A-96-01
II-A-766

FAA-EE-84-16

Office of Environment
and Energy
Washington, D.C. 20591

Land Use Compatability Study: Aircraft Noise and Land Use

Richard L. Harris
Norman W. Arnold
George J. Shepherd

PEER Consultants
Rockville, Maryland 20852

June 1984

Final Report

US Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Land Use Compatibility Study	June 1984
	6. Performing Organization Code
7. Author(s): Richard L. Harris, Norman W. Arnold, George J. Shepherd	8. Performing Organization Report No.
9. Performing Organization Name and Address PEER Consultants, Inc. 1160 Rockville Pike, Suite 202 Rockville, MD 20852	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFA01-83-Y-10575
12. Sponsoring Agency Name and Address Federal Aviation Administration Office of Environment and Energy 800 Independence Ave., S.W. Washington, DC 20591	13. Type of Report and Period Covered Final Report August 1983 to June 1984 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Part 150 of the Federal Aviation Regulations (FAR Part 150), Airport Noise Compatibility Planning, includes in Part B of Appendix A a table titled "Land Use Compatibility with Yearly Day-Night Average Sound Levels". The table presents various land uses that are compatible and incompatible with specific ranges of sound levels (in decibels).

The objective of this study was to investigate, identify and document original source material for the table appearing in FAR Part 150 and to prepare a report comparing and analyzing the results obtained from these sources considered in the development of the table. To the extent that sources could be identified, they have been reviewed and the detailed results presented in a chronological narrative.

Noise level guidelines for various land uses shown in the FAR Part 150 table were found to be reasonable and supportable based on this review of historical rating and measurement procedures used to assess the compatibility between land use, the noise environment, and human activity. The table is consistent with previous land use compatibility studies and no changes in the table are recommended.

17. Key Words	18. Distribution Statement
Aircraft Noise Land Use	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

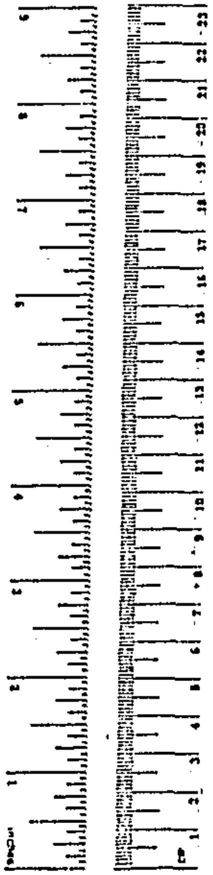
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

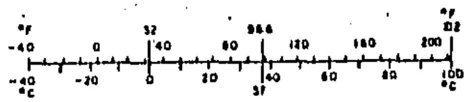


TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

1. INTRODUCTION

Part 150 of the Federal Aviation Regulations (FAR Part 150), Airport Noise Compatibility Planning, includes in Part B of Appendix A a table titled "Land Use Compatibility with Yearly Day-Night Average Sound Levels" (Table 1-1). The table presents various land uses that are compatible and incompatible with specific ranges of yearly day-night average sound levels (Ldn). Conceptually, through all five land uses shown - residential, public use, commercial use, manufacturing and production, recreational - three main noise levels are primarily considered. First, as shown in the first two columns of Table 1-1, less than 65 to less than 70 dB noise levels are considered compatible for various land uses and related structures, without restrictions. Second, a noise level of greater than 80 dB, as shown predominantly in the last two columns of Table 1-1, is mainly prohibited since land use and related structures are incompatible at this Ldn level. Third, in reference to the middle columns of Table 1-1, noise level reductions (NLR) of 25 to 30 dB from outdoors to produce indoor noise levels of approximately 40 to 50 dB are required through the incorporation of noise attenuation methods (e.g., insulation) into the design and construction of buildings or portions of buildings such as where the public is received, or where office areas or noise sensitive areas exist.

The objective of this study was to investigate, identify and document orginal source material for the table appearing in FAR Part 150 (Table 1-1) and to prepare a report comparing and analyzing the results obtained from these sources considered in the development of the table. In the following discussion in this report, references are made to an attached set of "Notes". These notes identify various pages of Appendix A containing specific information detailing particular points reviewed from the attached list of relevant references.

In contrast to the physical measurement of sound, an assessment of the relation of land to prevailing noise is less precise especially in view of such factors as type of human activity associated with a specific land use, differing responses of individuals to the same noise environment, and the annoyance caused by the noise. However, as will be discussed in more detail in Appendix A, criteria of 40 to 50 Ldn for indoor noise levels and maximum permissible upper limits of 70 to 80 Ldn for various land uses and related structures can be substantiated in the literature by reviewing the many rating and measurement procedures used to assess the compatibility between land use, the noise environment and human activity. The literature shows that a reasonable basis exists for the noise levels used to develop Table 1-1, over and above the unquantifiable factors of experience and judgment, and that the table is consistent with previous land use compatibility studies.

The history leading up to these designations of land uses compatible with various sound levels is a long one, and many of the questions originally identified in developing these designations are still present. In this country, the first proposal for a noise metric to predict community response

TABLE 1-1

LAND USE COMPATIBILITY* WITH YEARLY DAY-NIGHT AVERAGE SOUND LEVELS

Land Use	Yearly Day-Night Average Sound Level (L_{dn}) in Decibels					
	Below 65	65-70	70-75	75-80	80-85	Over 85
RESIDENTIAL						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
PUBLIC USE						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoriums, and concert halls	Y	25	30	N	N	N
Governmental services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
COMMERCIAL USE						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail - building materials, hardware and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade - general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
MANUFACTURING AND PRODUCTION						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
RECREATIONAL						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts and camps	Y	Y	Y	N	N	N
Golf courses, riding stables and water recreation	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

TABLE 1-1 (Continued)

* The designations contained in this table do not constitute a Federal determination that any use of land covered by the program is acceptable or unacceptable under Federal, State, or local law. The responsibility for determining the acceptable and permissible land uses remains with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise compatible land uses.

KEY TO TABLE 1-1

SLUCM	Standard Land Use Coding Manual.
Y (Yes)	Land Use and related structures compatible without restrictions.
N (No)	Land Use and related structures are not compatible and should be prohibited.
NLR	Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35	Land use and related structures generally compatible measures to achieve NLR of 25, 30, or 35 must be incorporated into design and construction of structure.

(1) Where the community determines that residential or schools uses must be allowed, measures to achieve outdoor to indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide a NLR of 20 dB, thus the reduction requirements are often stated as 5, 10 or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year round. However, the use of NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR of 25 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(3) Measures to achieve NLR of 30 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal noise level is low.

(4) Measures to achieve NLR of 35 must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise sensitive areas or where the normal is low.

TABLE 1-1 (Continued)

(5) Land use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

to noise was made in 1953. Since this initial work, many metrics and prediction methods have been developed, including studies about the compatibility of various land uses with levels of noise. To the extent that sources could be identified, they have been reviewed and the detailed results presented in a chronological narrative in Appendix A.

2. FAR PART 150 AND ANSI LAND USE COMPATIBILITY

As earlier noted, in Table 1-1 land uses are divided into five categories: residential, public use, commercial use, manufacturing and production, and recreational. Sound levels are in six Ldn ranges: below 65, 65-70, 70-75, 75-80, 80-85, and above 85 dB. Each category contains several typical uses, and for each sound level, each use is classified as either compatible without restriction, not compatible and should be prohibited, or requiring a specified level of sound reduction in construction in order to be compatible.

Coincidentally, the American National Standard, "Sound Level Descriptors for Determination of Compatible Land Use" ANSI S3.23-1980 (referred to as the Standard in the remainder of this document), appeared at about the same time as Table 1-1 (see Figure 2-1). The Standard contains an Appendix, "Land Use Compatibility with Yearly Day-Night Average Sound Levels", for information only. In discussing the basis for Figure 2-1, obtained from the Appendix, the Standard states: "Guidelines given in the Appendix for yearly day-night average sound levels that are likely to be compatible with land uses associated with residential living are based on studies of noise-induced annoyance. Values specified for other land use are based on noise-induced interference with speech communication".

The same land use categories appear in Figure 2-1 as in Table 1-1 although differently organized. A comparison of the two documents shows that they present nearly the same recommendations (Note a).

Residential use differs in a fundamental way from most of the uses in the other four categories. Residential use is a twenty-four hour a day use. With the exception of health care facilities in the public use category, and perhaps some manufacturing, the other uses are not on a twenty-four hour a day basis.

There is also a difference between residential and other uses upon which judgments as to compatibility have been made. As in the ANSI guidelines for residential use, the compatibility judgments in FAR Part 150 appear to be based upon studies of noise-induced annoyance. The judgments about compatibility of land uses other than residential with aircraft noise are based upon interference with communication.

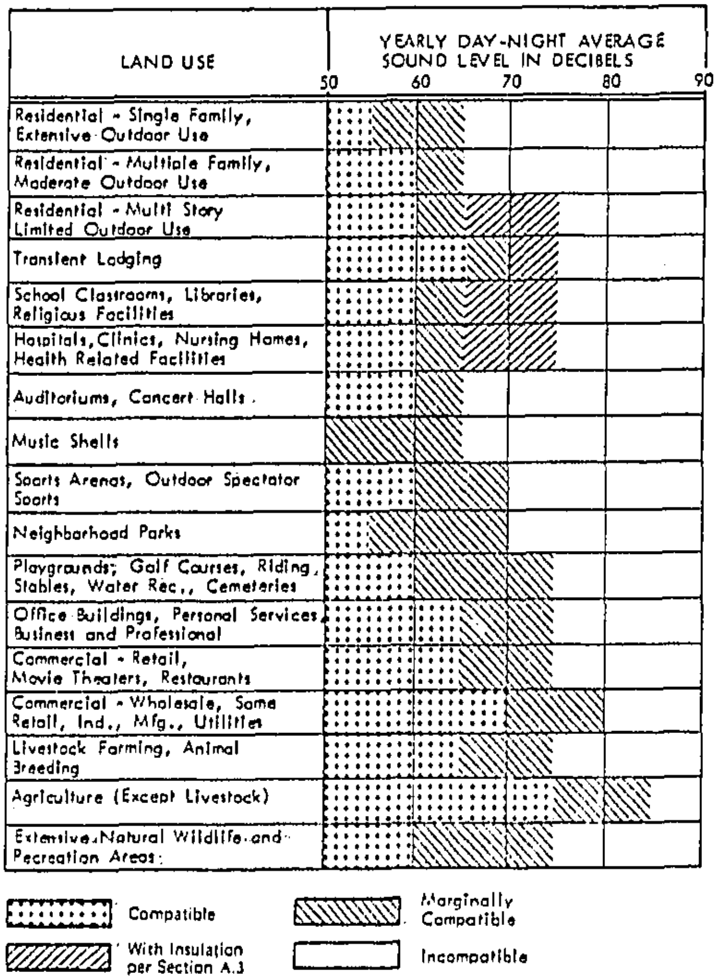


Figure 2-1. Land use compatibility with yearly day-night average sound level at a site for buildings as commonly constructed. [For information only; not a part of American National Standard for Sound Level Descriptors for Determination of Compatible Land Use S3.23-1980.]

3. NOISE EFFECTS USED TO DEVELOP CRITERIA FOR LAND USE

Various effects of aviation noise have been considered in determining the compatibility of aviation noise and human activity. These include:

1. Effects on hearing
2. Effects on health
3. Effects on communication
4. Effects on sleep
5. Effects on community acceptance (annoyance)

Each of these are discussed briefly below and in more detail in Appendix A.

3.1 Effects on Hearing

The Department of Labor, Occupational Safety and Health Administration (OSHA) regulations require every employer to limit workers' noise exposure to 90 decibels (dB(A)) over an 8 hour period. For each increase of 5 dB(A), the allowable exposure time is cut in half. This is not a criterion for speech communication. It is a criterion for the protection of hearing, accepted in many countries. However, the halving rate, that is the increase in dB(A) which necessitates cutting the allowable exposure time in half, is 3 dB(A) in several countries such as the United Kingdom, Denmark, and Australia. In Sweden the limit is 85 dB(A), with a halving rate of 3 dB(A) (Note b).

3.2 Effects on Health

In order to discuss noise effects on health, a definition is required as to what healthy means. The U.S. Environmental Protection Agency has adopted the very broad definition of "complete physical, mental and social well-being and not merely the absence of disease and infirmity" (Note c). Thus, if we accept this definition, aviation noise which might cause disease or infirmity is considered to be unacceptable. However, noise levels which have been implicated as potential causal agents of disease or infirmity have been found to first result in severe hearing loss (Note d).

3.3 Effects on Communication

Communication effects are the result of noise that masks conversation, or interferes with listening to radio or TV. Recent work on the effects of room reverberation on indoor noise levels and speech intelligibility demonstrate that there is a lower limit below which intruding noise will have no effect (Note e). That is the effective noise generated by the reverberation within the room would be larger than the intruding noise. In general, the reverberation levels are about 5 dB(A) below the speaker's level.

Most communication research is concerned with steady state noise, or at least noise with modest variations such as traffic noise (Note f). In 1970, it was suggested that the reasons that speech interference had not been adopted as a criterion for residential land use were that complaints could not be correlated with speech interference, and that a simple way of calculating the effects of aircraft noise on speech masking had not been found (Note-g).

In 1973, a task group organized by the U.S. Environmental Protection Agency (EPA) estimated, on the basis of calculations near a major airport, that an average aircraft noise level (Leq) of 65 dB(A) provided the same sentence intelligibility outdoors as 60 dB(A) of more or less steady noise; that is, 95% sentence intelligibility at a distance of two meters between two people communicating (Note h). Indoors, even at an Leq of 45, speech intelligibility has been found to remain high even under extreme fluctuations of external noise levels (Note i). This 1973 study also concluded that because of the annoyance caused by high noise levels sufficient to completely interrupt speech, annoyance is a better criterion than speech interference. But this conclusion implicitly assumes that annoyance can be predicted with some degree of assurance.

The difference between noise effects indoors and outdoors is, of course, dependent upon the building construction and how many windows, if any, are open. In the 1973 study, the following ranges of external to internal noise reduction were given (Note j).

In a warm climate, from 12 to 24 dB(A), depending on the windows.
In a cold climate, from 17 to 27 dB(A), depending on the windows.
Approximate national average, from 15 to 25 dB(A).

An Ldn of 65 outdoors therefore implies an Ldn of 40 to 50 indoors. Speech communication at these levels is not a problem in a residence. Sentence intelligibility of 95% at normal voice levels should be possible at distances of at least 4 meters. If consideration is given to a 5 dB(A) allowance for intermittent sounds, even farther distances are possible for a sentence intelligibility of 95% (Note h).

3.4 Effects on Sleep

The effects of noise on sleep depend upon the definition of sleep disturbance used. A change in electroencephalogram (EEG) patterns is one definition, a change in sleep state is another, and being awakened is a third possibility (Note k). However, there is a wide variation among individuals in disturbance caused by a given noise. This alone makes the use of noise effects on sleep as a criterion extremely difficult (Note l).

An Ldn of 65 implies an Leq of 55 at night. Inside a house, with the windows open, an Leq no higher than 40 would be expected. Under other inside conditions, it might be lower (Note j). This is the level recommended as a threshold to avoid sleep interference in hospitals (Note g). From experiments conducted in France (Note m), it was found that there were no EEG reactions to mid-range noise levels. No data on the number of awakenings were given;

but a change in sleep state (including awakenings) would have been expected in 13% of those where the peak was 30 dB(A) above the ambient noise level. At an outside Leq of 55, these levels equal peaks of 85 dB(A), which are not at all common (Appendix B). One general conclusion is "the significance on health and well-being of noise-induced sleep disturbance remains unresolved" (Note n).

3.5 Effects on Community Acceptance

Residential land use compatibility criteria are primarily based upon community acceptance, which is not predictable with any degree of confidence. In general, estimates are made of the number of people annoyed by specified levels of noise, and a judgment is then made as to whether this degree of annoyance is acceptable or not. Of course, there are many intangibles in this method of estimation.

First, noise levels historically have been expressed in many different units, and translation from one to another is not usually direct and explicitly defined. Assumptions must be made about frequency content, duration, peak levels, number of incidents, or some combination of these assumptions in order to convert noise measured or calculated in one unit or metric to another metric. The consequence is that a comparison between one experiment, or experience, and another more often than not will contain an unknown, although perhaps defineable, error. However, the error is often neither stated or estimated (Note o).

Second, experiments or surveys must, of necessity, use qualitative expressions to estimate community reaction. Conversion of these from one to another is uncertain. Is "highly unacceptable" equivalent to "highly annoyed"? Is "acceptable" equivalent to "no annoyance" or "mild annoyance" or "mild complaints"? On a scale of 0 to 10, where does one place "seriously annoyed" compared to "little annoyed"? (Note p)

Third, within any population, there will be a considerable spread of reaction. An individual will assess a specific level of noise differently at different times, and will assign the same level of acceptability, or unacceptability, to different noise levels. Different individuals will not only have different reactions at different times, they will react differently from each other to the same noise exposure at the same time. Consequently, there will always be a wide spread in the data (Note q).

Fourth, there have been a considerable number of tests and experiments conducted in different places at different times. It was generally hoped that, on the average, similar results would be produced. However, if there have been any controlled experiments to demonstrate this, they have not been identified in this study. Rather, several cases have been found in which assumptions have been made which lead to statistical comparisons which sometimes demonstrate similarities, and sometimes differences, for the same original data. Because of these uncertainties, interpreting the results from these tests and experiments is very difficult (Note r).

3.6 Summary of Noise Effects

Even with a margin of safety, no effects on hearing are expected below an Ldn of 75 dB(A). Research on non-auditory effects of noise on health is proceeding, but no evidence has yet been found of noise as a cause of disease at levels below that which may affect hearing. Somewhat more is known about noise interference with communication. While causing some interference with speech communication, a steady background noise of 60 dB(A) still permits 95% speech intelligibility. An EPA group has estimated that fluctuating noise of 65 dB(A) average (Leq) outdoors would permit the same level of communication. This level outdoors would cause no problems with speech communication indoors. As regards sleep interference, some reactions, in terms of EEG activity, can be expected at essentially any noise level. Although levels of 40 dB(A) have been recommended to avoid interference with sleep in hospitals, there is some evidence that more severe responses, such as awakenings, require peak levels of the order of 85 dB(A) outside to cause sleep impacts inside. Such levels are not likely to occur in areas, particularly with aviation noise of 65 Ldn outside. Finally, as noise increases, by any metric, so does community annoyance and adverse public reaction. However, an objective measurement of public annoyance is not easily defined. Many other factors, explored in detail in Appendix A, difficult to determine and measure, enter into the reaction of a community to a specific noise level (Note s).

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the extensive literature research undertaken for this study and detailed in Appendix A, the FAR Part 150 table (Table 1-1) was found to be reasonable and supportable in its delineation of land use compatibility at specified noise levels. No changes are recommended for this table.

The use of available aviation noise metrics has been limited in its ability to predict noise impacts on a community. Additional research is needed to develop better predictors of noise impacts and community annoyance. Existing noise metrics are at present more reliable as predictors of hearing loss and interference with speech communication. Possibly, emphasis could be placed on effects of aviation noise on communication as an element in the development of criteria for residential land use compatibility with aviation noise. More study of the effects of noise on speech communication might provide one basis for local authorities to make decisions about compatible land uses.

The threshold for effects of noise on hearing loss is well above the threshold for interference with speech communication. Additionally, based on this literature survey (Appendix A), effects on communication from various noise levels probably are comparable with effects on sleep. However, sleep interference is not at present sufficiently understood to be used as a basis for establishing allowable noise levels for specific land uses. Research is needed on the effects of aviation noise on sleep disturbance with emphasis on the effects of fluctuating noise levels.

5. NOTES

This list is a cross reference from the text of the report to appropriate sections of Appendix A which contains a chronological presentation and detailed discussion of the literature reviewed.

a. Comparison of FAR Part 150 and ANSI Noise Compatibility Standard
Page A-87

b. Hearing loss
Pages A-53 to A-54
Page A-66

c. Public health and welfare
Page A-65

d. Non-auditory noise effects
Munich, Page A-63
Jones, Page A-80
Tarnopolsky and Francois, Pages A-86 to A-87

e. Reverberation
Pages A-80, A-92

f. Effect of variation in level on communication
Pearsons, Page A-80

g. Communication as a criterion
Pages A-54 to A-55

h. Speech communication
Pages A-54 to A-55
Page A-67

i. Speech communication indoors
Page A-54

j. Noise Reduction, outdoors to indoors
Page A-52

k. Noise and sleep, definition of effect
Miller, Page A-73
Lukas, Page A-73

l. Variation in effect of noise on sleep
Miller, Page A-73
Team VI, Page A-82
Team 5, Page A-93

m. Noise and sleep, French experiments
Vallet, Page A-31

n. Noise and sleep, conclusions
Greifan, Pages A-81 to A-82

o. Noise metrics used
CNR, Pages A-1 to A-5, A-8 to A-12
NNI, Pages A-6 to A-7
Isopsophic Index, Pages A-20 to A-22
Netherlands, Pages A-18 to A-20
NEF, Pages A-16 to A-18, A-27, A-49
Ldn, Pages A-51 to A-53
Lr, Page A-91

p. Response scales, metrics and translations among them.
Page A-1
Page A-3
Pages A-5 to A-7
Pages A-12 to A-13
Pages A-22 to A-24
Pages A-35 to A-37
Pages A-55 to A-58
Pages A-68 to A-69
Page A-84
Pages A-87 to A-88
Page A-96

q. Data spread - community response
Page A-1
Page A-3
Pages A-6 to A-7
Pages A-10 to A-12
Page A-16
Pages A-37 to A-38
Pages A-62 to A-65
Page A-68
Rice, Page A-84
Yaniv and Bauer, Page A-84
Cheifetz and Borsky, Page A-84
Schultz, Pages A-84 to A-85
Rylander, Pages A-85 to A-86
Ollerhead, Page A-86
Fields and Walker, Pages A-86 to A-87
Francois, Page A-87
Griffiths, Page A-95
Borsky, Page A-95

r. Conclusions from data from different experiments
Heathrow & Farnborough, Page A-5
Heathrow, Farnborough & Los Angeles, Pages A-10 to A-12
Pages A-22 to A-24
Pages A-54 to A-55
Pages A-57 to A-58
Pages A-94 to A-95

s. On adequacy of current criteria for residential use
Foster, Page A-80
Karlsson, Page A-87
Rylander, Page A-87
Griffiths, Page A-94

REFERENCES

1. Knudsen, E. O. and Harris, L. M., Acoustical Designing in Architecture, John Wiley and Sons, New York, NY, 1950.

2. Rosenblith, Walter A. and Stevens, Kenneth N., "Handbook of Acoustic Noise Control, Volume II, Noise and Man," WADC TR 52-5204, Volume II, Wright Air Development Center, Dayton, OH, June 1953.

3. Stevens, K. N., Rosenblith, W. A., and Bolt, R. H., "A Community's Reaction to Noise: Can it be Forecast," Noise Control 1, 63-71, 1955.

4. Beranek, L. L., "Revised Criteria for Noise in Buildings," Noise Control 3, 19-27, 1957.

5. Parrack, H. O., "Chapter 36 - Community Reaction to Noise," Handbook of Noise Control, McGraw-Hill Book Company, New York, NY, 1957.

6. Kryter, K. D., "Scaling Human Reaction to the Sound from Aircraft," J. Acoust. Soc. Am. 31, 1415-1429, 1959.

7. Beranek, L. L., "Chapter 20 - Criteria for Noise and Vibration in Buildings and Vehicles," Noise Reduction, McGraw-Hill Book Company, New York, NY, 1960.

8. Cavenaugh, W. J., Farrell, W. R., Hirtle, P. W., and Walters, B. G., "Speech Privacy in Buildings," J. Acoust. Soc. Am. 34, 475-492, 1962.

9. Kosten, C. W. and Van Os, G. J., "Paper F-5, Community Reaction Criteria for External Noises," Symposium No. 12 - The Control of Noise, National Physical Laboratory, London, England, 1962.

10. Her Majesty's Stationary Office, "Appendix 11 - Social Survey in Vicinity of London (Heathrow) Airport," Noise - Final Report, Comnd. 2056, London, England, July 1963.

11. Bishop, D. E., "Analysis of Community and Airport Relationships/Noise Abatement, Volume II, Development of Aircraft Noise Compatibility Criteria for Varied Land Uses," Federal Aviation Agency, SRDS Report No. RD-64-148, Volume II, December 1964.

12. Bolt, Beranek and Newman, "Land Use Planning Relating to Aircraft Noise," Federal Aviation Agency, October 1964.

13. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., "Chapter 14 - Sound Control," ASHRAE Guide and Data Book -Fundamentals and Equipment for 1965 and 1966, New York, NY, 1965.

14. Bolt, Beranek and Newman, "Analysis of Community and Airport Relationships/Noise Abatement," Federal Aviation Agency, SRDS Report No. RD-65-130, December 1965.

15. Bishop, D. E., "Judgements of the Relative Acceptability of Aircraft Noise," J. Acoust. Soc. Am. 40, 108-122, 1966.

16. Galloway, W. J. and Von Gierke, H. E., "Individual and Community Reaction to Aircraft Noise, Present Status and Standardization Efforts," International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, Lancaster House, London, England, November 1966.

17. Transportation Consultants, Inc., "Compatible Land Use Planning On and Around Airports," Federal Aviation Agency, June 1966.

18. Bishop, D. E. and Horenjeff, D., "Procedures for Developing Noise Exposure Forecast Areas for Aircraft Flight Operations," U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-DS-67-10, August 1967.

19. Board of Trade, "Aircraft Noise: Report of an International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft," Her Majesty's Stationary Office, London, England, 1967.

20. The Institution of Electrical Engineers, "Conference on Acoustic Noise and Its Control," Savoy Place, London, England, January 1967.

21. Williams, C. E., Stevens, K. N., Hecker, M. H. L., and Pearsons, K. S., "The Speech Interference Effects of Aircraft Noise," U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-DS-67-19, September 1967.

22. Rettinger, M., Acoustics - Room Design and Noise Control, Chemical Publishing Company, Inc., New York, NY, 1968.

23. Sperry, W. C., "Aircraft Noise Evaluation," U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-NO-68-34, September 1968.

24. International Civil Aviation Organization, "Agenda Item 1 - Description and Measurement of Aircraft Noise, Aircraft Noise Exposure, Paper No. 15," Working Paper by the United States, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

25. International Civil Aviation Organization, "Agenda Item 2 - Human Tolerance to Aircraft Noise," Draft U.S. Position Paper, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

26. International Civil Aviation Organization, "Agenda Item 2 - Human Tolerance to Aircraft Noise, Paper No. 1," Working Paper by the Secretariat, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

27. International Civil Aviation Organization, "Agenda Item 2 - Human Tolerance to Aircraft Noise in the Vicinity of Aerodromes, Paper No. 2," Working Paper by France, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

28. International Civil Aviation Organization, "Agenda Item 2 - Human Tolerance to Aircraft Noise in the Vicinity of Aerodromes, Paper No. 14," Working Paper by France, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November, 1969.

29. International Civil Aviation Organization, "Agenda Item 5 - Land Use Control, Paper No. 1,"Working Paper by the Secretariat, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November, 1969.

30. International Civil Aviation Organization, "Agenda Item 5 - Land Use Control, Paper No. 2," Working Paper by France, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

31. International Civil Aviation Organization, "Agenda Item 5 - Land Use Control, Paper No. 4," Working Paper by the IATA, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

32. International Civil Aviation Organization, "Agenda Item 5 - Land Use Control, Paper No. 11," Working Paper by Federal Republic of Germany, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, November 1969.

33. International Civil Aviation Organization, "Agenda Item 5 - Land Use Control, Paper No. 12," Working Paper by the United States, Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, Montreal, Canada, November 1969.

34. International Civil Aviation Organization, "Report of the Special Meeting on Aircraft Noise in the Vicinity of Aerodromes," Doc. 3357, NOISE (1969), Montreal, Canada, 1969.

35. Williams, C. E., Stevens, K. N., and Klatt, J., "Judgements of the Acceptability of Aircraft Noise in the Presence of Speech," J. Sound and Vibration 9, 263-275, 1969.

36. Chalupnik, J. D., ed., Transportation Noises - A Symposium on Acceptability Criteria, University of Washington Press, Seattle, WA, 1970.

37. Galloway, W. J. and Bishop, D. E., "Noise Exposure Forecasts: Evolution, Evaluation, Extensions, and Land Use Intepretations," U.S. Department of Transportation, Federal Aviation Administration, Report No. FAA-NO-70-9, August 1970.

