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ANALOG TAPE MICROSAMPLING

OF

ENVIRONMENTAL NOISE

January 1978

by

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A comparison of several sampling methods with regard to noise level statistical accuracy and to noise source identification accuracy

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PREFACE

This report represents a portion of the research supported by the EPA Office of Noise Abatement and Control in the noise monitoring methodology program as called for in Section 14(c) of PL 92-574, The Noise Control Act of 1972. The results of this work should assist in making noise monitoring more accurate and economical.

INTRODUCTION

The criteria used to judge whether a certain noise exposure in a community is excessive or not, or fits some trend, determine the monitoring methodology and the noise level descriptors required to measure the noise exposure.

The Office of Noise Abatement and Control of the United States Environmental Protection Agency (EPA), directed by Congress under the Noise Control Act of 1972 (PL 92-574), determined and published in the "Criteria Document"[1] and the "Levels Document"[2] that the total A-weighted noise energy (corrected for nighttime sensitivity) received by an individual or a community over a full 24 hour day is a significant and a recommended indicator of noise exposure which correlates well with human response. Thus, the L_{eq}/L_{dn} noise exposure level descriptors and their concomitant maximum recommended indoor and outdoor environmental levels necessary to protect the public health and welfare became important nationwide concerns. Prior to the introduction of these descriptors, professional noise control engineers and other Federal agencies such as DOD, DOL (OSHA), DOT, HUD and others were using various different criteria from the above. Full day, continual monitoring at each measuring site became important, necessary considerations by all in their future monitoring plans.

It is the full day monitoring period which places the severe requirements on the methodology and the monitoring budget. The costs of automatic digital data acquisition and reduction systems are very high per monitoring station. However, the personnel costs for automatic systems are lower and it is safer and more convenient to use such equipment than to place eight-hour shifts of people per site in the field (with all of the creature-comfort problems of people) with accurate inexpensive hand-held equipment. The advantage of placing personnel at the sites has been to identify the noise sources as well as to take the levels data and meterological data. It is considered a

[1]"Public Health and Welfare Criteria for Noise", EPA 550/9-73-002, July 27,1973.

[2]Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety", EPA 550/9-74-004, March 1974.

luxury to place automatic digital acquisition equipment plus a source observer at each site but it is considered necessary to do so in order to quantify and identify the major contributors to the noise environment. Identification of the sources and their contributions to the total noise energy is absolutely vital to any meaningful noise control measures such as the establishment and enforcement of a community noise control ordinance with source controls and acoustical criteria in its constitution.

Analog tape microsampling has been recommended, used, and reported by several noise control professionals[3,4,5,6] including the Authors[7] as a method by which environmental level data and noise source signature information can be obtained automatically and accurately in the field (at a lower cost than other methods) and by which the data reduction and source identification can be performed in the laboratory later by trained operators and observers.

Analog microsampling is the intermittent recording of an analog acoustic signal with a magnetic tape recorder. The control of the on and off times of the recorder is performed by another instrument called a microsampler.

Since only a small portion of the sampling period is actually recorded, time appears to be compressed when the tape is played back, and a single 1-1/2 hour reel of tape can contain 24 or more hours of sampled data. Time compression ratios of up to 30:1 have been used successfully. This time reduction has great benefits in reduced cost of data acquisition and reduction, especially the latter. However, the technique has its trade-offs, for as time compression ratios increase, accuracies of source identification and of the level descriptors

[3] Kamperman, G.W., "Techniques for Sampling Environmental Noise" Proc. Inter-Noise 72, p. 393-398, 1972.

[4] Schultz, T. J., "Some Sources of Error in Community Noise Measurement" Sound and Vibration, Feb. 1972.

[5] Safeer, H.B., Wesler, J.E. and Rickley, E.J., "Errors due to Sampling in Community Noise Level Distributions" J. of Sound and Vibration, (1972) Vol. 24, No. 3, pp. 365-376.

[6] Safeer, H.B., "Community Noise Levels - A Statistical Phenomenon" J. of Sound and Vibration (1973) Vol. 26, No. 4, pp. 489-502.

[7] Watson, H., Jr.. et.al, "Environmental Noise Monitoring at Three Sites in Irving, Texas" U.S. Environmental Protection Agency Report No. EPA 906/9-75-001, Feb. 1975.

decrease. For this reason error estimation and analysis is a crucial part of any microsampling scheme.

Random, periodic, and demand sampling have all been used, the first two more commonly than the third. Kamperman[3] reported the accuracy of the use of a small, portable, periodic, analog tape microsampler with regard to obtaining noise level percentiles. Schultz[4] performed both random continuous sampling (2 min/60 min) and periodic sampling (10 sec/5min.). Safeer et. al[5] compared random continuous sampling with periodic sampling at 30:1 time compressions and found periodic sampling to be more accurate. The Authors[7] applied the periodic microsampling method (1 sec/20 sec) to a community-aircraft flyover noise problem and succeeded in measuring the level statistics and L_{eq}/L_{dn} accurately (as compared to an automatic digital sampler) as well as to identify 90 of 98 jet aircraft flyovers over a 9 hour test period.

SUMMARY

In the present work reported herein, twenty-two analog tape recordings comprising sixteen hours of outdoor environmental sound from the following sources were analyzed: (1) construction sites (2) ground transportation centers (3) stationary (plant) sites (4) airport/aircraft and (5) other sites with no dominant source, such as residential and commercial business areas. Each tape was analyzed for its L_1, L_{10}, L_{90} noise level percentiles and its L_{eq}. Afterwards, several (six) different microsampled tapes were made from each of the originals by each of the following microsampling methods:

(1) Periodic - 2/20. Two-second-sample every twenty seconds. (P1)
(2) Periodic - 4/90. Four-second-sample every ninety seconds. (P2)
(3) Demand - L_5. Demand threshold at the L_5 percentile level. (D)
(4) Random 4/40. Four-second-sample on the average of every forty seconds during the sample period. (R)
(5) Demand/Periodic 4/120-L_1. Four-second-sample every one-hundred-and-twenty seconds or above the L_1 threshold on demand. (DP)
(6) Demand/Random 4/130-L_1. Four-second-sample on the average of every one-hundred-and-thirty seconds or above the L_1 threshold on demand. (DR)

A total of one hundred and thirty two (132) microsample tapes were made and analyzed for their percentile statistics. All but fifteen of these were used in the source identification part of the research program.

In the noise source identification work, each full-length analog tape was listened to by an expert* while the sound level was being recorded on a graphic level recorder and the sources were identified and corroborated with both written and taped cue-track data whenever supplied. The number and types of sources as well as the rank of dominance of each source was determined for each tape. The same was done for each microsampled tape. From a comparison of the two sets of data, a grade for each microsample method could be established based on the ability of the microsampling method to reflect the number of different sources and the rank of dominance of each source being monitored.

* The expert was a person experienced at taking noise data in the field and at identifying sources; in addition he was privy to the furnished source information supplied and listened to each tape as many times as necessary to accurately identify the sources.

Another part of the source identification program was to play back the microsampled tapes to a group of non-expert listerners who had had some training in identifying sources from such tapes. Seven students from various disciplines, including both scientific and non-scientific interests, were carefully chosen. The students were all between the ages of 19-24 and were college students of Southern Methodist University, and all had normal hearing as determined from audiometric tests except for one student, and his hearing loss was in one ear only and not considered a serious problem. The seven were played a two-hour training tape which was a composite tape made up from all of the 22 tapes furnished. Each listener learned to identify the various source types with a set of special symbols and to mark the symbol on the paper tape of the simultaneous graphic level recording. At the end of the training period, each listener had to pass a listening exam with a grade of 85% before proceeding to the next task of identifying sources from the microsampled tapes.

The six microsample methods were then compared two ways for noise source identification: (1) Listener Accuracy-Feasibility and accuracy of the method to represent source information in such a way that a trained listener could accurately identify the source when played back in real time. (2) Method Accuracy-Accuracy of the method in containing enough information to represent the number of different sources present and the degree of dominance of each source type. It is possible to microsample accurately with 1/2 second samples taken each 12 seconds. The samples will contain information that reflects the number and dominance of source types. However, when played back in real time, identification becomes very difficult (and inaccurate) for the listener, being bombarded by a continuous stream of 1/2 second samples. Human Complex Reaction is of the order of 1/2 - 3/4 second; thus there is simply not enough time to record the source type even if it can be identified in such time. A two-second sample was found to be the minimum length that a listener could deal with accurately.

The results of all the tests are summarized in the table below in which the rank order (descending) of the top microsample methods are shown for each source type and for each of the three test programs.

The first column "Listener Accuracy" shows the microsample method with which the student listeners were able to identify accurately the sources represented by the microsample tape as compared to the expert with the same tapes. Thus, these comparisons are measures of listener accuracy with a particular method not method accuracy. Columns labelled "Representation of Number of Sources" and "Representation of Dominance of Sources" show the accuracy of the microsample tapes to reflect the total number of different sources present and the rank order of dominance of each source type. These rankings were made based on comparisons of sources identified from each microsample tape and from each full time continuous tape by the expert. Thus, these comparisons reflect the accuracy of the particular microsample method in representing the number of different source types and the rank order of dominance of each source type.

The last column is a rank ordering of each microsample method in so far as its accuracy in quantitative determination of the L_{eq} and L_1 descriptors over the measurement period with the accuracy of the L_{eq} deemed more important. L_1 was chosen since that was the set point for the threshold of the demand sampler.

SOURCE TYPE	Listener Accuracy in Source Identification	Method Accuracy in Identification: Representation of Number of Sources	Method Accuracy in Identification: Representation of Dominance of Sources	Method Quantitative Accuracy (L_{eq} & L_1)
CONSTRUCTION	1) P1 2) D 3) R	P1,R DP DR	P1 R,DP D	P1 R DP,DR
TRANSPORTATION (Ground)	1) D,DP 2) DR 3) None	P1,R D,DP,DR P2	P1 DP DR,D,R	DP DR P1
STATIONARY	1) DR 2) DP,R,P1,D 3) None	P1 D,R P2	P1 R P2,D	P1 DP,R DR
AIRCRAFT	1) DR 2) DP 3) R	DR R,P1 P2	P1,R DP,DR,P2	DP P1,R DR
OTHER	1) P1,DR 2) D,R 3) P2	P1 P2 R DR	P1 P2 DR	DR,DP P2 R
OVERALL	1) DR 2) DP 3) P1	P1,R DR DP	P1 R DP	DP DR

TABLE S1 - Rank Ordering of Microsample

Methods of Each Test Program: (1) Listener Accuracy in Source Identification (2) Method Accuracies in representation of number of Sources and/or their dominance and (3) Method Quantitative Accuracy in measurement of the L_{eq} and L_1 levels.

CONCLUSIONS AND RECOMMENDATIONS

This test program has shown that microsampling can be employed as a method for reduction of cost of data acquisition and of time and cost of data reduction by the reduction of the amount of personnel and expensive automatic digital acquisition equipment which must be placed at each monitoring site. Microsampling is accurate both in representing the L_{eq} and the noise level percentiles and in representing the types and dominance of the noise sources. However, there is no one microsampling method which is universal for all source types. The proper method must be chosen judiciously.

In the table below are the recommended microsampling methods for each source type. The choice of the recommended method is most cases was a trade-off between the best method for quantitative results and the best method for qualitative results (source identification). Overall the best method appeared to be the Demand/Random 4/130-L_1 method, which has the capability of compressing 24 hours of data on one hour of tape. Although the Periodic 2/20 appears to be superior in several source categories, it has a low time compression, storing only 15 hours of data on a 1-1/2 hour tape. However, one must keep in mind that periodic microsamplers are easier and inexpensive to construct and employ while demand and random samplers are not. Furthermore, in the case of demand samplers, one must have an educated estimate of the threshold level. This would require prior knowledge of the types of major sources and their expected noise levels and duration at the microphone location. This is not a prohibitive requirement since often a great deal is known about a site and its major sources in advance, or a day of pure digital sampling can be done the first day to establish the percentile levels for selection of a threshold level.

In the course of the work, it was found that some form of electronic aid would perhaps assist greatly in source identification. A keyboard with source symbols on each key, connected electronically to switching circuits which would shunt the source level signals to separate storage cells would in the read out process reveal the energy contribution of each source type and permit the rank ordering of the dominance of each source and the determination of its contribution to the L_{eq}. It is proposed that this be done.

At the end of the work, time did not permit the desired field testing of each of the recommended microsampling methods. This work should also be done in the near future.

TABLE S-2

RECOMMENDED SAMPLING METHOD FOR EACH SOURCE TYPE

SOURCE TYPE	IDENTIFICATION ONLY	NOISE LEVEL STATISTICS ONLY	BOTH STATISTICS & SOURCE ID
CONSTRUCTION	P1 DP	P1 R	P1 or R (10:1) DP or DR (24:1)
TRANSPORTATION	DP	DP DR	DP or DR
STATIONARY	P1	P1 DP	P1 (10:1) DP (24:1)
AIRCRAFT	DR	DP	DP
OTHER	P1 DR	DP,DR	DP or DR
OVERALL			DP or DR

On the basis of this work, the authors expect that others will employ microsampling methods such as those described herein and assist in the establishment of microsampling methods as important, economical monitoring tools in the business of controlling environmental noise.

MAIN BODY OF REPORT

Summary of Work Performed

The following tasks were performed as required by the contract work:

1) Analysis of full time continuous tapes for L_{eq} and L_x percentiles.

2) Autocorrelation analysis of full-time continuous tapes.
Determination of duty cycle and subsample times of microsampling.

3) Equipment checkout for sampling errors.
Analysis of tape recorder on-off errors.

4) Construction of 132 microsample tapes for six different sampling techniques from all full-time, continuous tapes.

5) Analysis of microsample tapes for noise level histograms.

6) Analysis of mathematical models to reduce demand-microsampled tapes.

7) Construction of L_{eq} and L_x percentiles for all microsampled tapes.

8) Selection and audiometric testing of seven students to serve as listeners in source identification tests with microsampled tapes.

9) Construction of continuous training tape and audio source examinations from full-time continuous tapes for listeners.

10) Playback of full-time continuous tapes and source identification of all sources by expert to establish source identification reference standard.

11) Listeners trained with training tape and examined.

12) Microsample tapes played back to seven listeners plus one expert in source identification tests.

13) Microsample methods graded as to fidelity of representation of number of sources and rank order of dominance of sources.

14) Listeners graded as to inaccuracy of misidentification of sources for each microsample tape (over 800 in all).

15) Statistical analysis of all data both level statistics and source identification grades.

16) Comparisons from results of statistical analyses.

Analysis of Full-Time Continuous Tapes

Twenty-two analog magnetic tapes comprising sixteen hours of recorded noise from five major source categories were furnished by EPA-ONAC for the contract study. The five major source categories were

Construction
Transportation (ground)
Stationary
Aircraft (airport)
Other (residential and business districts)

Six tapes were furnished for the first source category, four tapes each for the next three, and three tapes for the last above.

Each tape was played back through a digital statistical noise level analyzer. The analyzer used is not commercially available but was constructed by the U.S. Army Corp of Engineers, Construction Engineering Research Laboratory of Champaign, Illinois (CERL) according to EPA specifications. The CERL unit consists of: (1) true rms log voltmeter (HP 7562A, 80 dB dynamic range ± 1 dB 50-200 Hz, ± 0.5 dB 200-20000 Hz with a 5:1 crest factor), (2) an analog-to-digital converter which establishes eighty 1 dB-wide noise level bins, or windows and samples at a rate of 10 per sec, (3) weighting networks (A, C, linear) and (4) a programmable calculator (Wang 605) and digital interface programmed to store the data in eighty different locations over any sample time blocks and to preserve data blocks on digital cassette magnetic tape. The calculator was also programmed to perform all necessary noise level statistical analyses. This analyzer with its accuracy of ± .5 dB and 10 samples/sec rate was taken as the reference standard for all analyses.

Each tape was played back on a magnetic tape recorder similar to one on which it was recorded, a Nagra SJ IV, dual channel recorder. This recorder has a single-channel dynamic range of 55-60 dB depending on the quality of tape used. With careful biasing of good quality tape, errors of ± 0.5 dB over the range of 150 Hz - 2000 Hz, ± 1 dB over the range of 40 Hz - 4000 Hz, and ± 2 dB over the range of 25 Hz - 10 KHz (all at 3.75 in/sec ± .12% transport speed) can be achieved. It is believed that the majority of the errors are of the order of ± 0.5 dB since most of the major environmental noise sources have most of their spectral energy in the range of 150 Hz - 2000 Hz.

The results of the analysis of the full time continuous tapes can be seen in Table 1* in which the L_{eq}, L_1, L_{10} and L_{90} are listed for each tape as required by contract. The L_0, not required, is also listed. The ranges of the L_{eq} and the L_x percentiles were quite broad as seen in list below

L	Range (dBA)
L_{eq}	59 - 90
L_1	70 - 100
L_{10}	64 - 95
L_{90}	48 - 81
L_0	77 - 106

or about a 30 dBA range for each L statistic. A site description and a list of the major sources at each site can be found in Appendix A-1.

* All Tables and Figures referred to in the Main Body can be found at the end of the Main Body. Others with prefix "A" can be found in the Appendix.

NOTE: All sound levels are "A" weighted with a "fast" meter time constant and re 20 micropascals.

