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NOISE CERTIFICATION CRITERIA AND IMPLEMENTATION CONSIDERATIONS FOR V/STOL AIRCRAFT. VOLUME I

MAN-Acoustics and Noise, Incorporated

Prepared for:

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MAN- Acoustics and Noise, Inc.
Seattle, Washington

November 1975

Final Report

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

Although this first phase of a two-phase program emphasized the extent that Perceived Noise Level in PNdB, Perceived Level in dBA, and corrections to these engineering calculation procedures reflected annoyance to next generation STOL aircraft noise signatures, other aspects of certification implementation were also considered and will be emphasized in a report on the second phase of the program.

As a means of determining the accuracy and reliability of engineering calculation procedures that could be utilized as a basis for noise certification of V/STOL commercial aircraft, 36 persons made annoyance judgments to 34 noise signals presented at 5 different levels. The signals included recordings of conventional jet aircraft operations, turboprop and reciprocating engine powered commercial aircraft, helicopter flybys, and simulations of V/STOL operations. Both relative annoyance and absolute acceptability judgments were obtained. Some of the results are:

- For flyover (not hover) operations EPNdB validly and reliably predicts annoyance.
- For hover type of operations EPNdB under predicts annoyance.
- When applied to all aircraft types, the FAR-36 tone correction degrades reliability for both PNdB and dBA while the duration correction improves reliability to a significant extent.
- A difference between calculated and judged values should be equal-to-or-greater-than 3 EPNdB in order to conclude that the difference is reliable.

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Annoyance to Noise

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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

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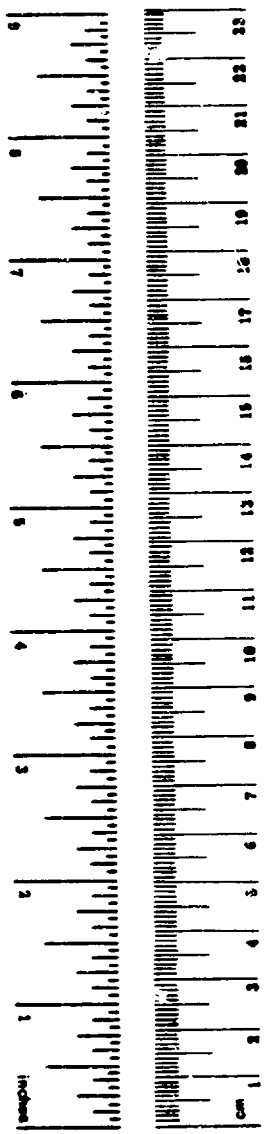
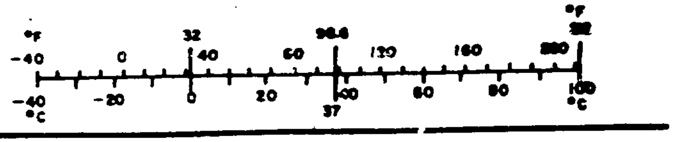
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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



PREFACE

This work involving noise certification and implementation for vertical and short takeoff and landing commercial aircraft (V/STOL) is being completed in two phases. Findings from the first phase are given in this report (Volume I) which emphasizes the accuracy and reliability of engineering calculation procedures that could be used as a basis for certification plus annoyance response to next generation STOL aircraft. A report on the second phase will be completed at a later date. This work will emphasize noise certification of helicopters but will also include community noise criteria considerations, and certification measurement and instrumentation recommendations for both V/STOL aircraft and helicopters. Results from this first phase will be considered in conjunction with those from the second phase.

A number of persons made significant contributions. A. F. Emanuel is the Principal Researcher for both phases and contributed to all aspects of the work. The quality magnetic tapes for obtaining judgment data were assembled and analyzed by B. M. Sullivan, and T. L. Hughes and D. B. Shields were responsible for the data analysis and reduction aspects of the program. Several staff members, including T. G. Dorrance, took part in obtaining flyover recordings of next generation STOL aircraft, and in collecting the human response data. J. E. Mabry functions as adviser and coordinator while P. B. Oncley is the consultant relative to physical acoustic and instrumentation problems. Finally, we want to thank Thomas Higgins of FAA Systems Research and Development Service for his interest and technical guidance in completing this first phase of the program.

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1. INTRODUCTION

Aircraft type certification for noise has played and will continue to play a significant role in reducing noise in areas around airports. As new aircraft, with different aerodynamic and operational characteristics and hence different noise characteristics, are introduced, type certification will continue to play an important part in continuing the present trend of decreasing airport noise. However, the extent that current certification technology for conventional takeoff and landing (CTOL) aircraft applies to these new or next generation aircraft requires consideration. Some of the present type certification technology will certainly apply to these new aircraft but due to such differing operational characteristics, modifications to type certification regulations for vertical and short takeoff and landing (V/STOL) aircraft will very likely be required. The broad aim of this research program is to develop the essentials for certification of V/STOL aircraft. There are four objectives associated with accomplishing this broad aim. They are:

1.1. Determine the engineering calculation procedure that validly reflects annoyance response to V/STOL aircraft.

The correct engineering calculation procedure is basic to aircraft noise certification. Since the eventual use at airports of noise certification programs involves mixes of various types of aircraft, what is required is an engineering calculation procedure that equally reflects annoyance effects from the various types.

1.2. Estimate noise levels that will be acceptable to communities surrounding airports.

This will not only contribute to criteria decisions involving airport noise but will also aid in establishing certification levels and measurement points.

1.3. Obtain results that will permit integration of noise produced by V/STOL into existing airport noise modeling approaches.

This objective is related to the first one (1.1. above) but involves determination of perceived levels for the various aircraft types utilizing any required engineering calculation procedure. Thusly, corrected noise distance curves can be employed to obtain total noise impact via noise models such as Noise Exposure Forecast (NEF) or Mode II Aircraft Sound Description System ($ASDS_{MII}$).

1.4. Determine the extent that existing certification technology for conventional takeoff and landing (CTOL) aircraft applies to V/STOL aircraft.

Since much effort and deliberation has been expended in the development of CTOL certification technology, where it is feasible and technically appropriate, this effort can be applied to V/STOL aircraft noise certification. Study is required concerning the extent that CTOL technology is applicable to V/STOL noise certification technology.

2. EXPERIMENT DESCRIPTION

2.1. APPROACH

As a means of obtaining data relevant to the broad aim and objectives, a psychophysical study was completed. Thirty-five persons made both magnitude estimations and absolute acceptability judgments to both actual and simulated recordings of aircraft fly-overs using the following instructions:

> "We are asking you to help answer the question, "How annoying are various kinds of sounds?" We will ask you to listen to some sounds and rate them in terms of annoyance. The sounds you are to rate will be presented to you one-at-a-time. Listen to all of each sound before making your judgment. In a moment, we will have you listen to a sound with an annoyance score of 10. Use that sound as a standard, and judge each succeeding sound in relation to that standard. For example, if a sound seems twice as annoying as the standard, you will write "20" in the space for that sound on the answer sheet. If it seems only one-quarter as as annoying, write 2-1/2. If it seems three times as annoying, write "30". If slightly more than twice as annoying, you may choose to write "21" or "22" or "23", whatever is appropriate. If slightly less annoying than the standard, use the number that best expresses the difference, such as "7" or "8", and so on.
>
> We will also ask you to judge if each sound you hear would be acceptable to you if you experienced it in your home four or five times an hour during your waking hours. This requires a simple "yes" or "no" answer in the space provided on the answer sheet.
>
> Your ratings should reflect only your own opinion of the sounds; that is what we want. Each sound is numbered to correspond to the numbers on your answer sheet.
>
> You will now hear the standard sound with an annoyance rating of 10, followed by five more sounds. Rate each of the sounds following the standard as previously instructed; a score of "20" if twice as annoying, "5" if half as annoying, and so on. Also indicate your judgment of the acceptability of each sound."

Each subject evaluated thirty-three noises of which thirty-two were aircraft flyovers from diverse types of aircraft plus eight seconds of USASI (Ref. 2-1) noise which was used as a standard. Subjects were individually tested in a small semi-reverberant chamber so that the spectral characteristics and level of the noises introduced were controlled. All noises were presented at five different levels and in a random order. Total testing time for each subject was approximately five hours. Evaluations were made during two testing sessions of two to two and one-half hours each, with each session taking place on a different day. The testing schedule was in accordance with the recommendations of Reference 2-2 (page 47) so that the subjects would not become fatigued by judging too many noises without rest. Ten to twelve judgments were made followed by rest periods. Since the same standard was used for both testing sessions and each noise was presented at five levels, each of the thirty-five persons evaluated 170 distinct noise events for a total of 5, 950 noise evaluations. Essentials of the experiment are:

- Thirty-two flyover signals and one standard noise. Each noise was presented at five different levels.
- The noise judgments were obtained using both magnitude estimation and absolute acceptability methods.
- Thirty-five persons evaluated 170 distinct noise events.
- Ten different engineering calculation procedures were related to the magnitude estimation results and analysis of variance was used to determine real differences among different calculation procedures and types of noises.

2.2. FLYOVER SIGNALS

A measure of the validity and usefulness of a particular engineering calculation procedure is the extent that its results correspond or correlate with direct judgment results. For example, if a group of noises with diverse spectral, temporal, and onset characteristics are all presented with their maximum level at 73 dBA, are all these noises judged equally loud or annoying by a representative group of subjects ? If all noises were rated as being equally annoying, it would be concluded that dBA validly reflects the effect on people of that diverse group of noises. So as to adequately test a particular engineering calculation procedure, a diverse group of noise signals is required. Thusly, one of our aims in selecting and simulating flyover signals was for their noise characteristics to markedly vary for groups of flyovers but at the same time utilize signals that are representative of current and future aircraft. Table 2-1 lists the noise signals utilized and gives a general description (where needed) of each signal. For the most part, four kinds of aircraft are involved. These included a sample of conventional takeoff and landing aircraft (CTOL) (Signals 1-8), commercial turboprop and reciprocating engine powered aircraft (Signals 9-13 and 23), helicopters (Signals 14-22), and simulations of V/STOL turbojet and turbofan powered concepts which are under consideration as next generation aircraft (Signals 24-30). Of the numerous aerodynamic/propulsion concepts studied for use in passenger or freight STOL or VTOL aircraft, only the helicopter and conventional turboprop are used commercially. Thusly, existing helicopter and turboprop flyover noise signatures were utilized. The noises from two VTOL aircraft, one an experimental tilt-wing turboprop (Signal 33), the other an operational military fighter (Signal 32) using vectored turbojet thrust, were also used as a means of investigating a wide variety of flyover noises. Though many turbojet and turbofan powered concepts have been evaluated for commercial V/STOL use, it is not yet known which, if any, will eventually become operational. Each of the proposed concepts, e.g. augmentor wing, upper surface blowing, lift fan, etc., has its own noise characteristics, but only a detailed parameter study of a particular airframe/propulsion combination can provide an approximation to what would be the actual flyover noise signature. Rigorous attempts to precisely describe the noise character of the different lift/propulsion concepts will not necessarily result in a clearly significant differentiation between one concept and another. The results could be and often are quite similar, depending on such factors as the type and size of the powerplant, type and extent of noise treatment, takeoff and approach gradients, and location of the measuring points. Even if there were clear differences, the resulting subjective data would be related to that particular hypothetical aircraft, and would not necessarily have general application. Consequently, the V/STOL simulations are designed to be representative of the general noise problems of these next generation aircraft and involve such problems as lengthened duration and other effects related to hover and slow flight. The rate of onset and decay of the noise, the broad-band spectral content, the dis-

TABLE 2-1. Listing of noise signals.

SIG.#	FLYOVER NOISE/SIMULATION	OPERATION	DESCRIPTION
1	Boeing 737	Takeoff	
2	DC-8	Takeoff	
3	Boeing 737	Approach	
4	DC-10	Approach	
5	Boeing 747	Approach	
6	DC-8	Approach	
7	DC-10	Takeoff	
8	Boeing 747	Takeoff	
9	Beech 99	Takeoff	Small commuter turboprop
10	Britten-Norman Islander	Takeoff	" " reciprocating
11	Convair 640	Takeoff	Medium turboprop
12	Beech 99	Approach	Small commuter turboprop
13	Britten-Norman Islander	Approach	" " reciprocating
14	Chinook	Takeoff	Twin engine, twin rotor helicopter
15	Chinook	Approach	" " " " "
16	Cobra	Approach	Single engine, single rotor helicopter
17	Cobra	Approach	" " " " "
18	Huey	Approach	" " " " "
19	Cobra	Approach	" " " " "
20	Huey	Takeoff	" " " " "
21	Kiowa	Approach	" " " " "
22	Chinook	Approach	Twin engine, twin rotor helicopter
23	Convair 640	Approach	Medium turboprop
24	SIMULATION		5 second duration, conventional time history
25	SIMULATION		15 second duration, conventional " "
26	SIMULATION		25 second duration, conventional " "
27	SIMULATION		VTOL sideline
28	SIMULATION		Strong tone, no Doppler
29	SIMULATION		" " , with Doppler
30	SIMULATION		With double peak
31	USASI		8 second duration
32	Harrier	Takeoff	VTOL military jet fighter
33	LTV XC-142		Tilt wing turboprop V/STOL
34	USASI		Again

crete tone content, the rate of doppler shift, and the duration (10 dB down or otherwise) are considered in constructing these simulated noise signals. Details of the method of simulation and the noise characteristics of these flyovers are given in paragraph 3.4. Lastly, signals 31 and 34 are the noises (USASI noise) that were used as a standard for the two testing sessions.

Engineering calculation procedures most often utilized to measure noise effects on persons are dBA and Perceived Noise Level in PNdB or EPNdB (Ref. 2-3). The latter has had wide application for determining response to transport class aircraft noise and the EPNdB unit is used for noise certification of these larger aircraft. The dBA measurement approach has been widely applied to community noise measurements and in particular to the measurement of surface transportation noise; in addition, it is used for certification of general aviation aircraft noise involving planes of 12,500 pounds and under. Thusly, this study emphasizes the effectiveness of dBA, PNdB, and variants of these two measurement units. In all, ten engineering calculation procedures are related to the subjects' evaluation of the noises. They are:

dBA
dBA$_T$
dBA$_D$
EdBA
PNdB
PNdB$_T$
PNdB$_D$
EPNdB
Mark VI
Mark VII

The subscript "T" means that dBA and PNdB are tone corrected in accordance with the specifications of FAR-36 (Ref. 2-3) while the subscript "D" is a correction for the duration of the flyover according to FAR-36. EdBA and EPNdB mean that dBA and PNdB are corrected for both tone and duration. Mark VI and Mark VII are the perceived level approaches based on the work of S. S. Stevens (References 2-4 and 2-5).

Each of the flyover signals and the standard noise of Table 2-1 was presented to the subjects at five different levels. The aim was to present, in the chamber, each signal at a peak dBA level of 57, 61, 65, 69, and 73 dBA. This range of levels was selected since it covers an expected range for persons in their homes with out-of-doors levels ranging from approximately 77 to 93 dBA. All of the signals at all levels were recorded in the chamber and the ten engineering calculation procedures described above were applied to these recordings (details of the physical acoustics are given in the next section, "3. EQUIPMENT DESCRIPTIONS AND SIGNAL ANALYSIS"). These 170 signals to which are applied the ten different engineering calculation procedures are the independent measures for this study. It is these values that are related to the judgment data as a means of defining the most effective engineering calculation procedure and to estimate level of acceptability of the various noise signals.

2.3. DEPENDENT MEASURES

As indicated in the instructions, the subjects were asked to make two evaluations of each of the 170 noises presented. They first used magnitude estimation as a noise rating approach and then made an absolute acceptability judgment as to whether-or-not they could accept that particular noise if experienced four or five times an hour during their waking hours. A description of these two methods of evaluating the noises follows.

2.3.1. Magnitude Estimation

This psychophysical method which was introduced by S. S. Stevens (Refs. 2-6 and 2-7) and has been used widely as a method of relating human response evaluations to physical stimuli. Results from many studies indicate that the relationship between sensation and the physical stimulus is a power function (Ref. 2-6, p. 166). The relationship is:

$$\psi = kI^n$$

where ψ = subjective response
I = stimulus intensity
k = constant of proportionality
n = constant exponent

If the intensity is expressed in decibels, then the equation after rearranging becomes:

$$\log_{10}\psi = \frac{n}{10} \times \text{dB} + \text{constant}$$

Consequently, a log-log plot of subjective response versus stimulus power gives a linear relation with a slope of n/10. The quantity n has been determined experimentally for many stimuli. For noise in particular it has the approximate value of 0.3.

The magnitude estimation method is then utilized to obtain a "Subjective dB" for each noise (Ref. 2-2). Subjective dB is the mechanism for evaluating the various engineering calculation procedures. Subjective dB answers the following question: "For a particular engineering calculation procedure as applied to a noise event, do the judges place the noise at the same level as does the engineering procedure and if there is a difference between the judged and calculated level, how great is that difference?" The Subjective dB method for investigating various engineering calculation procedures can best be understood by reference to Figure 2-A.

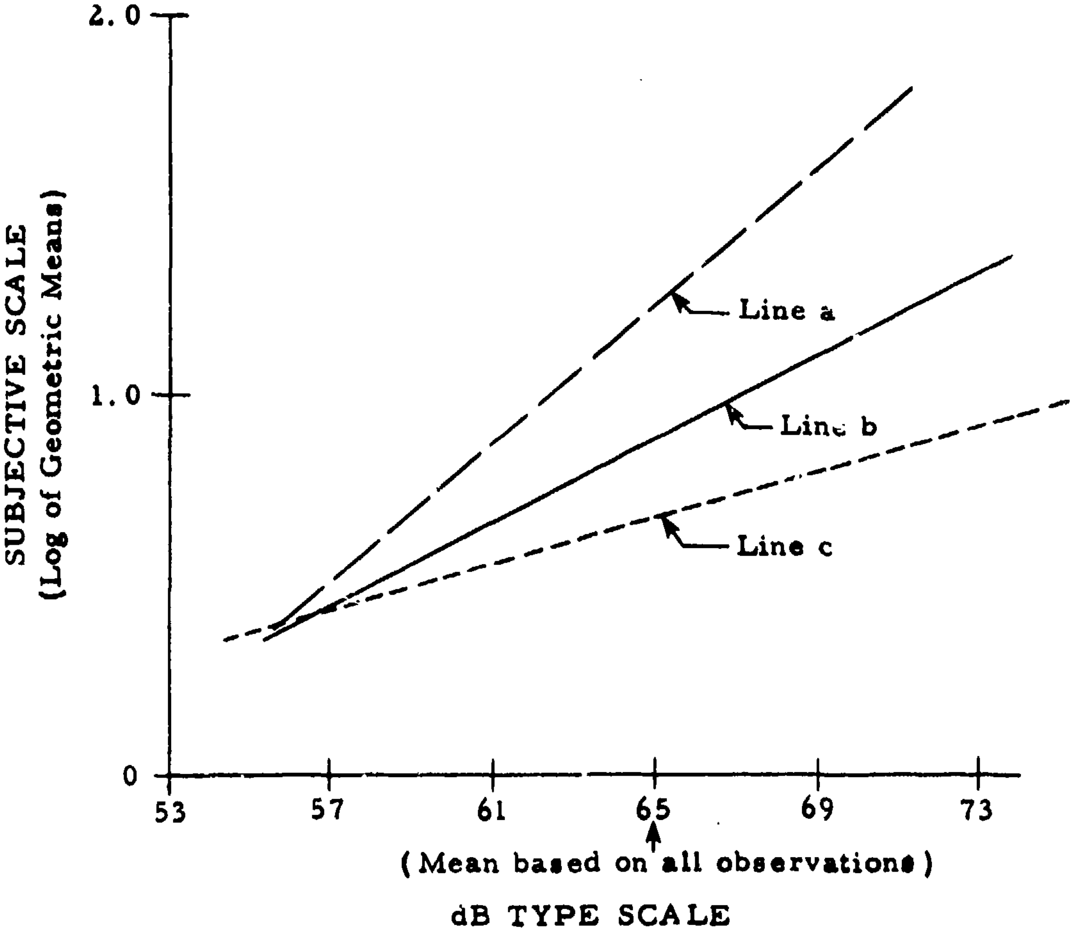

FIGURE 2-A. Derivation of Subjective dB.