38. Kryter, K. D., The Effects of Noise on Man, Academic Press, New York, NY, 1970.

39. Peterson, A. P. G., and Gross, E. E., Handbook of Noise Measurement, General Radio Company, Concord, MA, 1970.

40. Serendipity, Inc., "A Study of the Magnitude of Transportation Noise Generation and Potential Abatement, Volume III, Airport/Aircraft System Noise," U.S. Department of Transportation, Report No. OST-ONA-71-1, Volume III, November 1970.

41. U.S. Department of Housing and Urban Development, Office of Metropolitan Planning and Development, "Airport Environs: Land Use Controls," May 1970.

42. Beranek, L. L., ed., Noise and Vibration Control, McGraw - Hill Book Company, New York, NY, 1971.

43. Bottom, C. G., "A Social Survey into Annoyance Caused by the Interaction of Aircraft Noise and Traffic Noise," J. of Sound and Vibration 19, 473-476, 1971.

44. Gordon, C. G., Galloway, W. J., Kugler, B. A., and Nelson, D. L., "Highway Noise -A Design Guide for Highway Engineers," Highway Research Board, NCHRPR 117, Washington, DC, 1971.

45. Kryter, K. D., "Non-Auditory Effects of Noise," National Academy of Sciences, National Research Council, Committee on Hearing, Bioacoustics and Biomechanics, Washington, DC, June 1971.

46. Schultz, T. J. and McMahon, N. M., "Noise Assessment Guidelines," U.S. Department of Housing and Urban Development, August 1971.

47. Wyle Laboratories, "Community Noise," U.S. Environmental Protection Agency, NTID 311.3, December 1971.

48. Beland, R. D., Mann, P. P., and Lafer, S. K., "Aircraft Noise Impact Planning Guidelines for Local Agencies," U.S. Department of Housing and Urban Development, TE/NA 472, November 1972.

49. Doelle, L. L., Environmental Acoustics, McGraw - Hill Book Company, New York, NY, 1972.

50. Kryter, K. D., "Impairment to Hearing from Exposure to Noise," J. Acoust. Soc. Am. 53, 1211-1234, 1973.

51. U.S. Environmental Protection Agency, "Impact Characterization of Noise Including Implications of Identifying and Achieving Levels of Cumulative Noise Exposure, Aircraft/Airport Noise Report," NTID 73.4, July 1973.

52. U.S. Environmental Protection Agency, "Public Health and Welfare Criteria for Noise," EPA 550/9-73-002, July 1973.

53. Vest, G. D., "Protecting Airports and Their Neighbors Through the Environmental Land Use Planning Process," AICUZ - Information Bulletin Two, Department of the Air Force, March 1973.

54. Ward, W. D., Ed., "Proceedings of the International Congress on Noise as a Public Health Problem," U.S. Environmental Protection Agency, EPA 550/9-73-008, 1973.

55. Galloway, W. J., Eldred, R. H. E., and Simpson, M. A., "Population Distribution of the United States as a Function of Outdoor Noise Level," U.S. Environmental Protection Agency, EPA 550/9-74-009, June 1974.

56. Miller, J. D., "Effects of Noise on People," J. Acoust. Soc. Am. 56, 729-764, 1974.

57. U.S. Environmental Protection Agency, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," EPA 550/9-74-004, March 1974.

58. Wooten, D. C. and Mestre, V., "California General Plan Noise Element," Inter-Noise 74 Proceedings, Washington, DC, 1974.

59. Bishop, D. E., "A Building Code for Exterior Noise Isolation with Respect to Aircraft Noise," Department of the Air Force, Report 2944, June 1975.

60. Lukas, J.S., "Noise and Sleep: A Literature Review and a Proposed Criterion for Assessing Effect," J. Acoust. Soc. Am. 58, 1232-1242, 1975.

61. Powell, C. A. and Rice, C. G., "Judgements of Aircraft Noise in a Traffic Noise Background," J. Sound and Vibration 38, 39-50, 1975.

62. Gierke, H. E., "Guidelines for Preparing Environmental Impact Statements on Noise," National Research Council, Committee on Hearing, Bioacoustics, and Biomechanics, Assembly of Behavioral and Social Sciences, Washington, DC, June 1977.

63. Goldstein, J., "Assessing the Impact of Transportation Noise: Human Response Measures," Noise - Con 77, NASA Langley Research Center, Hampton, VA, 1977.

64. International Civil Aviation Organization, "Airport Planning Manual: Part 2, Land Use and Environmental Control," DOC 9184-AN/902, Montreal, Canada, 1977.

65. Trans Systems Corporation and Wyle Laboratories, "Study of Soundproofing Public Buildings Near Airports," U.S. Department of Transportation, Federal Aviation Administration, Report No. DOT-FAA-AEQ-77-9, April 1977.

66. U.S. Department of Transportation, Federal Aviation Administration, "Airport -Land Use Compatibility Planning," Report No. AC 150/5050-6, 1977.

67. U.S. Department of Transportation, Federal Aviation Administration, "Impact of Noise on People," May 1977.

68. U.S. Environmental Protection Agency, "Department of Defense, Federal Noise Program Reports, Volume I, Air Installation Compatible Use Zones (AICUZ) Program," EPA 550/9-77-353, Volume I, April 1977.

69. U.S. Environmental Protection Agency, "Federal Noise Program Reports Series, Volume II, Department of Housing and Urban Development: Noise Abatement and Control Policy," EPA 550/9-77-354, Volume II, April 1977.

70. Carver, B., "Environmental Protection Planning in the Noise Environment," Departments of the Air Force, the Army and the Navy, AFM 19-10; TM 5-803-2; NAVFAC P-970, June 1978.

71. Schultz, T. J., "Synthesis of Social Surveys on Noise Annoyance," J Acoust. Soc. Am. 64, 377-405, 1978.

72. U.S. Environmental Protection Agency, "Federal Noise Program Report Series, Volume III, Department of Transportation, Federal Highway Administration - Noise Policy and Related Environmental Procedures," EPA 550/9-77-357, Volume III, July 1978.

73. Department of the Air Force, "Air Installation Compatible Use Zone (AICUZ) Handbook," Environmental Planning Bulletin 10, Volumes 1 and 2, June 1979.

74. Galloway, W. J. and Schultz, T. J., "Technical Background for 1979 Noise Assessment Guidelines," Department of Housing and Urban Development, December 1979.

75. Goldstein, J., "Descriptors of Auditory Magnitude and Methods of Rating Community Noise," Community Noise, ASTM STP 692, American Society for Testing and Materials, 1979.

76. McGaughey, J. W., Dennison, E. E., and Ying, S. P., "Practical Methods of Environmental Noise Assessment," Community Noise, ASTM STP 692, American Society for Testing and Materials, 1979.

77. Sperry, W. C., "Abatement of Aircraft Noise and Related Regulatory Actions," Community Noise, ASTM STP 692, American Society for Testing and Materials, 1979.

78. Tedrick, R. N.; "Technical Considerations in Federal Regulation of Aircraft Noise at the Source," Community Noise, ASTM STP 692, American Society for Testing and Materials, 1979.

79. "American National Standard, Sound Level Descriptors for Determination of Compatible Land Use," ANSI 53.23-1980/ASA 22-1980, Acoustical Society of America, New York, NY.

80. Federal Interagency Committee on Urban Noise, "Guidelines for Considering Noise in Land Use Planning and Control," June 1980.

81. Galloway, W. J. and Schultz, T. J., "Interim Noise Assessment Guidelines," Department of Housing and Urban Development, October 1980.

82. Ronk, L. A., "Final Report: Assessment of the Applicability of Existing Health and Welfare Criteria to General Aviation Aircraft Noise and to General Aviation Airport Communities," U.S. Environmental Protection Agency, EPA 550/9-82-102, March 1980.

83. Tobias, J. V., Jansen, G., and Ward, W. D., "Proceedings of the Third International Congress on Noise as a Public Health Problem," American Speech-Language-Hearing Association, ASHA Report 10, Rockville, MD, April 1980.

84. Cohen, S., Krantz, D.S., Evans, G.W., and Stokols, D., "Cardiovascular and Behavioral Effects of Community Noise," American Scientist 69, 528-535, 1981.

85. Fidell, S., Horonjeff, R., Teffeteller, S., and Pearson, K., "Community Sensitivity Changes in Aircraft Noise Exposure," National Aeronautics and Space Administration, NASA CR 3490, December 1981.

86. Peat, Marwick, Mitchell and Company, "Final Report, Appendix A, Aircraft Noise and Land Use Analysis Related to the Airport Master Plan for Stapleton International Airport," San Francisco, CA, May 1981.

87. U.S. Department of Transportation, Federal Aviation Administration, "Evaluation of Three Noise Abatement Departure Procedures at John Wayne Airport," November 1981.

88. Fidell, S., Mills, J., Teffeteller, S., and Pearsons, K., "Community Response to Three Noise Abatement Departure Procedures at John Wayne Airport," National Aeronautics and Space Administration, Langley, VA, June 1982.

89. Eldred, K.M., "An Assessment of Noise Impact Aspects of Aircraft and Airport Compatibility," Transportation Research Board, Transportation Research Circular No. 247, Washington, D.C., 1982.

90. Kryter, K. D., "Community Annoyance from Aircraft and Ground Vehicle Noise," J. Acoust. Soc. Am. 72, 1222-1242, 1982.

91. Kryter, K. D., "Rebuttal by K. D. Kryter to Comments by T. J. Schultz," J. Acoust. Soc. Am. 72, 1253-1257, 1982.

92. Schettino, J. and Staiano, M., ed., "Second National Conference on General Aviation Airport Noise and Land Use Planning: Summary of Proceedings," U.S. Environmental Protection Agency, EPA 550/9-82-377, April 1982.

93. Schultz, T.J. "Comments on K. D. Kryters' Paper, "Community Annoyance from Aircraft and Ground Vehicle Noise," J. Acoust. Soc. Am 72, 1243-1252, 1982.

94. U.S. Environmental Protection Agency "Guidelines for Noise Impact Analysis," EPA 550/9-82-105, April 1982.

95. Rossi, G., "Proceedings of the Fourth International Congress on Noise as a Public Health Problem," Centro Ricerche E. Studi Amplifon, Milan, Italy, November 1983.

APPENDIX A

A REVIEW OF PERTINENT LITERATURE

A.1 Composite Noise Rating, 1953-1960

In 1953, Rosenblith, Stevens, et al[2], published a curve, shown in Figure 1, that presented a community response scale from "No Annoyance" to "Vigorous Legal Action". The curve is based on "empirical data". The noise levels, or "Noise Ranks", from A to I, are defined by a series of curves of "equal loudness", separated by about 5 dB. The separation is smaller at low intensities, larger at high, and less at low frequencies than high. The procedure proposed for predicting community response is to determine a "Level Rank", i.e. a noise curve matching the noise, more or less. Corrections are then applied for Spectrum Character (Pure tones), Peak Factor (Impulsive), Repetitive Character, Level of Background Noise, Time of Day, Adjustment (How long has it been going on), and Other Factors (psychological, public relations, economic, etc.). Correction numbers are unit numbers, changing the curve selection. Therefore, each "correction" is on the order of 5 dB. After the corrections are applied, the result is a composite noise rating or "Noise Rating".

The community response curve recognizes the uncertainties; it is presented as a band, about 10 dB wide. The report[2] says: "The inherent assumption is that in the absence of dramatic events or particular psychological circumstances, stimuli that have the same noise ratings (although perhaps quite different level ranks) all produce the same response within a range of statistical variations. It is a truism that all residents do not react alike to a given stimulus. There is a distribution of response, and it is necessary, therefore, to express the response in terms such as expected 'average response', and 'range of expected response from a normal population'. The noise range from 'No Annoyance' to 'Vigorous Legal Action' on the community response scale is about 40 dB. From 'Mild Annoyance' to 'Threats of Legal Action', the range is about 15 dB. 'Strong Complaints' therefore, could be expected from Noise Ratings D,E or F; and 'Threats of Legal Action' from E, F or G. In total, the linear response scale has six equally spaced points".

The authors[2] point out that "the scheme for evaluation of neighborhood reaction can be justified only by checking it against empirical data...We have, of course, used some of our case histories in setting up the scheme, and it is hardly conclusive now to use their case histories to show the validity of the scheme. The real test for the scheme will come in the future when its ability to predict behavior of communities will be tested in new situations". A summary is given of the eleven case histories upon which the method is based. Of these eleven cases, one is an examination of aircraft in flight, and one deals with ground runups at an airport. Two others are concerned with engine tests at factories. The remaining seven involve a number of different noise sources ranging from a weapons range, to fans and wind tunnels to transformer noise in a very quiet residential area. The single

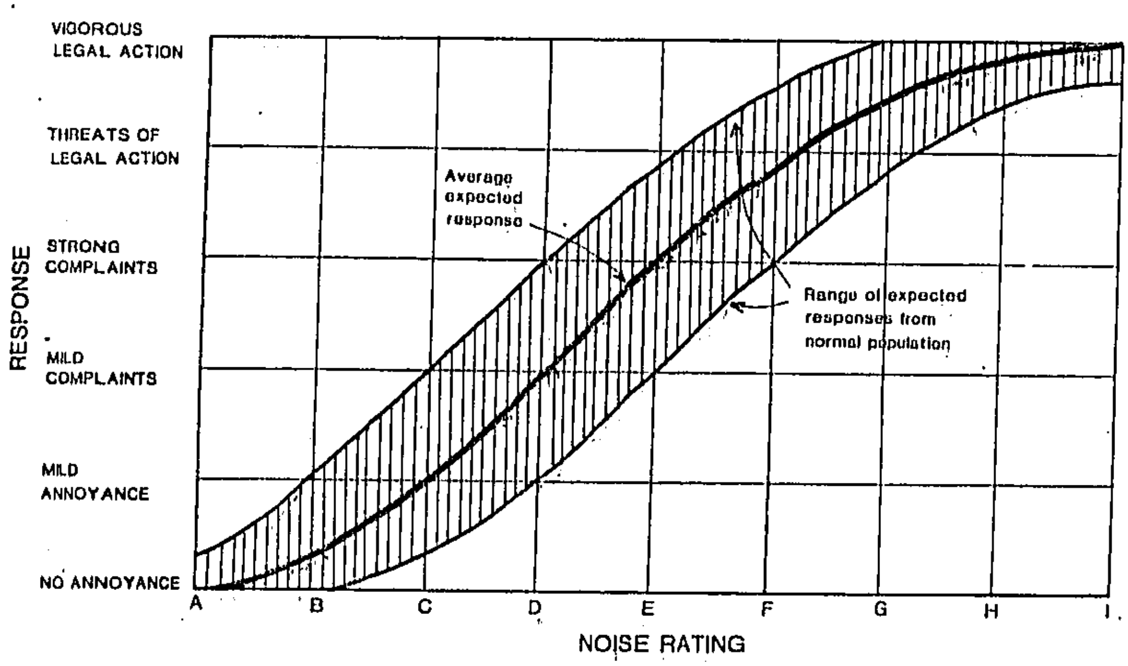


Figure 1. Community Response Scale To Noise

case of aircraft in flight produced noise at a Noise Rating of H. Corrections of -2 for repetitive character and -1 for exposure adjustment reduced the Noise Rating of H to a Noise Rating of E. The consequent predicted average response was "strong complaints". The actual response was reported as "Vigorous complaints by letter and telephone. One town attempted to prevent passage of aircraft". Similar information is given for each of the eleven case histories.

In 1955, an article by the same authors[3] contained similar information as a previous paper published in 1953. The community response curve was revised, Figure 2, with the 11 cases plotted. The list of correction factors was modified and reorganized. The response scale had five values plotted on a linear scale, instead of six: "No Observed Reaction", "Sporadic Complaints", "Widespread Complaints", "Threats of Community Action", and "Vigorous Community Action". The lower portion was redrawn, so that the average expected response reaches the "No Observed Reaction" line at Noise Rating B. After discussing the behavior that characterizes each of the response points, the authors commented that "The points on our response scale are not so well defined as we might wish. It is a relatively simple matter to measure the intensity of noise with a meter...to obtain...the time schedule of the noise, the background noise, and so forth. Our information on the community response, however, is gleaned from comments on the number of telephoned complaints and the number of letters of complaint, and from impressions of the severity....voiced by the complainers...We recognize that such data are often ill-defined and vague and that the frequency of the complaints and their severity cannot always be clearly separated".

There were also revisions in the summary of case histories. The single case of aircraft in flight was now defined as "Aircraft in flight four miles from airport", and the level rank was changed from H to L, about 20 dB. Corrections of -1 for background noise (not present before), -4 for repetitive character (formerly -2), and -1 for previous exposure changed the Noise Rating to F (formerly E).

The conclusion stated that "twenty odd" case histories were studied. The authors said that they have not been able to give a clearcut answer to the question of "...how many decibels it takes to make people squack how loudly. It just doesn't seem to be that simple...We need to know whether this scheme will work when you try it".

By 1960, the Composite Noise Rating (CNR) was described by Beranek[7] in a text prepared for a special summer program at the Massachusetts Institute of Technology. The application to aviation is not discussed, but Perceived Noise Level (PNL) was introduced. The PNL "is defined as the sound-pressure level of a band of noise from 910 to 1090 cycles per second (cps) that sounds as 'noisy' as the sound or noise under comparison. The principal difference between loudness level and perceived-noise level is that 'equal annoyance contours' in place of 'equal loudness contours' were used in derivation. As proof of its validity for judging the 'noisiness' of aircraft flyover noise,

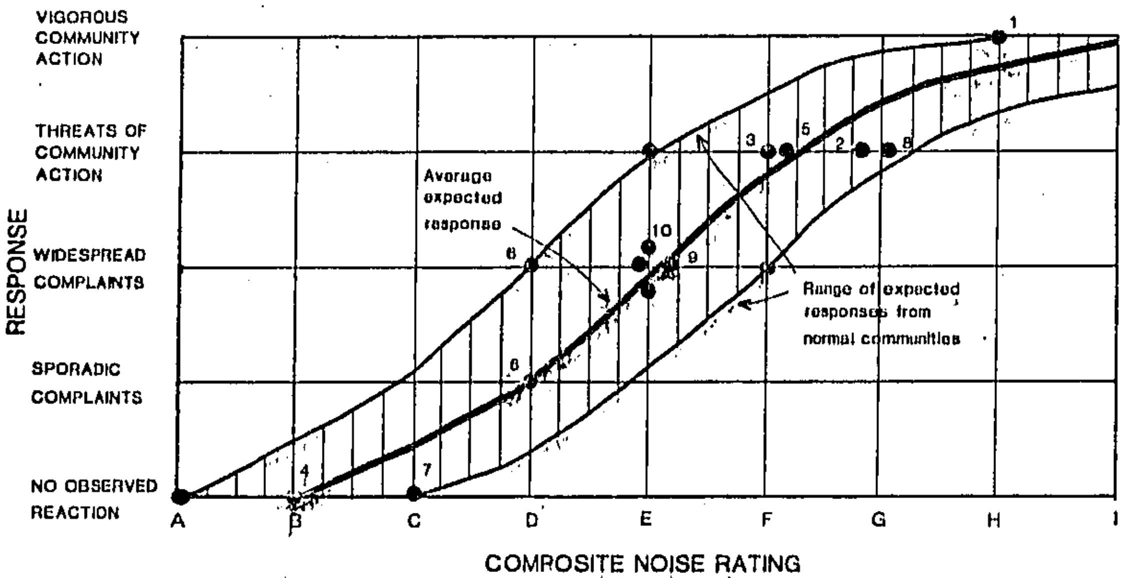


Figure 2. Community Response Scale To Noise (Revised)

a series of experiments was conducted in which people judged the relative acceptability of the fly-over noise made by various jet- and piston-aircraft more accurately than did loudness level, speech interference level, or sound-pressure level".

A.2 London (Heathrow) Airport and Farnborough Surveys, 1961

The London (Heathrow) Airport survey[10] has been cited and reexamined many times. One thousand seven hundred thirty one (1,731) people were chosen at random from the areas around Heathrow, and interviewed. There were 42 questions, designed to explore how people felt about their living conditions. Noise was not mentioned until question 11, and aviation was not mentioned until question 13. Question 13B was: "Does the noise of aircraft bother you very much, moderately, a little, or not at all?". The scale used was formed from the answers to 13B, and five other questions: "Does the noise of aircraft ever (a) wake you up, (b) interfere with listening to TV or radio, (c) make the house vibrate or shake, (d) interfere with conversation, or (e) interfere or disturb any other activity, or bother, annoy or disturb you in any other way"? An individual scored one point if he rated himself at least a little annoyed by aircraft in question 13B, and an additional point for each kind of disturbance from aircraft -sleep, TV or radio, house vibrating or interference with conversation - which he said annoyed him when it occurred. Those who mentioned another kind of disturbance received another point. There were only a few of these, who were all in the most extremely annoyed group.

Quoting from the report on the Heathrow survey, "The selection of the items and the degree of annoyance associated with each item was determined by the specialized technique known as the Guttman scale criterion. This ensured that the scale established was not an arbitrary one, but gave a continuous measure of annoyance...The scale gave annoyance rating from 0 to 6, but the number of people scoring 6 was so small that for most purposes they could be combined with those scoring 5. The answers to question 13B showed that the scale points 0, 2, 3 and 4 correspond approximately to the verbal categories 'not at all,' 'a little,' 'moderately' and 'very much' annoyed."

For analysis, the group was divided into twelve cells, defined by the average number of aircraft per day and the noise level range. The noise level was in PNdB, that is, a measure of peak level per event. The number of people in each cell was tabulated against their annoyance scores as follows:

Noise Level PNdB	Aircraft per day Average	Annoyance Score 0	1	2	3	4	5	Average Annoyance Score	Number of People in Cell
84-90	5.75	230	128	113	5	5	31	1.1	512
	22.5	45	33	26	17	12	22	1.9	155

Noise Level PNdB	Aircraft per day Average	Annoyance Score 0	1	2	3	4	5	Average Annoyance Score	Number of People in Cell
	81	5	7	2	7	10	7	2.8	38
91-96	5.75	51	41	28	17	11	10	1.5	158
	22.5	90	64	55	45	35	32	1.9	321
	81	18	15	13	23	18	23	2.7	110
97-102	5.75	2	1	-	3	1	-		7
	22.5	13	9	20	16	11	13	2.5	82
	81	20	22	38	26	30	64	3.1	200
103-108	5.75	-	-	-	-	-	-	-	-
	22.5	1	-	1	5	2	2	3.2	11
	81	11	7	17	16	19	67	3.6	137

Because of their small sample size, the cells with less than forty people were discarded, and the analysis is based on the remaining eight cells.

From this point, the average scores were used as typical of the group in the cell. Examination indicated that quadrupling the number of operations was equivalent to a 9 dB increase in Perceived Noise dB (PNdB), or 15 log N. The total noise exposure then was defined as the Noise and Number Index (NNI). The NNI = (average level in PNdB) x 15 log N - 80, where N is the number of operations, and 80 makes NNI = 0 at about zero annoyance.

These results were compared with the results of interviews conducted in Farnborough[10] at about the same time. The Farnborough experiments used a scale based on "intrusiveness". In Farnborough, the noise was measured in dB(A). These were changed to PNdB by adding 14 dB(A) to the dB(A) readings. The correction for the number of operations in the Farnborough data was 0, because the judgments were based on single events.

"Taking into account all the inevitable uncertainties of the above comparisons, we consider that exposure to aircraft noise reaches an unreasonable level in the range of 50 - 60 NNI. Support for this conclusion comes from the fact that it corresponds roughly with the exposures judged to be 'very annoying' in the Farnborough experiments, and at which people considered themselves 'very much annoyed' in the Social Survey, and from the fact that Cranford, which is known to be a particularly sensitive area, is exposed to just these levels of NNI."

The NNI in the cell with the highest noise and most aircraft per day, PNdB = 103-108 and N (average) = 81, is 54.1. The range in the number of aircraft in this cell was 40 - 110 per day. At a PNdB of 103 and 40 aircraft, if such a situation actually occurred, the NNI would be 47. At a PNdb of 108, and 110 aircraft, should this combination occur, the NNI would be 58.6. Of the people in this cell, the annoyance scores were distributed as follows:

Annoyance Score	Percent
0	8%
1	5%
2	12%
3	12%
4	14%
5	49%

The average score was 3.6.

Using the criteria of a score of 3.5 as "seriously annoyed", data showing the percent "seriously annoyed" at various PNdB levels (not NNI) were given:

PNdB	Percent "seriously annoyed"
85	10%
85-87	16%
88-90	23%
91-93	24%
94-96	36%
97-99	48%
100-102	51%
103	68%

The report[10] does not indicate how the criteria of 3.5 as "seriously annoyed" was determined.

A.3 Composite Noise Rating, 1964

Bolt, Beranek and Newman[12] published in October, 1964 a document which describes procedures for applying CNR to aviation operations. A minimum number of contours for various types of aircraft are supplied, in PNdB. Corrections are applied for number of operations, runway utilization and time of day, all in 5 PNdB steps. At any point, the total of all operations are summed. The rules are simple: "Only those CNRs that are within 3 units of the maximum CNR need to be considered. If there are three or more CNRs fulfilling this requirement, add 5 units to the highest one to determine the CNR that applies for all flight operations; if there are less than three, the highest applies". The chart for estimating response, based on this determination is (considering takeoffs and landings):

CNR	Zone	Description of Expected Response
100	1	Essentially no complaints would be expected. The noise may, however, interefere with certain activities of the residents.
100-115	2	Individuals may complain, perhaps vigorously. Concerted group action is possible.

CNR	Zone	Description of Expected Response
115	3	Individual reactions would likely include repeated vigorous complaints. Concerted group action might be expected.

The October 1964 report does not give a source or basis for these descriptions of expected response. Between 1957 and 1964, however, the corrections for background noise, winter-summer, and previous exposure disappeared. The correction for nighttime operations is 10 dB. However, the statement is made that "Only when the nighttime activity is disproportionately high will the nighttime correction affect the Composite Noise Rating".

In December, 1964, a Bolt, Beranek and Newman (BBN) report[11] included a land use compatibility chart which indicated, that, up to CNR 100, residential use is compatible with aviation noise; over 115, such use is not compatible with aviation noise. Between 100 and 115 CNR, "Case history experience indicates that individuals in private residences complain, perhaps vigorously. Concerted group action is possible. New single dwelling construction should generally be avoided". For apartments, "Avoid construction unless a detailed analysis of noise reduction requirements is made and needed noise control features are included in building design".

A.4 Composite Noise Rating, 1965

In December, 1965, the final report[14] of a two year contract by BBN was published. This report synthesized much of the information that contributed to the overall pattern of the prediction of community response to noise as it existed at that time. The abstract cautions: "The improvement of procedures for accurately predicting different degrees of community response in particular airport - community situations does not seem feasible at this time. However, present empirical methods for predicting community response to aircraft noise provide extremely useful guides to typical response expected from a broad sampling of communities".

The report presents a chart, reproduced as Figure 3, which shows CNR values as computed by this procedure, and the overt community response for 21 case histories.

A survey of attitudes toward aviation noise conducted by BBN in Los Angeles is reported in the December 1965 study. Since 1960, three surveys or tests of the judgment of aircraft noise had been conducted: judgments of "intrusiveness" by 60 subjects in Farnborough, England; determination of subjective "annoyance" in the vicinity of London (Heathrow) Airport in 1961 involving attitude questionnaires of 1731 people and 100 noise measurements at each of 85 locations; and judgments of aircraft noise in terms of "acceptability" conducted near Los Angeles International Airport in 1964.

