

A REAL-EAR FIELD METHOD
FOR THE MEASUREMENT OF THE NOISE ATTENUATION
OF INSERT-TYPE HEARING PROTECTORS

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ABSTRACT

A method has been developed that can be used to measure the real-ear noise attenuation of insert-type hearing protectors as they are worn in work places. The method involves the use of a circumaural headphone set comprised of a muff-type hearing protector fitted with earphone drivers. This system was tested and used to measure noise attenuation for five models of insert-type hearing protectors. Attenuation data were also measured for each of the five insert-type protectors in accordance with the laboratory testing procedure of the ASA STD 1-1975/ANSI S3.19-1974, "Standard Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs." Statistical analyses showed strong correlations between the attenuation data measured by the field-method and standard-method procedures for all nine one-third-octave-band test signals. The necessary statistical relationships were determined for converting field-method attenuation data to laboratory attenuation values. General recommendations on a measurement procedure are given for the field method. This method is intended primarily as a technique for documenting the variability of hearing protector performance in the work place, rather than as a replacement for the existing ASA/ANSI Standard in rating the performance of a given protector.

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1. INTRODUCTION

1.1 GENERAL

Occupational noise may impair the hearing of exposed workers depending upon many interrelated and complex factors that include: individual susceptibility and the level, type, and duration of exposure. In the absence of effective engineering-control or administrative measures to reduce an excessive level of noise exposure, a hearing conservation program may require the use of personal hearing protection equipment to protect the exposed working population. For any given duration, these hearing protectors must effectively reduce the noise exposures below the limits that have been established to prevent the development of a permanent threshold shift of hearing. The noise attenuation characteristics of hearing protectors are normally determined in accordance with a standard procedure of measurement under laboratory conditions. However, hearing-protector attenuation values measured in the laboratory may not always be representative of the protection provided with field use because it may be expected that more care will be taken with fitting and mounting the protectors in the laboratory than in the field. Reduced noise attenuation in the field may also result from the effects of such factors as loosening of hearing-protector "seal" due to head/jaw motions or perspiration, and deterioration of protectors with extended use. As a consequence of this reduced attenuation, exposures to noise may result that are in excess of recommended limits even though a supposedly proper hearing conservation plan has been formulated. Clearly, then, a method is needed whereby the noise attenuation of hearing protectors may be measured in the field, under conditions of actual industrial use, to verify that workers are receiving the level of protection expected. This report presents the results of an investigation to develop such a human subjects test for determining hearing protector effectiveness in preventing noise-induced hearing loss. Specifically, this field method was intended to be one that employs circumaural headphones to measure the attenuation of earplugs (insert-type hearing protectors). Attenuation values measured with the field method should be directly correlated to those determined with the standard (laboratory) method. The field-test procedure is to be designed for use in a mobile test van containing a single-wall audiometric test chamber having moderately low background noise levels. It has been anticipated that these measurements will provide an indication of the effectiveness and variability in performance of hearing protectors.

1.2 OBJECTIVES AND SCOPE OF WORK

The purpose of this investigation has been to develop a field method for measuring the noise attenuation of insert-type hearing protectors. The basic procedures used in this field method would be similar to the Acoustical Society of America (ASA)/American National Standards Institute (ANSI) Standard Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Ear-muffs, ASA STD 1-1975/ANSI S3.19-1974¹; however, the test stimuli would

be generated in headphone cavities rather than in a diffuse-field chamber. This field method would provide a means for measuring the on-the-job attenuation being provided to workers who are wearing earplugs.

An important part of the development of a field method for attenuation measurement of insert-type hearing protectors was the selection of suitable headphones for presenting test signals to listeners. It was implicit in the contract's scope of work that no major effort would be expended on research and development of a headphone per se. Rather, the selection of a final headphone from among available types and configurations was to be based upon several considerations:

- (1) compatibility of headphones with the external ear and earplugs,
- (2) flexibility for fitting different people,
- (3) attenuation of ambient noise by the headphone, and
- (4) requirements for operational performance of the headphones in order to relate field-method data with the data taken by the ASA/ANSI standard procedure.

A circumaural type of headphone is dictated by the first three of these considerations, and the latter consideration suggested certain tests which were performed to evaluate the quality of performance of headphones. In addition to the headphones, other instrumentation and appurtenances of the equipment system were selected from standard apparatus, considering availability and possible use in a mobile test van. The instrumentation and headphones are discussed in Chapter 3 of this report.

Having selected headphones and instrumentation for a field-method test of earplug attenuation, it was next necessary to perform a series of comparison measurements and a statistical analysis of data to establish the nature of the relationship between the data obtained by the field-method and the data obtained by the ASA/ANSI standard laboratory method. This aspect of the investigation, determining the validity of the field-method test, required a major portion of the involved time. Five models of earplugs were tested to determine the applicability of the field method. The noise attenuation of each was measured a total of 30 times, using listeners meeting the requirements of the ASA/ANSI standard. Each listener/earplug trial included the nine test signals (one-third-octave bands) of the ASA/ANSI standard. The selection of five models of earplugs was made so as to represent the variety of construction types and materials commercially available and in common use. In addition, the earplugs were chosen to exhibit a wide range of noise attenuation capabilities. The particulars of these specifications are discussed in detail in Chapter 4. However, it should be emphasized that, without a single exception whatsoever, the values of attenuation measured and reported for the five models of earplugs used in this study do not represent an ASA/ANSI standard determination of the performance capability of these earplugs because the fitting and analysis

procedures used were different from those of the standard.

Care was taken in the design of the testing procedures to minimize extraneous effects that could reduce the correlation between the two methods. First, each individual combination of listener/earplug was measured using both the field and laboratory methods, with special care taken to minimize the possibility that attenuation would change either during or between these measures by the two methods due to physical effects (eg: earplug becoming loosened). Second, the tests were arranged to minimize learning and sequence effects; and third, an experimental design was developed that would maximize the power of the correlation. These procedures are covered explicitly in Chapter 4.

The measured data and results of statistical analyses are presented in Chapter 5. The correlation found between the field method and standard laboratory method of testing is sufficient to establish the validity of a human subjects test using the headphones. Consequently, a recommended testing procedure--one based upon the laboratory procedures and utilizing the regression formulas--has been recommended (in Chapter 6) for measuring earplug attenuation in the field.*

This report was prepared by the Environmental Acoustics Laboratory (EAL), The Pennsylvania State University, 110 Moore Building, University Park, Pennsylvania 16802, for the Physical Agents Effects Branch Division of Biomedical and Behavioral Science (DBBS), National Institute for Occupational Safety and Health (NIOSH), U. S. Department of Health, Education, and Welfare under Contract No. CDC-99-74-63. The Principal Investigator for this research was Paul L. Michael, Ph.D., Professor of Environmental Acoustics and Head, Environmental Acoustics Laboratory. Roger L. Kerlin, Ph.D., Research Associate, served as project coordinator and Gordon R. Bienvenue, Graduate Assistant, James H. Prout, Associate Professor of Engineering Research, and Jack I. Shampam, Graduate Assistant, served as research investigators. Terry L. Henderson, Ph.D. and Roy M. Fleming of DBBS acted as NIOSH Project Officer and Alternate respectively.

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EAL is a research and development laboratory at The Pennsylvania State University (PSU), College of Education, Department of Special Education, Speech Pathology and Audiology Program. With the many and varied facilities of the University available for supporting roles, the laboratory engages in contract- and grant-funded research in environmental acoustics and related fields. The staff of the laboratory is comprised of University faculty, staff, and students with backgrounds in the physical sciences, engineering, and physiological disciplines. The laboratory acknowledges with appreciation the assistance and cooperation of the PSU Applied Research Laboratory and Engineering Acoustics Graduate Degree Program.

*Additional discussion of the test implementation and treatment of data is presented in Appendix C.

2. HISTORY AND BACKGROUND

2.1 OCCUPATIONAL HEARING CONSERVATION

Exposure to high levels of noise over a sufficiently long period of time may cause a permanent hearing impairment.² This hazard to personal health and well-being may exist in the work-place and consequently, legislation has been enacted that has resulted in noise-exposure standards and criteria for occupational safety and health.^{3,4,5} Whenever the mandatory noise-exposure limits for duration and level set by these standards are exceeded, steps are required to reduce the exposures. The protective procedures involve alternatives that include: (1) reducing the level of noise through engineering noise-control treatment of the sources or surroundings, (2) administrative control of the noise dose by varying an individual's job assignments during the work day, and (3) reducing the level of noise exposure with the use of personal protective equipment (i.e., hearing protectors). The use of hearing protectors is the least preferred of these alternatives because continued supervision is required in order for a hearing-protector program to be effective. However, it may be the only practical means for reducing exposures.

The capability of hearing protection equipment to reduce effective noise-exposure levels is usually described by the protector's attenuation characteristics. The attenuation data developed from laboratory measurements on a given protector are subtracted from noise exposure levels to provide estimated effective noise exposure levels while wearing the protectors.^{5,6} However, the actual noise reduction found in practice may be less than that measured in the laboratory depending upon the fitting, maintenance, and use of the hearing protection equipment in a hearing conservation program. The implementation of a hearing conservation program is complicated by the need for (1) proper education, supervision, and inspection, (2) continuing employee enthusiasm and cooperation, and (3) subjective anomalies. Consequently, the reduction in noise exposure level afforded by hearing protectors may deviate from the levels calculated using the laboratory-derived attenuation data to the extent that some individuals receive very little protection.

2.2 HEARING PROTECTION EQUIPMENT

2.2.1 Types. A hearing protector's function is to prevent the harmful effects of high level sound on the auditory system. Protectors may be categorized either as (1) earplugs: worn within the ear canal (aural), or in the concha against the entrance to the ear canal (semi-aural), or as (2) earmuffs: a headband with earcups worn snugly against the head surrounding the pinna (circumaural), or against the pinna (supra-aural). Earplugs are produced from a variety of materials and in various forms and shapes. The several types of earplugs include custom-molded, pre-molded (many models come in various sizes), and wearer-molded (such as wax-impregnated fiber). An individual earplug model may be considered as suitable for unlimited reuse, suitable for

limited reuse, or disposable. Many models representing these various types are in common use today and have been so selected for their various features that include attenuation characteristics, cost, comfort, and personal-preference considerations.

2.2.2 Measurement of Noise-Reduction Characteristics. The noise attenuation of hearing protectors has been measured by both subjective and physical methods.⁶ A standardized, real-ear, threshold-shift procedure set forth in the "American Standard Method for the Measurement of the Real-Ear Attenuation of Ear Protectors at Threshold," Z24.22-1957⁷ has been used widely for this purpose. A revision of this standard was recently completed and has been approved and issued as ASA STD 1-1975/ANSI S3.19-1974, "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs."¹ This standard specifies procedures for evaluating real-ear attenuation on the basis of a shift in auditory thresholds on human observers caused by wearing a hearing protector. A principal change from the previous standard in the real-ear method is the substitution of narrow bands of noise (one-third-octave bands) instead of discrete tones as the test stimuli. These one-third-octave band stimuli are to be presented in a diffuse (random incidence) field generated within a suitable testing room.

The attenuation data measured according to the ASA STD 1-1975 specifications are disseminated by hearing protection manufacturers to describe the performance of a particular model of protector. However, these measurements have been carried out under laboratory conditions requiring a specialized test room and equipment, and do not include such uncertain factors as fit, wearability, and individual acceptance such as will be encountered in field use. Therefore, this project was undertaken to develop a field method for measuring the performance of insert-type protectors as they are used in practice.

The method proposed for the field test makes use of a set of headphones that are used to measure threshold shifts caused by insert-type protectors as worn at the work place in much the same manner as the ASA STD 1-1975 standard specifies laboratory measurements of attenuation. The data derived from the field method of measurement was evaluated by correlations with data obtained on the same protectors and subjects using the standard laboratory method.

3. HEADPHONES AND INSTRUMENTATION

3.1 HEADPHONES

3.1.1 Criteria and Types Considered. Criteria for the selection of a headphone to be used in the field method have been listed in Section 1.2. These physical and performance criteria were such that they excluded many of the commonly available headphones from consideration. The test signals to be produced by the headphones are the pulsed or interrupted one-third-octave bands of noise centered at 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz as specified in the ASA/ANSI standard. Consequently, the selection of headphones was, in part, based upon a consideration of its performance over the frequency range encompassing these nine one-third-octave bands (112 to 9000 Hz).

Other requirements in the selection of headphones were a high attenuation to ambient noise and that the headphones should not interfere with the way earplugs are normally worn. This latter requirement dictated that a circumaural type of headphone be used. Consequently, several representative models of circumaural headphones were examined and tested with the following results.

An inexpensive stereo headphone, NPC Model NP-9850, was the first tested. This headphone is one having relatively thick seals. The frequency response of each earphone (right and left side) was recorded on a dummy head⁸ for a 1.0 volt rms pure-tone, swept input over the frequency range 20 to approximately 20,000 Hz. The responses for right and left earphones were generally similar, with an enhanced response between approximately 100 and 1000 Hz. However, under close and direct spectral comparison, the response did vary significantly, with one earphone having a markedly low response at approximately 4000 Hz. For this reason this headphone did not receive further consideration.

A set of KOSS Model PRO-4AA Professional Dynamic Stereophones was similarly measured for frequency response of right and left earphones using a 0.2 volt rms input. In addition, the attenuation of this headphone was determined using the physical-method procedure of the ASA/ANSI standard. Once again, observed differences in the responses between right and left earphones were judged unsatisfactory for our purposes. In addition, the KOSS headphones were unsatisfactory because of the low values of attenuation that were measured on the dummy head. Three separate trials were performed on one earphone of the headphones set, and the results (means and standard deviations) are given in Table I. A KOSS Model ESP-9 Electrostatic Studio Monitor headphone set was similarly evaluated for attenuation characteristics and disregarded from further consideration due to poor attenuation (see data in Table I).

A KOSS Model KO-727B Wide-Range Dynamic Stereophone was the last of the commercially-available headphones to be selected and evaluated. Although otherwise very similar to the other KOSS headphones tested, the responses for these earphones each had a markedly sharp reduction in response at approximately 3150 Hz. In addition, the values of attenuation were low, comparable to the data presented in Table I for

Table I. Means and standard deviations of hearing protector attenuation for two models of KOSS stereo headphones. Data were collected from three trials on one earphone of each headphone set using the physical-method procedure of the ASA/ANSI Standard Method (ASA STD 1-1975/ANSI S3.19-1974) for the nine one-third-octave-band test signals with center frequencies beginning 125 Hz and ending 8000 Hz.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Attenuation of Headphone Models, in dB			
	KOSS PRO-4AA		KOSS ESP-9	
	Mean	S.D.	Mean	S.D.
125	-4.0	-0-	-4.3	0.6
250	12.6	2.1	6.6	0.6
500	17.0	2.6	19.3	1.2
1000	23.0	-0-	25.3	0.6
2000	32.0	-0-	25.3	1.5
3150	39.0	-0-	40.3	2.9
4000	43.3	1.2	43.0	1.7
6300	43.6	0.6	44.3	0.6
8000	43.0	1.0	49.3	0.6

the other KOSS models of headphones. In fact, only for the one-third-octave band centered at 2000 Hz were the values (33 dB right earphone and 37 dB left earphone) higher than either of those means reported in Table I. (See Table II in Section 3.1.3 for the measured values of attenuation.) Consequently, this headphone also was eliminated from consideration.

Concurrent with the testing of the commercially available headphones just described, a configuration of headphones was also being fabricated and tested in the Environmental Acoustics Laboratory (EAL). This configuration was one comprised of an earmuff type of hearing protector and a suitable set of earphone transducers or drivers. The basis for such a headphone configuration has been fairly well established in prior investigations^{9,10} and was not considered to involve an extensive research and development effort. An important design parameter of this configuration was that the enclosed volume within the headphone was large, thereby affording good low frequency reduction of ambient noise. It was hypothesized and subsequently confirmed that this headphone set would have important features that include: (1) relatively smooth frequency response, (2) high, undistorted sound-output level, (3) good isolation from external noise, and (4) large earcups that do not disturb the natural position of the pinna and would provide space for protruding earplug tabs. Consequently, a headset-configuration was fabricated as will be discussed in the next section.

It was anticipated that a headphone judged to have acceptable frequency response performance characteristics, might later prove to have certain limitations such that after comparison testing, not all nine one-third-octave-band test signals would correlate across methods. However, this did not turn out to be the case. It was also anticipated that certain limits may exist in the levels of attenuation that will be measurable under actual field use because of the maximum undistorted earphone output. This might arise when testing subjects who have significantly elevated thresholds. Thus, in particular cases, the combined effect of an elevated threshold and a high earplug attenuation may preclude the measurement of occluded thresholds of audibility owing to the maximum output capability of the headphones. The listeners used in this investigation were all normal-hearing subjects, and therefore, such a limitation was not encountered.

3.1.2 Construction of EAL Field-Method Headphones. The field-method headphones used in this investigation are easily made from the following commercially available components and materials:

Beyer DT-48S earphone drivers (5 ohm driver units from a Beyer DT-48S Dynamic Stereo Headphones),*

American Optical Corporation Model 1200 A0 Hear-Guard Hearing Protector,

spring-retainer-clip pieces, 4 each, fabricated from beryllium-copper, and

*Available from Revox Corporation, 155 Michael Drive, Syosset, NY 11791.

Dow Corning 4 Compound, silicone dielectric grease.

The Americal Optical Model 1200 earmuff-type hearing protector is modified by first removing each earcup shell from its headband yoke. The ear seals, and foam pads are next removed, and a hole is machined in the center of the back of each earcup. This hole is machined to a diameter (approximately 28 mm) so as to slip-fit with the boss structure on the front of the Beyer DT-48S earphone drivers (see Figure 1). Next, the surrounding surface is faced off to provide a flat annular surface around the hole on the back of each earcup which will seal with the front surface of the earphone drivers. All the machining of the AO 1200 earcups was carried out on a lathe. As a jig for this operation, each earcup was mounted "head-side" down on a thin layer of plaster-of-paris on 14 cm square pieces of 18 mm-thick plywood. The earcups were secured to the boards through small L-brackets attached to the earcup mounting studs. The plaster-of-paris is used to provide (when dried) a matching contour for the ear-seal surface of the earcups. This prevents wobbling of the earcup when the assembly is fitted in a conventional four-jaw chuck for the machining operations which are both carried out with this same jig.

The boss structure on the front of the earphone drivers has a deep groove approximately 1.5 mm wide; thus, the facing operation is carried out until the thickness of the earcup shell at the perimeter of the hole is complementary with that of the spring-retainer-clip pieces which are used inside the earcup shells to retain the drivers. The retainer pieces used here were four strips of hard beryllium-copper, 0.4064 mm (16 mils) thick, measuring 6 mm in width and approximately 40 mm in length. The right and left earphone drivers are mounted on the outer machined surface of the respective earcups, with a light coating of Dow Corning 4 Compound silicone grease on the mating surfaces to further insure a good acoustical seal. The drivers are positioned with the cables downwards. Once inserted into the hole of the earcup, the boss structure extends beyond the inner surface of the earcup shell such that a portion of the groove of this structure is also above the surface. Two of the retainer-clip pieces are placed parallel to each other on the inside surface of the earcup and inserted tangentially into the grooves of the boss structure. Careful positioning is maintained such that the earphone drivers remain centered on the earcup shells. To further secure this arrangement, the outer two corners of each retainer clip were previously crimped (approximately 3 mm from the corner) to an angle of about 30° and inserted so that these protruding points bore down on the inner surface of the earcup shell. The retainer clips used here proved to be entirely satisfactory in that the earphone drivers have remained securely mounted throughout the work of this investigation. Finally, the foam pads normally used inside the earcups are modified by cutting a 17 mm diameter hole in the center of the pads to conform with the earphone-driver faces. The foam pads and ear seals are replaced on the earcups which are then remounted on the headband yoke.

3.1.3 Performance Characteristics of EAL Field-Method Headphones.

The attenuation characteristics of the EAL headphones were first measured in accordance with the physical-method procedure of the ASA/ANSI

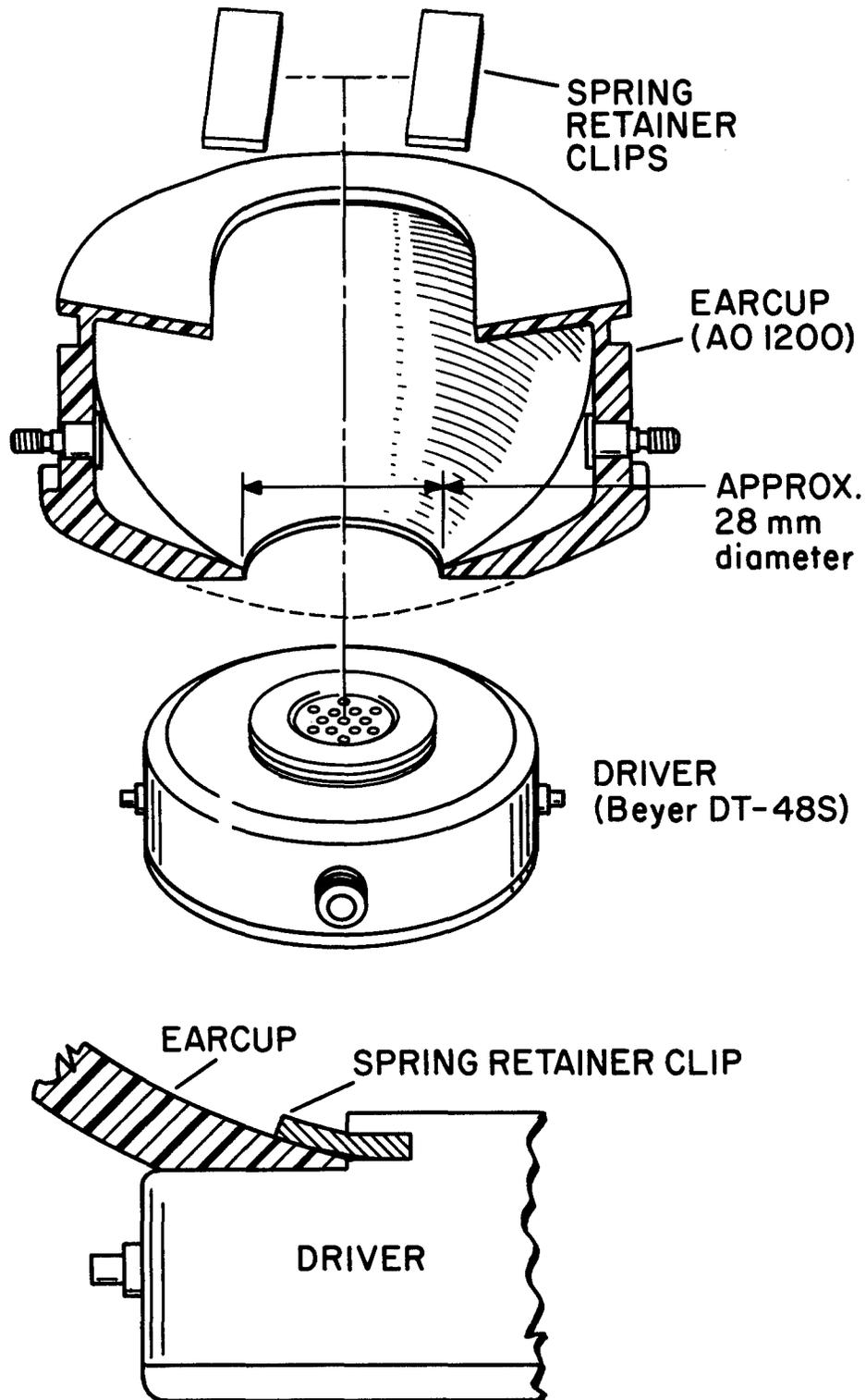


Figure 1. Cross-sectional view of an earphone of the EAL field-method headphones showing details of mounting the driver units to the earcup shells.

standard. The attenuation data for both the right and left earphone assemblies were determined using the dummy head and are given in Table II along with that for the KOSS Model KO-727B headphones discussed in Section 3.1.1. The attenuation data of the EAL headphones are significantly greater than those of the KOSS headphones for the lower frequencies represented by the four one-third-octave bands with center frequencies 125, 250, 500, and 1000 Hz. In fact, the attenuation of the EAL headphones is larger for all nine one-third-octave-band test frequencies if averages of left and right earphones are compared or alternately, the minimum values of either left or right earphone attenuation are compared. The linear sound pressure level of the acoustic test field used for the measurement was 110 dB with reference to $20\mu\text{N}/\text{m}^2$ * measured at the microphone. This feature of good attenuation by the EAL headphones indicated that the configuration was still performing as a hearing protector similar to the original component Model 1200 AO earmuffs, and that these headphones would provide very good attenuation of ambient noise.

A second measure of the attenuation of the field-method headphones was one made in accordance with the real-ear method of the ASA/ANSI standard. Actually, this measurement was included among those tasks carried out during the comparison-testing portion of this investigation (see Section 4.4.1). Ten of the trained listeners were used in the test procedure which employed subject-fit of the headphones. An exception to the procedure of the standard was that only one set of EAL headphones was used in the testing, whereas a minimum of two individual units of a hearing protector model are required for testing by the standard. The results of this test (three separate trials on ten listeners) are presented in Table III, where the means and standard deviations of real-ear protection at threshold are presented for the nine one-third-octave test bands of noise.

The frequency response of the EAL headphones was measured on the dummy head using a Bruel & Kjaer (B & K) Piezoelectric Microphone Type 4117 with diaphragm fitted flush with the surface of the head. The microphone output was suitably amplified and recorded on a B & K Level Recorder Type 2305. The level recorder was synchronized to drive a B & K Beat Frequency Oscillator Type 1022. The oscillator provided a continuously-swept, pure-tone output over the frequency range from 20 Hz to 20,000 Hz. The EAL headphones were driven in parallel from the 6-ohm output of the Type 1022 oscillator with a 0.5 volt rms level. This arrangement acted as a constant-voltage source that produced a sound pressure level of approximately 104 dB at 1000 Hz. The system was calibrated using a B & K Pistonphone Type 4220 as an input to the microphone, which is removed from the dummy head for this step. The frequency response curves for the right and left earphones are shown in Figure 2. The upper curves incorporate the correction for high-frequency roll-off of the Type 4117 microphone. These responses were recorded separately for the placement of the headphones on the dummy

*Unless otherwise noted, all sound pressure levels reported hereafter will be in dB with reference to $20\mu\text{N}/\text{m}^2$, without so designating the reference.

Table II. Attenuation data for the EAL field-method headphones and the KOSS Model KO-727B Wide-Range Dynamic Stereophone. Data were measured using the physical-method procedure of the ASA/ANSI Standard Method (ASA STD 1-1975/ANSI S3.19-1974) for the nine one-third-octave-band test signals with center frequencies beginning 125 Hz and ending 8000 Hz. Data are reported for each earphone assembly.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Attenuation of Headphone Models, in dB			
	KOSS KO-727B		EAL Headphones	
	Left Earphone	Right Earphone	Left Earphone	Right Earphone
125	-4.0	-3.0	11.5	14.0
250	4.0	1.0	20.0	25.0
500	16.5	16.0	32.0	36.0
1000	19.5	16.0	44.0	46.5
2000	37.0	33.0	42.0	47.5
3150	26.5	30.0	37.5	36.5
4000	35.0	37.0	35.5	42.5
6300	31.5	32.0	32.5	33.0
8000	29.5	29.0	35.5	35.0

Table III. Measured real-ear attenuation at threshold for EAL field-method headphones. Means and standard deviations are for subject fit of headphones using the real-ear method of the ASA/ANSI Standard Method (ASA STD 1-1975/ANSI S3.19-1974) for the nine one-third-octave-band test signals with center frequencies beginning 125 Hz and ending 8000 Hz.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Real-Ear Attenuation at Threshold, in dB	
	Mean	S.D.
125	16.0	6.1
250	17.3	5.6
500	24.6	5.2
1000	34.4	4.7
2000	33.9	4.4
3150	35.1	4.4
4000	33.1	4.7
6300	27.6	4.4
8000	26.4	4.4

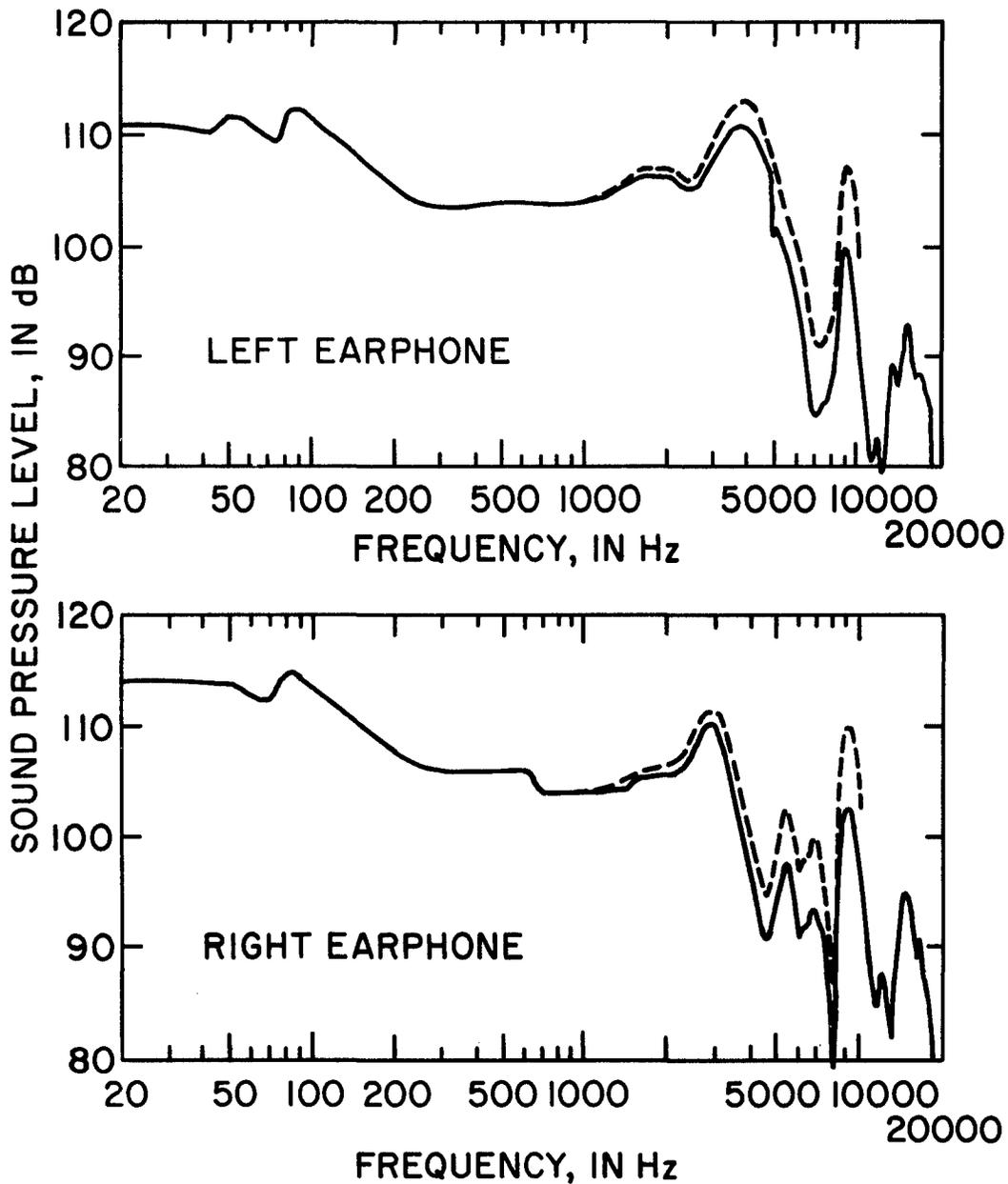


Figure 2. Frequency response of left and right earphones of EAL field-method headphones measured on dummy head (headphones are AO Model 1200 earmuff fitted with Beyer DT-48S earphone drivers). The upper curves incorporate the correction for high-frequency roll-off of the measurement microphone.

head with the respective earphone in position covering the test microphone. A feature not evident from the curves of Figure 2 is a pronounced roll-off in the sound-pressure-level response of the earphones below 100 Hz whenever the headphones are not well-sealed to the dummy head. However, the responses of Figure 2 are reproducible with a minimum of care in fitting the headphones. The responses for both right and left earphones are very similar and exhibit relatively smooth response characteristics over the frequency range of interest (112 to 9000 Hz). In fact, it is not until the higher frequencies (4000 Hz and above) that possible significant differences exist between the earphones in their response characteristics. These response characteristics were among the better ones observed for all the headphones considered, and consequently favored the choice of this headphone.

The maximum sound-pressure-level outputs of the earphones of the EAL field-method headphones for signals of one-third-octave bands of noise are presented in Table IV. These were measured on the dummy head for each of the earphones while that earphone was driven at the maximum allowable power rating of the earphone drivers (200 mW or max. 1 v per system) for each of the nine one-third-octave bands of interest. The Beyer DT-48S earphone drivers are specified as having very low distortion, and in fact, within the maximum allowable power rating of the earphone drivers the total harmonic distortion for the EAL headphones did not reach 3 percent. At maximum power input for frequencies of 250, 500, and 1000 Hz, the total harmonic distortion was less than 1.5%. This test was conducted using a Hewlett Packard 331A Distortion Analyzer on the output signal from the headphones mounted on the dummy head.

