of stricter limits, based on continued introduction of quieter equipment. The Administration is prepared to meet future noise goals of the State Department of Health and Mental Hygiene and of the EPA in accordance with the same policy, meeting standards through application of the benefits of noise reduction tecnology.

b. The Fleet Noise Level (FNL), similar to that proposed by the FAA, will determine the logarithmic average of the commercial aircraft fleet operating in the U.S. Phase-in of new aircraft (e.g., DC-10 and L-1011), and retrofit of old jet aircraft with quieting equipment will reduce the Fleet Noise Level. Following this approach, a 5 dB change in limits will reflect a reduction in noise level at a given point, but will not reduce the area of the noise zone for a given airport and a given set of operations.

c. For purposes of comparison, Table XIV gives the numbers of people who live in urban areas exposed to noise from major transportation sources. Reducing the average source level of aircraft noise 5 dB will reduce the exposure level 5 dB if all other conditions remain the same. Taking the example of a change in exposure level from 65 to 60 the population exposed to a level of 65 decreases some 55% from 7.5 million to 3.4 million.

Table XIV

ESTIMATED CUMULATIVE NUMBERS OF PEOPLE IN MILLIONS WHO LIVE IN URBAN AREAS WITHIN WHICH THE YEARLY AVERAGE DAY-NIGHT SOUND LEVEL EXCEEDS VARIOUS VALUES

	GENERAL SOURCE OF NOISE			
Outdoor L_{dn} Exceeds	Urban Traffic	Freeway Traffic	Aircraft Operations	Total
55	93.4	13.7	24.5	131.6
60	59.0	3.1	16.0	78.1
65	24.3	2.5	7.5	34.3
70	6.9	1.9	3.4	12.2
75	1.3	0.9	1.5	3.7
80	0.1	0.3	0.2	0.6

d. All buildings provide the residents or users a degree of protection against exterior noise. The values here are those assumed in developing the noise limits.

Proposal 3.

Based on the need to inform buyers and lessees of properties of the existance of Noise Zones, the Administration proposes real property notice requirements:

a) All buyers or tennants signing deeds or leases for properties which are partially or wholly within a noise zone will acknowledge, by signing, a statement such as:

"I _______ acknowledge that this property is partially or wholly within a zone of airport noise for an existing or proposed airport and that the level of aircraft noise may exceed the noise limits established by the Maryland State Aviation Administration."

Real property notices such as these provide a basis for assuring that land users are aware of the noise environment. This approach is similar to provisions of "truth in lending" laws which describe interest rates and require that borrowers acknowledge the terms of a loan. In the instance of aircraft noise, a prospective buyer or tenant may not hear any noise when they visit a location if there is no aircraft activity, even though the activity of an average day produces a great deal of noise at the location. For this reason a noise warning is particularly critical as a safeguard.

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