Two assumptions form the basis for acquiring a Subjective dB for any one of the thirty-three noises. These assumptions are:

- That the group of subjects is matching numbers in a manner that reflects the amount of annoyance.

- That rate of change of annoyance is different across noises and is a function of a particular noise under investigation.

The abscissa in Figure 2-A gives values for a particular calculation procedure under investigation while the ordinate represents the mean evaluations by the judges. Line b is the least squares, best-fitting straight line based on judgments to all noises at all levels. Line b would be based on 170 points, 34 noises at 5 levels. Lines a and c are best-fitting lines for two hypothetical, individual noises (both Lines a and c would be based on the five levels for a particular noise or on five points).

The operations in calculating a Subjective dB are:

(1) Obtain equation for best-fitting line using all levels of all noises investigated. This gives an estimate of how well an engineering calculation procedure performs for a wide variety of noises.

(2) Obtain equation for best-fitting line for each individual noise (Lines a, c, ...)

(3) Using the mean of a particular engineering calculation procedure, find, for each individual noise (Lines a and c), the subjective response score predicted by this grand mean.

(4) Using the subjective response score obtained in (3), calculate the engineering calculation procedure value using best-fitting line based on all observations (Line b). THIS VALUE IS THE Subjective dB for ME.

Using results from Figure 2-A as an example: For the noise on which Line a is based, when the noise is calculated to be at 65 on a dB-type scale, the judges place it at approximately 71, Sub. dB is 71. For the noise on which Line c is based, when the noise is calculated to be at 65 on a dB-type scale, the judges place it at approximately 61, Sub. dB is 61. Each of the 34 noises investigated will be assigned a Sub. dB as described. The predicted results, for each engineering calculation system investigated, will be similar to results presented in Figure 2-B.

For a perfect engineering calculation procedure and no experiment error, all values in Figure 2-B would be zero and the rate of change of annoyance for all noises would be equal. The engineering calculation procedure with the least range of differences

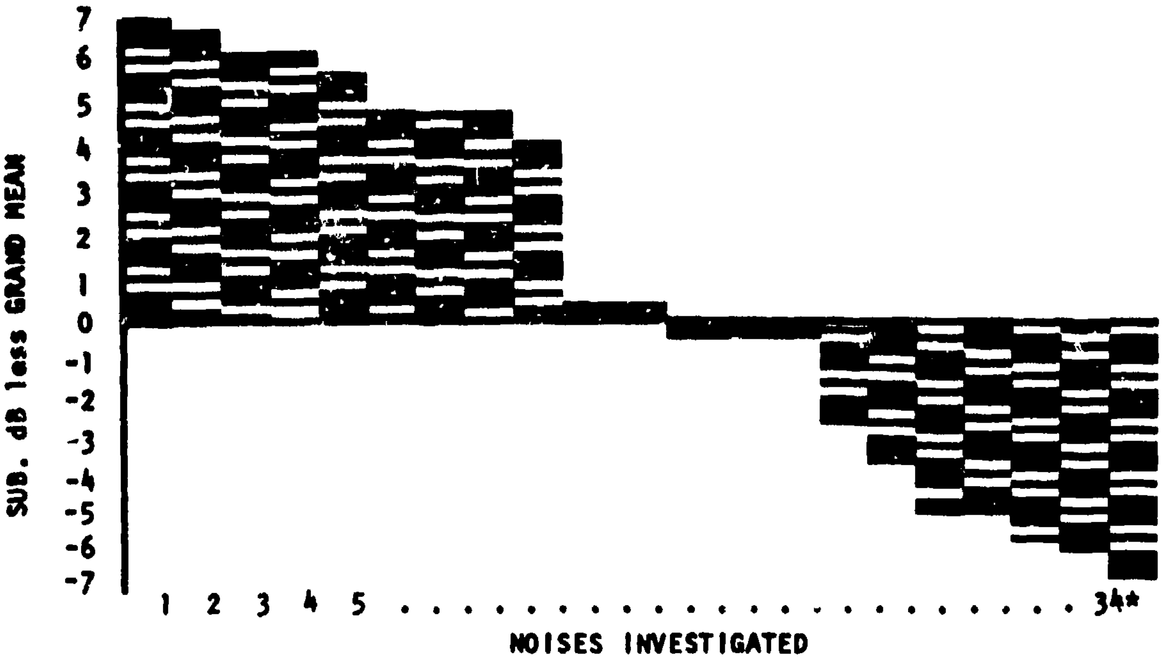

FIGURE 2-B. Predicted Sub. dB results, ME

*** The standard is investigated on two occasions so it is included for both to give a total of 34 signals.**

is the procedure which has the greatest application potential.

2.3.2. Absolute Acceptability

The aim with this approach is to provide data for establishing noise levels that will be acceptable to persons in communities surrounding various kinds of airports. Thusly, we are seeking results relative to establishing a threshold of acceptability. Since this method does involve a prediction in the sense that the subjects are instructed to estimate if an individual sound would be acceptable if experienced in their home four or five times per hour during their waking hours, the intent is to utilize these results in conjunction with other methods for establishing thresholds of acceptability. Results will be presented as the percent of persons accepting a particular noise at each of the five levels.

2.4. SUBJECTS

Prior to collecting the data for this study, we had completed two studies involving thirty-six adult males and thirty-six adult females using our Community Noise Simulation Systems. These persons were utilized as subjects for the present experiment. Each subject was examined audiometrically so that any persons with serious hearing deficiencies could be eliminated. Also, a noise oriented questionnaire was administered to each subject; we were particularly interested in making certain that the group could be considered representative of an adult population in general. Following are summaries of pertinent characteristics of persons taking part. The question or characteristic investigated is given along with the response information. Twenty females and fifteen males took part in the study.

1. How do you like living in this neighborhood? Do you rate it as an excellent, good, fair, poor, or very poor place to live?

	FEMALE	MALE
Excellent	65%	40%
Good	25%	33%
Fair	10%	27%
Poor	---	---
Very Poor	---	---
Don't Know	---	---

The females have a higher tendency than do the males to rate their neighborhood as excellent.

2. Do you like many things, just a few things, hardly anything, or nothing at all about living around here?

	FEMALE	MALE
Many things	85%	67%
A few things	10%	33%
Hardly anything	5%	---
Nothing at all	---	---
Don't know	---	---

Again, the females are more positive about their neighborhood than are the males. Also, there is a greater tendency for both sexes to report liking many things about living around here than to rate their neighborhood as excellent (see question 1.).

3. What are some of the things you DON'T like about living in your neighborhood?

This open-ended question was examined for whether-or-not noise was mentioned. Thirty-five percent of the females spontaneously reported that noise was one of the things they did not like about their neighborhood while forty percent of the males mentioned noise. Traffic noise and barking dog complaints predominated and were given approximately equally by both males and females.

4. How noisy or quiet do you think this neighborhood is? Very noisy, somewhat noisy, somewhat quiet, very quiet?

	FEMALE	MALE
Very noisy	5%	13%
Somewhat noisy	35%	33%
Somewhat quiet	40%	47%
Very quiet	15%	7%
Don't know	---	---

There is not a great deal of difference between the sexes relative to rating their neighborhood as noisy or quiet. Both are slightly more inclined to rate their neighborhood as being on the quiet side.

5. When you're inside your house, does noise in the neighborhood bother or annoy you very much, moderately, very little, or not at all?

	FEMALE	MALE
Very much	10%	---
Moderately	15%	27%
Very little	40%	40%
Not at all	35%	33%

Males are slightly less annoyed by neighborhood noise than are the females. Approximately 75% for both sexes are bothered very little or not at all by neighborhood noise when inside their homes.

6. When you're inside your house, which is the MOST bothersome noise from the neighborhood that you hear?

CATEGORY	FEMALE	MALE	CATEGORY	FEMALE	MALE
Children	10%	13%	Neighbors	10%	13%
Airplanes	10%	---	Motorcycles	5%	13%
Trucks	15%	13%	Cars	15%	13%
Traffic	5%	13%	Barking dogs	25%	22%
Sonic boom	5%	---			

The responses to this question does not mean that the persons are unusually disturbed by the noises since they were directly asked to give the, "MOST bothersome noise from the neighborhood?" Some 40% of the females and 52% of the males gave a surface transportation source as the "MOST bothersome noise" while barking dogs were mentioned approximately by 25% of the subjects. In general, these results agree with larger attitudinal studies involving noise in that surface transportation of one kind or another is often the largest single source of community noise concerns.

7. Each adult participant responded to a ten item noise sensitivity test which had been utilized in a number of previous studies (Ref. 2-8). The ten items are:

(1) To hear water dripping from a tap.
(2) To hear a neighbor's radio, television or phonograph playing loudly.
(3) To hear chalk squeaking on a blackboard.
(4) To hear heavy traffic continually pass my house.
(5) To hear dogs barking or cats fighting when I am trying to go to sleep.
(6) To hear a low-flying jet pass overhead.
(7) To hear a pneumatic drill working outside my house.
(8) To hear the prolonged crying of someone else's baby.
(9) To hear the telephone ring for a long time.
(10) To hear interference on the television or radio.

Subjects responded using:
____ a. Extremely annoying
____ b. Moderately annoying
____ c. Slightly annoying
____ d. Not annoying

The ten items were scored as 0, 1, 2, or 3 with "0" for Not Annoying and "3" for Extremely Annoying. This means that scores could range from 0 to 30. Results are presented in Table 2-2.

TABLE 2-2. Mean and range of scores to noise sensitivity test.

	FEMALES	MALES
MEAN	22.4	20.8
RANGE	15 - 28	11 - 25

Both the females and males scored high on this noise sensitivity test with the females indicating greater sensitivity to noise than the males. In an earlier study (Ref. 2-8) involving 180 adult subjects (both sexes), the mean response to this same test was 15.4 and the scores ranged from a low of "2" (very insensitive to noise) to a high of "27" (very sensitive to noise). For a second previous study involving 40 English subjects (Ref. 2-9), the mean score was 14.9. The persons taking part in this study see themselves as being more sensitive to noise than do the subjects of these previous studies. Thusly, absolute acceptability results from this study may be on the conservative side.

8. Compared to other people, are you more aware of noise than others, about the same as others, or less aware of noise than other persons?

	FEMALE	MALE
More aware	30%	20%
Same	55%	53%
Less aware	15%	27%

The females rate themselves as being slightly more aware of noises than do the males. However, approximately one-half of both groups think that they are, "Same as others", relative to awareness of noises.

9. Some people have said that "pollution is one of the biggest problems of modern times". Would you agree strongly, agree somewhat, disagree somewhat, or disagree strongly with that statement?

	FEMALE	MALE
Agree strongly	75%	40%
Agree somewhat	20%	53%
Disagree some	5%	7%
Disagree strongly	---	---
Don't know	---	---

Clearly the females are more inclined to "agree strongly" that "pollution is one of the biggest problems of modern times". However, both sexes believe about equally that pollution is a problem since only a small number from both groups "disagree somewhat" with the statement.

10. This section provides characteristics relative to socio-economic level such as number of years of schooling completed, income, and occupation plus the age of the participants.

The subjects were, for the most part, above average in respect to education. All of the females were high school graduates and many of them had college experience. Average and range of years schooling completed are given in Table 2-3.

TABLE 2-3. Schooling completed.

	FEMALES	MALES
AVERAGE YEARS Schooling Completed	14.6	14.5
RANGE OF YEARS Completed	12 - 20	10 - 21

Yearly income for the males is given in Table 2-4. Four of the females did have part-time work but the rest were functioning as housewives. Median income is approximately $12,500 and the range is from under $5,000 per year to greater than $20,000.

TABLE 2-4. Income for males.

YEARLY INCOME	% INCLUDED
Under $5,000	7%
5,000 - 9,999	27%
10,000 - 14,999	40%
15,000 - 19,999	13%
20,000 or more	13%

Ages of the participants are presented in Table 2-5. The median age for both the females and males was approximately 32 years and both groups covered a wide range of ages, from early twenties to late fifties.

TABLE 2-5. Summary of ages [illegible] participants.

AGE CATEGORY	FEMALES	MALES
20 - 24	25%	13%
25 - 29	25%	34%
30 - 34	8%	7%
35 - 39	8%	20%
40 - 49	25%	13%
50 - 59	9%	13%

11. Results from the attitudinal questions are more meaningful when compared to those obtained from a sample of persons that are representative of a larger population. Responses to these same questions were obtained from adult respondents residing in 659 randomly selected households (Ref. 2-10). Table 2-6 gives pertinent results from this earlier study and those for the females and males of this study. The Paragraph Number heading the first column of Table 2-6 corresponds to the numbered paragraph of this section in which more detailed results are presented. Under "Item" in Table 2-6, a synopsis of the question is given while the third column gives the "Category" that was selected for comparison. The last three columns provide percents of persons responding to that category so that comparisons can be made.

In addition to the attitudinal items discussed above, the thirty-five subjects were also asked to rate twelve neighborhood characteristics on a five-point category scale. The twelve characteristics were rated as, Very Good, Good, Fair, Poor, or Very Poor. Results, along with those for the same items from Reference 2-10, are given in Table 2-7. The rank of neighborhood characteristics along with the percent responding either Very Good or Good is given.

TABLE 2-6. Comparison of some attitudinal results to those from a previous study (Ref. 2-10).

PARA. NO.	ITEM	CATEGORY	PREVIOUS STUDY	FE-MALES	MALES
1.	Rate neighborhood?	Excellent	28%	65%	40%
2.	How many things like?	Many things	54%	85%	67%
3.	Things you don't like?	*(Open-end ques.)	28%	35%	40%
4.	How noisy or quiet?	Somewhat quiet	42%	40%	47%
8.	Awareness of noise?	More aware	24%	30%	20%
9.	Pollution question	Agree strongly	66%	75%	40%

* Percent is for those who mentioned that some noise event was not liked.

TABLE 2-7. Subjects' ratings of 12 neighborhood characteristics in comparison to a previous study (Ref. 2-10).

NEIGHBORHOOD CHARACTERISTIC	MALES		FEMALES		PREVIOUS STUDY	
	RANK	VG,G	RANK	VG,G	RANK	VG,G
Reasonable rent or housing costs	1	94%	3.5	75%	6	60%
Safety of area	2	93%	9.5	50%	8	50%
Shopping facilities	3.5	87%	3.5	75%	2	77%
Low noise	3.5	87%	6	70%	9	43%
Close to work or place of business	5	74%	3.5	75%	5	68%
Public transportation	6.5	73%	1	90%	1	78%
Cleanness of air	6.5	73%	11	40%	10	41%
Satisfaction with neighbors	8	66%	7	60%	3	74%
Parks	9	60%	12	35%	7	58%
Quality of schools	10	54%	3.5	75%	4	71%
Traffic conditions	11	53%	8	55%	11	34%
Entertainment facilities	12	40%	9.5	50%	12	24%

Using the results from the previous numbered paragraphs and the comparison data of Tables 2-6 and 2-7, a profile of the subjects is provided.

(a) Both the females and males of this study are more likely to rate their neighborhood as "Excellent" than persons (both sexes combined) interviewed on a randomly selected basis but in addition, the females for this study rate their neighborhood higher than do the male subjects (65% vs 40%). Also, they are inclined to like "many things" concerning their neighborhood to a greater extent than persons in the larger, random sample and again the females are more positive toward the neighborhood than are the males. Both the females and males are positive toward their living environment but the females are more so than the males.

(b) However, noise was mentioned as one of the things (open-ended question) that was not liked by both the males and females to a slightly greater extent than for the previous study and both females and males rate their neighborhood for noise at about the same level as the persons composing the larger, random sample.

(c) Both the females and males report that they are much more sensitive to noise than are other groups of persons responding to the identical noise sensitivity test with the females reporting more sensitivity to noise than do the males. In respect to "awareness of noise", both the females and males indicate that they are aware of noise to about the same extent as reported by the random sample.

(d) Turning to Table 2-7, Subjects' Ratings of 12 Neighborhood Characteristics in Comparison to a Previous Study, there are a number of differences among females and males of this study and results for the random study. For example, the males rate "Safety of area" quite high (93% report Very Good or Good), while only 50% of the females and 50% of the random sample rate their neighborhood as Very Good or Good relative to its being a safe area. In respect to "Low noise", 87% of males rate their neighborhood as Very Good or Good, 70% of the females rate it as Very Good or Good, while but 43% of the random sample rate their neighborhood Very Good or Good in respect to absence of noise.

(e) In summary, the data presented in paragraph 10. shows that the subjects of this study represented a wide range of occupations and incomes, that they like their neighborhood, are fairly highly educated, perceive their living environment as being somewhat on the quiet side, and report that they are more sensitive to noise than other groups exposed to the same noise sensitivity test.

2.5. DATA ANALYSIS CONSIDERATIONS

There are two sets of dependent measures that are to be related to the ten engineering calculation procedures. The first set involves the magnitude estimation approach which is basic to the question, "Which engineering calculation procedure best defines or reflects annoyance to a diverse group of noises?" The second set of dependent measures involves the level at which persons would find a particular flyover "acceptable" if experienced four to five times per hour during usual daytime living activities.

2.5.1. Magnitude Estimation Analysis

A productive approach for investigating the effectiveness of various engineering calculation procedures is to relate the mean of the log-magnitude estimations (log of the geometric means) to the various measured values as determined by each engineering calculation procedure and as described in Section 2.3 above. The engineering calculation procedure that provides the least range of "Subjective dB" determinations would thusly have the widest application to a diverse set of noises and would be judged as the "best" procedure. However, this approach does not quantify from a statistical inference point of view whether-or-not there are real (not chance) differences among the noises as evaluated by the thirty-five judges. A statistical model which permits an evaluation of the extent that the various noises differ reliably utilizes analysis of variance. Instead of relating the mean of the log-magnitude estimations of the thirty-five subjects to measured levels for each engineering calculation procedure, subjective dB's are first obtained for each individual subject. For the present study, each subject judged thirty-four noises at five different levels. Using Figure 2-A as a basis for understanding the individual approach vs the approach based on all thirty-five subjects, **one would:**

(1) Obtain equation for best-fitting line using all levels of all noises investigated for each individual subject. This would involve 5 levels x 34 noises and involve 170 pairs of points.

(2) Obtain equation for best-fitting line for each individual noise (lines a, c, . . .). Each individual noise determination is based on five pairs of points.

(3) Using the mean for the particular engineering calculation procedure under investigation, for each noise (Lines a and c), determine the subjective response score determined by this grand mean.

(4) Using this subjective response score (obtained from (3)), calculate the engineering calculation procedure value via best-fitting line based on all observations (Line b).

Applying this approach on a subject by subject basis means that subjective dB's are obtained for each of the thirty-four noises but based only on the judgments of one person. Consequently, subjective dB's for one subject are independent of those obtained from a second, third, or fourth subject. Thusly, they are used as the dependent measure in a randomized block design with subjects conceptualized as the blocks and the noises as randomly assigned within a particular subject or block. Such an approach provides a 35 subjects x 34 noises matrix and the interaction between subjects and noises is the appropriate error term. Thusly, the extent of real (not chance) differences among subjects or noises can be determined. Each of the ten engineering calculation procedures will be investigated utilizing this analysis of variance approach.

2.5.2. Absolute Acceptability Analysis

The main interest is the extent that persons predict that they would accept flyovers at a particular level. This is important relative to establishing noise levels around airports with which communities would and could live. These results are based on "0-1" datum (not accept or accept) which can also be evaluated using analysis of variance. The mathematical basis for this approach is given in Reference 2-11, p. 249.