The EAL headphones were next calibrated with one-third-octave-band test signals on a flat-plate coupler.* The test signal was selectable by means of a one-third-octave-band filter that received the pink-noise filtered output of a noise generator. The test signal was next amplified and used to drive the EAL headphones (connected in parallel) through a 2.5-ohm impedance-matching pad. Each earphone was, in turn, mounted on the flat-plate coupler, and the sound pressure level output measured on a General Radio (GR) Type 1558-BP Octave Band Noise Analyzer using a GR Type 1560-P42 Preamplifier and B & K Type 4144 Condensor Microphone. The outputs from both right and left earphones were measured with the same input voltages of 0.045 v rms to the headphones for the one-third-octave bands centered at 125 Hz through 2500 Hz, and 0.043 v rms for the bands centered at 3150 Hz through 8000 Hz (see Table V). The data indicate a relatively smooth response for each earphone and close agreement in output level between right and left earphones, particularly through the one-third-octave bands from 125 Hz (center frequency) to 3150 Hz (± 2.5 dB).

The effects of phasing between the two earphones of the EAL headphones were measured by making binaural threshold measurements with 0° and 180° phase shift between earphones of the headphones on each of six

*This coupler was developed at EAL; the specifications and details of construction are to be published (in preparation).

Table IV. Sound pressure level output of EAL field-method headphones for one-third-octave bands of noise delivered at maximum allowable power rating of earphone drivers.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Sound Pressure Level, in dB	
	Left Earphone	Right Earphone
125	117.5	120.5
250	113.0	116.0
500	112.5	114.0
1000	112.5	112.5
2000	115.0	115.0
3150	118.5	118.0
4000	121.0	110.0
6300	112.0	111.0
8000	109.0	109.5

Table V. Sound pressure level calibration of EAL field-method headphones on a flat-plate coupler. Earphones connected in parallel and output levels of right and left earphones (to nearest $\frac{1}{2}$ dB) for one-third-octave band test signals with approximately constant input voltage.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Input Voltage, in mv	Sound Pressure Level, in dB	
		Left Earphone	Right Earphone
125	45	86.5	88.0
160	45	86.0	86.0
200	45	83.5	82.5
250	45	82.5	82.0
315	45	81.0	81.5
400	45	81.0	82.0
500	45	81.5	82.5
630	45	80.0	82.0
800	45	81.0	80.5
1000	45	81.5	81.5
1250	45	82.5	81.0
1600	45	84.0	82.0
2000	45	86.0	85.0
2500	45	85.5	88.0
3150	43	93.0	91.5
4000	43	97.5	82.0
5000	43	91.0	79.5
6300	43	74.5	74.5
8000	43	68.0	72.5

normal-hearing listeners. The test signals were one-third-octave bands of noise with the earphones connected normally, i.e., in parallel (0° phase shift), and then with polarity reversed to the right earphone (180° phase shift). Thresholds were observed to be unchanged with the 180° phase shift; however, when continuous, broad-band white noise was presented in-phase and 180° out-of-phase to the two earphones, several listeners reported that the apparent localization of the signal changed and that the "quality" of the noise changed slightly. These changes in apparent localization and quality did not produce any measurable effect on threshold measurements so it was decided that testing with the EAL headphones could proceed binaurally with parallel (in-phase) input to the headphone set.

A final test of the performance characteristics of the EAL headphones was to measure the monaural frequency response of the earphones when worn on a real head with the ears occluded and unoccluded. This test was carried out to determine if there were any effects on the output characteristics of the earphones caused by the change in enclosed volume by insertion of the ear protectors. Such an effect might be expected to significantly alter the measurements of attenuation using the headphones and, thereby, could reduce the correlation with the ASA/ANSI standard method. The probe-tube microphone system that was used to perform these response measurements was patterned according to recommendations of Villchur and Killion.¹¹ The microphone used in this system was a Knowles Electronics Type BL-1685 with internal preamplifier wired as a source follower. This microphone was mounted inside the left earcup of the EAL headphones, on the forward-facing, ear-seal-contour surface adjacent to the inner edge about midway between the top and bottom. The microphone-cavity opening was directed toward the back of the earcup. When the headphones were worn, the microphone assembly was situated in a plane approximately parallel to the left side of the head and anterior to the ear canal entrance. A B & K Type ZC0007 Input Stage and Type 2603 Microphone Amplifier were used to amplify the microphone output signal which was then recorded on a B & K Type 2305 Graphic Level Recorder. The headphones were driven with amplified one-third-octave-band test signals derived from a B & K Type 2113 Audio Frequency Spectrometer that was fed pink noise. The system, which was calibrated electrically, employed remote control drive from the level recorder to the spectrometer for stepped one-third-octave-band analysis as follows. With the headphones operating and in place on a subject, the microphone input was acoustically blocked and its output recorded for the one-third-octave bands from 31.5 Hz (center frequency) to 8000 Hz driving the headphones. (The upper frequency limit of the microphone response is approximately 8000 Hz.) This recorded plot indicated that the microphone was not responding in any significant manner to structural vibrations of the earcup. Subsequently, the microphone was unblocked and several recorded plots of output were run for each of the cases of (1) the ear unoccluded (no earplug), (2) the ear occluded with a custom-molded earplug having quite large handles, and (3) the ear occluded with a premolded-type earplug. These fluctuating responses were averaged for each of the cases to produce the smoothed plots of the sound-pressure-level outputs shown in Figure 3. It may be noted from these data that there is relatively little difference in the measured sound field between the two cases of occluded ear

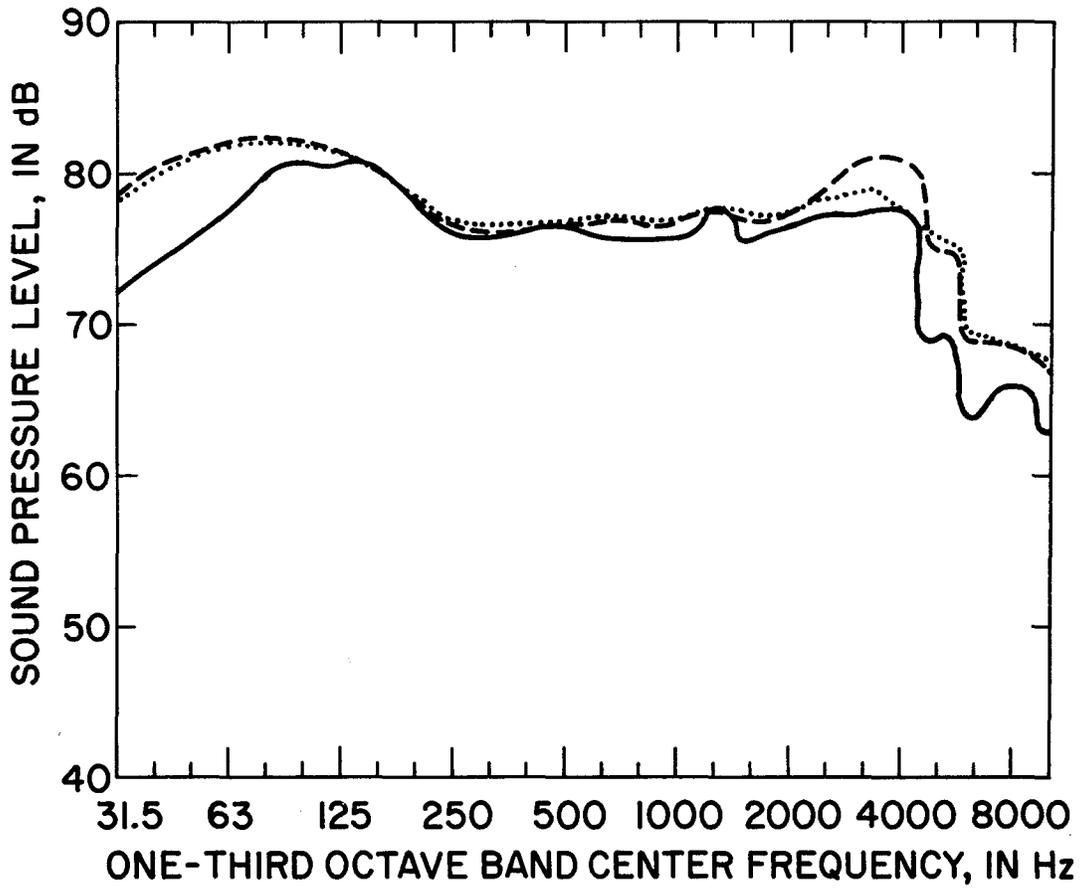


Figure 3. Smoothed plot of the one-third-octave-band response of the EAL field-method headphones while in place over a real ear. Solid-line curve was measured with open ear (unoccluded). Dashed and dotted curves were measured with ear occluded by a custom-molded and premolded earplugs.

and, in fact, between the occluded and unoccluded data. The definitive exception occurs for frequencies below 100 Hz which are below the frequency range of interest here. It should also be noted that a pronounced roll-off in sound pressure level below 250 Hz was observed whenever the headphones were not well sealed against the head. This was similarly noted previously for the frequency response of the headphones measured on the dummy head.

3.2 INSTRUMENTATION

3.2.1 Components. For purposes of comparison testing, a system of instrumentation was designed so that either the EAL field-method headphones or the real-ear laboratory method specified in the ASA/ANSI standard could be used for measuring earplug attenuation. A block diagram of this system is shown in Figure 4. It can be noted that the input-signal equipment used with the field-method headphones was the same as that used with the test room (diffuse field) of the standard method so that it could be switched between the two according to the test method being used. Thus, the field-method headphones required nothing unusual in the way of equipment. The signal input was switch-selected between either the white noise output from a GR Type 1390-B Random Noise Generator (for fitting the hearing protectors) or, the recorded test sounds of one-third-octave bands of noise from a Crown 700 Series tape player consisting of Model CX722 Magnetic Tape Equipment and Model CX Electronic Equipment. The signal-input was next passed through a B & K Model 124 Graphic Spectrum Equalizer that was adjusted to maintain maximum dynamic range of the attenuator for each test signal. Then the signal was amplified using a 15-watt, general-purpose laboratory power amplifier. The output from this amplifier was monitored by an oscilloscope and voltmeter and adjusted for required level up to a maximum of 4.5 volts rms--the limit for the next stage which consisted of a Grason-Statler Model E3262A Recording Attenuator with Control Box E3262D, remotely controlled from the test room by a Model E3262A-2 push button. The Model E3262A attenuator is designed to operate from a 10 ohm source and was so matched to the output from the amplifier. Likewise, the output impedance of the attenuator was designed for 10 ohm load and was matched with a 10 ohm to 2.5 ohm minimum-loss pad when switched to drive the field-method headphones (earphones connected in parallel). For operation of the test-room loudspeakers, the output of the attenuator was switched to a 10 ohm-load isolation transformer that fed a Crown Model DC300 Solid State Amplifier. A more detailed description of the test room and equipment used in the standard method is contained in reports by Michael and Bolka¹² and Michael, et al.⁸

3.2.2 Test System. The test system for measurement of earplug attenuation involved subjects who were seated appropriately inside the test room so that they could be viewed by the operator in the control room. Two-way communication was provided between the operator and the subject. The subjects responded to test sounds by pressing the push button of the recording attenuator which controlled the signal level in the continuous mode. By pressing the button as long as the sound could be heard, the level continuously decreased until the sound was no

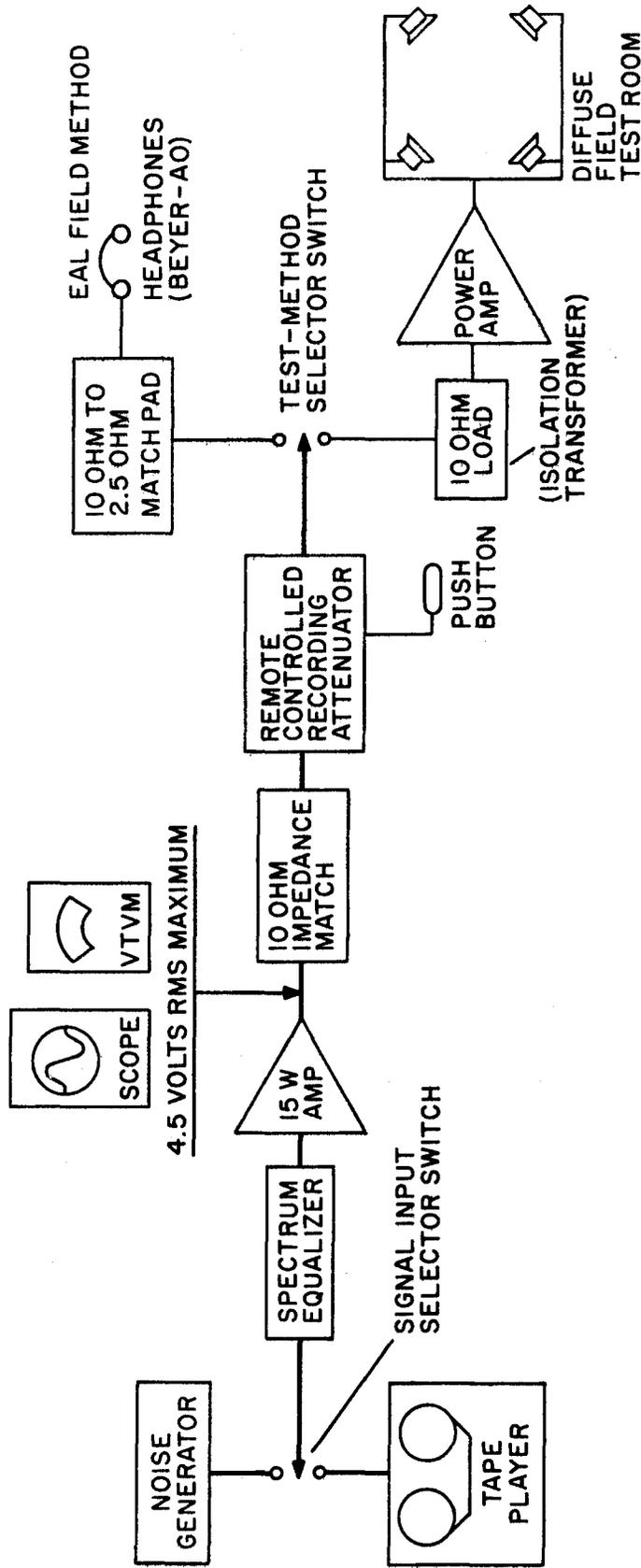


Figure 4. Block diagram of instrumentation system for measuring hearing protector (insert-type) real-ear noise attenuation. ASA/ANSI standard method (diffuse field) or field-method (EAL headphones) is switch-selected.

longer heard, at which time the button was released and the level increased. In this way a threshold of audibility was traced for all test signals. The attenuation of a hearing protector was determined by calculating the difference in dB between occluded and open-ear thresholds of audibility.

Six complete replications of the test sound program were recorded on a $\frac{1}{4}$ -inch, 2-track tape to be played at a speed of 15 inches per second (ips). The program consisted of ten thirty-second segments of one-third-octave-band noise having center frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, 8000, and 1000 Hz (repeated). These were presented in 250 milliseconds (msec.) pulses with 50 msec. rise and decay times, and with a repetition rate of one pulse every 930 msec. These test sounds were copied from an original tape recording that had been recorded at a level of -6 VU. Each recorded program of test sounds was preceded by three warble tones and concluded by two warble tones at +3 VU level to alert the listener to the beginning and end of the test. These warble tones consisted of an 800 Hz signal undergoing a frequency deviation of 100 Hz at a modulation frequency of 25 Hz.

4. COMPARISON - TESTING PARTICULARS

4.1 GENERAL

The EAL field-method headphones and related instrumentation system discussed in Chapter 3 were designed to measure relative levels of the binaural threshold of audibility. Differences between these levels for unoccluded and occluded ears were intended to provide a measure of the attenuation characteristics of earplugs. Testing was planned and carried out to determine the relationship between the attenuations measured by (1) this field-method and (2) the real-ear, laboratory-method specified in the ASA/ANSI standard. The testing was designed so that the data from 150 separate trials with each of the two procedures could be compared. This number of trials had been selected as suitable for the testing of five different models of earplugs (30 trials with each model). An established relationship between the two measures of attenuation would permit the use of the headphones in a field test to determine the effectiveness of insert-type hearing protectors. The regression equation would predict (within a certain level of statistical confidence) the score expected from the standard (laboratory) method using the field method data.

A total of twenty listeners was used in the comparison testing of attenuation for the five models of earplugs. Each subject participated in three two-hour (approximate maximum time duration) sessions that each involved completing three or four tests. The thirty attenuation-comparison measurements (trials) performed with each model of earplug included: (1) single trials on each of the 20 subjects with the earplugs fitted in a proper manner (initial condition), and (2) single repeat trials (retest condition) on ten of these same subjects with the earplugs purposely fitted in a manner so as to foster a change in protector attenuation values. This retest condition varied for the different models of earplugs and consisted of either: (1) an over- or under-sized earplug in the case of the two pre-molded types, or (2) employing poor fitting practices in the cases of the custom-molded and two wearer-molded types. For most of the refit cases the noise attenuation was degraded; however, there were a few instances where either a smaller or larger-sized protector used for the retest condition did provide improved attenuation.

The number of subjects selected for testing (20), and the provision for a retest condition on ten of these subjects, provided the basis for a two-fold regression analysis of the data from thirty trials for each earplug. First, the initial-condition data for the twenty different subjects was analyzed, and second, the data from the retest condition for ten of the subjects was analyzed along with the initial-condition data from the ten subjects who did not participate in the retesting of that particular earplug. In the design of the testing, it was anticipated that this second analysis would be more powerful and

show better correlation since the data would have a larger range of values. Every subject participated in the initial-condition testing of each model of earplug, and then subsequently in the retest condition for either two or three of the models.

4.2 MODELS OF EARPLUGS SELECTED FOR TEST

The five models of earplugs selected for testing were chosen principally for being representative of the variety of construction types and materials that are both commercially available and in common use today. No endorsement, either positive or negative, is intended by their having been selected for use in this work or, most important, by reporting the noise attenuation data of this investigation. It should be emphasized here again that the values of attenuation reported for the test cases of comparison-testing of the measurement methods on the five models of earplugs do not represent any standard determination of the protector's performance capabilities because the fitting and analysis procedures used were different from the standard procedures. Only relative values of attenuation were needed for this study. An additional consideration for the selection of the five models of earplugs to be tested was that they should exhibit a wide range of noise attenuation capabilities. This aspect of the selection criteria was not given priority in view of the provisions for retesting the earplugs under altered fitting conditions suitable for extending the measured attenuation range to include lower values. The five models of earplugs selected for testing do represent protectors of various noise attenuation capabilities with the single exception that no earplug of "negligible" attenuation value was selected (such as facial tissue or cotton).

The model of earplug designated as earplug No. 1 is a pre-molded type suitable for unlimited reuse. It is constructed of silicone rubber in the shape of a cylinder having three circumscriptive flanges and comes in three sizes.

Earplug No. 2 is also a pre-molded type and suitable for unlimited reuse. It is constructed of soft plastic with conforming flanges surrounding the inner and outer ends of the plug and is available in five sizes. (These first two models of the pre-molded type of earplug are from among ones representative of the many shapes and designs of such plugs that have been in common use for some period of time.)

Earplug No. 3 is a custom-molded type of earplug that is formed in place. The finished protectors are composed of silicone rubber that has been fitted with handles. A set of this type of protector was custom fitted for each of the subjects participating in the testing.

Earplug No. 4 is a wearer-molded type of insert hearing protector that is intended for disposal after one use. It consists of ready-made plugs of glass down that are inserted into the ear canal.

The last model, earplug No. 5, is also a wearer-molded type of earplug, but is one suitable for reuse. It is comprised of a foamed

polymer in the shape of a cylinder which, after being compressed and inserted into the ear canal, expands to occlude the ear canal.

4.3 SUBJECTS USED AS LISTENERS

The twenty subjects used for the comparison testing of attenuation-measurement methods were selected from a group of individuals who have performed similar listening tasks involving the use of insert-type hearing protectors so that they can be considered to be experienced and reliable listeners. The subjects were comprised of an equal number of females and males, all of whom had hearing threshold levels that meet the specifications for listeners of the ASA/ANSI standard method (ASA STD 1-1975, Section 3.2.1).¹ The average age of the subjects was approximately 26½ years (females: 23½ years and males: 30 years), with a range of ages between 22 years and 48 years.

Because human subjects were involved in this investigation, the proposed procedures involving subjects were reviewed and approved by the University's Biomedical Review Committee in accordance with the Institutional Assurance on file with the Division of Research Grants, NIH, DHEW. At no time were subjects exposed to noise that exceeded the NIOSH recommended limits for daily occupational noise exposure.⁵

The subjects used as listeners were required to sign an EAL Informed Consent Form prior to their participation in the testing. This form outlined: (1) the procedure of testing, (2) the risk (none) and discomfort from participation, (3) the benefits to participants (monetary), and (4) the anticipated benefits of the results of the research. At any time, subjects were entitled to make inquiries about the investigation and procedures, and were free to withdraw from the study without penalty or prejudice (none withdrew).

4.4 PROCEDURES

4.4.1 Tests Performed. Thirteen different tests were included in this study, and each subject was scheduled to perform a certain ten of the 13 during three two-hour testing sessions. Shown in Figure 5 is a diagram of the assignment of tests among the 20 subjects and three sessions. Ten of the 13 tests were designed to accomplish the comparison-testing of attenuation-measurement methods on the different models of earplugs (five models tested under initial and retest conditions of earplug-fit, tests 1-5 and 1*-5* in Figure 5). The remaining three tests were used to determine the real-ear noise attenuation provided by (1) the EAL headphones (laboratory standard method), and by (2) earplug No. 5 (both laboratory and field methods). All of these latter three tests were performed in accordance with the procedures for determining attenuation that are specified in the ASA/ANSI standard except that the test signals were presented through the EAL headphones during the field method test of earplug No. 5. The results of the EAL headphones test have been presented in Section 3.1.3 and Table III of this report. The remaining two tests (performed using earplug No. 5) were done first, in accordance with the ASA/ANSI standard method (diffuse field) and

TESTING SEQUENCE DIAGRAM

Note: Sequence of testing protectors and use of test methods were randomized (see text).

SESSION/ NO. SITTINGS	I/3			II/3					III/4						
TEST/TASKS (see legend)	1	2	6	1*	2*	3	4	7	3*	4	4*	5*	5	8	9
01	↓	↓	↓	↓				↓	↓	↓					
02	↓	↓	↓												
03	↓	↓	↓												
04	↓	↓	↓												
05	↓	↓	↓												
S 06	↓	↓	↓												
U 07	↓	↓	↓												
B 08	↓	↓	↓												
J 09	↓	↓	↓												
E 10	↓	↓	↓	↓				↓	↓	↓				↓	
C 11	↓	↓	↓												
T 12	↓	↓	↓												
S 13	↓	↓	↓												
14	↓	↓	↓												
15	↓	↓	↓												
16	↓	↓	↓												
17	↓	↓	↓												
18	↓	↓	↓												
19	↓	↓	↓												
20	↓	↓	↓												

Lengend - Test/Tasks

1. Earplug No. 1: Comparison Testing of Attenuation-Measurement Methods.
2. Earplug No. 2: Comparison Testing of Attenuation-Measurement Methods.
3. Earplug No. 3: Comparison Testing of Attenuation-Measurement Methods.
4. Earplug No. 4: Comparison Testing of Attenuation-Measurement Methods.
5. Earplug No. 5: Comparison Testing of Attenuation-Measurement Methods.
6. Mold Custom-molded Earplug No. 4.
7. EAL Headphones Attenuation: as a hearing protector in diffuse field, same-subject replications, standard (laboratory) method.
8. Earplug No. 5 Attenuation: same-subject replications in diffuse field, standard (laboratory) method.
9. Earplug No. 5 Attenuation: same-subject replications with headphones.

* An asterisk indicates testing with retest (altered) condition of fit of the earplugs in 1-5.

Figure 5. Diagram of the assignment of tests to the 20 subjects participating in the program of comparison-testing of attenuation-measurement methods. Three two-hour sessions for each subject were divided into either three or four time periods or sittings during which the scheduled tests were accomplished. In order to prevent procedural bias, the sequence of tests was varied across subjects for each session.

second, in accordance with this same (standard) procedure excepting that the EAL field-method headphones were used to present the test signals and not the diffuse field. These attenuation data on earplug No. 5 are presented in Chapter V where they are discussed and compared (tests 8 and 9 in Figure 5).

Each subject was fitted with the custom-molded earplug No. 3 at the end of the first session. This task appears as test/task 6 in Figure 5.

4.4.2 Constitution and Sequencing of Tests. There were several features of the testing program that were consistent across sessions and tests. First, each subject completed the three test sessions in numeric order: I, II, and III. Second, every subject started each session with a "practice" run. This practice run was an open-ear (reference) threshold, performed using the headphone-method. These practice runs were conducted in exactly the same manner as was used to obtain the headphones-reference thresholds required in the comparison testing. Because the subjects were experienced listeners, these practice runs had a marked degree of reliability; nonetheless, they were treated as practice runs and were not included in the analyses.

For the comparison of the two methods of measuring attenuation, a definite pattern of testing was followed. Four thresholds were consecutively measured. The first was a reference (unoccluded-ear) threshold using either the headphones or standard method. The earplugs undergoing test were then fitted by the subject while white noise was being introduced into the test room. The subject manipulated both the earplugs and portions of the head to insure a fit that was secure and would not undergo change (become loosened) during the next two threshold measurements. This fit was either a proper fit for maximum attenuation (initial condition) or one of the retest-condition fits. The white noise was turned off and an occluded-ear (protected) threshold was run using the same method (either headphones or standard) as done with the first run. Next, a protected threshold was run (with no change in protector fitting) using the alternate method of measurement. Finally, the earplugs were removed and a reference threshold was run using the alternate method. To summarize: four thresholds were measured consecutively--reference, protected, protected, and reference, with the testing method (laboratory or field) changed at the end of the first protected measurement. The choice of the test method to be used initially was varied across subjects for each case of earplug model and its order of testing in the session. As mentioned in the previous section, the sequence of tests was varied across subjects for each session. The task of custom-molding earplug No. 3 was scheduled for the last task of the first session for each subject in all cases.

A different pattern of testing was followed for the measurements of the attenuation of the EAL headphones (standard method) and earplug No. 5 (standard method and with the headphones). In these tests, protected and reference thresholds were measured alternately with the subject fitting the hearing protector properly for each of the protected runs by adjustment for maximum attenuation in the presence of white noise.

4.4.3 Instructions to Listeners. The subjects used as listeners were trained and experienced individuals who exhibited a high degree of motivation and interest towards this type of testing. Each was told the nature of the comparison testing being performed and that consequently, the earplugs should not become loosened or changed during the two measurements of protected thresholds. Any such change would negate a valid comparison and was to be reported by the listener in order to abort that test. It was anticipated that the operation of putting on and removing the circumaural EAL headphones for the field-method measurement might cause the earplug to become loosened. Therefore, the subjects were cautioned to use special care during these steps and, in addition, to make sure of the stability of the inserted plug by performing oscillatory manipulations with out-spread fingers of both hands on the tissue surrounding the ears when fitting earplugs and judging the security of the fit. This manipulation was designed to approximate the disturbance that occurs when putting on and removing the circumaural headphones. No report of change in the fit of earplugs was received during the entire testing program and consequently, no test was aborted. Subjects removed eyeglass frames and earrings prior to testing.

Each subject received instructions for the proper fitting of the five models of earplugs used in testing; these were given just prior to the actual tests. For the earplugs Nos. 1 and 2, (pre-molded types), each subject was fitted with the appropriate size earplug by the investigator prior to testing. In some cases, this required earplugs of different sizes for the two ears of the subject. Earplugs Nos. 1 through 4 (pre-molded, custom-molded, and wearer-molded disposable down types) required only routine instructions regarding proper fitting by the subject during testing. However, earplug No. 5 (wearer-molded, foam cylinder) received a more stringent set of instructions. Each ear was to be fitted carefully according to the following procedure for best possible (maximum) attenuation: (1) compress one earplug at a time cylindrically to a small diameter by rolling between the hands and fingers; (2) quickly insert the compressed earplug into ear canal that is "straightened" by reaching behind the head with the opposite hand and pulling up and back on the pinna; and (3) place pressure on the end of the compressed earplug at entrance of ear canal for at least one full minute while earplug is expanding back to normal state. If this procedure is carried out carefully, markedly better attenuation is obtained than when not done so.

For the retest conditions of comparison testing, the instructions to listeners for fitting the earplugs were different for earplugs Nos. 3, 4, and 5. (Earplugs Nos. 1 and 2 were provided in sizes different from those of the initial test, but otherwise fitted "properly" for maximum attenuation. It has been noted previously that, in a few cases, the attenuation actually improved for these refits.) Earplug No. 3 (custom-molded type) was fitted with the earplugs not properly seated under the helix of the pinna. Earplug No. 4 was fitted less diligently than possible with these pre-formed plugs of down. Finally, earplug No. 5 (wearer-molded, foam cylinder) was misfitted by rolling a cone-shaped rather than cylindrical-shaped plug that was inserted (and pressed for one minute) into the ear canal.

4.4.4 Representative Session. The following is a description of a first session of testing, but it is representative of any of the three comparison-testing sessions. The subject arrived at the appointed time for a scheduled two-hour period of testing. Pre-molded type earplugs Nos. 1 and 2 were scheduled for initial-condition test and the subject was given fitting instructions along with sizes of the earplugs that were then tried for fit and either found acceptable or exchanged for one or more individual earplugs of next appropriate size. The subject was then seated at a location in the test room where the proper diffuse-field conditions have been determined to exist. The subject's head was positioned accurately within the test field to assure good test-retest consistency by having them align the center of their forehead with a small weight suspended from the ceiling by a string. The appropriate model of earplugs scheduled for their first test of the session was given to the subject and the order of testing was reviewed with the subject. This order was randomized for different subjects to avoid procedural bias; however, the review of procedure for a particular case of an initial-test of a first session is presented here. A headphones reference threshold was to be measured first (practice run) after which the subject would remove the headphones and prepare to do a reference threshold in diffuse-field. Upon completion of the diffuse-field reference threshold, white noise would be turned on in the room, and the subject would fit the earplugs and indicate when they had obtained a proper and secure, non-degrading fit of best attenuation. After indicating that they were ready by voice communication to the investigator in the control room, the subject's occluded-ear threshold would be measured in the diffuse-field. After completion, the subject was to don the field-method headphones and their occluded-ear thresholds would be measured by this method. Finally, the earplugs were removed, the headphones replaced, and a reference threshold was measured. When the subject indicated that they understood the testing procedure to be followed, the investigator reminded them concerning the "push-when-you-hear, release-when-you-don't" technique for operating the recording attenuator to control the sound level and determine the threshold. The investigator then left the test room, closing the acoustical-seal door, and entered the adjoining control room.

The test instrumentation in the control room had been turned on at least one-half hour prior to the scheduled testing time, and because the threshold measurements were relative, the gain settings of the power amplifiers were not varied during testing. This procedure resulted in threshold measurements having the same reference level. With the tape of the test sounds cued to the start of the first recorded program and the system input set for tape recorder, the investigator had only to select the appropriate test method for the initial test (here, headphones), and adjust the recording attenuator: (1) to a level slightly above an open-ear threshold for the first test sound, and (2) such that the pen aligned with a vertical line of the chart paper. The operator asked the subject if he/she were ready, and receiving an affirmative response, replied that "we are beginning." The tape recorder was then placed in operation and, at the end of the third of the warble-tones that preceded the test sounds, the operator started the drive of the recording attenuator. This operation synchronized the recorded chart of levels for each of the thirty-second,

one-third-octave-band test sounds to appear between vertical lines of the chart paper. Upon completion of the recorded program of test signals, the tape recorder and attenuator were stopped. During testing, the program of test sounds was monitored by the operator with a headphone connected to the recorder in the control room.

The subject was instructed to prepare for the second test, while the operator selected the method for the next test and again cued the tape recorder and attenuator. For occluded-ear thresholds, the level of the recording attenuator was cued to a higher level, one above unoccluded-ear threshold for the first test sound. The procedure of test was repeated for the remaining tests as previously described. The operator was required to be attentive to the selection of test method, to monitoring that the subject was performing the appropriate test (wearing headphones, etc.), and to the selection of white-noise input to the test room for fitting the earplugs. In addition, the recording of thresholds was monitored frequently and checked for reliability by (1) observing the character of the recorded excursions, and (2) comparing the threshold of the retest of the 1,000 Hz center frequency test sound with that recorded in sequence.

The first test sitting of the session was completed in approximately 30 minutes, after which time the subject took a ten to fifteen minute rest break. Subjects' remarks during the entire program of testing sessions were generally indicative that the earplugs were remaining "sealed" between protected measurements and otherwise did not suggest deficiencies in the measurement procedures.

After indicating that they were ready to begin again, the subject and investigator returned to the test room with the second test's earplugs and repeated the procedure previously described. However, no practice run was required, and consequently only four thresholds were measured: reference, protected, protected, and reference. This fewer number of thresholds permitted completion of the second sitting of testing in approximately 25 minutes. The remainder of the time of this test session was spent in molding a set of earplug No. 3 for the subject. These were simultaneously fitted in both ears of the subject by two of the investigators in order to optimize the time during which the protector material is pliable and best suited for fitting. (A single, skilled operator should be able to properly fit both custom-molded plugs in this same time period.)

When a particular test sitting was concluded by a reference threshold using the same method as called for initially in the following test sitting, one of these scheduled reference thresholds was eliminated. This procedure was not detrimental to accuracy because such thresholds were reproducible if no change was made in instrumentation gain settings, and this was the case. In addition, subject fatigue was reduced by the lessened number of required thresholds.