Autocorrelation Analysis of Continuous Tapes

Prior to the construction of the microsample tapes several tapes of different major source types were analyzed on a hybrid digital-analog computer. The full-time continuous tapes were played back through the RMS log voltmeter and the noise level output was sampled at a high rate, digitized, and fed into a computer program which performed a normalized digital approximation to the autocorrelation function defined below

$$r(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T L_p(t + \tau)\ L_p(t)\ dt$$

which was normalized with respect to r(o). Several examples of autocorrelograms of different major source tapes can be seen in Figure 1. These autocorrelograms show the degree of independence between noise levels spaced τ seconds apart and the degree of randomness or periodicity of the levels. This information is helpful in the determination of how long a time one should wait between samples (duty cycle), how long a subsample should be taken, and whether the noise source is random or periodic in its levels. If it is random, then periodic sampling could be used. If it is periodic, care must be taken to avoid a duty cycle or subsample length which has a comparable period or length.

The first zero crossing time of the autocorrelogram is indicative of the time spacing required between subsamples for independence (duty cycle) and an oscillatory correlogram with evenly spaced zero crossings indicates periodicity at a frequency of twice the zero crossing rate. For example correlogram of tape No. 7 in Fig 1 shows a first zero crossing at 32 seconds and a zero crossing rate of one per 20 to 30 seconds. For independent sampling one should sample this source approximately once every 40 seconds or longer with as short a subsample length as possible (2 to 4 seconds). One would expect a random microsample strategy to work best. Correlogram of tape No. 17 of aircraft takeoffs shows a zero crossing rate of once per 40-50 seconds and a time between independent samples of more than 40 seconds. Correlogram of tape No. 6 of construction noise and correlogram of tape No. 12 of the batching plant indicate a high correlation between successive levels, show no zero crossings, and a high degree of randomness. Hence periodic sampling with small subsample lengths and a large duty cycle would suffice in each case.

Construction and Analysis of Microsample Tapes

Due to the fact that a large number of source tapes had to be analyzed with very limited time and monetary resources, critical decisions had to be made as to the number of different microsample tapes which could be made and reduced for each microsample strategy. Past experience with microsampling by the authors has shown them that:

a) Subsample lenghts of less than two seconds are too short to permit accurate source identification and
b) Time compression ratios greater than 25:1 are inaccurate and unnecessarily high
c) The peak levels of the extremely loud intrusive sources, though infrequent, contribute significantly to annoyance if not to the L_{eq}. Thus the upper level percentiles were deemed important. Choice of which percentile to set the threshold level is arbitrary but usually must lie between the L_4 and the $L_{0.1}$ or levels exceeded approximately one hour per day and 1 1/2 minutes per day for practical time considerations. The L_1 level was deemed significant in that it represents the loudest sounds occurring 14.4 minutes per day and still allows a 30:1 time compression periodic (or random) sampling to accompany it for an overall sampling rate of 24:1. Choice of mix of demand time and periodic (or random) time is arbitrary and the trade off depends on whether one is interested in recording all of the sources or the loudest source(s).
d) One should be able to time compress and record at least one day's data on a tape without a change of reel or recalibration (1800-3600 ft tape 1 mil thick at 3-3/4 ips). This keeps time in the field for calibration and time in the lab for data reduction to a reasonable economical level.

Consistent with the guidelines for experience above the following types of microsample tapes were constructed:

a) Periodic (P1) - two second subsample for 20 second duty cycle (2/20) - a 10:1 time compression.
b) Periodic (P2) - four second subsample for 90 second duty cycle (4/90) - a 22-1/2:1 time compression.

c) Demand (D) - demand threshold set at the L_5 percentile level of each continuous, full time tape - a 20:1 time compression

d) Random (R) - four second subsample for a 40 second average duty cycle (one standard deviation - 20 sec). A 10:1 compression.

e) Demand - Periodic (DP) - four second subsample for a 120 second duty cycle plus all levels above a demand threshold set at the L_1 percentile level of each continuous, full time tape - a time compression comprised of a 30:1 and a 100:1 or approximately 23:1 or more depending upon overlap.

f) Demand-Random (DR) - four second subsample for an average 130 second duty cycle (77 second standard deviation) plus all levels above a demand threshold set at the L_1 percentile level of each continuous full time tape - a time compression of 33:1 average and 100:1 or about 25:1 or more on the average or more depending on the overlap.

Microsample Equipment

The microsample tapes were constructed by playing back the full time, continuous tapes on the Nagra SJ tape recorder to another magnetic recorder under the control of a programmed microsampler.

The microsample tape recorder must have in addition to the usual good recording features such as good amplitude and phase response, low distortion, and wide dynamic range - the property of being able to be started and stopped quickly by an electrical signal. This usually means the recorder must have solenoid controls and servocontrolled drive motors. The recorder used in all microsampling reported here was a Sony T850 dual channel. Numerous tests were conducted with this recorder to establish its start-stop characteristics and any errors introduced into the microsample tape due to tape "dropout" caused by starting and stopping the tape. A typical measurement of the start and stop response time of the recorder can be seen in Fig 2 in which a constant 1000 Hz signal recorded every 1.5 seconds by microsampling was played back through a graphic level recorder. As the graph shows the stop time is 5 times longer (50 milliseconds) than the start time (10 milliseconds) and the total dropout time is about 60 milliseconds compared to a subsample length of 1.5 seconds - a ratio of about 260:1. Errors induced into the recorded analog signal on the tape obviously depend on this ratio of subsample length to dropout length. The dropout errors result from two sources: loss of amplitude during the dropout and Doppler shifts in the recorded frequencies causing by the tape speeding up and slowing down. The amplitude errors are immediately obvious and should result in lower levels in general. The frequency shift errors are not so obvious and depend on the frequency content of the recorded signal and the fact that the playback is made through an A-weighting network (filter) the output of which depends on the input frequency. This effect can be understood by study of Fig 3 in which frequency shifts are superposed on the A-filter response curve as the recorder would playback due to Doppler shifts of low (LF), medium (MF), and high (HF) frequency signals. As the recorder stops and starts, the tape is moving slower than normal; therefore a Doppler shift upward in frequency is induced upon playback. Played through an "A" filter this becomes an apparent gain in amplitude at low frequencies, no change at middle frequencies, and a loss at the higher frequencies (see Fig 3). For environmental noise with most of the spectral energy between 50 Hz and 5000 Hz this would translate to a slight gain or positive error. This gain would oppose the amplitude loss. How much total error to be expected for a given microsample length can be predicted from the graph in Fig 4. This graph shows that errors less than about ± 1 db are to be expected in the energy decibel level for the tape recorder starts and stops provided the subsample length is two seconds or longer. (This graph was determined experimentally for a 1 second subsample and extrapolated analytically for the other subsample lengths). Since subsample lengths used were two seconds or longer, these start-stop errors are shown to be negligible.

Several different microsampler controllers were used during this work depending on the sampling strategy. For periodic, demand, and demand periodic strategies a special controller specified by the authors and designed and constructed by a graduate electrical engineering student was used. This unit had the capability of selection of a subsample length and a duty cycle from 1 second to 100 hours each in 1 second increments and a demand threshold selection accurate to ± 0.5 dB. In addition, in the demand mode, it had selective delay times (time constants) in turning on and off so as to eliminate errors caused by recording subsample lengths (and events) of duration less than 1/2 second above the threshold. For random sampling and demand-random sampling the equipment arrangement can be seen in Figure 5 in which a pseudorandom binary pulse generator (PRBPG) is connected to a rectangular pulse generator (RPG) which is set to deliver a rectangular pulse of four seconds duration to a meter relay upon receiving the shorter pulse from the PRBPG. The threshold of the meter relay was set below the output pulse level of the RPG. Therefore, when the PRBPG produced a random pulse, the RPG produced a four second signal which caused the meter relay to turn on the tape recorder transport for four seconds. In the demand-random mode, a second meter relay controller was used in parallel with the random sampler and also turned on the tape transport when the A weighted output of the log voltmeter converter (signal analagous to L_A "fast") exceeded the predetermined meter relay threshold. (See Fig 5). During all demand sampling, the accumulated time of demand recording was measured by means of an automatic timer. The total demand time was needed input to the data reduction scheme devised for demand data.

Demand Sampling Data Reduction

When demand-periodic or demand-random microsample tapes are played back through the automatic statistical analyzer (CERL) the resulting noise level vs sample bin count (noise level density function) is a distorted version of the parent distribution being sampled. In Fig 6 this distortion is represented conceptually. Part (a) of this figure shows the parent distribution being sampled; part (b) shows the theoretical distribution of subsamples expected (one expects reasonable agreement with the parent distribution everywhere except above the demand threshold level where extreme skewness and a bimodal character is expected.); and part (c) shows the actual distribution obtained experimentally. Due to time delays in equipment and circuit responses all samples below the demand threshold are not instantaneously cut off when the demand subsample level suddenly drops below threshold. Thus, some demand subsamples get mixed in with the periodic or random subsamples below threshold. Of course there is also a probability of periodic or random subsamples being mixed in with demand subsamples above the threshold when both samplers are on coincidentally.

In order to reduce a demand-periodic/random distribution to a proper sample distribution resembling the parent distribution, a mathematical model must be employed to deflate the number of samples around the demand threshold level. Two such models were used in this work: a linear data model and an exponential data model (Fig 7). The exponential model proved to be more accurate than the linear one; however, it is believed better models could have been obtained if more development time had been available.

Results of Microsample Tape Analyses

The noise level statistical results of playing the microsample tapes back through the digital statistical analyzer (CERL) system can be seen in Tables 2 through 7 for each microsampling strategy employed and for each of the twenty-two continuous tapes sampled. The demand-only strategy does not yield a sample distribution which resembles the parent distribution except for the part of the parent distribution above the demand threshold (here the L_5). Therefore percentile levels (except above the threshold level percentiles) resulting from analysis of demand-only microsample tapes are almost meaningless and are not included (Table 5). An L_{eq} (or noise energy analysis) can be done if only to compare what the contribution to the overall noise energy is above the threshold level. The demand L_{eq} data for "edited" excludes all demand samples obtained incidentally below the threshold level due to time delays of sampling. The "unedited" data includes these samples.

Comparisons of the microsample tape analyses with the analyses of the continuous tapes yields error differences in the derived percentile levels; i.e. ΔL_x where $L_x = (L_x)_{continuous} - (L_x)_{microsampled}$. Tables 8 through 13 show these error differences for each strategy, for each continuous tape sampled, and for the noise level percentiles L_{eq}, L_1, L_{10}, L_{90}, and L_0. Figures 8 through 12 depict the average error and ± one standard deviation about the average error of each percentile level for all 22 tapes sampled for each microsample method. For example Fig. 8 indicates that the average errors in the percentiles are less than ± 1 dBA (black dots) and that the ± one standard deviations (solid lines) indicate about a ± 1 - 2 dBA range except for L_{99} and L_0. Thus one expects good accuracy with the P1 (2/20, 10:1) strategy except for the extreme percentiles. Figures 8-10 show the same type of error bounds for random or periodic sampling. Figures 11 and 12 which show demand-periodic and demand-random errors do not show similar bounds. These show similar errors and bounds for the L_{90} and L_{99} percentiles but less average errors and smaller error ranges for the L_1 and L_0 percentiles, as expected. However, they also show slightly larger average errors in the L_{50} and much larger ranges of errors for the L_{50} and L_{10}. In Figure 13 are shown the average L_{eq} errors ± one standard deviation for all 22 tapes for each microsampling strategy. Clearly, the demand-periodic method is superior for this description. Overall, from Figures 8-13 it is evident that unless the peak noise level is needed that any of the methods are accurate enough for most applications while the demand-periodic or demand-random methods are best for L_{eq} and upper level percentile levels at the expense of the accuracy of the mid-percentile levels.

Table 14 shows the average mean-square errors associated with each microsample strategy for each percentile level and each source type. Mean-square error is defined as follows

Mean Square Error

of the P_{th} percentile = (Mean of $\Delta L_p)^2$ + (standard deviation of $\Delta L_p)^2$

where $\Delta L_p = (L_p)_{continuous} - (L_p)_{microsampled}$

and where the mean and the standard deviation are averaged for each source group. Which method is best for each source type depends on which percentile is regarded as most important. Table 15 shows a rank ordering of each method by accuracy (mean-square error) for each description or combination of descriptors required for some expected criterion. Again, except for mid-percentiles the methods which are more accurate for most source types and overall are the demand-periodic and demand-random methods with the dense (10:1) periodic a close third. The column showing the ordering for the combination of L_{eq} and L_1 accuracies was regarded as the most important by the authors since the L_{eq} is the EPA designated descriptor and the L_1 percentile usually reflects the infrequent loud, intrusive source levels which occur 14.4 minutes per day; furthermore L_1 and L_{eq} were called for in the contract.

Accuracy of Method in Representing Sources

In this phase of the study an evaluation of each microsample strategy was made to determine its accuracy in representing (1) total number of all the different sources and (2) the rank order of dominance of all the sources as determined from the full-time continuous tape.

First, the full-time continuous tapes were heard by an expert. During the playback a graphic level recording was made and the source symbol marked on the recording. At the end of each tape playback a determination was made as to the number of different sources present and their rank order of dominance. This ordering was based on the expert's opinion as to the effect each source had on the overall noise energy, i.e. the effect on the L_{eq}. This was done for all 22 tapes.

Second, each microsampled tape was played back in a similar manner to the full-time continuous tapes, as many times as necessary, until the expert felt an accurate determination of the number and rank of sources on the tape had been made. This was done for all 132 tapes.

Third, a table of the number of different source types and rank order of each source type was made (see Appendix A-2) for each tape. Then the microsample strategy was graded on a five point scale A=5, B=4, C=3, D=2, F=1 as to its accuracy in representing the number and rank of dominance of the sources on the full-time continuous tape being microsampled. From this table average numerical grades were assigned for each strategy and source type, and a general overall average was determined for all strategies. These averages are reflected in Table 16. On the whole it appears that in the expert's opinion the methods reflect approximately 80% accuracy in representing the number and rank of sources. Generally speaking, all of the methods were more successful at representing the rank order of dominance of the sources rather than the total number of different, individual sources. This would be expected from any sampling scheme. The averages also reflect the time compression of sampling with the lower time compression methodologies P1 and R (10:1) showing greater accuracy than the D (20:1), P2 (23:1), DR (25:1), or DP (23:1). The grades also reflect the degree of homogeneity of the mix of sources. The accuracy for Aircraft (airport) noise was highest and for "Other", the lowest. The aircraft noise tapes indicate only 3 or 4 sources most of the time while "Other" tapes indicate 6 or 7 different sources. The average grades for construction, transportation, and stationary were all about the same overall. Some of the tapes had only three sources some had seven or eight. On the average they showed less sources than "Other" and more than "Aircraft". Therefore, it appears that as the number of different sources increases the accuracy of microsampling decreases in accuracy both in identification of the number of sources and in rank ordering them as well. This is, of course, expected in any sampling methodology.

The results indicate that for accurate source identification the microsampling methodology should be to either (1) sample often with short duration subsamples (2 sec) or (2) sample frequently with short duration subsamples and on demand. Infrequent, long duration subsamples or demand-only subsamples appear to yield lower accuracies.

Table 17 shows an ordering of the microsample methods as to their grades of sources for each source type and overall for all source types.

One must be careful in using Table 17 as a sole criterion in selecting a microsample method. Just because a method can be employed which <u>can capture</u>

all of the important sources doesn't necessarily mean it is the best choice. Another consideration which must be made is that of whether or not a listener can actually identify the sources from the microsample tape. For example, a method of microsampling can be employed in which samples 1/2 second in duration are taken every ten seconds. This method, if the listener were good enough and fast enough, would be better than any of those reported above in its representation of sources. However, no one is capable of listening to such a tape played back with a continuous bombardment of one 1/2 second sample after another and identify them accurately over an hour's time.

The complex reaction time of human beings (1/2-1 seconds) simply does not permit such identifications. For these reasons the methods were further tested with human listeners.

Listener Accuracy in Source Identification

Seven student listeners were recruited from the University student body to participate in the source identification phase of the study. The students' ages ranged from 19-24 years of age. Four were engineering majors and three were social science majors.

Each student was tested for hearing ability at the University speech and hearing clinic and all tested out normal as reflected by the audiograms shown in Tables A-3 to A-10. An expert (Listener No. 8) was also tested.

Each listener was required to listen to a two-hour training tape which was a composite tape of all of the identifiable sources on the 22 full-time continuous tapes furnished by EPA. At the end of the training tape an aural exam was given which each student had to pass with a grade of 85% or better before advancing to the next test stage, that of identifying microsampled sources.

The microsampled tapes were played back to each student individually in a quiet room through good quality earphones. The student had control of earphone loudness. At the beginning of each listening period, the student was required to listen to the first portion of the tape for a few minutes in order to "clear his mind" and become mentally focussed on the aural environment. Then the tape was rewound and the level recorder turned on when the tape was started. During a source identification test the listener had to listen to the sound, watch the graphic recorder level, identify the source, and mark a special source symbol on the paper level recording near the trace. Each listener did this for all 117 microsampled tapes and listened to each tape only once.