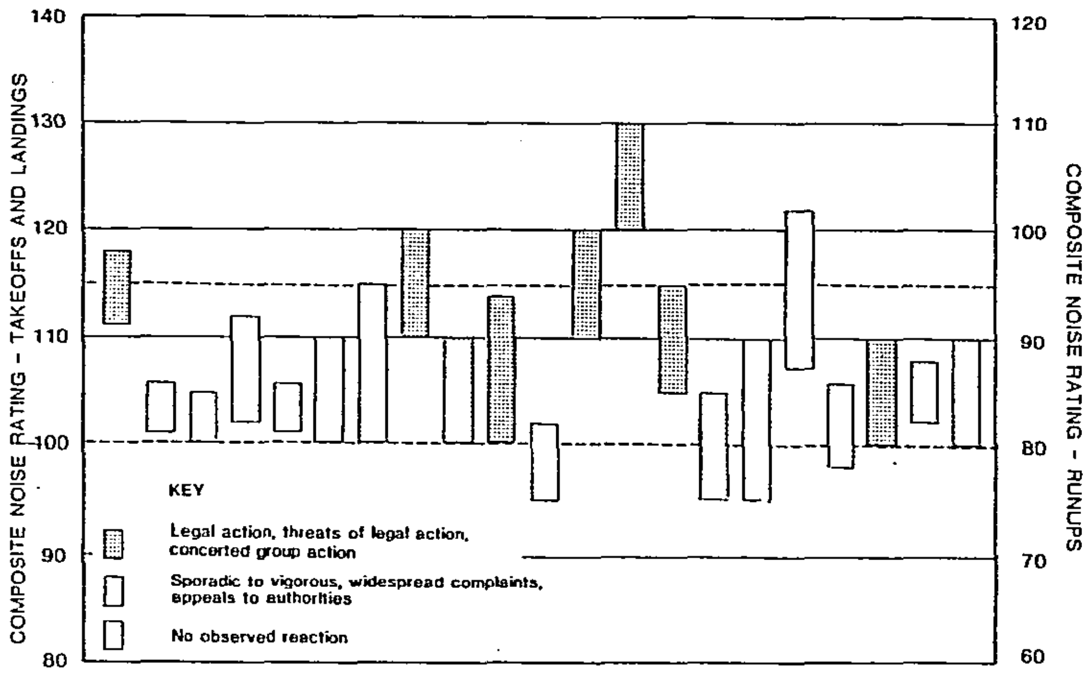


Figure 3. CNR Values And Overt Community Response For 21 Case Histories

As noted, the descriptive scales do not match. On a scale of 0-10, the report placed them as follows:

Scale	Farnborough	London	Los Angeles
0	"Intrusiveness"	"Annoyance"	"Acceptability"
0.5	Not Noticeable	Not at all	
1			
1.5			
2			Of no concern
2.5	Noticeable		
3			
3.5			
4		Little	Acceptable
4.5	Intrusive		
5			
5.5		Moderate	
6	Annoying		Barely Unacceptable
6.5			
7			
7.75	Very Annoying		
8		Very Much	Unacceptable
8.5			
9			
9.5			
10			

On this basis, the three scales when plotted against outdoor PNdB + 10 (or 15) log N do not coincide. However, they are not radically different.

The 1965 BBN report also makes other comparisons of the three studies. Among these is a listing of the changes in PNdB in each of the three cases which resulted in a significant shift in ratings:

Test	Farnborough	London	Los Angeles
Shift From	Intrusive	Little	Acceptable
Shift To	Very Annoying	Very Much	Unacceptable
Increase in PNdB	20* to 22**	23	17* to 21**

*Outdoors **Indoors

On this basis the report states that "it is evident that a shift in noise exposure of the order of 20 PNdB is required to provide a pronounced shift in mean attitudes toward aircraft noise".

The report postulates that both stimulus and response are distributed about an ideal single number. That is, in the idealized situation, a given stimulus would produce a specific response. Instead, both stimulus and response have a distribution about these idealized (presumably mean) values. Based on the statistical analysis resulting from an examination of the estimated increase in noise level to increase the percentage of people judging noise as unacceptable or very annoying from 5% to 50% or from 10% to 50%, the report concludes that: "a sizeable proportion of the existing 15 CNR unit spread between CNR response zones 1 & 3 is due to variability in subject responses and variability in aircraft noise stimuli....even if we had a much fuller understanding of the linkage between individual responses ....and observed community reaction, there would be a considerable spread of noise stimulus in which a given degree of community response might be observed in a particular airport-community".

A detailed discussion on the Los Angeles tests mentioned above was presented in the report. The tests indicate that the same noise level is likely to be less acceptable indoors than outdoors. A similar conclusion was reached at Farnborough. In Farnborough the displacement was about 18 dB(A); in Los Angeles, 14 PNdB. In both, the shift was "somewhat less" than the noise reduction provided by the test buildings, 7 to 10 PNdb greater than the mean observed displacement in judgments.

The report also compares Los Angeles and Farnborough on the basis of PNdB values and the category scales. The unacceptable level in Los Angeles was from 107 CNR (outdoors, as judged inside with building attenuation) to 115 CNR (as judged outdoors). The very annoying level at Farnborough is about 127 CNR. The report suggests that the difference may be due to instructions given to the subjects in the Los Angeles test to rate each incident in the context of 20-30 occurrences per day. This would account for an additional 13-15 or 20-22 dB depending upon whether one used a multiplier of 10 or 15.

There is considerable scatter in the data. "For example,...one can say that while 50% of subjects located outdoors may assign a rating of 'barely acceptable' or better to a flyover with a noise level of 99 PNdB, 95% of the subjects are not likely to register a rating of 'barely acceptable' or better until the flyover noise level has been lowered to 82.4 PNdB."

There is some analysis of the sources of dispersion, and it is concluded that "the variability resulting from differences between subjects, individual subject inconsistency and correlation between objective and subjective scales are (all) of the same order of magnitude".

One conclusion from the test indicates a change of 16 PNdB is required for a doubling of noisiness as opposed to 10 PNdB as postulated by Kryter[6]. Stevens[3] also concluded that 10 PNdB is required for doubling.

The 1965 BBN report[14] also contains a section in which the CNR noise technique as described a year earlier is applied. The development of the land use criteria is described thus: "On the basis of case histories involving aircraft noise problems at various military installations and civil airports, an empirical relationship has been developed between composite noise ratings and the expected response of residential communities".

Thus, by the end of 1965, the CNR methodology had become established. The basic metric was PNdB. All of the experimental data showed that there was a large spread of individual reactions to the same noise level. The correction for multiple events was 10 times the logarithm (base ten) of the number of daily operations.

A.5 Noise Measures for Aircraft Noise, 1966

A paper by Galloway and von Gierke[16] given late in 1966 sums up the situation well. The authors point out that aircraft noise specifications fall in three different categories. The first is concerned with noise levels for certification; the second with noise exposure for planning purposes; and the third with noise levels for monitoring purposes. In the second category, it is necessary to have some scale of community response; the issue of response can be found in the other two categories. Experiments indicate that "the variances in the correlation of group response to aircraft noise exposure are large. Thus...specifications based on prediction of an absolute scale of response must recognize the broad uncertainty in the experimental data... It therefore becomes clear that the final choice of aircraft noise limits is an operational or administrative decision which can only be made in the context of the purpose of the specification--and in the context of specific states of society and law".

The paper assumes that PNdB is the more acceptable measure for aircraft noise as of the time of the paper, and uses this measure in the discussion.

There are three broad categories of experiments that had been conducted on estimating reaction to aircraft noise. These categories include: psychoacoustic judgment on evaluations; sociological opinion surveys; and analysis of complaint histories. The psychoacoustic experiments provide valuable information about individual responses, and the effect of changes in frequency, duration, tonal components, etc. However, they do not provide estimates of community response. The other two approaches are more useful for that purpose.

"Social surveys provide a great deal of fascinating information on the reported attitudes of the respondents...(For) the administrator faced with the selection of allowable noise exposure limits, it is often difficult to extract from an opinion survey of the community quantifiable information on just how far he can be permitted to go in balancing allowable noise limits with the economic limitations imposed upon the air traffic operating from the airport... While the airport operator or air carrier may be very sympathetic to the feelings of the community surrounding the airport and may have a sincere desire to minimize the nuisance value caused by aircraft noise, his fundamental fear in reality is legal action which will restrict airport operations."

The authors compare the results of field experiments conducted at various times and places. Field experiments attempt to approximate "real life" conditions. People are asked to indicate their reactions or response to various known or measured noise on a category scale. Figure 4, taken from the report, compares various tests of this nature. The British data, originally recorded in dB(A), have been converted to PNdB using the average difference reported by the British of 13 dB. Noise levels measured inside have been converted to the equivalent outside levels by the noise reduction reported for the various buildings involved. The mean values for the various word descriptors used are indicated on the vertical bars. The upper and lower noise levels for each test are shown by the horizontal bars.

The differences among the experimental results are discussed at some length, with possible explanations hypothesized. With the first four sets, B and D were 3,000 feet from the runway; A and C were approximately 500 feet to the side. "We can conclude only that the mean noise levels at which different groups of people designated particular descriptors such as 'quiet', 'moderate', or 'noisy' was strongly a function of the physical environment in which the people were performing their judgments". Because the displacements in the scales are large compared to the standard deviation of the means, the authors conclude that "It is not likely that the displacements between the two scales are merely a function of the variability in the judgments of different groups of people".

From the Los Angeles experiment, the authors conclude that people expect inside noise levels to be lower than they do outside for the same descriptors. Regarding the final three scales, the authors hypothesize that Groups A and B might have been "conditioned" by participation in a test the previous day which involved somewhat higher noise levels than this test. The differences between inside and outside follow the Los Angeles data. "The results of these various category scale judgments show the typical variability of this type of experiment." Figure 4 certainly illustrates the difficulty in drawing general conclusions about community reaction from these experiments.

The report discussed the National Opinion Research Center (NORC) surveys on eleven major airport communities in the United States conducted between 1952 and 1960. Eight were communities with civilian airports and three were communities with Air Force bases operating jet aircraft. Figure 5 illustrates the results of an analysis of the NORC data. The attempt was to determine the percentage of residents who would be annoyed by a large number of operations as a function of the noise exposure, fear of crashes, and feeling of considerateness on the part of the base. The authors have converted the noise scale to CNR from the original duration in seconds of noise exposure about a speech interference level of 60 dB. The figure indicates that the percentage of people much annoyed depends as much on fear of crashes and a feeling that the operators are or are not considerate as it does on a change of CNR from 100 to 115 or more.

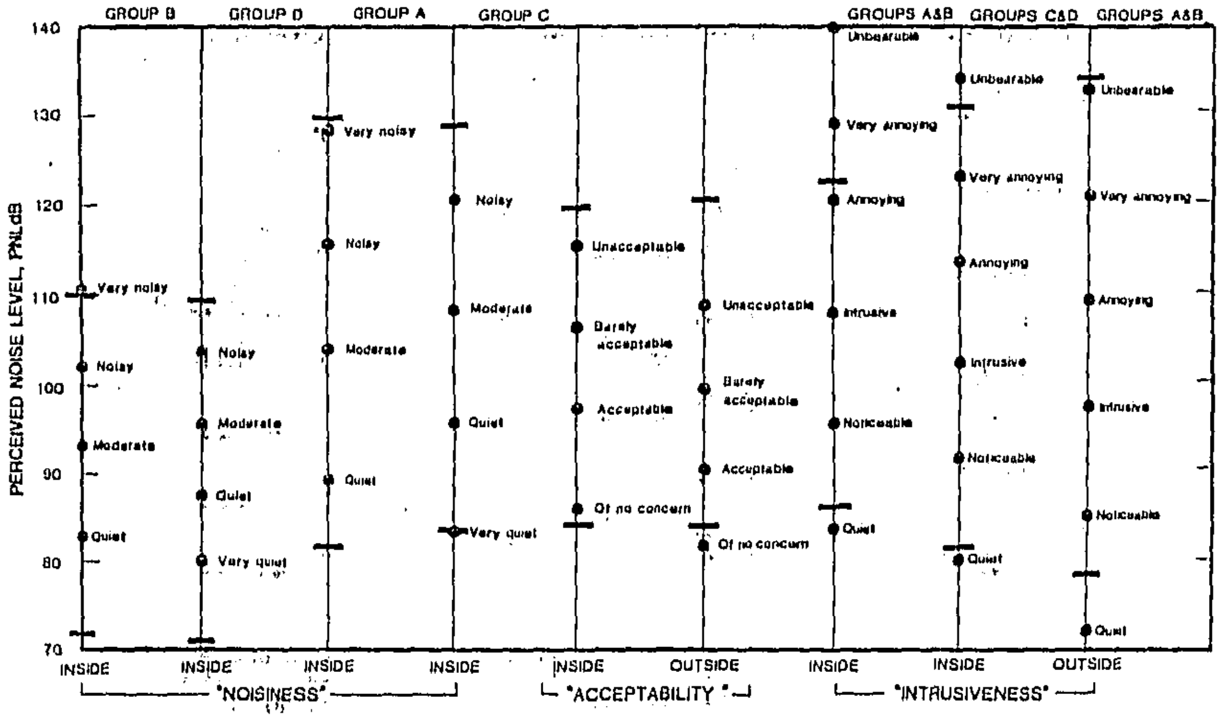


Figure 4. Comparison of Response Scales Obtained from Various Field Studies

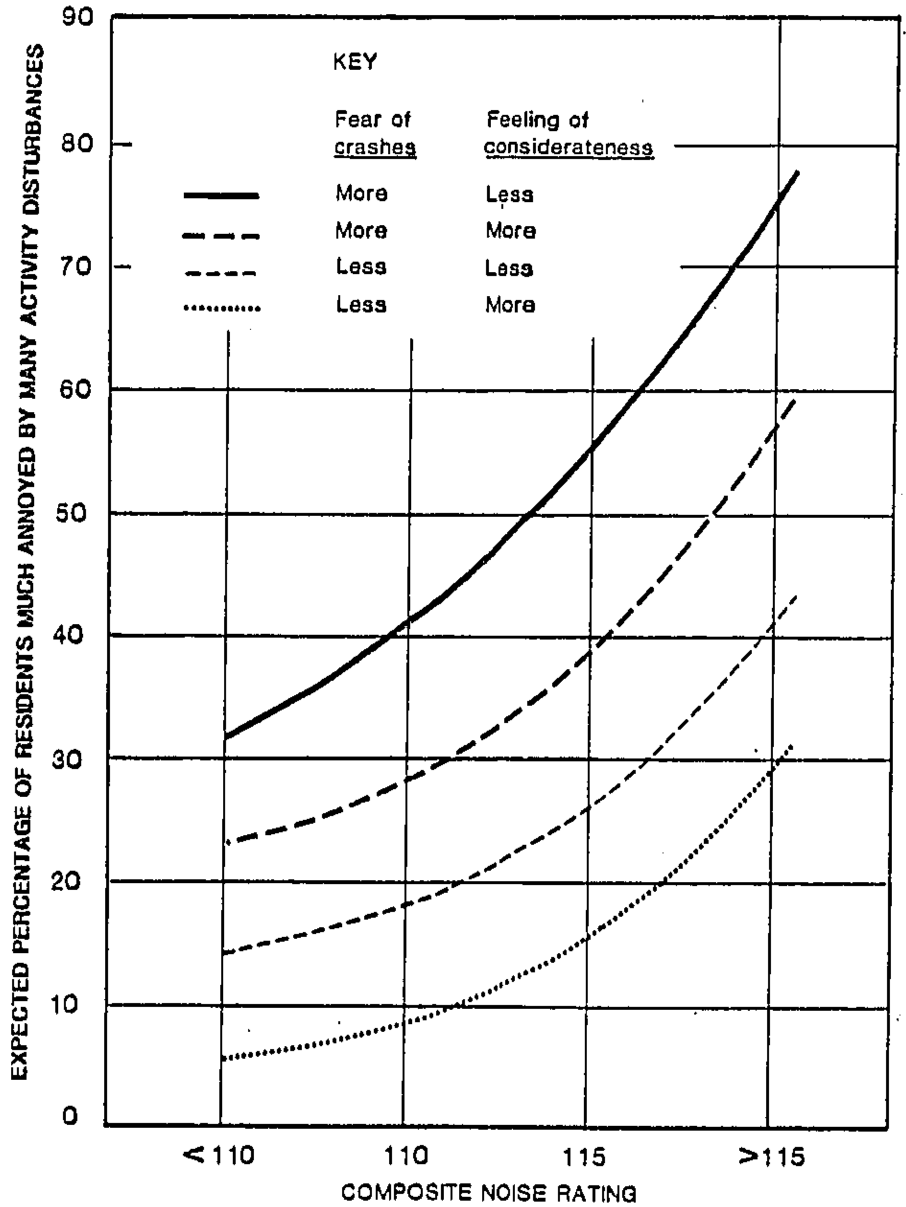


Figure 5. Graph Illustrating the Interpretation of a Portion of the NORC Model for Annoyance

The NORC studies also developed a relationship between the percentage of people who had "felt like complaining" and the percentage who had "actually complained". These results are shown below.

Actually Complained(%)	Felt Like Complaining(%)
1	10
2	15
4	25
6	30
10	40

The authors state that, "The incipient feeling of people that they should complain is often sparked into action by a strong political or social orientation in a given community. Therefore, even a small percentage of complaints in a community should be considered in evaluating the likelihood that a community will take legal action against an aircraft operation".

The authors also comment on the London (Heathrow) Airport survey. CNR values were calculated for the London number and exposure level categories and plotted against the category scale of annoyance, with the results shown in Figure 6. The standard deviations on the annoyance scale are on the order of one and a half categories or greater, corresponding to about 15 units of CNR.

This 1966 paper also repeats the chart of 21 case histories found in Figure 3. The authors note that "Examination of the range of reactions would indicate that the separation between Zones 2 and 3 might more properly be placed at a CNR of 110. However, due to variances in reaction, it was decided that to avoid overpenalizing airport operations, a CNR of 115 should be chosen".

A.6 Noise Exposure Forecast, 1967

In 1967, the Noise Exposure Forecast (NEF) was introduced[18]. It differed from CNR in that it: used Effective Perceived Noise Level (EPNL) as the metric instead of PNL, calculated noise exposure on the basis of energy rather than peak value; introduced a continuous correction for the number of operations; and, eliminated step corrections and standard profiles.

Effective Perceived Noise Level was developed over a number of years from the work of several investigators. A 1968 report[23] described it and the procedures for calculating it.

The 1967 report states: "the CNR boundaries defining different CNR or Noise Sensitivity Zones were based on considerable case history and detailed examination of noise requirements for different work activities. It was deemed desirable to utilize this accumulated noise exposure information in selecting NEF boundary values for determining land use compatibility. A complicating factor in establishing this correlation is the fact that the relationship between the perceived noise level and the effective perceived noise level varies with aircraft operations and with distance from the given aircraft. Hence, there is no single value that can be used to establish a translation in terms of noise level measurement". (emphasis added).

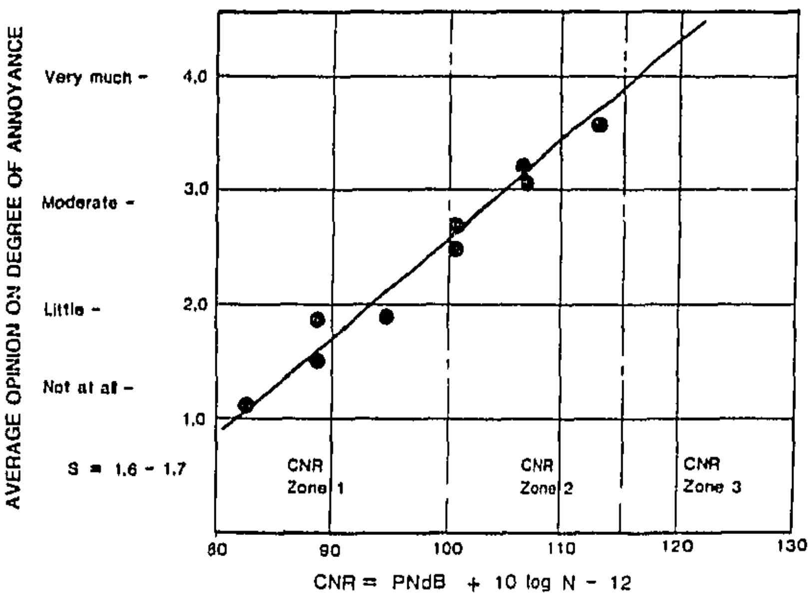


Figure 6. Calculated CNR as a Function of Social Survey Annoyance Scale – London Survey Data

To provide an estimate of the relationship, the authors calculated, for median values of the number of operations which established CNR corrections of 0, +5 and +10 for daytime periods, "the distances from the aircraft at which CNR values of 115 and 110 would occur. At these distances, the corresponding effective perceived noise levels and accompanying NEF values were determined". These were done for large turbojet and turbofan aircraft. A sample of the results is shown in Figure 7. On this basis, the authors determined that, "to the nearest five units, a CNR of 115 corresponded approximately to a NEF value of 40 and a CNR of 100 corresponds to an NEF of 30". The examples shown give the impression that CNR 100 would be more like NEF 27 than 30. Further based on the range of numbers of operations for corrections of 0, +5 and +10 in CNR, the corresponding range of NEF corrections would be 4.3 dB, 5.4 dB and 4.3 dB. That is, if a CNR of 115 were the result of a correction of + 15 for the number of operations, the corresponding NEF could fall anywhere within a range of 4.3 dB depending upon the number of operations.

Of course, in the reverse direction, any value of NEF 30 could be more or less than CNR 100, depending upon whether it was considering approaches or departures, the size of the correction for number of operations, and whether the actual number of operations was near the bottom or the top of the range. A similar statement can be made about NEF 40 and CNR 115. One can, it appears, be fairly certain than a NEF 35 would fall between CNR 100 and 115.

A.7 Special Meeting on Aircraft Noise in the Vicinity of Aerodromes, 1969

A special International Civil Aviation Organization (ICAO) meeting on aircraft noise was convened in Montreal on Nov. 25, 1969. At this meeting, various countries who had been working in the field presented their positions[24-34].

A discussion paper prepared by the ICAO staff points out that "two general classes of unwantedness can be identified". The first is learned reaction, where the sound carries information or connotations that the hearer associates with danger or unpleasantness. The second is related to the physical quality of the sound, and hence is more universal. However, there are large variations in the individual subjective responses to the same sound because of psychological factors and social attitudes. "In view of the number of sources of variance ... it is to be expected that opinions as to what basically constitutes noise, and what represents acceptable and unacceptable noise situations, will differ considerably between individuals, from community to community, and with time, environment and circumstances."

The ICAO staff summarized the results of the "jury" tests at Farnborough in 1961 and 1964 and in Los Angeles in 1964 as:

"i) Equivalent noises from different sources (vehicles and aircraft) do not evoke the same response.

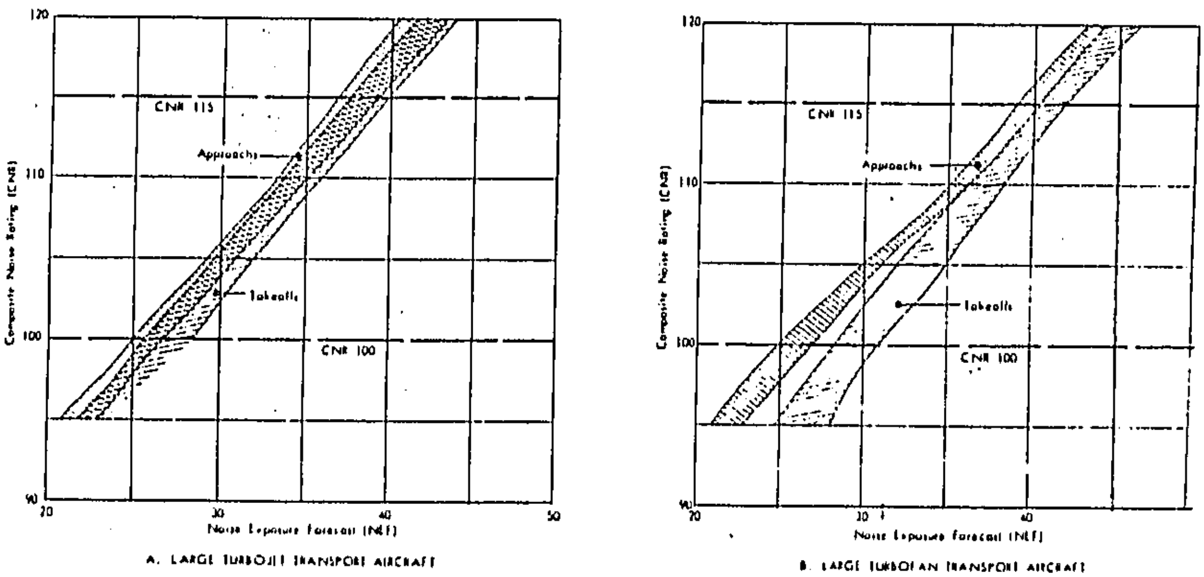


Figure 7. Comparison of CNR and NEF Values

ii) Subjective judgment of noisiness is influenced by the hearer's knowledge of the proximity or remoteness of the source.

iii) A given noise is judged to be more noisy when heard indoors than when heard outdoors."

The ICAO staff report also referred to sociological surveys done in the United States (NORC), London (Heathrow) Airport 1961, and at Amsterdam's Schipol Airport in 1964. The Amsterdam work resulted in a noise measure structurally similar to the others discussed. However, the constants used were different. For example, instead of using a single multiplier for night operations, or one for night and another for evening, a factor which varied in accordance with the following table was used:

Time of movement	Multiplier	Time of Movement	Multiplier
12-6 a.m.	10	7-8 p.m.	3
6-7 a.m.	8	8-9 p.m.	4
7-8 a.m.	4	9-10 p.m.	6
8 a.m.-6 p.m.	1	10-11 p.m.	8
6-7 p.m.	2	11 p.m.-12 a.m.	10

Reporting on the Schipol data, the ICAO staff stated: "On the basis of the survey results, psychologists were of the opinion that a relative annoyance score of 45% was the limit, and that aircraft noise exposure levels causing higher average relative annoyance scores were unacceptable. It should be stressed that already at this limit value, 27% of the people involved are often disturbed in their conversations; 66% are sometimes frightened; 12% are often and 21% are sometimes awakened by aircraft noise. Thus for about one-third of the population involved, the tolerance limit was reached".

The French submitted a paper discussing their surveys and the noise index developed for land use planning purposes. The index is labeled "N", but written in script. By means of a questionnaire, surveys were conducted in the vicinities of Orly, Le Bourget, Marseilles and Lyons Airports in 1966. The results were analyzed in terms of a noise index, the Isopsophic Index, "N", which combined the effects of noisiness levels and repetitions. It is based on the noise level, measured in PNdB. The French stated that they were in the process of converting to Effective Perceived Noise Level (EPNL), the units being EPNdB. EPNL takes into account four characteristics of noise: level, broad band frequency distribution, maximum tone and duration. Separate calculations were made for day and night. The general expression for the Isopsophic Index was equal to N - K log T/t, where:

N = noise level in PNdB, for one movement of a given type of aircraft, along a path

T = maximum duration of noise exposure during the day (16 hours)

t = actual duration of noise exposure, and

K = a multiplier or coefficient which equals 10 for the daytime value of N.

On the basis that aircraft movements can follow each other at a maximum rate of one per minute, the maximum number of exposures in a day (0600 to 2200 hours) is 960. The expression T/t for daytime becomes therefore 960/A where A is the actual number of movements. The formula is used for each aircraft, whether landing or taking off. Because 10 log 960 is approximately 30, the index for daytime can be written as:

Isopsophic Index = N - 30 + 10 log A.

At night (2200 to 0600 hours) the application of the basic formula is different. On the basis that sleep disturbance is more significant during the first half of the night, operations during the first half are rated more heavily than operations during the second half. T and t are replaced by $3T_1 + T_2$ and $3t_1 + t_2$ respectively. The subscripts 1 and 2 refer to the first and second halves of the eight hour night period. As the maximum rate is one per minute, the value of $3T_1 + T_2$ becomes (3x60x4) + (60x4) which equals 960. The movement number, A, becomes $3n_1 + n_2$, where n_1 and n_2 are the number of movements during the first and second halves of the night.

The multiplier or coefficient K, in the expression K log T/t, which was 10 for the daytime value of N, is treated differently at night. "A value of 10 is considered valid when the number of aircraft movements taking place during the night does not exceed that producing an acceptable amount of disturbance of night rest. From studies carried out by the Centre d'Etude de Physiologie Appliquee of the Strasburg Faculty of Medicine, it was concluded that 32 take-offs of Caravelle type aircraft, equally distributed during the night and producing a total indoor noise level of 75 db, will not cause more than an acceptable amount of disturbance."

"When the number exceeds 32, (the) coefficient ... (K) should be given a value increasing in accordance with a logarithmic law with the number of occurrences, until a value of 17 is reached for the maximum number of occurrences."

This leads to different values of K in the nighttime expression of the Isopsophic Index which equals:

$N - 17 \log 960 + K \log (3n_1 + n_2)$, or
$N - 51 + K \log (3n_1 + n_2)$
where,
$K = 10$ when $(3n_1 + n_2)$ is 64 or less, and
$K = 6 \log (3n_1 + n_2) - 1$ when $(3n_1 + n_2)$ is greater than 64.