5. RESULTS

5.1 REDUCTION OF DATA

The data for measured attenuations were extracted from the recorded tracings of open-ear and occluded-ear thresholds, which had been plotted sequentially on the chart paper output of the recording attenuator. These threshold tracings were each averaged by first, disregarding the initial and the last excursion of threshold level in the test-sound period for each frequency, and then, drawing a straight line on the chart paper at the mean level.

With the average levels drawn for each of the measured thresholds, the charts were separated and the attenuation determined by superimposing the respective test-method reference and protected levels with the aid of a light table. The attenuation for that particular test sound was the corresponding difference rounded off to the nearest whole number in dB, between the levels, and was easily read from the superimposed charts. This procedure was carried out for each of the ten test sounds and, for both of the test methods that were performed for each case of earplug model and testing condition. The data for both the field-method and standard (laboratory) method measurements of hearing protector attenuation at each test frequency except 1,000 Hz were the values of differences between occluded, and open-ear thresholds. The 1,000 Hz center frequency test-sound attenuation data were determined from the average of the two measured values (test and retest).

The data were transferred to 029 Keypunch cards for purposes of data storage and the computational analyses. An individual card contained the data from a single measurement of attenuation, that is, the nine attenuation measures (in dB) for the test sounds of one-third-octave bands with center frequencies 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. These data were preceded by a six-digit code number that identified the data.*

* The first two digits (01-02) of the code number designated each of the 20 different subjects (ten males and ten females) with even numbers 02, 04, . . . 18, 20 used for male subjects and odd numbers for females. The third digit (1-6) identified the hearing protector for which the attenuation data were measured, with 1-5 corresponding to earplug Nos. 1-5 and 6 used to identify the EAL field-method headphones. The fourth digit was used to designate the test-condition fit: 1 for initial or proper fit condition and 2 for retest condition. (It should be noted that the complete data for a retest-condition analysis include that for ten of the twenty subjects with the earplug "refitted" and that for the other ten subjects with proper-fit initial condition.) The fifth digit (1-4) designated that the data were measured either: 1 during a comparison-test sitting of attenuation measurement methods, or 2-4 during the first, second, and third trials of a standard method. The last digit

5.2 REGRESSION ANALYSIS

5.2.1 Computer Program. The program used for analysis of the comparison-testing data is an external program in the library of the IBM System/370 of the Computation Center, The Pennsylvania State University (PSU). Entitled "Stanford Center for Research and Development for Teaching, Regression Analysis (SCRDTI)", the program was originally written by Robert Proctor of the SCRDT, Stanford University, and was subsequently adapted for use on the S/370 at the PSU Computation Center. This program provides scatterplots, descriptive statistics, and computes the regression lines for selected variable pairs. It is particularly useful for comparing regression lines in several different groups as it provides an F-ratio for testing parallelism of regression, a pooled within-groups regression coefficient, and a plot for combined groups. The program will accept data from either cards or tape.

5.2.2 Initial and Retest Conditions of Earplug Fit for Each of Five Models Tested. A regression analysis was first computed across twenty different subjects for each of the 90 sets of data that were measured for the (nine test sounds) x (five models of earplugs) x (two conditions of fit). These results are presented in Table VI where the computed equation of the regression line and correlation coefficient are given for each analysis of data. The scatterplots and additional results of analyses are presented in Appendix A. The variables have been designated y: field-method (headphones) attenuation, and x: standard-method (diffuse sound field) attenuation. The two fitting conditions of the attenuation data for 20 subjects for each earplug have been alternately designated A: initial condition (all standard fit) and B: retest condition (ten standard fit and ten "altered" fits).

Comparisons among the results of Table VI for individual test signals and specimens of earplugs show that fit-condition B gave correlation coefficients that were either equal to or larger than those of fit-condition A in 34 of the 45 cases. In the 11 cases where the correlation coefficients of fit-condition A were greater than those for B, the differences in correlation coefficients were generally small, averaging approximately 0.043. By contrast, in those 34 cases where correlation coefficients of fit-condition B were greater than those for A, sizable differences were noted, averaging 0.140. This result supported the original prediction that the retest condition of testing should generally provide a stronger correlation between measurement methods due to increasing the range of the attenuation data. In addition, in

(1-2) was used to designate the attenuation-measurement method, either 1 diffuse-field, ASA/ANSI standard (laboratory) method/procedure, or 2 conducted with the EAL field-method headphones. An example of the comparison to be made between the data for the two measurement methods on a model of earplug would be the comparisons of data for the twenty different subjects under initial condition of fit (cf. 011111 vs. 011112, 021111 vs. 021112, 031111 vs. 031112, and so on).

Table VI. Computed equations of regression lines and correlation coefficients for the regression analyses across twenty different subjects that compare values of earplug noise attenuation data measured with the EAL field-method headphones (y variable) and the ASA/ANSI Standard Method (x variable). Analysis results are presented for each of the nine test-signals (one-third-octave bands) for which the earplugs Nos. 1-5 were each measured under conditions of either initial (proper) fit on twenty different subjects (fit-condition A), or retest fit on ten of these subjects along with the proper-fit condition data of the ten other subjects (fit-condition B).

One-Third-Octave Band Test Signal Center Frequency, in Hz	Earplug No.- Fit Condition	Equation of Regression Line (y = a + bx)	Correlation Coefficient
125	1-A	y = 4.95 + 0.6041 x	0.709
	1-B	y = 5.12 + 0.5654 x	0.822
	2-A	y = 5.04 + 0.5598 x	0.798
	2-B	y = 2.97 + 0.6942 x	0.887
	3-A	y = 0.18 + 0.6408 x	0.715
	3-B	y = 1.46 + 0.4294 x	0.537
	4-A	y = 3.68 + 0.2926 x	0.427
	4-B	y = -0.38 + 0.7462 x	0.797
	5-A	y = 1.11 + 0.8145 x	0.713
	5-B	y = 0.29 + 0.7668 x	0.833
250	1-A	y = 11.04 + 0.5905 x	0.694
	1-B	y = 5.55 + 0.7375 x	0.880
	2-A	y = -0.60 + 0.9664 x	0.944
	2-B	y = 3.04 + 0.8877 x	0.860
	3-A	y = 1.43 + 0.7704 x	0.560
	3-B	y = 1.15 + 0.6454 x	0.481
	4-A	y = 2.08 + 0.7601 x	0.800
	4-B	y = 1.91 + 0.8482 x	0.831
	5-A	y = -0.95 + 1.0000 x	0.813
	5-B	y = 1.05 + 0.8809 x	0.861
500	1-A	y = 11.14 + 0.5857 x	0.798
	1-B	y = 3.16 + 0.8352 x	0.943
	2-A	y = 2.07 + 0.9356 x	0.938
	2-B	y = 3.04 + 0.9591 x	0.904
	3-A	y = 3.43 + 0.7996 x	0.615
	3-B	y = 2.02 + 0.9781 x	0.616
	4-A	y = 6.62 + 0.7541 x	0.777
	4-B	y = 2.51 + 0.9900 x	0.921
	5-A	y = 1.82 + 1.0056 x	0.925
	5-B	y = 1.73 + 0.9814 x	0.907

Table VI (continued)

One-Third-Octave Band Test Signal Center Frequency, in Hz	Earplug No.- Fit Condition	Equation of Regression Line	Correlation Coefficient
1000	1-A	$y = 7.81 + 0.7246 x$	0.725
	1-B	$y = 5.74 + 0.7825 x$	0.934
	2-A	$y = 2.14 + 0.9206 x$	0.940
	2-B	$y = 2.12 + 0.9679 x$	0.916
	3-A	$y = 3.96 + 0.7252 x$	0.586
	3-B	$y = 1.92 + 0.8816 x$	0.717
	4-A	$y = 4.83 + 0.7768 x$	0.804
	4-B	$y = 0.87 + 0.9917 x$	0.901
	5-A	$y = 0.08 + 1.0207 x$	0.914
	5-B	$y = -1.19 + 1.0302 x$	0.932
2000	1-A	$y = 13.87 + 0.5874 x$	0.586
	1-B	$y = 7.63 + 0.7915 x$	0.792
	2-A	$y = 12.58 + 0.6099 x$	0.713
	2-B	$y = 5.37 + 0.8437 x$	0.864
	3-A	$y = 1.04 + 0.9041 x$	0.792
	3-B	$y = 1.01 + 0.8656 x$	0.761
	4-A	$y = 1.25 + 0.9615 x$	0.840
	4-B	$y = 1.71 + 0.9540 x$	0.919
	5-A	$y = 11.77 + 0.6847 x$	0.752
	5-B	$y = 5.70 + 0.8590 x$	0.835
3150	1-A	$y = -0.21 + 1.0315 x$	0.832
	1-B	$y = 0.95 + 1.0397 x$	0.922
	2-A	$y = 7.86 + 0.7559 x$	0.714
	2-B	$y = 5.28 + 0.8272 x$	0.913
	3-A	$y = 5.67 + 0.7410 x$	0.838
	3-B	$y = 1.85 + 0.9815 x$	0.794
	4-A	$y = 12.84 + 0.6326 x$	0.594
	4-B	$y = -2.50 + 1.1332 x$	0.950
	5-A	$y = 5.58 + 0.8990 x$	0.614
	5-B	$y = -1.37 + 1.0513 x$	0.703
4000	1-A	$y = -12.25 + 1.3877 x$	0.927
	1-B	$y = -3.20 + 1.1819 x$	0.903
	2-A	$y = 7.52 + 0.7106 x$	0.679
	2-B	$y = 10.55 + 0.6555 x$	0.919
	3-A	$y = 2.74 + 0.9205 x$	0.756
	3-B	$y = 1.08 + 1.1061 x$	0.851
	4-A	$y = 5.42 + 0.8333 x$	0.785
	4-B	$y = -3.23 + 1.1109 x$	0.962
	5-A	$y = 22.91 + 0.4755 x$	0.414
	5-B	$y = -1.35 + 1.0352 x$	0.781

Table VI (continued)

One-Third-Octave Band Test Signal Center Frequency, in Hz	Earplug No.- Fit Condition	Equation of Regression Line	Correlation Coefficient
6300	1-A	$y = -9.72 + 1.4054 x$	0.781
	1-B	$y = 3.92 + 0.9924 x$	0.781
	2-A	$y = 1.15 + 0.9674 x$	0.879
	2-B	$y = -0.58 + 1.0497 x$	0.837
	3-A	$y = 4.73 + 0.8819 x$	0.671
	3-B	$y = 4.21 + 0.9846 x$	0.710
	4-A	$y = 9.60 + 0.8236 x$	0.558
	4-B	$y = 1.59 + 1.0381 x$	0.762
	5-A	$y = 0.95 + 1.1139 x$	0.721
	5-B	$y = -10.50 + 1.3624 x$	0.926
8000	1-A	$y = 3.78 + 1.1118 x$	0.746
	1-B	$y = 1.86 + 1.1287 x$	0.907
	2-A	$y = 0.91 + 1.1286 x$	0.911
	2-B	$y = 2.18 + 1.0471 x$	0.915
	3-A	$y = 8.22 + 0.6831 x$	0.579
	3-B	$y = 6.25 + 0.7627 x$	0.573
	4-A	$y = 10.61 + 0.8000 x$	0.587
	4-B	$y = 5.06 + 0.9893 x$	0.819
	5-A	$y = 13.98 + 0.8679 x$	0.792
	5-B	$y = -2.32 + 1.2640 x$	0.846

order for the regression equations to be meaningful predictors, they should be derived from a data base that is representative of the population to be predicted. In this case, the retest-condition data shows a wide range of attenuation values, typical of that found in the industrial setting. Consequently, subsequent analyses were restricted to the data from the retest condition of fit.

5.2.3 Retest Condition of Earplug Fit Lumped Across All Five Models Tested. An F-test for parallelism of regression lines was computed across all five models of earplugs for the data of each test signal and retest condition (B) of earplug fit. The results are presented in Table VII. For all test signals the F ratio was non-significant ($\alpha = 0.05$), indicating that the slopes of the regression lines for a given test-signal were not significantly different from one another when comparing all five earplugs under the retest condition of fitting. This indicates that the data can be lumped across all protectors. Consequently, these results from the F-test computation are presented in Table VIII. Because the data lumped across protectors are not from 100 different subjects, but rather 20 subjects repeated with each protector, the pooled regression equation* and corresponding correlation coefficients are given in Table VIII. The scatterplots and computed results of the analyses are presented in Appendix B with the exception of the pooled regression equation.

The correlation coefficients of Table VIII are all equal to or greater than 0.867. Testing for the significance of this value indicated a probability of error much less than 0.001! In other words, the probability is extremely small that the correlation that is observed between the field-method and the ASA/ANSI standard method of measurement of earplug attenuation is due to chance. This correlation is defined by the pooled regression equations for the nine one-third-octave-band test signals given in Table VIII where the field-method measure (y) is given as a function of the corresponding ASA/ANSI standard measure (x).

5.3 COMPARISON OF ATTENUATION MEASUREMENT METHODS

Two tests of the comparison-testing program were designed for purposes of an overall comparison between the standard (laboratory) and field methods of measuring earplug attenuation (see section 4.4.1). Attenuation data were measured for three separate subject-fit trials of earplug No. 5 on each of the twenty subjects. Ten of these subjects were tested by the ASA/ANSI standard-method (diffuse field, real-ear method) and the other ten were tested by the same procedure excepting that the EAL field-method headphones were used to measure the occluded and open-ear thresholds. The data from these measurements are presented in Table IX along with three additional values for the standard-method of measuring attenuation that: (1) in column C, have been

* The method for developing a pooled regression equation is detailed in the program discussion of the SCRDTI Regression Analysis program.

Table VII. Computed F-test for parallelism of regression across five models of earplugs.* The regression analyses are for comparisons of earplug noise attenuation values measured with the EAL field-method headphones and the ASA/ANSI Standard Method for each of nine test-signal sounds (one-third-octave bands) on twenty different subjects with the earplugs fitted under retest conditions (ten subjects fitted properly and ten subjects with altered fit). All F ratios were non significant.

One-Third-Octave Band Test Signal Center Frequency, in Hz	F Ratio
125	1.1406
250	0.4231
500	0.3768
1000	0.9092
2000	0.2138
3150	0.9216
4000	3.4921
6300	0.7124
8000	0.9679

* Degrees of Freedom: 4 and 90.

Table VIII. Computed pooled regression equations and correlation coefficients for the regression analysis that was lumped across data for five models of earplugs and that compares values of earplug noise attenuation data measured with the EAL field-method headphones (y variable) and and ASA/ANSI Standard Method (x variable). Analysis results are presented for each of the nine test-signals (one-third-octave bands) that were measured under conditions of retest fit on twenty different subjects for each earplug.

One-Third-Octave Band Test Signal Center Frequency, in Hz	Pooled Regression Equation ($y = a + bx$)	Correlation Coefficient
125	$y = 1.96 + 0.6574 x$	0.903
250	$y = 2.36 + 0.8304 x$	0.898
500	$y = 2.51 + 0.9353 x$	0.931
1000	$y = 1.94 + 0.9330 x$	0.939
2000	$y = 4.17 + 0.8614 x$	0.904
3150	$y = 1.55 + 0.9816 x$	0.913
4000	$y = 1.35 + 1.0015 x$	0.884
6300	$y = 0.60 + 1.0793 x$	0.867
8000	$y = 2.86 + 1.0725 x$	0.909

Table IX. Noise attenuation at threshold for earplug No. 5. Attenuation data are presented for the nine one-third-octave band test signals with center frequencies beginning 125 Hz and ending 8000 Hz. The data represent: (A) real-ear method of the ASA/ANSI Standard Method (ASA STD 1-1975/ANSI S3.19-1974); (B) procedure of the real-ear method of the ASA/ANSI Standard Method carried out using the EAL field-method headphones to measure thresholds; (C) the values predicted using the pooled regression equations (see Table VIII); and (D), (E) values calculated using the regression equations computed for comparison tests under: retest condition 5-B, and initial condition 5-A (see Table VI).

One-Third-Octave Band Test Signal Center Frequency, in Hz	(A) Standard-Method Mean (S.D.)	(B) Field-Method Mean (S.D.)	(C) Predicted Value for (A) (Difference A-C)	(D) Calculated Values for (A)	(E) Calculated Values for (A)
125	28.4 (7.8)	21.7 (6.8)	30.0 (-1.6)	27.9	25.3
250	30.3 (7.7)	25.6 (7.9)	28.0 (+2.3)	27.9	26.6
500	34.3 (7.1)	31.0 (7.5)	30.5 (+3.8)	28.8	29.0
1000	34.3 (5.7)	32.4 (7.0)	32.6 (+1.7)	32.6	31.7
2000	32.9 (3.6)	32.5 (5.9)	35.2 (-2.3)	33.5	33.2
3150	39.9 (2.1)	40.3 (3.8)	39.5 (+0.4)	39.6	38.6
4000	40.6 (3.1)	41.5 (4.7)	40.1 (+0.5)	41.4	39.1
6300	40.9 (4.1)	45.3 (8.6)	41.4 (-0.5)	41.0	39.8
8000	39.9 (5.8)	45.7 (7.0)	39.9 (0.0)	38.0	36.5

predicted by the pooled regression equations of Table VIII; and (2) in columns D and E, have been calculated from the regression equations of Table V, 5-B and 5-A. The differences between the measured and predicted values of standard-method attenuation range from 0 to 3.8 dB, with an average value of 1.5 dB for the nine test signals. Such agreement is quite good and particularly noteworthy considering that these differences place the predicted values well within one standard deviation of the measured mean values determined in the standard-method (laboratory) tests. In addition, the average difference of 1.5 dB compares favorably with the typical reliability of threshold measurements. For the four test signals beginning at 3150 and ending at 8000 Hz, the measured and predicted values are within $\frac{1}{2}$ dB of one another. This best agreement for the higher frequencies may well be due to acoustical and/or headphones-performance characteristics, but no such explanations have been attempted because of the limits to the scope of this investigation.

The calculated attenuation values given in Table IX, columns D and E, demonstrate that in general, the better agreement with measured mean values is found from the analysis of data with greater range. This was the assumption made in selecting the retest-condition for the regression analysis lumped across all protectors and used for predicting standard-method values in column (B) of Table IX. For the calculations of column D, the regression equations from the analysis of the data for retest, condition 5-B (see Table VI) are used. These data have a larger range than that of initial-condition 5-A which was analyzed for the regression equations (see Table VI) used to calculate column E. It is the values of column D that are generally closer to those measured by the standard method and given in column A. This supports the selection of the pooled regression equations of Table VIII as predictors of a laboratory-standard value of earplug noise attenuation using field data measured with the EAL headphones.

6. SUMMARY AND RECOMMENDATIONS FOR A FIELD TEST PROCEDURE

6.1 GENERAL

This investigation was designed to determine if a circumaural headphone set (the EAL field-method headphone) could be used to measure meaningful values of the noise attenuation being provided by insert-type hearing protectors. If the results of this investigation were positive, this headphone set would be used as a part of a field-method procedure to determine the actual amount of protection being provided by insert-type protectors as they are normally worn at the work place. The field-method was designed closely after the ASA/ANSI standard method (a real-ear measurement performed in a diffuse-field laboratory setting), and the correlation of attenuation data measured according to the field-method and the ASA/ANSI laboratory method were examined. The same insert protectors and the same subjects were used for these attenuation measurements.

The EAL headphones were fabricated from a commercial set of earmuff-type hearing protectors that were fitted with earphone drivers. This headphone set provides satisfactory reduction of ambient noise level to prevent threshold masking, and its acoustical characteristics were the best found for any of several headphones tested. The headphone set was used without any difficulties throughout the investigation and continues to meet its original performance characteristics.

The investigation was designed so that a correlation between the field and the laboratory data would measure the validity of the field method. The correlation was performed on attenuation data measured with the two methods during 150 tests on five models of earplugs that were chosen to be representative of various types, and to exhibit a wide range of attenuation characteristics. In fact a wide range of attenuation characteristics was assured by including a measurement of a retest of the earplugs for altered fit (retest condition of earplug fit).

Each comparison test involved determining earplug attenuation data by measuring the relative real-ear thresholds, with and without the insert protectors inserted, by each of the two methods: laboratory/standard and headphones/field. These tests carried out in the laboratory were designed so that any particular earplug's attenuation would not change between measurements by the two methods. The instrumentation for this testing was the same as that specified by the ASA/ANSI standard (laboratory) method. Test sounds were reproduced from magnetic tape recordings. The sound levels were varied above and below threshold levels by the subject who controlled a recording attenuator. This provided a chart output showing relative thresholds at the various test-frequencies of one-third-octave bands of noise.

For test purposes, the field-method apparatus was designed to be connected to the existing ASA/ANSI laboratory instrumentation by switching the output of the attenuator from the power amplifier leading to the diffuse-field, test room loudspeakers, to the EAL headphone set.

Initial regression analyses that compared attenuation data from the two measurement methods confirmed the appropriateness of the testing design. The results of these initial analyses suggested that the data be lumped across all models of earplugs for the comparison testing on twenty different subjects. The twenty subjects included ten subjects with initial (standard) condition of earplug fit and ten subjects with retest condition of altered earplug fit. This analysis provided pooled regression equations with strong correlations between data measured by the EAL field-method headphones and data measured by the ASA/ANSI standard laboratory method. Consequently, the basis for measuring the noise attenuation of insert-type hearing protectors in the field has been established. General recommendations for a field-test method are presented in the next section.

6.2 APPARATUS AND PROCEDURES FOR A RECOMMENDED HUMAN SUBJECTS FIELD TEST

6.2.1 Equipment. The testing carried out in this investigation was performed in the laboratory and utilized those typical facilities that included a diffuse-field test room and instrumentation that meets the requirements and specifications for performing ASA/ANSI standard-method attenuation measurements. The field-method headphones to be used for testing may be fabricated from commercially available components as has been described in Section 3.1.2 of this report. No special significance is attributable to the exact manner by which the earphone drivers were secured to the earcup shells of the hearing protector, except for their location on the outside of the shells and the maintenance of a good acoustical seal. Consequently, improvements in the mechanical design of the retainer clips is deemed permissible. If a different design is used the headphones should be tested in order to ascertain a suitable, and similar frequency response for each earphone, such as has been reported in Section 3.1.3. The headphones operational requirements are specified by those of the component Beyer DT-48S (5 ohm impedance) earphone drivers. These specifications stipulate a required input voltage of approximately 10 mv per system, with 1 volt or 200 mw max. power demand per system. These requirements must be satisfied by the usual electrical considerations for the connecting circuitry and signal handling equipment. The maximum sound-pressure-level output of the headphones is in the range of 110 - 120 dB for the one-third-octave-band test signals at the maximum permissible power rating.

The field-test system should be comprised of instrumentation such as will provide: (1) the test sounds as specified in Section 3.1.1.2 of ASA STD 1-1975/ANSI S3.19-1974, (2) a means for varying and recording the levels of signals, and (3) monitoring information on the system performance (headphones or loudspeaker, oscilloscope, and voltmeter).

The ambient noise level in the test room must be sufficiently lower than the test signal level so that threshold measurements will not be masked. While the EAL headphone provides a reasonable amount of room noise attenuation, interference with threshold testing could occur with some listeners, particularly at low frequencies. It is

possible to determine if masking may have occurred in the unprotected, threshold testing of a subject by comparing his test results with the known characteristics of the testing environment. The features which must be determined include:

- a) the sound pressure level in dB re. 0.00002 N/m^2 of the one-third-octave-band noise signal for the listener's threshold (L_T),
- b) the sound pressure level in dB re. 0.00002 N/m^2 of the room ambient noise in the one-third-octave-band at which the listener is being tested (L_R),

and

- c) the mean attenuation of the EAL headphones for a one-third-octave-band of noise centered at the testing frequency (A).

To obtain a 97½ percent confidence limit, two standard deviations (S.D.) should be subtracted from the mean attenuation of the EAL headphones measured by the ASA/ANSI standard method (see Section 3.1.3, Table III). The following formula may then be applied in evaluating test results:

$$L_C = L_R - (A - 2 \text{ S.D.}) + 6 \text{ dB}$$

where L_C is the criterion sound pressure level for the room noise that is acceptable for threshold testing. A factor of +6 dB is included to insure that the threshold will be sufficiently above the audible room noise. If $L_T > L_C$, the threshold data in the unoccluded case will probably not be masked significantly. If $L_T \leq L_C$, it is possible that the unprotected threshold is masked. In such a case, the measurement of hearing protector attenuation will be reduced by some unknown amount. For this reason, it is recommended that data obtained from cases where $L_T \leq L_C$ should not be used, as it is in error and cannot be corrected. Note that (A - 2 S.D.) is estimated statistically and therefore some 2.5% of the persons tested will have headset attenuation less than these values.

6.2.2 Instructions to Subjects. The subjects will be tested initially for occluded-ear threshold. Consequently, it would be most helpful if they have received a comprehensive preliminary briefing so that they will not disturb the earplug once it has been fitted and inserted. Such action would negate the desired result for the measurement, that is, an evaluation of the effectiveness of the earplug under actual conditions of wearer-use.

A preliminary briefing should inform the subjects that they are to have their hearing tested while wearing their hearing protectors. This test is to be done to evaluate how well these devices are protecting them; therefore, they should not disturb the protectors when selected for testing. As a later time in the testing sequence, they will be asked to remove the earplugs. They will be instructed on the testing procedure and they should feel free to ask questions until

they are confident about what is required. They will be asked to be seated in a specially designed, quiet test booth and to remove eye-glass frames, earrings, special headgear, etc., but not their earplugs. A pair of headphones will be fitted on them for the tests. When ready, they will be asked to listen for sounds from these headphones that vary in loudness when they press and release a signal button. When they hear the sounds, they are to respond by pushing a button and holding it so long as they continue to hear the sounds. The sounds will begin to get softer when they push the button, and they are to continue listening. When they no longer can hear the sounds, they are to release the button. The sounds will again start to get louder, and they should once again start to hear them and follow the same procedure of responding by pushing and holding the button. They should continue to do this operation of pushing and holding the button when they hear the sounds and releasing the button when they don't for as long as the sounds continue. There will be different sounds presented for which the same procedure should be followed. The entire test for all test sounds will take about five minutes. These initial instructions should be sufficient to prepare the subject for all of the following tests.

The operator should be experienced with audiometric testing procedures. They will thus be prepared to recognize and correct the many and varied procedural errors inherent in such testing. It may be helpful to have explicit instructions placed in front of the subjects in writing. At the end of the occluded-ear threshold measurement, the operator may explain to the subject that this is the time for removal of the earplugs and now the same test will be repeated without plugs inserted. It is also an opportunity for the operator to inquire of the subject for their comments on any aspects of the testing. For instance, a subject who does not receive any significant noise reduction from the headphones may be able to relate that he has heard room noise. This would alert the operator that the listener may have received some masking of open-ear threshold from ambient noise.

6.2.3 Particulars for the Operator. There are several important considerations for the operator. First, the headphones should be mounted on, and removed from the subject by the operator. This procedure will help to ensure suitable fit, good noise reduction by the headphones, less chance for disturbance of earplugs, and proper handling of the headphone set. Second, since the thresholds measured will be relative ones, any change in the reference levels for the two thresholds should be noted. Third, signal levels for the start of occluded-ear and open-ear tests should be set above threshold for the first test sound (different levels). Finally, it may be helpful to have some indication of any binaural hearing loss for a particular subject, perhaps from examining subjects' audiograms prior to testing. Combined with a significant measure of earplug hearing protection, this would indicate the level of test sound at which to begin testing. Otherwise, an unsatisfactory measurement may be performed for the threshold of the first occluded-ear test sound, because the time of signal presentation would be spent while the recording attenuator increases to a level for threshold. This final consideration must be tested in the field before its importance can be evaluated.

6.2.4 Determination of Earplug Attenuation Values. Field-method earplug attenuation data are determined from the differences between the occluded- and open-ear thresholds for the nine one-third-octave-band test sounds with center frequencies beginning 125 Hz and ending 8000 Hz. Pooled regressive equations may then be used to correlate these field-method data with the data measured according to the ASA/ANSI standard method (Section 5.2.3). This relationship is given here as: $A_n = (F_n - a_n) / b_n$ where $n = 1, 2, 3 \dots 9$ designates the nine one-third-octave bands with center frequencies 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz, A_n are the earplug attenuation values, F_n are the field-method attenuation data, and a_n and b_n are given by:

<u>n</u>	<u>a_n</u>	<u>b_n</u>
1	2.0	0.66
2	2.4	0.83
3	2.5	0.94
4	1.9	0.93
5	4.2	0.86
6	1.6	0.98
7	1.4	1.00
8	0.6	1.08
9	2.9	1.07

The values of a_n and b_n are taken from the pooled regression equations (Table VIII).

NOTE: A different approach for treatment of the data is described in Appendix C.

6.3 CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

A field method for the measurement of the real-ear protection of earplug-type hearing protectors has been established that employs a circumaural headphone set comprised of an earmuff-type hearing protector fitted with earphone drivers. This headphone set is easily fabricated and exhibits good noise reduction and test-signal generation performance characteristics. The headphone is capable of measuring real-ear thresholds for open-ears and earplug-occluded ears for the test sounds of one-third-octave bands of noise with center frequencies 125, 250, 500, 1000, 2000, 3150, 4000, 6000, and 8000 Hz. Instrumentation requirements for this procedure are not complex. The differences between the thresholds measured with ear canals occluded with earplugs and open canals are used to calculate the earplug noise attenuation data. These data correlate well with attenuation data developed by the ASA/ANSI standard method. Consequently, for a particular case of earplug hearing protection, earplug attenuation values may be estimated from headphones-measured data that will specify the protection that is being achieved. General recommendations for a field-measurement procedure are suggested. However, further study is required to test such a procedure for the field and then implement it in a practical way. The equipment suitable for a field procedure would be best contained in a mobile van. It is anticipated that this equipment may vary from that used in this investigation without detriment. Initial tests in the field should always be made

to determine if the background noise in the van will mask open ear canal thresholds.

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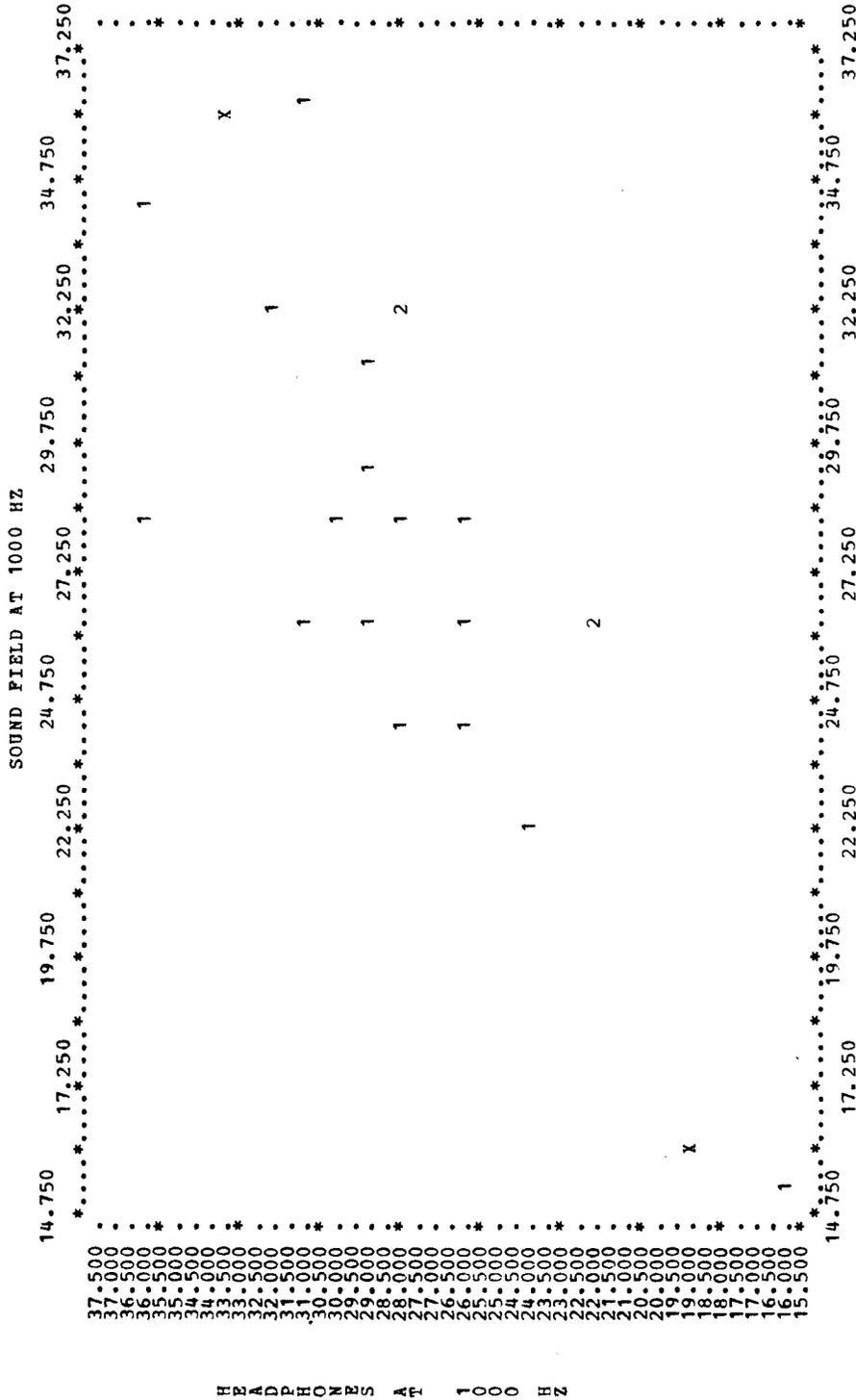
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APPENDIX A

SCATTERPLOTS AND COMPUTED RESULTS FOR THE REGRESSION ANALYSES ACROSS TWENTY DIFFERENT SUBJECTS

The 90 sets of scatterplots and computed results that follow are for the regression analyses across 20 different subjects that compare values of earplug noise attenuation data measured with the EAL field-method headphones and the ASA/ANSI standard (diffuse sound field) method. Analysis results are presented for each of the nine test signals (one-third-octave bands) for which the earplugs Nos. 1-5 were each measured under conditions of either initial (standard) fit on 20 different subjects (fit-condition A), or retest fit on ten of these subjects along with the standard-fit condition data of the ten other subjects (fit-condition B).