Afterwards the microsampled tapes were graded for listener inaccuracy. The measure chosen for inaccuracy was the percent of misidentifications of sources per tape. There were, of course, some non identifications of sources but the number of these were very small since the listeners were asked to identify all sources. The results of the grading, the percent listener inaccuracies can be seen in Tables A-3 through to A-10 for each listener, method, and source type. Scores for each microsampling method averaged over all source types and scores for each source type averaged over all methods are also shown. The same results are listed in Tables A-11 through A-15 by source types and permit comparisons of listeners as well as methods of sampling. The average percent inaccuracies for all eight listeners are compiled into Table 18 in which the average listener inaccuracy for each method and source type is shown. This table shows that aircraft were more accurately identified than stationary sources with construction, other, and ground transportation in the middle and that the average overall inaccuracy of the group of listeners was 15.6% with a standard deviation of 3.5%. The table also shows that all of the demand methods were more accurate than the purely periodic or random methods.

Most of the errors of identification were caused by mistaking one source for another of similar characteristics. For example autos, trucks, and buses were often mistaken one for the other, or prop jets and pure jets, but it was rare that a truck was mistaken for a jet. Sources with unique spectral or temporal characteristics such as aircraft, motor cycles, and helicopters were almost never misidentified. Machines with similar power sources such as earthmovers, trucks, concrete mixers, etc. were often misidentified. Multiple listenings to microsampled tapes could of course reduce these errors. A few subjects, including the expert, were made to repeat a few tapes to see if multiple listenings yielded any better results. In every case some improvement was attained in accuracy and none lost. However, there was not enough time or funds to fully explore the effect of multiple listenings on the accuracy of each listener for each method.

Summary of Overall Results

The results of all tests on microsampling methods are summarized in Table 19 below in which the rank order of the best microsample comparison: (1) listener accuracy (2) capability of representing the number of different sources (3) capability of representing the rank of dominance of each source (4) capability of representing noise level percentiles L_{eq} and L_1. As this and previous tables have shown: (1) listener inaccuracy overall was approximately 16% and that this could be improved a few percentage points by employing a microsampling method that includes some form of demand sampling, (2) overall accuracy of representation of the number and dominance of sources by the several methods is approximately 70%-80% in each case and this can be improved by sampling with short duration subsamples more often, (3) accuracies of the methods to represent the L_{eq} and L_x percentiles varied greatly though demand-periodic and demand-random methods are more accurate in determining L_{eq}, L_1, and L_0, (4) no one single method is a standout in all categories.

Conclusions and Recommendations

This test program has shown that microsampling can be employed as a method for reduction of cost of data acquisition and of time and cost of data reduction by the reduction of the amount of personnel and expensive automatic digital acquisition equipment which must be placed at each monitoring site. Microsampling is accurate both in representing the L_{eq} and the noise level percentiles and in representing the types and dominance of the noise sources. However, there is no one microsampling method which is universal for all source types. The proper method must be chosen judiciously.

In Table 20 are the recommended microsampling methods for each source type. The choice of the recommended method in most cases was a trade-off between the best method for quantitative results and the best method for qualitative results (source identification). Overall the best method appeared to be the Demand/Random 4/130-L_1 method, which has the capability of compressing 24 hours of data on one hour of tape. Although the Periodic 2/20 appears to be superior in several source categories, it has a low time compression, storing only 15 hours of data on a 1-1/2 hour tape. However, one must keep in mind that periodic microsamplers are easier and inexpensive to construct and employ while demand and random samplers are not. Furthermore, in the case of demand samplers, one must have an educated estimate of the threshold level. This would require prior knowledge of the types of major sources and their expected noise levels and duration at the microphone location. This is not prohibitive requirement since often some source information is available for a site in advance.

Furthermore, one day of purely digital monitoring automatically provide good estimates of the percentiles for threshold level selection.

In the course of the work, it was found that some form of electronic aid would perhaps assist greatly in source identification. A keyboard with source symbols on each key, connected electronically to switching circuits which would shunt the source level signals to separate storage cells would in the readout process reveal the energy contribution of each source type and permit the rank ordering of the dominance of each source and the determination of its contribution to the L_{eq}. It is proposed that this be done.

At the end of the work, time did not permit the desired field testing of each of the recommended microsampling methods. This work should also be done in the near future.

On the basis of this work, the authors expect that others will employ microsampling methods such as those described herein and assist in the establishment of microsampling methods as important, economical monitoring tools in the business of controlling environmental noise.

TABLES

Table 1

CONTINUOUS FULL TIME STATISTICS (dBA)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	72·3	81·67	75·50	59·14	86	Fill Site Ft. Carson	CONSTRUCTION
2	73·95	80·02	76·65	67·73	95	Fill Site	
3	64·03	73·01	69·70	53·99	82	Block Masons	
4	71·04	79·53	76·39	61·46	87	Foundation	
5	60·79	70·35	64·10	54·76	77	Hammer, Saw	
6	90·00	99·31	94·94	81·18	106	ARL Construction	
7	78·83	93·18	77·4	59·3	102	Railroad Humpyard	TRANSPORTATION
8	68·52	79·98	72·76	56·67	100	I74	
9	67·26	77·00	60·14	60·05	86	Street	
10	72·40	82·79	75·23	64·59	92	Intersection	
11	78·44	86·37	84·03	56·31	91	Maloney's Concrete	STATIONARY
12	85·32	91·64	89·21	64·81	96	Batch Plant	
13	87·17	99·67	90·52	77·45	108	Fencing Plant	
14	84·03	91·98	88·41	73·41	99	Hyman Construction	
15	68·87	80·66	73·63	55·62	86	Airport Oper.	AIRCRAFT
16	73·13	84·64	78·77	58·30	90	Airport Oper.	
17	79·83	93·36	82·37	58·70	101	Aircraft Takeoffs	
18	81·70	96·24	77·49	69·01	106	Aircraft Landings	
19	63·46	71·91	66·53	58·61	81	Urbana Business	OTHER
20	58·55	70·70	60·49	47·53	83	Mid Class Dist.	
21	68·84	73·82	70·31	57·22	99	Champaign Business	
22	77·61	89·34	81·15	66·27	97	Bus Garage	

Table 2

PERIODIC (20:2) STATISTICS (dBA)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	72.85	82	77	60	85	Fill Site Ft. Carson	CONSTRUCTION
2	74.49	82	77	68	89	Fill Site	
3	65.37	76	69	54	83	Block Masons	
4	72.1	79	76	62	82	Foundation	
5	62.67	71	66	56	80	Hammer, Saw	
6	91.61	98	95	87	101	ARL Construction	
7	76.46	90	76	59	96	Railroad Humpyard	TRANSPORTATION
8	68.67	80	73	56	84	I74	
9	68.72	79	71	61	85	Street	
10	71.89	81	75	64	86	Intersection	
11	78.58	86	84	58	88	Maloney's Concrete	STATIONARY
12	84.88	91	88	66	94	Batch Plant	
13	85.43	99	87	76	104	Fencing Plant	
14	83.67	91	87	73	96	Hyman Construction	
15	69.38	81	73	56	84	Airport Oper.	AIRCRAFT
16	72.56	84	77	58	86	Airport Oper.	
17	81.75	94	83	60	103	Aircraft Takeoffs	
18	83.6	98	79	71	104	Aircraft Landings	
19	63.55	71	66	58	80	Urbana Business	OTHER
20	57.28	67	59	47	81	Mid Class Dist.	
21	64.65	73	70	57	90	Champaign Business	
22	78.26	90	81	67	96	Bus Garage	

Table 3

PERIODIC (90:4) STATISTICS (dBA)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	74·00	81	79	61	83	Fill Site Ft. Carson	CONSTRUCTION
2	73·13	78	76	67	83	Fill Site	
3	63·05	74	66	54	79	Block Masons	
4	69·42	76	74	61	77	Foundation	
5	60·79	68	65	54	72	Hammer, Saw	
6	87·53	95	92	79	97	ARL Construction	
7	75·63	89	77	59	92	Railroad Humpyard	TRANSPORTATION
8	68·39	78	74	56	80	I74	
9	64·38	84	67	60	75	Street	
10	68·76	74	72	64	75	Intersection	
11	78·11	85	83	58	86	Maloney's Concrete	STATIONARY
12	87·22	96	90	66	102	Batch Plant	
13	87·94	102	89	76	105	Fencing Plant	
14	83·62	90	88	73	94	Hyman Construction	
15	71·29	82	76	57	84	Airport Oper.	AIRCRAFT
16	72·91	83	78	59	86	Airport Oper.	
17	76·25	89	80	56	91	Aircraft Takeoffs	
18	79·30	90	78	69	101	Aircraft Landings	
19	62·27	69	65	59	72	Urbana Business	OTHER
20	57·03	68	61	47	72	Mid Class Dist.	
21	66·96	72	69	56	91	Champaign Business	
22	79·81	90	82	67	97	Bus Garage	

Table 4

RANDOM (40:4) STATISTICS (dBA)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	72.75	82	77	59	83	Fill Site Ft. Carson	CONSTRUCTION
2	71.85	77	75	66	79	Fill Site	
3	63.15	71	67	54	75	Block Masons	
4	70.31	78	75	60	83	Foundation	
5	60.35	69	63	54	74	Hammer, Saw	
6	88.77	97	93	80	101	ARL Construction	
7	68.98	82	70	57	96	Railroad Humpyard	TRANSPORTATION
8	68.21	78	72	54	86	I74	
9	68.43	81	70	60	82	Street	
10	70.10	77	73	65	78	Intersection	
11	78.28	86	83	56	87	Maloney's Concrete	STATIONARY
12	85.49	92	89	65	97	Batch Plant	
13	85.87	97	89	76	106	Fencing Plant	
14	83.58	90	88	73	97	Hyman Construction	
15	70.97	82	75	56	84	Airport Oper.	AIRCRAFT
16	72.82	84	77	58	86	Airport Oper.	
17	70.67	93	82	61	99	Aircraft Takeoffs	
18	80.52	95	78	69	100	Aircraft Landings	
19	63.35	72	66	57	83	Urbana Business	OTHER
20	59.42	70	60	47	82	Mid Class Dist.	
21	64.18	73	70	57	78	Champaign Business	
22	77.01	89	80	66	91	Bus Garage	

Table 5

DEMAND (L_5) STATISTICS (dBA)

EPA TAPE NO.	L_{eq} (uned.)	L_{eq} (ed)	L_{10}	L_{90}	L_0	DESCRIPTION	
1	78.67	80.4			85	Fill Site Ft. Carson	CONSTRUCTION
2	77.56	80.4			93	Fill Site	
3	66.53	74.02			83	Block Masons	
4	75.91	78.12			80	Foundation	
5	66.26	69.67			77	Hammer, Saw	
6	91.91	97.85			104	ARL Construction	
7	87.11	90.59			99	Railroad Humpyard	TRANSPORTATION
8	76.44	77.88			85	I74	
9	75.79	78.12			87	Street	
10	81.38	83.11			91	Intersection	
11	84.62	85.69			90	Maloney's Concrete	STATIONARY
12	90.13	92.45			103	Batch Plant	
13	97.88	101.03			107	Fencing Plant	
14	86.34	92.67			97	Hyman Construction	
15	78.24	79.34			86	Airport Oper.	AIRCRAFT
16	82.03	84.06			90	Airport Oper.	
17	90.72	92.36			101	Aircraft Takeoffs	
18	92.41	94.86			103	Aircraft Landings	
19	70.21	71.96			80	Urbana Business	OTHER
20	68.00	70.25			80	Mid Class Dist.	
21	82.56	85.22			99	Champaign Business	
22	87.97	89.52			99	Bus Garage	

Table 6

DEMAND-PERIODIC (120:4 + L_1) STATISTICS (dBA)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	71.6	81.81	76.63	59.15	84	Fill Site Ft. Carson	CONSTRUCTION
2	74.2	81.92	77.13	68.97	93	Fill Site	CONSTRUCTION
3	62.9	71.02	67.99	54.50	83	Block Masons	CONSTRUCTION
4	69.4	78.91	72.87	61.85	80	Foundation	CONSTRUCTION
5	61.8	70.87	66.98	54.68	78	Hammer, Saw	CONSTRUCTION
6	87.6	94.55	91.81	80.03	101	ARL Construction	CONSTRUCTION
7	78.3	92.59	77.25	57.14	99	Railroad Humpyard	TRANSPORTATION
8	67.6	80.76	69.13	55.39	86	I74	TRANSPORTATION
9	67.5	78.94	69.65	59.76	86	Street	TRANSPORTATION
10	72.3	84.34	72.88	63.68	93	Intersection	TRANSPORTATION
11	79.6	86.92	85.61	57.05	90	Maloney's Concrete	STATIONARY
12	84.8	93.18	90.29	64.90	103	Batch Plant	STATIONARY
13	85.8	99.58	87.43	75.96	107	Fencing Plant	STATIONARY
14	82.5	90.21	87.63	73.35	99	Hyman Construction	STATIONARY
15	69.4	82.24	73.01	55.52	89	Airport Oper.	AIRCRAFT
16	74.0	86.07	78.31	58.71	91	Airport Oper.	AIRCRAFT
17	80.1	94.92	79.42	57.45	101	Aircraft Takeoffs	AIRCRAFT
18	82.3	97.00	79.00	68.38	103	Aircraft Landings	AIRCRAFT
19	62.8	72.32	65.10	57.47	82	Urbana Business	OTHER
20	57.3	70.38	58.60	47.35	82	Mid Class Dist.	OTHER
21	69.0	74.61	65.14	57.15	101	Champaign Business	OTHER
22	78.3	90.42	80.85	64.80	99	Bus Garage	OTHER

Table 7

DEMAND-RANDOM (130:4 + L_1) STATISTICS (dBA)
(EXPONENTIAL MODEL)

EPA TAPE NO.	L_{eq}	L_1	L_{10}	L_{90}	L_0	DESCRIPTION	
1	73.6	82.04	79.39	60.72	85	Fill Site Ft. Carson	CONSTRUCTION
2	74.7	82.12	79.08	68.20	94	Fill Site	CONSTRUCTION
3	64.5	71.94	69.57	55.21	81	Block Masons	CONSTRUCTION
4	68.5	79.58	71.24	60.53	81	Foundation	CONSTRUCTION
5	61.2	70.82	64.67	54.52	73	Hammer, Saw	CONSTRUCTION
6	87.8	95.92	91.57	81.40	104	ARL Construction	CONSTRUCTION
7	79.5	93.10	81.22	57.44	105	Railroad Humpyard	TRANSPORTATION
8	66.7	80.38	68.66	55.48	89	I74	TRANSPORTATION
9	68.3	79.02	70.88	61.03	87	Street	TRANSPORTATION
10	74.4	84.87	77.35	68.23	92	Intersection	TRANSPORTATION
11	79.2	86.16	84.89	56.65	89	Maloney's Concrete	STATIONARY
12	83.9	93.07	89.70	64.88	101	Batch Plant	STATIONARY
13	84.6	97.38	86.63	76.52	107	Fencing Plant	STATIONARY
14	81.6	90.28	85.98	73.45	96	Hyman Construction	STATIONARY
15	68.4	81.96	71.10	56.26	87	Airport Oper.	AIRCRAFT
16	76.3	86.06	81.94	59.71	90	Airport Oper.	AIRCRAFT
17	81.1	94.89	80.40	58.05	101	Aircraft Takeoffs	AIRCRAFT
18	82.8	97.03	83.50	68.28	103	Aircraft Landings	AIRCRAFT
19	63.7	73.69	66.12	58.71	82	Urbana Business	OTHER
20	58.2	71.00	59.85	47.74	83	Mid Class Dist.	OTHER
21	69.1	74.65	64.40	57.10	100	Champaign Business	OTHER
22	78.7	90.26	80.15	67.78	99	Bus Garage	OTHER

Table 8

PERIODIC (20:2) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	- .55	- .33	- .5	-0.86	2	Fill Site Ft. Carson	CONSTRUCTION
2	- .54	-1.98	- .35	-0.27	6	Fill Site	
3	-1.34	-2.99	0.70	-0.01	- 1	Block Masons	
4	-1.06	0.53	0.39	-0.54	5	Foundation	
5	-1.88	- .65	-1.9	-1.24	- 3	Hammer, Saw	
6	-1.61	1.31	- .06	-5.82	3	ARL Construction	
7	2.37	3.18	1.4	0.30	6	Railroad Humpyard	TRANSPORTATION
8	- .15	- .02	- .24	0.67	16	I 74	
9	-1.46	-2.00	- .86	-0.95	1	Street	
10	0.51	1.79	0.23	0.59	5	Intersection	
11	- .10	0.37	0.03	-1.69	3	Maloney's Concrete	STATIONARY
12	0.44	0.64	1.21	-1.19	2	Batch Plant	
13	1.74	0.67	3.52	1.45	4	Fencing Plant	
14	0.48	0.98	1.41	0.41	3	Hyman Construction	
15	- .51	- .34	0.63	-0.38	2	Airport Oper.	AIRCRAFT
16	0.57	0.64	1.77	0.30	4	Airport Oper.	
17	-1.92	- .64	-0.63	-1.30	- 2	Aircraft Takeoffs	
18	-1.90	-1.76	-1.51	-1.99	1	Aircraft Landings	
19	-0.09	0.91	0.53	0.61	1	Urbana Business	OTHER
20	1.27	3.70	1.49	0.53	2	Mid Class Dist.	
21	4.19	0.82	0.31	0.22	9	Champaign Business	
22	- .61	- .66	0.15	-0.73	1	Bus Garage	