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3. EQUIPMENT DESCRIPTIONS AND SIGNAL ANALYSIS

3.1. FLYOVER RECORDINGS

A special effort was made to maximize the dynamic range of the aircraft flyover recordings in order to eliminate any effects which might be ascribed to background noise; and to provide a good test for the 10 dB down duration correction. Flyover signals with a very limited dynamic range will not provide a convincing test for the hypothesis that the energy bounded by the 10 dB down points is a good representation of the entire energy of the signal, for purposes of correcting for duration effects.

In normal airport operations, the same aircraft type will produce a wide variety of noise levels at a given measuring point, depending on weight, operational procedures, and pilot idiosyncrasies. It therefore becomes difficult to predetermine the recording gain settings necessary to maximize the dynamic range of the recording system. This problem is greatly complicated when recordings of a large variety of aircraft types are needed, as was the case in this study. For this reason, a dbx compressor-expander recording/playback device was used to effectively increase the dynamic range of the recording/playback system by more than 30 dB, thus making it possible to record aircraft sounds producing a wide range of levels while maintaining good signal-to-noise ratio, and to make a tape presentation of those sounds with no audible noise between them.

The non-rotary wing aircraft (Harrier and LTV XC-142 excluded) were recorded in the vicinity of the Seattle-Tacoma International Airport, Washington. The recording sites for the jet transports were at about four miles from brake release on takeoff, and about two miles from the runway threshold on approach. The general aviation aircraft were recorded at sites approximately 6,000 feet from brake release on takeoff, and 2,000 feet from runway threshold on approach.

Helicopter noises were recorded at GRAY Army Air Base, Fort Lewis, Washington. For both approach and takeoff, the helicopters were approximately 300 feet above the microphone at the overhead point.

All of the above recordings were made using a UHER Model 4200 two track tape recorder with a General Radio one-half inch electret microphone and associated preamplifier.

Recordings of two types of VTOL aircraft were generously supplied by the manufacturers. A VTOL Harrier fighter aircraft spool-up and lift-off recording was provided by Hawker Siddely Aviation Limited, Arlington, Virginia.

The Acoustics and Vibration Group, VOUGHT Systems Division, LTV Aerospace Corporation, supplied a recording of the tilt-wing turboprop LTV XC-142 on a flat-wing approach with a conversion to the vertical mode, and then touchdown, with the microphone about 100 feet from the touchdown point.

3.2. SIMULATION SYNTHESIS

Simulations 1 through 6 (see Figures 3-A to 3-F) are of the flyover type, with the aircraft assumed to be passing directly over the observer at a fixed altitude and a constant velocity of 100 knots. These six flyovers (1 through 6) all share the same onset and decay characteristics. The seventh simulation (Figure 3-G) represents a vertical takeoff as experienced by an observer abreast of the aircraft at lift-off.

All of the simulations were produced from random, broadband noise shaped and recorded to produce a representation of the forward quadrant noise and of the aft quadrant noise of a modern high by-pass turbine engine at takeoff power. These two noises were then mixed in time-varying proportions to imitate the spectral changes which occur as the aircraft position changes with respect to the observer. In all cases, a discrete sine wave tone was injected to depict machinery noise fundamental frequency, and was, when appropriate, varied to correspond to doppler shift effects. Two single-engine facsimiles, identical in all respects except for a slight difference in frequency of the discrete tones, were mixed to produce beats characteristic of engines which are not exactly synchronized, thus providing a more realistic multi-engine effect for the noises used in the experiment. Figure 3-H shows typical peak spectra for simulations.

Simulations 1, 2, and 3 (see Figures 3-A, 3-B, and 3-C) all contain just perceptible tones which are doppler shifted, and are the same in all respects other than the respective nominal 10 dB down durations of 5, 15, and 25 seconds.

Number 4 simulation is the same as simulation number 2 except that it contains a conspicuous tone (Figure 3-H) with no doppler shift; while number 5 is the same as number 4, but with a doppler-shifted conspicuous tone.

Simulation number 6 (Figure 3-F) differs from number 3 in that the noise level reaches a peak, dips below the 10 dB down level, and again peaks before the final decay slope.

Number 7 simulation (Figure 3-G) is of a VTOL takeoff with an initial low power setting, an increase in thrust to takeoff power, a lift-off and hover phase, and a final horizontal translation and climb-out, with an overall 10 dB down duration of about 45 seconds and a just perceptible tone which is doppler-shifted as translation progresses.

The simulations were designed to test some of the effects of duration, tone, and doppler shift to be included with the results of the other aircraft noises tested. The "hump-back" simulation, number 6, was constructed to resemble the unique noise signature of a direct lift aircraft configuration with a cone of reduced noise amplitude around the aft engine or fan axis, and provides an unusual test for the FAR 36 definition of duration correction.

Contrary to the treatment of the actual flyover noises used in the experiment, the simulations were shaped to "smooth out" the spectral non-linearities of the listening environment, so the only spectral component analyzed as tone would be the discrete tone built into the flyover noises. However, the simulations were shaped by the "house filter" (see Section 3. 3), as were the actual flyovers.

The dbx compander (see Section 3. 1) was incorporated in the processing of all simulated flybys in order to provide the wide dynamic range discussed previously.

Figures 3-I and 3-J are block diagrams illustrating the method of simulation and construction.

3. 3. CONSTRUCTION OF EXPERIMENTAL TAPE

The thirty-two experimental signals -- flyover recordings and simulations -- were divided into two sets of sixteen signals, each containing a representative cross section of types of noises. The eight-second USASI noise used as the standard noise was added to each set as an experimental signal. All of the signals -- the flyover recordings, the simulations, and the USASI noise -- were encoded by the dbx compressor and were manipulated throughout the experimental tape construction in the encoded state.

Since the signals were to be presented to the subjects as they would hear them inside a home, the flyovers and simulations were shaped to approximate the effects of an average house (see Figure 3-K).

As much of the actual flyover recording was used as was uncontaminated by other noises (e. g., traffic, birds, other planes, etc.), and the signals were faded on and off to produce subjectively smooth transitions. These encoded, house-filtered signals with smooth transitions were used as master recordings to produce the final experimental tape.

The simulations were also house-filtered but fading in and out was not necessary since it was done in the construction of the simulations. The dbx encoded, house-filtered simulations were also used as master recordings to produce the final experimental tape.

The master recordings were adjusted relative to each other so they all produced equal peak dBA levels when played into the listening environment. Each signal was then adjusted and rerecorded at the five different levels required for the study.

The other track of the two-track tape was used to provide a vocal number cue which preceded each noise at each level.

The two sets of 16 different signals and the USASI noise, with each signal presented at 5 different levels, were divided into a total of fifteen smaller groups (sessions) of noises. The presentation order in each set was randomized by drawing numbers corresponding to each noise at each level out of a bowl.

To standardize playback levels, and to facilitate noise analysis, a calibration tone of one kiloHertz was recorded on each of the six 7-inch reels of tape required to record all fifteen sessions.

A tape containing the experiment instructions and five example signals was also constructed for presentation to the subjects.

3.4. LISTENING ENVIRONMENT

The listening environment was selected to provide a non-distracting setting with low ambient noise, thus avoiding any possible complications resulting from background noise effects.

As discussed in Section 3.1., a dbx compander was used in the recording and playback process, resulting in no audible tape or electronic noise between the signals presented.

The listening chamber internal walls are lined with acoustic wallboard to provide a semi-reverberant response. The subject was seated in a comfortable armchair located on the axis of a large Advent acoustic suspension speaker mounted directly overhead.

At the left and to the rear of the subject, approximately one foot from the ear, was a shock-mounted BRUEL & KJAER Type 2205 sound level meter feeding a BRUEL & KJAER Type 2307 level recorder, thus providing a simultaneous dBA trace of the signals as they were presented in the chamber.

To the right, and to the rear of the subject, about one foot from the ear, was a shock-mounted General Radio one-inch electret microphone with a General Radio Type 1560-P42 microphone preamplifier which was used to record, for later analysis, the signals representing what the subject actually heard.

The entire chamber is mounted on springs and lined with 1/64-inch lead sheet and absorbent 1-inch fiberglass blanket to provide acoustic and vibration isolation.

3.5. SIGNAL PRESENTATION

The experimental tapes were played to the subjects using a TEAC 3300 tape recorder, a dbx expander, and a SAE preamplifier, feeding a McIntosh Model 250 amplifier and a large Advent acoustic suspension loudspeaker. The flyover signals from one track of the tape recorder were mixed in the SAE preamplifier with the vocal numbering cues from the other track for presentation through one loudspeaker. Thus, the flyovers could be played at the required levels, while the numbering cues could be separately adjusted to an appropriate listening level.

Throughout the experiment, the sounds in the listening chamber were monitored by a Bruel & Kjaer Type 2205 sound level meter, in the A-weighting mode, and were fed into a Bruel & Kjaer level recorder, thus providing a simultaneous dBA record. The level recorder trace also provided a readout used to adjust the tape presentation level, employing the 1 kHz calibration tone recorded at the beginning of each tape reel.

Prior to the beginning of the study, the experimental tapes were played in the chamber (with no subject present) and recorded on a TEAC 7030 tape recorder via a General Radio 1-inch electret microphone and preamplifier. Each succeeding week the tapes were again played into the chamber and recorded as a check on experimental tape condition and system stability. One of these chamber tapes was also analyzed to provide the objective data used in the calculations representing the signals the subject actually heard (see Section 3. 6.).

After three weeks of experimentation, it was observed that the peak levels presented to the subjects differed from those at the beginning of the study. Analysis of some of the signals showed some loss of the high frequency energy on the experimental tape, indicating a possible loss of oxide. Visual inspection also indicated an inordinately high rate of oxide depletion.

A second series of experimental tapes (Series B) was constructed and used for the remainder of the experiment. The Series B tapes were played into the chamber with no subject present and recorded prior to use in the experiment, for each succeeding week of the experiment, and immediately following use in the study. An A-weighted level recorder trace was also made simultaneously with the chamber recording.

3. 6. PHYSICAL ANALYSIS

The levels recorded in the chamber (see Section 3. 5.) were analyzed using a General Radio 1921 real time analyzer interfaced with a Digital Equipment Corporation PDP-11 computer. For each signal, a one-third octave spectrum was acquired every one-half second, and peak, tone-corrected, and duration-corrected noise unit values were calculated.

As described in Section 3. 5. , both the Series A and the Series

B tapes were played into the chamber, with no subject present, and recorded prior to use in the study, once during each succeeding week, and again immediately following use in the study. Also, an A-weighted level recorder trace provided a simultaneous record of the levels which existed in the listening chamber during the chamber recording and throughout the subjective testing.

A comparison was made between the calculated peak PNL and dBA levels for a representative one-half of the signals from the chamber recordings made from the first set of experimental tapes (Series A) before and after their use in the experiment, and also between the similarly calculated levels from the Series A and Series B tapes, recorded before use. No systematic differences could be found between the before and after use recordings of Series A tapes, nor between the before use recordings of the Series A and Series B tapes. It was therefore decided that the before-use recordings of the Series A tapes would be the basis for the calculation of the physical data representing what the subjects actually heard.

The peak dBA level for each signal as indicated on the level recorder trace during presentation to the subjects was tabulated, and averages computed. These averages were compared with the level recorder trace produced from the before-use chamber recording made from the Series A tapes, and the differences between these two levels was used to adjust the physical analysis data to agree with the average presentation level.

The physical data used in the noise unit calculations were corrected for the non-linearities in the frequency response of the TEAC 7030 tape recorder and associated recording/playback equipment, using a recording of pink noise played into the General Radio 1921 Analyzer.

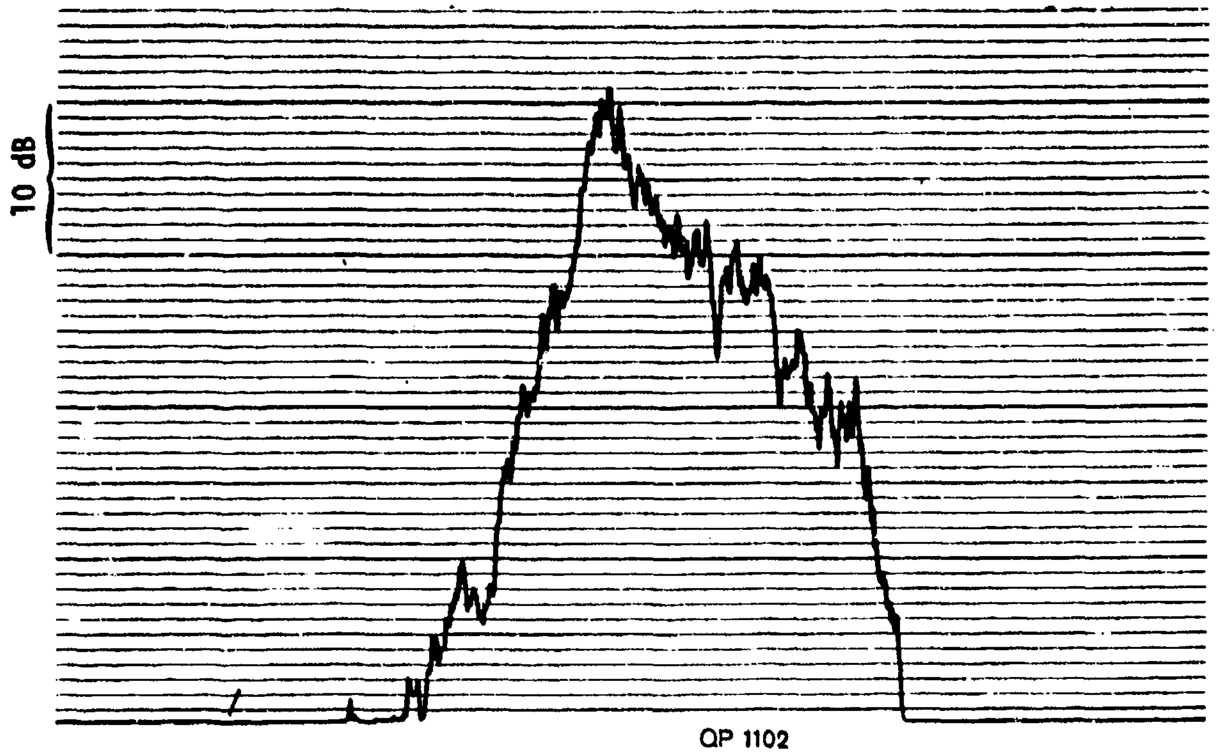

FIGURE 3-A. SIMULATION
Nominal 5 sec. duration, subtle tone, with doppler.

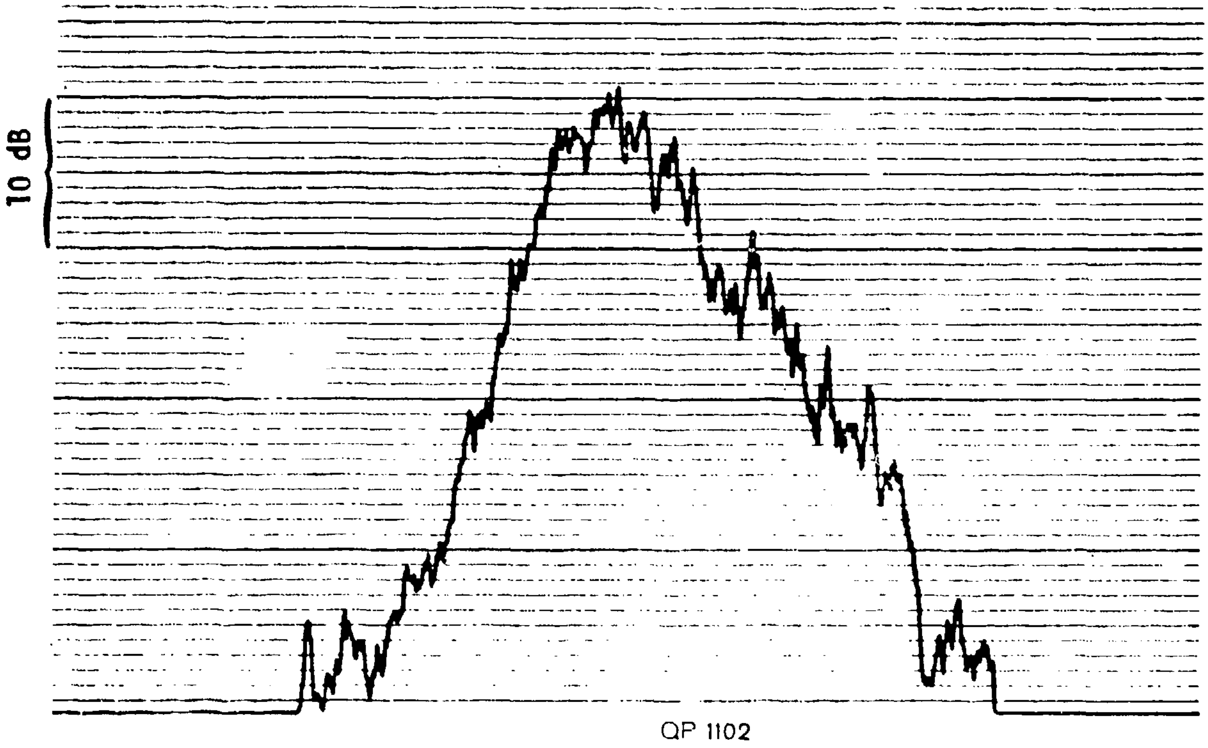

FIGURE 3-B. SIMULATION
Nominal 15 sec. duration, subtle tone, with doppler.

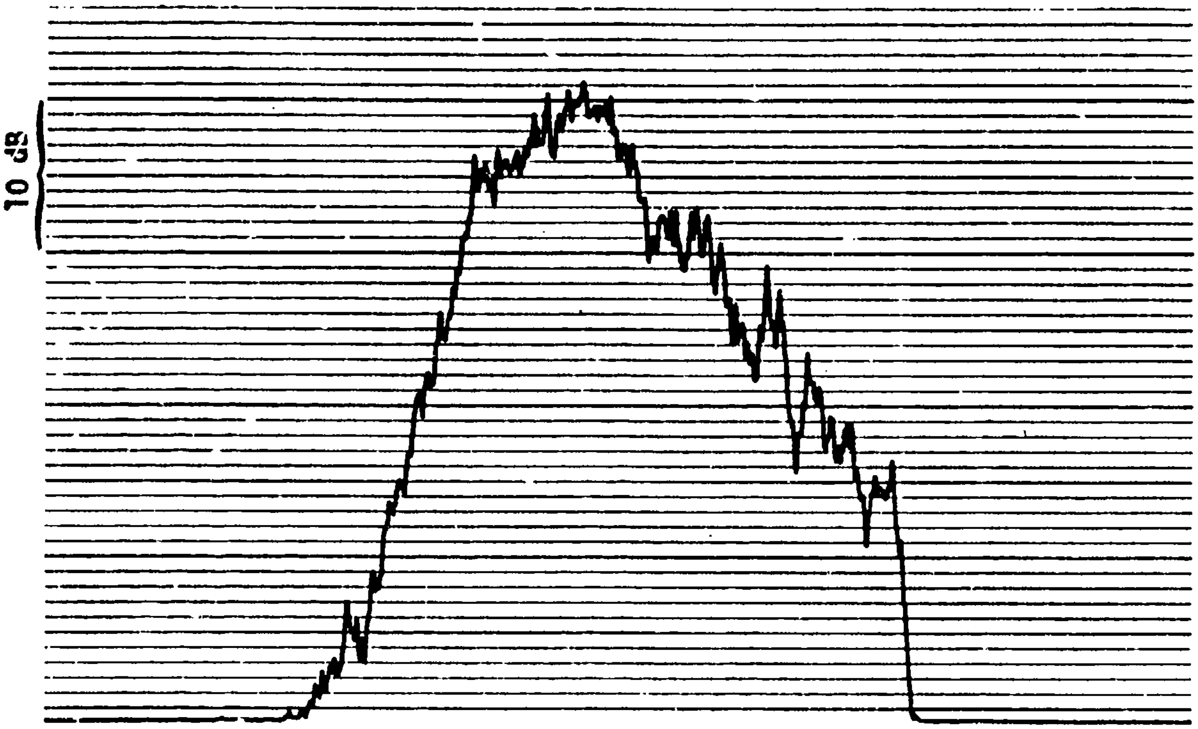

FIGURE 3-C. SIMULATION
Nominal 25 sec. duration, subtle tone, with doppler.