The United States' position on the various questions raised were summed up in a position paper. The United States felt that the best available basic measure was EPN dB, as previously described. For approximating either PNL or tone corrected PNL, the United States proposed the following corrections to dB(A) and dB(N) (the N represented a different proposed frequency weighting):

	PNdB		Tone Corrected PNdB	
	dB(A)	dB(N)	dB(A)	dB(N)
Turbofan Takeoff	13	7	13	7
Landing	13	7	15	9
Turbojet Takeoff	13	7	13	7
Landing	13	7	13	7
Noise from unknown aircraft	13	7	13	7

The United States took the position that the selection of absolute criteria for "acceptable" community noise levels is an administrative decision which can only be reached by authorities having the power to enforce such decisions after careful evaluation. However, the United States stated that "it appears that one could agree for planning purposes on an upper bound for community noise exposures, choosing this limit so high that for most practical cases and for most countries the allowable limit criteria would be lower. A NEF of 40 (CNR of 115, NNI of 55, Q of 85) is proposed as such an upper limit for community planning with the understanding that wherever possible, planning should aim at exposures of NEF levels of 25 or less". The metric Q was developed in Germany.

Comparisons among CNR, NNI and Q were presented by Galloway and Von Gierke in 1966[16]. Figure 8 shows the values of CNR, NNI and Q as functions of the number of aircraft operations where the average maximum noise level is 110 PNdB with a duration of 15 seconds. For this situation, the three values coincide at about 50 aircraft a day, 55 NNI, 115 CNR and Q 85. The chart indicates that Q 85 lies in Zone 1, which is described as "No residential building". However, the zone boundaries depend on local conditions, and the report states only that Q 82 has been chosen for some applications. We are not informed where this value lies with respect to other applications. Further, the report gives no indication of the effect of using other maximum noise levels or durations.

A.8 Metric Comparisons (Worldwide), 1970

In 1970, a report on Noise Exposure Forecasts (NEF)[37] contains a similar chart, comparing CNR, NNI and Q with each other and other measures. The calculation process was similar, except that a duration of 10 seconds was used. The noise exposure measures NEF and Weighted Equivalent Continuous Perceived Noise Level (WECPNL) use Effective Perceived Noise Level (EPNL)

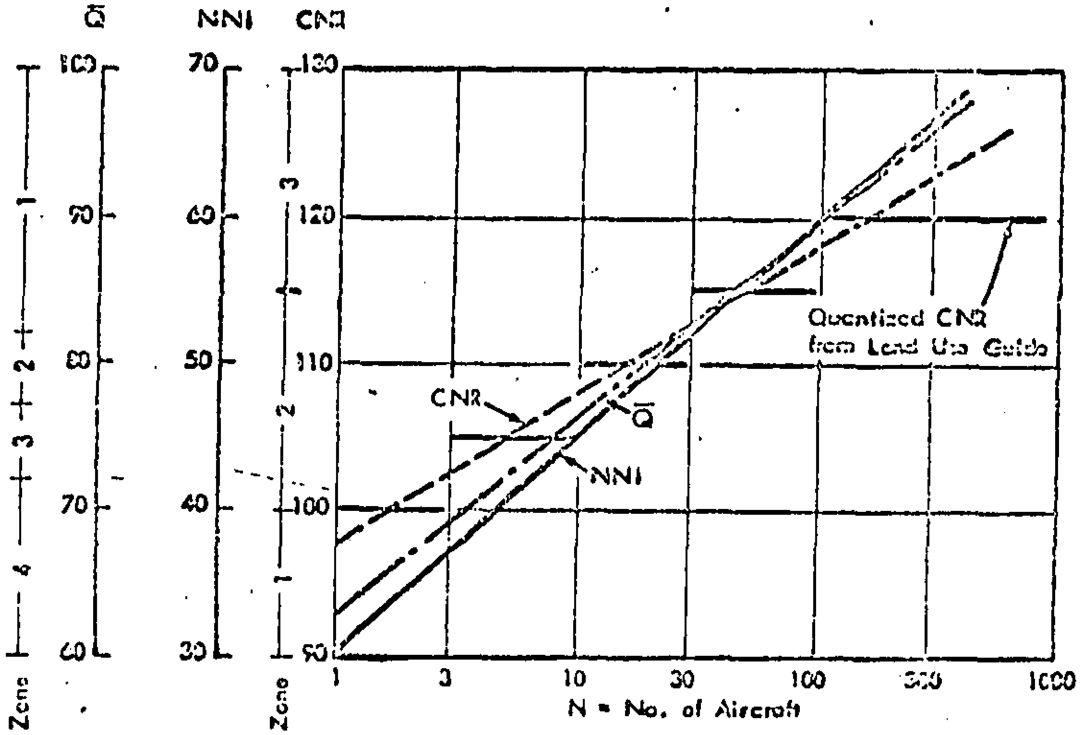


FIGURE 8. COMPARISON OF CNR, NNI, AND $\overline{Q}$ FOR N AIRCRAFT TAKEOFFS PRODUCING AN AVERAGE MAXIMUM NOISE LEVEL OF 110 PNdB DURING DAYTIME HOURS

instead of Perceived Noise Level (PNL). WECPNL is an ICAO metric. In this calculation it was assumed that 110 EPNL = 110 PNL. The results of the comparison are shown in Figure 9.

Another figure from the same report, Figure 10, compares the different scales, and adds material on the land use guidance associated with each. Comparing these with Figure 8 done in 1966, one finds that, not surprisingly, the relationships fluctuate. The approximate equivalences between CNR, NNI and Q for 1966 and the two 1970 charts are:

	1966		1970			
	Figure 8		Figure 9		Figure 10	
CNR	NNI	Q	NNI	Q	NNI	Q
90	30	60	30	55	20	50
95	35	65	35	60	25	53
100	40	70	40	65	32.5	60
105	45	75	45	70	40	67
110	50	80	50	75	48	74
115	55	85	55	80	55	80
120	60	90	60	85	62	87

The report states: "One should note that if one were to hold the number of operations constant, and instead vary the noise levels (and flyover signal durations) in accord with the way flyover signals characteristically change with distance from an aircraft, the correlations among indices would be somewhat different from those expressed above. ...... (For example) as distance from an aircraft is varied, the relationship between EPNL and PNL values change. (In this case, the EPNL, which explicitly includes a duration factor, decreases with distance at a lesser rate than PNL)".

When one remembers that a particular value calculated for any of these indices is dependent upon the number of operations, their individual distances from the ground point, and the aircraft mix, it is apparent that any given value may be calculated from any of a very large number of combinations of initial conditions. Taking into account the facts that: a) different constants are used in calculating the effect of the number of operations; b) different noise measures are used which vary with respect to each other depending on frequency content and distance (duration); c) different weights are placed on day and night operations, it is apparent that the relationships among the various indices are, to say the least, not exact. It is, nevertheless, interesting to examine Figure 9, to compare the descriptions of land use restrictions for the various zones for each of the indices. The scales may shift up or down, stretch or shrink with respect to each other, but all of the noise bands where compatibility of residential use appears uncertain seem to be narrower than from 110 to 115 CNR.

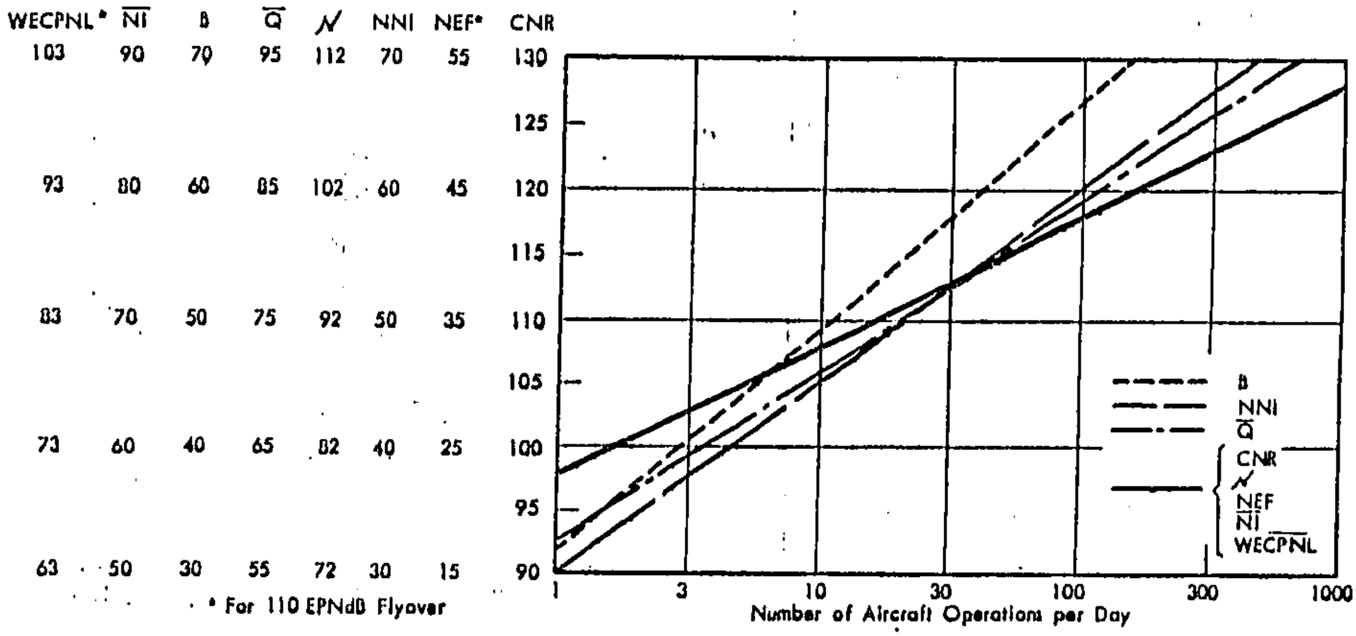


FIGURE 19. COMPARISON OF VARIOUS NOISE EXPOSURE INDICES FOR A FLYOVER NOISE LEVEL OF 110 PNdB, EFFECTIVE DURATION OF 10 SECONDS, AND VARIABLE NUMBER OF OPERATIONS

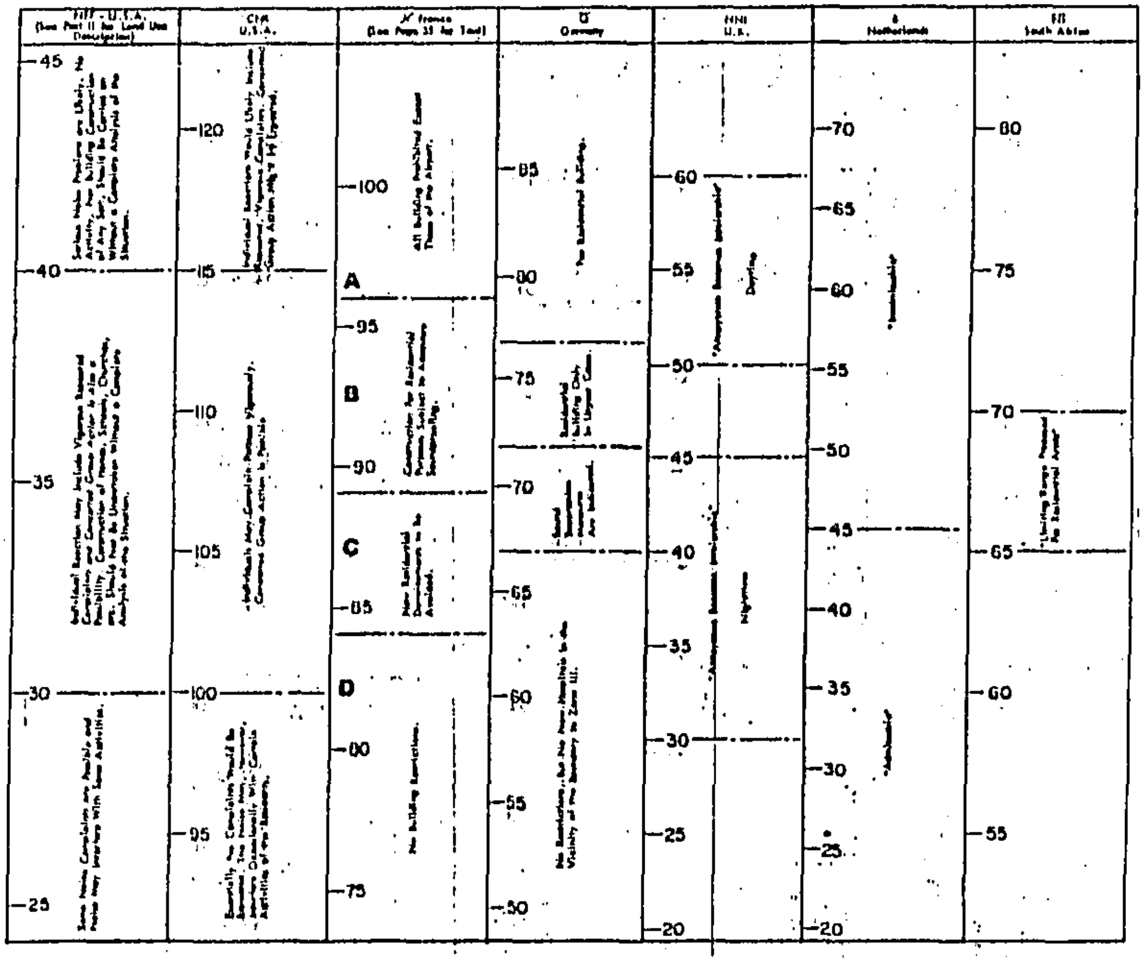


Figure 10. Approximate Equivalences Between Noise Exposure Indices and Response or Land Use Description

A.9 Noise Exposure Forecast, 1970

In August 1970, a new report[37] provided an excellent history of developments from 1953 to 1970, and as already described, compared the noise indices used in the United Kingdom, France, Netherlands, Germany, and South Africa with the ICAO index, CNR and NEF.

The August 1970 report also included new estimates of residential (and other) land use compatibility with noise levels expressed in NEF. The assessments were based, according to the report, on:

1. Accumulated case history experiences of noise complaints near civil and military airports;
2. Speech interference criteria;
3. Subjective judgment tests of noise acceptablity and relative "noisiness";
4. Need for freedom from noise intrusions; and
5. Typical noise insulation provided by common types of building construction.

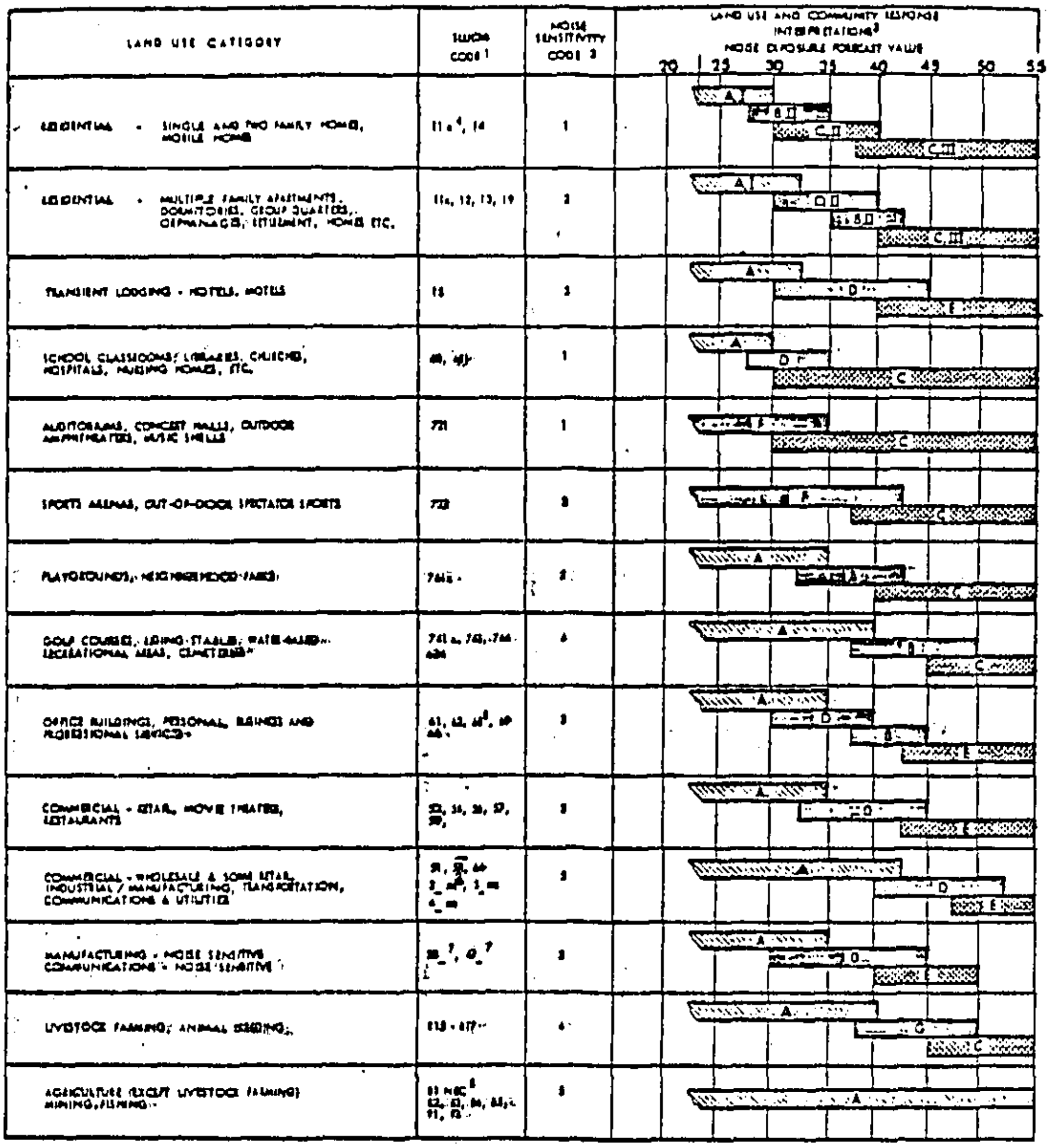
"In determining the effects of noise upon residential land use, case history experience, acceptability criteria and speech communication criteria are most important ... The land use interpretations given herein have evolved from the community response and land use interpretations of Composite Noise Rating (CNR) ... The interpretations are basically similar to those developed in the initial NEF studies ... However, the land use interpretations given herein reflect additional information about land use categories, aircraft noise impact upon speech communication, and building noise insulation."

The detail in the compatibility charts and tables is best illustrated by repeating them. See Figure 11 and Tables 1 and 2. The accompanying discussion emphasizes that local considerations may affect the choices, and that the incompatibility ranges overlap to provide for such considerations. Local considerations may include previous experience, local construction practice, and ground noise environment, for example.

A.10 Information Developed by the Department of Housing and Urban Development (HUD), 1970

A report[41] prepared by HUD for an ICAO meeting in November and December 1969 and published in May 1970 incorporates a table with the same title and land use classifications as in the table just discussed in the August 1970 report[37]. The noise codes are assigned to each activity, ranging from 1 to 5, with 1 the most sensitive, just as in the August report. Most of the noise codes are the same as the noise sensitivity codes in the August report.

There is no discussion of the considerations that went into either table In the HUD report, the table is described as "a tentative classification of land uses by noise sensitivity (which) has been developed to assist planning



NOTES
1. STANDARD LAND USE CODING MANUAL
2. RELATIVE RANKING OF LAND USES WITH RESPECT TO NOISE SENSITIVITY, SEE TEXT FOR APPROXIMATE RELATIONSHIPS TO NEF VALUES
3. INTERPRETATIONS ARE LISTED IN TABLE I
4. "a" REPRESENTS A SLUCM CATEGORY BROADER OR NARROWER THAN, BUT GENERALLY INCLUSIVE OF, THE CATEGORY DESCRIBED
5. EXCLUDING HOSPITALS
6. "m" SOME EXCEPTIONS MAY OCCUR FOR PARTICULAR OR SPECIALIZED NOISE SENSITIVE ACTIVITIES
7. DEPENDENT UPON SPECIFIC TASK REQUIREMENTS
8. NOT ELSEWHERE CLASSIFIED

Figure 11. Land Use Compatability Chart for Aircraft Noise

TABLE 1

NOISE COMPATIBILITY INTERPRETATIONS FOR USE WITH FIGURE 11

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 activities 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 system should be included in the basic design.

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

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

TABLE 1 (Con't)

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.

** 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.

TABLE 2

LAND USE - AIRCRAFT NOISE COMPATIBILITY CLASSIFICATION

SLUCM Code[2]	Category	Noise Sensitivity Code[1]
1	RESIDENTIAL	
11x[3]	Single family	1
11x	2-4 family	1
11x	Multi-family apartments	2
12	Group quarters	2
13	Residential hotels	2
14	Mobile home parks or courts	1
15	Transient lodging	3
19	Other residential, NEC[4]	2
2	INDUSTRIAL/MANUFACTURING	
21	Food and kindred products	4
22	Textile mill products	5
23	Apparel	4
24	Lumber and wood products	5
25	Furniture and fixtures	4
26	Paper and allied products	5
27	Printing, publishing	5
28	Chemicals and allied products	5
29	Petroleum refining and related industries	5
3	INDUSTRIAL/MANUFACTURING	
31	Rubber and misc. plastic goods	5
32	Stone, clay and glass	5
33	Primary metals	5
34	Fabricated metals	5
35	Professional, scientific and controlling instruments	3
39	Miscellaneous manufacturing NEC[4]	4
4	TRANSPORTATION, COMMUNICATIONS & UTILITIES	
41	Railroad, rapid rail transit	5
42	Motor vehicle transport	5
43	Aircraft transport	5

TABLE 2 (Con't)

SLUCM Code[2]	Category	Noise Sensitivity Code[1]
	TRANSPORTATION, COMMUNICATIONS & UTILITIES	
44	Marine craft transport	5
45	Highway and street ROW	5
46	Auto. parking	5
47	Communication	3
48	Utilities	5
49	Other trans. communications & utilities NEC[4]	5
o[5]	COMMERCIAL/RETAIL TRADE	
51	Wholesale trade	5
52	Building materials retail	5
53	General merchandise retail	3
54	Food retail	3
55	Automotive retail	4
56	Apparel and accessories retail	3
57	Eating and drinking places	3
59	Other retail NEC[4]	3
o	PERSONAL AND BUSINESS SERVICE	
61	Finance, insurance and real estate	3
62	Personal services	3
63	Business service	3
64	Auto repair service	5
65	Professional services[6]	3
66	Contract construction services	5
o	Indoor recreation services.	3
69	Other services NEC[4]	3
	PUBLIC AND QUASI-PUBLIC SERVICES	
67	Government services	2*
68	Education services	1
711	Cultural activities	1
651	Medical and other health services	1
624	Cemeteries	4
69x	Nonprofit organization, incl. churches	2
o	Other puplic and quasi - public services NEC[4]	2

TABLE 2 (Con't)

SLUCM Code[2]	Category	Noise Sensitivity Code[2]
o	OUTDOOR RECREATION	
761x	Playgrounds and neighborhood parks	3
762x	Community and regional parks	3
712	Nature exhibits	3
722	Sports assembly	3
741x	Golf courses, riding stables	4
743,744	Water based recreation areas	4
75	Resorts and group camps	3
721	Entertainment assembly	2**
o	Other outdoor recreation NEC[4]	3
o	AGRICULTURE, MINING AND OPEN LAND	
81,NEC	Farms, except livestock	5
815,817	Livestock farms	4
82	Agriculture related activities	5
83	Forestry activities	5
84	Fishery activities	5
85	Mining activities	5
91	Undeveloped land	5
93	Water areas	5

FOOTNOTES:

1/ Noise Code 1 contains the most noise sensitive land uses; Noise Code 5 the least sensitive.

2/ Standard Land Use Classification Manual.

3/ "x" after SLUCM numbers means it represents a category broader or narrower than, but generally inclusive of, the category described.

4/ NEC - Not elsewhere classified.

5/ "o" denotes no closely comparable grouping or category in SLUCM code.

6/ Ordinarily medical services would be subsumed under this heading, but noise sensitivity considerations led to a separate listing.

TABLE 2 (Con't)

* A noise sensitivity code rating of 2 is appropriate for many government services. However, this land use encompasses activities having varying noise sensitivities, hence noise ratings for some specific services may range from 1 to 4.

** The noise sensitivity code rating is 1 for outdoor theaters and outdoor music amphitheaters or pavilions.

agencies ...... Although specific ranges of acceptable noise levels have not yet been assigned to the sensitivity ratings, the tables may prove useful as a guide and as an initial effort".

A.11 Environmental Noise and Its Evaluation, 1970

In 1970, Kryter's book, "The Effects of Noise on Man"[38], appeared. In Chapter 9, Kryter reviews much of the work that has been covered thus far, and presents some additional data.

In the discussion of noise from subsonic aircraft, Kryter states: "A rather consistent and relatable pattern of findings emerges from the laboratory, field and community studies of human response to aircraft noise". Kryter reports that laboratory studies have been primarily paired comparison studies. He describes these as "tests of the subjective relative noisiness or unacceptability of noise from aircraft". The data cited, however, all relate to judgments of relative noisiness as compared to the values of various "objective" units (i.e. units measured or calculated from recorded sounds). No judgments of "unacceptablity" are mentioned.

The summaries of several field studies of "acceptability, intrusiveness and noisiness" are shown in Figure 12. The noise levels are peak or maximum perceived noise level, PNL, measured outside. Results are shown for four field studies. The results from the latter two are not reported on a scale. However, at Edwards AFB, the point at which 50% of the people rated jet noise as less than "just acceptable" was reported. Outside, 50% rated jet noise at 110 PNdB as less than "just acceptable". Inside the level with the same judgement was 115 PNdB outside. At Wallops, jet noise rated midway between "very acceptable" and "very unacceptable" was reported. Outside, noise at 102 PNdB was rated between "very acceptable" and "very unacceptable". Inside, noise with an outside level of about 104 PNdB received this rating.

In the other cases, previously discussed, a scale of outside values was used. In Los Angeles, 82 PNdB was "of no concern", 90 PNdB was "acceptable", 99 PNdB was "barely acceptable", and 108 PNdB was "unacceptable". At Farnborough, intrusiveness and noisiness judgments were made. On the intrusiveness scale, 92 PNdB was "noticeable", 108 PNdB were "intrusive", 118 PNdB was "annoying" and 128 PNdB was "very annoying". On the noisiness scale, 81 PNdB was "quiet", 99 PNdB was "moderate", 114 PNdB was "noisy" and 128 PNdB was "very noisy". These values are the "average" values, that is the values of a curve fitted to the observations, which are, in turn, the average judgments of a number of observers to a particular event. There is scatter both in the judgments of the observers, and in the average judgments around the fitted curve. It was observed in all cases that the difference between indoor and outdoor judgments was considerably less than the 20 PNdB one would expect from normal attenuation.

If one accepts the proposition that all communities will respond in the same way to the same noise levels, the data seem to indicate the following equivalencies:

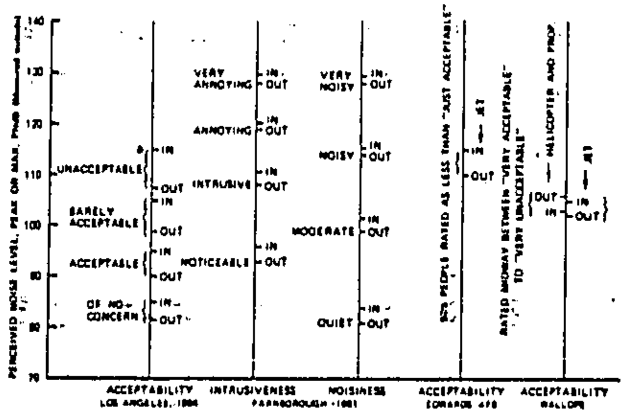


Figure-12.- Comparison Between Perceived Noise Level of Aircraft Flyovers and Category Scales of Acceptability, Intrusiveness, and Noisiness

Quiet	=	Of No Concern
Acceptable	=	Noticeable
Barely Acceptable	=	Moderate
Unacceptable (Outside)	=	Intrusive
Unacceptable (Inside)	=	Noisy
Very Annoying	=	Very Noisy

This differs considerably from relationships implied by Bishop[14] in the December 1965 BBN report, reported on earlier.

Kryter discusses the idea that annoyance from aircraft sounds should be evaluated in terms of speech masking effectiveness. He states that it has not been adopted or implemented because (1) some complaints do not appear to be concerned with masking, (2) some noises (for example, high frequency, narrow band or impulsive noises) are perceived as annoying, although they do not effectively mask speech, and (3) no simple way of calculating, or inferring, masking characteristics of sound from aircraft has been proposed. He concludes, on the basis of various experiments, that levels of 85 peak PNdB are barely acceptable.