0*EVALUATION OF PROTECTOR 1A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

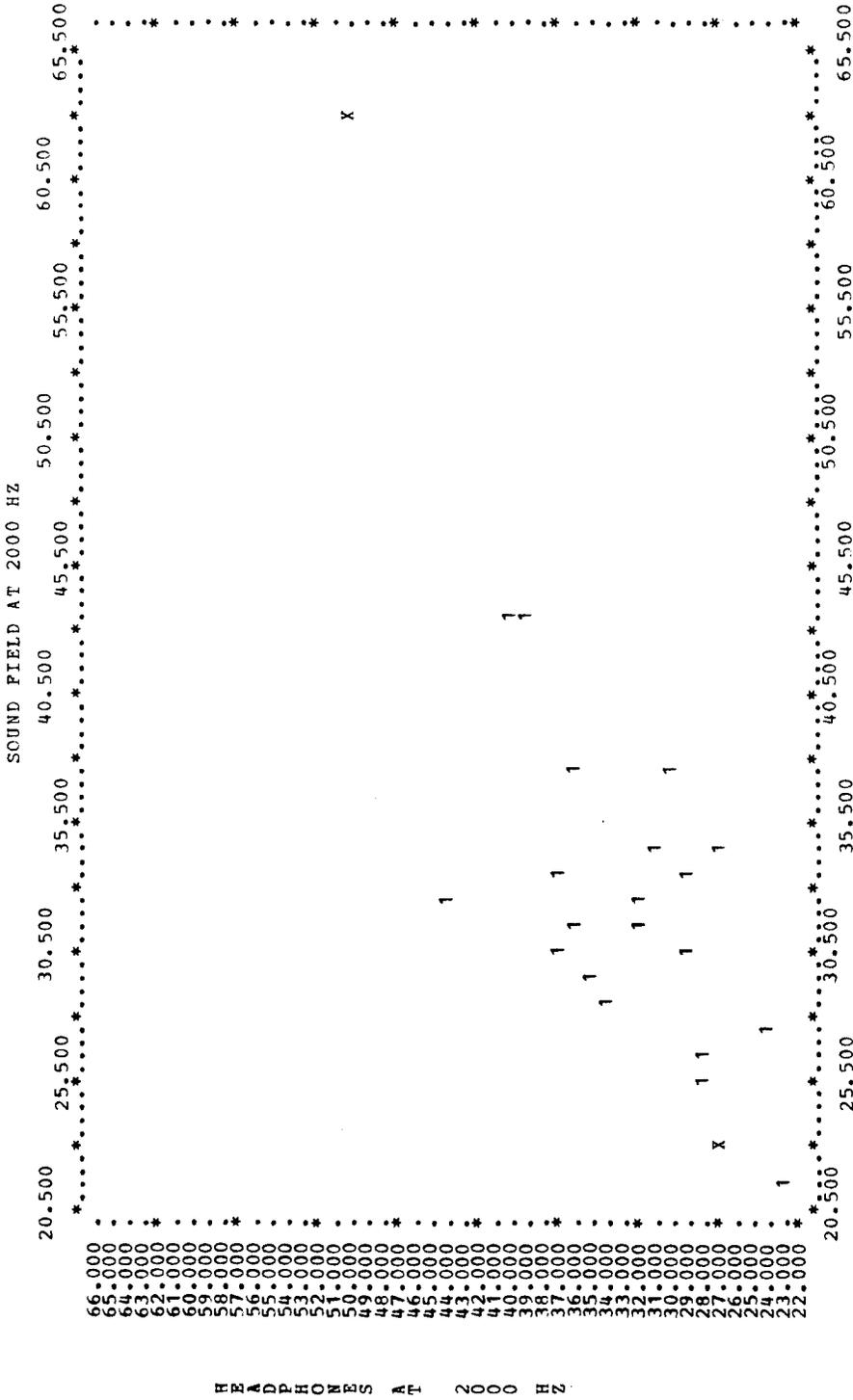
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	4	20	27.650	4.660	21.713	36.000	15.000	21.000	-0.640	1.079
Y	13	20	27.850	4.660	21.713	36.000	16.000	20.000	-0.485	0.720

EQUATION OF REG. LINE Y = 7.81 + 0.7246 X

STANDARD ERROR OF ESTIMATE 3.48

CORRELATION COEFFICIENT 0.725

0*EVALUATION OF PROTECTOR 1A*

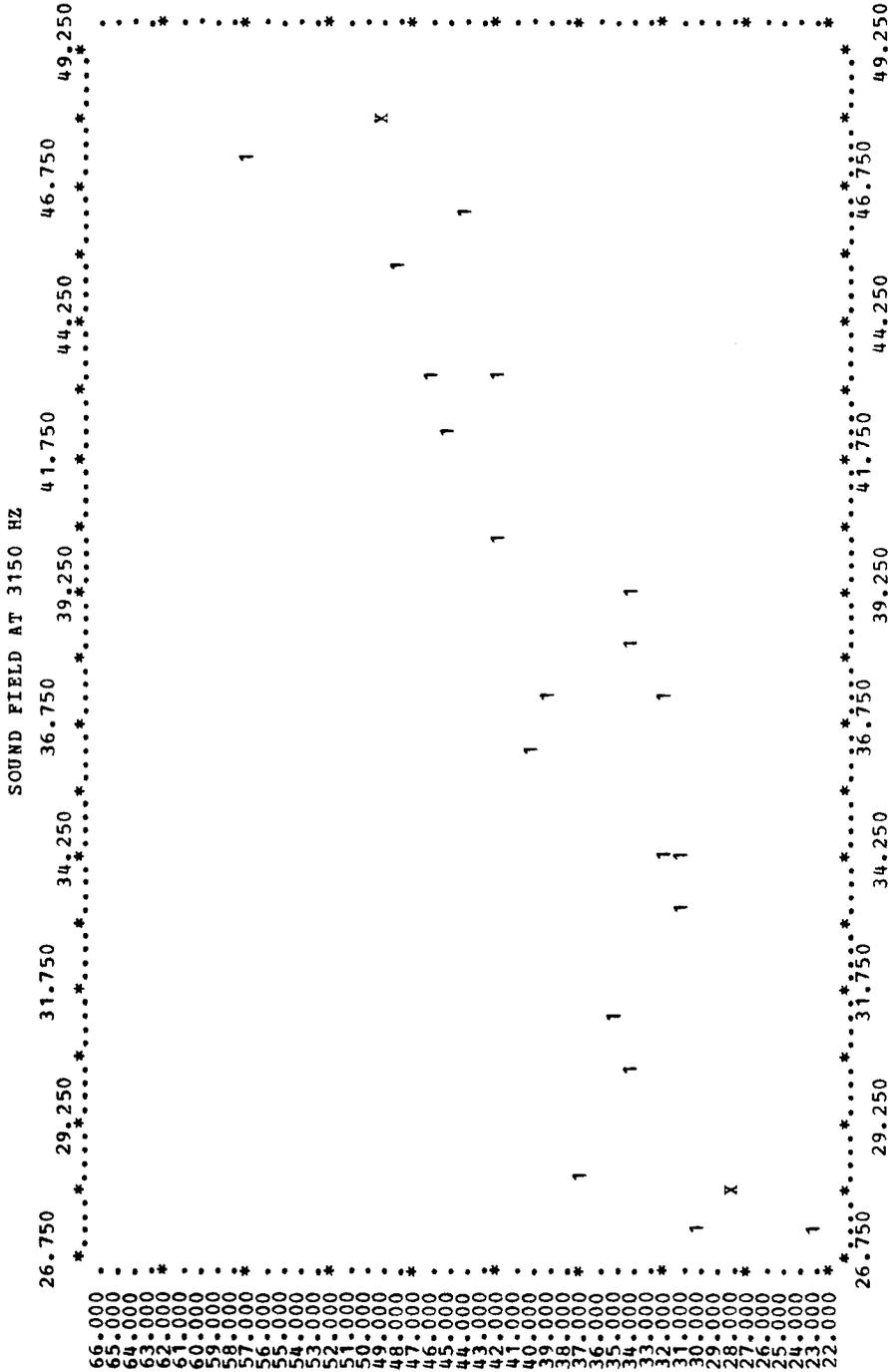


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	5	20	31.800	5.464	29.853	43.000	21.000	22.000	0.380	0.151
Y	14	20	32.550	5.482	30.050	44.000	23.000	21.000	0.162	-0.611

EQUATION OF REG. LINE Y = 13.87 + 0.5874 X
 STANDARD ERROR OF ESTIMATE 4.81
 CORRELATION COEFFICIENT 0.586

0*EVALUATION OF PROTECTOR 1A*



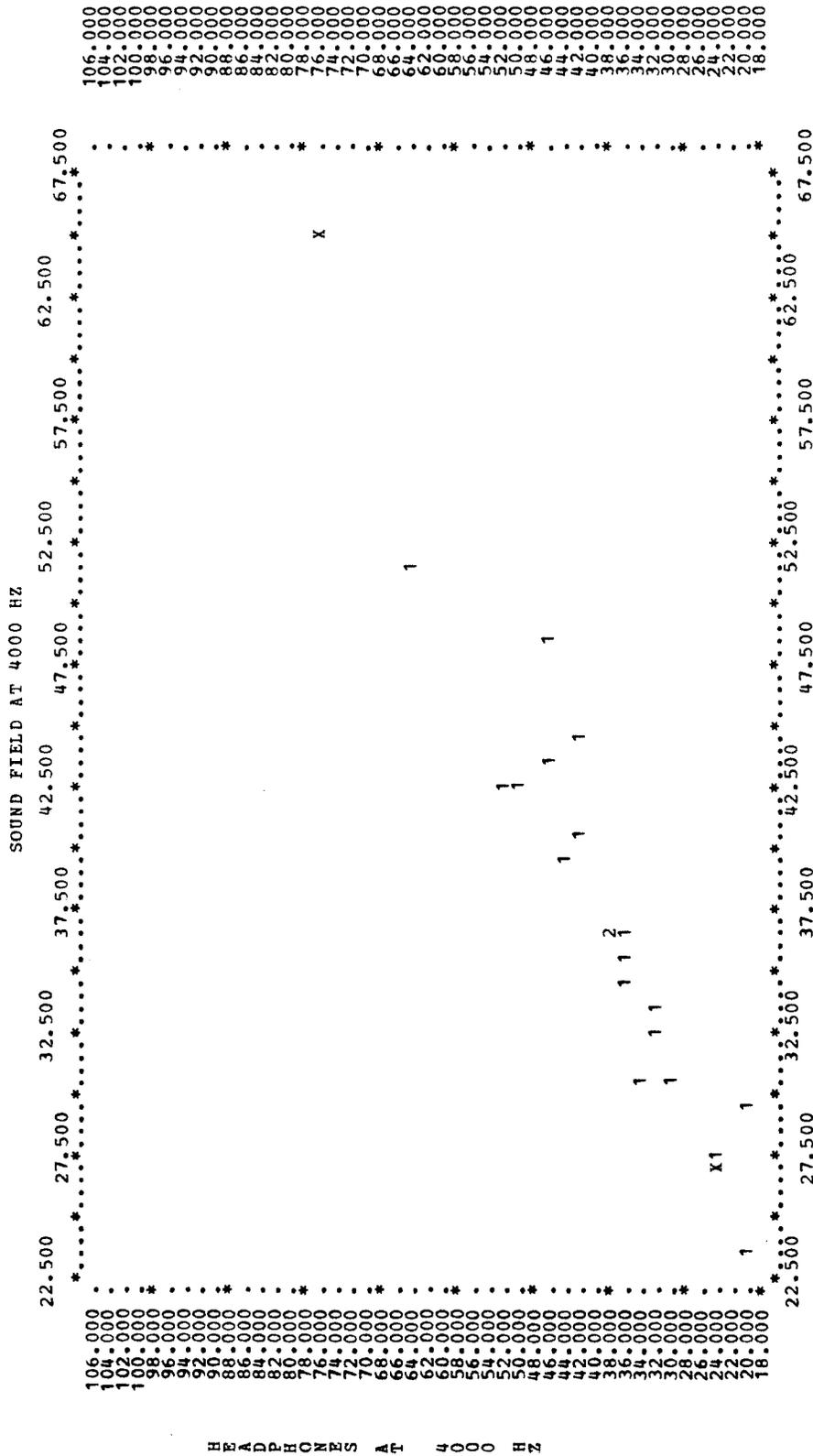
HEADPHONES AT 3150 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	16	20	36.850	6.310	39.818	47.000	27.000	20.000	-0.050	-1.099
Y	15	20	37.800	7.824	61.221	57.000	23.000	34.000	0.512	0.177

EQUATION OF REG. LINE Y = -0.21 + 1.0315 X
 STANDARD ERROR OF ESTIMATE 4.70
 CORRELATION COEFFICIENT 0.832

0*EVALUATION OF PROTECTOR 1A*

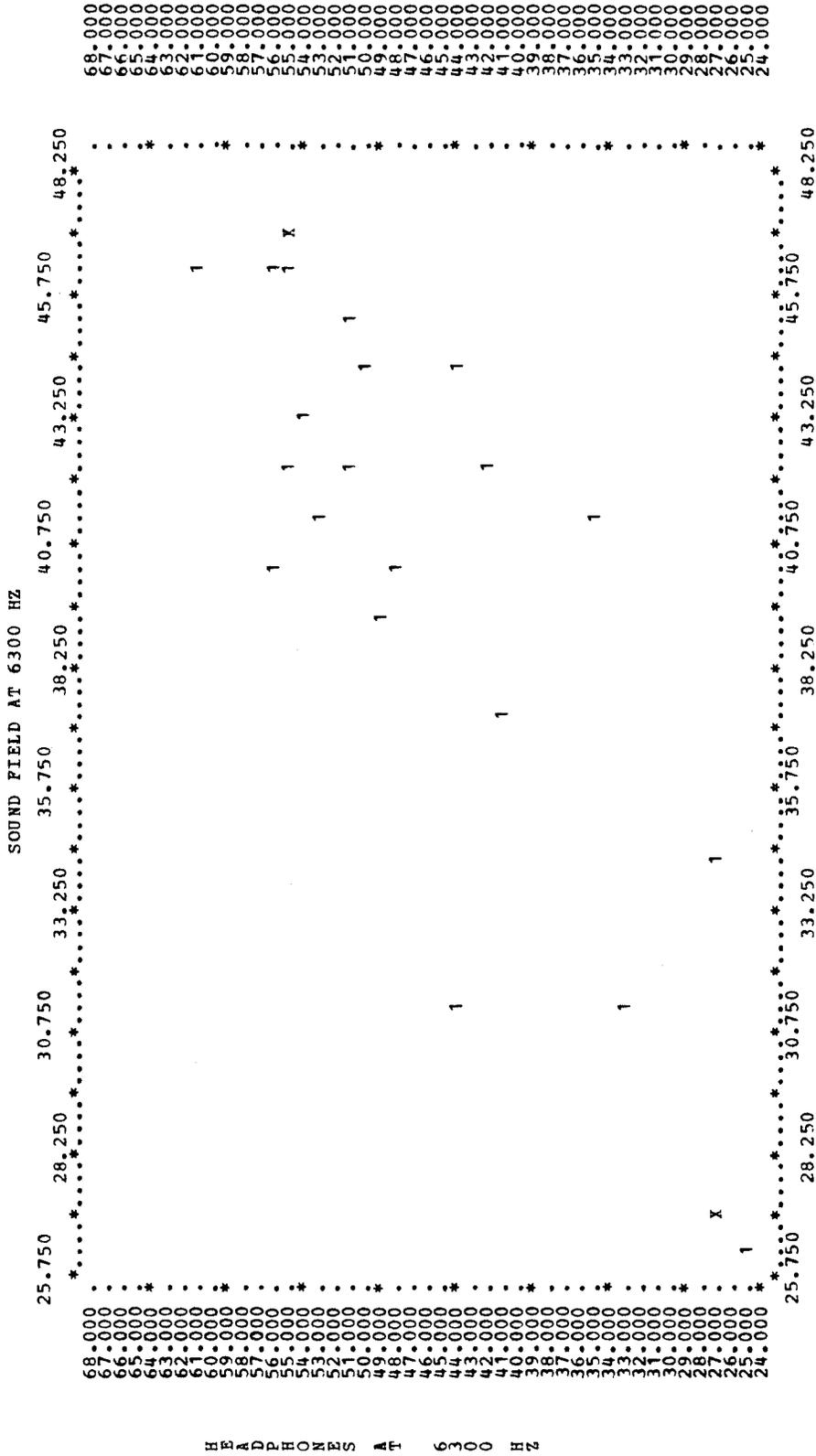


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
Y	7	20	36.500	7.164	51.316	51.000	23.000	28.000	0.178	-0.531
X	16	20	38.400	10.728	115.095	64.000	20.000	44.000	0.286	0.136

EQUATION OF REG. LINE Y = -12.25 + 1.3877 X
 STANDARD ERROR OF ESTIMATE 4.37
 CORRELATION COEFFICIENT 0.927

0*EVALUATION OF PROTECTOR 1A*



VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	8	20	40.000	5.582	31.158	46.000	25.000	20.000	-1.084	0.314
Y	17	20	46.500	10.039	100.789	61.000	25.000	36.000	-0.784	-0.343

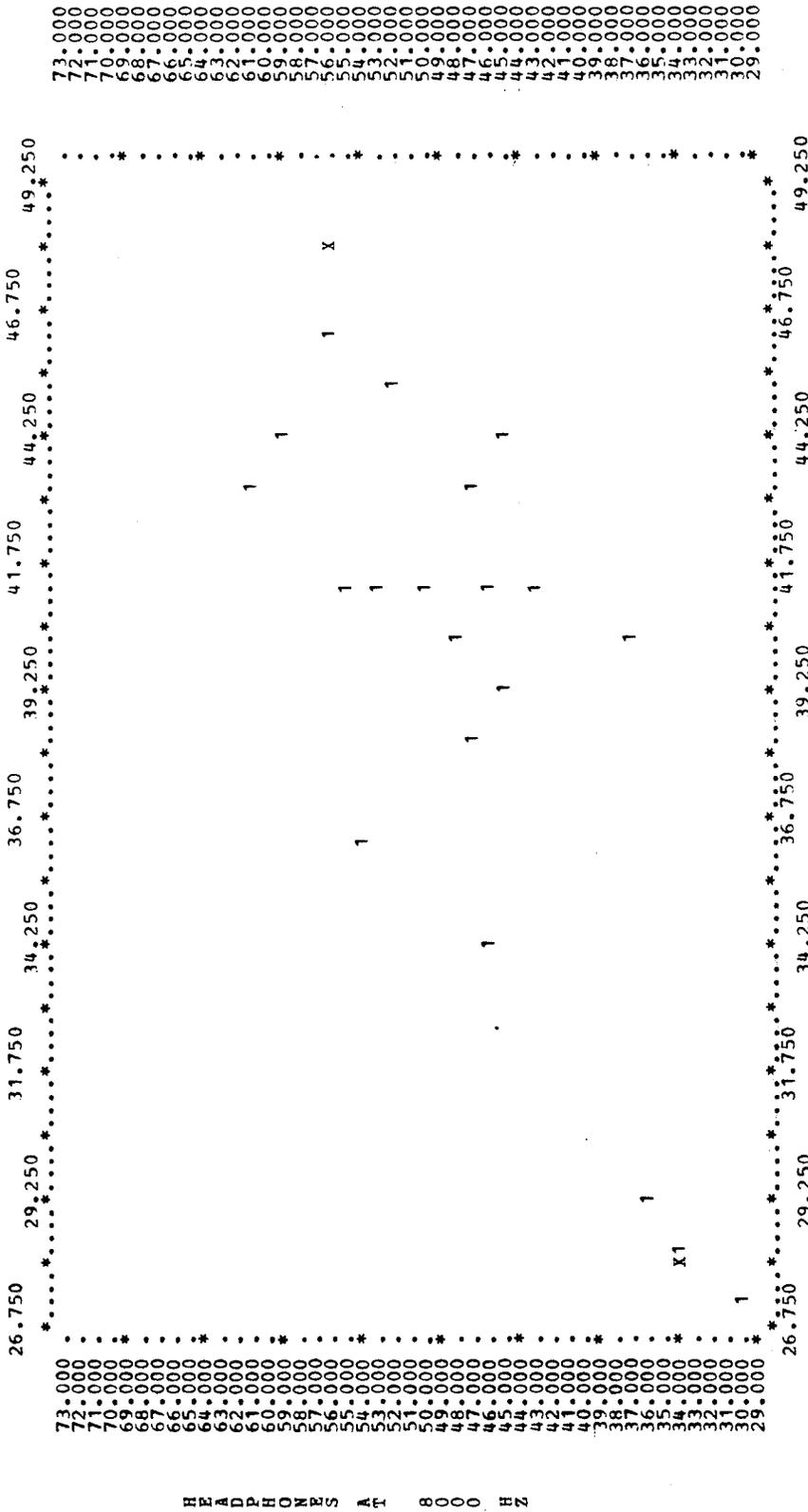
EQUATION OF REG. LINE Y = -9.72 + 1.4054 X

STANDARD ERROR OF ESTIMATE 6.78

CORRELATION COEFFICIENT 0.781

0 EVALUATION OF PROTECTOR 1A*

SOUND FIELD AT 8000 HZ

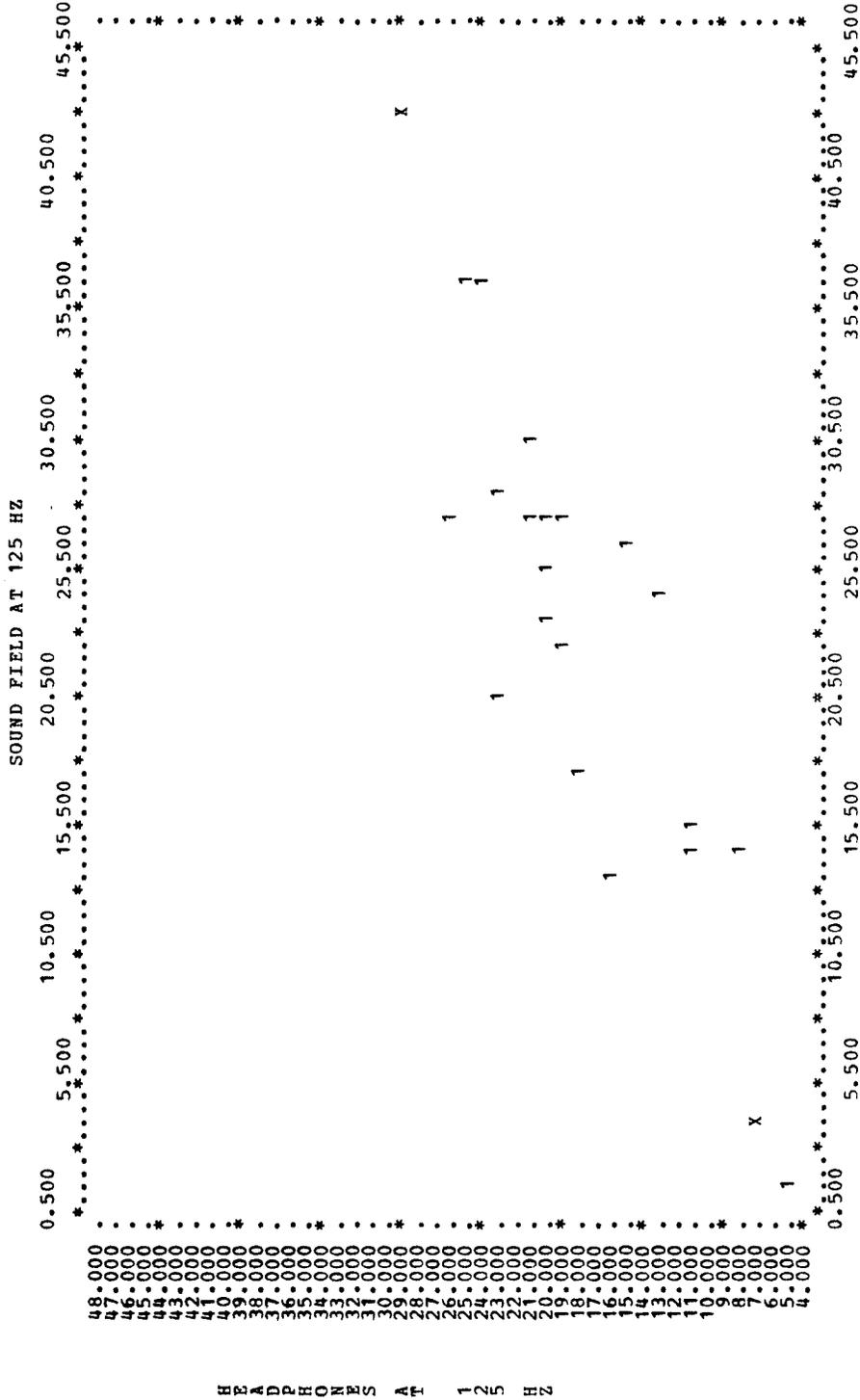


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	39.050	5.568	30.997	46.000	27.000	19.000	-1.039	0.014
Y	18	20	47.200	8.301	68.905	61.000	30.000	31.000	-0.367	-0.503

EQUATION OF REG. LINE Y = 3.78 + 1.1118 X
 STANDARD ERROR OF ESTIMATE 5.99
 CORRELATION COEFFICIENT 0.746

0*EVALUATION OF PROTECTOR 1B*

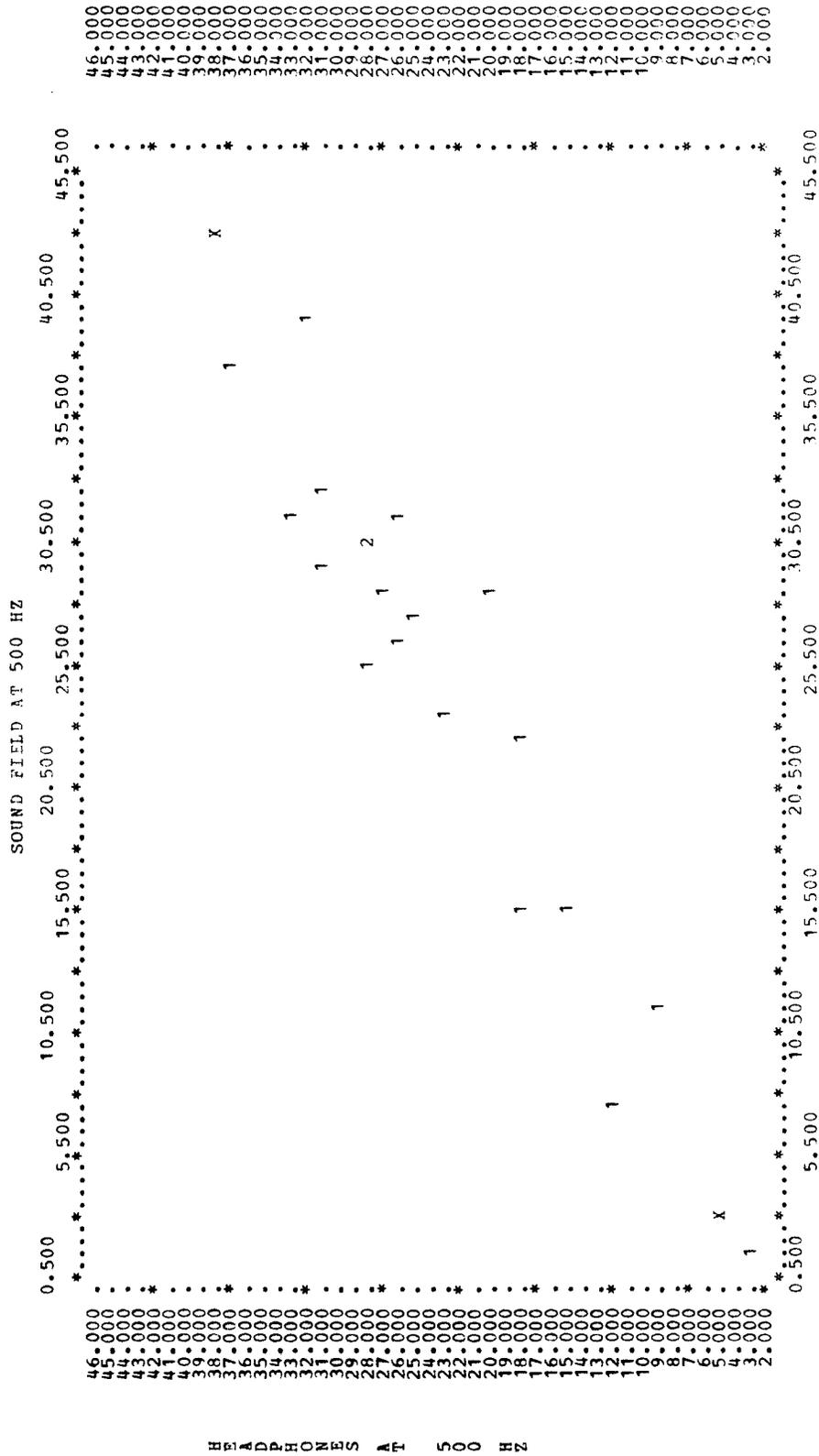


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	1	20	22.600	8.407	70.674	36.000	1.000	35.000	-0.645	0.455
Y	10	20	17.900	5.785	33.463	26.000	5.000	21.000	-0.684	-0.411

EQUATION OF REG. LINE Y = 5.12 + 0.5654 X
 STANDARD ERROR OF ESTIMATE 3.57
 CORRELATION COEFFICIENT 0.822

0*EVALUATION OF PROTECTOR 1B*

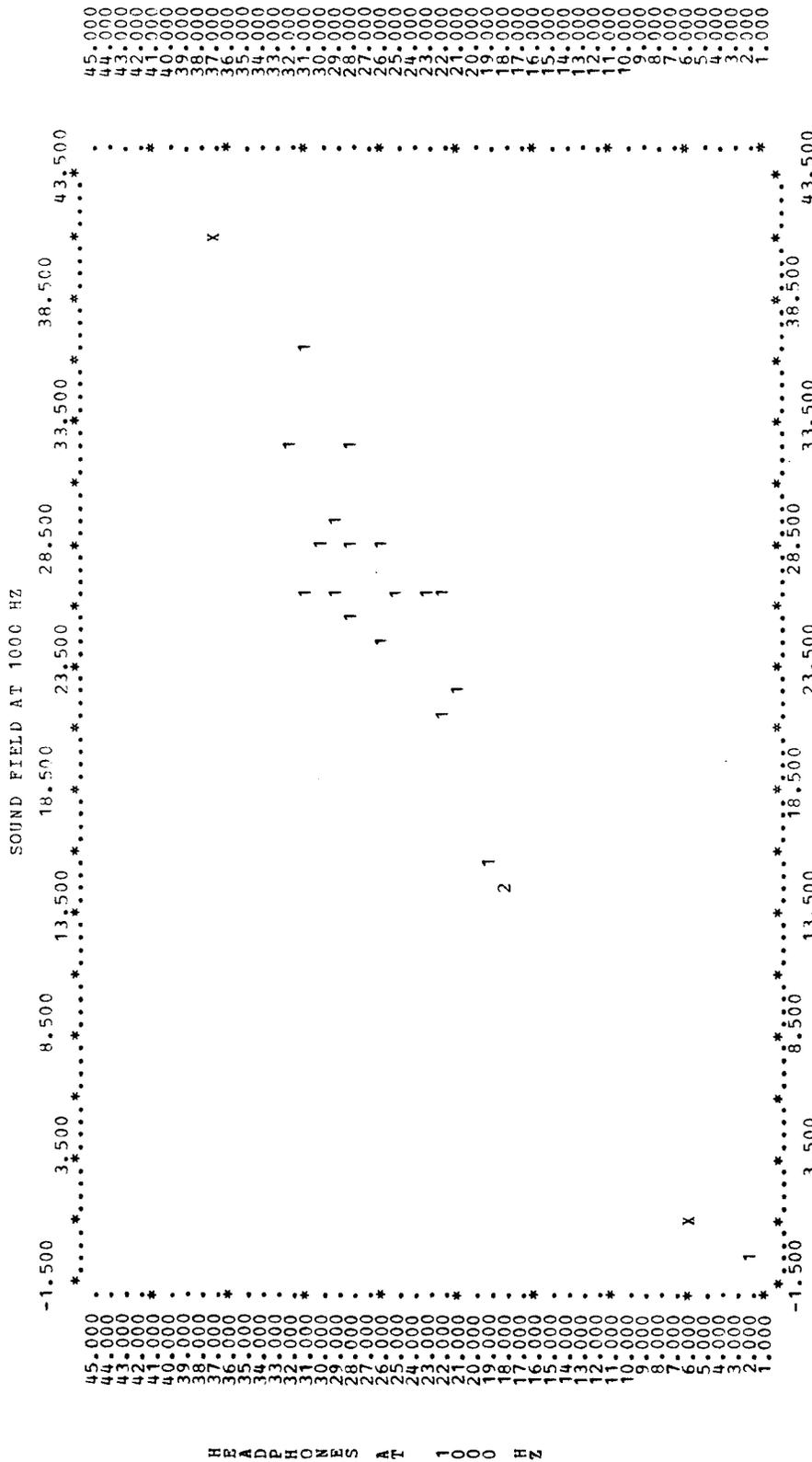


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	3	20	24.350	9.869	97.397	39.000	1.000	38.000	-0.854	0.019
Y	12	20	23.500	8.745	76.474	37.000	3.000	34.000	-0.731	-0.159