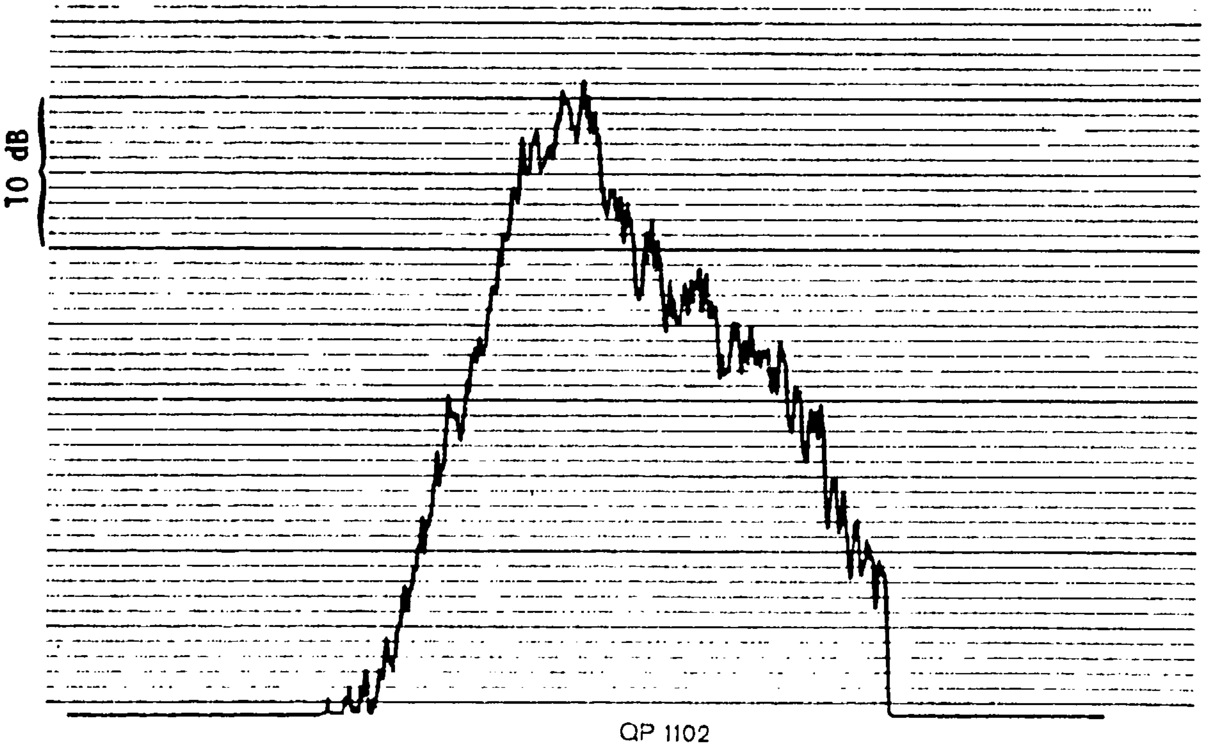

FIGURE 3-D. SIMULATION
Nominal 15 sec. duration, strong tone, no doppler.

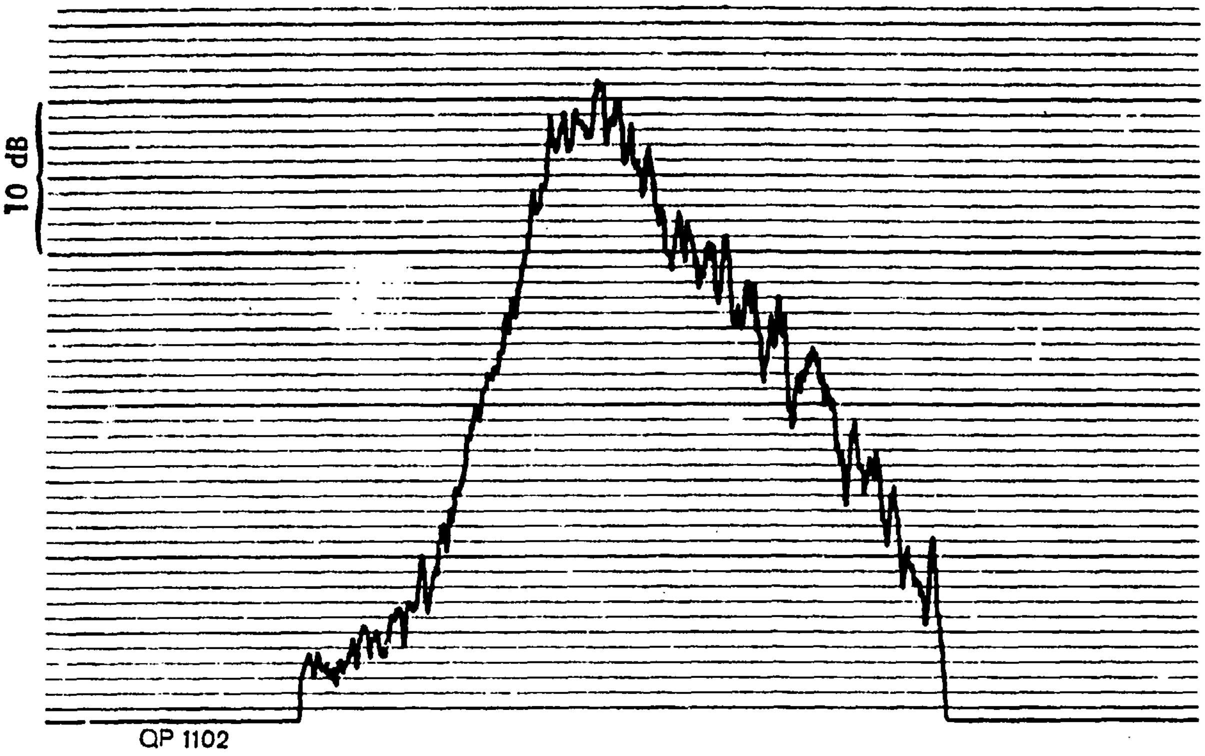

FIGURE 3-E. SIMULATION
Nominal 15 sec. duration, strong tone, with doppler.

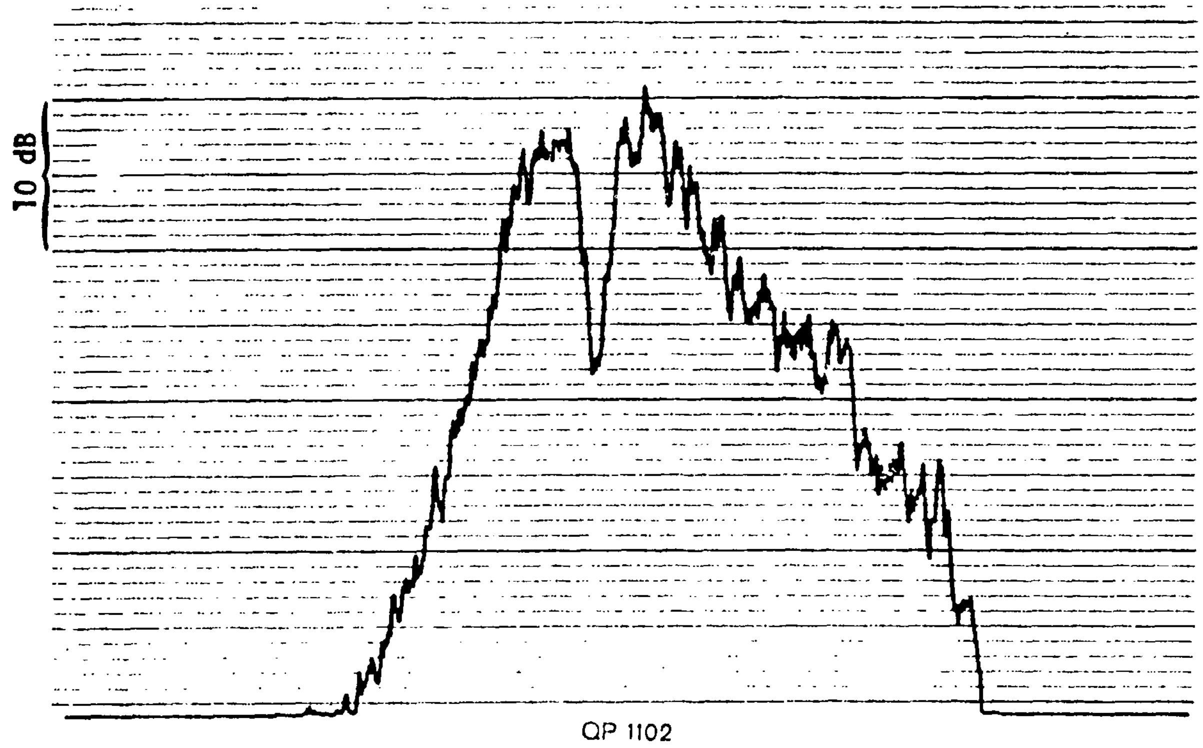

FIGURE 3-F. SIMULATION
Nominal 25 sec. duration with dip, subtle tone, with doppler.

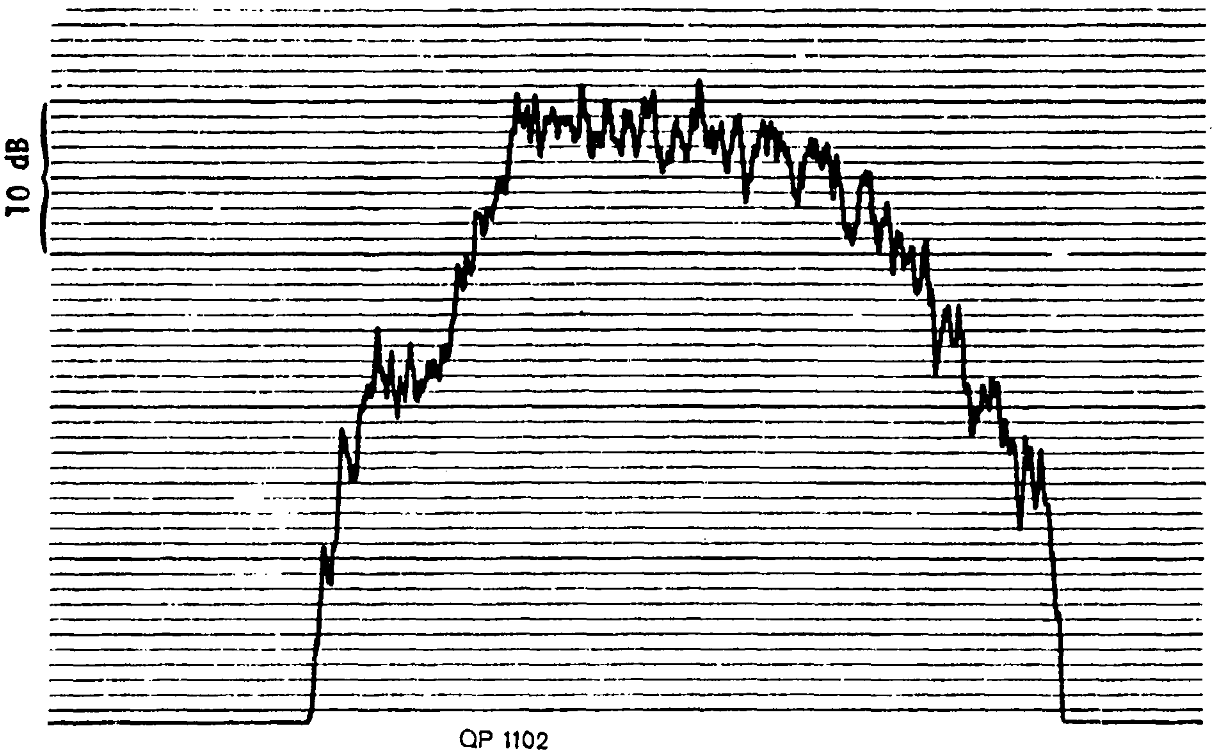

FIGURE 3-G. SIMULATION
Nominal 45 sec. duration, subtle tone, doppler shift.

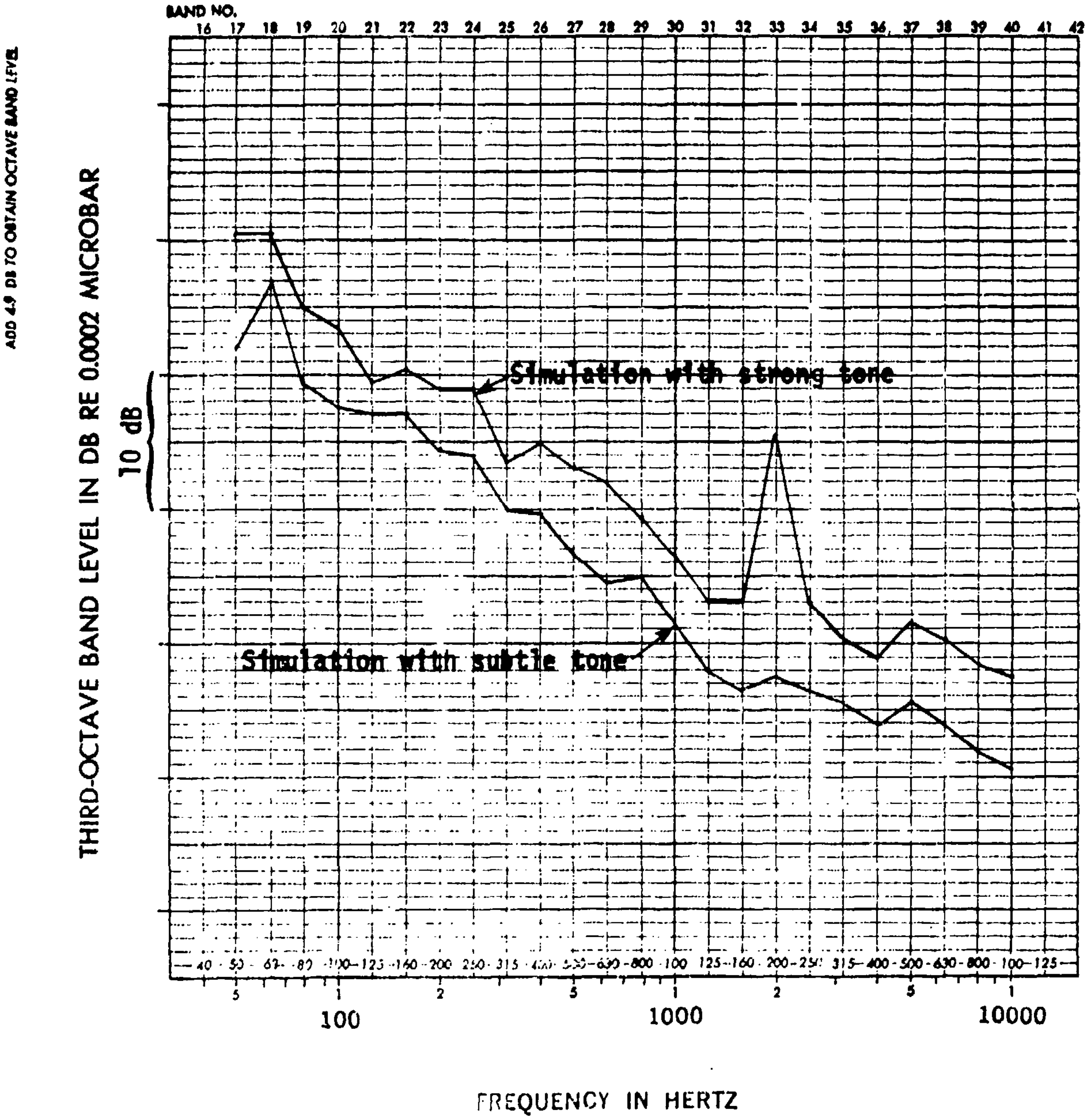

FIGURE 3-H. Typical simulation peak spectra.

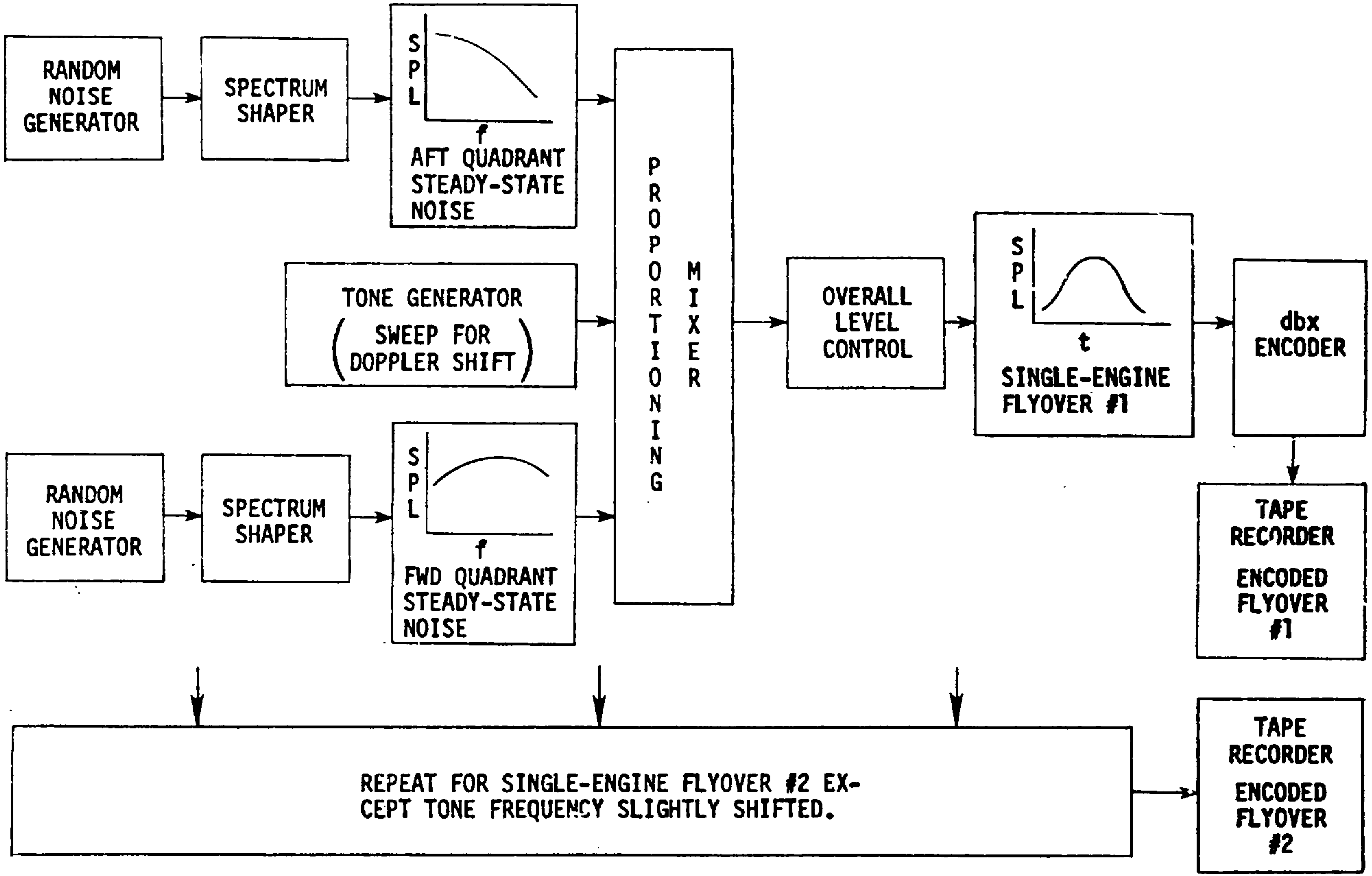

FIGURE 3-I. Construction of single-engine simulation.