Table 9

PERIODIC (90:4) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	-1.7	0.67	-2.5	-1.86	4	Fill Site Ft. Carson	CONSTRUCTION
2	0.82	2.02	0.65	0.73	12	Fill Site	CONSTRUCTION
3	0.98	-0.99	3.70	-0.01	3	Block Masons	CONSTRUCTION
4	1.62	3.53	2.39	0.46	10	Foundation	CONSTRUCTION
5	0	2.35	-0.9	0.76	5	Hammer, Saw	CONSTRUCTION
6	2.47	4.31	2.94	2.18	7	ARL Construction	CONSTRUCTION
7	3.2	4.18	0.4	0.30	10	Railroad Humpyard	TRANSPORTATION
8	0.13	1.98	-1.24	0.67	20	I74	TRANSPORTATION
9	2.88	-7.00	3.14	0.05	11	Street	TRANSPORTATION
10	3.64	8.79	3.23	0.59	16	Intersection	TRANSPORTATION
11	0.33	1.37	1.03	-1.69	5	Maloney's Concrete	STATIONARY
12	-1.90	-4.36	-0.79	-1.19	6	Batch Plant	STATIONARY
13	-0.77	-2.33	1.52	1.45	3	Fencing Plant	STATIONARY
14	0.53	1.98	0.41	0.41	5	Hyman Construction	STATIONARY
15	-2.42	-1.34	-2.37	-1.38	2	Airport Oper.	AIRCRAFT
16	0.22	1.64	0.77	-0.70	4	Airport Oper.	AIRCRAFT
17	3.58	4.36	2.37	2.70	10	Aircraft Takeoffs	AIRCRAFT
18	2.4	6.24	-0.51	0.01	4	Aircraft Landings	AIRCRAFT
19	1.19	2.91	1.53	-0.39	9	Urbana Business	OTHER
20	1.52	2.70	-0.51	0.53	11	Mid Class Dist.	OTHER
21	1.88	1.82	1.31	1.22	8	Champaign Business	OTHER
22	-2.03	-0.66	-0.85	-0.73	0	Bus Garage	OTHER

Table 10

DEMAND SAMPLING (L_5) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq} (uned.)	ΔL_{eq} (ed.)	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	-6.57	-8.1			2	Fill Site Ft. Carson	CONSTRUCTION
2	-3.76	-6.45			2	Fill Site	CONSTRUCTION
3	-2.53	-9.99			- 1	Block Masons	CONSTRUCTION
4	-4.71	-7.08			7	Foundation	CONSTRUCTION
5	-5.76	-8.88			0	Hammer, Saw	CONSTRUCTION
6	-1.51	-7.85			0	ARL Construction	CONSTRUCTION
7	-8.21	-11.76			3	Railroad Humpyard	TRANSPORTATION
8	-7.34	-9.36			15	I74	TRANSPORTATION
9	-8.89	-10.86			- 1	Street	TRANSPORTATION
10	-8.98	-10.71			0	Intersection	TRANSPORTATION
11	-6.02	-7.25			1	Maloney's Concrete	STATIONARY
12	-4.38	-7.13			- 7	Batch Plant	STATIONARY
13	-10.68	-13.86			1	Fencing Plant	STATIONARY
14	-2.44	-8.64			2	Hyman Construction	STATIONARY
15	-9.14	-10.47			0	Airport Oper.	AIRCRAFT
16	-8.63	-10.93			0	Airport Oper.	AIRCRAFT
17	-10.72	-12.53			0	Aircraft Takeoffs	AIRCRAFT
18	-10.61	-13.16			2	Aircraft Landings	AIRCRAFT
19	-6.71	-8.5			1	Urbana Business	OTHER
20	-9.3	-11.7			3	Mid Class Dist.	OTHER
21	-13.36	-16.38			0	Champaign Business	OTHER
22	-10.47	-11.91			- 2	Bus Garage	OTHER

Table 11

RANDOM (40:4) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	-0.45	-0.33	-0.5	0.14	4	Fill Site Ft. Carson	CONSTRUCTION
2	2.10	3.02	1.65	1.73	16	Fill Site	
3	0.88	2.01	2.70	-0.01	7	Block Masons	
4	0.73	1.53	1.39	1.46	4	Foundation	
5	0.44	1.35	1.10	0.76	3	Hammer, Saw	
6	1.23	2.31	1.94	1.18	3	ARL Construction	
7	9.85	11.18	7.4	2.30	6	Railroad Humpyard	TRANSPORTATION
8	0.31	1.98	0.74	2.67	14	I74	
9	-1.17	-4.00	0.14	0.05	4	Street	
10	2.30	5.79	2.23	-0.41	13	Intersection	
11	0.16	0.37	1.03	0.31	4	Maloney's Concrete	STATIONARY
12	-0.17	-0.36	0.21	-0.19	- 1	Batch Plant	
13	1.30	2.67	1.52	1.45	2	Fencing Plant	
14	0.57	1.98	0.41	0.41	2	Hyman Construction	
15	-2.10	-1.34	-1.37	-0.38	2	Airport Oper.	AIRCRAFT
16	0.31	0.64	1.77	0.30	4	Airport Oper.	
17	0.16	0.36	0.37	-2.30	2	Aircraft Takeoffs	
18	1.18	1.24	-0.51	0.01	5	Aircraft Landings	
19	0.11	-0.09	0.53	1.61	- 2	Urbana Business	OTHER
20	-0.87	0.70	0.49	0.53	- 1	Mid Class Dist.	
21	4.66	0.82	0.31	0.22	21	Champaign Business	
22	0.64	0.34	1.15	0.27	6	Bus Garage	

Table 12

DEMAND-PERIODIC (120:4 + L_1) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	0.5	-0.14	-0.13	-0.01	2	Fill Site Ft. Carson	CONSTRUCTION
2	-0.4	-1.90	-0.48	-1.24	2	Fill Site	
3	1.1	1.99	1.77	-0.51	- 1	Block Masons	
4	1.8	0.62	3.52	-0.39	7	Foundation	
5	-1.3	-0.52	-2.88	0.08	- 1	Hammer, Saw	
6	2.8	4.76	3.13	1.15	5	ARL Construction	
7	0.6	0.59	0.15	2.16	3	Railroad Humpyard	TRANSPORTATION
8	1.5	-0.78	3.63	1.28	14	I74	
9	-0.6	-1.94	0.49	0.29	0	Street	
10	0.1	-1.55	2.35	0.91	- 1	Intersection	
11	-1.0	-0.55	-1.58	-0.74	1	Maloney's Concrete	STATIONARY
12	0.5	-1.54	-1.08	-0.09	- 7	Batch Plant	
13	1.4	0.09	3.09	1.49	1	Fencing Plant	
14	1.4	1.77	0.78	0.06	0	Hyman Construction	
15	-0.3	-1.58	0.62	0.10	- 3	Airport Oper.	AIRCRAFT
16	-0.6	-1.43	0.46	-0.41	- 1	Airport Oper.	
17	-0.1	-1.56	2.95	1.25	0	Aircraft Takeoffs	
18	-0.5	-0.76	-1.51	0.63	3	Aircraft Landings	
19	0.7	-1.41	1.43	1.14	- 1	Urbana Business	OTHER
20	1.4	0.32	1.89	0.18	1	Mid Class Dist.	
21	0.1	-0.79	5.17	0.07	- 2	Champaign Business	
22	-0.8	-1.08	0.3	1.47	- 2	Bus Garage	

Table 13

DEMAND-RANDOM (130:4 + L_1) ERRORS (dBA)

EPA TAPE NO.	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	DESCRIPTION	
1	-1.5	-0.37	-2.89	-1.58	1	Fill Site Ft. Carson	CONSTRUCTION
2	-0.9	-2.1	-2.43	-0.47	1	Fill Site	
3	-0.5	1.07	0.13	-1.22	1	Block Masons	
4	2.7	-0.05	5.15	0.93	6	Foundation	
5	-0.7	-0.47	-0.57	0.24	4	Hammer, Saw	
6	2.6	3.39	3.37	-0.22	2	ARL Construction	
7	-0.6	0.08	-3.82	1.86	- 3	Railroad Humpyard	TRANSPORTATION
8	2.4	-0.40	4.1	1.19	11	I74	
9	-1.4	-2.02	-0.74	-0.98	- 1	Street	
10	-2.0	-2.08	-2.12	-3.64	0	Intersection	
11	-0.6	-0.21	-0.86	-0.34	2	Maloney's Concrete	STATIONARY
12	1.4	-1.43	-0.49	-0.07	- 5	Batch Plant	
13	2.6	2.29	3.89	0.93	1	Fencing Plant	
14	2.3	1.70	2.43	-0.04	3	Hyman Construction	
15	0.7	-1.3	2.53	-0.64	- 1	Airport Oper.	AIRCRAFT
16	-2.9	-1.42	-3.17	-1.41	0	Airport Oper.	
17	-1.1	-1.53	1.97	0.65	0	Aircraft Takeoffs	
18	-1.0	-0.79	-6.01	0.73	3	Aircraft Landings	
19	-0.2	-1.78	0.41	-0.10	- 1	Urbana Business	OTHER
20	0.5	-0.30	0.64	-0.21	0	Mid Class Dist.	
21	0	-0.83	5.91	0.12	- 1	Champaign Business	
22	-1.2	-0.92	1.00	-1.51	- 2	Bus Garage	

TABLE 14

MICROSAMPLE
MEAN-SQUARE ERRORS (dBA)

TAPE NO.	PERIODIC (20:2)					DEMAND-PERIODIC (120:4 + L_1 = 23:1)					
	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	ΔL_{eq}	ΔL_1	ΔL_{10}	ΔL_{90}	ΔL_0	
1- 6	1.66	2.98	0.91	6.88	16	2.76	6.05	6.64	0.65	15.71	CONSTR.
7-10	2.643	5.59	0.93	0.59	89.67	0.94	2.09	5.41	1.96	63.33	TRANS.
11-14	1.017	0.51	4.49	2.16	9.67	1.61	1.94	4.58	0.92	16.48	STAT.
15-18	2.333	1.252	2.07	1.72	7.81	0.19	1.93	3.73	0.66	6.31	AIR
19-22	6.044	4.73	0.75	0.40	25.48	0.99	1.11	9.2	1.00	3.00	OTHER
TOTAL	2.312	2.585	1.523	2.462	25.803	0.922	2.63	5.2	0.89	17.58	OVERALL

TAPE NO.	PERIODIC (90:4)					DEMAND-RANDOM (130:4 + L_1 = 25:1)					
1- 6	2.55	7.63	6.89	1.88	59.26	3.55	3.47	10.45	1.01	10.55	CONSTR
7-10	8.58	47.9	6.69	0.24	224.65	3.97	2.45	12.01	6.31	42.65	TRANS
11-14	1.46	9.85	1.29	2.16	30.65	4.11	3.29	6.83	0.32	12.98	STAT.
15-18	7.86	18.34	4.03	3.22	37	3.32	1.69	18.36	1.11	3.25	AIR
19-22	3.66	5.55	1.63	0.81	72.33	0.56	1.29	10.85	0.72	1.67	OTHER
TOTAL	4.0187	14.266	3.729	1.385	79.459	2.518	6.6	9.7	1.47	11.62	OVERALL

TAPE NO.	RANDOM (40:4)					
1- 6	1.39	4.01	3.05	1.27	63.39	CONSTR.
7-10	31.94	54.83	17.8	3.75	110.48	TRANS.
11-14	0.62	3.32	0.99	0.72	7.31	STAT.
15-18	1.97	1.27	1.8	1.72	12.81	AIR
19-22	7.2	0.36	0.52	0.85	148.67	OTHER
TOTAL	6.728	10.26	4.15	1.44	61.87	OVERALL

TABLE 15

Rank Order of Methods Which Most Accurately Determined the Descriptions Shown

		L_{eq} & L_1	L_{eq} & L_0	L_0	L_1	L_{10}
CONSTRUCTION	1.	P1	P1	DR	P1	P1
	2.	R	DP	DP	DR	R
	3.	DP, DR	DR	P1	R	DP
TRANSPORTATION	1.	DP	DP	DR	DP	P1
	2.	DR	P1	DP	DR	DP
	3.	P1	DR	P1	P1	P2
STATIONARY	1.	P1	R	R	P1	R
	2.	DP, R	P1	P1	DP	P2
	3.	DR	DP	DR	DR	P1
AIRCRAFT	1.	DP	DP	DR	P1	R
	2.	P1, R	DR	DP	R	P1
	3.	DR	P1	P1	DR	DP
OTHER	1.	Dr, DP	DP	DR	R	R
	2.	P2	DR	DP	DR	P1
	3.	R	P1	P1	DP	P2
OVERALL	1.	DP	DP	DR	P1	P1
	2.	DR	DR	DP	DP	P2
	3.	P1	P1	P1	DR	R

TABLE 16

Average Grades of
Noise Source Representation on Microsample
Tapes by Microsample Method and Source Type
(Grading: A=5, B=4, C=3, D=2, F=1)

Source Type \ Method		P1	P2	D	R	DP	DR	Averages & Grades All Methods	
Construction	Number	4.2	3.0	3.0	4.2	3.8	3.5	3.6/B-	
	Rank	4.7	3.5	3.8	4.2	4.3	3.7	4.0/B	
Transportation	Number	3.8	3.0	3.5	3.8	3.5	3.5	3.5/C+	
	Rank	4.3	3.5	4.0	4.0	4.3	4.0	4.0/B	
Stationary	Number	4.0	3.3	3.8	3.8	3.0	3.0	3.5/C+	Overall Averages & Grades
	Rank	4.7	3.8	3.8	4.3	3.5	3.3	3.9/B	Number = 3.6 = B- Rank = 4.0 = B
Aircraft	Number	4.5	4.0	3.8	4.5	3.8	4.8	4.2/B	
	Rank	4.5	4.3	4.0	4.5	4.3	4.3	4.3/B	
Other	Number	4.0	3.7	2.7	3.5	3.0	3.3	3.4/C	
	Rank	4.0	4.0	3.3	3.0	3.0	3.7	3.5/C+	
Method Averages and Grades	Number	4.1/B	3.3/C	3.4/C	4.0/B	3.5/C+	3.6/B-		
	Rank	4.5/B+	3.8/B-	3.8/B-	4.1/B	4.0/B	3.8/B-		

TABLE 17

Ranking of Microsampling Methods in Ability to Represent the Number of Different Sources and Rank Order of Dominance of each Source. In Descending order of accuracy.

Source Type	Number of Sources	Dominance of Sources
Construction	P1, R DP DR	P1 DP, R D
Transportation	P1, R DP, DR	P1, DP D, DR, R
Stationary	P1 D, R	P1 R P2, D
Aircraft	DR R, P1	P1, R DP, DR
Other	P1 P2 R	P1 P2 DR
Overall	P1, R DP, DR	P1 R, DP

Table 18

Average Percent Inaccuracies for All Eight Listeners

Method / Source Type	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	6.9	13.8	8.8	12.3	13.3	15.9	11.8
Ground Transportation	18.5	22.8	10.2	21.3	11.4	13.2	16.2
Stationary	27.0	38.3	26.0	24.0	28.3	22.4	28.1
Aircraft	18.4	14.3	11.3	10.2	6.1	3.3	7.4
Other	10.0	17.3	14.1	14.6	31.1	10.4	15.2
Method Weighted Overall Averages	15.3	20.8	13.6	16.1	14.8	13.1	
Overall Averages			$\hat{\mu}$ = 15.6		(12.9 without stationary sources)		
Standard Deviation			$\hat{\sigma}$ = 3.5		(2.8 without stationary sources)		
Rank Average (Scale 1 to 6) 1 top	3.4	5.4	2.4	3.4	3.8	2.6	

TABLE 19

Descending Order of Best Method for Each Test of Comparison by Accuracy

Source Type	Listener Accuracy	Number of Sources	Dominance Rank of Sources	L_{eq} & L_1 Statistics
(1)	P1	P1, R	P1	P1
Construction (2)	D	DP	R, DP	R
(3)	R	DR	D, DR	DP, DR
Ground Transportation	D, DP	P1, R	P1	DP
	DR	D, DP, DR	DP	DR
	—	P2	DR, D, R	P1
Stationary	DR	P1	P1	P1
	DP, R, P1, D	D, R	R	DP, R
	—	P2	P2, D	DR
Aircraft	DR	DR	P1, R	DP
	DP	R, P1	DP, DR, P2	P1, R
	R	P2	—	DR
Other	P1, DR	P1	P1	DR, DP
	D, R	P2	P2	P2
	P2	R, DR	DR	R
Overall	DR	P1, R	P1	DP
	DP	DR	R	DR
	P1	DP	DP	P1

TABLE 20

RECOMMENDED SAMPLING METHOD FOR EACH SOURCE TYPE

SOURCE TYPE	IDENTIFICATION ONLY	NOISE LEVEL STATISTICS ONLY	BOTH STATISTICS & SOURCE ID
CONSTRUCTION	PI DP	PI R	PI or R (10:1) DP or DR (24:1)
TRANSPORTATION	DP	DP DR	DP or DR
STATIONARY	PI	PI DP	PI (10:1) DP (24:1)
AIRCRAFT	DR	DP	DP
OTHER	PI DR	DP, DR	DP or DR
OVERALL			DP or DR