EQUATION OF REG. LINE Y = 3.16 + 0.8352 X
 STANDARD ERROR OF ESTIMATE 3.16
 CORRELATION COEFFICIENT 0.943

0*EVALUATION OF PROJECTOR 1B*



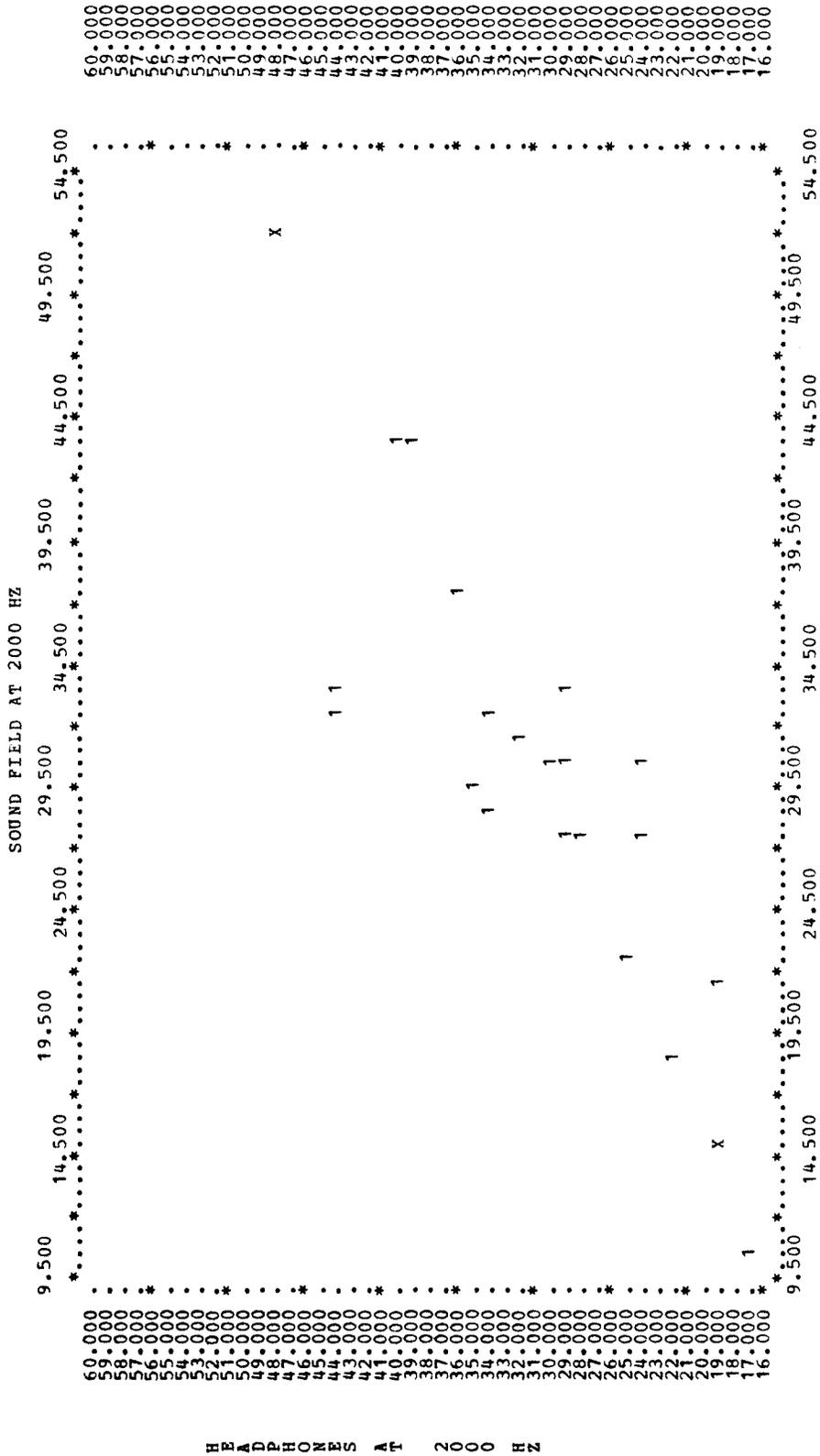
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	4	20	23.850	8.222	67.608	36.000	-1.000	37.000	-1.428	2.317
Y	13	20	24.400	6.886	47.411	32.000	-2.000	30.000	-1.730	3.549

EQUATION OF REG. LINE Y = 5.74 + 0.7825 X

STANDARD ERROR OF ESTIMATE 2.66

CORRELATION COEFFICIENT 0.934

0*EVALUATION OF PROTECTOR 1B*



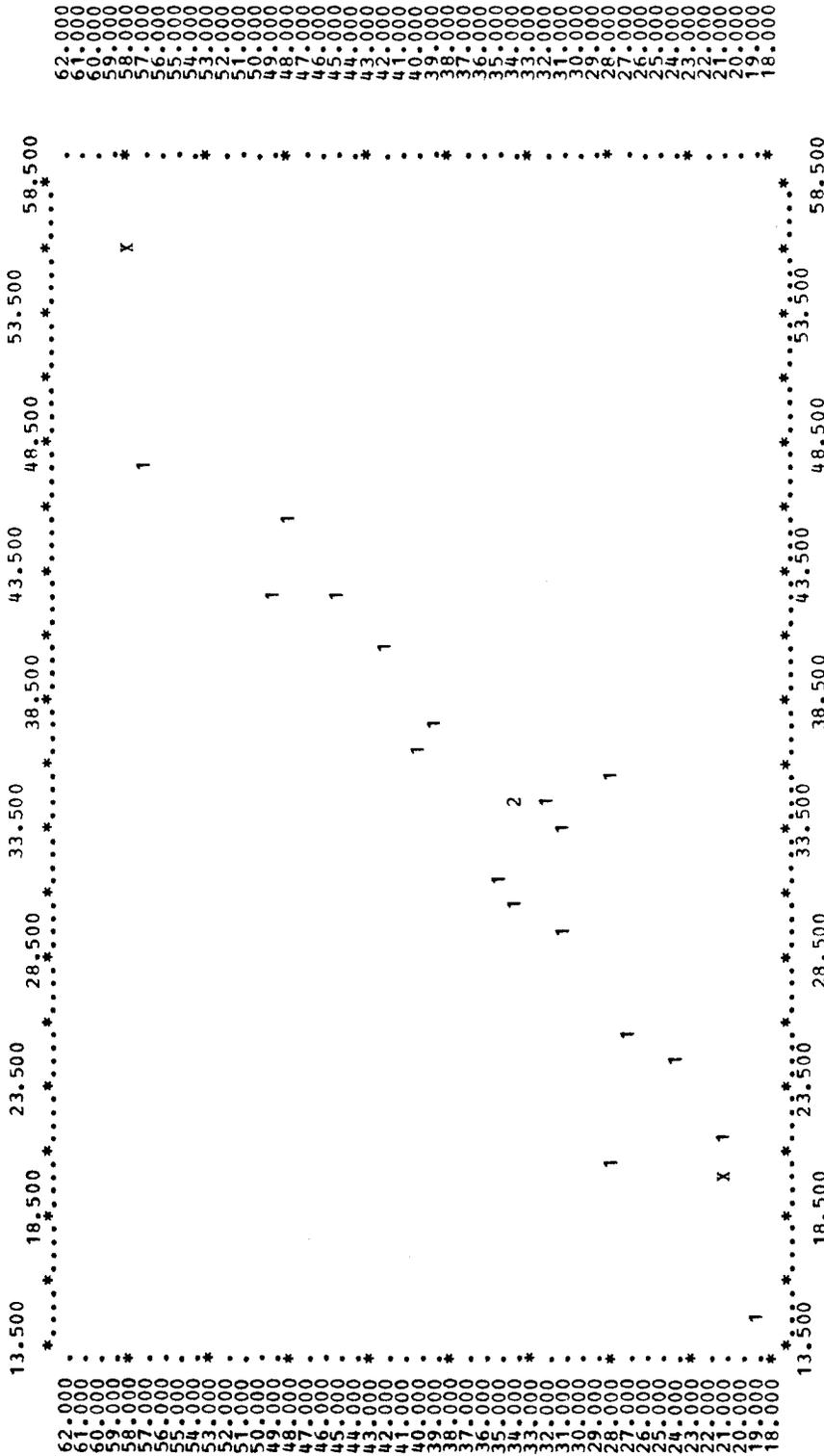
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKWENESS	KURTOSIS
X	5	20	29.150	7.680	58.976	43.000	10.000	33.000	-0.403	0.743
Y	14	20	30.700	7.672	58.853	44.000	17.000	27.000	0.087	-0.744

EQUATION OF REG. LINE Y = 7.63 + 0.7915 X
 STANDARD ERROR OF ESTIMATE 5.07
 CORRELATION COEFFICIENT 0.792

0*EVALUATION OF PROTECTOR 1B*

SOUND FIELD AT 3150 HZ



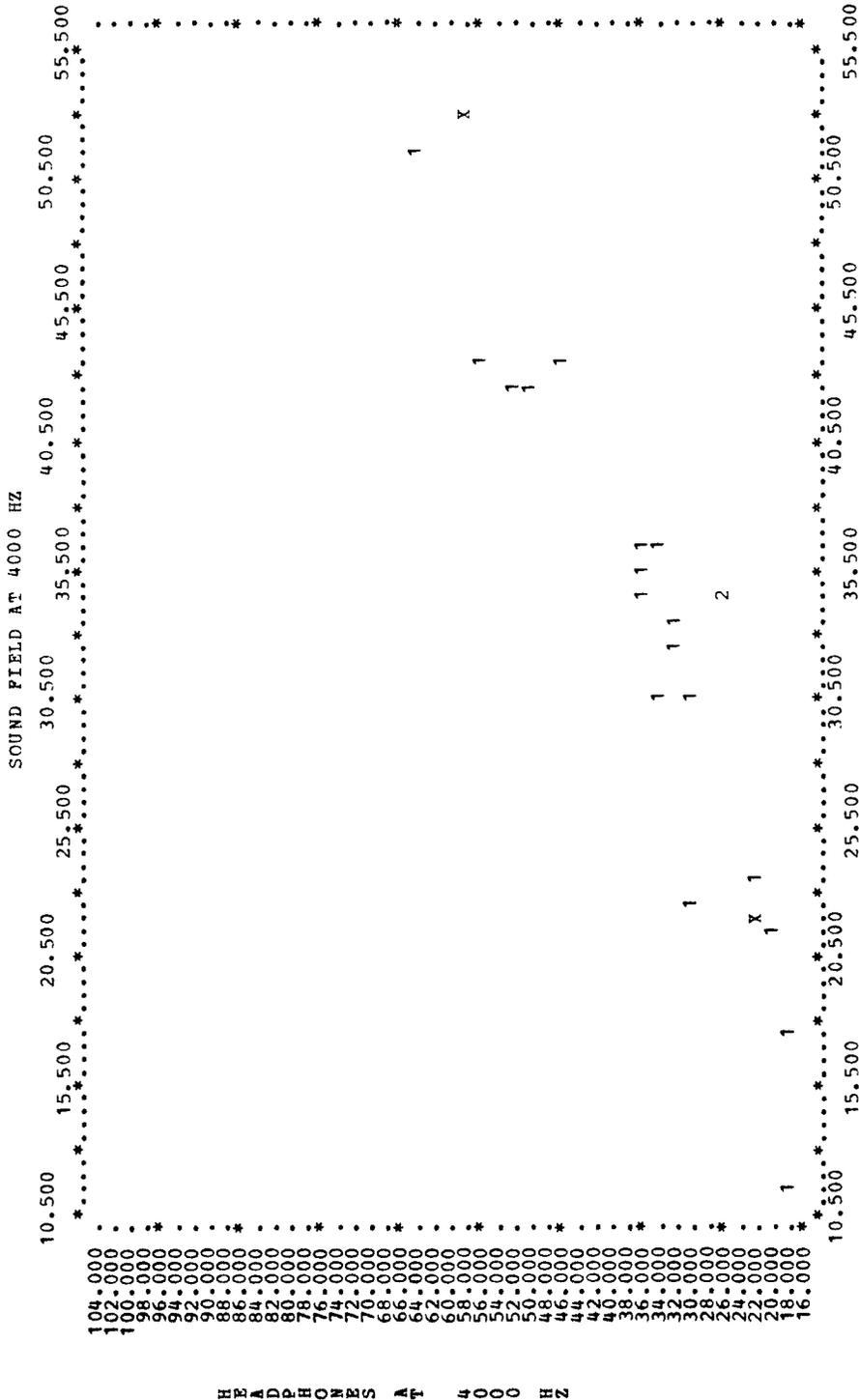
HEAD PROTECTORS AT 3150 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
Y	16	20	32.650	8.671	75.187	47.000	14.000	33.000	-0.352	-0.465
X	15	20	34.900	9.781	95.674	57.000	19.000	38.000	0.470	-0.302

EQUATION OF REG. LINE Y = 0.95 + 1.0397 X
 STANDARD ERROR OF ESTIMATE 4.11
 CORRELATION COEFFICIENT 0.922

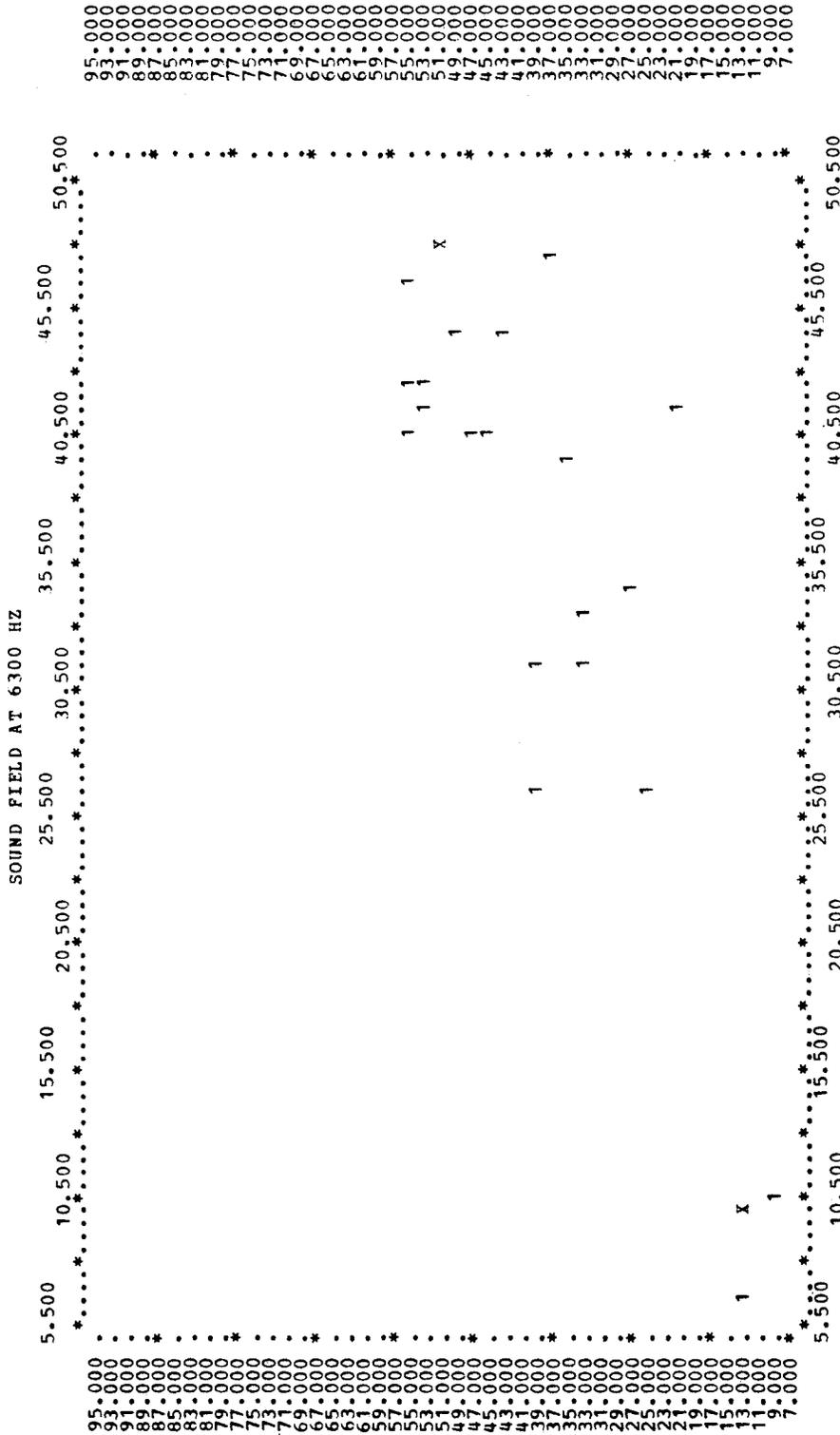
0*EVALUATION OF PROTECTOR 1B*



VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	32.450	9.811	96.261	51.000	11.000	40.000	-0.371	-0.214
Y	16	20	35.150	12.844	164.976	64.000	18.000	46.000	0.645	-0.355

EQUATION OF REG. LINE Y = -3.20 + 1.1819 X
 STANDARD ERROR OF ESTIMATE 5.98
 CORRELATION COEFFICIENT 0.903

0*EVALUATION OF PROTECTOR 1B*



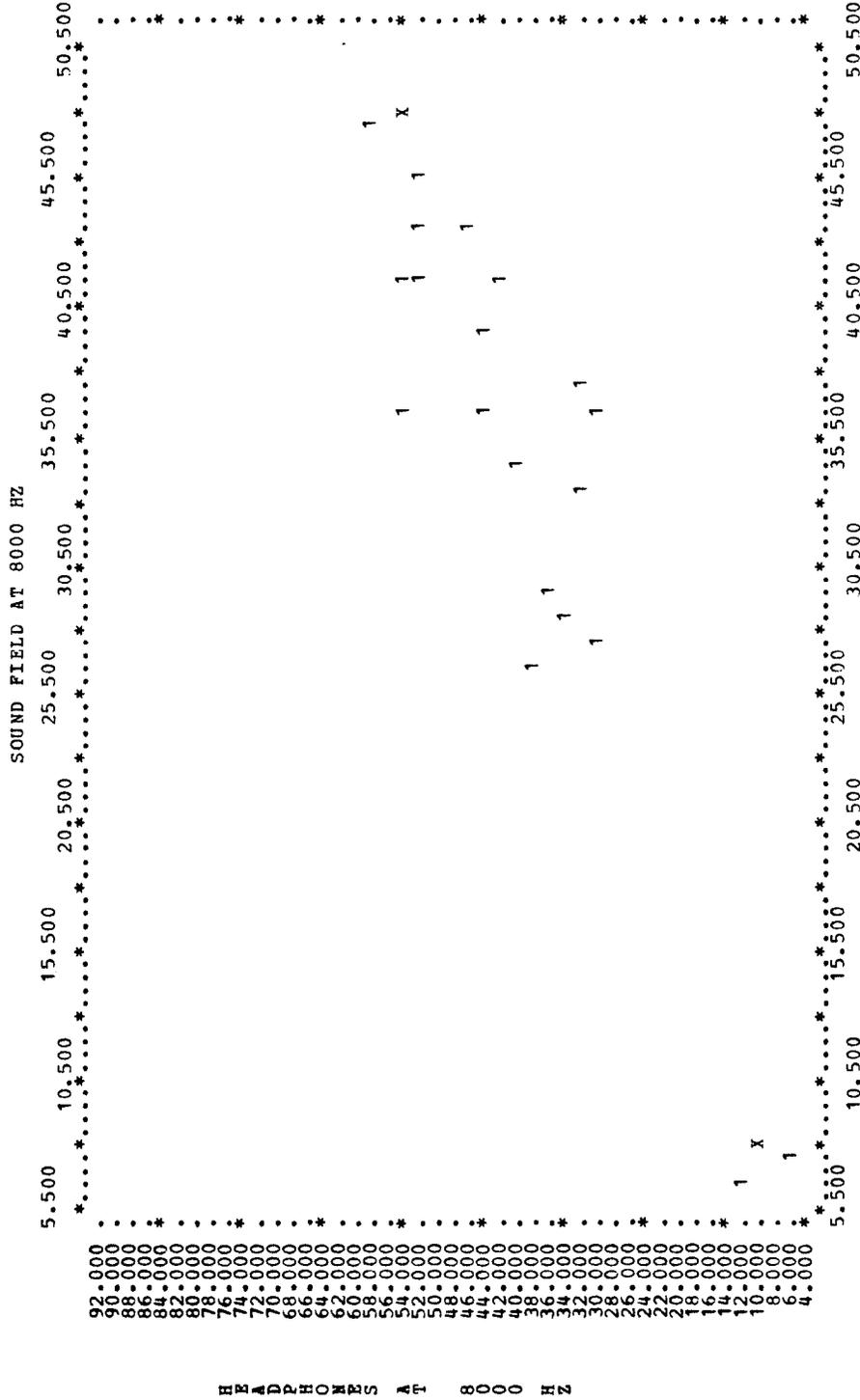
HEADPHONES AT 6300 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	35.150	11.127	123.818	47.000	6.000	41.000	-1.434	1.305
Y	17	20	38.800	14.144	200.063	56.000	9.000	47.000	-0.566	-0.603

EQUATION OF REG. LINE Y = 3.92 + 0.9924 X
 STANDARD ERROR OF ESTIMATE 9.57
 CORRELATION COEFFICIENT 0.781

0*EVALUATION OF PROTECTOR 1B*

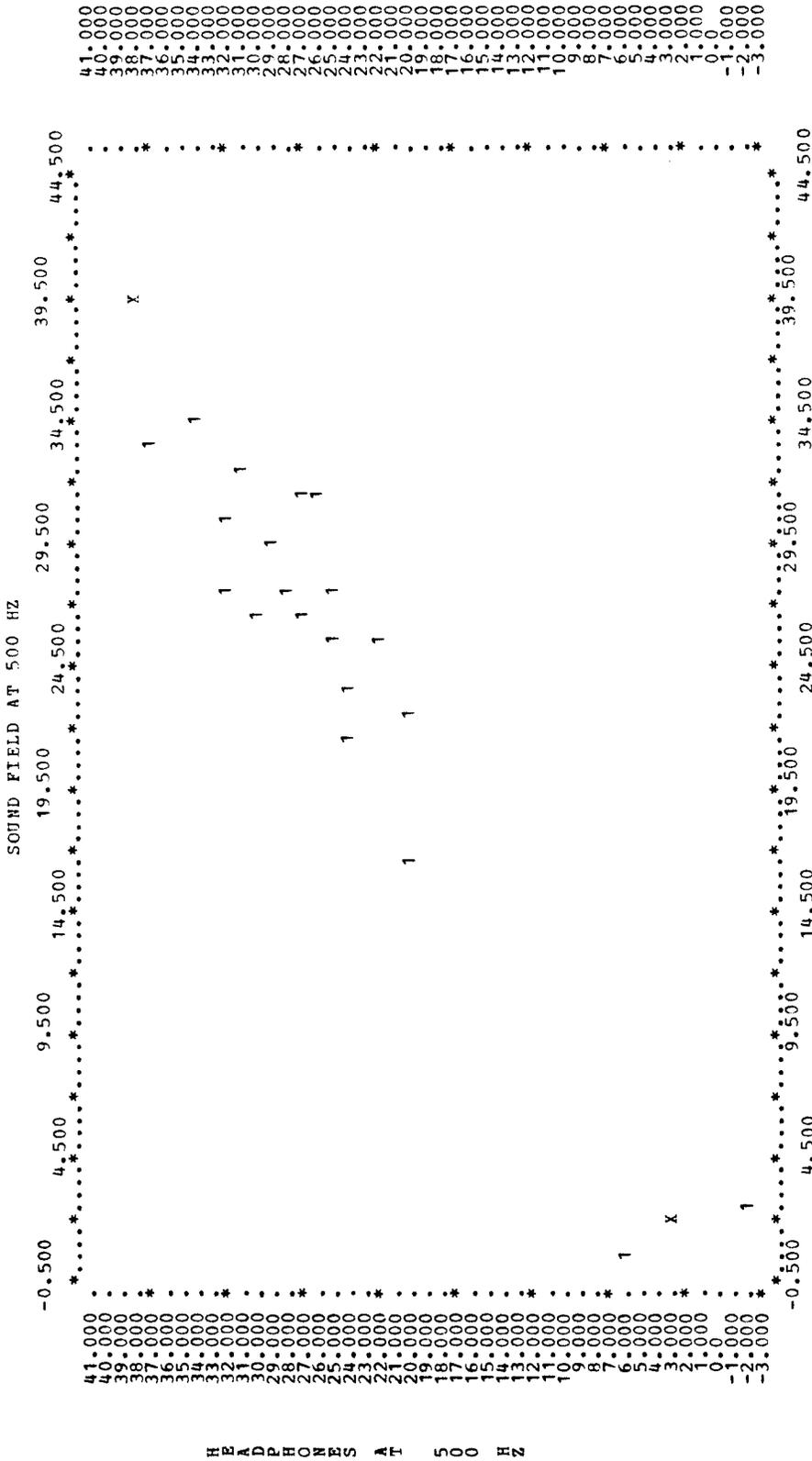


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	33.750	11.078	122.724	47.000	6.000	41.000	-1.386	1.352
Y	18	20	39.950	13.786	190.050	59.000	6.000	53.000	-0.911	0.463

EQUATION OF REG. LINE Y = 1.86 + 1.1287 X
 STANDARD ERROR OF ESTIMATE 6.29
 CORRELATION COEFFICIENT 0.907

0*EVALUATION OF PROTECTOR 2A*



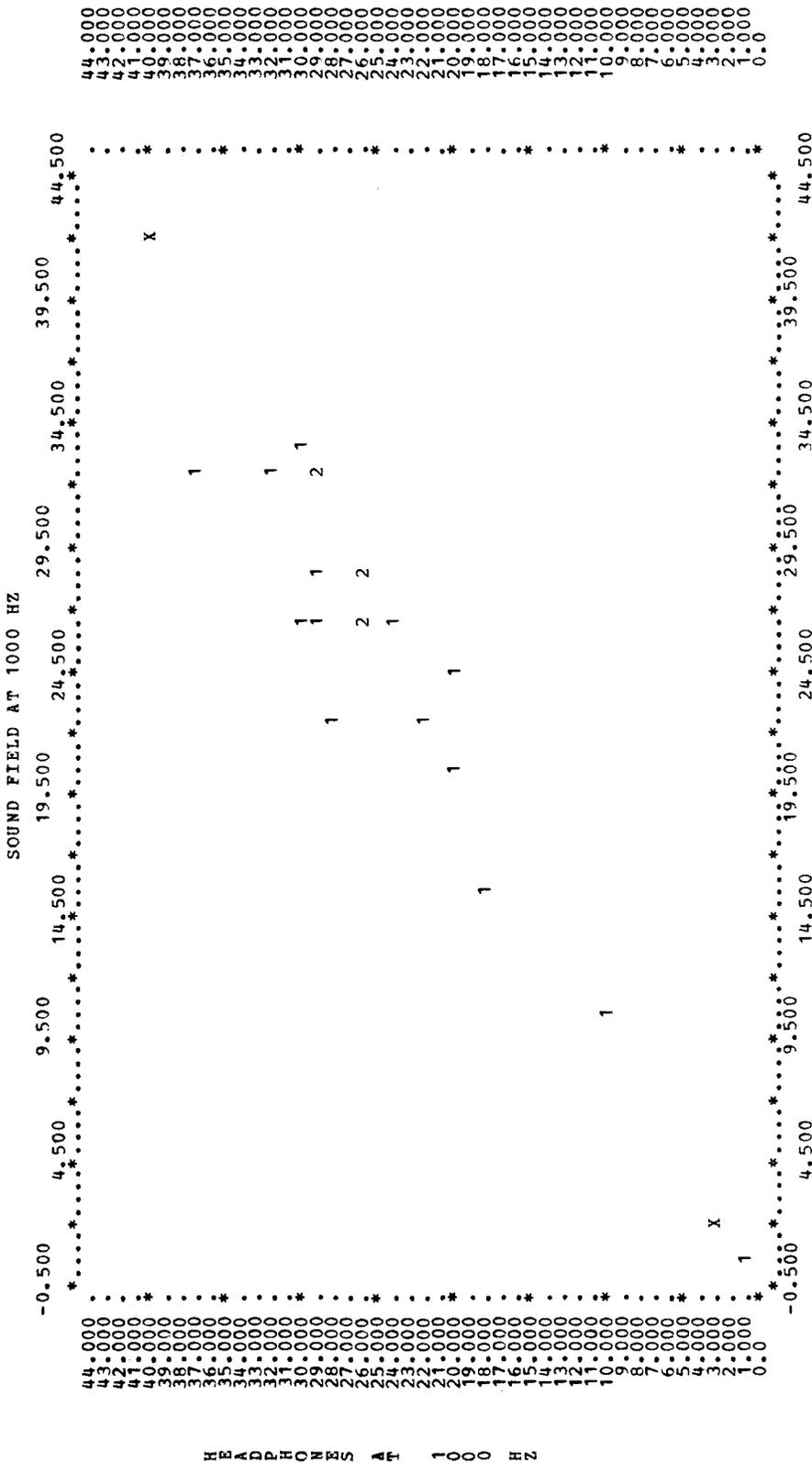
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	3	20	24.350	9.109	82.976	34.000	0.0	34.000	-1.665	2.064
Y	12	20	24.850	9.086	82.555	37.000	-2.000	39.000	-1.621	2.558

EQUATION OF REG. LINE Y = 2.07 + 0.9356 X

STANDARD ERROR OF ESTIMATE 3.41

CORRELATION COEFFICIENT 0.938

O-EVALUATION OF PROTECTOR 2A*

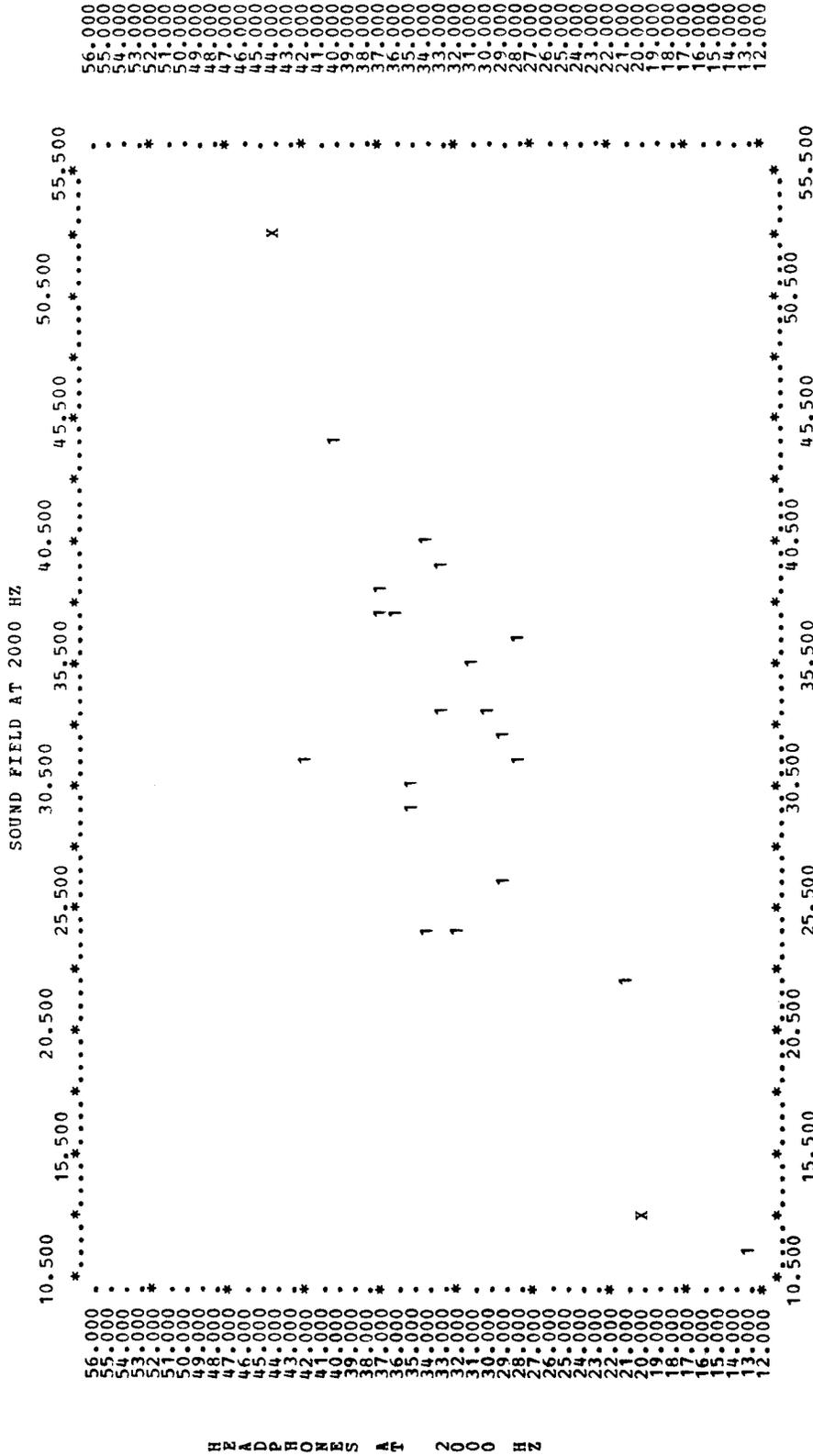


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	4	20	24.400	8.204	67.305	33.000	0.0	33.000	-1.555	2.198
Y	13	20	24.600	8.035	64.568	37.000	1.000	36.000	-1.430	2.162