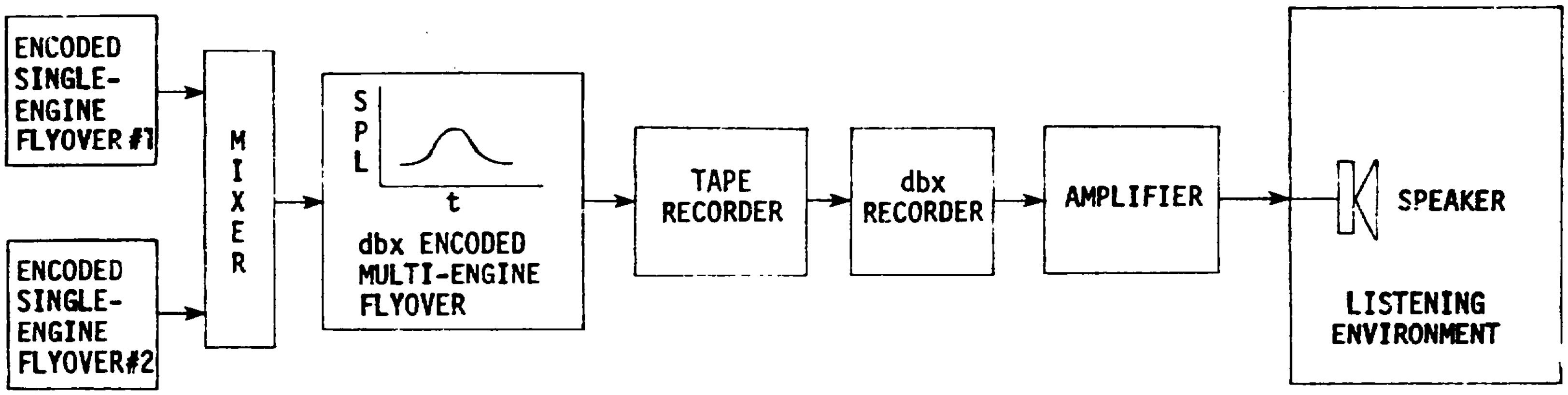

FIGURE 3-J. Multi-engine simulation construction and presentation.

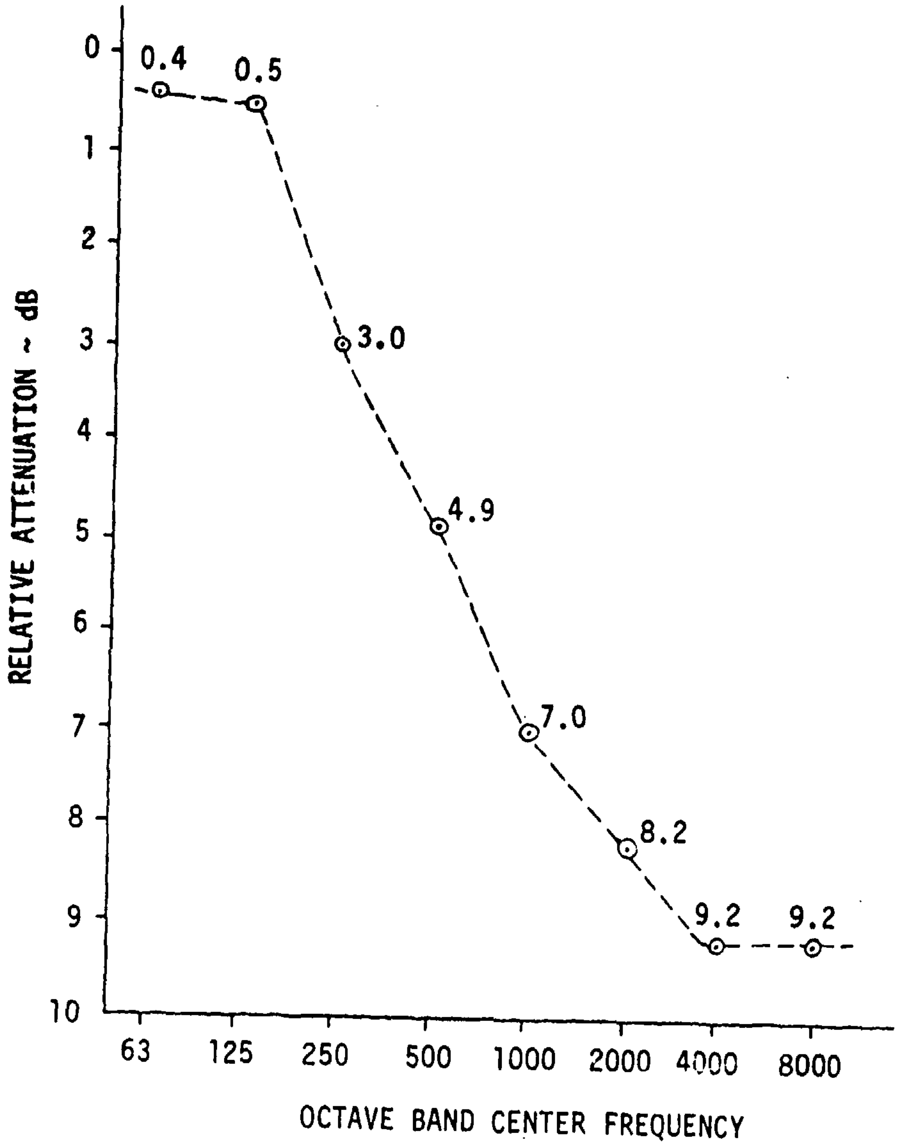

FIGURE 3-K. Relative house attenuation for grand average of house noise reductions.*

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* Taken from: Aerospace Information Report 1081, House Noise-Reduction Measurements for Use in Studies of Aircraft Flyover Noise, Society of Automotive Engineers, Inc., New York, N.Y., October 1971.

4. ENGINEERING CALCULATION PROCEDURES

Each flyover or standard noise in this study was presented in the listening chamber at five nominal dBA levels - 57, 61, 65, 69, and 73. Tape recordings of these sounds were made in the unoccupied chamber as described in Section 3.5, and were analyzed according to the method discussed in Section 3.6. The data thus produced, corrected for tape recorder and other equipment non-linearities, was used in calculating the noise values which are presented in tabular form as follows:

TABLE	ENGINEERING CALCULATION UNIT
4-1	Perceived Noise Level (PNL)
4-2	Perceived Noise Level, tone corrected (PNLT)
4-3	Perceived Noise Level, duration corrected (PNLD)
4-4	Effective Perceived Noise Level (EPNL)
4-5	"A"-Weighted Decibels (dBA)
4-6	"A"-Weighted Decibels, tone corrected (dBAT)
4-7	"A"-Weighted Decibels, duration corrected (dBAD)
4-8	"A"-Weighted Decibels, tone and duration corrected (EdBA)
4-9	Perceived Loudness Level, Mark VI (PLL-VI)
4-10	Perceived Loudness Level, Mark VII (PLL-VII)

The calculations for PNL, PNLT, and EPNL are according to the procedures detailed in Reference 4-2. PNLD is calculated by applying a duration correction to PNL in exactly the same manner that the duration correction is used with PNLT to obtain EPNL.

The one-third octave "A" weighting values used in the dBA calculations are taken from Reference 4-2. Calculations for dBAT, dBAD, and EdBA are exactly analogous to the PNL based calculations. PL_6 values are based on Reference 4-3 and PL_7 calculations are accomplished according to Reference 4-4.

Table 4-11 contains the average of the logarithms of the magnitude estimation ratings for each noise at each of the five levels. The magnitude estimation ratings were obtained as described in Section 2.3.

TABLE 4- 1 PHYSICAL ANALYSIS OF NOISE SIGNALS - PNL UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	72.1	75.6	79.2	82.8	87.0	77.9
2	70.5	74.0	77.9	82.0	86.2	81.7
3	71.6	74.7	79.3	83.1	85.9	81.4
4	71.4	74.8	79.0	82.8	87.6	82.5
5	71.0	74.7	78.3	82.4	86.2	82.0
6	70.9	74.9	78.4	83.4	85.8	80.6
7	70.4	74.3	78.3	82.1	86.0	78.2
8	72.5	75.1	80.0	83.6	87.4	79.8
9	75.2	76.9	81.6	85.6	89.9	68.8
10	71.2	74.1	77.6	82.6	86.0	77.0
11	72.0	76.3	80.8	84.0	88.1	72.1
12	71.9	75.3	81.7	84.6	88.1	75.1
13	70.5	75.1	78.5	81.6	85.7	79.2
14	74.3	78.1	82.0	85.5	89.0	74.3
15	72.4	76.9	80.2	84.2	88.1	75.3
16	71.8	75.8	79.4	83.3	87.4	73.7
17	71.2	75.3	79.2	82.4	85.8	78.8
18	71.8	77 1	81.0	85.2	88.5	78.8
19	73.2	77.4	81.9	86.2	90.0	84.3
20	70.8	73.0	78.2	80.6	85.3	79.3
21	70.1	73.9	77.7	81.0	84.8	78.2
22	73.8	77.9	83.9	85.0	89.1	76.6
23	71.7	75.4	78.5	82.7	86.3	78.8
24	72.8	76.8	81.4	85.9	90.2	82.4
25	70.1	73.7	78.3	81.8	86.2	86.0
26	72.8	77.6	81.4	86.2	89.6	83.6
27	74.7	79.0	83.6	86.3	91.1	83.4
28	76 9	80.4	84.2	88.4	91.7	80.3
29	71.7	75.8	79.4	83.6	87.7	85.1
30	71.9	75.8	81.8	85.9	89 3	85.9
31	71.0	75.3	79.4	83.7	87.3	79.6
32	73.7	77.2	79.7	83.7	87 5	84.4
33	68.3	71.4	75.0	78.9	83.3	82.2
34	70.7	74.6	78.6	82.8	87.1	81.8

TABLE 4- 2 PHYSICAL ANALYSIS OF NOISE SIGNALS - PNLT UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	74.0	77.8	80.8	85.2	89.0	80.8
2	72.6	76.9	80.3	84.8	88.9	84.0
3	76.8	80.3	84.7	87.5	90.9	81.5
4	73.4	77.2	81.5	85.5	89.8	85.1
5	73.0	76.9	80.8	85.2	88.7	84.5
6	73.7	78.1	81.8	87.0	89.4	82.2
7	72.3	76.3	80.3	84.0	88.3	80.9
8	74.5	77.3	81.9	85.6	89.5	82.7
9	78.1	79.8	84.5	88.5	92.8	70.4
10	72.2	75.8	78.8	84.3	87.8	80.1
11	74.6	78.9	82.4	86.6	90.6	74.2
12	74.0	77.6	82.9	86.9	90.3	77.7
13	72.1	76.7	80.1	82.9	87.9	82.3
14	76.1	79.9	83.8	87.3	91.0	77.4
15	74.7	79.2	82.6	86.5	90.3	77.7
16	73.6	77.8	81.6	85.6	89.8	76.3
17	73.0	76.6	81.2	84.6	88.1	81.7
18	76.6	78.9	83.1	86.8	90.9	81.0
19	76.3	80.4	85.1	89.3	93.0	86.3
20	72.7	75.0	79.9	82.6	87.6	82.2
21	74.8	76.9	80.2	83.4	87.5	80.2
22	75.3	79.3	82.9	87.4	91.2	79.6
23	75.1	79.0	82.1	86.0	89.3	80.1
24	74.4	78.1	82.0	86.7	91.1	86.5
25	70.9	72.8	79.4	82.4	87.1	90.5
26	73.4	77.9	82.9	87.3	91.0	87.6
27	76.2	81.0	85.4	88.4	92.9	86.6
28	81.6	85.0	88.9	93.2	96.1	80.0
29	75.2	79.3	83.4	87.7	91.4	86.2
30	75.8	77.4	83.0	87.2	90.6	89.0
31	73.2	77.1	81.7	86.1	89.1	82.4
32	78.1	81.8	84.2	88.2	92.1	85.2
33	70.3	73.3	77.4	81.6	86.2	84.5
34	72.6	76.5	80.9	84.8	89.4	84.7

TABLE 4- 3 PHYSICAL ANALYSIS OF NOISE SIGNALS - PNLD UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	75.2	78.3	81.1	84.5	88.8	72.2
2	74.1	77.5	80.8	85.0	89.3	76.4
3	72.6	74.0	79.2	82.6	86.2	78.9
4	71.9	75.3	79.8	83.3	87.2	79.6
5	70.7	74.0	77.7	81.5	85.3	80.1
6	68.9	73.3	76.4	81.4	83.5	79.9
7	68.3	71.2	74.7	78.3	82.9	78.8
8	73.8	76.0	79.9	83.8	87.7	76.5
9	69.6	71.6	76.0	80.3	84.6	72.4
10	67.8	70.2	73.7	77.9	81.4	78.4
11	67.4	71.8	76.0	79.3	83.0	75.0
12	65.2	68.0	72.3	75.6	79.4	82.3
13	70.0	74.8	77.4	81.0	85.4	76.9
14	70.7	74.1	78.2	82.0	85.8	75.9
15	68.7	72.6	76.5	80.2	84.4	76.8
16	66.4	69.5	72.5	76.3	80.1	78.9
17	73.4	76.1	80.0	83.6	87.2	74.8
18	75.0	78.6	82.7	85.9	90.5	74.6
19	75.7	79.5	83.1	86.6	92.4	80.0
20	70.8	73.8	78.0	80.6	84.7	76.6
21	70.7	73.6	77.5	80.7	84.2	75.8
22	70.0	73.5	76.5	81.1	85.4	78.3
23	66.0	70.2	72.7	77.4	80.8	82.5
24	71.0	74.0	78.2	82.6	87.2	82.6
25	70.7	73.6	78.6	81.6	86.3	83.0
26	74.9	78.4	82.3	87.1	91.0	79.6
27	78.0	81.5	86.9	89.4	94.9	77.9
28	75.8	78.8	82.8	87.2	90.8	79.0
29	70.1	73.9	77.0	81.7	84.8	84.6
30	73.4	77.0	81.0	85.5	89.6	82.7
31	69.8	74.1	78.1	82.0	85.6	78.4
32	74.6	77.4	80.8	84.9	88.4	81.2
33	68.2	70.6	74.1	78.0	82.6	80.4
34	69.3	73.4	77.5	81.5	85.9	80.4

TABLE 4- 4 PHYSICAL ANALYSIS OF NOISE SIGNALS - EPNL UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	76.4	79.8	82.7	86.2	90.6	74.7
2	75.6	79.1	82.5	86.8	91.2	78.6
3	74.3	77.2	81.6	85.5	89.0	80.4
4	73.8	77.4	82.0	85.7	89.7	81.3
5	72.6	75.9	79.8	83.7	87.5	82.0
6	72.1	76.4	79.9	85.2	87.4	80.3
7	69.9	72.8	76.3	80.1	84.7	81.0
8	75.0	77.8	81.8	85.8	89.7	78.7
9	71.8	74.0	78.4	82.6	86.8	73.8
10	69.9	72.2	75.9	80.2	83.6	80.1
11	69.8	74.0	78.3	81.8	85.5	76.3
12	66.9	70.2	74.6	78.2	81.9	83.6
13	71.4	75.9	79.1	82.9	87.1	79.3
14	72.5	75.7	80.0	83.8	87.6	77.9
15	70.3	74.4	78.3	82.2	86.3	78.8
16	67.5	70.9	74.4	78.3	82.2	80.7
17	74.8	77.6	81.8	85.6	89.3	76.9
18	76.0	80.3	84.6	87.9	92.3	76.9
19	77.8	81.6	85.3	90.9	94.6	81.8
20	72.5	75.7	79.9	82.6	86.7	78.5
21	71.8	75.3	79.4	82.6	86.3	77.9
22	71.8	75.0	78.2	82.8	87.2	80.4
23	68.9	73.3	76.0	80.6	84.1	83.0
24	71.4	74.2	78.9	83.0	87.6	86.4
25	71.5	73.8	78.7	82.1	86.8	86.7
26	75.0	78.9	83.0	87.7	91.6	83.1
27	78.7	82.6	88.1	90.7	96.3	80.8
28	79.3	82.9	87.1	91.2	94.8	79.7
29	72.7	77.0	80.3	85.3	88.3	85.2
30	73.3	77.6	81.6	86.3	90.3	86.2
31	71.6	76.0	80.1	84.1	87.7	80.3
32	76.3	79.1	82.9	87.2	90.7	83.2
33	70.4	72.9	76.8	80.6	85.3	81.7
34	71.3	75.4	79.5	83.6	88.0	82.3

TABLE 4- 5 PHYSICAL ANALYSIS OF NOISE SIGNALS - DBA UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	59.8	63.6	66.8	70.8	75.3	62.2
2	58.0	61.7	65.6	69.5	73.8	66.7
3	57.5	60.5	65.3	69.3	72.1	67.8
4	57.9	61.5	65.6	69.2	73.6	68.6
5	58.3	62.0	65.7	69.7	73.4	67.3
6	56.2	60.2	63.7	68.7	71.1	67.8
7	58.0	62.3	66.0	70.1	73.6	62.8
8	59.8	62.7	67.6	71.4	75.3	64.7
9	59.4	61.9	65.8	70.5	74.4	56.8
10	58.7	61.1	64.9	69.5	73.1	62.3
11	58.7	62.5	67.3	71.0	75.0	57.8
12	58.7	62.0	68.2	71.1	74.5	60.8
13	57.3	61.3	65.2	68.5	72.3	64.9
14	59.9	63.8	67.8	71.2	74.6	61.1
15	59.4	64.1	67.4	71.5	75.2	60.3
16	59.1	63.8	66.7	70.3	74.5	58.8
17	58.1	62.4	65.9	69.9	72.6	64.1
18	58.1	62.7	66.1	70.0	73.1	65.7
19	59.4	63.7	67.6	71.2	74.4	71.0
20	58.2	60.7	65.5	68.2	73.1	63.9
21	57.9	62.1	66.2	69.6	72.5	62.2
22	59.5	63.4	66.9	71.2	74.5	63.3
23	56.6	60.6	63.3	67.8	71.3	66.5
24	58.8	62.5	66.3	70.2	73.7	70.2
25	57.0	60.4	64.8	68.1	72.0	72.2
26	57.8	61.6	65.3	69.0	72.9	72.3
27	58.4	62.0	66.2	68.8	73.2	73.2
28	61.8	65.2	68.8	72.9	76.0	68.4
29	56.8	60.9	64.1	68.2	72.3	73.0
30	57.7	61.7	65.4	69.5	72.7	74.1
31	58.0	62.8	66.3	70.3	73.7	65.3
32	59.0	62.5	65.1	69.1	72.9	71.5
33	56.6	60.0	63.9	67.9	72.2	66.0
34	57.9	61.5	65.4	69.4	73.6	67.6