In a discussion of community reaction to aircraft noise, Kryter first draws from a Beranek, Kryter and Miller report which examined data collected at a center in New York City established for receiving complaints about aircraft noise. The greatest single complaint was concerned with interference with talking and listening, the second (in number but not intensity of feeling) was concerned with the disturbance of sleep and rest, and the third was with fear of crashes. Further, examination of the data showed how complaint activity varied with other factors than aircraft activity. Complaints were lowest from October through April, and peaked in July. This was presumably related to open and closed windows. The ratio of complaints between open and closed windows was calculated to be the equivalent of 8 PNdB. A comparison between aircraft activity and complaint activity showed that the ratio between complaints and activity was highest between 10 p.m. and 12 a.m. at night. The difference between this ratio and the daytime ratio was calculated to be 10 dB. On the other hand, the complaint activity ratio was lowest from 2 a.m. until 7 a.m. Percentages of the day's aircraft and complaint activity, per hour, and the ratios were approximately as follows:

Period	Hour	Aircraft	Complaints	Ratio
1	12-2 a.m.	3%	6.5%	2.17
2	2-7 a.m.	0.5%	0.5%	1.00
3	7 a.m.- 6 p.m.	6.5%	2.5%	0.38
4	6 - 10 p.m.	2.5%	5%	2.00
5	10 p.m. - 12 a.m.	5%	17.5%	3.50

From these data one can make the following calculation. If we assume as a base the daytime ratio of complaints to aircraft activity, then the apparent noisiness as measured by complaints of operations at other times is:

Period	Ratio to Daytime	dB Higher than Daytime
1	5.71	3.7
2	2.63	1.8
4	5.26	3.4
5	9.21	8.3

These data provide some justification for the practice in California of weighting the evening hours higher than daytime, but do not support the practice of giving the same weight to the hours from 10 p.m. to 7 a.m.

Kryter follows with a discussion of surveys. The first is the 1961 London (Heathrow) Airport survey. Kryter summarizes these conclusions:

1. Aircraft noise is not significantly annoying below 80 PNdB.
2. Annoyance increases with number of operations.

Kryter prefers, and recommends that 10 log N to 15 log N be used in NNI.

From work done by Hazard in 1968, Kryter summarizes the following predictors of annoyance:

1. Aware of aircraft between midnight and 6 a.m.
2. Live in high aircraft exposure areas
3. Have high noise susceptibility
4. Perceive a steady increase in the amount of air traffic
5. Argue that they would be unable to adapt to increased noise exposure
6. Have knowledge of how to complain effectively

Kryter goes on to explain that the TRACOR work done in 1969 was the product of further analysis of the same data as Hazard. Given in order of importance, the predictor variables of annoyance identified by TRACOR are:

1. Fear of aircraft crashing in the neighborhood
2. Distance from the airport
3. Susceptibility to noise
4. Noise adaptability
5. Aircraft noise exposure (CNR)
6. City of residence
7. Belief in misfeasance by aircraft or airport operators
8. Extent to which airport is considered to be important to the local economy.

It is interesting that TRACOR identifies a number of predictors of annoyance as being more important than noise as measured by CNR.

In a discussion of CNR, Kryter identifies two basic ideas in CNR: 1) the basic response is a function of the sum, on an energy basis (10 log) of the perceived noise, and 2) there is a greater sensitivity during night than day which is equivalent to a 10 dB difference in noise level.

Regarding background noise, and its effect on tolerance of aviation noise, Kryter says "In the original forms of CNR, this factor was recognized by adding 'corrections' to the CNR value depending upon the level of background noise and peak factor of the intruding noise; in the present use of CNR no such corrections are used, but rather somewhat higher tolerable limits are allowed for areas having more background noise; for example, the tolerable limits for rural vs. city residential areas are set, for this reason, at somewhat different values of CNR".

"However, this concept of a generally favorable effect of background noise leads to the seemingly absurd conclusion that increasing the number of occurrences that are greater than 90% or so of the peak would result in increased satisfaction with the noise environment...It is sometimes implied... that it is not the absolute but the relative level of noise that bothers people.....A more likely interpretation ... is that the absolute level of annoyance is rather high to begin with in the high background noise level, and the aircraft noise cannot add much to the general level of annoyance."

The discussion of CNR concludes with two Figures (reproduced here as Figures 13 and 14) which "summarize the general relation between CNR, and related measures of noise, for a noise environment, and various human reactions to that sound environment". Note that the latter indicates equivalence between CNR and NEF as NEF = CNR - 76. On this basis, NEF 24 is equivalent to CNR 100. Later in Kryter's Chapter 9, a table is found (Table 3), which indicates that NEF = CNR - 66.

Kryter also argues, on the basis of CNR Zones I (CNR 100), II (CNR 100-115), and III (CNR 115) shown in Table 3, that noise analyses "would appear to greatly underestimate typical behavior of people exposed to noise". Continuing, "We would submit that the weight of the sociological, psychological and political evidence is that in typical residential communities an appreciable percentage (approximately 10%...) of the people will complain, or feel like complaining, vigorously when the CNR reaches 90 and that legal or 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".

A.12 Community Noise Exposure Level (CNEL), 1970

In 1970, California adopted noise regulations for California airports. These regulations specified that noise would be specified in terms of CNEL. CNEL is based upon the peak noise measured in dB(A), corrected for the duration of the sound, on an energy basis. The result, SENEL, is a number expressed in dB that gives the energy during the time the level is within 10

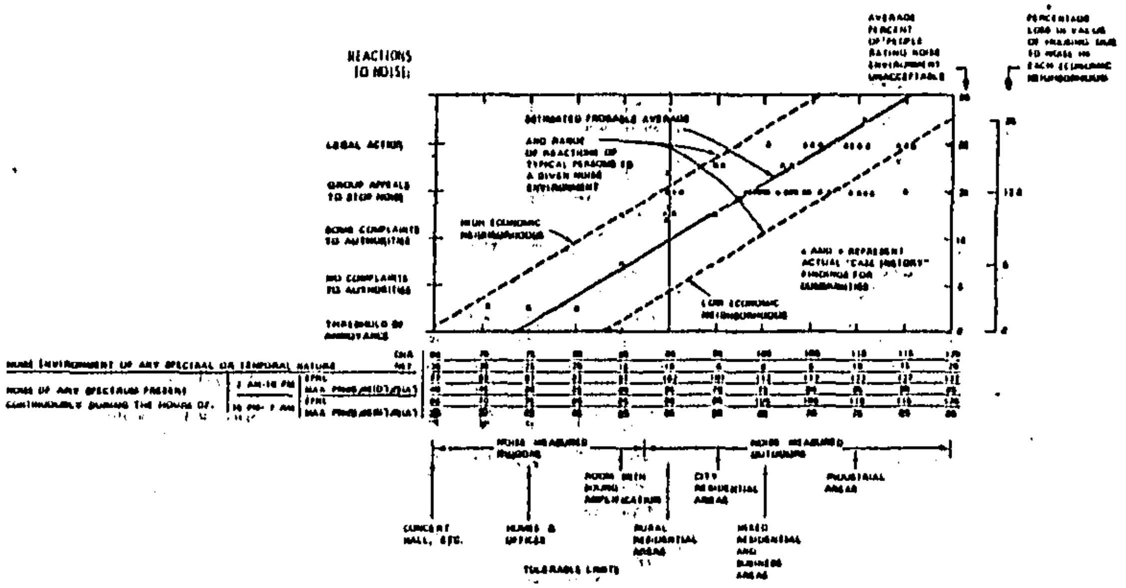


Figure 13. Relation Between a Habitual Composite Noise Rating and Community Reactions to Noise, Attitudes of Individuals of the Unacceptability of the Noise, and Percentage Loss in Value of Housing

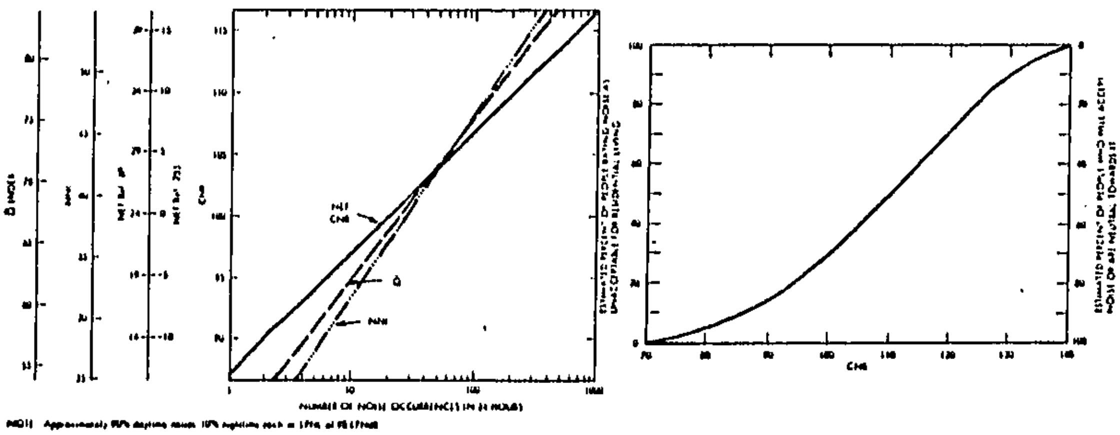


Figure 14, Left Graph: Typical Relations Between Various Composite Noise Rating Schemes.

Right Graph: Estimates of Attitudes to be Expected from Nonfear Provoking Noise in Residential Living Areas.

TABLE 3

LAND USE COMPATABILITY CHART FOR AIRCRAFT NOISE

NOISE SENSITIVITY ZONE	CNR	NEF^{75B}	NEF^{69}	LAND USE COMPATIBILITY: Residential	Commercial	Hotel, Motel	Offices, Public Buildings	Schools, Hospitals Churches	Theaters, Auditoriums	Outdoor Amphi-Theaters, Theaters	Outdoor Recreational (Non-spectator)	Industrial
I	Less Than 90	Less Than -10	(Approx.) Less Than 24	yes	yes	yes	yes	yes	Note (A)	Note (A)	yes	yes
II	90-100	-10-0	24-34	yes	yes	yes	yes	Note (C)	Note (C)	no	yes	yes
III	100-115	0-15	34-49	Note (B)	yes	Note (C)	Note (C)	no	no	no	yes	yes
IV	Greater Than 115	Greater Than 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.

dB of its peak, if that energy occurred in one second. The correction for the number of events is 10 log N, where operations between 0700 and 1900 hours have a weight of 1, between 1900 and 2200 hours a weight of 3, and, between 2200 and 0700 hours, a weight of 10.

A.13 Community Noise Surveys, 1971

With the establishment of the U.S. Environmental Protection Agency (EPA) in 1970, reports on noise from that organization started being published. In December 1971, "Community Noise"[47], prepared by Wyle Laboratories, addressed the subject of outdoor noise. Measurements of background noise in dB(A) were made at eighteen different locations ranging from the North Rim of the Grand Canyon to the downtown area of a large city.

Sample records collected illustrate these observations:

1. Level variations were large, on the order of 33 dB over fairly short periods of time.
2. There was a fairly steady lower value, called the residual noise level.
3. Distinct sounds above the residual level, such as aircraft, automobiles, etc. are intrusive sounds and these sounds vary significantly in both duration and number.
4. The residual noise level may vary during the day. In one case, it was 40 dB(A) at midnight, about 30 dB(A) between 4 a.m. and 6 a.m., and rose to about 42 dB(A) at 10 a.m.

To simplify their discussion, statistical descriptors were used, i.e. the level exceeded a stated percent of the time. L_1 means the level exceeded 1% of the time. The level exceeded 90% of the time (L_{90}) was selected as the approximate residual noise level. Figure 15 shows the results from one 24 hour record. The maximum noise levels are often greater than L_1, showing that they appeared for less than 1% of the time. The hourly value of Leq is also shown. Leq is the energy averaged noise level over a specified period of time.

The residual level, in general, was between L_{99} and L_{90}. L_{90} was used to estimate the residual level. It varied from close to 80 dB(A) outside a third floor apartment next to a freeway in the daytime to about 15 dB(A) on the North Rim of the Grand Canyon in the daytime. In urban areas, the daytime residual levels in detached housing areas were found to be:

Quiet suburban residential	36 - 40 dB(A)
Normal suburban residential	41 - 45 dB(A)
Urban Residential	45 - 51 dB(A)
Noisy Urban Residential	51 - 55 dB(A)
Very Noisy Urban Residential	56 - 60 dB(A)

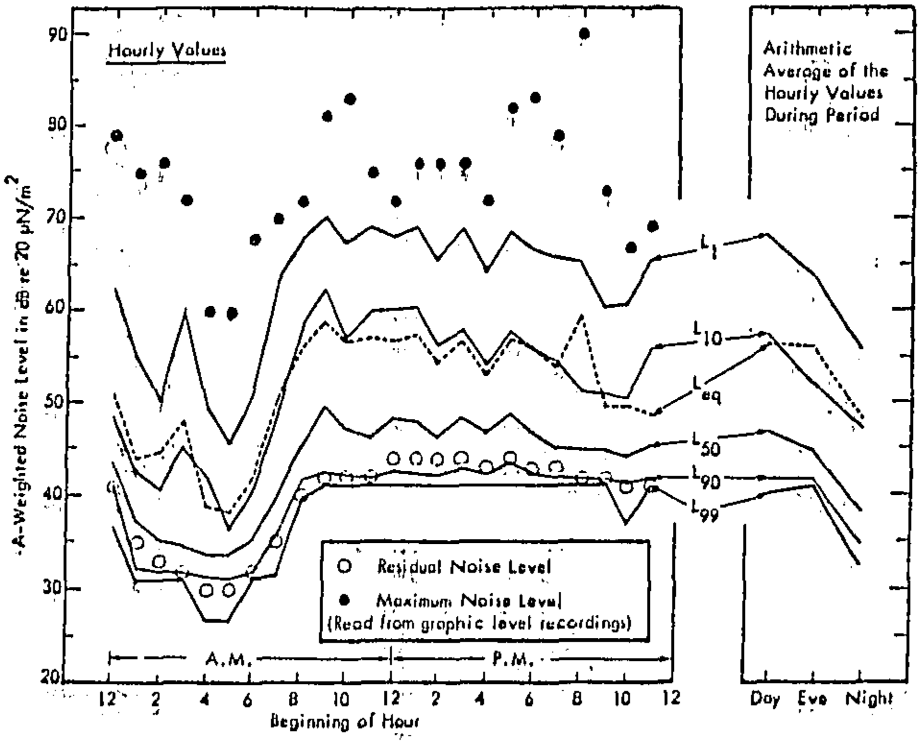


Figure 15. Community Noise at a Residence in a Normal Suburban Neighborhood

Wyle collected the data from 55 case histories, and calculated for each the "normalized" CNEL. "Normalization" refers to corrections along the lines proposed by Rosenblith and Stevens. The factors used are shown in Table 4. The breakdown of the 55 cases by noise source and type of reaction is shown in Table 5. Twelve of the 55 involved aircraft. The 55 cases include the 11 cases cited by Rosenblith and Stevens in 1953[2]. Details of the translation from other metrics to dB(A) and SENEL are not given, although generalized expressions are included. The results are shown in Figure 16.

The data were used to test the normalizing factors and the duration and time period corrections of CNEL on the degree of correlation between the community reaction and normalized CNEL. The results show that the duration was the most important factor in reducing the standard deviation in the correlation between the community reaction and the normalized CNEL. With all of the corrections, the standard deviation was 3.3 dB(A). With all corrections except duration, the standard deviation was 8.1 dB(A). With only duration and time of day, the standard deviation was 7.5 dB(A), indicating that the "normalizing" corrections are indeed important. Of these corrections, the most important in reducing the standard deviation is the correction for residual noise level. With all corrections, except residual noise, the standard deviation is still 6.4 dB(A).

The Wyle investigation, therefore, makes a case for including consideration of the residual or background noise in estimating the effects of noise. However, it should be remembered that a minority of the cases are aviation related, and that the effects of including consideration of residual noise in the aviation cases only is unknown. Further, the effects on the standard deviation of problems of translation from other metrics into CNEL are not identified.

Using the previously published data from the London (Heathrow) Airport survey as interpreted by Galloway, Wyle relates the normalized CNEL to "very much annoyed" and concludes that a small but significant percentage of the population is still very much annoyed at 55 CNEL, where no community reaction is expected. "Thus, the true impact of the polluting effects of intrusive noises as measured by annoyance goes deeper than indicated by the 'no reaction' point."

In discussing personal factors affecting aircraft annoyance, the report on the London (Heathrow) Airport study suggests that about 32% of the people are not "seriously annoyed" no matter what the noise level is[10]. "These individuals form a hard core of imperturbables who are present in about the same proportions in all noise strata." However, "even in the quietest locations there are about 10 percent of people who are seriously disturbed by aircraft". In general, the more things people disliked about their area, the higher their scores on the aircraft annoyance scale. In view of these findings, it is perhaps not surprising that people who are very much annoyed are found at 55 CNEL.

TABLE 4

CORRECTIONS TO BE ADDED TO THE MEASURED COMMUNITY NOISE EQUIVALENT LEVEL (CNEL) TO OBTAIN NORMALIZED CNEL

Type of Correction	Description	Amount of Correction to be Added to Measured CNEL in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	-5
Correction for Outdoor Residual Noise Level	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediatley adjacent to heavily traveled roads and industrial ares)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	-5
	Very noisy urban residential community	-10
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good.	-5
	Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	-10
Pure Tone or Impulse	No pure tone or impulsive character	0
	Pure tone or impulsive character present	5

TABLE 5

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories: Vigorous or Threats of Legal Action	Wide Spread Complaints	No Reaction or Sporadic Complaints	Total Cases
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2			2
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

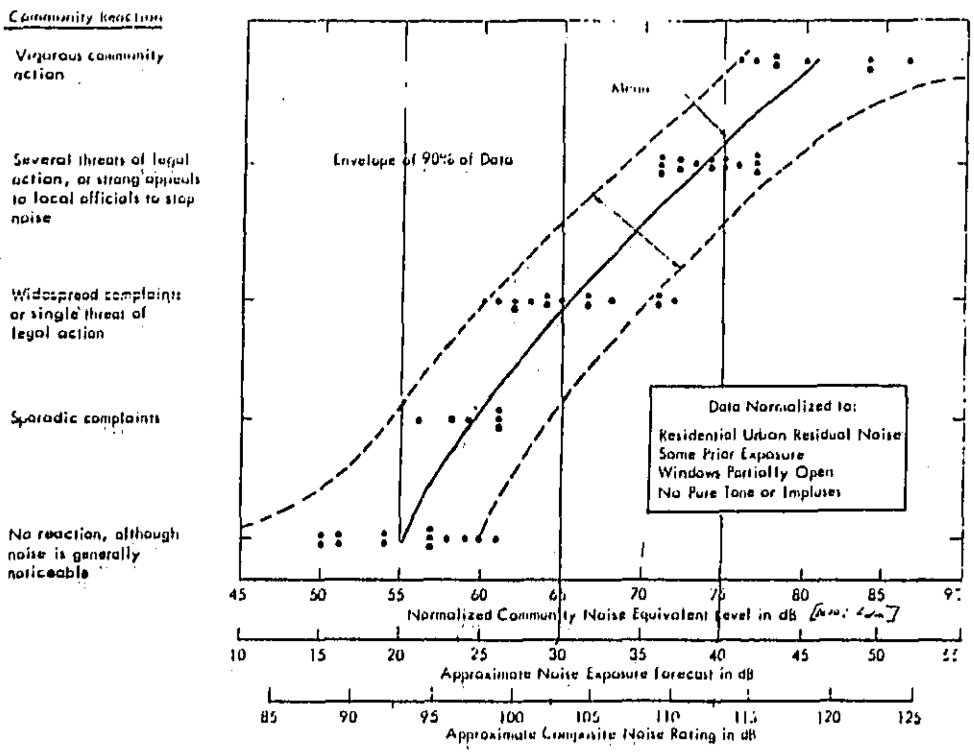


Figure 10. Community Reaction to Intrusive Noises of Many Types as a Function of the Normalized Community Noise Level

Wyle concludes that the "normalized" CNEL, including corrections for residual noise, "appears to give reasonable predictions of community complaints to noise intrusion......". A summary is given in Table 6.

A.14 Department of Housing and Urban Development's Noise Assessment Guidelines, 1971

In August 1971, HUD published their Noise Assessment Guidelines[46]. The Guidelines give a procedure for providing approximate NEF contours when none are available. In the procedure nighttime operations are multiplied by 17 and added to the daytime operations to determine the effective number of operations. The length of the contour beyond the end of the runway, and the width beside the runway are then determined from a table.

With contours furnished by the FAA, or developed as above, sites were classified as follows:

Beyond NEF 30 more than the distance between NEF 30 and NEF 40 - Clearly Acceptable - "the noise exposure is such that both the indoor and outdoor environments are pleasant".

Beyond NEF 30 to a distance equal to the distance between NEF 30 and NEF 40 - Normally Acceptable - "the noise exposure is great enough to be of some concern but common building constructions will make the indoor environment acceptable, even for sleeping quarters, and the outdoor environment will be reasonably pleasant for recreation and play".

Between NEF 30 and NEF 40 - Normally Unacceptable - "the noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment tolerable.

Within NEF 40 - Clearly Unacceptable - "the noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable".

A.15 Environmental Protection Agency Task Group III Report, 1973

In the spring of 1973, in its effort to comply with the Noise Control Act of 1972, the Environmental Protection Agency convened a series of task groups to consider questions mandated by the Congress. One of the Congressional mandates was to "conduct a study of ..... implications of identifying and achieving levels of cumulative noise exposure around airports". The stated function of Task Group III was to "consider the characterization of the impact of airport community noise and to develop a community noise exposure measure". Task Group III was asked to: determine

TABLE 6

SUMMARY OF EXPECTED COMMUNITY REACTION AND APPROXIMATE ANNOYANCE AS A FUNCTION OF NORMALIZED COMMUNITY NOISE EQUIVALENT LEVEL

Expected Community Reaction	Approximate Difference Between Normalized CNEL and Average Daytime Residual Noise Level (L_{90}) in dB		Approximate Percent Very Much Annoyed	Approximate Percent Little or Not Annoyed
	Mean	Range of Data		
No reaction	7	2 to 13	20	45
Sporadic complaints	11	8 to 13	26	37
Widespread complaints	17	12 to 24	37	26
Threats of legal action	26	23 to 29	60	14
Vigorous action	33	28 to 39	87	7

the merits and shortcomings of methods to characterize the impact of noise of present or proposed airport/aircraft operations on the public health and welfare; determine which of such methods is most suitable for adoption by the Federal Government; and determine the implications of issuing Federal regulations establishing a standard method for characterizing the noise, and of specifying maximum permissible levels for public health and welfare.

The report[51] recommended:

1. Adoption of the day night average sound level (Ldn) as the measure for environmental noise.
2. This measure should be used for aircraft noise studies and aircraft noise standards.
3. The prediction procedures should be standardized.
4. Predictions for land use planning purposes of noise from aircraft operations should not consider noise from other sources.
5. An outdoor yearly limit of 80 Ldn should be adopted as the maximum permissible limit to project against hearing loss and completely unacceptable amounts of annoyance and speech interference.
6. The long-range goal for environmental noise quality in residential areas should be 60 Ldn.
7. The time schedule for achieving the long range goal should be based on economic and technological feasibility studies.

As pointed out in a letter of comment on the draft from the Department of Commerce, "Although Congress directed that a study of the implications of a cumulative noise exposure be undertaken, Task Group III has, in fact, designed a cumulative noise exposure method and recommended specific acceptable levels".

A.15.1 Day Night Average Sound Level (Ldn), 1973

As developed in the report, Ldn has the following characteristics:

1. The measure of sound level to be used is the A frequency weighted sound pressure level.
2. The average sound level will be the constant sound level which would convey the same sound energy as does the actual time-varying sound.
3. A nighttime penalty of 10 dB(A) will be used for the period 2200 to 0700 hours.
4. No seasonal corrections are incorporated.
5. No indoor-outdoor factors are included.
6. No psychological/sociological factors are included.
7. The noise from one event, the sound exposure level, is the level of the time integral of A-weighted squared sound pressure for a specified time interval or event, with reference to a duration of one second.

Psychological/sociological factors had been included in previous measure, such as CNR. They were not included in Ldn for two reasons:

1. To permit verification of predicted values with measured values and
2. Because the basic purpose is not to project response/complaint behavior, but to establish average noise level goals.

The report estimates that the accuracy of predicted average sound levels is within 5 dB(A); the accuracy of measured levels is within 1 dB(A). The report also provides these estimates of relationships:

Ldn = CNEL
Ldn = NEF + 35 (+/-3)
Ldn = CNR - 35 (+/-3)

(These relationships would give NEF = CNR - 70 +/-, or NEF 30 = CNR 100 +/- and NEF 40 = CNR 110 +/-)

The report provides these estimates of the sound level reduction in houses:

	Windows Open dB(A)	Windows Closed dB(A)
Warm Climate	12	24
Cold Climate	17	27
Approximate National Average	15	25

In discussing the basis for the maximum permissible average noise levels, the report starts with the statement that "the final choice of maximum permissible levels is not a technical/scientific one ... Such a decision involves value judgments in the political, social, ethical, and economic domain ... and must be resolved in the administrative or ultimately in the political-legal-legislative domain".

The approach is to examine the relationship: between cumulative exposure and noise induced hearing losses; between average sound levels and percent of individuals annoyed; and between average sound levels and percentage of the time speech communication will be interrupted. The latter two are not identified with direct disease producing effects, but are asserted to be within the domain of public health and welfare according to the intent of the Noise Control Act. From the results of these analyses, two maximum permissible average sound levels are recommended. "Setting limits for average environmental noise, as proposed in this report, would not eliminate the need to protect people from occasional individual very noisy events and to restrict, by source emission standards, the contributions of individual noise sources to the public noise environment. .... Once maximum permissible average sound levels are accepted, the Federal or local authorities must still decide how the total permissible noise dose should be allocated between the major individual noise contributions; i.e., for example, what percentage of the total dose should be used for aircraft noise and what percentage for traffic noise."

A.15.2 Hearing Loss

The threshold of hearing damage is defined in this report as the environmental noise level expected to cause a permanent threshold shift of 5 dB(A) at 4000 Hz in the most sensitive 10 percent of the population. The report states that: a) individual changes in hearing less than 5 dB(A) are not generally considered noticeable or significant; b) a person is considered to suffer a hearing handicap when his average puretone threshold at frequencies of 500, 1000 and 2000 Hz exceeds by 25 dB(A) or more the international standard zero; and c) the greatest change in hearing threshold generally occurs at 4000 Hz. This shift would be expected after 40 years of exposure, eight hours a day, to broadband noise at a level of approximately 75 dB(A). Because intermittent noise, like aircraft flyover, provides an opportunity for the ear to recover between noisy events, the threshold is increased to an average level of 80 dB(A).

To recapitulate, after 40 years, 8 hours a day, of being subject to intermittent noise at an average level of 80 dB(A), the most sensitive 10 percent of the population may have a change in the hearing threshold at 4000 Hz of 5 dB(A). The loss at 500, 1000 and 2000 Hz will be less, and not significant, averaging 1 dB(A). Ninety percent of the population would have a smaller loss, or as the report says, "no measureable loss".

The above is a direct effect. Because it is concerned with a daily 8 hour period, the remaining 16 hours must be at some lower noise level. The report says that, in order to allow time for recovery, this level should not exceed 65 dB(A). If the outside level is 80 dB(A), then, on the average the inside level with windows open would be 65 dB(A). Therefore, an individual among the most sensitive 10% who spends 8 hours a day outside, subject to an intermittent noise with an average level of 80 dB(A), and then spends the other 16 hours inside might, after 40 years, be expected to have a measureable loss of hearing at 4000 Hz only.

The hearing loss estimates are based on average noise. Ldn would be higher (86) because of the nighttime weighting, if the level were a constant 80 dB(A) day and night. The actual value of Ldn would depend on the actual difference between day and night levels. There is some evidence that the difference between day and night levels tends to be larger as the daytime levels become lower. The scatter is wide, but at Ldn values above 65, the maximum difference between day and night shown is 8 dB(A). Below 65, there is a maximum difference of 19 dB(A) at an Ldn value of 55. Whether these are locations where aircraft noise is a major component is not known. To be conservative, the author(s) selected an Ldn of 80 as the recommended maximum permissible level to protect the public health and welfare with respect to hearing loss. This is the equivalent of an average level of 74 Leq for each 8 hour period which based on the data, would certainly provide adequate protection.