EQUATION OF REG. LINE Y = 2.14 + 0.9206 X
 STANDARD ERROR OF ESTIMATE 2.97
 CORRELATION COEFFICIENT 0.940

0*EVALUATION OF PROTECTOR 2A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKWENESS	KURTOSIS
X	5	20	31.600	7.563	57.200	44.000	11.000	33.000	-0.885	0.925
Y	14	20	31.850	6.467	41.818	42.000	13.000	29.000	-1.223	1.995

EQUATION OF REG. LINE Y = 12.58 + 0.6099 X
 STANDARD ERROR OF ESTIMATE 4.91
 CORRELATION COEFFICIENT 0.713

0*EVALUATION OF PROTECTOR 2A*

SOUND FIELD AT 3150 HZ

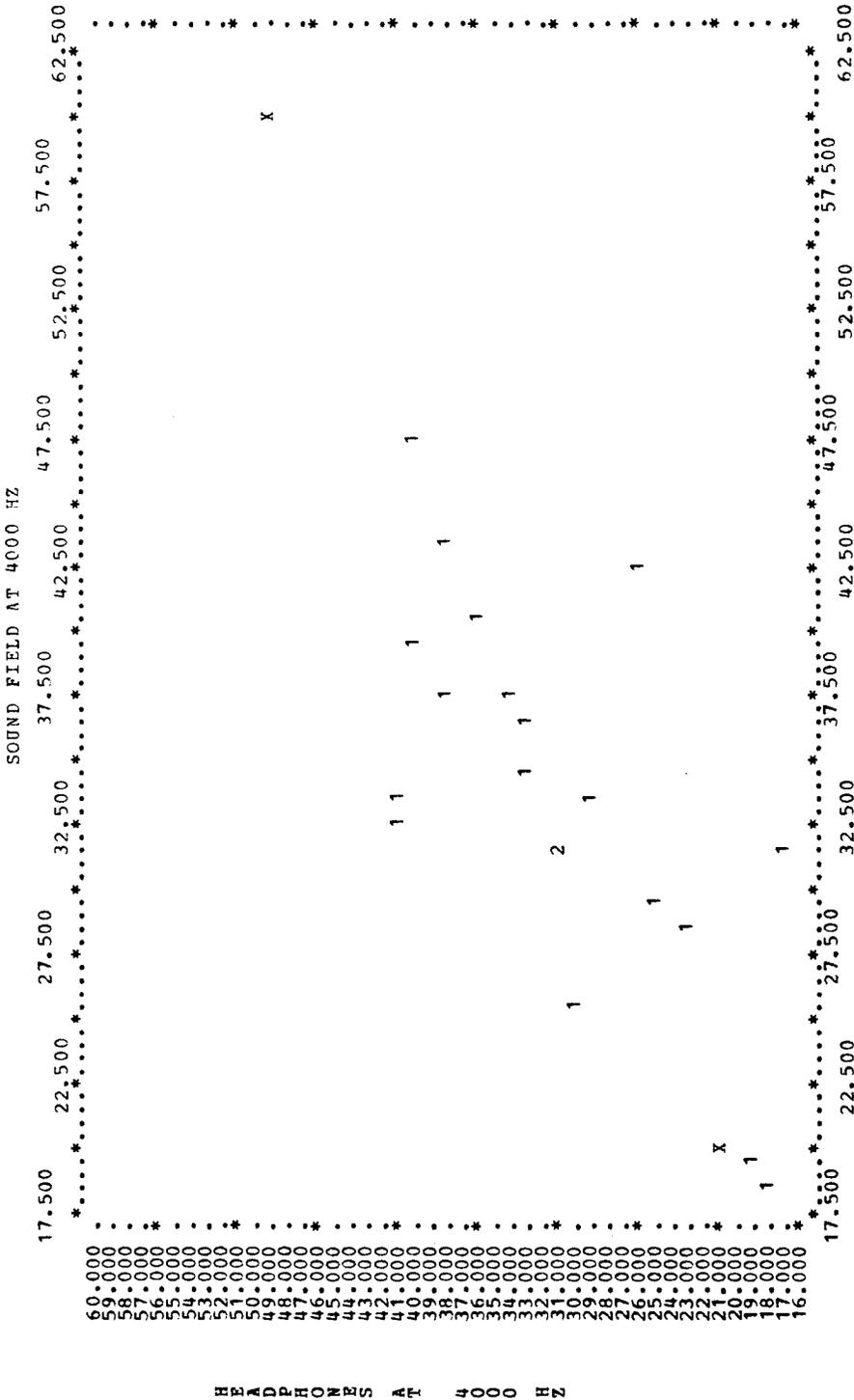
HEARD PHONES	18.500	23.500	28.500	33.500	38.500	43.500	48.500	53.500	58.500	63.500
60.000	*	*	*	*	*	*	*	*	*	*
59.000	*	*	*	*	*	*	*	*	*	*
58.000	*	*	*	*	*	*	*	*	*	*
57.000	*	*	*	*	*	*	*	*	*	*
56.000	*	*	*	*	*	*	*	*	*	*
55.000	*	*	*	*	*	*	*	*	*	*
54.000	*	*	*	*	*	*	*	*	*	*
53.000	*	*	*	*	*	*	*	*	*	*
52.000	*	*	*	*	*	*	*	*	*	*
51.000	*	*	*	*	*	*	*	*	*	*
50.000	*	*	*	*	*	*	*	*	*	*
49.000	*	*	*	*	*	*	*	*	*	*
48.000	*	*	*	*	*	*	*	*	*	*
47.000	*	*	*	*	*	*	*	*	*	*
46.000	*	*	*	*	*	*	*	*	*	*
45.000	*	*	*	*	*	*	*	*	*	*
44.000	*	*	*	*	*	*	*	*	*	*
43.000	*	*	*	*	*	*	*	*	*	*
42.000	*	*	*	*	*	*	*	*	*	*
41.000	*	*	*	*	*	*	*	*	*	*
40.000	*	*	*	*	*	*	*	*	*	*
39.000	*	*	*	*	*	*	*	*	*	*
38.000	*	*	*	*	*	*	*	*	*	*
37.000	*	*	*	*	*	*	*	*	*	*
36.000	*	*	*	*	*	*	*	*	*	*
35.000	*	*	*	*	*	*	*	*	*	*
34.000	*	*	*	*	*	*	*	*	*	*
33.000	*	*	*	*	*	*	*	*	*	*
32.000	*	*	*	*	*	*	*	*	*	*
31.000	*	*	*	*	*	*	*	*	*	*
30.000	*	*	*	*	*	*	*	*	*	*
29.000	*	*	*	*	*	*	*	*	*	*
28.000	*	*	*	*	*	*	*	*	*	*
27.000	*	*	*	*	*	*	*	*	*	*
26.000	*	*	*	*	*	*	*	*	*	*
25.000	*	*	*	*	*	*	*	*	*	*
24.000	*	*	*	*	*	*	*	*	*	*
23.000	*	*	*	*	*	*	*	*	*	*
22.000	*	*	*	*	*	*	*	*	*	*
21.000	*	*	*	*	*	*	*	*	*	*
20.000	*	*	*	*	*	*	*	*	*	*
19.000	*	*	*	*	*	*	*	*	*	*
18.000	*	*	*	*	*	*	*	*	*	*
17.000	*	*	*	*	*	*	*	*	*	*
16.000	*	*	*	*	*	*	*	*	*	*

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENESS	KURTOSIS
X	6	20	34.850	6.777	45.924	48.000	19.000	29.000	-0.526	0.760
Y	15	20	34.200	7.172	51.432	43.000	17.000	26.000	-0.626	-0.311

EQUATION OF REG. LINE Y = 7.86 + 0.7559 X
 STANDARD ERROR OF ESTIMATE 5.44
 CORRELATION COEFFICIENT 0.714

0*EVALUATION OF PROTECTOR 2A*

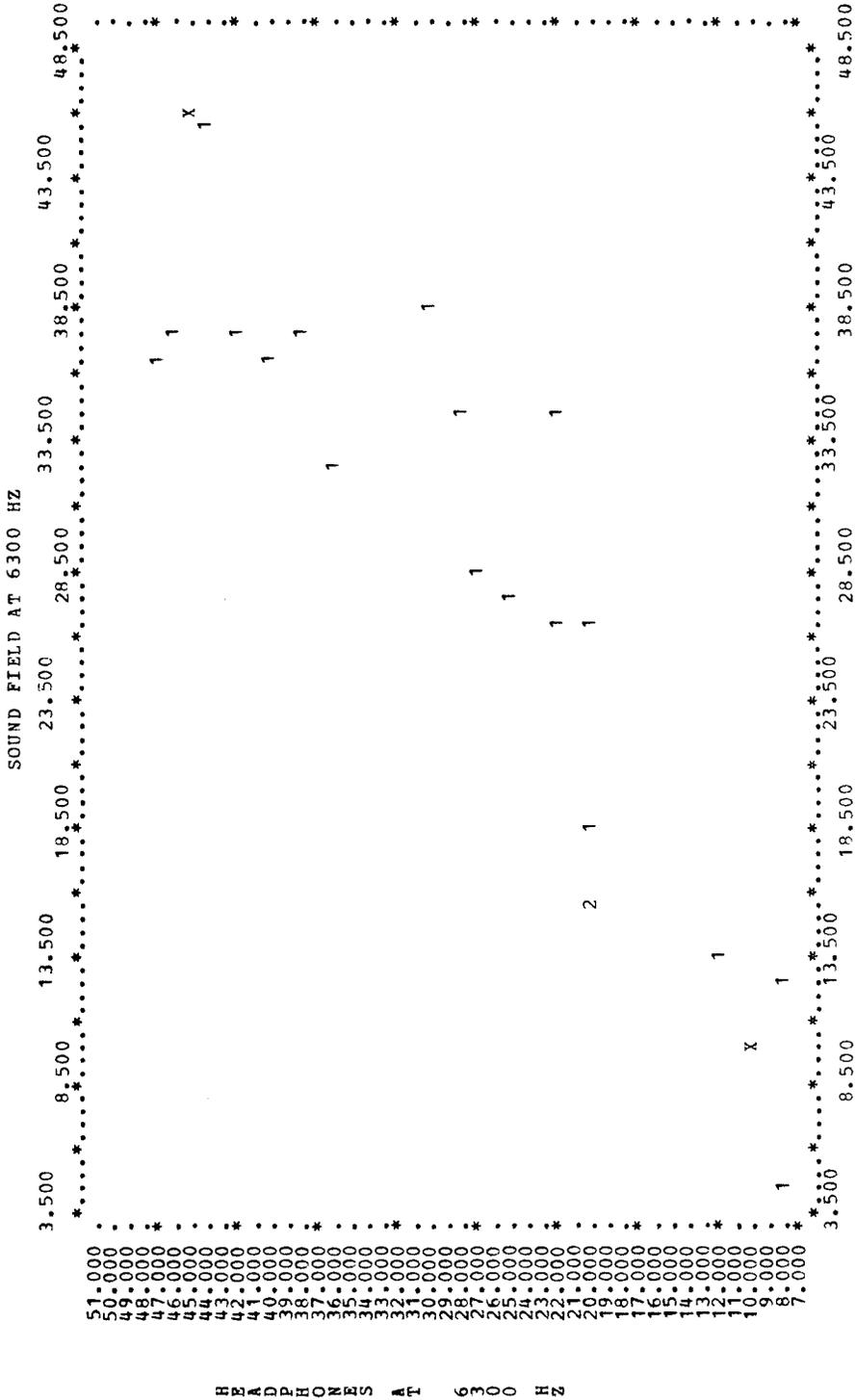


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	7	20	33.250	7.405	54.829	47.000	18.000	29.000	-0.324	-0.136
Y	16	20	31.150	7.748	60.029	41.000	17.000	24.000	-0.433	-0.932

EQUATION OF REG. LINE Y = 7.52 + 0.7106 X
 STANDARD ERROR OF ESTIMATE 6.16
 CORRELATION COEFFICIENT 0.679

0*EVALUATION OF PROTECTOR 2A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

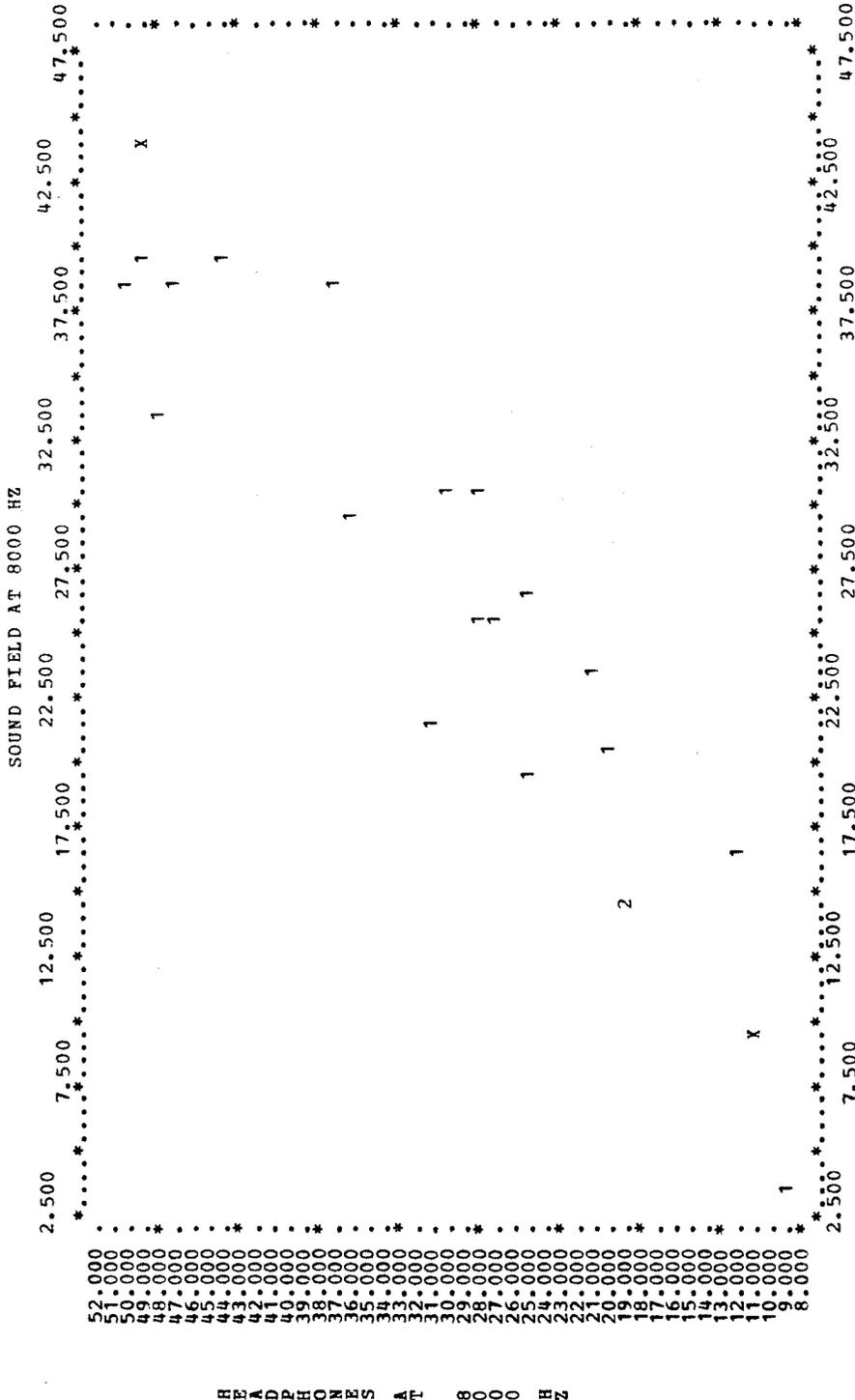
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	27.500	11.114	123.526	45.000	4.000	41.000	-0.533	-0.790
Y	17	20	27.750	12.230	149.566	47.000	8.000	39.000	0.068	-1.068

EQUATION OF REG. LINE Y = 1.15 + 0.9674 X

STANDARD ERROR OF ESTIMATE 6.31

CORRELATION COEFFICIENT 0.879

0*EVALUATION OF PROTECTOR 2A*



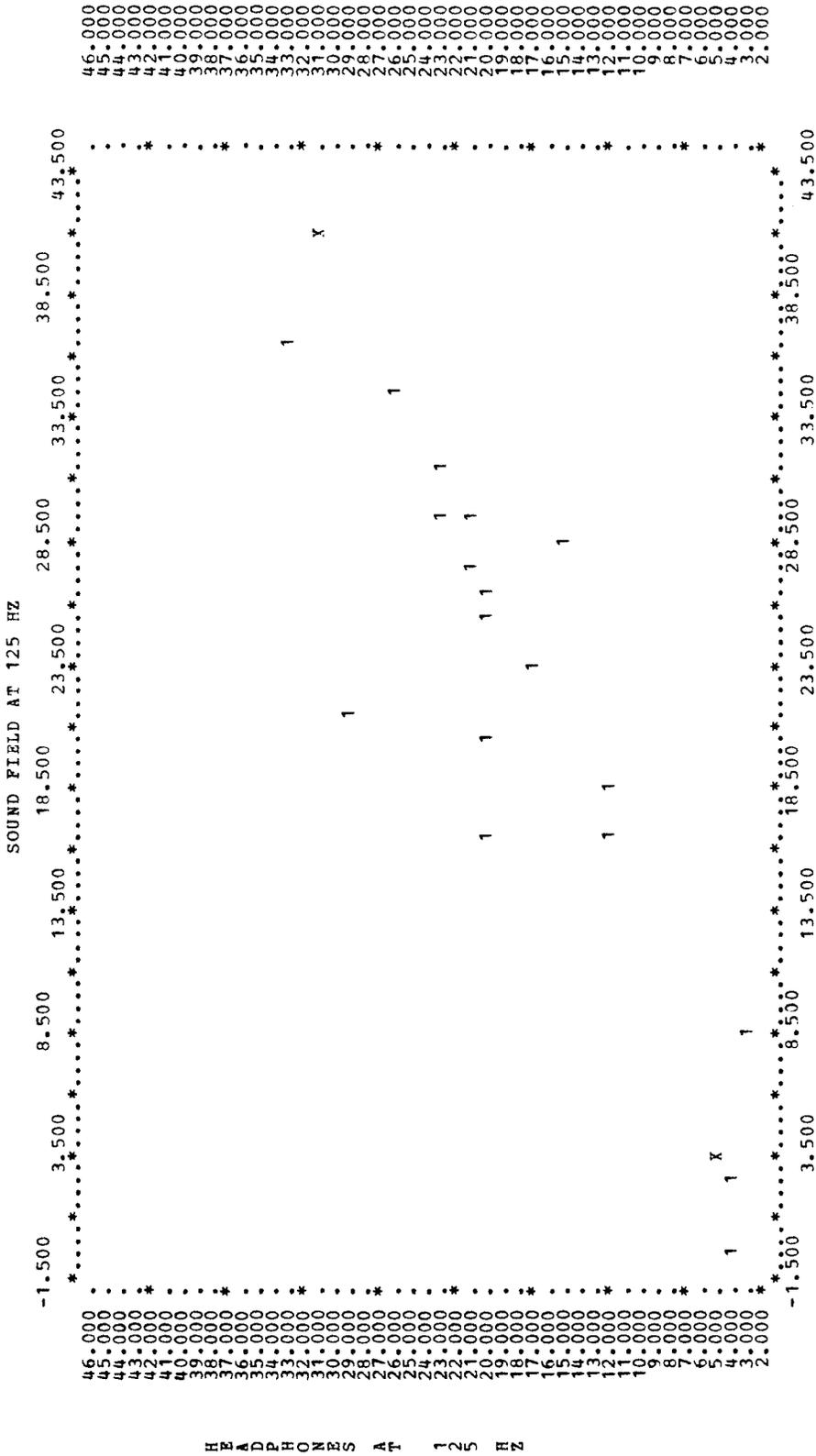
HEADPHONES AT 8000 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	26.000	9.995	99.895	39.000	3.000	36.000	-0.393	-0.457
Y	18	20	30.250	12.375	153.145	50.000	9.000	41.000	0.198	-0.970

EQUATION OF REG. LINE Y = 0.91 + 1.1286 X
 STANDARD ERROR OF ESTIMATE 5.51
 CORRELATION COEFFICIENT 0.911

0*EVALUATION OF PROTECTOR 2B*

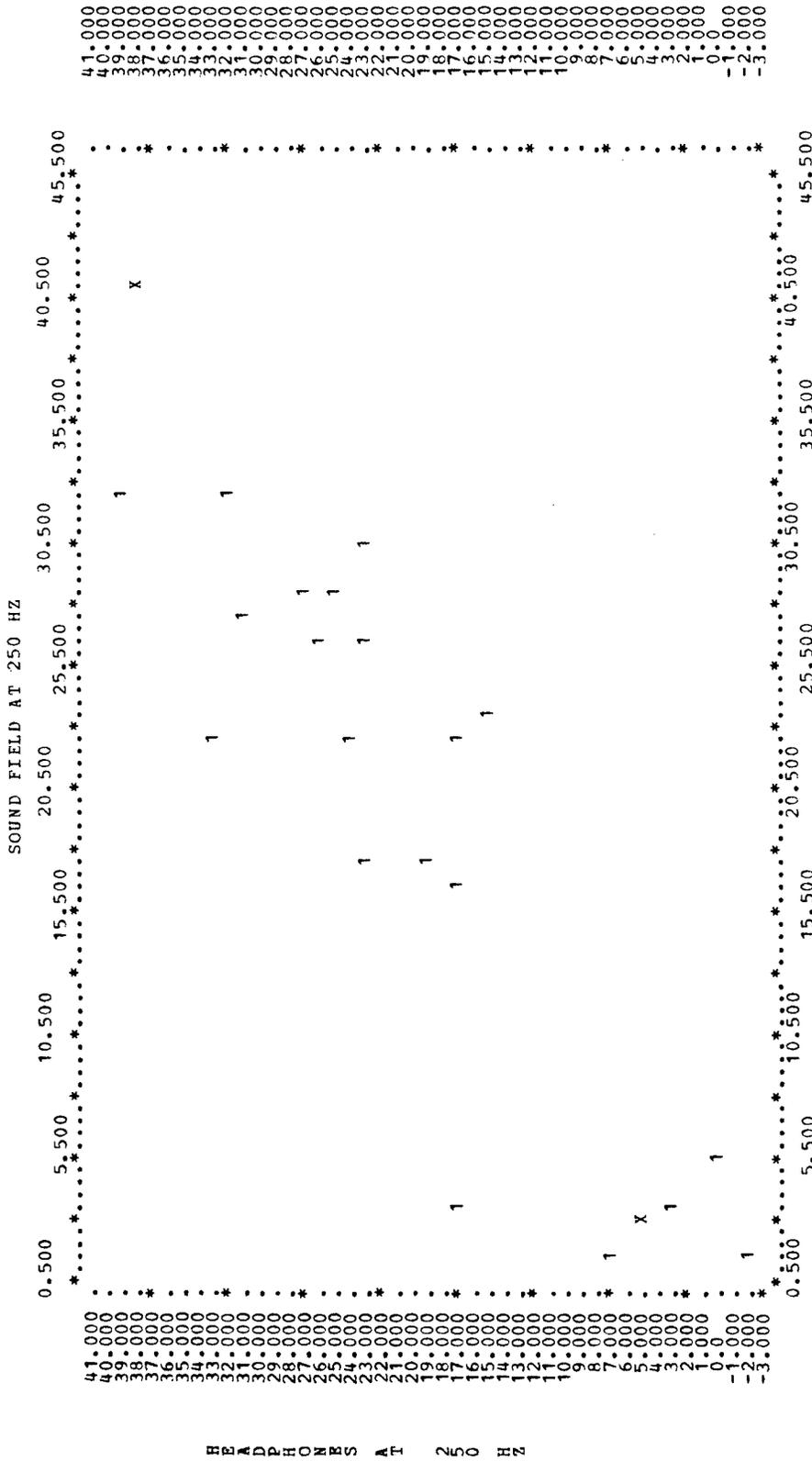


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	1	20	19.700	11.333	128.432	36.000	-1.000	37.000	-0.510	-0.951
Y	10	20	16.650	8.869	78.660	33.000	3.000	30.000	-0.160	-0.936

EQUATION OF REG. LINE Y = 2.97 + 0.6942 X
 STANDARD ERROR OF ESTIMATE 4.44
 CORRELATION COEFFICIENT 0.887

O*EVALUATION OF PROTECTOR 2B*

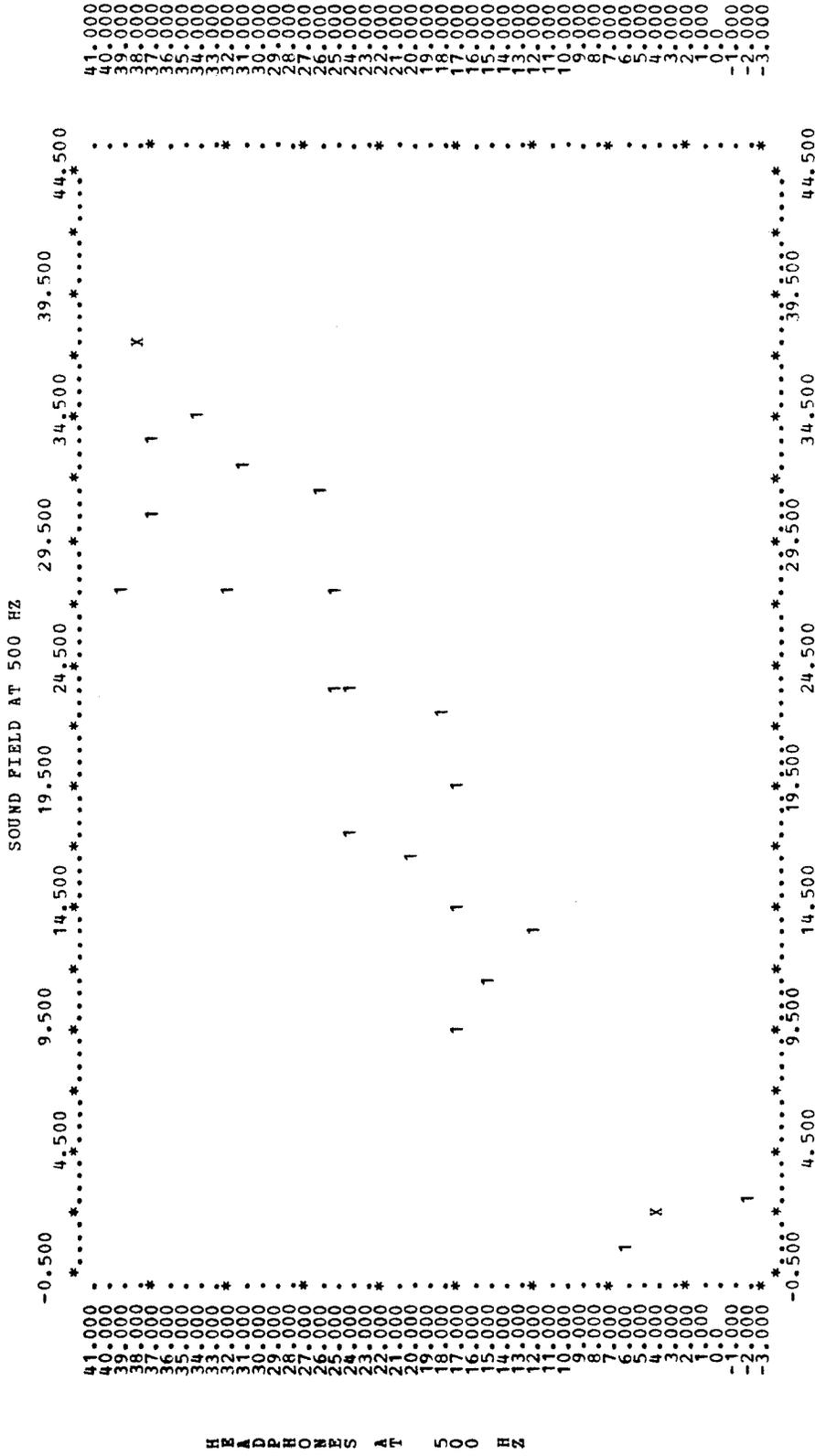


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	1	20	19.050	10.759	115.734	32.000	1.000	31.000	-0.627	-1.028
Y	2	20	19.950	11.105	123.313	32.000	-2.000	41.000	-0.500	-0.436

EQUATION OF REG. LINE Y = 3.04 + 0.8877 X
 STANDARD ERROR OF ESTIMATE 6.14
 CORRELATION COEFFICIENT 0.860

0*EVALUATION OF PROTECTOR 2B*

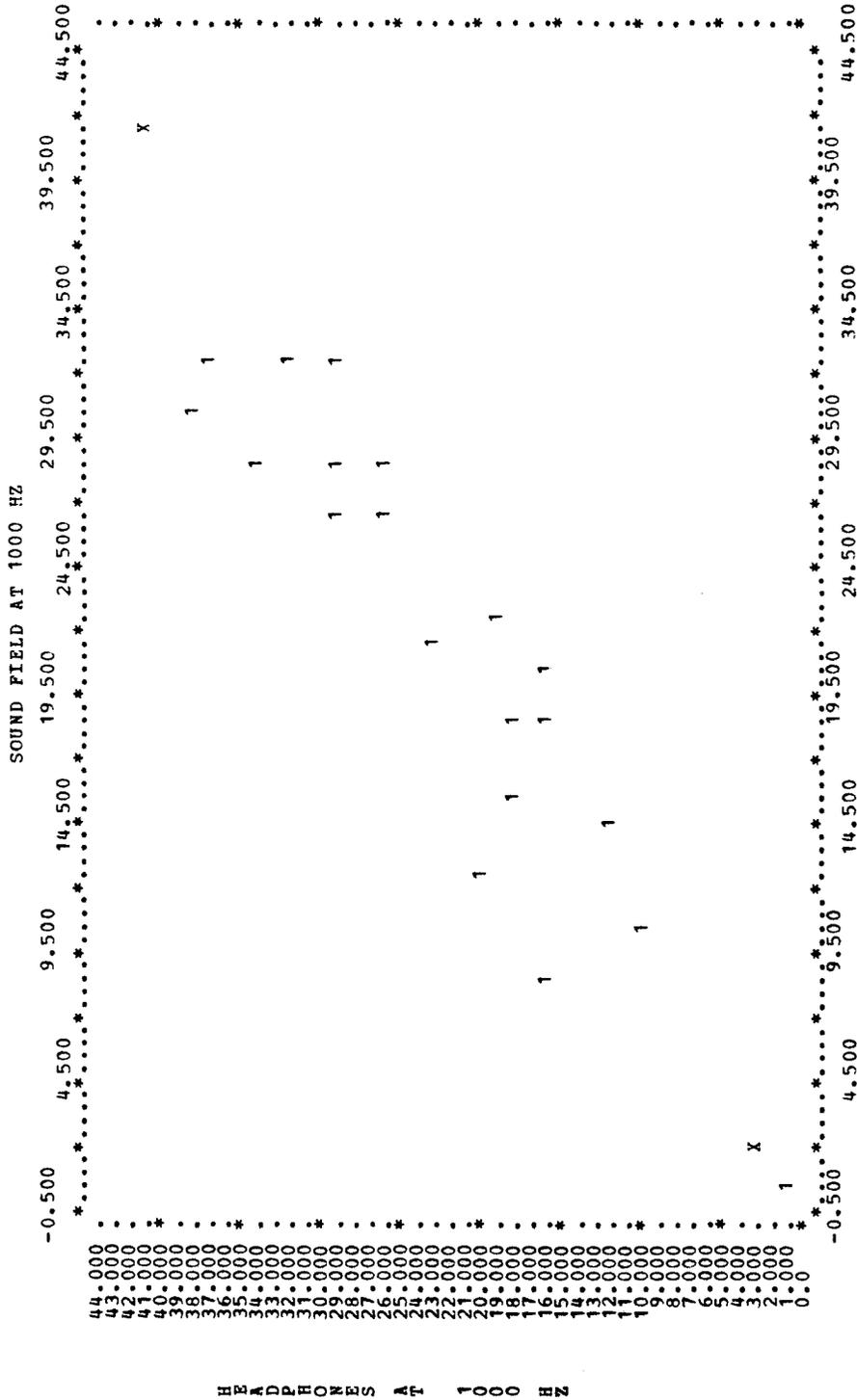


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	3	20	20.500	10.081	101.631	34.000	0.0	34.000	-0.493	-0.716
Y	12	20	22.700	10.692	114.326	39.000	-2.000	41.000	-0.399	-0.231