TABLE 4- 6 PHYSICAL ANALYSIS OF NOISE SIGNALS - DBAT UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	61.7	65.7	69.0	73.2	77.2	64.9
2	60.1	64.4	67.8	72.4	76.2	69.1
3	61.7	65.7	70.3	72.9	76.3	68.5
4	59.9	63.8	68.1	71.7	76.1	71.0
5	60.3	64.2	68.2	72.5	75.9	69.7
6	58.8	62.4	66.6	72.2	74.6	69.3
7	60.1	64.3	68.0	72.0	75.7	65.6
8	61.8	64.9	69.7	73.5	77.3	67.2
9	61.8	64.0	68.2	72.5	76.4	59.3
10	59.8	63.3	66.3	71.6	74.9	65.3
11	61.2	65.1	69.9	73.5	77.5	59.8
12	60.7	64.4	70.4	73.4	76.7	63.3
13	58.7	62.8	67.0	70.5	74.4	68.0
14	61.7	65.6	69.6	73.0	76.6	64.1
15	61.7	66.4	69.8	73.9	77.4	62.7
16	60.9	64.8	68.9	72.6	76.9	61.4
17	60.0	63.7	67.5	71.0	74.7	67.4
18	61.8	64.5	68.7	71.6	75.6	68.1
19	62.1	66.7	70.8	74.4	77.8	72.9
20	60.1	63.7	67.2	70.8	74.9	66.7
21	62.1	64.6	68.7	72.0	76.2	64.1
22	61.4	65.2	69.0	73.8	77.3	65.9
23	59.9	63.8	66.7	70.7	74.3	68.0
24	59.7	63.4	67.7	71.4	74.7	74.4
25	57.8	60.7	66.0	68.6	73.0	76.6
26	58.8	62.4	66.5	70.5	73.8	76.3
27	59.9	63.8	67.9	70.7	75.1	76.4
28	66.5	69.9	73.6	77.7	80.5	67.8
29	60.3	64.4	68.2	72.3	76.0	73.9
30	61.0	63.3	66.9	71.2	74.3	77.3
31	60.2	64.7	68.5	72.8	75.8	67.9
32	63.4	67.1	69.6	73.6	77.4	72.1
33	58.6	61.9	66.4	70.6	75.0	68.3
34	59.8	62.4	67.8	71.5	76.0	70.3

TABLE 4- 7 PHYSICAL ANALYSIS OF NOISE SIGNALS - DBAD UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	61.5	65.2	68.2	71.6	76.2	57.6
2	61.0	64.4	67.8	72.0	76.0	61.8
3	58.9	60.9	65.1	68.7	72.3	64.8
4	58.3	61.7	65.9	69.5	73.3	65.4
5	57.5	60.8	64.5	68.4	72.1	65.5
6	54.3	58.5	61.6	66.7	68.8	66.8
7	55.5	58.6	62.0	65.6	70.2	63.6
8	59.9	62.9	66.9	70.9	74.7	62.0
9	56.2	58.1	62.1	66.0	70.2	58.7
10	53.9	56.7	60.1	64.2	67.2	64.5
11	53.8	57.8	62.2	65.9	69.5	60.7
12	51.6	54.2	58.5	62.0	65.5	68.2
13	56.0	60.2	63.4	66.8	70.9	63.5
14	57.0	60.3	64.4	68.0	71.7	61.9
15	55.8	60.1	63.9	67.7	71.7	61.5
16	53.0	56.5	60.0	63.5	67.5	63.5
17	59.7	62.4	66.4	70.0	73.4	60.6
18	60.3	63.8	67.9	70.8	74.8	61.5
19	61.2	64.7	68.1	72.9	76.3	66.8
20	57.7	60.8	65.2	67.9	72.0	61.3
21	57.4	60.7	64.9	68.3	72.0	60.7
22	55.6	58.9	61.7	65.6	70.1	65.5
23	51.0	54.9	57.5	62.1	65.5	70.2
24	56.5	59.5	62.2	67.0	70.8	70.3
25	56.9	59.8	64.1	67.0	71.1	69.6
26	60.7	64.0	67.2	71.4	74.9	66.4
27	63.4	66.5	71.1	72.2	78.1	64.7
28	60.8	63.6	67.4	71.2	74.6	66.6
29	55.6	59.2	62.3	66.7	69.6	71.7
30	59.0	62.7	66.4	70.2	73.8	69.4
31	56.8	61.2	65.0	68.6	72.2	63.8
32	60.9	63.7	67.0	71.1	74.6	67.1
33	55.7	58.2	62.3	66.0	70.6	64.7
34	56.5	60.5	64.4	68.3	72.6	65.6

TABLE 4- 8 PHYSICAL ANALYSIS OF NOISE SIGNALS - EDBA UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	62.9	66.7	69.8	73.4	78.0	59.9
2	62.5	66.0	69.6	73.9	77.9	63.9
3	60.2	63.1	67.5	71.5	75.0	66.5
4	60.1	63.8	68.0	71.9	75.8	67.2
5	59.4	62.7	66.6	70.5	74.3	67.3
6	57.4	61.4	65.0	70.4	72.5	67.3
7	57.0	60.2	63.8	67.4	72.0	65.8
8	61.5	64.7	68.6	72.8	76.7	64.0
9	57.9	60.2	64.4	68.4	72.5	60.1
10	56.0	58.7	62.3	66.5	69.5	66.1
11	56.3	60.0	64.4	69.4	71.9	62.0
12	53.3	56.4	61.0	64.5	67.9	69.5
13	57.3	61.5	65.0	68.7	72.6	65.8
14	58.6	62.0	66.1	69.9	73.5	64.0
15	57.4	62.0	65.8	69.7	73.6	63.4
16	54.3	58.2	61.9	65.7	69.6	65.2
17	61.0	64.1	68.2	72.0	75.4	62.7
18	61.4	65.5	69.7	72.9	76.6	63.7
19	63.2	66.6	70.2	75.1	78.3	68.7
20	59.4	62.7	67.2	69.9	74.1	63.2
21	59.1	62.6	66.7	70.2	74.0	62.6
22	57.1	60.2	63.3	67.4	71.4	68.0
23	54.0	58.2	60.8	65.4	68.8	70.5
24	57.1	59.6	62.7	67.3	71.4	74.3
25	57.6	60.0	64.3	67.4	71.6	73.5
26	60.8	64.3	67.8	71.9	75.4	70.2
27	64.2	67.6	72.4	74.4	79.5	67.7
28	64.3	67.6	71.7	75.4	78.7	66.2
29	58.2	62.3	65.6	70.3	73.1	72.2
30	59.4	63.3	66.9	70.8	74.5	73.0
31	58.6	63.1	67.0	70.7	74.3	65.7
32	62.6	65.5	69.1	73.3	77.0	69.1
33	57.9	60.7	65.0	68.7	73.4	65.9
34	58.5	62.5	66.4	70.4	74.7	67.4

TABLE 4- 9 PHYSICAL ANALYSIS OF NOISE SIGNALS - PLL-VI UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	73.7	76.5	79.8	82.7	85.8	78.7
2	72.4	75.4	78.5	82.0	85.3	81.8
3	71.5	73.9	78.7	81.7	84.2	82.6
4	73.1	76.0	79.0	82.1	87.0	82.6
5	72.5	75.8	79.0	82.2	85.5	82.1
6	71.2	74.9	77.8	82.1	84.1	82.0
7	72.1	75.7	79.0	82.0	85.4	78.8
8	74.0	76.4	80.4	83.0	86.2	80.3
9	76.3	77.6	81.2	84.8	88.7	71.0
10	73.8	76.2	79.1	83.0	85.9	77.1
11	73.6	77.1	80.7	83.3	86.9	73.9
12	73.4	76.1	81.4	84.0	86.9	76.5
13	73.0	76.8	79.4	81.8	85.2	79.3
14	75.9	78.7	81.9	84.9	88.0	75.4
15	73.9	77.5	80.2	83.5	87.0	76.5
16	73.5	76.9	79.7	82.9	86.3	75.1
17	73.4	76.8	79.9	83.1	85.3	78.9
18	74.3	79.0	82.1	85.5	88.1	78.5
19	75.3	79.3	82.8	86.1	89.1	83.3
20	72.8	74.5	78.9	80.9	84.7	79.7
21	71.8	75.0	78.0	81.0	83.8	79.1
22	75.6	78.9	81.2	84.7	88.2	77.1
23	72.0	75.4	78.1	81.8	84.9	80.5
24	75.7	79.0	82.5	86.2	89.6	81.0
25	73.1	75.9	79.8	82.7	86.5	84.4
26	75.7	79.6	82.2	86.1	89.2	82.3
27	77.1	80.6	84.0	86.2	90.5	82.2
28	77.7	80.5	83.8	87.2	90.1	80.7
29	72.7	76.3	79.1	82.7	86.2	85.3
30	73.6	78.2	82.9	86.0	89.0	84.6
31	72.8	76.6	80.0	83.5	86.5	79.9
32	73.3	76.2	78.5	81.9	85.1	85.5
33	69.9	72.5	75.5	78.9	82.5	82.8
34	72.6	75.9	79.3	82.8	86.5	81.8

TABLE 4-10 PHYSICAL ANALYSIS OF NOISE SIGNALS - PLL-VII UNITS

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5	SUBJDB
1	65.4	68.2	70.7	74.0	78.2	69.3
2	63.5	66.8	70.1	72.5	77.1	72.8
3	62.8	65 1	76.7	74.2	76.2	73.1
4	65.4	68.4	70.8	74 6	78.5	72.8
5	64.8	68.0	71.0	74.9	77.6	72.3
6	62.7	66.4	69.2	73.4	75.4	72.9
7	63.6	66.4	69.7	73.2	76.8	70.0
8	65.4	67.6	72.3	74.7	78.3	70.9
9	65.7	67.1	71.4	75.5	79.7	63.5
10	64.9	66.6	69.8	73.5	77.2	68.6
11	63.5	67.3	71.4	74.6	78.6	65.5
12	64.9	67.6	73.1	75.7	79.0	67.1
13	62.8	66.9	69.5	72.3	76.1	71.5
14	65.4	69.1	72.3	75 8	79.2	67.6
15	64.0	67.8	70.9	74.8	78.6	68.1
16	65.0	68.1	72.1	74.4	78.3	65.7
17	65.0	68.3	70.4	74.8	76.4	69.9
18	65.4	69.5	72.4	76.0	78.9	70.1
19	65.1	70.0	73.3	76.6	80.2	75.1
20	64.0	65.7	70.2	73.2	76.3	70.3
21	62.7	65.9	69.1	72.7	75.6	70.0
22	65.4	68.9	72.4	75.4	79.4	69.0
23	62.9	66.2	69.6	72.8	76.0	71.7
24	66.2	70.2	73.2	77 0	80.3	72.6
25	65.2	68.1	72.0	74 7	77.6	74.6
26	65.5	69.2	71.4	76.0	79.1	75.0
27	66 5	69.8	73.5	75.9	80.5	75.1
28	68.5	71.5	75.2	78.3	81.6	72.1
29	63.8	67.3	70.0	74 1	77 3	76.5
30	64.9	68.3	72 4	76 9	78.7	76.5
31	65.1	68.7	72.1	75.5	78.5	70.2
32	65.0	67.9	70.2	73.6	77.1	76.1
33	61.7	64.1	67.1	70.7	74.5	73.3
34	64.7	68.0	71.4	75 2	78.5	71.9

TABLE 4-11 AVERAGE OF LOGARITHMS OF MAGNITUDE ESTIMATION RATINGS FOR EACH NOISE SIGNAL

NOISE	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1	0.8	0.9	1.0	1.1	1.2
2	0.9	1.0	1.1	1.2	1.2
3	0.9	1.0	1.1	1.2	1.2
4	0.9	1.1	1.1	1.2	1.3
5	0.9	1.0	1.1	1.2	1.3
6	0.9	0.9	1.0	1.2	1.2
7	0.8	0.9	1.0	1.1	1.2
8	0.9	0.9	1.0	1.2	1.3
9	0.6	0.7	0.8	0.9	1.1
10	0.8	0.9	0.9	1.1	1.1
11	0.6	0.7	0.9	1.0	1.1
12	0.7	0.8	1.0	1.1	1.2
13	0.8	0.8	1.0	1.1	1.3
14	0.7	0.8	1.0	1.1	1.2
15	0.7	0.9	1.0	1.1	1.2
16	0.7	0.8	0.9	1.0	1.1
17	0.8	0.9	1.0	1.1	1.2
18	0.9	0.9	1.1	1.1	1.2
19	1.0	1.1	1.2	1.2	1.4
20	0.7	0.9	1.0	1.1	1.2
21	0.8	0.8	1.0	1.0	1.2
22	0.8	0.9	1.0	1.2	1.2
23	0.8	0.9	1.0	1.1	1.2
24	0.9	1.0	1.2	1.3	1.4
25	0.9	1.0	1.2	1.3	1.4
26	1.0	1.1	1.2	1.3	1.4
27	1.0	1.1	1.2	1.3	1.4
28	1.0	1.1	1.2	1.4	1.4
29	1.0	1.0	1.2	1.3	1.4
30	1.0	1.1	1.2	1.4	1.4
31	0.9	0.9	1.1	1.1	1.2
32	1.0	1.1	1.2	1.3	1.3
33	0.8	0.9	1.0	1.1	1.2
34	0.9	1.0	1.1	1.2	1.3

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4-3. STEVENS, S. S., "Procedure for calculating loudness: Mark VI", J. Acoust. Soc. Am., Vol. 33, No. 11, November 1961.

4-4. STEVENS, S. S., "Perceived level of noise by Mark VII and decibels (E)", J. Acoust. Soc. Am., Vol. 51, No. 2, February 1972.

5. RELATIONSHIP OF HUMAN RESPONSE RESULTS TO ENGINEERING CALCULATION PROCEDURE RESULTS

Two sets of dependent measures were obtained. The one set involved magnitude estimation judgments by the thirty-five subjects of 170 separate noise events while the second set of dependent measures was concerned with the absolute acceptability of these same 170 noises, i.e., ". . . to judge if each sound you hear would be acceptable to you if you experienced it in your home four or five times an hour during your waking hours". The magnitude estimation judgments contribute results relevant to objectives 1.1, 1.3, and 1.4. The absolute acceptability results were obtained as a means of providing evidence relative to objective 1.2, "Estimate levels that will be acceptable to communities surrounding airports". Since subjects were predicting their "acceptability response" in the real life living situation on the basis of hearing the noise on one occasion in the laboratory, the data obtained from this approach will be considered in conjunction with results from other studies and methods.

5.1. MAGNITUDE ESTIMATION AND TEN ENGINEERING CALCULATION PROCEDURES

As discussed in Section 2. "EXPERIMENT DESCRIPTION", the basis for evaluating engineering calculation procedures that are designed to reflect extent of loudness or annoyance of individual noise events involves the "Subjective dB" approach. The magnitude estimation psychophysical method is basic to this "Subjective dB" approach for evaluating the various engineering calculation procedures. The approach can be summarized as a question, "If a particular noise event is calculated to be at a given level by a particular engineering calculation procedure, at what level do the listeners place that noise event in terms of that same engineering calculation procedure?" Since no transformation of the physical acoustic data can account for all of the interacting characteristics of a noise event, human response is utilized to both evaluate and, when required, to correct these various transformations of the physical data.

So that a valid statistical inference model could be utilized to quantify the extent that judged differences among the various noises were reliable, Subjective dB's were obtained for each subject as described in Section 2.5.1. "Magnitude Estimation Analysis - ".

Thusly, each of the thirty-five subjects contributed thirty-four subjective dB's (one for each noise) independently from any other subject. Such an approach permits utilization of a randomized blocks analysis of variance design with subjects being analogous to the blocks and the various noise events are the thirty-five conditions that are randomly assigned to each subject or block (see Ref. 5-1). However, each engineering calculation procedure does involve the same physical acoustic data and is thusly related to (not independent of) the other calculation procedures being evaluated, so each calculation procedure is studied separately. Table 5-1 summarizes the analysis of variance results for each of the ten engineering calculation procedures under investigation. Each has 34 noises x 35 subjects to equal 1190 dependent measures which are the subjective dB's calculated within each subject individually. The error term for each is the interaction between noises and subjects. The F-ratio for differences among mean subjective dB based on each of the thirty-four noises are highly significant for all ten engineering calculation procedures. This means that the annoyance effects among various noises are reliably different for any of the ten engineering calculation procedures investigated. However, there are differences in the magnitude of the F-ratios indicating that some calculation procedures are more effective when applied to a diverse group of flyover noises than are others. The F-ratios based on the mean of each subject's response to the thirty-four noises are all less than one. On the average, the thirty-five subjects responded to the noises in a highly consistent manner.

Table 5-2 provides summary information relative to the magnitude estimation results. Column (1) gives the range of subjective dB's for the thirty-four noises while column (4) lists the level of the calculation procedure at which the subjective dB was calculated. Using PNdB as an example, the noise event with the smallest subjective dB has a subjective dB of 68.85 and the noise event with the largest subjective dB has a value of 85.91. The absolute range is 17.06 for the thirty-four noises (column (2)) but each of the thirty-four noises was calculated to be at 79.72 PNdB; PNdB calculates noise number "9" (see column (6)) approximately 11 PNdB greater than the subjects rate the noise and approximately 6 PNdB lower than the subjects rate noise number "30" (see column (6)). PNdB does not apply equally well to a diverse group of noises. Each of the ten engineering calculation procedures evaluated can be examined in the same manner but a helpful comparison involves differences among the various engineering calculation procedures utilizing the Absolute Ranges of column (2) and the F-ratios of

TABLE 5-1. Summary of analysis of variances for individual Subjective dB's based on ten engineering calculation procedures.

ENGINEER. CAL.PROC.	SOURCE OF VARIANCE	SUM OF SQUARES	df	MEAN SUM OF SQUARES	F-RATIO	SIGNIF. POINT
PNdB	Noises	18388.12	33	557.55	46.42	P<.005*
	Subjects	14.75	34	.43	.04	------
	Error	13473.19	1122	12.01		
PNdB$_T$	Noises	20503.53	33	621.32	47.61	P<.005
	Subjects	21.31	34	.63	.05	------
	Error	14642.43	1122	13.05		
PNdB$_D$	Noises	10423.16	33	315.85	24.58	P<.005
	Subjects	111.66	34	3.28	.26	------
	Error	14416.31	1122	12.85		
EPNdB	Noises	11272.81	33	341.60	26.10	P<.005
	Subjects	184.78	34	3.08	.24	------
	Error	14688.50	1122	13.09		
dBA	Noises	24451.66	33	740.96	60.29	P<.005
	Subjects	11.28	34	.33	.03	------
	Error	13786.94	1122	12.29		
dBA$_T$	Noises	25462.28	33	771.58	60.28	P<.005
	Subjects	13.28	34	.39	.03	------
	Error	14358.72	1122	12.80		
dBA$_D$	Noises	13564.59	33	411.05	33.20	P<.005
	Subjects	91.19	34	2.68	.22	------
	Error	13884.75	1122	12.38		
EdBA	Noises	14895.19	33	451.37	35.71	P<.005
	Subjects	86.09	34	2.53	.20	------
	Error	14184.59	1122	12.64		
PL$_6$	Noises	12974.50	33	393.17	44.99	P<.005
	Subjects	21.72	34	.64	.07	------
	Error	9805.75	1122	8.74		
PL$_7$	Noises	11982.81	33	363.12	43.28	P<.005
	Subjects	14.47	34	.43	.05	------
	Error	9416.38	1122	8.39		

* For 30 and 120 degrees of freedom, "F" = 1.98 for P<.005.

TABLE 5-2. Summary information for Magnitude Estimation method.