To illustrate, assuming for simplicity that the night is 8 hours long, the following combinations of day and night levels would give an Ldn of 80:

Day Leq	Night Leq
80	70
79	71
78	72
77	73
76	73
75	74
74	74

In other words, if the Ldn is 80, and the difference between day and night is 8, then the daytime level is 79 Leq. If the difference is 4 (the "expected level" in the report), the daytime level is 73 Leq.

A.15.3 Speech Communication

The acceptable threshold for speech communication in a noise environment is defined in this report as the level of background noise where it is not necessary to increase the the voice level above a normal, comfortable effort in order to communicate effectively.

Speech intelligibility of 95% permits reliable communication because of the redundancy in normal conversation. The following table from the report shows the distances in meters outdoors for 95% intelligibility at normal voice levels with various A-weighted noise levels:

Noise level	72	66	60	56	54	52	dB(A)
Distance	0.5	1	2	3	4	5	meters

Indoors, the distances are different because of sound reflections from the walls and other surfaces. A criterion of long-standing for living rooms and similar spaces is 38 to 47 dB of A-weighted background noise. A level of 45 dB(A) "will allow relaxed, face-to-face converstaion with essentially 100% sentence intelligibility for all locations of talker and listener in a typical room". With an open window, this is the level with 60 dB(A) outdoors in the average case. If the windows are closed, the background noise would be lower.

The above disucussion is based on the assumption that the background noise is more or less constant. If, as is the case with aviation noise, there is considerable fluctuation, then for the same average noise, the background will be lower. Consequently, the overall intelligibility will depend upon the fraction of the time that the noise exceeds the background, and the amount by which the background is exceeded. Clearly, depending on the situation, a higher average noise level may be allowable for a given level of intelligibility if the noise is fluctuating. In a particular case near a major airport, calculations reported in the EPA document demonstrate that an average aircraft noise level of 65 dB(A) provided the same 95% sentence intelleigibility as 60 dB(A) of more or less steady noise.

Inside, when speech interference is evaluated as a percentage of time, the fluctuations must become extreme before there is significant speech interference at Leq 45. When the intruding noise exceeds 70 dB(A) inside, which means that with the windows open the outside level must exceed 85 dB(A), speech is interrupted. Interruption, even though brief, may be very annoying, so the annoyance factor may be more important that the percent of speech interference. The effect of a aircraft noise outside with an average level of 65 dB(A) should cause no problem inside unless the peaks are very large. Figure 17 shows the relationship between Ldn and the maximum percentage sentence interference, using steady state continuous noise as the sound source.

The conclusion of the report is that the use of average sound level is conservative when applied to non-steady noises, unless the maximum values are sufficiently high as to interrupt communication entirely, in which case the effect should be measured in terms of annoyance. A goal of Ldn 60 is recommended from the standpoint of speech communication, although the report concludes that the Ldn should not exceed 63 dB(A) "if people are to enjoy their normal domestic activities indoors or to converse without difficulty outdoors at a two meter distance".

A.15.4 Annoyance

The annoyance criterion is developed in terms of the results of surveys, which have already been discussed in this report. In each case, the noise levels were converted to Ldn, and the categorical scales were converted to determine those "highly annoyed". Data from three studies were used: the first and second London (Heathrow) Airport surveys, and the NORC studies as analyzed by Tracor and Borsky. In the latter case, data for those interviewees who were "moderate" with regard to "fear" and "misfeasance" were used.

The data are presented in two graphs of percent highly annoyed vs. noise level in Ldn, for the first Heathrow study and from the second Heathrow and U.S. studies combined. The differences are small - from about 3% at Ldn 55 to 1% at Ldn 80. The difficulties in comparing data from multiple sources has already been discussed.

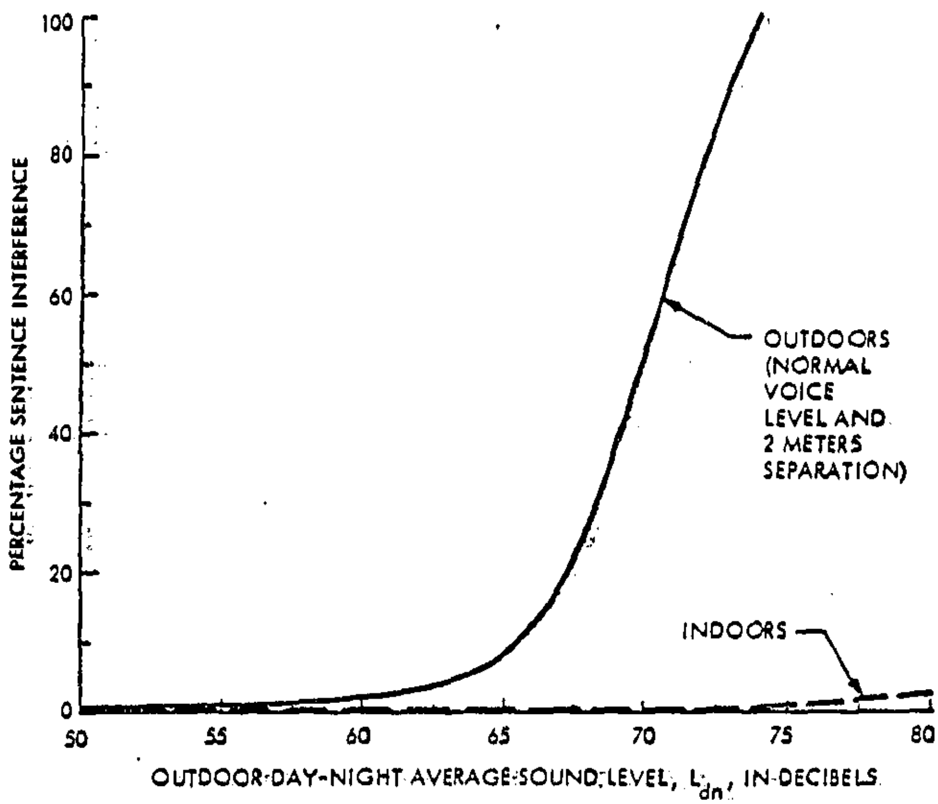


Figure 17: Maximum Percentage Interference with Sentences as a Function of the Day-Night Average Noise Level. (Percentage Interference Equals 100 Minus Percentage Intelligibility, and L_{dn} is Based on $L_d + 3$)

Data from the 55 case histories discussed in the Wyle report by Eldred[47] are also presented to provide a scale of community reaction as a function of Ldn. A discussion of this report appeared earlier in this historical account. In the Wyle work, the results are presented in terms of a "normalized" CNEL. If the normalizing factors are removed and we assume that Ldn is close to CNEL (the only difference is the weighting factor for evening operations), then the estimates of Ldn are as good as the translations of the original data into CNEL. The original reaction classifications are compared here with the classifications reported in the EPA Task Group III report[51], with the CNEL values before "normalization".

EPA Reaction Classes	No. of Cases	Ldn Average	Original Reaction Classes	No. of Cases	Ldn Average	Ldn Range
Vigorous	8	72	Vigorous	8	72	63-84
Complaints and Threats of Legal Action	34	62	Threats of Legal Action	14	64	54-76
			Widespread Complaints	14	59	50-67
			Sporadic Complaints	6	60	51-71
None	13	55	None Observed	13	55	40-69

Note that the ranges for reactions from "Sporadic Complaints" to "Threats of Legal Action" are almost the same, and that the average and the high and low range limits of the values are all higher for "Sporadic Complaints" than for "Widespread Complaints".

On page A-16 of this report, the results of a comparison developed in the analysis of the NORC data between the percentage of people who "Actually Complained", and those who "Felt Like Complaining" are shown. In the EPA report is a chart presenting data from apparently the same source showing "Percentage Highly Annoyed" and "Percentage Complainants" against outdoor Ldn. Combining these two charts, assuming that "Actually Complained" are the same as "Percentage Complainants", gives the following.

Ldn	Complainants	Felt Like Complaining(%)	Highly Annoyed(%)
50	1		13
55	1	15	17
60	2		23
	4	25	
65	5		33
	6	30	
70	10	40	44
75	15		54
80	120		62

Based on consideration of annoyance, the report reaches the conclusions that on the average adverse community reaction to noise becomes of serious concern at values of Ldn over 60, and that "higher noise levels must be considered to be annoying to an appreciable part of the population, and consequently to interfere directly with their health and welfare".

The report takes the position that, although it is highly unlikely that noises of lower level and duration than those sufficient to protect from hearing loss would induce any non-auditory disease, concerns exist and research to identify such effects should be pursued.

"It clearly makes little sense to establish criteria for external noise that would lead to indoor levels lower than the 'self-noise' of residential living." Of the values quoted in the report, the lowest is Leq 40-45 for "Typical people movement, no TV or radio". With speech, the level goes to 55 Leq, and with TV or stereo, from 55 to 70 Leq. It is concluded that there is no reason to reduce outdoor daytime levels below 60 Leq, which, on the average will result in an indoor level of 45 Leq, with the windows partly open. If the windows are closed, the outdoors level could be 10 dB higher.

A.16 The First International Conference on Noise as a Public Health Problem, 1973

In May 1973, an international conference on noise as a public health problem was held in Dubrovnik, Yugoslavia. Two sessions were devoted to community response. The fourteen papers presented on community response present an interesting diversity of viewpoints[54].

Three papers reported on work done in Sweden on annoyance from aircraft noise. In the first, Dr. Erland Jonsson et al. of Sweden reviewed the methodology of studies on community response to noise. Studies generally start with a dose-response assumption, that the subjective response to noise can be correlated with an objective measure of sound dosage. The traditional approach is to use a survey. Because differently phrased questions elicit different responses, individuals have been variously classified as disturbed by noise. Studies of what a respondent really means when he states that he is disturbed, or bothered, or irritated, or annoyed, have not been done, so it is not possible to know what exposure gives the respondent an experience of displeasure. The degree or intensity of disturbance which produces displeasure is not always specifically known. Inconsistent answers appear; a given respondent may spontaneously state that aircraft noise is a disturbing factor in the environment, but in answer to a direct question, deny any inconvenience caused by aircraft noise. The percentage of individuals indicating an injurious effect from exposure can vary with the choice of expression in the questionnaire. "Several traffic and aircraft noise investigations show, however, that not more than 10-20% of the total variance (variance among individuals irrespective of the exposure level) can be explained by the difference in dose level; the remaining variance must originate from individual differences."

In the second Swedish investigation, Rylander and Sorensen collected data on annoyance in such a fashion that the effects of a number of events could be separated from noise level. In other studies, high noise level tended to accompany a large number of events. It was found that the correlation of annoyance was better with a different approach from that in the "equal-energy" indices (using Leq). The new approach was to classify areas according to the overflight frequency. In areas where the exposures exceeded 50 per day, annoyance was determined by the peak noise level, in dB(A), of the noisiest aircraft. Correlation was very high. In areas with less than 35 exposures, annoyance was low (less than 10%), up to noise levels of 90 dB(A). Over 90 dB(A), data were scant but indicated an increase. In contrast, in the areas with more than 50 exposures, the percent very annoyed was approximately 20% at 80 dB(A) and over 30% at 90 dB(A).

The third Swedish paper by Sorensen et al. reported the results of investigations on the dose-response relationship, different expressions of annoyance, and individual characteristics. It was found that the reactions of people with 50-120 exposures a day were the same as those with 120-180 exposures a day. Once the number of exposures exceeds 50 per day, the annoyance is not a function of the number of exposures. An investigation of different levels of annoyance (very annoyed, rather annoyed and little annoyed) showed that, as the level of annoyance dropped, the correlation with the dose dropped. For the expression "little annoyed" the extent of the reaction is independent of the noise level. The increase of percent veryannoyed with increasing peak noise level was much less for the 21 to 30 year old population than for the older population; the percentage of women annoyed tended to be about 5% lower than for men; and fewer of those working outside the community during the day were annoyed at the higher levels than those who remained in the community. An analysis of expressions for annoyance and different levels of noise exposure showed that television flicker was poorly correlated with noise level, but there was a high correlation between dB(A) level and disturbance of telephone conversation, normal conversation and listening to radio or TV. A considerable amount of annoyance due to aircraft noise exposure ".... can be defined as communication interference". However, this is not all of the picture. At the lower noise levels, most of the variance can be explained by fear, nervousness and awakening. At the higher levels, most of the variance is explained by interference with relaxation and sleep. The second most important factor at both high and low levels is the communication factor already mentioned. Further analysis showed that the communication factor did not vary with age, but the younger group reported less sleep disturbance due to aircraft noise. Finally, it is pointed out that several of the components analyzed have been used by other researchers in the construction of Guttman scales for annoyance scores, and because several of the factors used in earlier studies have been found to be less important for annoyance, the Guttman scales are not ideal for measuring the extent of annoyance in exposed communities.

Ariel Alexandre combined findings of five aviation studies, two British, two French and one on the Netherlands. All used a Guttman scale, with different numbers of steps. The raw scores (average annoyance) were converted into percentages of the maximum score, called annoyances indices. The results were plotted against NNI. The correlation coefficients between the average annoyance scores and the aircraft noise indices was above 0.9, but the correlation between the individual annoyance scores and the noise was below 0.5. All the studies conclude that even at high noise levels, some people will suffer little or no annoyance. At low noise levels, some people are always annoyed. Alexandre states that in truly quiet surroundings (below 15 NNI, which Alexandre equates approximately with 75 CNR or 5 NEF) only 5% are annoyed, and that in extremely noisy surroundings (above 65 NNI, or 125 CNR or 55 NEF), "only 10 to 15% remain relatively unaffected, of whom only 5% are not at all annoyed". Above 30 NNI, or 90 CNR, or 20 NEF, the percentage of annoyed people can be predicted by 2X (noise level in NEF - 15) or 2X (noise level in CNR - 85). These are, of course, estimates of the sum of individual reactions, and not the reaction of the community as a whole.

Aubrey McKennell of England started with the observation that the ultimate criterion for an administrator of what constitutes a noise problem is not the characteristics of the source, but the nature and extent of the public protest generated. However, noise does not lead directly to complaints. Noise leads to annoyance, which leads to complaints. Curves showing the means of individual annoyance scores against exposure predict the central tendency of the annoyance response, not the individual reaction. Psycho-social variables may affect the annoyance more than the noise level itself. Some results of the 1961 London (Heathrow) Airport survey show that the correlation between noise level and individual scores on the annoyance scale was 0.46, but the following factors had the correlations with annoyance shown:

Fear of aircraft crashing	0.52
General attitude toward noise	0.50
Reported feelings and activities and neighbors	0.45
Aircraft held to affect health	0.38
Preventability	0.35
Number of things disliked	0.30
Annoyance scale for noise other than aircraft	0.25

McKennell feels that "one can expect to find whole communities reacting quite differently to noise even though subjected to much the same physical conditions of exposure". To investigate the characteristics which influence those annoyed to become complainants, McKennell analyzed a special sample of complainants. "Complainants, in short, come from that section of the politically active articulate middle class who are sensitive to noise. There was no evidence that they are any more neurotic than the equally annoyed non-complainants, but they tend to be even more convinced that the noise could be prevented and that it was affecting their health." However, "there has been little social research into the conditions under which individual noise annoyance becomes translated into social action". McKennell also makes a point that is often forgotten. Even though both mean percentage annoyed and percentage of complainants increase with increasing noise, the major portion of the annoyed people, and of the complainants, are found in areas of lower noise levels. This is true because there are more people living in the lower noise levels. Consequently, decisions should be based upon the number of people affected in the various areas, not the percentage.

A report by Etienne Grandjean, et al., on a survey around three airports in Switzerland in which a self-rating scale of annoyance was used, showed that the mean annoyance value correlated better with NNI than with Leq, or some other less common metrics. However, the data from the three airports grouped best when the number of operations was treated as 6.6 log N rather than 15 log N. On the self-rating scale, 10 was intolerable annoyance and 0 was not at all annoyed. These data were presented in terms of mean annoyance, not number or percentage of people annoyed.

Leonard and Borsky reported on the results of an investigation of the casual relationships among noise exposure, psycho-social variables and aircraft noise annoyance. Interviews were conducted with 1465 residents distributed among areas near Kennedy Airport, with followup telephone interviews as necessary to obtain annoyance ratings. The three locations were 1.1, 2.5 and 5.2 miles from the ends of runways at Kennedy. The emphasis was on understanding of aircraft noise - annoyance relationships rather than predicting them. There were eleven items on the annoyance scale; each was scored 0 to 4, with 4 representing the highest annoyance. Hence, a maximum score of 44 was possible. The eleven items were:

Interferes with listening to radio or TV
Makes the TV picture flicker
Startles or frightens anyone in the family

Disturbs family's sleep
Makes house rattle or shake
Interferes with family's rest or relaxation
Interferes with conversation
Makes you keep your windows shut during the day
Makes you keep your windows shut during the night
Makes you feel tense and edgy
Gives you a headache

CNR was used as the measure of community aircraft noise exposure. Fear was measured by a scale with four items, each of which could be scored 0 to 4, with 4 being the highest. These questions concerned:

Dislike of unsafe low-flying airplanes

How much the noise from airplanes startles or frightens

How often they felt airplanes were flying too low for the safety of the residents

How often they felt there was some danger that they might crash nearby

Similarly, misfeasance, health attitudes and the importance of aircraft were measured in the questionnaire. The misfeasance questions investigated the feeling that various agents could do something about the noise, but for some insufficient reason do not. The agents were airline operators, airport operators, other government officials, pilots, airplane designers and makers, and community leaders. Again, each could be scored 0 to 4, with a maximum score of 24. Regarding health attitudes, a single question, scored 0 to 4 was asked: "How harmful do you feel the airplane noise is to your health"? In addition, respondents were asked how important they felt commercial airplanes were to national welfare, the community and their own family.

Annoyance data were collected for two periods, June and August. Analysis of the data indicated that fear and health attitudes were much more strongly correlated with annoyance than with CNR or misfeasance. Multiple regression analysis indicated that these four explained about 50% of the annoyance variance. Aircraft importance and sex seemed to have little relationship with the annoyance. By examining partial correlations (the relationship between two variables that exists when the effects of other variables have been held constant or "partialled out"), a possible causal model was developed. For example, it was found using the June data that the partial correlation between CNR and annoyance dropped to near zero when the effects of fear, health attitudes and misfeasance were partialled out. Hence, there is little or no direct causal effect of CNR upon annoyance. Using similar reasoning, the causal lines would run from CNR to Fear; from Fear and Misfeasance to Health Attitudes; and from Health Attitudes and Fear to Annoyance. In addition, there may be reciprocal effects from Health

Attitudes to Fear and Misfeasance. A causal diagram for the August data is the same, except that a weak effect relationship may exist in this case between CNR to Annoyance.

Patterson and Connor reported on a comparison of community response to aircraft noise in large and small cities, using data from Chicago, Dallas, Denver, Los Angeles, Boston, Miami and New York on the one hand, and data from Chattanooga and Reno on the other. The comparison showed a significant difference, with the annoyance level increasing with additional noise at a much slower rate in the small cities than in the large cities. At CNR 85, the percent annoyed was about the same, approximately 7%; at CNR 125, the percent annoyed in large cities was almost twice as high as in the small cities, approximately 27% as compared to 15%. Investigation of the other variables, fear, misfeasance, importance of aircraft, etc. and alteration of the constants in calculating CNR failed to identify the reason. Possible reasons were postulated: seasonal effects, differential response to takeoff vs. landing noise, and different degrees of social interaction. The range of daily operations in small cities was 50 - 54; in the large cities, it was 353 to 1,573. The possibility that the difference is attributable to these differing activity levels, as reported by the Swedes, was not explored.

In 1969, an interdisciplinary study of aviation noise and its effect on the community was conducted in neighborhoods around Munich airport. In a preliminary study, a control group was compared with the noise exposed group. For the main study, an area was selected where a aircraft noise dominated all other sources. The number of daily flyovers varied from 20 to 80; the noise levels in dB(A) ranged from 75 to 107. Thirty two levels of noise exposure were selected. About 30 respondents were selected from clusters at each noise level, with a total of 952 respondents. The data collection program had four steps: a social scientific interview, psychological and physiological tests, medical case histories, examinations and tests, and acoustical measurements at each cluster. There were 660 usable interviews; 357 individuals went through the entire program. Noise measurements were carried out over seven weeks. Noise levels were calculated using Q, NNI, CNR, NEF etc. A plot of noise levels against number of flyovers per day indicated that from 20 to 50 flyovers, seven points, noise levels (average dB(A)) ran from 81 to 87; above 50, the noise levels rose rapidly. At 79 to 80 flyovers, nine points, levels ranged from 95 to 100 dB(A). Between 51 and 78 flyovers, sixteen points, there were no noise levels above 93 dB(A), two were below 87 dB(A). From correlation between the various measures and disturbance and annoyance, the experiments identified a tendency for the frequency of flyovers to be more highly correlated with annoyance than the noise levels of flyovers. They selected a measure, FB1, as best suited to the data:

FB1 = 10 log summation antilog L_{Ai} + 10 log N - 50, where:
L_{Ai} = A - weighted flyover level
50 = constant, N = number of overflights per day.

Using their collected data, FB1 was calculated for each of the 32 points, and the correlation determined for each of the three relationships-for the 7 points below N = 50 and for the 25 points above N = 50. The results are:

Correlation Between	32 Points	7 Points	25 Points
L_{Ai} and N	0.849	0.385	0.892
L_{Ai} and FB1	0.987	0.897	0.999
N and FB1	0.920	0.752	0.908

Two types of variables were identified: reaction variables which significantly related to one of the stimulus variables, and moderator variables which had little or no correlation with the stimulus variables but which contributed to the reaction independently of the stimulus. The highest correlation for a reaction variable was 0.56 for disturbance in conversation or listening to radio/TV. The next highest correlation was 0.51 for dissatisfaction with the neighborhood, especially recreation value. The perceived number of aircraft noise events had almost as high a correlation with the aircraft noise, 0.47, but it is less than the correlation between the actual number and the aircraft noise, as calculated above.

A series of psychophysiological laboratory experiments were conducted to explore information processing behavior in the presence of aircraft noise. Two different responses were hypothesized - "adaptive coping" which assumes learning of techniques for disturbance-free processing in spite of the noise and a decrease in physiological responses to noise, and "defensive blocking" which assumes an interruption of information processing and a "physiological state of defense against noise as a consequence of frequent and intense day-by-day aircraft noise". No quantitative data are given on the number of participants, the noise levels or the length of the experiments. The results did not confirm the "adaptive coping" hypothesis. "With increasing day-by-day aircraft noise exposure, the physiological response to the onset of noise in the laboratory increases. The response consists of a constriction of blood vessels at the finger and at the temple, an increase in the electrical muscle activity, a decrease of the heart rate and an increase in the tracking error rate." No description of the information processing activity used in the experiments is provided. "The reaction correlates positively both with the intensity and frequency of aircraft movements (r = 0.21) and it occurs especially with persons of low mobility, strong conservative tendencies and very high blood pressure." It should be noted that the correlation, although positive, "explains" a very small percentage of the variation of response with stimulus. The report adds that "Other aspects of human behavior, such as information processing in complex stimulus situations, are not so much affected by aircraft noise as such, but are affected indirectly via negative attitudes or annoyance related to aircraft noise, especially the performance requiring attention to noisy conditions".

The results of the medical investigation "demonstrate that aircraft noise does not cause manifest illness, but that it contributes as a tendency to changes in vegetative functions, especially the blood pressure". No data are given.

A chart was also produced showing the relationship between percentage of people annoyed by aircraft noise and the noise levels expressed in different measures, including NEF, and indicates the following:

NEF Zone Boundary	Percentage annoyed (least squares fit) a	b	c
I	70	40	50
II	45	20	30

(Percentage annoyed is expressed in three different measures: a) disturbance of communication, b) disturbance of rest and recreation, and c) aircraft spontaneously mentioned as a disturbing factor.)

A.17 The EPA "Levels Document", 1974

In March, 1974, the EPA published a report[57], "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", which has come to be known as the "Levels Document". The EPA was directed by the Noise Control Act of 1972 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". In the foreword, the EPA points out that knowledge in the area is not complete, that a considerable amount of investigation remains to be done, and that some investigations require a long elapsed time before the results are meaningful. The EPA goes on to say that, nevertheless, extrapolations from existing information are possible, even though revisions will occur as knowledge is expanded, improved and refined.

In the case of the noise study, EPA says that the margin of safety "has been developed through the application of a conservative approach at each stage of the data analysis". The foreword concludes by pointing out that the report is published to comply with a statutory requirement, that its contents do not constitute EPA regulations or standards and should not be applied to a particular individual. In spite of these admonitions, the Levels Document has been erroneously cited as saying that deafness or other adverse health impacts will ensue if an individual is exposed to more than 55 Ldn.

The Levels Document recommends 55 Ldn "as a goal for outdoors in residential areas in protection the public health and welfare with an adequate margin of safety. However, it is not a regulatory (original italized) goal. It is a level defined by a negotiated scientific consensus without concern for economic and technological feasibility or the needs and desires of any particular community".

The public health and welfare is defined in the Levels Document in the broadest terms, as "complete physical, mental and social well-being and not merely the absence of disease and infirmity". The phrase, "health and welfare", is taken to include personal comfort and well being and the absence of mental anguish and annoyance. However, the document points out that annoyance is not recognized as a compensable injury, in the absence of interference with a personal or property right.

Much of the background material in the Levels Document is identical with that in the July 1973 document[51] previously discussed.

A.17.1 Hearing Loss

In the discussion of the effects of noise on hearing, both EPA reports contain a table on permanent hearing damage effect expected for continuous noise exposure at various values of the A-weighted average sound level. Both quote the same reference. Both tables express the data in terms of the Noise Induced Permanent Threshold Shift, NIPTS, for values of 8 hours per day continuous noise from 75 dB(A) to 90 dB(A).

The analysis, though, is different in the two documents. In the Levels Document, the estimate of the NIPTS for a percentile is calculated by subtracting the hearing level of that percentile of the noise exposed group from the hearing level of the percentile of the non-noise exposed group. After pointing out the inadequacies of the data, the analysis proceeds to calculate the "critical percentile point". This is the percentile at which the hearing loss for the non-noise exposed population equals the 40 year, 8 hours per day noise level which is estimated to cause an NIPTS of 5 dB(A). This is approximately the 96th percentile, at an averaged value of 73 dB(A). All of this is at a frequency of 4000 Hz, where the hearing loss is expected to be greatest. From this derivation, it is concluded that a 40 year noise exposure below an average of 8 hours per day of 73 dbA "is satisfactory to prevent the entire statistical distribution of hearing levels from shifting at any point by more than 5 db". Expressed differently, "the entire population exposed to Leq(8) of 73 is protected against a NIPTS of more than 5 db".

Having gone thus far, the report says the "argument ... does not, in fact, provide 100% protection of the entire population" because "we cannot be absolutely certain that it (the data base) is representative of the whole population". Assuming that the NIPTS of the exposed population is a normal distribution the data are extrapolated to the 99th percentile and to the 5 dB(A) NIPTS. This value is 71.5 dB(A) exposure for 40 years, 8 hours a day. The Levels Document points out that "similar analysis of the same and similar data may be made using other assumptions and considerations. Some analysis leads to essentially the same conclusions and others do not. However, no such analysis has identified a level of much less than 65 db or much greater than 80 db for the same conditions (i.e., 5 db NIPTS at 4000 Hz for 40 years of exposure)". Nevertheless, there is a requirement to identify the level requisite to protect the public health safety. For that purpose, for conservation of hearing alone, the level of 73 dB(A) "appears to be the most reasonable choice..."

However, the question of "adequate margin of safety" is then raised, and the following argument developed. Considering that environmental noise is not continuous, but intermittent (defined as being below 65 dB(A) at least 10% of the time), an allowance of 5 dB(A) is developed, the same as in the earlier document. In other words, if the noise is intermittent, an average level of 78 dB(A) is expected to have the same effect (or lack of effect) as a continuous noise of 73 dB(A). On the other hand, using the equal energy rule, the report states that there is a 5 dB(A) correction to go from 8 hours a day to 24 hours a day. An implicit assumption is that "8 hours a day" really means 8 working hours, with occupational data based on annual exposure dose. In summary:

Continuous noise 8 hours per day, 250 days/year	73.0 dB(A)
Intermittent noise 8 hours per day, 250 days/year	78.0 dB(A)
Intermittent noise 8 hours per day, 365 days/year	76.4 dB(A)
Intermittent noise 24 hours per day, 365 days/year	71.4 dB(A)

(Note that the correction for 250/365 is 1.64, and for 8/24 is 4.77; the total is 6.41. Therefore the final value, if tenths of a db are worth quoting at all, would be 71.6.)