EQUATION OF REG. LINE Y = 3.04 + 0.9591 X
 STANDARD ERROR OF ESTIMATE 4.94
 CORRELATION COEFFICIENT 0.904

0*EVALUATION OF PROTECTOR 2B*

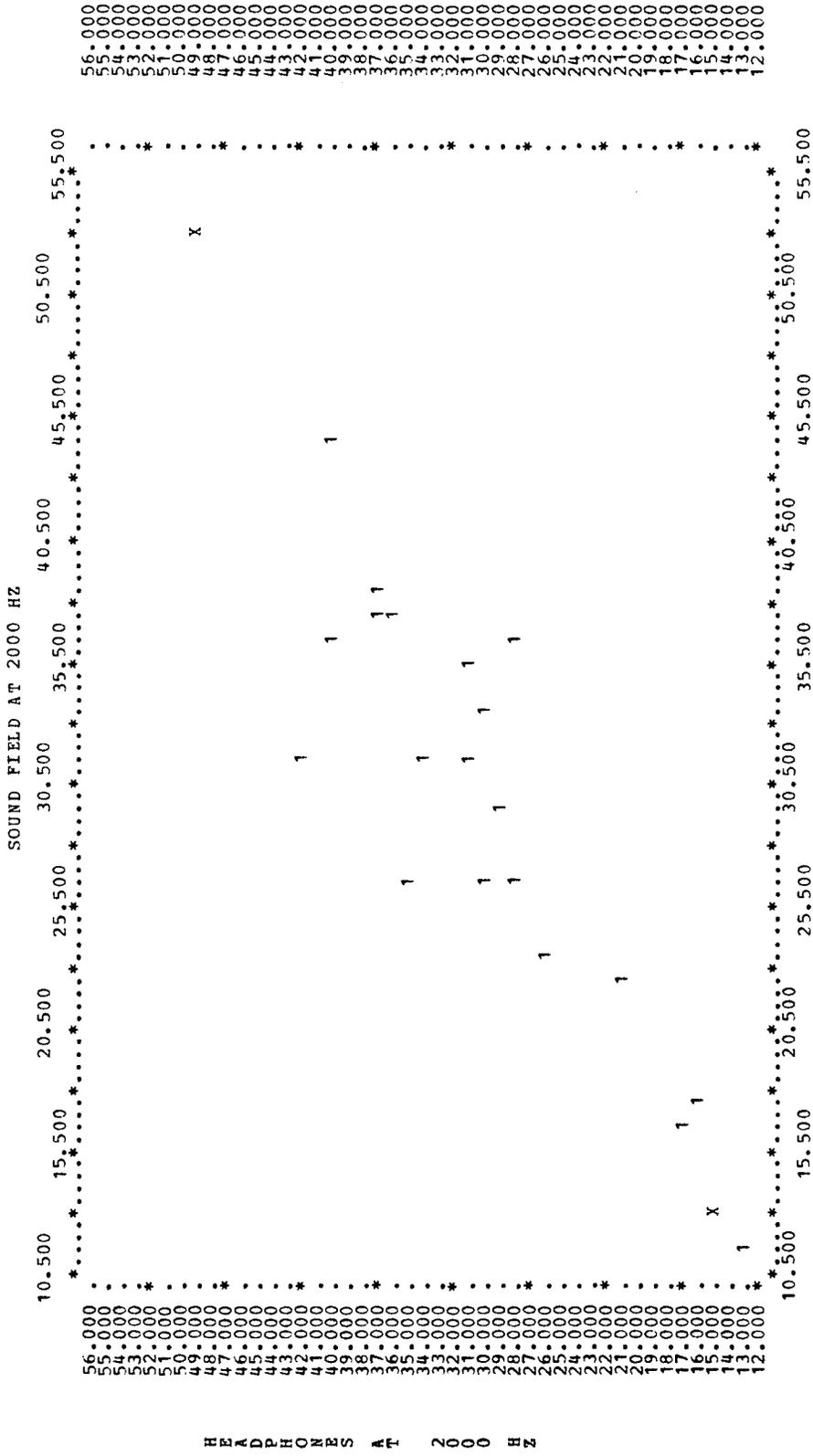


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
Y	4	20	21.000	9.055	82.000	32.000	0.0	32.000	-0.591	-0.470
X	13	20	22.450	9.567	91.524	38.000	1.000	37.000	-0.234	-0.427

EQUATION OF REG. LINE Y = 2.12 + 0.9679 X
 STANDARD ERROR OF ESTIMATE 4.15
 CORRELATION COEFFICIENT 0.916

0*EVALUATION OF PROTECTOR 2B*



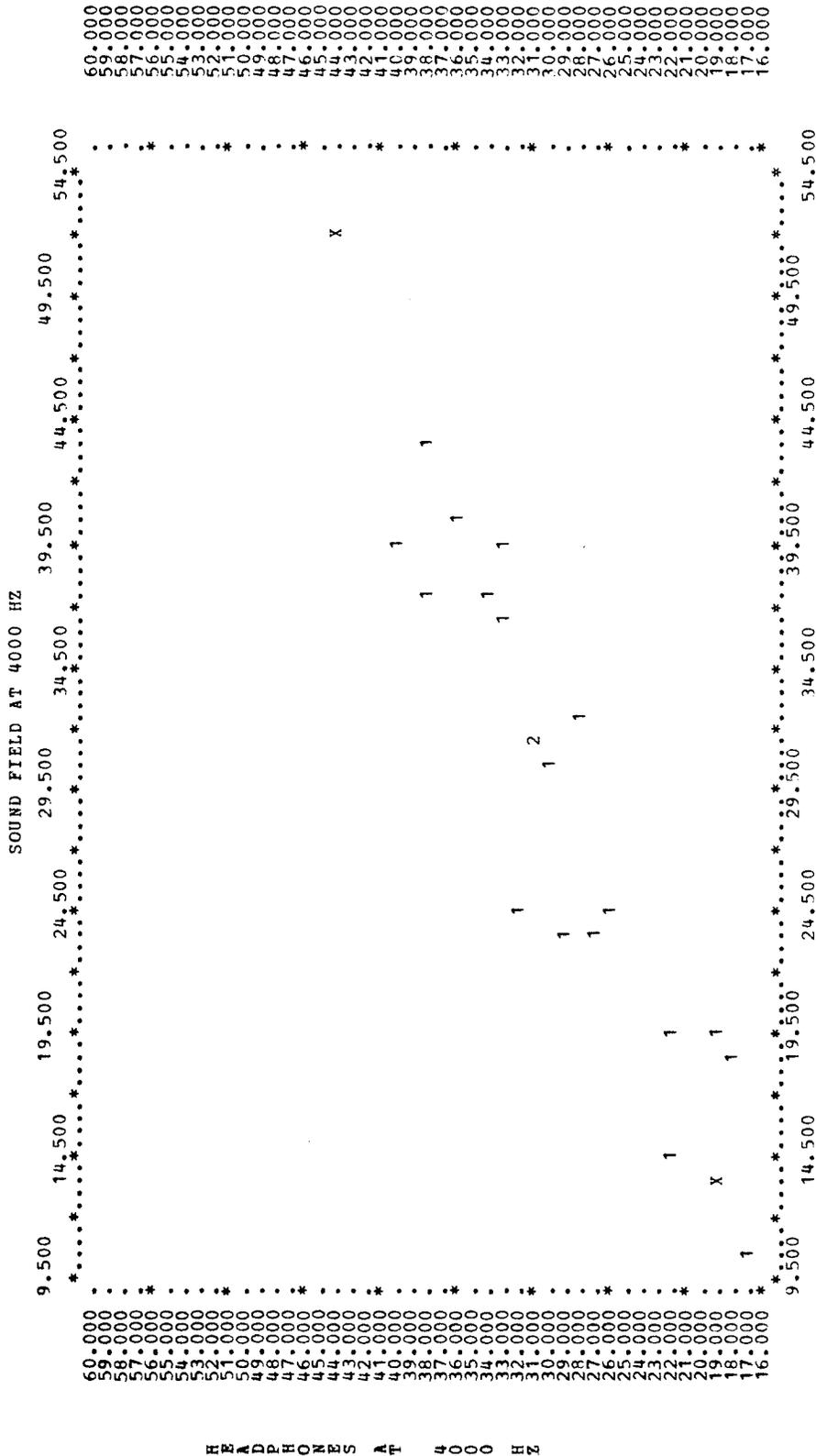
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENESS	KURTOSIS
X	5	20	29.250	8.410	70.724	44.000	11.000	33.000	-0.480	-0.400
Y	14	20	30.050	8.211	67.419	42.000	13.000	29.000	-0.589	-0.486

EQUATION OF REG. LINE Y = 5.37 + 0.8437 X

STANDARD ERROR OF ESTIMATE 4.47

CORRELATION COEFFICIENT 0.864

0*EVALUATION OF PROTECTOR 2B*

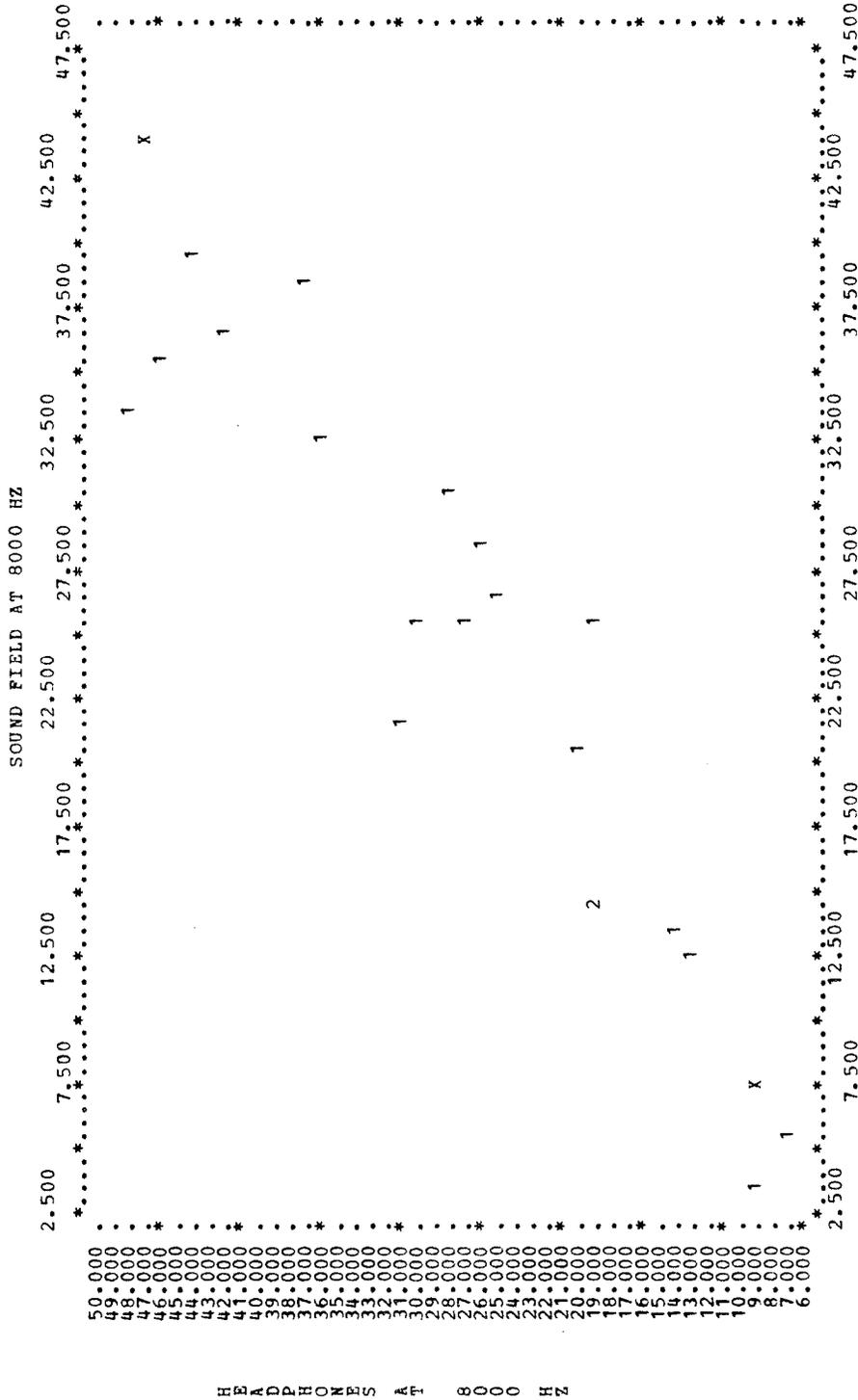


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
Y	7	20	28.450	9.556	91.313	43.000	10.000	33.000	-0.241	-1.063
Y	16	20	29.200	6.818	46.484	40.000	17.000	23.000	-0.521	-0.872

EQUATION OF REG. LINE Y = 10.55 + 0.6555 X
 STANDARD ERROR OF ESTIMATE 2.92
 CORRELATION COEFFICIENT 0.919

O*EVALUATION OF PROTECTOR 2B*



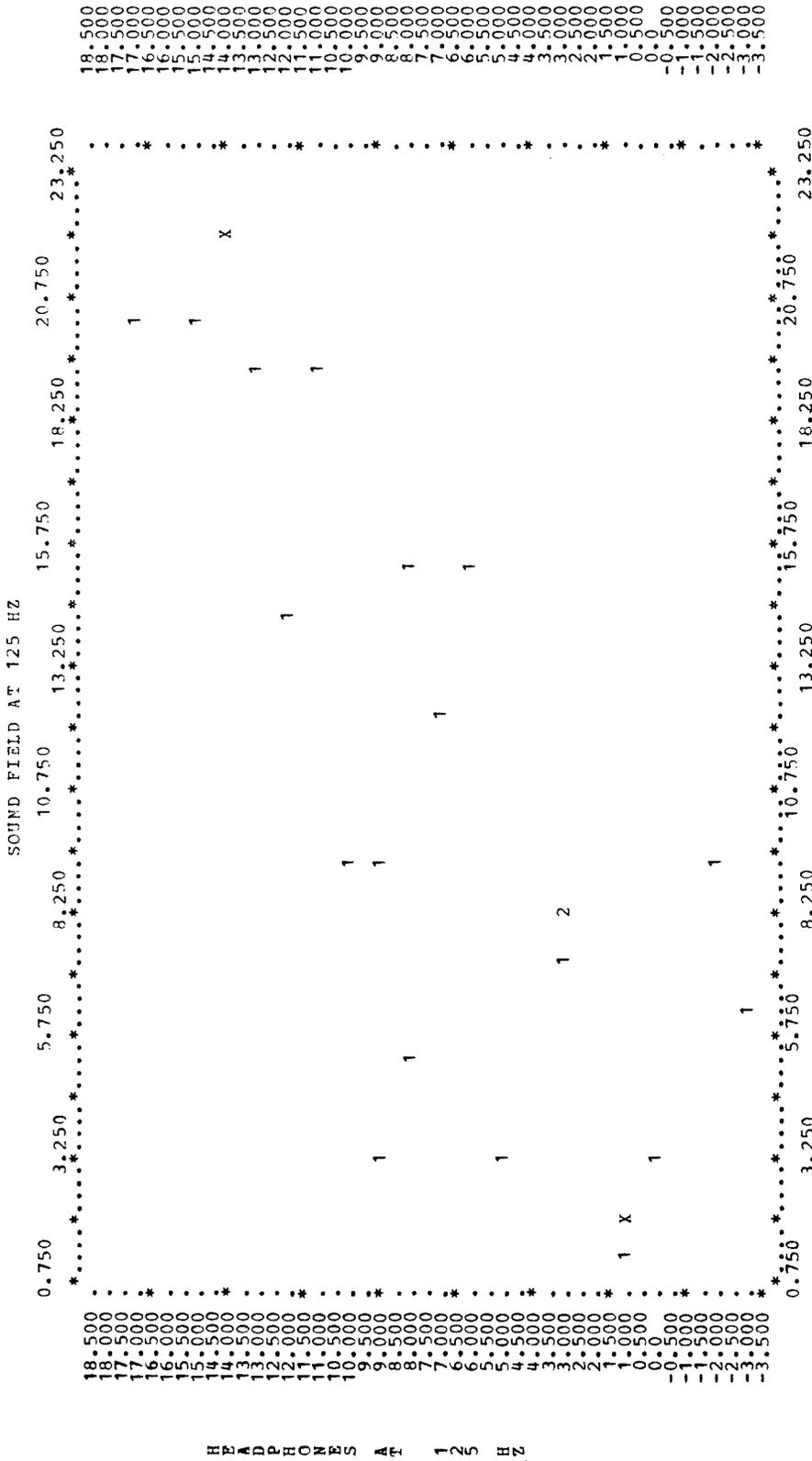
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	23.700	10.712	114.747	39.000	3.000	36.000	-0.378	-0.872
Y	18	20	27.000	12.265	150.421	48.000	7.000	41.000	0.163	-0.986

EQUATION OF REG. LINE Y = 2.18 + 1.0471 X

STANDARD ERROR OF ESTIMATE 5.37

CORRELATION COEFFICIENT 0.915

0*EVALUATION OF PROTECTOR 3A*

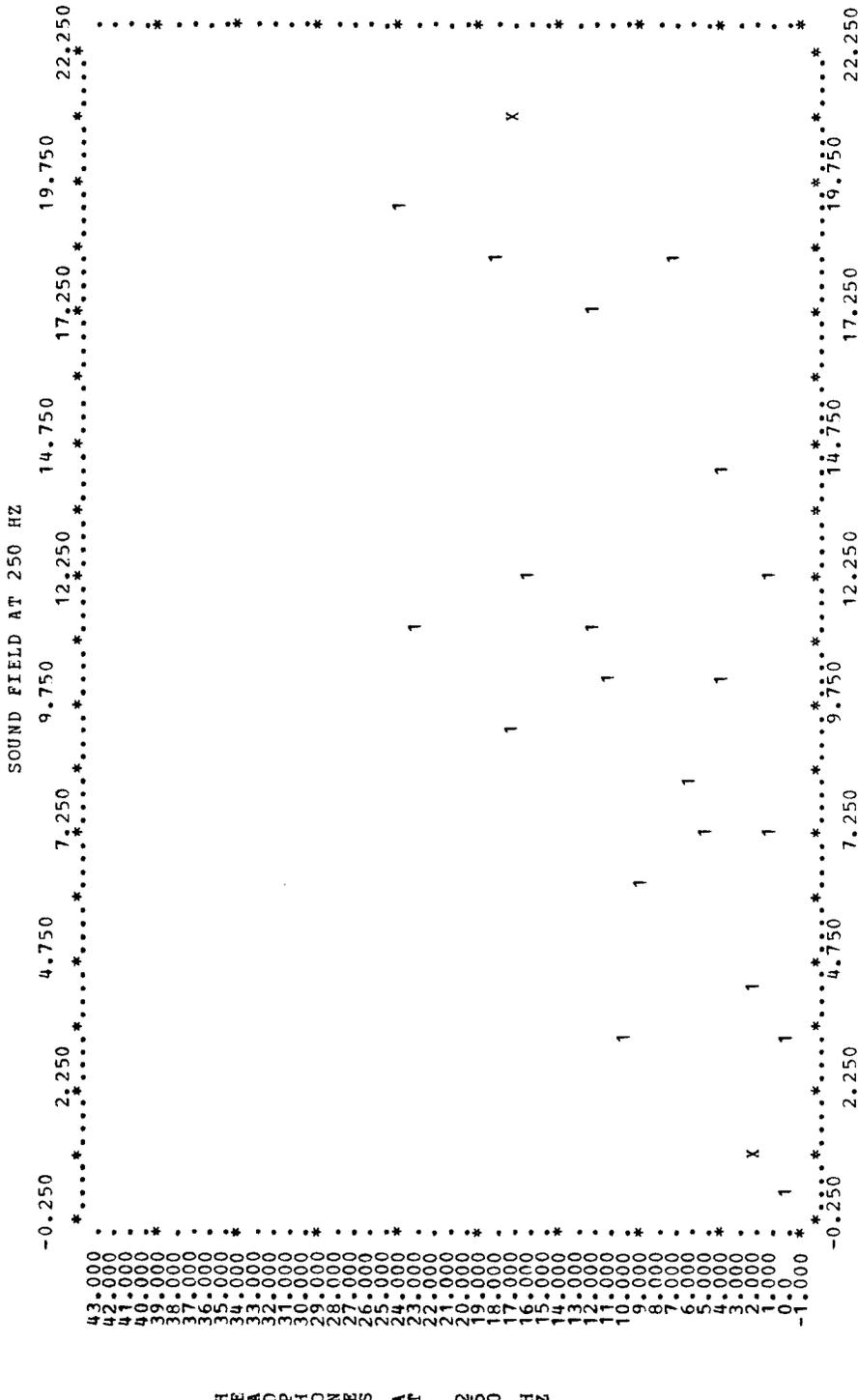


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKWNESS	KURTOSIS
X	1	20	10.250	6.155	37.882	20.000	1.000	19.000	0.289	-1.151
Y	10	20	6.750	5.514	30.408	17.000	-3.000	20.000	-0.030	-0.776

EQUATION OF REG. LINE Y = 0.18 + 0.6408 X
 STANDARD ERROR OF ESTIMATE 4.17
 CORRELATION COEFFICIENT 0.715

O*EVALUATION OF PROTECTOR 3A*



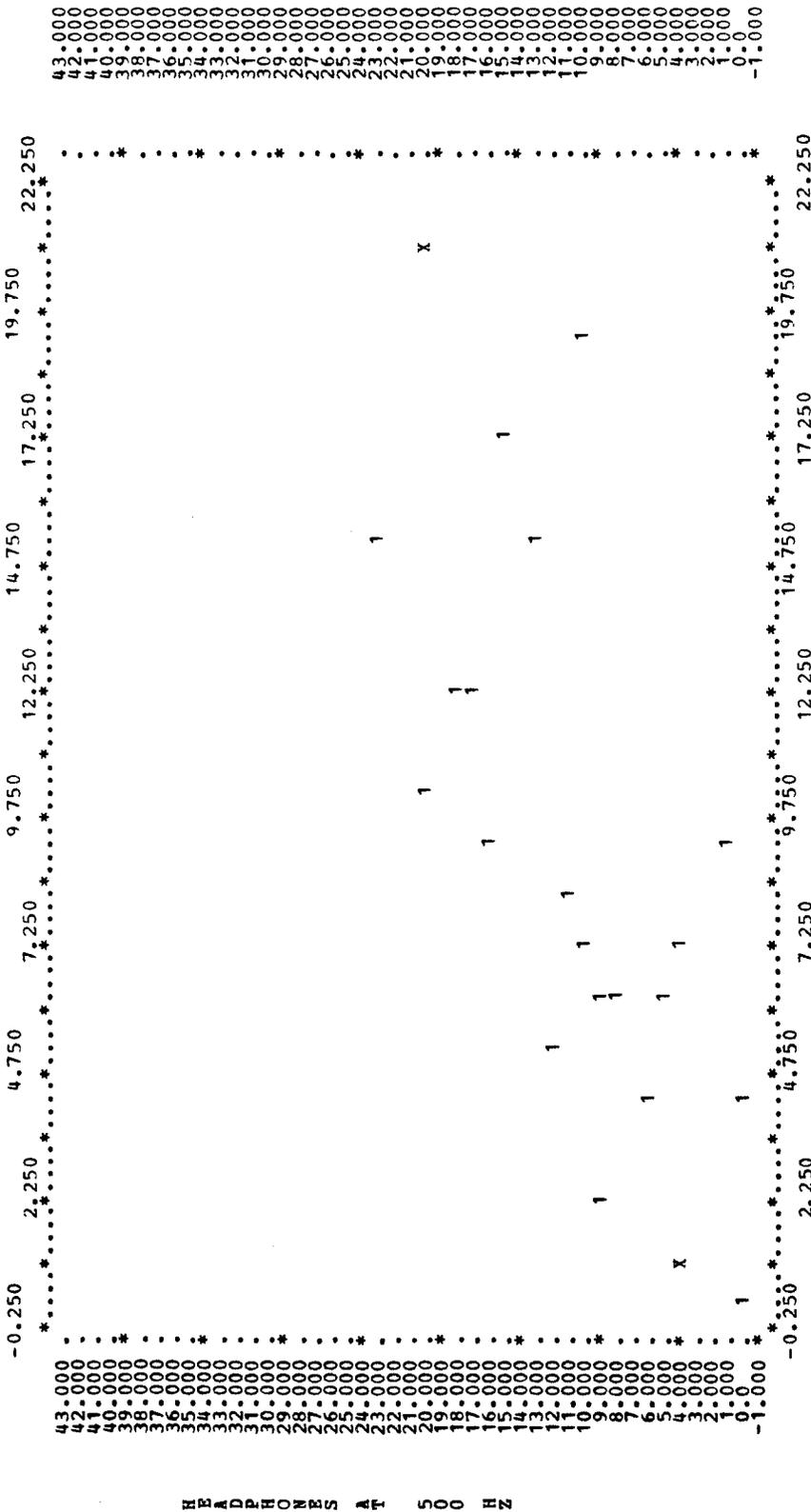
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	2	20	9.950	5.414	29.313	19.000	0.0	19.000	0.079	-0.907
Y	11	20	9.100	7.454	55.568	24.000	0.0	24.000	0.557	-0.743

EQUATION OF REG. LINE Y = 1.43 + 0.7704 X
 STANDARD ERROR OF ESTIMATE 6.69
 CORRELATION COEFFICIENT 0.560

0*EVALUATION OF PROTECTOR 3A*

SOUND FIELD AT 500 HZ

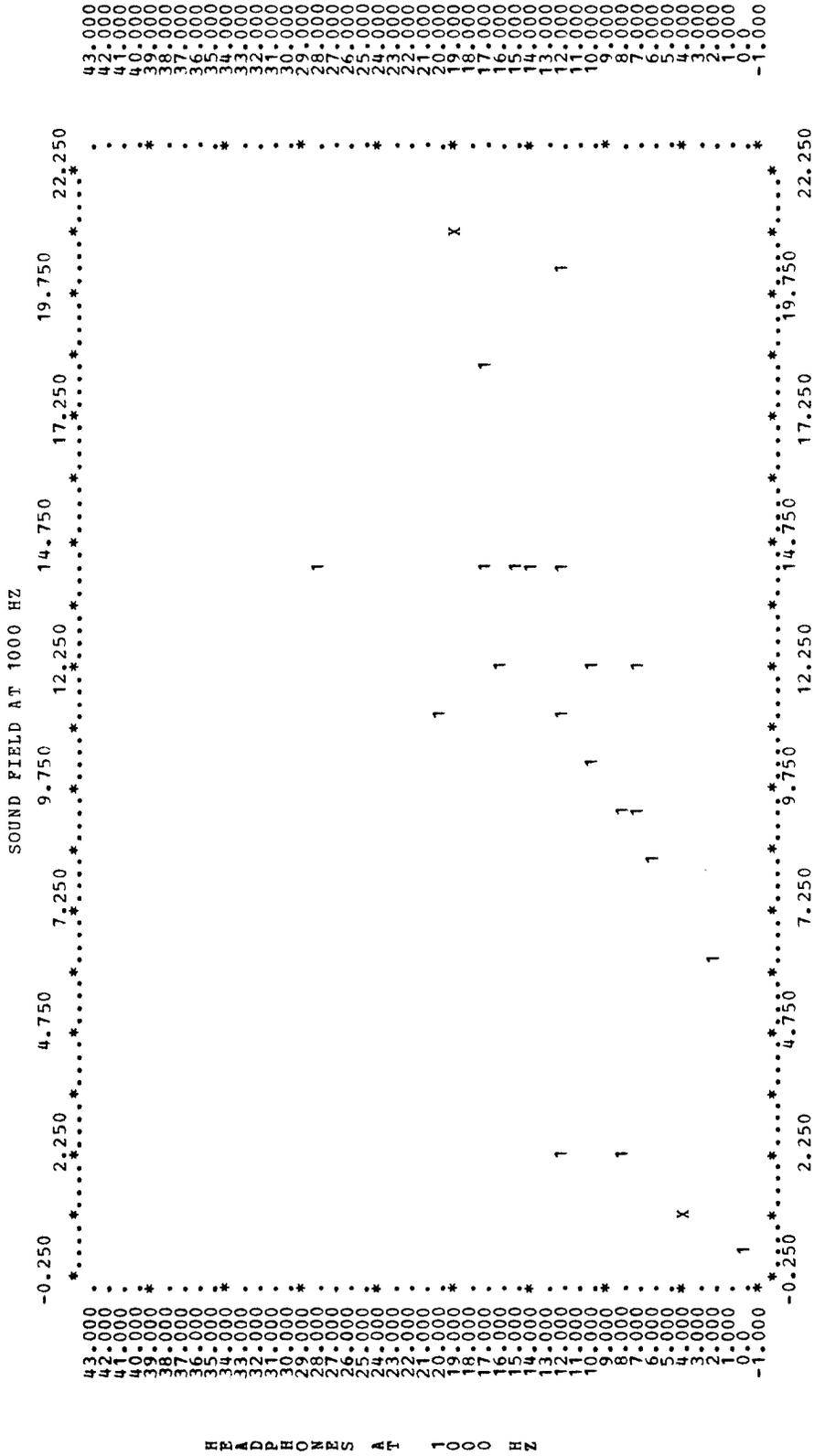


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	3	20	8.650	5.050	25.503	19.000	0.0	19.000	0.430	-0.558
Y	12	20	10.350	6.564	43.082	23.000	0.0	23.000	0.081	-0.772

EQUATION OF REG. LINE Y = 3.43 + 0.7996 X
 STANDARD ERROR OF ESTIMATE 5.60
 CORRELATION COEFFICIENT 0.615

0*EVALUATION OF PROTECTOR 3A*

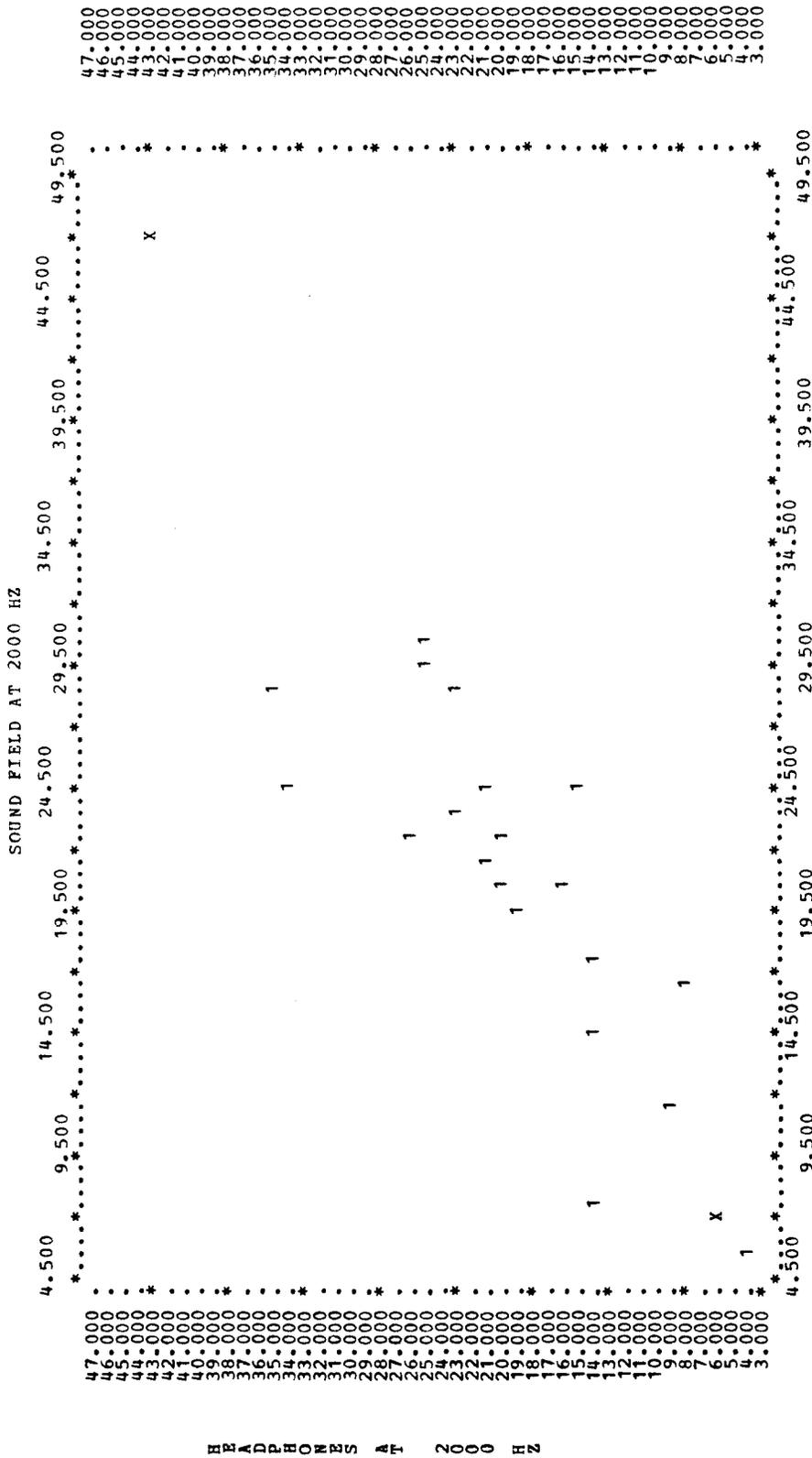


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
\bar{Y}	4	20	10.600	5.134	26.358	20.000	0.0	20.000	-0.457	-0.164
\bar{X}	13	20	11.650	6.352	40.345	28.000	0.0	28.000	0.511	0.672