FIGURES

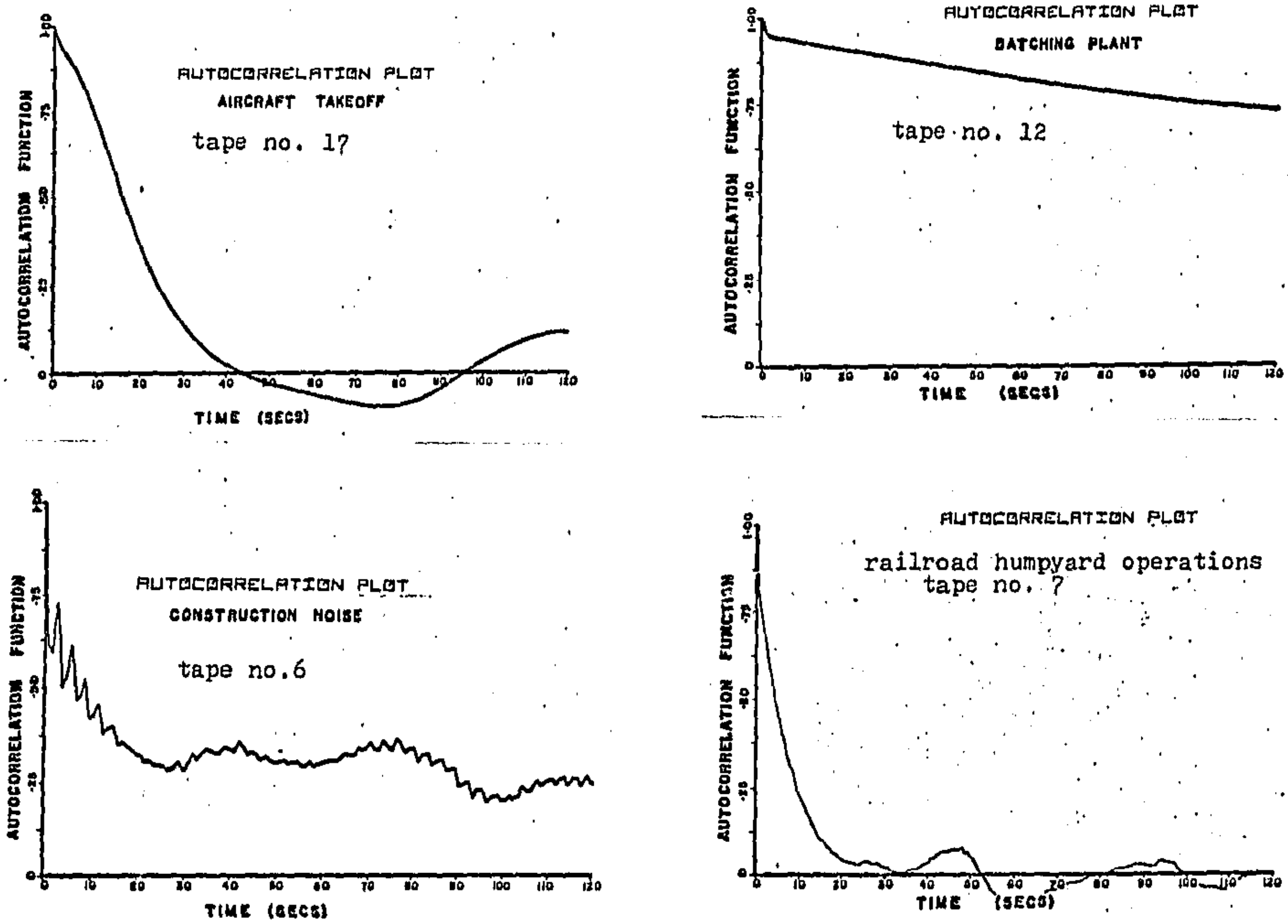


FIGURE 1. Autocorrelation function vs. lag time for several different source types. 45 minute tapes were sampled at data rate of 1 per second. Autocorrelation function plotted is r(τ/r(o) as defined on page 13.

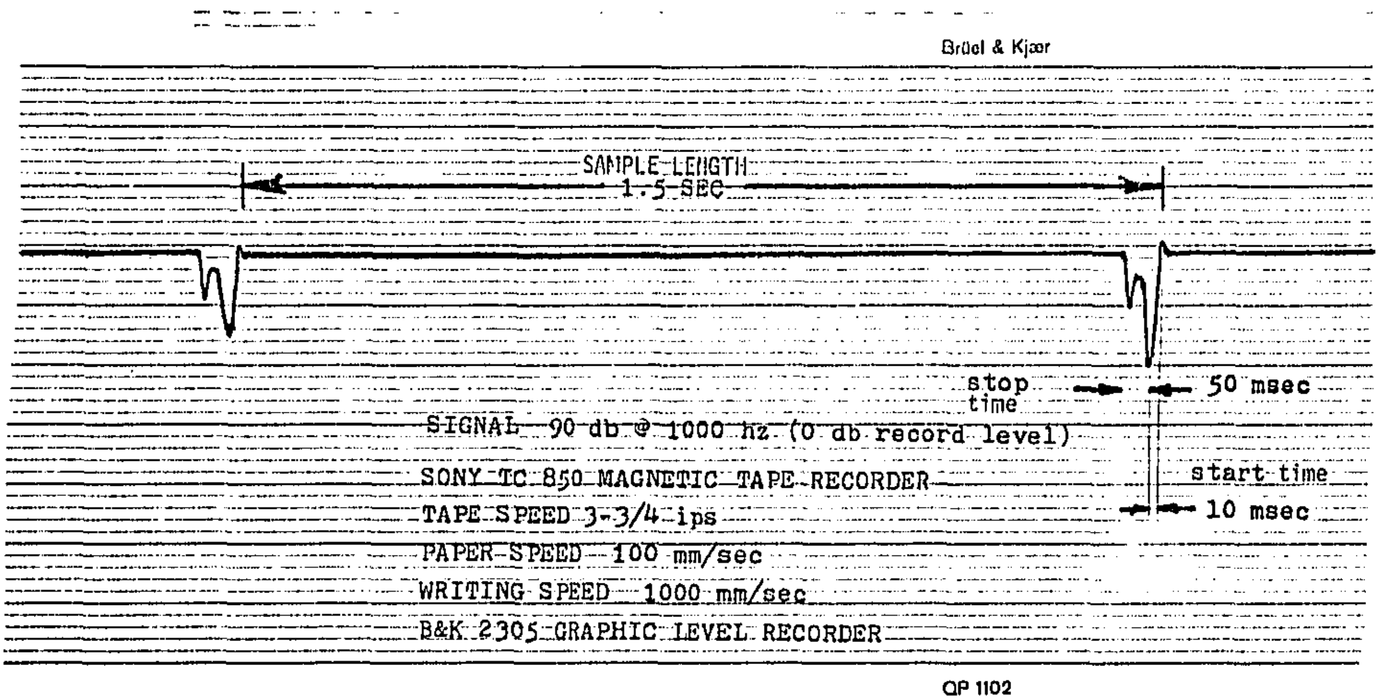


FIGURE 2. Start and stop response time of microsampling tape recorder. Sample time length shown is 1.5 sec with a start time of 10 msec and a stop time of 50 msec as measured from the 10 dB down points. Thus, the overall "dropout time" is 60 msec or about 4% of total record time.

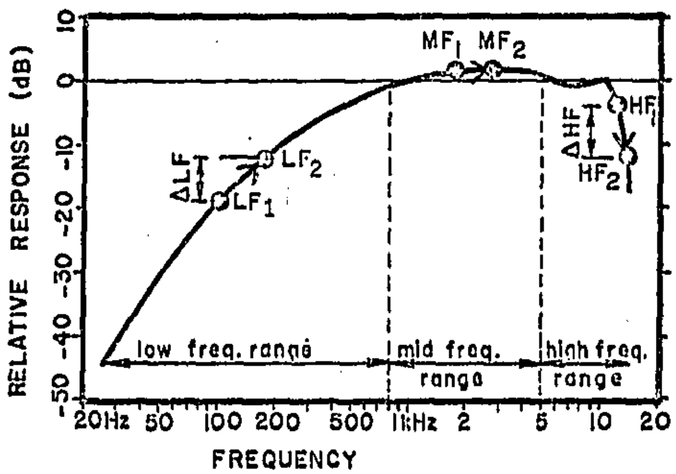


FIGURE 3 Graph showing how an upward shift in frequency of a microsampled signal caused by playback through a weighting network incurs errors. Frequency shifts on the A weighting curve are shown.

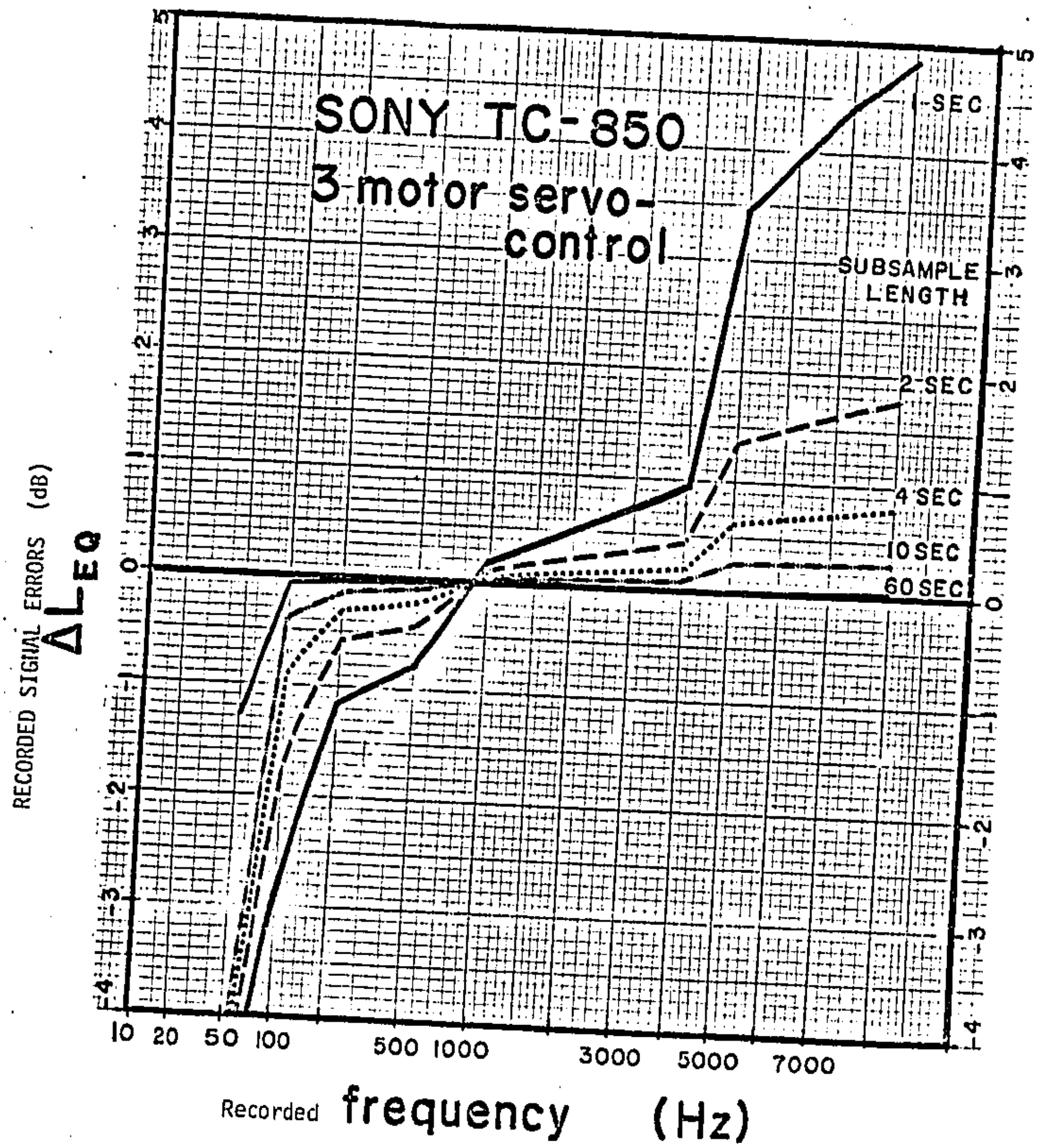


FIGURE 4. Errors in L_{eq} of recorded signal caused by on-off response time of recorder. Solid line measured experimentally; others theoretically extrapolated.

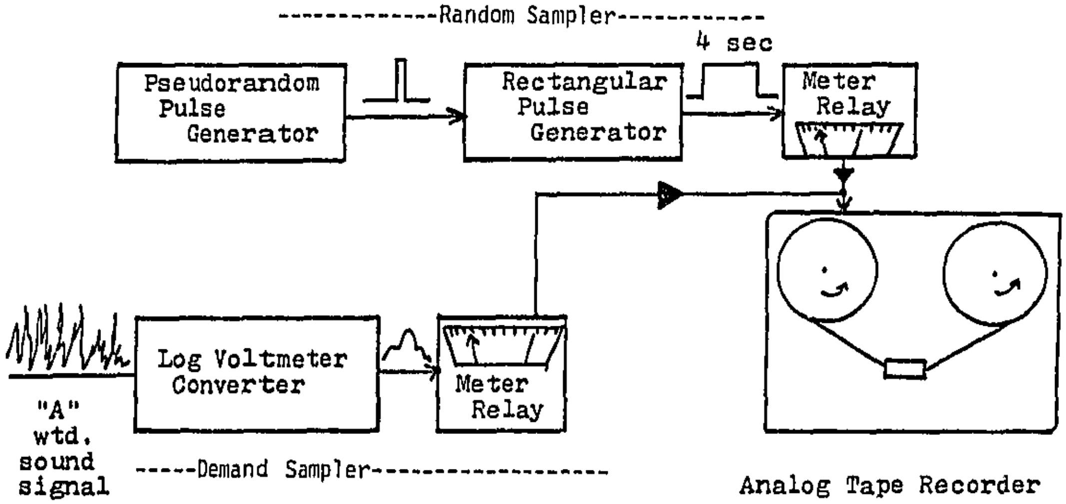


FIGURE 5. Random and Demand-Random microsampler controller.

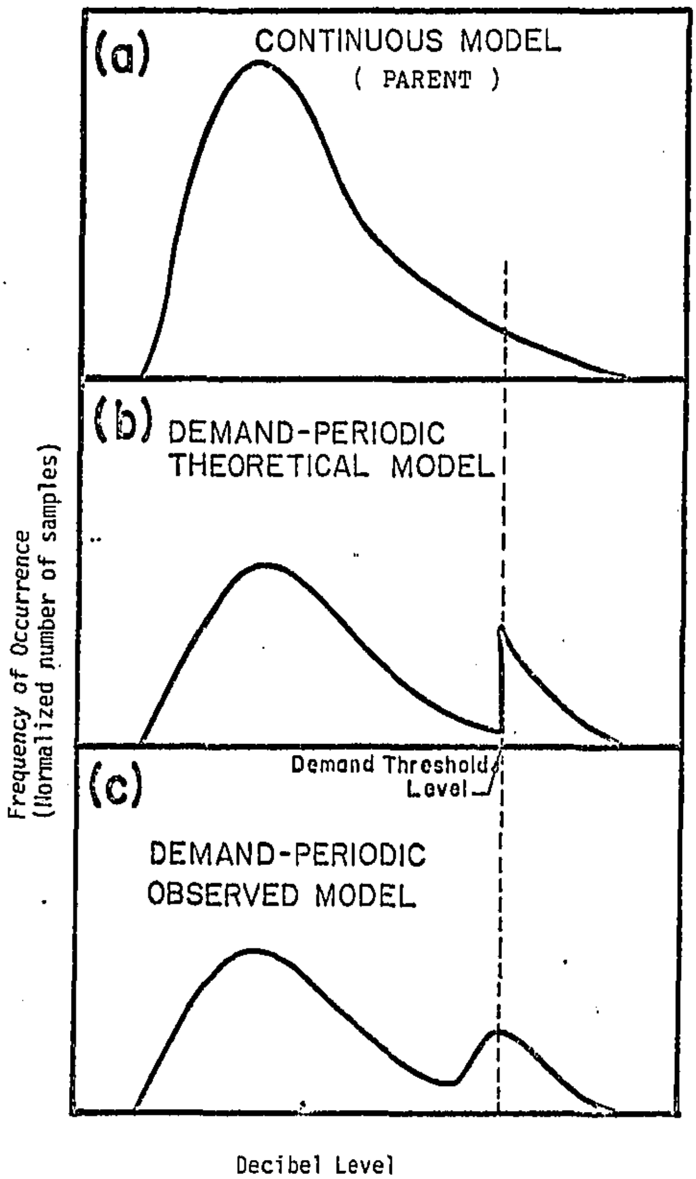


FIGURE 6. Amplitude density functions obtained from analysis of demand-periodic and demand-random microsampled tapes compared to parent density function.