ENGINEERING CALCULATION PROCEDURE	(1) RANGE	(2) ABSOLUTE RANGE	(3) F-RATIO	(4) MEAN CALCULATION PROCEDURE VALUE	(5) STANDARD VALUE	(6) NOISE NUMBER FOR RANGE	(7) CORRELATION BASED ON ALL VALUES	(8) RANGE OF CORRELATION FOR INDIVIDUAL NOISES	(9) SLOPES BASED ON ALL NOISES	(10) RANGE OF SLOPES FOR INDIVIDUAL NOISES
PNdB	68.86 - 85.91	17.06	46.42	79.72	79.0	9 to 30	.822	.966 - 1.000	.026	.022 - .034
PNdB_T	70.39 - 90.48	20.09	47.61	82.17	81.3	9 to 25	.816	.966 - 1.000	.026	.022 - .033
PNdB_D	72.22 - 84.58	12.36	24.58	78.48	77.8	1 to 29	.893	.961 - .999	.027	.022 - .034
EPNdB	73.82 - 86.74	12.92	26.10	80.34	79.8	9 to 25	.888	.964 - .999	.026	.021 - .033
dBA	56.85 - 74.11	17.26	60.29	65.95	65.8	9 to 30	.768	.970 - .998	.026	.021 - .035
dBA_T	59.34 - 77.27	17.93	60.28	68.34	68.2	9 to 30	.773	.964 - 1.000	.026	.022 - .034
dBA_D	57.61 - 71.69	14.08	33.20	64.48	64.7	1 to 29	.862	.969 - .999	.027	.022 - .035
EdBA	59.98 - 73.53	13.55	35.71	66.40	66.7	1 to 25	.857	.967 - .998	.027	.021 - .034
PL_6	71.03 - 85.51	14.48	44.99	80.10	79.6	9 to 32	.821	.969 - .999	.031	.024 - .043
PL_7	63.48 - 76.48	13.00	43.28	71.25	71.8	9 to 29,30	.832	.965 - 1.000	.031	.022 - .040

column (3). The engineering calculation procedure with the smallest range and the smallest F-ratio (least variability) has the widest application and is thusly accepted as the most applicable. The absolute range for subjective dB utilizing PNdB is 17.06 dB and the F-ratio is 46.42. When PNdB is tone corrected according to FAR-36, the range is increased by 3 dB to 20.09 and the F-ratio is increased slightly. The tone correction procedure degrades PNdB. However, if only the FAR-36 duration correction is applied to the PNdB calculation procedure, it is markedly improved as indicated by a decrease in the range to 12.36 dB and a marked decrease in the F-ratio, from 46.42 to 24.58. Applying both tone and duration corrections to PNdB to obtain EPNdB only slightly increases the range and the F-ratio. It is concluded that:

- The tone correction degrades the PNdB calculation procedure.
- The duration correction markedly improves the PNdB calculation procedure.
- The combined tone and duration correction interact and provide approximately the same result as does the duration correction applied individually.

Turning to dBA and application of tone, duration, and tone and duration corrections simultaneously, in respect to the absolute ranges for the subjective dB's, dBA functions about as well as PNdB. However, the corresponding F-ratios are much larger (indicating greater variability) and it is concluded that the PNdB family of engineering calculation procedures is superior to the dBA approaches. Finally, the evaluations of S.S. Stevens' Mark VI and Mark VII show that either has wider application to a diverse set of noises than does PNdB and dBA if no correction for duration is applied. The results suggest the expectation that Stevens' Mark VII would have the widest application if it were corrected for duration effects. Of the first six columns, only column (5) has not been used in the above discussion; it will be recalled that USASI noise was used as a standard for the two testing sessions. The values in column (5) are the mean of the calculation procedure values for the two standards; comparison of column (5) with column (6) shows that the levels of the standard were quite similar to the levels used to calculate the 34 noises utilizing each engineering calculation procedure, PNdB to PL_7 (Stevens' Mark VII).

So that an error term would be available for determining whether-or-not the various noises show reliable differences, subjective dB's were obtained for each subject individually and separate analysis of variance was completed for the ten engineering calculation procedures. Another approach involves working with the group as a whole. Prior to relating the magnitude estimation judgment data to engineering calculation procedure determinations, the log of the magnitude estimations to each noise event is averaged over the 35 subjects and these results are then related to the engineering calculation procedure results. Columns (7) through (10) of Table 5-2 re based on this total group approach. Column (7) provides the product-moment coefficients of correlation for the mean of the log magnitude estimations vs. the various engineering calculation procedure results for all of the noises. The correlations range from .768 for peak dBA to .893 for $PNdB_D$. These results also indicate that duration corrected PNdB is superior to the remaining engineering calculation procedures investigated. Again there is evidence that PL_7 (Stevens' Mark VII) is slightly superior to the uncorrected approaches (PNdB, dBA, and PL_6 (Stevens' Mark VI)).

Column (8) gives the range of product-moment coefficients of correlation for each individual noise (34 coefficients for each calculation procedure). They are all high, ranging from .961 to 1.000 and account for 92 to 100 percent of the covariation; all 340 coefficients are so similar that it is concluded that there is no real difference among them. The telling inference is provided by comparing these almost perfect relationships with those obtained in column (7) where judgment data to all of the noises is related to the various engineering calculation procedure results. These coefficients are all lower than those based on only the individual noises, thusly, providing evidence that each noise is somewhat uniquely evaluated by the subjects.

Column (9) presents slopes for rate of change of annoyance based on all the noises while column (10) gives the range of rates of change for each noise evaluated separately. Slopes based on all noises range from .026 to .031 (Powers of .26 to .31, see Section 2.3.1) which means that doubling or halving of annoyance ranges from approximately 11.5 to 9.7 dB depending on the calculation procedure utilized. The range of slopes based on individual noises is .021 to .043 indicating that there are differences in rates of change of annoyance for individual noises. In terms of doubling or halving annoyance, the individual noises' rates of change vary from approximately 14.3 dB to 7.0 dB. For rates of change based on all

TABLE 5-3. Mean and range of differences of Subjective dB from calculated values by aircraft type.

AIRCRAFT TYPE		PNdB	PNdB_T	PNdB_D	EPNdB
CTOL	MEAN	0.79	0.54	-0.67	-0.81
	RANGE	4.56	4.30	7.90	6.69
Propeller	MEAN	-4.53	-4.72	-0.55	-0.88
	RANGE	10.39	11.96	10.15	9.74
Helicopter	MEAN	-2.03	-1.90	-1.60	-1.47
	RANGE	10.51	9.97	5.44	4.96
VTOL	MEAN	3.98	3.73	2.74	3.23
	RANGE	5.63	10.48	6.72	8.01

of the noises, only PL_6 and PL_7 (Stevens' Mark VI & VII) are in the 9 to 10 dB area commonly used to evaluate increases or decreases in single event noise effects. The remaining engineering calculation procedures require 11 dB or greater increase or decrease for doubling or halving the annoyance of a single event.

Since the results show that the family of engineering calculation procedures based on PNdB (PNdB, PNdB_T, PNdB_D, and EPNdB) have wider application to a diverse group of noises than other procedures evaluated, this group is investigated further. Figure 5-A shows the mean subjective dB difference from the calculated value for each of the four engineering calculation procedures. The noises are grouped by the various aircraft types. With the exception of the duration correction (PNdB_D) for Noise Number 1 which was a takeoff of a 737 aircraft with a rather long 10 dB down duration, all four engineering calculation procedures function unusually well in depicting annoyance to CTOL aircraft. As shown in Table 5-3, the mean of the subjective dB differences from the calculated value for PNdB_T is 0.54 PNdB_T and the range of differences is but 4.30 PNdB_T. Unless the propeller type aircraft are duration corrected, they are judged significantly less annoying (4 to 5 dB on the average) than calculated. If duration corrected only (PNdB_D), the mean subjective dB difference from the calculated value is -0.55 PNdB_D. Helicopters, on the average, are judged slightly less annoying than the engineering calculation procedures indicate. For EPNdB, their mean subjective dB difference from their calcu-

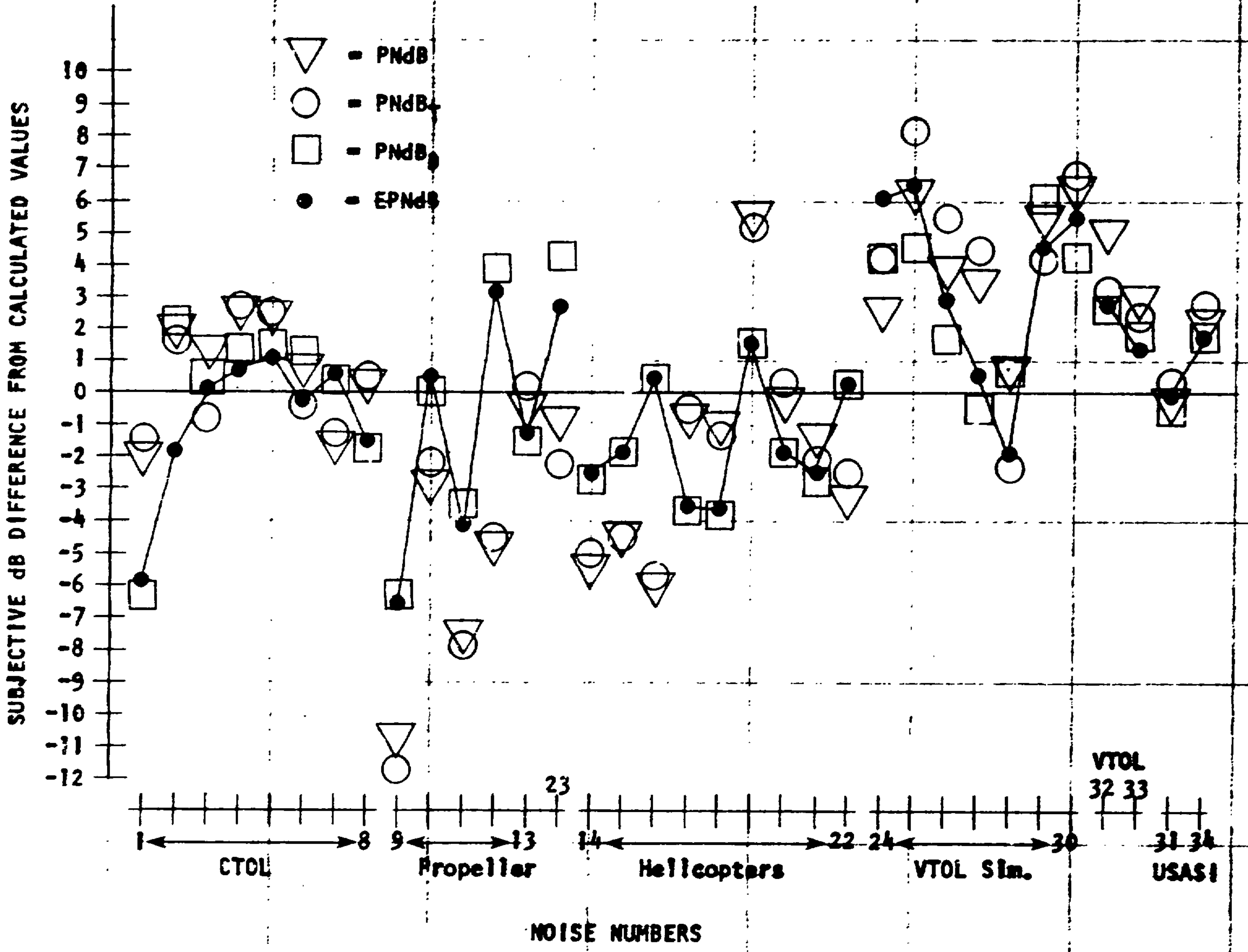


FIGURE 5-A. PNdB, PNdB$_T$, PNdB$_D$, and EPNdB Subjective dB's based on mean individual response.

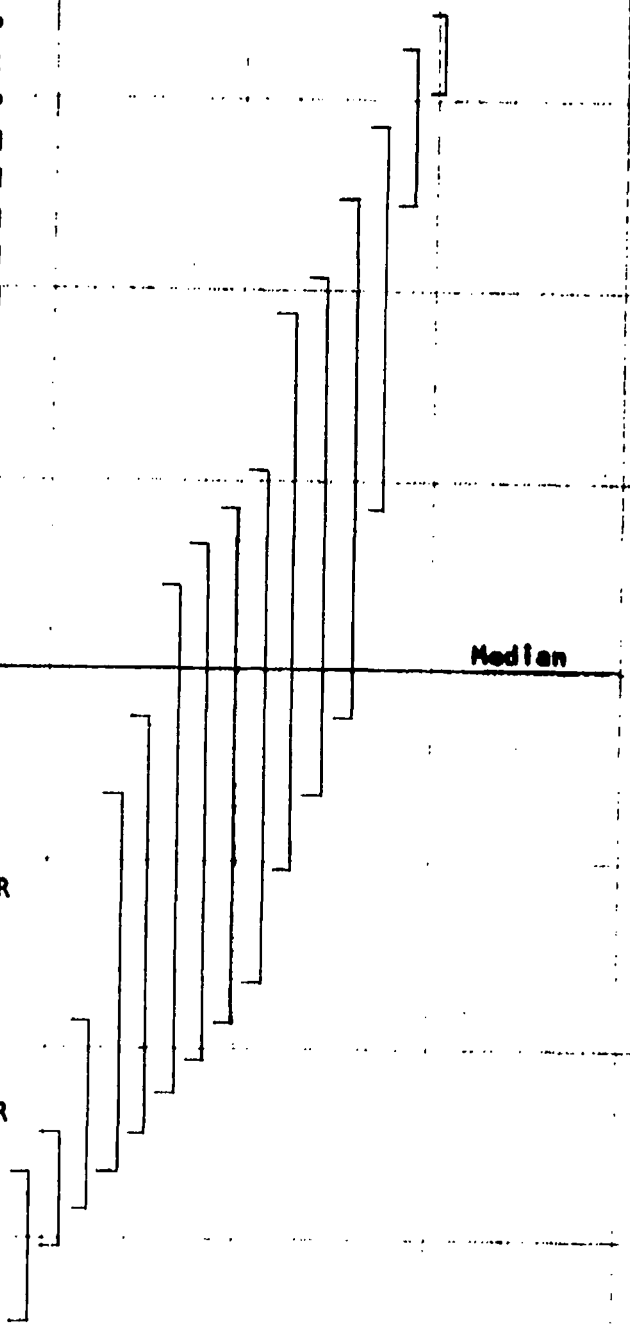
lated EPNdB is -1. 47 and the range of the differences is 4. 96 EPNdB. However, it will be remembered (Section 3. 0) that all of the noises were filtered to provide an indoor listening experience so the rise time of the "beats" is markedly increased and also that only helicopter flybys (not hovering flight) were investigated. Both conditions should contribute to a less annoying experience. The VTOL aircraft (both the simulations and the two recordings of actual flights - Noises 32 and 33) were judged the most annoying. The most effective procedure was PNdB corrected for duration ($PNdB_D$) but the mean of the subjective dB differences from the calculated $PNdB_D$ was 2. 74 and the range of the differences was 6. 72 $PNdB_D$.

Returning to Figure 5-A, the nine VTOL noises can be used to illustrate how the duration correction contributes to improving the relationship between the judgment results and the engineering calculation procedure values. If the "□" decreases the distance between the "△" and "O" (no difference between subjective dB and the calculated value), the relationship between the judged result and calculated result is improved. For the VTOL flights, the duration correction improves or does not alter the correspondence of seven out of nine noises. Thusly, for this group of noises, it is effective but not perfect.

Another question relative to the 34 subjective dB's obtained for each noise is, "How large is a reliable [illegible] one chance) difference between two noises?" Is it, 1, 2, 3 or more EPNdB? Utilizing the error term from the analysis of variance (Table 5-1) in conjunction with Duncan's Multiple Range Test (Ref. 5-1), these values can be determined. Table 5-4 gives the results. The first column gives the rank of each mean subjective dB, the second column the mean subjective dB based on within subject determinations, the next column provides the noise or flyover number, and the last column the code for aircraft type. The calculated value for each subjective dB was 80. 34 EPNdB so one noise was judged approximately 6 EPNdB lower than calculated and another noise approximately 6 EPNdB higher than calculated. The greater the number of means compared, the larger the difference between means must be before means are considered significantly different. For example, for 29 to 34 means, the difference must be 2. 75 EPNdB to be significantly different at $P < .01$. For 2 means, the difference required is 2. 23 EPNdB, for 3 means it is 2. 32 EPNdB, and so on. As shown in Table 5-4, any two means bracketed by the same line are <u>NOT</u> significantly different. As an example, noises 29, 30,

TABLE 5-4. Significant differences among 34 noises at P<.01 level utilizing Duncan's Multiple Range Test.

RANK	(EPNdB)	FLYOVER NUMBER	*CODE
1	73.8	9	P
2	74.7	1	C
3	76.3	11	P
4.5	76.9	17	H
4.5	76.9	18	H
6.5	77.9	14	H
6.5	77.9	21	H
8	78.5	20	H
9	78.6	2	C
10.5	78.7	8	C
10.5	78.7	28	V
12	78.8	15	H
13	79.3	13	P
14	80.1	10	P
15.5	80.3	6	C
15.5	80.3	31	U
17.5	80.4	3	C
17.5	80.4	22	H
19	80.7	16	H
20	80.8	27	V
21	81.0	7	C
22	81.3	4	C
23	81.7	33	VR
24	81.8	19	H
25	82.0	5	C
26	82.3	34	U
27	83.0	23	P
28	83.1	26	V
29	83.2	32	VR
30	83.5	12	P
31	85.2	29	V
32	86.2	30	V
33	86.4	24	V
34	86.7	25	V



Any two means not bracketed by the same line are significantly different at P<.01 level.

Any two means bracketed by the same line are NOT significantly different at P<.01 level.

*C = CTOL
P = Propeller
H = Helicopter
V = VTOL sim.
VR = VTOL recording
U = USASI stand.

24, and 25 are all bracketed by the same line and thusly are not significantly different and belong in the same set. Noise 12 is not bracketed by the same line as noises 24 and 25 so it is significantly different from those two noises. Since ranks 9 through 22 are all bracketed by the same line, these 14 noises (subjective dB of 78.6 to 81.3) are not significantly different and all belong to the same set. Since each was calculated at 80.34 EPNdB, it is not surprising that values that are less than 1.75 EPNdB from the calculated value would be considered identical to that value.

For the most part, relationships between magnitude estimation and engineering calculation procedure results have been based on the mean response of the subjects' individual responses (within each subject subjective dB). The traditional approach involves obtaining the mean of the log of the magnitude estimation judgments and relating these mean results (based on 35 subjects for this experiment) to the engineering calculation procedure results. The question that may be raised is, "Are the two approaches comparable?" Figure 5-B shows plots of the two approaches for each of the 34 noises. The differences from the calculated values for the two approaches are remarkably similar. Each follows the same pattern and any differences are approximately 1 EPNdB or less. Identical inferences are obtained from the two approaches but obtaining subjective dB on an individual subject basis does provide an error term for determining the extent that differences between noises are reliable.