At this point the report states, "In view of the possible uncertainties ... it is considered reasonable to round down from 71.4 db to 70 db".

A.17.2 Activity Interference/Annoyance

The human activity susceptible to noise interference which has been most examined is that of speech communication. The July 1973 report[51] deemed a speech intelligibility level of 95% as acceptable outdoors; so does the Levels Document. Inside, the criterion is taken as 100% intelligibility in both documents.

Although, by the reasoning presented in the July 1973 EPA report, an average level (Leq) of 60 dB(A) outside would meet the criteria, the Levels Document in three sentences goes from 60 Leq to 55 Ldn:

"Although speech interference has been identified as the primary interference of noise with human activities and is one of the primary reasons for adverse community reactions to noise and long-term annoyance, the 10 db nighttime weighting (and, hence, the term Ldn) is applied to give adequate weight to all the other adverse effects on activity interference. For the same reason, a 5 db margin of safety is applied to the identified outdoor level. Therefore, the outdoor Ldn identified for residential areas is 55 db."

In a lengthy appended discussion, the results from the surveys at London (Heathrow) Airport, New York, Amsterdam, and a U.S. surface vehicle noise survey are all reviewed, along with a discussion of community reaction. Although the Heathrow data has been translated into Ldn (subject already discussed), the Levels Documents reports "Unfortunately, most of the studies do not provide activity interference as a function of noise exposure". The phenomenon cited in the Heathrow study as causing the largest percentage of people disturbed is "causes TV picture flicker". This is not a result of aircraft noise, but of reflections of the TV signal from the aircraft.

A discussion of the 55 communities covered in the earlier noted Wyle report[47] covers essentially the same ground as in the July 1973 EPA report[51]. In the Levels Document, the 55 cases are "de-normalized", with the observation that below 55 Ldn, there is no evidence of even sporadic complaints. There is no questioning of the conversions, nor the equally valid observation that there are cases as high as 70 Ldn with no reaction from the community.

An examination of the twelve aviation related cases in the 55 cases discussed by Wyle shows the following distribution, by type of activity, community reaction and CNEL as calculated by Wyle:

Reaction	Activity	CNEL
No Reaction	Runup	46
No Reaction	Overflight	53
No Reaction	Landing & Takeoff	57
Widespread Complaints	Landing	57
Threats of Legal Action	Overflights	58
No Reaction	Landing	60
Widespread Complaints	Takeoff	63
Vigorous	Takeoffs	69
Vigorous	Takeoffs	71
Vigorous	Landings	72
Threats of Legal Action	Ground Runup	72
Vigorous	Landings	84

The Levels Document summarizes the effects of an outdoor noise level of 55 Ldn:

Speech	100% sentence intelligibility at .35 meters 99% sentence intelligibility at 1.0 meters 95% sentence intelligibility at 3.5 meters

Average Community Reaction	None; 7 db below level of significant "complaints and threats of legal action"
Complaints	1% depending on attitute and other non-level related factors
Annoyance	17% dependent on attitude and other non-level related factors

At 65 Ldn, outdoors, according to the Levels Document, one would expect 95% sentence intelligibility with a normal voice at a distance of two meters.

Appendix D of the Levels Document contains a general summary of the relationships among day-night sound level, percent complainants and percent highly annoyed. "The results indicate that below an outdoor day-night sound level of 55 db, less than 1% of the households would be expected to complain, although 17% of the people may respond as highly annoyed when questioned in a social survey. 'No reaction' would be expected in the average community...When the outdoor Ldn is 60 db, approximately 2% of the households might be expected to complain, although 23% of the people may respond as highly annoyed when questioned, and some reaction may be expected from the average community. If the levels increase over 65 db, more than 5% may be expected to complain, and over 33% would be highly annoyed. Increasingly, vigorous community reaction could be expected, and noise becomes the dominant factor in disliking an area."[57] The data indicate that at 75 Ldn about 50% of the population is "highly annoyed", and that 13% are actively complaining.

The Levels Document points out that the effects of intruding noise may be dependent upon the noise level absent the intrusion. In 1976, the EPA proposed use of a predictor of ambient or indigenous noise based on population density. As a predictor, the relationship was expected to have a standard deviation of about 4 dB(A). If the relationship between population density and indigenous noise is a normal distribution, then 66% of the observations are within 4 dB(A), 95% within 8 dB(A) and almost all within 12 dB(A). The proposal was not adopted, and considerable doubts were expressed about its validity. The Levels Document states, "....it appears that no community reaction to an intruding noise is expected, on the average, when the normalized day-night sound level of an identifiable intruding noise is approximately 5 db less than the day-night sound level that exists in the absence of the identifiable intruding noise".

A.18 Land Use Compatibility, 1974-1977

A report[58] presented in 1974, discusses an application of the California Noise Law to planning a community. The residential land uses for aircraft noise compatibility were reported as follows:

Land Use	CNEL Ranges				
	60-65	65-70	70-75	75-80	80-up
Single Family (Detached)	NLR 25	NLR 30	NP	NP	NP
Single Family (Attached)	P	NLR 30	NLR 35	NLR 40	NP
Multi-Family (Low-Rise)	P	NLR 30	NLR 35	NLR 40	NP
Multi-Family (Mid-Rise)	P	NLR 30	NLR 35	NLR 40	NP
Multi-Family (High-Rise)	P	NLR 30	NLR 35	NP	NP
Mobile Home Parks	P	NP	NP	NP	NP
Dormitories	P	NLR 30	NLR 35	NLR 40	NP
Convalescent Homes	NLR 25	NLR 30	NLR 35	NP	NP

NLR - Required outdoor-to-indoor noise level reductions in dB
P - use permitted NP - use not permitted

The required noise level reductions are based upon achieving an indoor CNEL of 40 or less, but the basis for this criterion is not given.

A 1975 BBN report[59] provides a draft building code for noise insulation with respect to aircraft noise. Five noise zones are defined:

Noise Zone	Ldn
A - 1	less than 60
A - 2	60 - 65
B - 1	65 - 70
B - 2	70 - 75
C	over 75

The uses permitted and not permitted are as shown in Table 7.

The BBN chart has two residential categories: 1) single family detached, duplex and mobile homes; and 2) multi-family buildings of all kinds, rooming and boarding houses, convalescent homes, dormitories and boarding schools.

A comparison of the BBN chart with the residential compatible uses reported for California show that, compared to the California uses, BBN recommends:

Land Use	CNEL Ranges				
	60-65	65-70	70-75	75-80	80-up
Single Family (Detached)	NLR 25	NLR 30	NP	NP	NP
Single Family (Attached)	P	NLR 30	NLR 35	NLR 40	NP
Mobile Home Parks	P	NP	NP	NP	NP
BBN Building Code	P	NLR 25	NP	NP	

TABLE V

PERMITTED ACTIVITIES AND/OR LAND USES AND MINIMUM SOUND LEVEL REDUCTION REQUIREMENTS FOR STRUCTURES

ACTIVITIES AND/OR LAND USES	SLUCM CODE	LAND USE NOISE ZONES				
		C	B-2	B-1	A-2	A-1
Residential	11 x (10), 14	Not Allowed	Not Allowed	Permitted with SLR 25	Permitted	Permitted
Residential , Educational and Institutional	11 x, 12, 13, 19, 68, 7111, 651	Not Allowed	Permitted with SLR 30	Permitted with SLR 25	Permitted	Permitted
Auditoriums, Concert Halls	721 x	Not Allowed	Not Allowed	Permitted with SLR 35	Permitted with SLR 30	Permitted
Outdoor Amphitheaters, Music Shells	721 x	Not Allowed	Not Allowed	Not Allowed	Not Allowed	Permitted
Offices, Personal, Business and Professional Services, Commercial-Retail, Movie Theaters, Restaurants	61, 62, 63, 69, 65 (11)	Permitted with SLR 30	Permitted with SLR 25	Permitted	Permitted	Permitted
Transient Lodging-Hotels, Motels	15	Permitted with SLR 35	Permitted with SLR 30	Permitted with SLR 25	Permitted	Permitted
Sports Arenas, Outdoor Spectator Sports	722	Not Allowed	Not Allowed	Permitted	Permitted	Permitted
Playgrounds, Neighborhood Parks	761, 762	Not Allowed	Not Allowed	Permitted	Permitted	Permitted
Golf Courses, Driving Ranges, Water-Recreation, Cemeteries,	741 x, 743 x, 744	Permitted	Permitted	Permitted	Permitted	Permitted
Commercial-Wholesale and Selected Retail, Industrial/ Manufacturing, Transportation Communication and Utilities	2, 3, 4, 51, 52, 64	Permitted	Permitted	Permitted	Permitted	Permitted
Animal-related services	82 x	Not Allowed	Permitted	Permitted	Permitted	Permitted
Agricultural	81, 82 x	Permitted	Permitted	Permitted	Permitted	Permitted

Land Use	CNEL Ranges				
	60-65	65-70	70-75	75-80	80-up
Multi-Family (Low Rise)	P	NLR 30	NLR 35	NLR 40	NP
Multi-Family (Mid-Rise)	P	NLR 30	NLR 35	NLR 40	NP
Multi-Family (High-Rise)	P	NLR 30	NLR 35	NP	NP
Dormitories	P	NLR 30	NLR 35	NLR 40	NP
Convalescent Homes	NLR 25	NLR 30	NLR 35	NP	NP
BBN Building Code	P	NLR 25	NLR 30	NP	

NLR - Required outdoor-to-indoor noise level reductions in dB
P - use permitted NP - use not permitted

If the California reductions are based on achieving an indoor noise level of 40 dB or less, then BBN's code is based on achieving an indoor noise level of 45 dB. The BBN report does state: "It must be stressed that when buildings are to be constructed to meet sound level reduction values of 30 and 35 db many residential (original italicized) construction methods and materials are no longer suitable or adequate. ... In particular, it becomes vital to use heavier and more elaborately constructed windows and doors in order to achieve the desired noise insulation performance". It appears possible that the differences arise from BBN's: a) unwillingness to specify more expensive construction and b) equal unwillingness to specify that residential construction should not be permitted in areas above 65 Ldn.

In September 1974, Miller[56] discussed the effects of noise on people. A chart of the quality of speech communication as a function of steady state background noise and distance between speaker and listener indicates communication is judged to be "satisfactory" or, alternatively, "practical" at the distances and background levels shown:

Background Level - dB(A)	Distances in feet for communication which is: Satisfactory	Practical	
40	35	35	
45	12	35	
50	5.5	20	
55	1	12	
60		6.5	8*
65		3.5	5*
70		2	3.5*

* Indicates a raised voice, the "expected voice level".

Commenting on the chart, Miller says "In face to face conversations, the distance from talker to listener is usually of the order of 5 feet and practical communication can proceed in A-weighted noise levels as high as 66 db. Many conversations involve groups, and for this situation distances of 5-12 feet are common and the intensity level of the background noise should be less than 50-60 db. At public meetings or outdoors in yards, parks, or playgrounds distances between talker and listener are often of the order of 12-30 feet and the A-weighted sound level of the background noise must be kept below 45-55 db if practical speech communication is to be possible".

Regarding effects of noise on sleep, Miller says that "it is the effects of relatively brief noises (about 3 minutes or less) on a person sleeping in a quiet environment that have been studied most thoroughly". However, the data presented from a number of experiments show that, as discussed by Lukas[60], the conclusions depend upon the definition of sleep disturbance, and other factors. As an example, in a series of experiments, the percentage of awakenings changed from 11% to 55% for the same stage of sleep and the same brief noises as the sleepers were motivated by instructions and punishment for failure to wake enough to push a convenient button. During this series, the noises were at about 35 dB(A). On the other hand, when instructed "if you happen to wake up, push the button", only 10% wakened from sleep stage II, and about 5% from the deeper stages III and IV by brief noises at 68 dB(A).

In a summary report of research in sleep and noise, Lukas[60] in 1975 suggested possible criteria for effects of noise on sleep. The more conservative is to limit sleep disruption to less than a change in sleep stage. An alternative is to limit the frequency of arousal or behavioral awakening. The available data showed better correlation using the former than using the latter. Using the former criterion, Lukas concludes that noise levels indoors must be maintained below 70 EPNdB to have little or no probability of disturbing sleep. He points out, however, that the sleep phenomena is not well understood, and that little is known about the relationship between laboratory experiments and home experience.

Appendix A of a 1977 report[65] prepared for the FAA on sound proofing public buildings develops, based on review of the literature at that time, threshold levels of noise applicable to schools and hospitals. Each of the potential impacts is considered, with the following results:

Hearing loss	Leq 75 dB(A), 8 hours
Long term adverse non-auditory	No effect Leq 75 dB(A)
Annoyance	Noise levels sufficiently low to produce no activity interference will probably produce little or no annoyance
Activity interference	
Speech in schools	45 dB(A), unless ambient is higher
Sleep in hospitals	40 dB(A)

A.19 Committee on Hearing, Bioacoustics, and Biomechanics Report on Documenting Noise Impacts, 1977

A report prepared by the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) of the National Research Council[62] in June 1977 recommended a methodology for documenting noise impacts in environmental impact statements. In essence, it proposed a single number which was a summation over the total population of the product of each residential person times a weighting factor which depends upon the Ldn of the residence of that person. The recommended weights were derived from the Schultz curve, published in 1978[71], based upon estimates of percentage of people highly annoyed. The higher the score, the greater the noise impact. The weights proposed are shown:

Ldn	Weight	Ldn	Weight
35	0.006	40	0.013
45	0.029	50	0.061
55	0.124	60	0.235
65	0.412	70	0.664
75	1.000	80	1.428
85	1.966	90	2.647

The inference is that there is 8 times as much annoyance at Ldn 75 as at Ldn 55; and 20 times as much at Ldn 55 as at Ldn 35.

The CHABA report includes material derived from the Levels Document and Schultz[71] and shown in Tables 8 to 11. These indicate that, indoors, there is little interference with speech communication up to 75 Ldn outside. Outside, of course, the situation is different. Above 65 Ldn, average sentence intelligibility drops below 95% at a distance of 1.3 meters.

A.20 Synthesis of Social Surveys on Noise Annoyance, 1978

In August, 1978, Schultz[71] combined data from 11 surveys including six airports, four streets and one railroad from 1961 to 1974 to develop a "proposed...best...estimate of public acceptance due to transportation noise of all kinds". In a discussion of this report[74], the author says "The difficulty ... is that the noise exposure in the various social surveys has been measured with a number of different noise ratings; and the question of who is 'highly annoyed' has been dealt with differently in the different surveys. The present study attempts to translate the different noise ratings into a common measure of noise exposure and to develop a uniform assessment of the percentage of the survey population who were highly annoyed... the author has gone back to basic data .... from eighteen social surveys dealing with noise of aircraft, street traffic, expressway traffic and rail traffic ... The various noise ratings were translated to day-night average sound level...". Results of eleven of the eighteen surveys were used because the eleven "clustered" about a common value. The others seen were "non-

TABLE 8

CRITERION FOR OUTDOOR SOUND LEVELS FOR ANALYSIS OF
ENVIRONMENTAL NOISE IMPACT FOR VARIOUS LAND USES

Observer	Land Use	L_{dn} (dB)	L_{eq} (dB)
1	Residential (1)	55	
2	Hospital (1)	55	
3	Motel, Hotel (1)	60	
4	School Buildings & Outdoor Teaching Areas (1)		60
5	Church (2)		60
6	Office Buildings (2)		70
7	Theater (3)		70
8	Playgrounds, Active Sports		70
9	Parks		60
10	Special Purpose Outdoors Areas		*

Note: The assumed average outdoor/indoor sound-level reduction, for each land use, is keyed to the numbers in parentheses above:

(1) 15 decibels - windows open

(2) 25 decibels - windows closed

(3) 35 decibels - windows closed

Where knowledge of the specific structure indicates an actual sound level reduction differing from these values, the criterion level may be altered accordingly.

* For outdoor amphitheaters, or other critical land uses requiring special consideration, the hourly average sound level (L_h) due to the new intruding noise should not be allowed to be higher than 5 dB below the existing hourly average sound level in the absence of speaking in the amphitheater.

TABLE 9

SUMMARY OF HUMAN EFFECTS FOR OUTDOOR DAY-NIGHT AVERAGE SOUND LEVEL OF 55 DECIBELS

Type of Effects	Magnitude of Effect
Speech - Indoors	No disturbance of speech 100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	Slight disturbance of speech with: 100% sentence intelligibility (average) at 0.35 meter or 99% sentence intelligibility (average) at 1.0 meter or 95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 5% of the population will be highly annoyed
Attitudes Towards Area	Noise essentially the least important of various factors

TABLE 10

SUMMARY OF HUMAN EFFECTS FOR OUTDOOR DAY-NIGHT AVERAGE SOUND LEVEL OF 65 DECIBELS

Type of Effects	Magnitude of Effect
Speech - Indoors	Slight disturbance of speech 99% sentence intelligibility (average) with a 4 dB margin of safety
- Outdoors	Significant disturbance of speech with 100% sentence intelligibility (average) at 0.1 meter or 99% sentence intelligibility (average) at 0.35 meter or 95% sentence intelligibility (average) at 1.2 meters
Average Community Reaction	Significant; 3 dB above level of significant "complaints and threats of legal action" but at least 7 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and other non-acoustical factors, approximately 15 percent of the population will be highly annoyed
Attitudes Towards Area	Noise is one of the most important adverse aspects of the community

TABLE 11

SUMMARY OF HUMAN EFFECTS FOR OUTDOOR DAY-NIGHT AVERAGE
SOUND LEVEL OF 75 DECIBELS

Types of Effects	Magnitude of Effects
Speech - Indoors	Some disturbance of speech sentence intelligibility (average) less than 99%
- Outdoors	Very significant disturbance of speech with: 100% sentence intelligibility not possible at any disance or 99% sentence intelligibility (average) at 0.1 meter or 95% sentence intelligibility (average) at 0.35 meter
Average Community Reaction	Very severe; 13 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
High Annoyance	Depending on attitude and non-acoustical factors, approximately 37% of the population will be highly annoyed
Attitudes Towards Area	Noise is likely to be the most important of all adverse aspects of the community

clustering". "The clustering surveys are mostly those that counted as highly annoyed the people who judged themselves to be highly annoyed or who reported in only the top two or three of a large number of categories of annoyance."

After a brief discussion of some of the problems encountered (the report quoted is a summary of the original), the author says "Now the question arises, is this exercise meaningful or does it only signify that one can prove almost any point by choosing the right data to average?" He concludes that "based on the available evidence, the best choice for the relationship between noise exposure and community response is the average of the clustering survey curves..."

A.21 The Third International Conference on Noise as a Public Health Problem, 1978

In September, 1978, the Third International Conference on Noise as a Public Health Problem was held in Freiburg, West Germany[83].

A.21.1 Opening Session

Rudolph Marrazzo, of the Environmental Protection Agency, presented the EPA's position on Ldn values adequate to protect the public health and safety in a slightly different fashion from the Levels Document:

Environment	Inside	Outside
Residential, Educational & Hospital Areas	45	55
All Others (Commercial, Industrial, Recreational, Interior Transportation, Farms and Unpopulated Areas)	55-70*	70

*Depending on Speech Communication

"It is very important that these noise levels ...... not be misconstrued. Because the protective levels were derived without any concern for technical or economic feasibility, and contain a margin of safety to ensure their protective value, they are not viewed as standards, criteria, regulations or goals. Rather, they are viewed as levels below which there is no reason to suspect that the population will be at risk from any of the identified effects of noise."

Charles Foster, FAA, pointed out that the same percentage of people were annoyed at noise levels which differed by amounts approaching 20 dB, and pointed out examples to illustrate that descriptors such as NEF or Ldn are not sufficient to tell the whole story. Among the noise factors not considered in these descriptors, but which affect the impact, are ambient levels and the number and timing of high levels. He concluded: "Today we demand very precise compliance with specific noise standards that could result in a pass or fail by 0.1 db. Yet we do this to reduce the adverse impact on health and welfare which we can predict or measure with much less precision, probably + or -5 db. How do we specifically quantify the perceived noise level which will result in accommodation between the airport neighbors and the airport, while maintaining the air transportation service our society has learned to expect?"

A.21.2 Team II - Noise and Communication

In an introductory paper for the session on noise and communication, Karl S. Pearsons of BBN noted that, while Leq may be a sufficient descriptor for time varying noise caused by traffic "Still unanswered is the amount of intelligibility for time varying noise situations more extreme than that of traffic noise, such as that associated with the environment around airports".

Tammo Houtgast of the Netherlands discussed the effect of reverberation on indoor noise level and speech intelligibility. Reverberation was expressed in terms of equivalent apparent noise level. This establishes a "floor", and unless the extraneous noise raises the "floor", it cannot interfere with communication.

Three cases were used as examples:

Situation	Noise Level of Speaker (at one meter)	Level of Noise for No Interference
Living Room (80 m^3)	50 dB(A)	35 dB(A)
Classroom (250 m^3)	59 dB(A)	45 dB(A)
Large Conference Room (500 m^3)	65 dB(A)	50 dB(A)

These are lower limit criteria, and depend upon the size of the room and the reverberation time, as well as the distance from the source to the receiver. For example, in the large conference room, the level of no interference changes with distance between the speaker and the listener from 50 dB(A) at over 4 meters to 65 dB(A) at 1 meter. Note also that these are not small rooms. If the ceiling is 2 meters from the floor, then the floor areas are 40, 125 and 250 m^2, respectively, or 430, 1345 and 2690 ft^2.

A.21.3 TEAM III - Non-Auditory Physiological Effect Induced by Noise

Many of the papers in the session on Nonauditory Physiological Effects involved conditions not pertinent to aircraft (for example, noise levels well above aircraft levels outside the airport for long periods of time), but three have some relevancy to this study. F. Nowell Jones of UCLA reviewed some investigations of possible connections between aviation noise at Los Angeles International Airport and interference with fetal development, without reaching any firm conclusions. Jones concluded that although nothing had been proved, the possibility that noise is implicated in increasing fetal distress in susceptible populations "should not be lightly dismissed, at least until we know a good deal more". The noise levels involved were not given.

The results of an investigation, by David J. Hand, et al from London, of the relationship between noise near London (Heathrow) Airport and psychiatric hospital admissions concludes "the conflicting results suggests that any effects which exist are subtle ones, involving complicated interactions, and that the simple direct relationships which have been established in earlier studies using small samples with inadequate controls should be considered cautiously. Furthermore, ... it is important to bear in mind the distinction between admission rate and the incidence of psychiatric illness: a referral to a psychiatric hospital is as much a social event as a medical one".

A report from the Netherlands by Paul Knipschild, concluded, based on patient visits to nineteen family doctors in one week that, over the range from 55 to almost 70 Leq(dn) the contact rate for hypertension was 72% higher in areas over 65 Ldn than in areas under 60 Ldn. In a community cardiovascular survey, taken in eight areas near the airport, it was found that in an area with Ldn 68 the prevalence rate was twice that in an area with 55 Ldn. The authors conclude "that aircraft noise is a risk factor to hypertension". (A report by Alex Cohen et al. of NIOSH, in another session, concluded "Clearly, it is too early to draw any conclusions about noise as a causal factor in cardiovascular disease.")

In two summary papers on this session, it was suggested that research should give special attention to "critical groups", i.e. pregnant women and their offspring, older people, and people with cardiovascular diseases, and that "proof of organic, extraaural, noise-induced diseases has not yet been obtained", but "experiments have shown that noise should be viewed as a risk factor".

A.21.4 Team V - Noise-Disturbed Sleep

The session, Effects of Noise on Sleep, opened with a review paper by Barbara Greifan of Germany. Summarizing several studies, "the authors came to similar conclusions. Of greatest importance is the general conclusion that the significance on health and well-being of noise-induced sleep disturbance remains unresolved".

Michel Vallet of France conducted an experiment in Paris where 40 men of various ages, who had been exposed to aviation noise for at least a year, were monitored for four nights after a habituation period. His work indicated that arousal rates were not as high as would be predicted by laboratory studies. The correlation with arousal was highest for the parameter of the difference between the peak noise level and the ambient level. Ambient levels were not reported; Leq ranged from 28 to 55; and L_1 (the difference between ambient and peak) ranged from 40 to 70 dB(A). From the relationship given between noise level difference and percentage of people with a sleep change, a change in sleep state, or awakening, would be expected for about 18% of the subjects exposed to a 50 dB(A) change from ambient. If transient effects in the EEG are included, the percent affected reaches 45%. There were reactions at any of the levels tested, no matter how low.

Jeffrey Goldstein of the EPA and Jerome Lukas of the California Department of Health Services presented two curves. The first relates probability of a noise induced sleep stage change against sound exposure level (SEL); the second, the probability of a noise induced awakening against SEL. The relationships are approximately:

Probability of sleep change = (1.35 x SEL) - 50
Probability of awakening = (1.1 x SEL) - 50

In both cases there is large scatter in the data. Whether the original data were from laboratory or in situ experiments was not specified, although the authors point out that "Vallet suggested that long time residents near one Paris airport are awakened much less frequently than expected with aircraft noise".

The other papers dealt primarily with traffic noise. There was some indication, in addition to the Vallet paper, that habituation may occur even in the short term.

A.21.5 Team VI - Community Response to Noise

The introductory paper by Paul N. Borsky of Columbia University in the Team VI - Community Response to Noise Session reviewed past work and presented conclusions from the review:

Measurement of Single Events:

a. dB(A) can be a standard descriptor of different noise sources in community noise studies.

b. - d. More laboratory research is need on:
The effects of duration on loudness, noisiness and annoyance judgements.
The effects of pure-tone components on loudness, noisiness and annoyance responses.
The interaction of low-frequency vibrations and noise intensity on loudness, noisiness and annoyance responses.

e. - f. More laboratory and field research is needed to:
Determine the effects of impulse noise on annoyance responses.
Study the intrusiveness of a single noise exposure against

different ambient noise levels and specific effects on loudness, noisiness and annoyance judgements.

Measurement of Multiple Events:

a. More laboratory and field research is needed to establish the relationship between annoyance responses and number and level of noise exposures of different sources per given time period.

b. More laboratory studies are needed on fluctuating rates of noise exposures, intervals between events per given time period, and annoyance responses.

c. More field research is needed to determine the possible different effects of noise exposures during time of day (day-evening and night) on annoyance responses.

d. More longitudinal field studies are needed to determine the effects on annoyance of seasonal and other changes in noise exposure over longer time periods.

e. More laboratory and field research is needed to determine the special relationships between different types of noise exposure and sleep disturbance.

f. More field research and possible laboratory studies are needed to determine whether the location of a residence directly under a flight track or off to the side makes a difference in annoyance judgements when the sound levels of both residential areas are comparable. This information is urgently needed to justify the use of noise level contours.

Measurement of Human Response:

a. More laboratory and field research is needed to establish the relationship between annoyance responses and number and level of noise exposures of different sources per given time period.

b. Standard methods of measurement are needed for determining feelings, of annoyance, acceptability and complaint potential.

c. A standard list of the principal psychological variables which influence annoyance and complaint responses and their methods of measurement is required.

d. Field studies are interdisciplinary and require more precise sampling and field measurements both of noise exposure variables and human responses. Laboratory studies can develop the hypothesis of relations between noise exposure and human response, but field studies provide the validation and measurement of absolute numerical relations. Laboratories can systematically test variables, while in the real environments not all combinations of variables are available for study.

Chris C. Rice of England, examined various dose-response relationships, including the Schultz curve, EPA's Levels Document, results from the early London (Heathrow) Airport work, and from the 1967 Heathrow studies, the Tracor seven cities data, the Tracor two cities data, and the Swedish, French, Munich and Swiss data. The results suggest that a single curve may not be applicable to all airports, and three different curves are suggested, depending upon the number of operations: less than 50,000 movements annually, from 50,000 to 200,000 (the Schultz curve), and over 200,000 annual operations. The smallest number of operations suggests percentages annoyed of less than half of the Schultz curve at the same Ldn. For over 200,000 operations, the percent annoyed is higher than the Schultz curve to about 75 Ldn, and below the Schultz curve at higher noise levels.