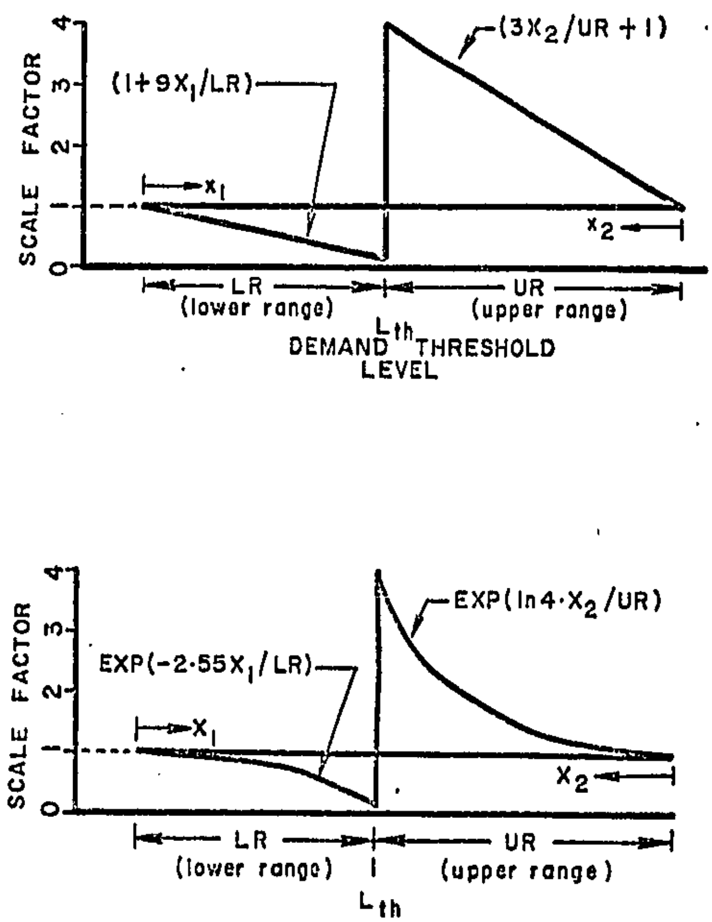


FIGURE 7. Linear and exponential math model correction factors used to deflate demand-periodic and demand-random density functions about the demand threshold level.

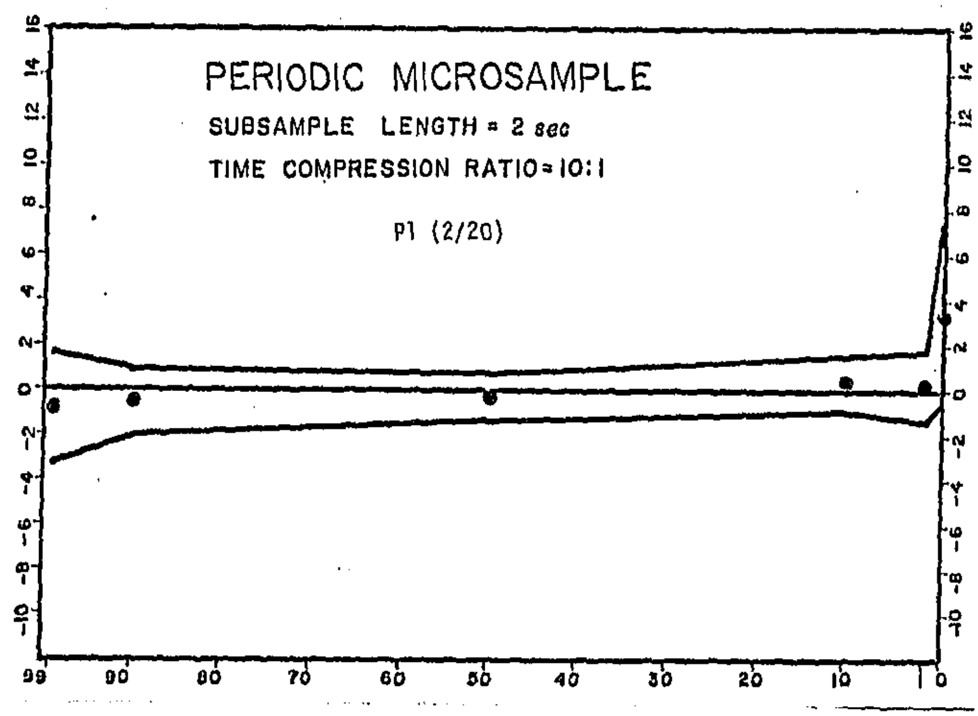


FIGURE 8: Decibel error average ± 1σ of level percentiles averaged over twenty-two microsample tapes. Solid lines define ± 1σ bend about average error (dot).

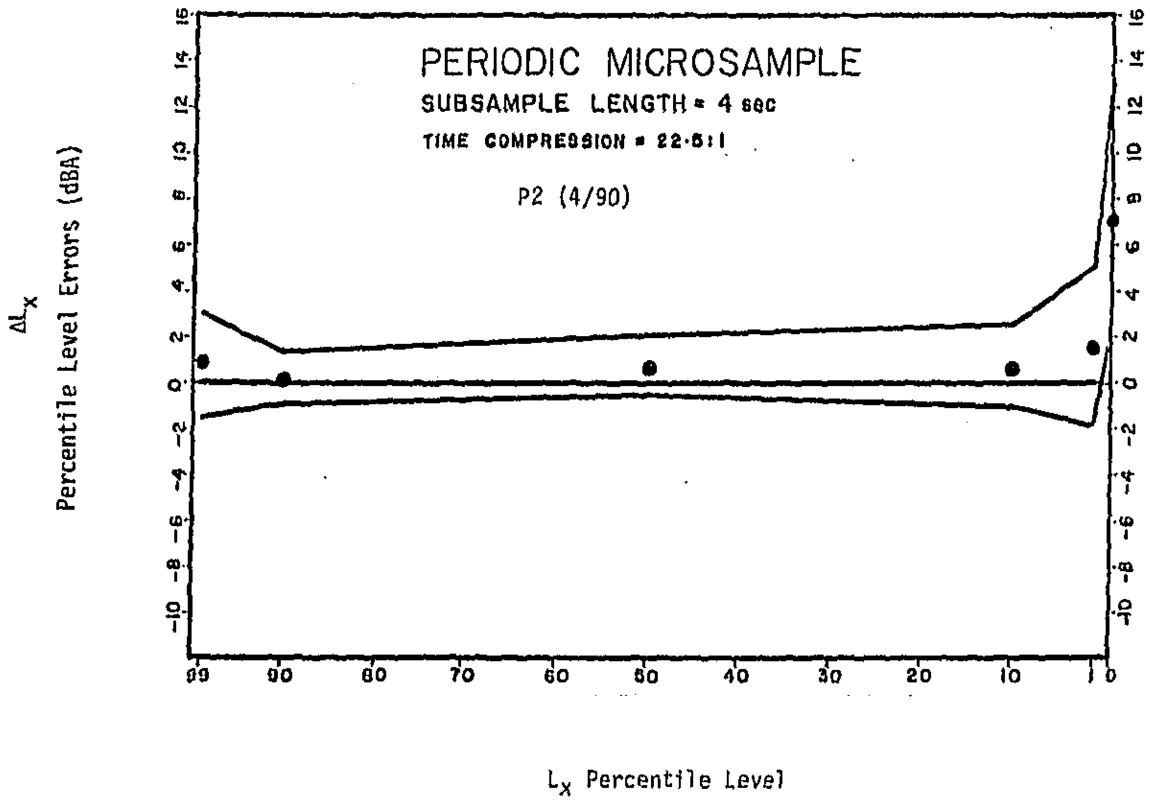


FIGURE 9: Decibel error average $\pm$ 1σ of level percentiles averaged over twenty-two microsample tapes. Solid lines define $\pm$ 1σ bend about average error (dot).

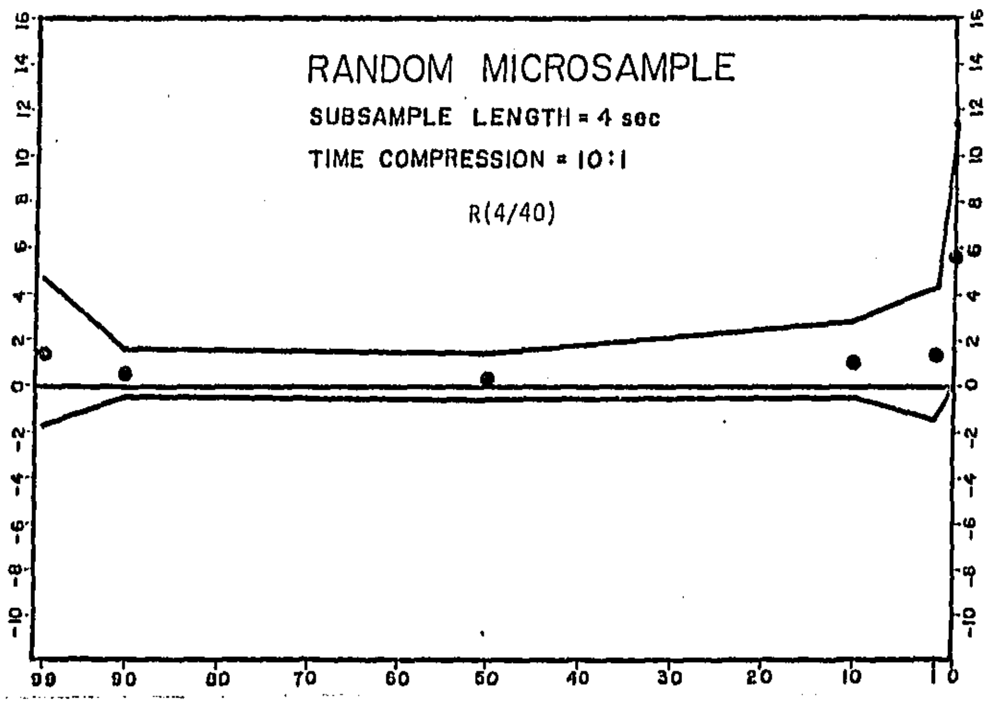
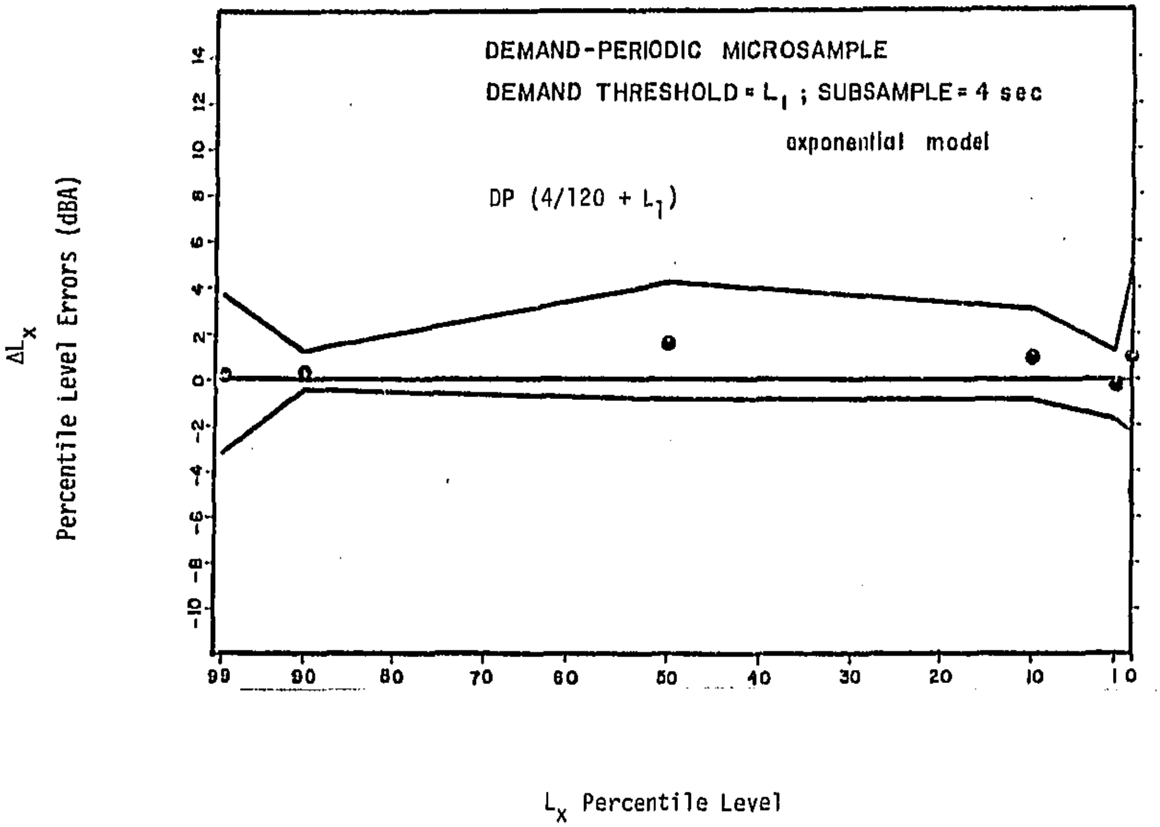


FIGURE 10: Decibel error average ± 1σ of level percentiles averaged over twenty-two microsample tapes. Solid lines define ± 1σ bend about average error (dot).



L_x Percentile Level

FIGURE 11: Decibel error average $\pm$ 1σ of level percentiles averaged over twenty-two microsample tapes. Solid lines define $\pm$ 1σ bend about average error (dot).

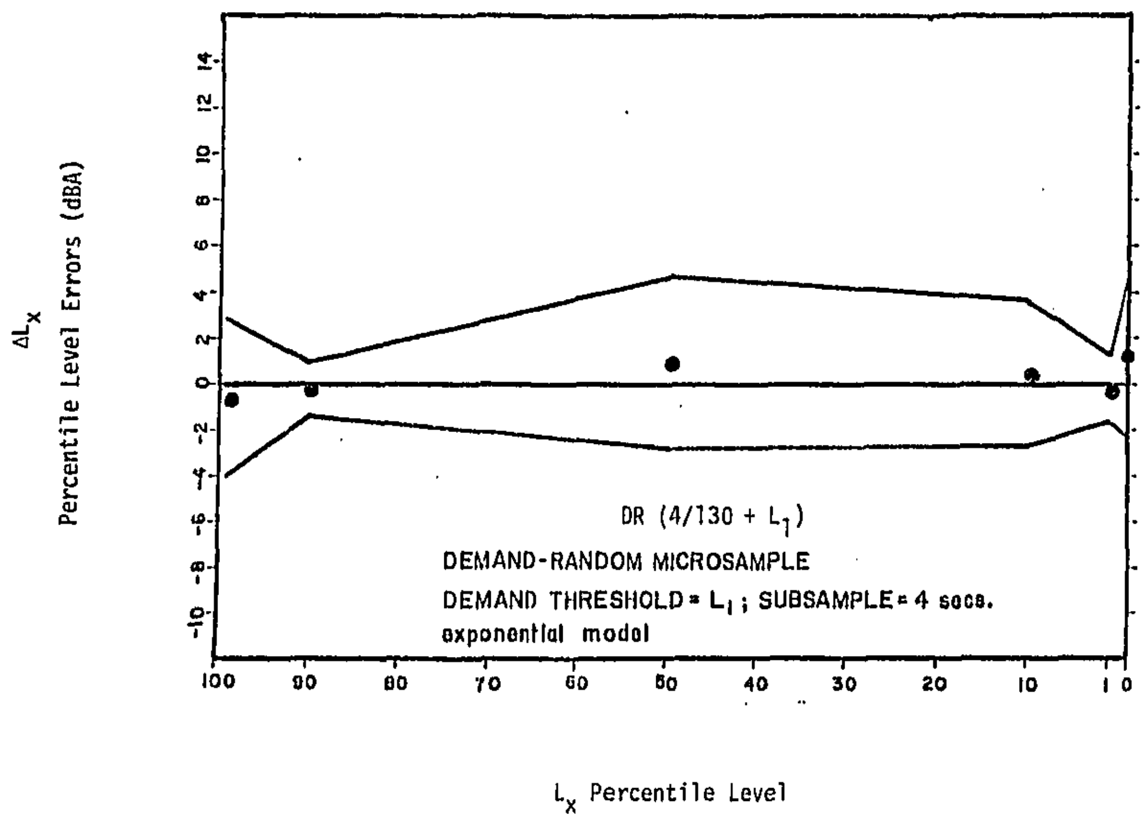
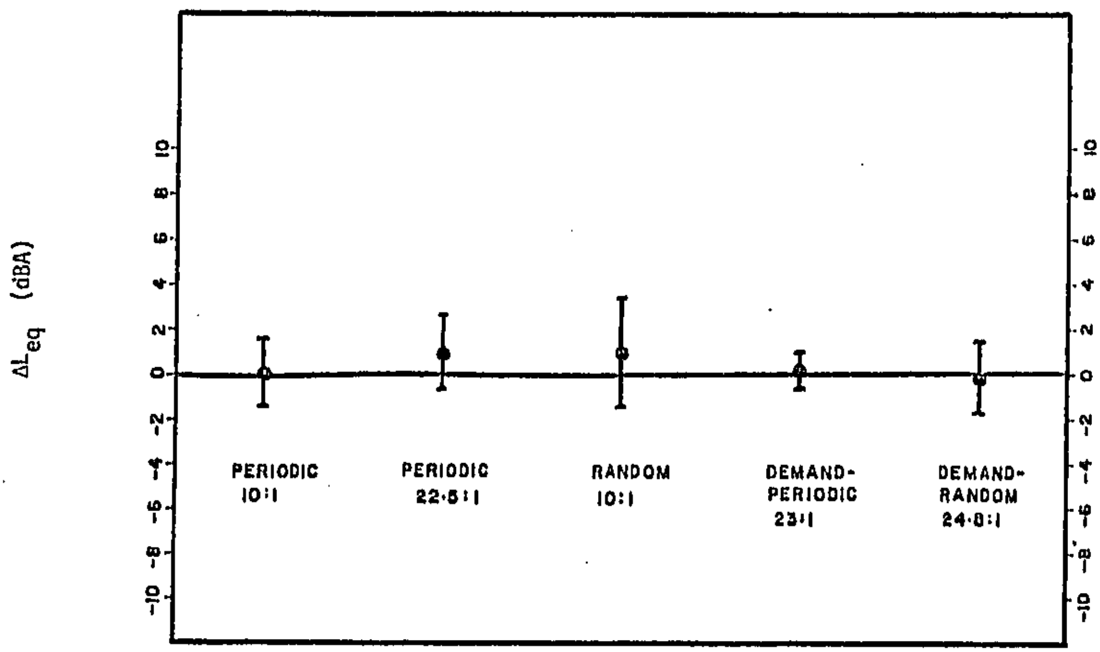


FIGURE 12: Decibel error average[illegible] of level percentiles averaged over twenty-[illegible] microsample tapes. Solid lines define ± 1σ bo[illegible] [illegible]t average error (dot).