5.2. ABSOLUTE ACCEPTABILITY

The aim of this approach was to obtain results that could aid in establishing thresholds of noise intrusion acceptability in living and/or working environments. Due to the fact that the subjects are making a prediction from the laboratory situation and environment to their daytime living environment, results are relevant only in conjunction with criteria established on the basis of other methodologies. At least two conditions are basic to this approach for obtaining and utilizing the results. One condition involves presenting a range of levels for the noises under investigation that includes a level that could be acceptable to some percentage of the subjects. The second condition involves the extent that a particular noise level must be accepted for that level to be considered as a threshold. Is a threshold based on 100%, 90%, 75%, or perhaps 50% acceptability? As a means of evaluating the obtained results,

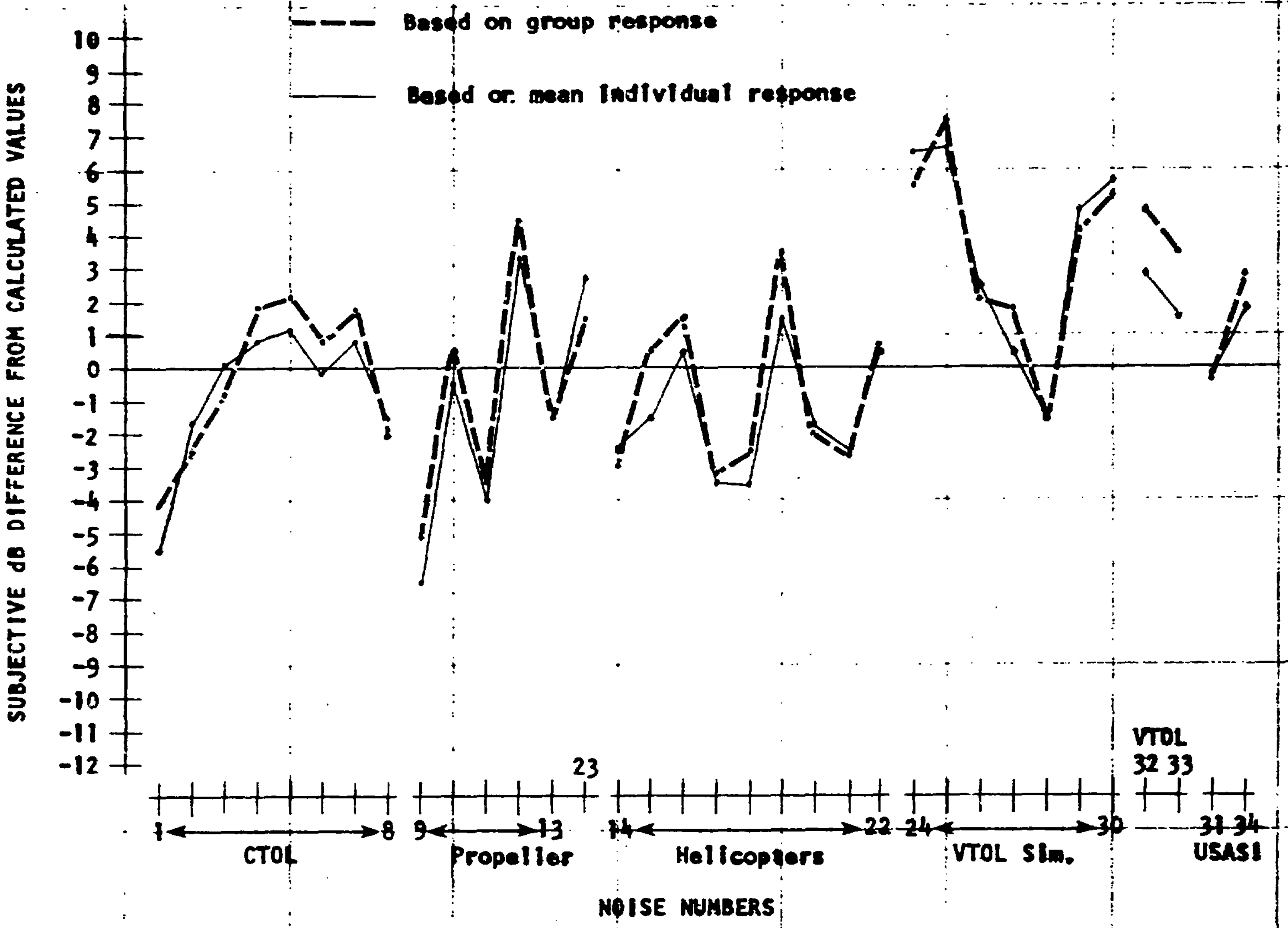


FIGURE 5-8. EPNdB Subjective dB's based on mean individual response vs. group response (mean of log Magnitude Estimations).

if a noise at a particular level is considered acceptable by 80% of the subjects, that level will be utilized as a threshold of acceptability for that particular noise.

Table 5-5 presents the results. The five levels in EPNdB are given for each noise followed by the percent that the subjects rated that noise event as acceptable if experienced in their home four or five times an hour during non-sleep hours. Using the 80 percent acceptable point as a criterion for the threshold of acceptability, only eight of the thirty-four noises at Level 1 (mean EPNdB of 72.8) are rated as acceptable. None of the 8 CTOL noises is rated acceptable, 4 of 6 propeller aircraft flyovers are acceptable at Level 1, 4 of 9 helicopter flybys are rated acceptable, none of the 9 VTOL flights is acceptable, and neither of the standard noises is acceptable at Level 1. For this particular listening situation, twenty-six of the noises were not presented at a low enough level so as to meet the 80 percent criterion for a threshold of acceptability. Table 5-6 gives the mean and range of acceptability by aircraft type for the noises at Level 1. By aircraft type, propeller aircraft, then helicopters, CTOL aircraft, and VTOL aircraft are rated from most to least acceptable.

Returning to the acceptability results of Table 5-5, an analysis of variance on the data was completed to determine the extent that the differences were reliable. The basis for this analysis of "0, 1" type of data is given in Reference 5-2. A summary of the analysis of variance is given in Table 5-7. Differences among the thirty-four noises, the five levels, and the interaction between noises and levels is highly significant. As expected, the differences between means for levels show the highest reliability. Clearly, as noise levels increase, acceptability of the noises decreases.

Since community noise determinations are usually given in terms of dBA, a comparison between the EPNdB engineering calculation procedure and dBA is provided in Table 5-8. The aim was to present all 34 noises for each of the five levels at the same dBA level and in 4 dB increments ranging from 57 to 73 dBA. The mean dBA for Level 1 was 58.4 and for EPNdB it was 72.8, a difference of 14.4. The mean difference between the two procedures for Level 5 is 14.7. The coefficient of correlation for dBA vs. EPNdB is .34 for the thirty-four Level 1 pairs of points and is .12 for Level 5. It is clear that dBA and EPNdB are not consistent in reflecting acceptability of single event noise intrusions.

TABLE 5-5. Percent accept individual noises at calculated *indoor EPNdB levels.

NOISE	L1	% ACCEPT	L2	% ACCEPT	L3	% ACCEPT	L4	% ACCEPT	L5	% ACCEPT	SUB dB
1	76.4	66	79.8	49	82.7	43	86.2	23	90.6	20	74.7
2	75.6	57	79.1	31	82.5	29	86.8	26	91.2	17	78.6
3	74.3	57	77.2	46	81.6	37	85.5	31	89.0	20	80.4
4	73.8	66	77.4	37	82.0	31	85.7	17	89.7	14	81.3
5	72.6	66	75.9	37	79.8	37	83.7	23	87.5	17	82.0
6	72.1	69	76.4	63	79.9	43	85.2	23	87.4	23	80.3
7	69.9	77	72.8	60	76.3	51	80.1	37	84.7	29	81.0
8	75.0	63	77.8	51	81.8	46	85.8	26	89.7	14	78.7
9	71.8	91	74.8	80	78.4	80	82.6	63	86.8	49	73.8
10	69.9	80	72.2	74	75.9	63	80.2	34	83.6	31	80.1
11	69.8	91	74.0	77	78.3	69	81.8	60	85.5	37	76.3
12	66.9	83	70.2	77	74.6	57	78.2	37	81.9	29	83.6
13	71.4	66	75.9	71	79.1	43	82.9	37	87.1	23	79.3
14	72.5	89	75.7	63	80.0	43	83.8	31	87.6	17	77.9
15	70.3	83	74.4	63	78.3	46	82.2	31	86.3	23	78.8
16	67.5	83	70.9	74	74.4	60	78.3	51	82.2	34	80.7
17	74.8	71	77.6	57	81.8	54	85.6	40	89.3	26	76.9
18	76.0	66	80.3	57	84.6	46	87.9	23	92.3	20	76.9
19	77.8	37	81.6	31	85.3	17	90.9	11	94.6	11	81.8
20	72.5	86	75.7	66	79.9	49	82.6	43	86.7	20	78.5
21	71.8	74	75.3	66	79.4	57	82.6	46	86.3	23	77.9
22	71.8	63	75.0	54	78.2	43	82.8	26	87.2	23	80.4
23	68.9	77	73.3	49	76.0	34	80.6	26	84.1	20	83.0
24	71.4	60	74.2	46	78.9	23	83.0	17	87.6	14	86.4
25	71.5	63	73.8	34	78.7	20	82.1	17	86.8	9	86.7
26	75.0	51	78.9	34	83.0	23	87.7	14	91.6	14	83.1
27	78.7	40	82.6	31	88.1	20	90.7	14	96.3	9	80.6
28	79.3	54	82.9	34	87.1	26	91.2	14	94.8	11	78.7
29	72.7	51	77.0	49	80.3	17	85.3	14	88.3	9	85.2
30	73.3	46	77.6	23	81.6	20	86.3	9	90.3	9	86.2
31	71.6	69	76.0	49	80.1	31	84.1	31	87.7	20	80.3
32	76.3	40	79.1	29	82.9	20	87.2	20	90.7	14	83.2
33	70.4	74	72.9	57	76.8	37	80.6	23	85.3	20	81.7
34	71.3	51	75.4	40	79.5	29	83.6	17	88.0	9	82.3

* Average outdoor levels would be approximately 20 EPNdB greater. See reference of page 3-15 of this report.

TABLE 5-6. Mean and range of acceptability for noises at Level 1 (Mean EPNdB is 72.8) by aircraft type.

	CTOL	PROPELLER	HELICOPTER	VTOL	STANDARD
MEAN	65%	81%	72%	53%	60%
RANGE	57%-77%	68%-91%	37%-89%	40%-74%	51%-69%
NUMBER	8	6	9	9	2

TABLE 5-7. Summary of analysis of variance for absolute acceptability data.

SOURCE OF VARIATION	SUM OF SQUARES	df	MEAN SQUARE	ERROR SOURCE	F-RATIO df	F-RATIO	PROBABILITY
Subjects(S)	574.794	34	16.906	------	-------	------	------
Noises (N)	98.246	33	2.977	SXN	33, 1122	21.572	P<.005
Level (L)	163.791	4	40.948	SXL	4, 136	65.833	P<.005
SXN	154.360	1122	.138	------	------	------	------
SXL	84.621	136	.622	------	------	------	------
NXL	16.507	132	.125	SXNXL	132,4488	1.603	P<.005
SXNXL	348.682	4488	.078	------	------	------	------

TABLE 5-8. Comparison of dBA and EPNdB calculated values for Levels 1 & 5.

	dBA		EPNdB	
	LEVEL 1	LEVEL 5	LEVEL 1	LEVEL 5
MEAN	58.4	73.5	72.8	88.2
RANGE	5.2	4.9	12.6	14.6
STAND. DEV.	1.1	1.2	3.0	3.3

If these results are used in isolation from those obtained using other methods, it would be concluded that many single event intrusions would not be acceptable at approximately 56 to 61 dBA. Other considerations presented in the next paragraph point to the strong possiblity that this conclusion is not valid.

There are three factors that contribute to the absence of acceptability of the low level noise intrusions and indicate that the results are not representative of persons generally. These are:

5.2.1. As shown in section 2.4, the subjects were above average in educational achievement, perceived their living environment as being on the quiet side, and reported that they were significantly above other groups in terms of being sensitive to noise.

5.2.2. A second factor that contributed to the low acceptability of some of the noise events was the low background noise level that was essential to completing the magnitude estimation part of the study. The background noise level was 24 dBA as opposed to usual levels in living environments of 35 to 45 dBA. This low background noise level caused the various noise events to clearly stand out. In another unpublished study utilizing the identical approach but with background noise levels greater than 60 dBA, some 90% of the subjects predicted that they could accept flyover intrusions in the 75 to 80 dBA range.

5.2.3. A third consideration involves the total listening situation in which the subject's only task is to evaluate the noises. Such an approach is essential for scaling via transformations of the physical noise parameters (magnitude estimation) but is not conducive to obtaining valid threshold of acceptability data. In a recent study involving community noise simulation systems where persons were responding to impulse noise randomly presented in their home (Ref. 5-3), the subjects reported that if they were actively engrossed in some activity, the noises were perceived as softer or less loud.

Although the results from the absolute acceptability part of the study are not considered as representative of opinion concerning noise events in the actual living environment, they are unusually helpful in emphasizing the need for investigating methods for extrapolating results from experimental approaches to community response criterion and prediction situations.

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6. RESULTS COMPARED TO FINDINGS FROM PREVIOUS STUDIES

One result that clearly surfaces is that the PNdB family of engineering calculation procedures predicts different amounts of annoyance for helicopter flybys than for the simulations and actual recordings of VTOL aircraft. The judgments results for the helicopter flybys show less annoyance than predicted by the various PNdB type of calculation procedures while they show more annoyance to the VTOL signals than predicted by the calculation procedures. Is this result consistent with findings from other studies and, if so, what is the explanation for the finding? One of the earliest studies utilizing judgment data (Ref. 6-1, 1967) concluded that PNdB was an adequate measure of annoyance to helicopter noise but this particular study investigated helicopter flybys only and not hovering noise. A second study (Ref. 6-2, 1968) investigated response to both terminal flight operations and cruise operations. The findings from this second study were identical to those of the present study. For the hovering type signals, the judgment results show more annoyance than predicted by the PNdB family of engineering calculation procedures; this is the same result that was obtained from the present study's VTOL signals which were long duration, hovering type of signals. For the cruise or flyby type signals, the judgment results indicated less annoyance than predicted by the engineering calculation procedures which is identical to the result obtained for the present study's helicopter noises and all of these were of a flyby and not hovering nature. Another study (Ref. 6-3), concluded that helicopter and tilt wing sounds must be 4 to 5 PNdB lower than a reference jet aircraft flyover in order to be equal in annoyance to the jet sound. Although time of exposure was varied for this study, low flight speeds and hover were dominant characteristics of the signals investigated. There is greater annoyance to hover type of signals for helicopter and tilt wing sounds than for flyby signals.

Another study (Ref. 6-4) concluded that annoyance to STOL takeoff and landing noises was under-predicted by both PNdB and EPNdB and that duration corrections provided improvement in the various engineering calculation procedures investigated with the exception of the STOL sounds. Again, the findings are consistent with those of the present study. Slow speed and hovering flights produce more annoyance and duration is not the only factor involved in this increased annoyance.

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7. CERTIFICATION IMPLEMENTATION CONSIDERATIONS

The purpose of aircraft noise certification is to limit noise at the source so that annoyance to aircraft operations in areas around airports will be reduced. However, how the aircraft are operated in general and also in more specific modes of operations at particular airports requires consideration when implementing certification procedures. For example, both helicopters and VTOL can produce flyby noise and/or noise as a result of slow speed, hover operations at a particular airport. Since annoyance in the community can result from both kinds of operations, perhaps both must be considered when operationally defining certification.

Although this study emphasized certification fundmentals of VTOL and helicopter aircraft, annoyance response to conventional takeoff and landing (CTOL) signals were also investigated. The other signals are not only used for comparative purposes but aid in accomplishing the aim of determining an engineering calculation procedure that validly reflects annoyance to a wide variety of aircraft. Since the basis of certification is an engineering calculation procedure that validly reflects annoyance, this aspect was emphasized. As the results show (Table 5-2) that the PNdB family of calculation procedures is superior to the dBA methods, the PNdB approaches are discussed in detail. The PNdB-type calculation procedures are first discussed for all types of airplanes together followed by application to the four types individually.

Assuming that the calculations and the tone and duration corrections worked satisfactorily, the PNdB points in **Figure 5-A** would be distributed around the zero difference line, and application of the tone and duration corrections would diminish the range to some acceptable value. Since Duncan's multiple range test showed that a 2.75 EPNdB difference is required between two signals to reflect valid differences in annoyance, ± 3 dB is used as an acceptable range around the zero difference point. What is actually observed is that, taken altogether, and presented in terms of PNdB (see Table 5-2), the range for the signals used in this study is greater than ± 8 dB, and the addition of a tone correction increases the range while the duration correction decreases the range, but only to about ± 6 dB, indicating that none of the PNdB family of calculation procedures satisfactorily reflects annoyance.

7.1. CONVENTIONAL TAKEOFF AND LANDING AIRCRAFT (CTOL)

An examination of Figure 5-A shows that the CTOL aircraft, with the exception of flyover 1, are reasonably accounted for. The variability of this category is slightly decreased (Table 5-3) by the tone correction, but increased by the duration correction. The duration correction for flyover number 1 is the outstanding offender, contributing most to the variability. With the exception of number 1, the CTOL group is well represented by the EPNL calculation now used in the certification of these aircraft.

7.2. PROPELLER

Of the propeller aircraft, two are in the turboprop transport category (Beech 99 and Convair 640) and would therefore be included under FAR 36 Appendix C for certification purposes. The other, a Britten-Norman Islander, would be covered by Appendix F as a small propeller-driven aircraft and would therefore be measured using dBA.

The PNdB points for these aircraft are clustered beneath the zero difference line, indicating that the noises appear less annoying than the calculation procedure predicts. The inclusion of the tone correction somewhat increases the variability, while the duration correction slightly decreases the variability or range (Table 5-3). All of the duration corrections are negative and do not significantly change the range, but do move the mean toward the zero-difference point. Even at best, the PNdB-based calculations do not acceptably accommodate the propeller aircraft, using the ± 3 dB criteria.

It should be noted that for the propeller aircraft, the duration corrections, all of which are negative, strongly tend to move the differences as plotted in Figure 5-A in the positive (more annoying) direction. Thusly, the assumption of a negative correction for short duration noises is confirmed by this set of results. However, the range (Table 5-3) is still too large to make the calculation acceptable using the ± 3 dB guideline.

7.3. HELICOPTERS

All of the helicopter noises used in the study are of the flyover type; no hover noises were studied. All but two of the flyovers are approaches and more than half of the approaches had a significant amount of blade slap or impulse noise.

Figure 5-A shows the PNdB differences to be biased below the zero line, meaning that the PNL calculation overestimates the annoyance. The tone correction decreases the variability slightly, and the duration correction markedly, with EPNdB doing an adequate job for certification of flyby noise but with rise time of blade slap increased due to investigating only indoor signals.

7.4. VTOL ACTUAL and V/STOL SIMULATIONS

The two actual VTOL noises are judged to be more annoying than the calculations procedures predict with both the tone and duration correction working in the correct direction to reduce the variability.

For the V/STOL simulations, all calculation procedures underestimated the annoyance. The tone corrections significantly increase the variability, while the duration correction increases the variability slightly and moves the mean toward the zero difference line.

Figure 5-A indicates that for these noises the actual VTOL sounds are rated similarly to the V/STOL simulations.

7.5. SUMMARY

In summary, none of the ten calculation procedures investigated are equally valid for the diverse range of signals investigated and thusly it would be difficult to model noise around an airport out of which such a diverse group of aircraft were operating. However, if the propeller type aircraft are excluded, with one exception, one of the PNdB family of calculation procedures both validly and reliably reflects annoyance to the remaining individual aircraft types. This one exception, involves the hover type of signals which are judged more annoying than predicted by any of the calculation procedures. A correction based on the velocity of the aircraft (not duration alone) could improve the validity of engineering calculation procedures evaluating hover types of noise and not degrade evaluations of flyby noise.

8. CONCLUSIONS

- In respect to flyby noise of V/STOL aircraft, it is concluded that EPNdB validly and reliably predicts annoyance.

- For hover type of operations of V/STOL aircraft, PNdB reliably evaluates the annoyance effects. However, in terms of accuracy or validity, PNdB underestimates annoyance but a correction based on aircraft velocity would improve the accuracy of the PNdB procedure.

- When applied to all aircraft types, the tone correction degrades reliability for both PNdB and dBA.

- When applied to all aircraft types, the FAR-36 duration correction to PNdB enhances both reliability and validity.

- Estimating noise levels that will be acceptable to communities surrounding airports from results obtained in a laboratory environment requires consideration of both background noise levels and noise sensitivity characteristics of the subjects.

- When calculating total noise effects due to airport operations, utilizing NEF or L_{DN}, the results show that corrections to standard noise-distance data are required. Corrections are a function of both aircraft type and kind of operation.

- When a new aircraft is introduced into commercial operation and noise certification levels are established via a particular engineering calculation procedure, the difference between the calculated value and the judged annoyance value should be equal-to-or-greater-than 3 dB in order to conclude that the engineering calculation procedure does not accurately reflect annoyance to the noise from the new aircraft.