Simone L. Yaniv and Jay W. Bauer of the National Bureau of Standards examined the literature on the effects of duration on adverse response. The "equal energy" relationship assumes that a doubling of duration is the equivalent of a 3 dB change in noise level. Experimental data range from 0.2 dB/dd (duration doubling) to 4.5 dB/dd, depending on instructions given to the subjects, the type of signal and the durations and levels of stimuli. Studies indicate that both annoyance and speech interference increase in direct proportion to the number of events per unit time, but disagree on the relationship between the effects and the "rate of events". Results of an experimental program at the National Bureau of Standards on traffic noise indicate that none of the indicies is sufficient to describe exposure to time-varying noise. As the time-varying characteristic is even more applicable to aviation than to highway traffic, presumably the conclusion is equally applicable to aviation.

In another laboratory experiment, with aircraft noise, Philip Cheifetz of New York and Borsky reported that "Although far from perfect, Leq is probably the best available measure of integrated noise exposure... the correlation with annoyance is quite high ... r = 0.53, accounting for 28% of the variance". On an annoyance score of 0-9, 0-4 was considered slightly annoyed, 5-6 moderately annoyed, and 7-9 highly annoyed. Overall, the percentage of people in 5-6 range rated the noise about equally between acceptable and non-acceptable. The mean annoyance score of 7 was approximately equal to 65 Leq.

Schultz made a number of points about his previously published work. Both the data, and an examination of the distribution of responses at various noise levels, indicate that the percent highly annoyed increases more rapidly as the noise increases, while the median response tends to be more constant with increasing noise. The percent highly annoyed is best fitted by a curvilinear regression, the median response by a linear regression. The problems of the choice of whom to count as "highly annoyed", the effects of the name given to the endpoint on the annoyance scale, the relationship between indoor and outdoor noise and a consequent requirement for a more careful accounting of peaks (because "only the noise peaks stand much chance of intruding indoors and competing for attention with the noises generated indoors") were all discussed.

Schultz also discusses the scatter in the data in these terms: "If the final report of the survey is written by the psychology/social science part of the team (which is usually the case), then the measure of noise exposure is typically accepted as given. That is, it is assumed that every subject was exposed to exactly the noise measured for his neighborhood. .... Then it becomes necessary to account for the observed scatter in the %HA (highly annoyed) responses, ranging from 12.5% to 40%; usually this entails the invocation of attitudinal or demographic variables unrelated to the noise". "On the other hand, if the final report were to be written by the noise measurement team (which it never is!), they might believe that exactly 23% of all subjects in the neighborhood were highly annoyed, corresponding to DNL = 70 db .... Then it would be necessary for them to account for errors in measurement of the noise level to which the subjects were exposed, ranging from 62 to 75 db, because of shielding by sound barriers, differences in house attenuation, and so on."

"The reasonable interpretation lies somewhere between these extremes; but to achieve it would require a continuing and trusting dialogue between the measurement and interview parts of the survey team during the entire course of the study."

In a continuation of the work reported at the 1973 conference, Ragnar Rylander of Sweden reported on a reanalysis of the Tracor data, to separate the effects of noise level and number of overflights. The results, in terms of percent highly annoyed as a function of noise level (in PNdB) and number of overflights are:

	Overflights				
	50	50-99	100-199	200-399	400
PNdB					
80-99	2	12	30	13	19
90-99	11	29	53	30	41
100-109	22	54	58	54	58
110	38		73	54	30

The data seem to indicate that at noise levels up to 100 PNdB, annoyance is highest with overflights in the range 100-199; at noise levels in the range 100-109 PNdB, annoyance is about the same for any number of overflights over 50; and that at levels above 110, annoyance with less than 50 overflights may be higher than with over 400.

A number of explanations for "this paradoxical reaction pattern" are postulated. One conclusion is "against this background, the general application of the equal energy concept may have shortcomings".

John B. Ollerhead of England summarized the results of investigations of two factors involved in the use descriptors like Ldn as indices of acceptability, "one measure of which is community annoyance". The first factor is the weighting of events at different times of day. A comparison of number of disturbances during the day, evening and night, at different Leq levels, "indicates that aircraft noise is more intrusive during the evening than during the day and causes very little disturbance at night". The implication of these results is that for predicting community annoyance, "an evening weighting of 5 or 6 dB is a clear requirement". For the night, 10 dB is too large. In fact, Ollerhead suggests that the evening should be extended to about 1:00 a.m. to cover the falling asleep period, and a zero weighting should be used for the rest of the night.

The second factor has to do with noise from different sources. "In the United Kingdom there is some doubt about generalized noise descriptors such as Ldn because it is known that people react differently to noise from different sources." An example is given showing regression lines fitted to several surveys which share common scales of both noise (Leq) and reaction but involve different noise sources. For the same values of Leq, there was more dissatisfaction with road traffic alone than with a combination of road and aircraft traffic. An analysis of results like this indicated that the effective level of aircraft noise was 9.5 dB greater than that of road traffic noise. "In other words, reactions to the two sources, heard separately, would be the same when their levels were 9.5 db different."

John M. Fields and J.G. Walker of England reported on surveys of effects of railway noise designed to be compatible with other studies. Comparison with Heathrow data indicated that "at higher railway noise levels (74 Leq or 55 NNI) railway noise is estimated to be less annoying (than the aircraft noise) by the equivalent ... of 13-30 NNI". At lower levels (below 50 Leq and 35 NNI) the differences are less. There is no explanation of the less annoyed response in the railroad study.

In a community survey (sample size 5885) comparing areas of high noise (NNI over 55, or Ldn over about 74) near London (Heathrow) Airport to control areas (below 35 NNI or about 50 Ldn), Tarnopolsky, et al. found no relationship between noise and psychiatric illness rates. "The weight of the evidence shows that noise per se is not associated with mental illness and cannot be thought a major cause of them. At every level of noise, however, the percent of psychiatric respondents expressing high annoyance was greater than the percent of 'normal' respondents expressing high annoyance. This does not mean that the noise caused the illness. The rate of illness is independent of the noise, as stated above. Nor does it mean that only the psychiatric complain. Psychiatric cases are a minority of the population, and are also a minority of those with the highest annoyance. Most of the 'very annoyed' are psychiatrically normal; most of the psychiatric cases are free of annoyance."

Jacques Francois of France reported on an investigation of the relationships between noise, annoyance and health and personality factors near Orly Airport. "The average degree of anxiety, neuroticism, and extroversion is in no way modified by aircraft noise level, even among respondents exposed to a loud noise for a very long period of time." Objective questions relating to health do not show significant variations. However, subjective questions do show such variation. At higher noise levels, people complained more of feeling fatigue, or having pains, and fewer said that their health was good during the last 12 months.

Two summary papers discussed the subject of research for the future. One of these, by Jan Karlsson of Sweden, concluded with this sentence: "It is a widespread opinion among decision makers that annoyance has nothing to do with effects; I think it is very difficult to argue for actions against noise until it is easier than it is today to analyze the expression 'annoyance' or to quantify other effects of noise." In the other, Rylander expressed the opinion that a) the approach of a single noise unit for all environmental noise can probably be forgotten, because humans don't respond in the same way to noise from different sources, b) the general acceptance at Dubrovnik of the equal-energy concept, a single index combining levels and numbers, was premature. "I think that it is our responsibility to give this information to the decision makers and continue with carefully designed studies to evaluate the importance of levels and numbers."

A.22 Comparison of 1980 Compatibility Criteria

In June, 1980, a Federal Interagency Committee issued a report[80] containing guidelines for the compatibility of land uses with noise. Also in 1980 an American National Standard[79] on the same subject was issued. The FAR Part 150 table issued by the FAA follows the Federal Interagency guidelines closely, differing in organization and detail rather than in the recommendations themselves. The ANSI standard differs in that it, in general, specifies compatible and incompatible ranges, with a range from 5 to 15 dB wide between designated ranges as "marginally compatible". In general, the upper limit of the "marginally compatible" range corresponds with the "compatible" recommendation of the FAR Part 150 table. In four categories (transient lodging; schools, libraries and religious facilities; hospitals, clinics, nursing homes and other related facilities; and multistory residential facilities), the ANSI standard extends use up to 75 Ldn with special sound insulation to bring the Ldn inside down to 45, just as FAR Part 150 does. In other cases, the ANSI "marginally compatible" classification extends into the areas where FAR Part 150 recommends sound insulation.

In the residential classification, the differences are more pronounced. The ANSI standard does not propose sound insulation for other uses, such as single family residences above 65 Ldn, which FAR Part 150 suggests as a possible procedure although it will not eliminate outdoor problems. Table 12 illustrates the difference. The ANSI standard does not mention mobile homes. For residential uses other than transient or multistory apartments, the ANSI compatibility standards are more stringent than FAR Part 150, classifying all of these residential uses as marginal over 60 Ldn, and single family home use as marginal above 55 Ldn.

In the ANSI standard, the marginal range (M) is expected to be used by authorities as a range from which to pick a suitable limit applicable to the community considering local climate and construction practices.

A.23 John Wayne Airport Measurements, 1981

In 1981, an evaluation of noise abatement departure procedures was conducted at John Wayne Airport in Orange County, California.[87] During the evaluation, noise levels were measured and telephone interviews were conducted along the flight path. Respondents were asked to rate their annoyance from street traffic noise, small propeller driven aircraft, and large airliners, on a scale running from 0 to 4 where:

0 = not at all annoyed,
1 = slightly annoyed,
2 = moderately annoyed,
3 = very annoyed, and
4 = extremely annoyed.

Only the Ldn values from the large aircraft were measured. The values for street traffic were estimated, based on measurements made at other times, and on population density. The data on small aircraft noise was not available because the noise from large aircraft dominated the measurements. Ldn from large aircraft ranged from approximately 58 to 68. Over this range, the percent "highly annoyed" ranged from 40% to 55%, with 50% highly annoyed at 65 Ldn. This is considerably higher than the Schultz estimate of 15%, the Kryter estimate of 27%, or the Levels Document estimate of 33%. If Kryter's comment about the difference between values measured and calculated from peak values is accepted, then the noise measured at 65 Ldn would be equivalent to Kryter and Schultz values of 60 Ldn. The percent highly annoyed by small aircraft ranged from about 3% to about 25%; while the percent highly annoyed by traffic noise appeared to be closer to the Schultz estimate, from 5 to 10% at about Ldn 55 to 60.

In a study done in 1981[85] on reactions to changes in aircraft noise exposure, at the Burbank airport, results similar to the results from John Wayne were obtained. The self rating scale had five steps, like the one used at John Wayne. The results were well above the Schultz scale.

TABLE 12

COMPARISON OF FAR PART 150 AND ANSI 53.23-1980

LAND USE/NOISE COMPATIBILITY CRITERIA

Standard & Use	Ldn 50-55	Ldn 55-60	Ldn 60-65	Ldn 65-70	Ldn 70-75	Ldn 75-80
FAR Part 150						
Mobile Home Parks	Y	Y	Y	N	N	N
Transient Lodgings	Y	Y	Y	N(1)	N(1)	N
All other residential	Y	Y	Y	N(1)	N(1)	N
ANSI 53.23-1980						
Transient Lodging	Y	Y	Y	M	(1)	N
Residential						
Single - Extensive Outdoor Use	Y	M	M	N	N	N
Multiple - Moderate Outdoor Use	Y	Y	M	N	N	N
Multistory - Limited Outdoor Use	Y	Y	M	(1)	(1)	N

(1) refers to a requirement for insulation to reduce the inside level to 45 Ldn or below.

In a 1982 report[88] of the community response to noise changes at John Wayne Airport, there is a discussion of possible explanations for the difference between the observed results at the two airports and the Schultz curve. This discussion includes speculation that the self reports of annoyance "are due not only to exposure to aircraft noise, but also in part to exposure to continuing press coverage, political debate, and other forms of publicity of airport noise problems." In any case, these results reconfirm that annoyance can be expected to increase as noise increases, but this does not mean that the percentage of people annoyed can be predicted with any assurance from knowledge of the noise level alone.

A.24 Analysis of Social Surveys on Noise Annoyance, 1982

Kryter, in October 1982[90], using the same basic aircraft data as Schultz did in 1978[71], developed a scale of the percent of people highly annoyed which differs from Schultz by about 6 dB(A). These results are:

	Percent Highly Annoyed	
Ldn	Schultz	Kryter
45	.1	
50	1.3	5
55	3.9	10
60	8.5	17
65	15.2	27
70	24.6	40
75	36.9	59
80	52.4	80

It should be kept in mind that the Schultz results are from a combination of eleven different surveys; the Kryter curve considers results from six of the same surveys, all aviation. In the range from 50 to 70 Ldn, both have a spread in the curves of about 10 percent. In addition, each of the curves was fitted to points which did not necessarily lie on a smooth curve and which were averages. In either case, therefore, it would not be surprising if the actual numbers differed by five percent.

Kryter suggests that actual measurements of noise energy and calculated noise using the FAA's integrated noise model (INM) will give Ldn values about 5 dB(A) higher than those listed above, which were calculated from peak noise levels. In other words, a noise level of 65 Ldn calculated by the INM would be the equivalent of 60 Ldn in the above table; at 65 Ldn from the INM, the highly annoyed population would be about 9% according to Schultz and 17% according to Kryter.

Comparing the above with the Levels Document shows that the latter predicts an even higher percentage as "highly annoyed". The problem is which of the responses in a survey are to be counted as "highly annoyed"? Both the

Schultz and the Kryter values could be justified by the results of the first London (Heathrow) Airport survey, depending upon where one draws the "highly annoyed" line.

A.25 The Fourth International Conference on Noise as a Public Health Problem, 1983

In June, 1983, the Fourth International Conference on Noise as a Public Health Problem was held in Turin, Italy[95]. The proceedings from this conference recently became available. Following an Introductory Session, half-day sessions were devoted to each of seven Teams having these subjects:

Team 1 - Noise Induced Hearing Loss
Team 2 - Noise and Communication
Team 3 - Non-auditory Physiological Effects Induced by Noise
Team 4 - Influence of Noise on Performance and Behavior
Team 5 - Noise Disturbed Sleep
Team 6 - Community Response to Noise
Team 7 - Noise and Animals

The meeting concluded with a closing session on Noise Reduction and Costs. The following discussion is concerned only with items of immediate significance to land use compatibility with aviation noise.

A.25.1 Noise Induced Hearing Loss

Many of the reports in the Team 1 session were concerned with impulsive noise. No evidence was developed in either these reports or from other investigations that would indicate potential hearing loss problems from areas subject to aviation noise of less than 80 dB.

A.25.2 Noise and Communication

The attention of the participants in Team 2, Noise and Communication, shifted to include much more consideration of the effects of noise on the ability of the hearing impaired to understand, rather than consideration only of the effects on those with normal acuity.

Lazarus, in a paper reporting on developments in Germany, mentioned a new rating level for noise, L_r. This unit was Leq, plus a correction for impulsive noise, and a correction for tonal noise. In general, therefore, it appears that the numerical value of L_r would be equal to or greater than Leq. He went on to present tables showing limiting values to insure "a certain speech intelligibility" (otherwise undefined) in restaurants, homes, auditoriums, offices and conference rooms during the day. The following values for L_r with no corrections for impulse or tonal noise were given for rooms "where noise comes from outside":

For homes in the daytime, auditoriums, conference rooms, hospitals and private offices, L_r = 30 - 40.

For homes at night, L_r = 25 - 35.
For offices for several persons, L_r = 35 - 45.
For restaurants, L_r = 40 - 50.

There was no discussion of the derivation of these values.

Houtgast reiterates and use the discussion of reverberation which was presented in the 1978 conference (page A-79) as a critical noise level below which noise at lower levels does not affect speech intelligibility. In the introductory paper for this session, Webster specified these as 35, 45 and 50 dB(A) for a living room, classroom and conference room respectively (page A-80). There was no discussion of the reverberation effects and the recommendations given by Lazarus.

A.25.3 Non-Auditory Physiological Effects Induced by Noise

Papers in this session reported on laboratory and field experiments both with humans and, in some cases, animals. They ranged from investigations of effects of noise on fetuses to comparisons of incidence of psychiatric disorders between those who were and those who were not noise sensitive. A general observation can be made: when noise levels are reported they are, in most cases, high - i.e., 90 dB(A) and up. For example, fetal habituation to auditory stimuli was demonstrated. That is, the reaction decreased with repetition (Granier-Deferre). The stimulus itself was 5 seconds of pink noise, low pass filtered at 800 Hz, delivered through a loudspeaker 20 cm. above the maternal abdominal wall at 106 dB S.P.L. This is a level unlikely to be encountered in the normal living room.

Effects of a background of both weak and loud impulse noise on reaction time were reported by Mantysalo. Weak noise was a background level of 60 dB(A), with bursts of impulse noise at 75 dB(A). Loud noise had a background of 75 dB(A) with peaks of 90 dB(A). Reaction time, in the test chosen, was less with the loud noise than with the weak noise background.

A comparison of blood levels of glucose and fatty acids of workers exposed to 95-111 dB noise with blood levels of a control group not so exposed was reported by Konarske. Glucose was the same in both groups. Free fatty acids were significantly lower in the exposed group, while total fatty acids were slightly lower. The author states "these changes seem not to be typical for wide-band noise influence."

In work reported by Rovekamp, laboratory experiments were conducted with fifteen subjects (7 women and 8 men) with recorded noise at 75 dB(A) of four different types for two hours. The percent of the subjects reported annoyed or very annoyed by each of the four types of noise were:

Impulse noise	76.9%
Railway noise	61.5%
Road traffic noise	50.0%
Aviation noise	57.1%

(There was no explanation of how 11.54, 9.23, 7.5 and 8.57 persons can be annoyed.) In each case, changes in heart and respiration rates, blood pressure and vasoconstriction were also measured. Nine "noise-sensitive" persons were also tested, and the same changes measured. It was concluded that exposure to noise with an equivalent sound level of 75dB(A) caused significant changes in heart rate (up to +4.5%) and respiration rate (from -1.6% to +4.9%). There were small changes in the systolic blood pressure. The other changes were generally not statistically significant. Sound-sensitive subjects reacted with larger changes than normal subjects. This experiment lead to the recommendation that there be a study of the effects of long-duration (8 hours) environmental noise exposure with levels lower than 75 dB(A) to establish the level which causes no effects.

Dijk reported the results of a test of 24 male subjects doing light physical work under noise levels (Leq) of 90 dB(A). The mean diastolic blood pressure was increased a small (1 mm Hg) but significant amount. The effect of systolic blood pressure and heart frequency was not significant. In Dijk's experiment the work-noise periods were 20 minutes long; in Rovekamp's experiment, there was no physical effort, and the noise lasted two hours for the "normal" and one hour for the "sound-sensitive" people.

A.25.4 Influence of Noise on Performance and Behavior

Although new techniques of testing were used to gauge the performance of laboratory tasks at noise levels below 90 dB, the application, if any, to land use compatibility with aviation noise was not evident.

A.25.5 Noise Disturbed Sleep

The second paragraph of the opening paper in this group (Muzet) stated: "Research on the direct and indirect effects of noise on sleep has given no definite answers as to what are the major factors of sleep disturbance." The sixteen papers in the group do present some interesting glimpses of the state of research. "The effects of noise on sleep are often immediate and of short duration." "Poor sleeper's auditory arousal thresholds have been found to be the same as those of good sleepers." "Long-term habituation of noise effects is certainly a major problem and it will have to be more deeply studied in the future." Some investigators have found no adaptation; others have noted rapid adaptation (Muzet).

"The results suggest that people who live in noisy locations are more sensitive to acoustical stimulation (Greifahn and Gros)." Traffic noise with "(p)eak levels around 45 dB(A) indoors caused awakenings in the field study. The results underline the importance of peak noise levels rather than total noise energy in Leq for sleep disturbance effects (Ohrstrom)." "We provided evidence that double glazing does not reduce measureable sleep disturbance due to traffic noise (Kumar et al)." "We conclude ... that there is practically no habituation of H(eart) R(ate) reactivity after a 6-year exposure to aircraft noise by night and, although people are subjectively rather well adapted, the physiological effect of noise persists (Vallet et al)."

Thiessen reported the probability of waking due to aircraft passes with a duration of 5 seconds as a function of peak level in dB. At 65 dB, the probability is about .25; at 70 dB, .45; and at 75 dB, .65. This observation indicates that Ohrstrom's observation noted earlier apparently does not mean that peak levels of 45 dB(A) always caused an awakening. Thiessen also reported that the waking reaction is reduced by about half in two weeks. After discussing various effects observed, Thiessen said "the relation to health is omitted entirely for obvious reasons."

A.25.6 Community Response to Noise

In the opening review paper, Griffiths made the following comments: "Community response has been implicitly defined as unfavourable, even to the extent that laboratory studies (which by definition provide no normal social context for noise evaluation) often fail to differentiate between loudness and noisiness... It may well be the case that the term 'community response' has reached the end of its useful life... It may well be that the continued use of the phrase allows researchers (and administrators) to escape two genuine problems which it is absolutely necessary to face: the first, that at the present time it is possible to predict individual responses to noise within only a very wide band of uncertainty; and the second, that knowledge of the scale of individual differences in response has a vital role to play in helping us set community noise standards... A considerable proportion of the literature now refers to dose-response relationships and it is, unfortunately, quite possible that similar considerations apply to this usage. In experimental toxicology, both dose and response are operationally-defined and objective phenomena... In the case, however, of noise, this is far from being the case, since even the dose requires subjective definition. The objective acoustic datum is sound, the physical characteristics of which are measured by our acoustic technology; noise itself has to be psychologically defined. The response we measure, it should be understood, is even less objective and the attempt to describe the relationship between received noise and expressed reaction as a crude input-output process in which there are no intervening variables within the black box (the human being) is doomed to failure. The phrase dose-response relationship seems to encourage that simplicity of thought, and remove the possibility of investigating human diversity."

In his review of the field of aircraft noise, Griffiths cited particularly the work of Taylor and Hall, et al. in Canada, and Rylander in Sweden. The latter had "continued to argue for a reassessment of the interaction of overflight frequency and peak noise level." They concluded that the number of overflights had an effect only up to about 50 overflights in 24 hours. Above 50 overflights in 24 hours, Rylander's group felt that the maximum noise level (dB(A)) which occurred at least three times in 24 hours best represented community response. Comparing two airports, the Canadian group found that "for the same NEF, however, the smaller airport of the two always generated more disturbance, thus confirming the operation of different models for varieties of the same noise source."

Griffiths devoted considerable time to a review and critique of the Schultz curve[71] (page A-74). "Both methodological and empirical points can be raised which cast doubt upon the validity of Schultz's procedures, and perhaps on some of the changes of attitude among noise researchers which seems to have followed the advent of Schultz's synthesis."

Borsky reported on a study done for the U.S. Air Force at seven Air Force Bases. Interviews and noise neasurements were conducted on and off the bases. Ten different cumulative noise measures were calculated, the highest and the average values of each of the following:

1. Ldn
2. Leq
3. Number of flights by dB(A) peak for day, evening and night (5 dB(A) intervals)
4. Sound exposure level (SEL) by time of day.
5. Integrated Hourly Noise Level (HNL) by time of day.

Each of these was correlated with a measure of annoyance (scale of 0-9) based on reported interference with communication, sleep, rest, concentration, etc. "The best predictor of annoyance proved to be a multiple correlation of the highest number of flights by peak dB(A), by day, evening and night periods. The second best physical predictor, just slightly less effective, was the average number of flights, by peak dB(A) and time period." Over a third of total individual variance in annoyance response was explained by the combination of number and peak dB(A) by time of day.

Turning to the personal attitude and experience differences in the population, Borsky reported that three personal variables were most significant with regard to annoyance: 1) fear of crashes, 2) belief that airplane operations were a hazard to health, and 3) readiness to complain. When these three factors were included in the correlation, along with the physical descriptors which were the best predictors, a multiple correlation coefficient of R = .81 was achieved, explaining over two-thirds of all individual variance in annoyance response. To simplify the calculation, the physical descriptors were collapsed from 5 dB intervals to three intervals, 70-84.9, 85-99.9, and 100+ dB(A). The correlation coefficient from the resulting 12 variables (9 physical descriptors and 3 personal descriptors) was R= .80. "While the prediction equation has 12 items which is not as simple to use as a single physical index, it clearly is more related to human annoyance and can be defended as more valid."

A.25.7 Noise and Animals

There was a paucity of papers on this topic. A literature review by Fletcher cited the conclusions of a workshop at San Diego on the potential effects of Arctic oil exploration, development and production on arctic marine mammals. The conclusion was "the evidence submitted at the workshop indicates that existing scientific knowledge is insufficient for a comprehensive appraisal of the impact of man-made noise from projected petroleum-related activity on arctic marine wildlife".

Two experimental programs, one with rhesus monkeys, the other with baboons, had apparently contradictory results. Monkeys exposed to Leq levels from 85 to 90 dB(A) showed sustained blood pressure elevatons. The increased blood pressure continued after the termination of the experiment which lasted three to nine months (Peterson et al.). Sub-adult baboons had an initial increase in blood pressure with noise levels of 83 to 97 dB(A) for eight hours a day, but these levels soon dropped; and over the long term both blood pressure and heart rate were lower than before the test. After completion of the experiment, both blood pressure and heart rate were approaching pre-test levels by the end of two weeks (Turkkan et al.).

Luz pointed out that, to make logical decisions about noise and wildlife, three questions must be answered:

1) How loud is the noise to the species of interest?
2) Does the noise, per se, pose a threat?
3) Can the species adapt without adverse physiological consequences?

The first question was based on different species having different auditory sensitivities. To use dB(A), which simulates human frequency response, to evaluate the effect of noise on other species is highly suspect. The other two questions brought one squarely up against the issues raised at the San Diego workshop.

A.25.8 Closing Session - Noise Reduction and Costs

In this session, Eldred proposed the use of a different, linear measure of sound exposure. The unit is the "time-integrated squared A-weighted sound pressure." The eight hour equivalent of 90 dB is 11,520 pascal squared seconds (or 11.5 kilo Pa^2S). The day-night weighted sound exposure of 1 Pa^2S is the equivalent of 44.614 Ldn. Ten Pa^2S would be 10 dB higher; 100 would be 20 dB higher. Adding sound exposure becomes simple. For example, one hour at 90 dB would be a sound exposure of 1440 Pa^2S. One hour at 60 dB would be 1.44 of the new units. A schedule of exposure could then be summed by simple addition. The following illustration was prepared by the reviewer:

Time Period	Time of Exposure (Hours)	Noise level, dB	Pa^2S
2400 - 0600	6	35	.036
0600 - 0700	1	40	.0144
0700 - 0900	2	50	.288
0900 - 1200	3	75	135.00
1200 - 1300	1	65	4.50
1300 - 1700	4	75	180.00
1700 - 1900	2	80	288.00
1900 - 2000	1	85	450.00
2000 - 2400	4	35	.009
Total		24 hr Leq 74.9	1057.85

APPENDIX B

TOTAL DAILY TIME ABOVE SPECIFIED NOISE LEVELS, AT 65 Ldn

The FAA requires that, under certain circumstances, environmental assessments provide information about the amount of time, in minutes, that the noise level in noise sensitive areas is expected to be above specified levels: 65 dB(A), 75 dB(A), 85 dB(A), etc. No attempt has been made to correlate this information with residential land use compatibility. However, it does provide a means of comparing the peak levels of aircraft noise with peak levels from other sources.

A recent environmental assessment[85] was examined for the relationship between Ldn and time above data. Points close to the 65 Ldn contour were selected for three different cases, i.e. different traffic samples. The results were as follows:

Time Above (Minutes)

			65 dB(A)	75 dB(A)	85 dB(A)
Case 1	Point 1	Day	163	63	3
		Night	18	8	0
		Total	182	71	3
	Point 2	Day	200	79	7.1
		Night	22	10	0.6
		Total	222	89	7.7
	Point 3	Day	148	36	-
		Night	18	5	-
		Total	166	41	-
	Point 4	Day	166	46	-
		Night	20	6	-
		Total	186	52	-
Case 2	Point 1	Day	401	149	1.2
		Night	39	15	0.1
		Total	440	164	1.3
	Point 2	Day	403	51	-
		Night	40	5	-
		Total	443	56	-
	Point 3	Day	413	22	-
		Night	44	2	-
		Total	457	24	-

Time Above (Minutes)

			65 dB(A)	75 dB(A)	85 dB(A)
Case 3	Point 1	Day	526	0.33	-
		Night	72	0.08	-
		Total	598	0.41	-
	Point 2	Day	590	89	-
		Night	59	2	-
		Total	649	91	-
	Point 3	Day	666	40	-
		Night	98	10	-
		Total	764	50	-

The first two points in Case 1, and the first point in Case 2, were inside the 65 Ldn contour. The other points were more nearly on the 65 Ldn contour..