METHODOLOGY

FIGURE 13: Decibel error average ± 1σ of L_{eq} averaged over twenty-two microsample tapes.

APPENDIX

TABLE A-1

SITE DESCRIPTIONS

Tape No.	Source Type	Description of Sources and Activity
1	Construction	Fill Site. Trucks, earthmovers, hammering, warning buzzers
2	Construction	Fill Site. Trucks, earthmovers, concrete mixers, warning buzzers
3	Construction	Wood Construction. Trucks, forklift, helicopter, hammering, saws
4	Construction	Concrete Pouring. Concrete mixer trucks, earth-movers, saws
5	Construction	Wood Construction. Hammering, sawing, forklift, dogs, voices, trucks, falling lumber
6	Construction	Concrete Pouring. Hammering, saws, concrete mixers, earthmovers, air blasts
7	Transportation	Railroad Humpyard Operations. Retarder squeal, locomotives
8	Transportation	Interstate Highway I74. Trucks and automobiles
9	Transportation	City Street. General traffic noise, trucks, cars, busses, motorcycles, airport.
10	Transportation	Busy City Intersection. Trucks, cars, motorcycles, busses, aircraft
11	Stationary	Concrete Batching Plant. Mixer, trucks, public address
12	Stationary	Batching Plant. Furnace, air blast, trucks, heavy equipment.
13	Stationary	Fencing Plant. Air blast, lumber rattle, hammering, public address
14	Stationary	Construction Firm. Helicopter, voices, jackhammer, concrete mixer, trucks, hammering, horns
15	Aircraft	Airport Operations. Jet takeoffs and taxi, propeller aircraft, helicopter, propjet.
16	Aircraft	Airport Operations. Jet taxi and takeoffs, prop-jets, propeller aircraft
17	Aircraft	Airport Operations. Jet takeoffs, propjets , propeller aircraft takeoffs
18	Aircraft	Airport Operations. Jet, propjet, and propeller aircraft landings, jet taxiing
19	Other	City Business District. Autos, busses, trucks, motorcycles, horns, brakes
20	Other	Middle Class Neighborhood. Autos, light trucks, motorcycles, small aircraft, stereo radio, dogs, bell

TABLE A-1 continued

Tape No.	Source Type	Description of Sources and Activity
21	Other	City Business District. Trucks, autos, busses, train passbys, motorcycles, horn, hammering
22	Other	Bus Terminal Garage. Busses idling and accelerating, autos, trucks, voices. (This tape was used in statistics tests but was not used in source identification tests).

TABLE A-2

Analysis and Grading of Noise
Source Representation on Microsample Tapes

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance — Microsample Tape: P1	P2	D	R	DP	DR
1	EM	EM	EM	EM	EM	EM	EM
	TK	TK	TK				TK
	BZ	HM	HM				
	HM						
	Grade-No. Sources	A	A	C	C	C	B
	Grade-Dominance Rank	A	A	B	B	B	A
2	EM	EM	EM	EM	EM	EM	EM
	CM	BZ		BZ	CM	BZ	V
	TK	V		V	TK	V	
	BZ				BZ		
	V						
	Grade-No. Sources	B	C	B	A	B	C
	Grade-Dominance Rank	B	B	B	A	B	B
3	S	S	FL	S	S	S	S
	FL	FL	S	FL	FL	FL	FL
	HC	HC	HM		HC	HC	
	TK	CL			TK	TK	
	CL	HM			CL		
	HM						
	Grade-No. Sources	A	C	C	A	A	C
	Grade-Dominance Rank	A	C	B	A	A	C

*Note: a list of symbols and the sources they represent can be found at the end of the Table A-2

**Grade on number of sources was based on the capability of method to represent the number of different sources and the number of times a source occurred. Grade on the rank of dominance was based on the capability of the method to represent the order in which sources contributed to the overall noise energy, ie. the L_{eq}; this depends on the number of occurrences, level, and durations. Minor sources in number, level, or duration have little influence on either of these grades.

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance — Microsample Tape P1	P2	D	R	DP	DR
4	CTK	CTK	VI	VI	CTK	CTK	VI
	VI	VI	CTK	CTK	VI	VI	EM
	EM	S	EM		EM	S	CTK
	S						
	Grade-No. Sources	B	B	C	A	B	B
	Grade-Dominance Rank	B	B	B	B	A	C
5	HM	HM	FL	FL	HM	FL	FL
	FL	TK	HM	HM	TK	HM	HM
	TK	FL		TK	S	TK	TK
	LM	S		S	B	B	S
	S	B		B	D	V	
	B						
	D						
	V						
	Grade-No. Sources	C	F	C	C	C	C
	Grade-Dominance Rank	A	C	B	B	B	B
6	HN	HN	EM	CMX	HN	HN	CMX
	S	CMX	HN	AB	EM	S	AB
	CMX	S	AB	HN	S	CMX	HN
	EM	EM			AB	HM	EM
	HM	HM			HM		HM
	AB						
	Grade-No. Sources	B	D	D	B	B	B
	Grade-Dominance Rank	A	D	C	C	B	C

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order Microsample Tape					
		P1	P2	D	R	DP	DR
7	SQ	SQ	SQ	SQ	SQ	SQ	SQ
	TR	TR	TR	TR	TR	TR	TR
	P	P			P		P
	HN	HN					
	Grade-No. Sources	A	C	C	B	C	B
	Grade-Dominance Rank	A	B	B	B	B	B
8	TK	TK	TK	TK	TK	TK	TK
	C	C	C	C	C	C	C
	MC						
	Grade-No. Sources	B	B	B	B	B	B
	Grade-Dominance Rank	A	A	A	A	A	A
9	TF	TF	TF	TK	TF	TF	TK
	TK	AP	AP	AP	TK	TK	AP
	AP	MTC		TF	AP	AP	
	MTC						
	Grade-No. Sources	C	C	B	B	B	C
	Grade-Dominance Rank	B	C	C	B	B	C
10	TK	TK	TK	TK	TK	TK	TK
	TF	TF	B	AP	TF	AP	AP
	AP	B			B	D	
	MC						
	B						
	Grade-No. Sources	C	D	C	C	C	C
	Grade-Dominance Rank	C	D	B	C	B	B

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance — Microsample Tape P1	P2	D	R	DP	DR
11	CMX	CMX	CMX	CMX	CMX	CMX	CMX
	HN	HN		HN		PA	HN
	TK	TK					
	PA						
	Grade-No. Sources	B	C	B	D	D	C
	Grade-Dominance Rank	A	B	B	B	B	B
12	BF	BF	BF	BF	BF	BF	
	AB	AB	EM	AB	TK	AB	
	TK	TK	AB	TK	AB	EM	
	EM			PA	EM		
	PA						
	Grade-No. Sources	B	B	A	A	B	
	Grade-Dominance Rank	B	B	A	B	B	
13	AB	AB	RTL	RTL	AB	RTL	RTL
	RTL	RTL	AB	AB	RTL	AB	AB
	TK	TK	TK		TK		
	HM						
	PA						
	Grade-No. Sources	B	B	B	B	B	B
	Grade-Dominance Rank	A	B	C	A	C	C

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance Microsample Tape					
		P1	P2	D	R	DP	DR
14	CMX		CMX	CMX	CMX	CMX	CMX
	TK		TK	TK	TK	TK	TK
	HM		HM		HM	HM	HM
	HN				AP		
	JH				V		
	AP						
	HC						
	V						
	Grade-No. Sources		D	D	B	D	D
	Grade-Dominance Rank		C	C	B	C	C
15	JTO		JTO	JTO	JTO	JTO	JTO
	PJ		P	JTX1	P	JTX1	P
	P		JTX1		TJX1	PJ	JTX1
	JTX1				PJ		HC
	HC				HC		
	Grade-No. Sources		B	C	A	B	A
	Grade-Dominance Rank		B	B	B	B	B
16	JTO		JTO	JTO	JTO	JTO	JTO
	PJ		PJ	PJ	PJ	PJ	PJ
	JTX1		JTX1		JTX1	JTX1	JTX1
	P		P		P	P	P
	Grade-No. Sources		A	B	A	A	A
	Grade-Dominance Rank		A	B	A	A	A

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance Microsample Tape P1	P2	D	R	DP	DR
17	JTO PJ P	JTO P	JTO PJ	JTO	JTO P	JTO	JTO P
	Grade-No. Sources	A	A	B	A	C	A
	Grade-Dominance Rank	A	A	B	A	B	B
18	JL P PJL JTX1	JL PJL JTX1	JL	JL PJL	JL PJL JTX1	JL	JL PJL
	Grade-No. Sources	B	D	B	C	C	B
	Grade-Dominance Rank	B	C	B	B	B	B
19	AU BUS TK BSQ MTC HN	AU TK BUS BSQ	AU TK MTC	TK AU	BUS TK HN	TK BUS AU	TK
	Grade-No. Sources	B	C	D	C	C	D
	Grade-Dominance Rank	B	B	C	C	C	C

TABLE A-2

Continuous Tape No.	Symbols* of all Major and Minor Sources on Continuous Tape in Descending Order of Dominance	Symbols* of Sources Identified from Microsampled Tapes in Descending Order of Dominance — Microsample Tape: P1	P2	D	R	DP	DR
20	AU		AU	AU	TK		AU
	DG		DG	DG	AU		DG
	RAD		TK	TK	MTC		TK
	TK		RAD		DG		P
	MTC		P				
	BL						
	P						
	Grade-No. Sources		B	C	B		B
	Grade-Dominance Rank		B	B	C		B
21	TR		TR	TR			TR
	AU		AU	TK			TK
	BUS		TK				AU
	TK		MTC				NH
	HN		HM				
	MTC						
	HM						
	Grade No. Sources		B	D			B
	Grade-Dominance Rank		B	C			B

Symbol	Source	Symbol	Source	Symbol	Source	Symbol	Sources
AP	Airport	D	Dog	JTXL	Jet Taxi	TK	Truck
AU	Automobile	EM	Earthmover	LM	Lumber Rattle	TR	Train
B	Bell	FL	Forklift	MC,MTC	Motorcycle	V	Voices
BUS	Bus	HC	Helicopter	P	Prop Plane		
BSQ	Brake Squeal	HM	Hammering	PJ	Prop Jet		
BZ	Buzzer	HN	Horn	PJL	Prop Jet Landing		
C	Car	JH	Jack Hammer	S	Sawing		
CL	Clanging	JL	Jet Landing	SQ	Squeal		
CM,CMX	Cement Mixer	JTO	Jet Take Off	TF	Traffic		

TABLE A-3

Percent Inaccuracies of Listener No. 1

Source Type \ Method	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	6.0	10.5	12.2	10.0	3.8	7.7	8.4
Ground Transportation	7.7	14.7	2.5	7.5	3.7	2.8	8.3
Stationary	23.3	16.0	8.5	1.0	9.3	8.3	11.2
Aircraft	37.0	10.0	2.5	2.3	1.5	6.5	7.5
Other	0.0	13.0	17.0	3.5	3.3	1.0	8.5
Method Weighted Averages	14.1	14.0	8.5	5.7	4.6	5.6	

Overall Weighted Average $\hat{\mu} = 8.75$

Overall Standard Deviation $\hat{\sigma} = 3.3$

Personnel Data:

Sex: Male
Age: 21 Years
College Major: Mechanical Engineering

Hearing Ability

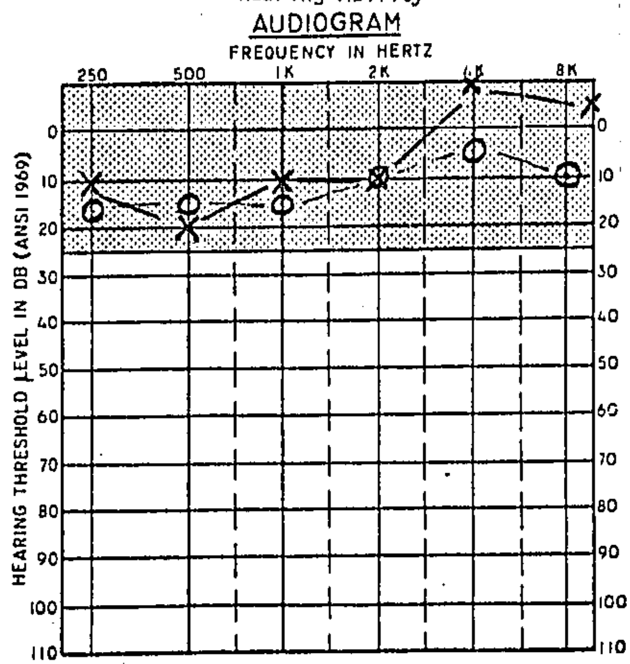


TABLE A-4

Percent Inaccuracies of Listener No. 2

Method / Source Type	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	5.3	7.5	1.8	13.8	10.3	16.7	9.3
Ground Transportation	7.3	8.3	19.8	39.0	19.5	23.4	18.7
Stationary	12.0	29.0	16.8	28.7	33.3	22.5	23.6
Aircraft	2.5	32.8	34.3	11.8	4.5	1.5	15.6
Other	0.0	6.3	11.0	3.5	16.5	8.3	8.1
Method Weighted Averages	6.4	16.4	15.6	18.9	16.2	15.0	

Overall Weighted Average $\hat{\mu} = 15.0$

Overall Standard Deviation $\hat{\sigma} = 4.96$

Personnel Data

Sex: Male
Age: 24 Years
College Major: Mechanical Engineering

Hearing Ability

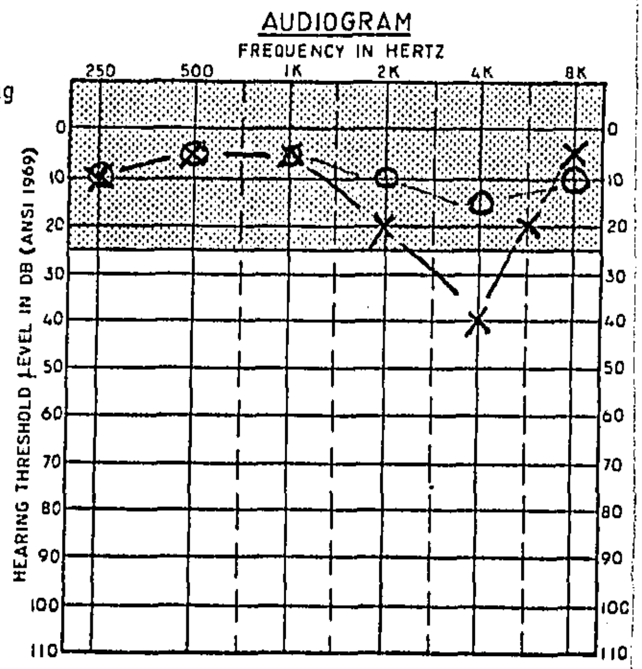


TABLE A-5

Percent Inaccuracies of Listener No. 3

Source Type \ Method	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	16.7	20.8	15.8	20.0	30.7	30.3	22.4
Ground Transportation	24.3	17.8	16.8	36.0	26.0	5.0	21.0
Stationary	56.3	52.5	38.3	47.5	40.0	28.7	42.2
Aircraft	16.5	30.0	22.8	7.0	9.5	3.0	14.6
Other	29.0	25.0	17.3	37.0	53.0	13.7	24.7
Method Weighted Averages	26.8	28.6	21.8	27.8	27.7	17.1	

Overall Weighted Average $\hat{\mu} = 24.6$

Overall Standard Deviation $\hat{\sigma} = 6.12$

Personnel Data

Sex: Female
Age: 19 Years
College Major: Social Science

Hearing Ability

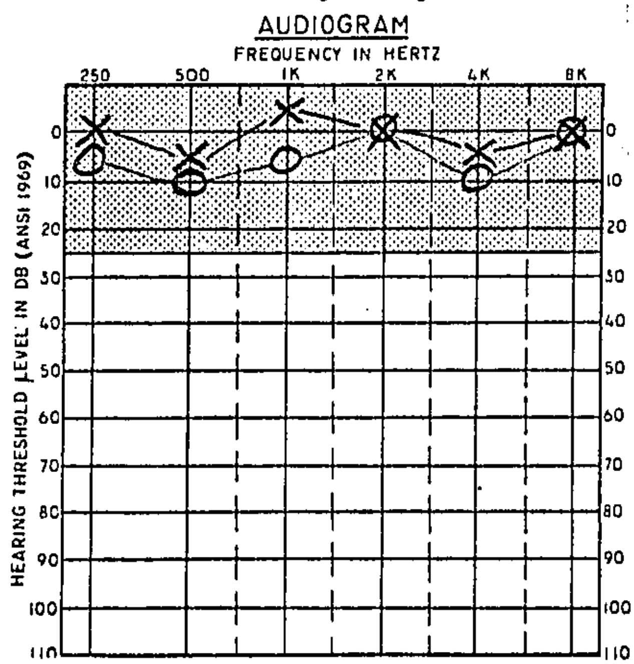


TABLE A-6

Percent Inaccuracies of Listener No. 4

Source Type \ Method	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	3.0	17.5	25.7	12.3	14.7	19.7	15.5
Ground Transportation	19.3	48.3	13.0	26.8	10.0	28.8	24.3
Stationary	10.3	50.0	3.3	18.0	5.8	19.0	19.8
Aircraft	11.0	11.8	2.3	19.8	9.5	5.5	9.9
Other	10.3	47.3	15.0	45.0	33.0	28.0	32.7
Method Weighted Averages	11.2	32.7	13.0	21.1	12.3	20.8	

Overall Weighted Average $\hat{\mu} = 18.9$

Overall Standard Deviation $\hat{\sigma} = 5.8$

Personnel Data

Sex: Male
Age: 20 years
College Major: Computer Science

Hearing Ability

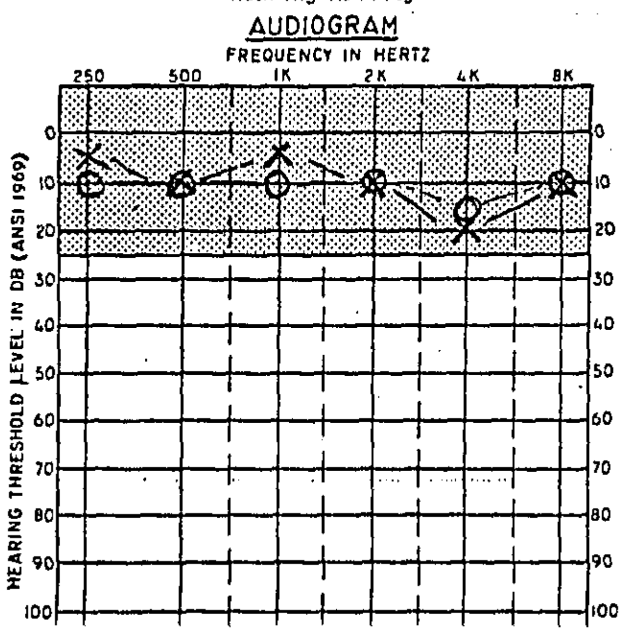


TABLE A-7

Percent Inaccuracies of Listener No. 5

Method / Source Type	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	2.3	8.2	2.8	11.3	13.0	6.3	7.3
Ground Transportation	32.8	34.8	9.0	19.0	14.3	30.5	23.4
Stationary	35.3	47.8	72.5	26.3	31.0	22.8	39.8
Aircraft	11.5	4.8	1.5	11.3	1.5	5.5	5.5
Other	0.0	18.0	13.3	28.0	71.0	8.3	18.9
Method Weighted Averages	17.1	21.5	18.5	17.5	16.9	14.2	

Overall Weighted Average $\hat{\mu} = 17.7$

Overall Standard Deviation $\hat{\sigma} = 8.0$

Personnel Data

Sex: Male
Age: 20 Years
College Major: Political Science

Hearing Ability

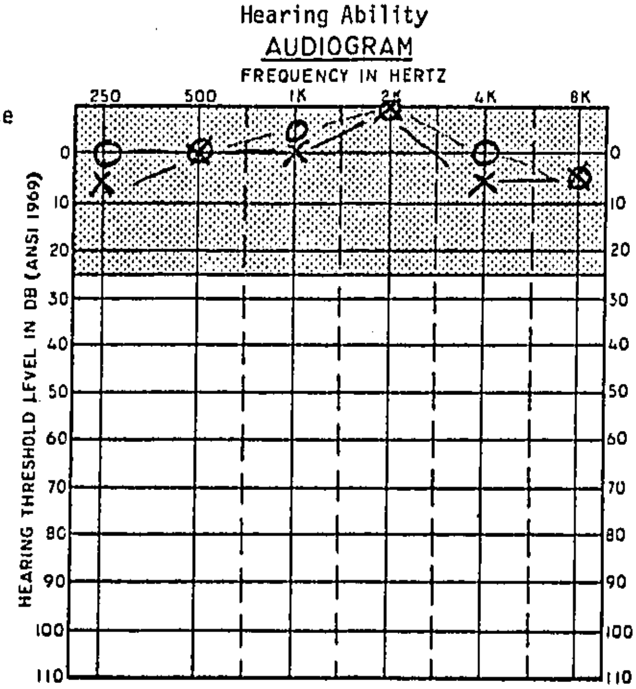


TABLE A-8

Percent Inaccuracies of Listener No. 6

Source Type \ Method	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	14.3	23.3	12.3	26.7	33.0	35.7	24.2
Ground Transportation	31.0	25.0	7.3	24.3	4.3	3.3	15.5
Stationary	28.3	44.5	21.5	41.3	56.3	45.5	38.7
Aircraft	36.0	20.3	9.8	16.3	3.0	4.3	13.0
Other	6.0	13.3	16.7	0.0	6.0	0.0	7.8
Method Weighted Averages	21.4	25.7	13.6	24.4	22.3	17.6	

Overall Weighted Average $\hat{\mu} = 21.0$

Overall Standard Deviation $\hat{\sigma} = 6.6$

Personnel Data

Sex: Male
Age: 22 Years
College Major: Social Science

Hearing Ability

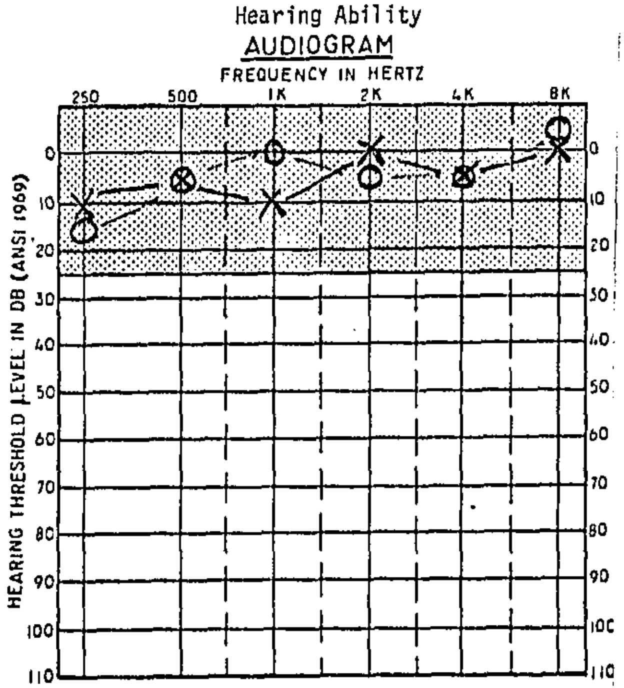


TABLE A-9

Percent Inaccuracies of Listener No. 7

Source Type \ Method	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	6.5	17.5	0.0	0.0	1.2	8.5	5.6
Ground Transportation	21.3	8.0	6.3	5.0	18.3	11.3	11.7
Stationary	41.0	35.5	41.3	33.5	48.7	26.7	38.1
Aircraft	23.0	3.3	17.8	10.8	11.3	0.0	9.3
Other	—	12.3	20.0	0.0	30.0	23.7	16.5
Method Weighted Averages	19.3	15.7	15.3	7.2	16.7	12.4	

Overall Weighted Average $\hat{\mu} = 14.3$

Overall Standard Deviation $\hat{\sigma} = 6.1$

Personnel Data

Sex: Male
Age: 22 Years
College Major: Mechanical Engineering

Hearing Ability

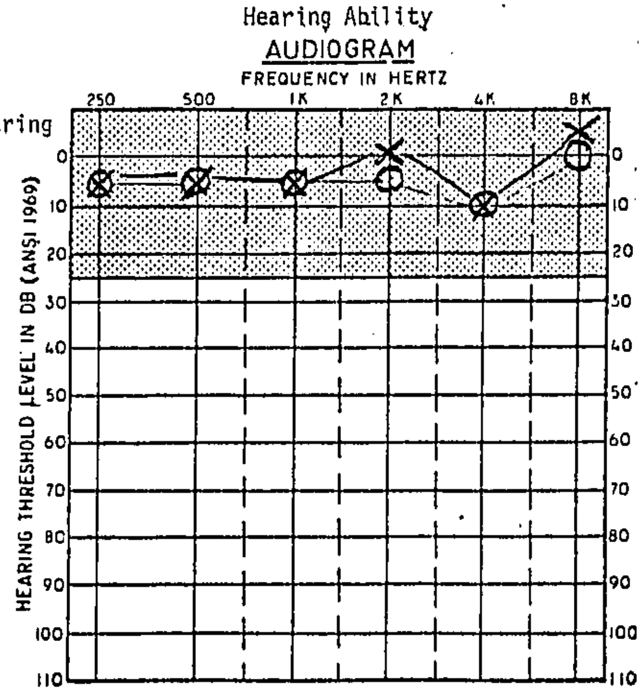


TABLE A-10

Percent Inaccuracies of Listener No. 8 (Expert)

Method / Source Type	P1	P2	D	R	DP	DR	Source Weighted Averages
Construction	0.8	4.2	0.0	3.8	0.0	2.7	1.9
Ground Transportation	3.3	18.8	0.0	15.0	0.0	0.0	6.2
Stationary	2.3	31.0	5.8	3.5	0.0	11.0	9.6
Aircraft	12.3	2.0	0.0	2.5	0.0	0.0	9.6
Other	14.	2.7	2.7	0.0	13.0	0.0	1.9
Method Weighted Averages	3.9	11.4	1.5	5.4	0.7	2.9	

Overall Weighted Average $\hat{\mu} = 4.4$

Overall Standard Deviation $\hat{\sigma} = 4.0$

Personnel Data

Sex: Male
Age: 37 Years
College Major: Engineering

Hearing Ability

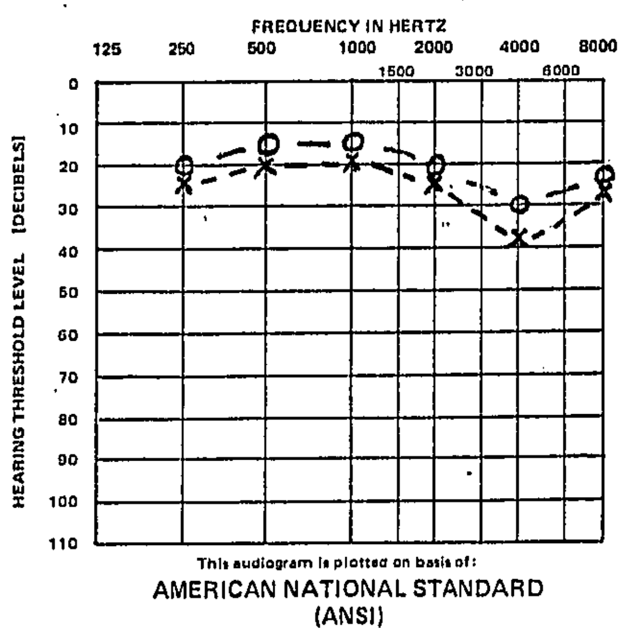


TABLE A-11

Construction

Average Percent Inaccuracies for Each Listener
For All Twenty-two Tapes

Listener \ Method	P1	P2	D	R	DP	DR	Listener Average
1	6.0	10.5	12.2	10.0	3.8	7.7	8.4
2	5.3	7.5	1.8	13.8	10.3	16.7	9.3
3	16.7	20.8	15.8	20.0	30.7	30.3	22.4
4	3.0	17.5	25.7	12.3	14.7	19.7	15.5
5	2.3	8.2	2.8	11.3	13.0	6.3	7.3
6	14.3	23.3	12.3	26.7	33.0	35.7	24.2
7	6.5	17.5	0.0	0.0	1.2	8.5	5.6
8 (Expert)	0.8	4.2	0.0	3.8	0.0	2.7	1.9

	P1	P2	D	R	DP	DR
Method Averages ($\hat{\mu}$)	6.9	13.8	8.8	12.3	13.3	15.9
Method Standard Deviation ($\hat{\sigma}$)	5.7	7.0	9.2	8.4	12.6	12.3
Normalized Errors ($\hat{\sigma}/\hat{\mu}$)	.83	.51	1.05	.68	.95	.77

Overall Average $\hat{\mu} = 11.8$

Overall Standard Deviation $\hat{\sigma} = 8.1$

TABLE A-12

Ground Transportation

Average Percent Inaccuracies for Each Listener
For All Twenty-two Tapes

Method / Listener	P1	P2	D	R	DP	DR	Listener Average
1	7.7	14.7	2.5	7.5	3.7	2.8	8.3
2	7.3	8.3	19.8	39.0	19.5	23.4	18.7
3	24.3	17.8	16.8	36.0	26.0	5.0	21.0
4	19.3	48.3	13.0	26.8	10.0	28.8	24.3
5	32.8	34.8	9.0	19.0	14.3	30.5	23.4
6	31.0	25.0	7.3	24.3	4.3	3.3	15.5
7	21.3	8.0	6.3	5.0	10.3	11.3	11.7
8 (Expert)	3.3	18.8	0.0	15.0	0.0	0.0	6.2

	P1	P2	D	R	DP	DR
Method Averages ($\hat{\mu}$)	18.5	22.8	10.2	21.3	11.4	13.2
Method Standard Deviation ($\hat{\sigma}$)	11.2	13.8	6.9	12.4	9.1	12.5
Normalized Errors ($\hat{\sigma}/\hat{\mu}$)	0.61	0.61	0.68	0.58	0.80	0.95

Overall Average $\hat{\mu}$ = 16.2

Overall Standard Deviation $\hat{\sigma}$ = 6.9

TABLE A-13

Construction

Average Percent Inaccuracies for Each Listener
For All Twenty-two Tapes

Method / Listener	P1	P2	D	R	DP	DR	Listener Average
1	23.3	16.0	8.5	1.0	9.3	8.3	11.2
2	12.0	29.0	16.8	28.7	33.3	22.5	23.6
3	56.3	52.5	38.3	47.5	40.0	28.7	42.2
4	10.3	50.0	3.3	18.0	5.8	19.0	19.8
5	35.3	47.8	72.5	26.3	31.0	22.8	39.8
6	28.3	44.5	21.5	41.3	56.3	45.5	38.7
7	41.0	35.5	41.3	33.5	48.7	26.7	38.1
8 (Expert)	2.3	31.0	5.8	3.5	0.0	11.0	9.6
Method Averages ($\hat{\mu}$)	27.0	38.3	26.0	24.0	28.3	22.4	
Method Standard Deviation ($\hat{\sigma}$)	17.9	12.6	23.5	16.7	20.8	11.5	
Normalized Errors ($\hat{\sigma}/\hat{\mu}$)	0.66	0.33	0.91	0.70	0.74	0.52	

Overall Average $\hat{\mu}$ = 28.1

Overall Standard Deviation $\hat{\sigma}$ = 13.4

TABLE A-14

Aircraft

Average Percent Inaccuracies for Each Listener
For All Twenty-two Tapes

Listener \ Method	P1	P2	D	R	DP	DR	Listener Average
1	37.0	10.0	2.5	2.3	1.5	6.5	7.5
2	2.5	32.8	43.3	11.8	4.5	1.5	15.6
3	16.5	30.0	22.8	7.0	9.5	3.0	14.6
4	11.0	11.8	2.3	19.8	9.5	5.5	9.9
5	11.5	4.8	1.5	11.3	1.5	5.5	5.5
6	36.0	20.3	9.8	16.3	3.0	4.3	13.0
7	23.0	3.3	17.8	10.8	11.3	0.0	9.3
8 (Expert)	14.0	2.7	2.7	0.0	13.0	0.0	1.9

	P1	P2	D	R	DP	DR
Method Averages ($\hat{\mu}$)	18.4	14.3	11.3	10.2	6.1	3.3
Method Standard Deviation ($\hat{\sigma}$)	12.3	11.9	12.2	6.7	4.7	2.6
Normalized Errors ($\hat{\sigma}/\hat{\mu}$)	0.67	0.83	1.1	0.65	0.76	0.78

Overall Average $\hat{\mu} = 7.4$

Overall Standard Deviation $\hat{\sigma} = 5.3$