EQUATION OF REG. LINE $Y = 3.96 + 0.7252 X$
 STANDARD ERROR OF ESTIMATE 5.57
 CORRELATION COEFFICIENT 0.586

0*EVALUATION OF PROTECTOR 3A*

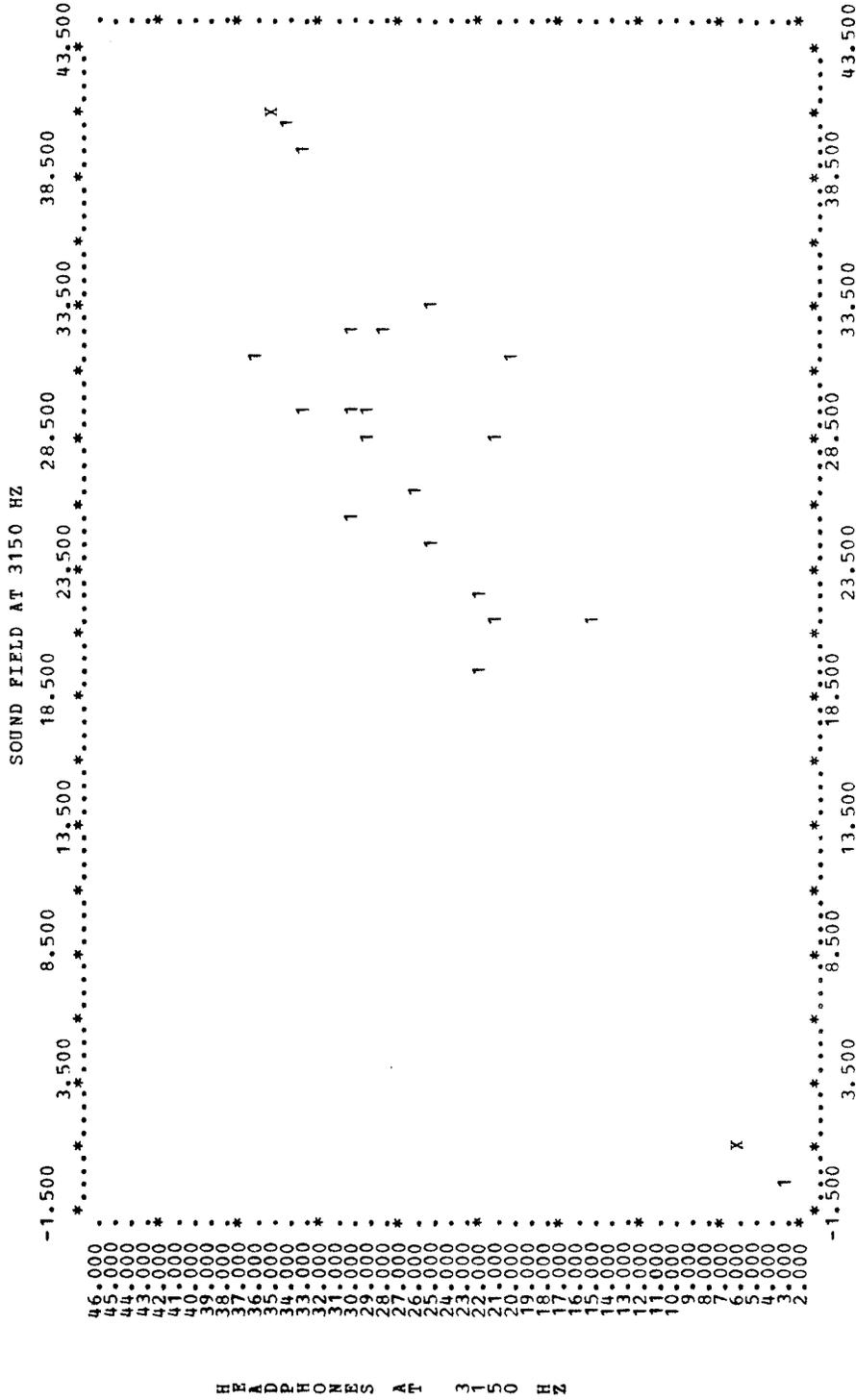


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	5	20	20.200	6.925	47.958	30.000	5.000	25.000	-0.677	-0.203
Y	14	20	19.500	7.908	62.537	35.000	4.000	31.000	0.126	-0.207

EQUATION OF REG. LINE Y = 1.04 + 0.9041 X
 STANDARD ERROR OF ESTIMATE 5.23
 CORRELATION COEFFICIENT 0.792

0*EVALUATION OF PROTECTOR 3A*

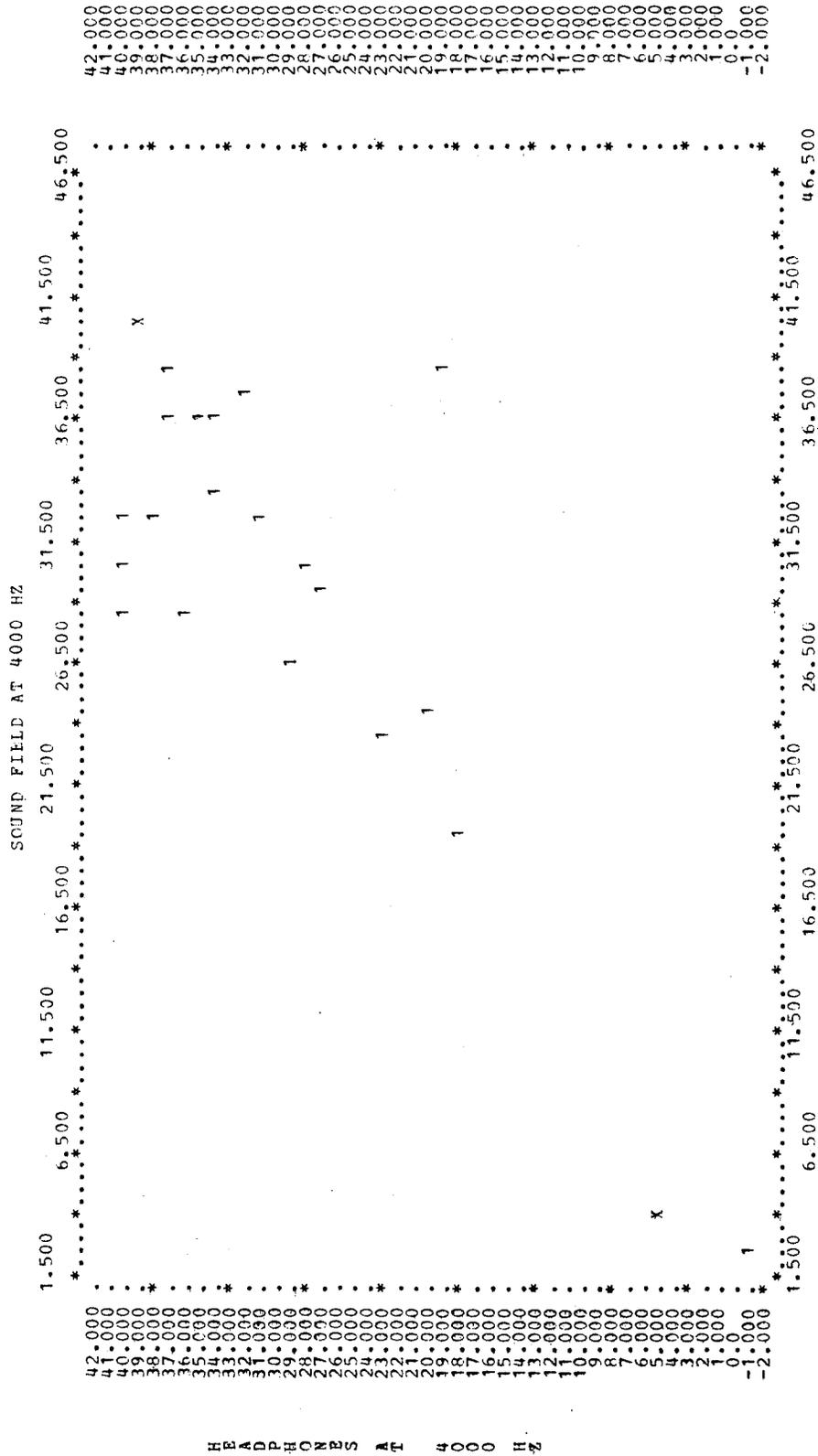


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
Y	16	20	26.900	9.596	73.884	40.000	-1.000	41.000	-1.538	3.771
X	15	20	25.600	7.605	57.832	36.000	-3.000	33.000	-1.267	1.966

EQUATION OF REG. LINE Y = 5.67 + 0.7410 X
 STANDARD ERROR OF ESTIMATE 4.50
 CORRELATION COEFFICIENT 0.838

0*EVALUATION OF PROTECTOR 3A*



VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	7	20	29.450	8.319	69.208	38.000	2.000	36.000	-1.846	3.966
Y	16	20	29.850	10.127	102.555	40.000	-1.000	41.000	-1.491	2.243

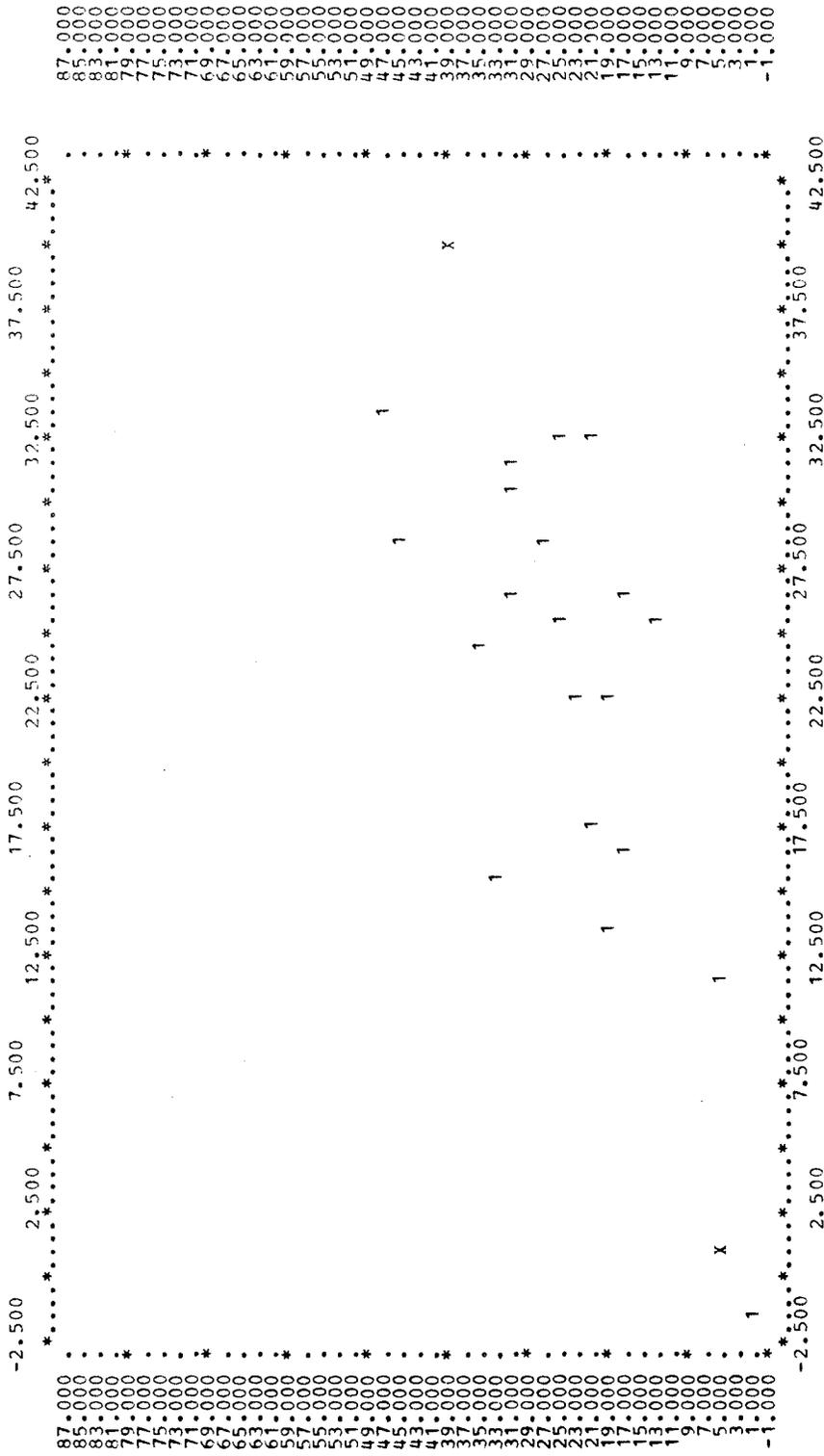
EQUATION OF REG. LINE Y = 2.74 + 0.9205 X

STANDARD ERROR OF ESTIMATE 7.18

CORRELATION COEFFICIENT 0.756

0*EVALUATION OF PROTECTOR 3A*

SOUND FIELD AT 6300 HZ



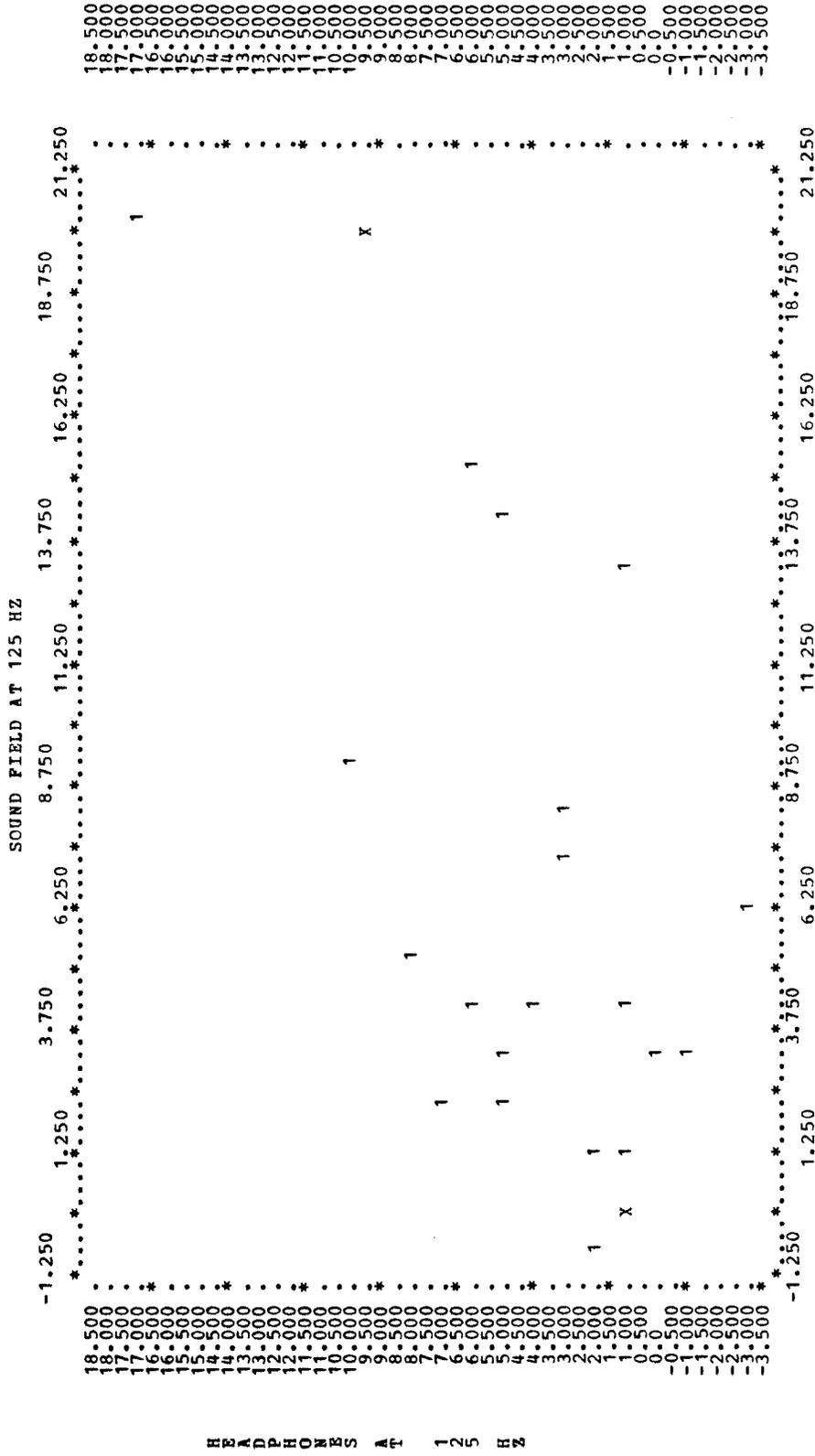
HEADPORES AT 6300 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	22.700	8.797	77.379	33.000	-2.000	35.000	-1.148	1.090
Y	17	20	24.750	11.553	133.460	48.000	-1.000	47.000	0.009	0.042

EQUATION OF REG. LINE Y = 4.73 + 0.8819 X
 STANDARD ERROR OF ESTIMATE 9.27
 CORRELATION COEFFICIENT 0.671

0*EVALUATION OF PROTECTOR 3B*

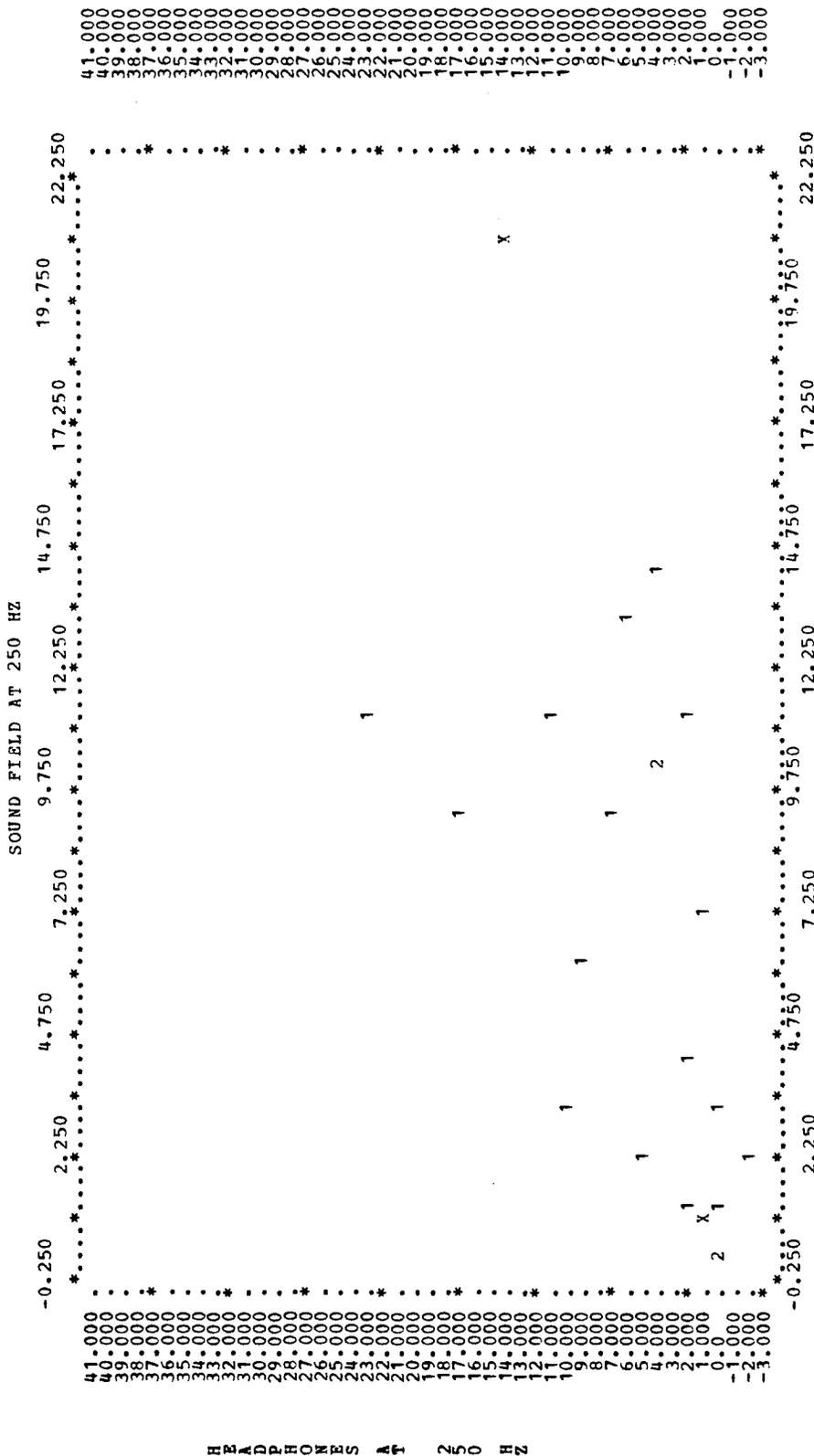


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	1	20	6.150	5.499	30.239	20.000	-1.000	21.000	1.065	0.271
Y	10	20	4.100	4.400	19.358	17.000	-3.000	20.000	1.130	1.887

EQUATION OF REG. LINE Y = 1.46 + 0.4294 X
 STANDARD ERROR OF ESTIMATE 4.02
 CORRELATION COEFFICIENT 0.537

0*EVALUATION OF PROTECTOR 3B*

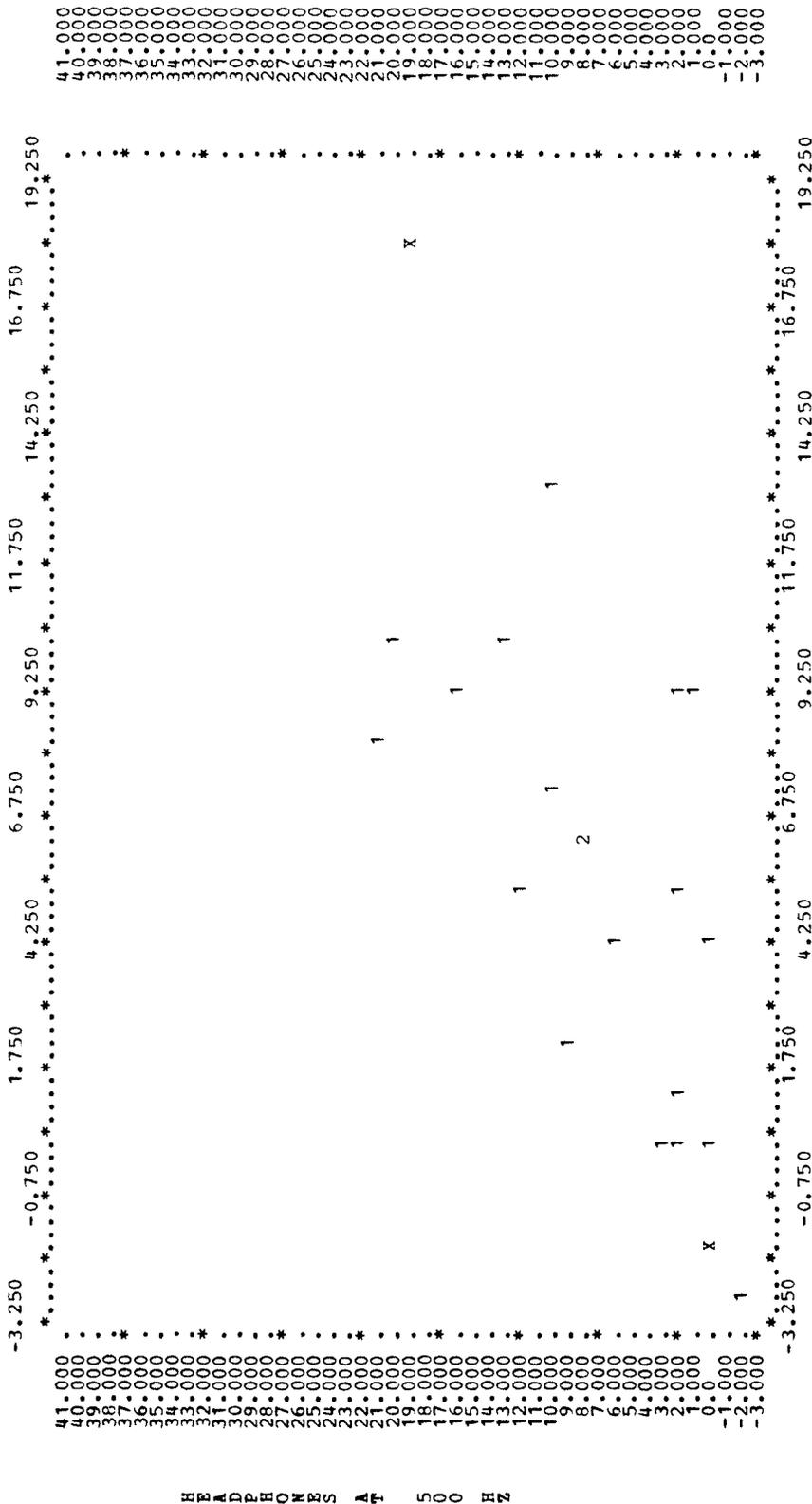


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	2	20	6.350	4.660	21.713	14.000	0.0	14.000	0.057	-1.458
Y	11	20	5.250	6.257	39.145	23.000	-2.000	25.000	1.417	1.577
EQUATION OF REG. LINE		Y =	1.15 +	0.6454 X						
STANDARD ERROR OF ESTIMATE		5.94								
CORRELATION COEFFICIENT		0.481								

0*EVALUATION OF PROTECTOR 3B*

SOUND FIELD AT 500 HZ

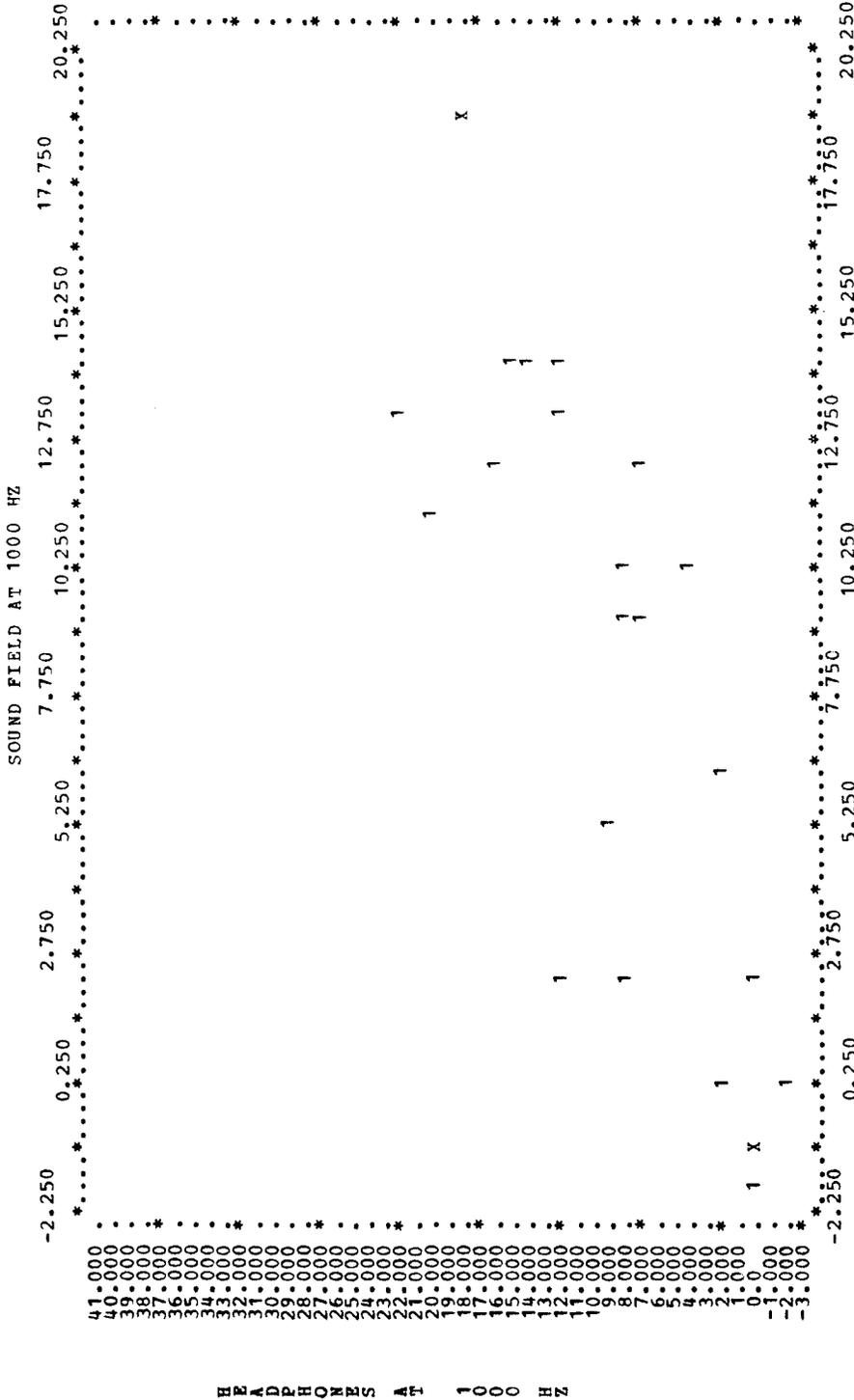


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	3	20	5.250	4.241	17.987	13.000	-3.000	16.000	-0.174	-0.835
Y	12	20	7.150	6.738	45.397	21.000	-2.000	23.000	0.616	-0.612

EQUATION OF REG. LINE Y = 2.02 + 0.9781 X
 STANDARD ERROR OF ESTIMATE 5.75
 CORRELATION COEFFICIENT 0.616

O*EVALUATION OF PROTECTOR 3B*

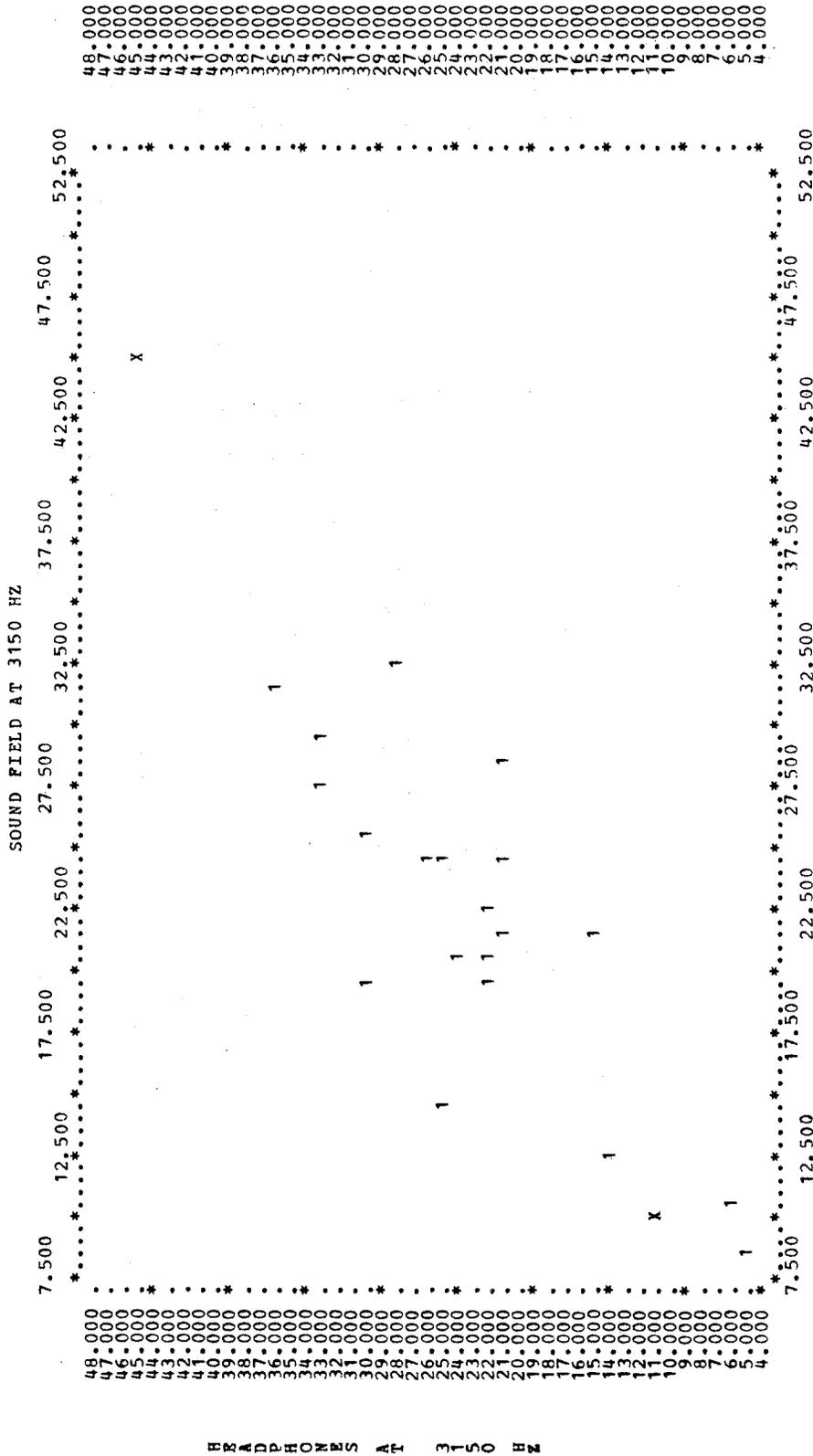


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	4	20	7.800	5.415	29.326	14.000	-2.000	16.000	-0.443	-1.276
Y	13	20	8.800	6.662	44.379	22.000	-2.000	24.000	0.216	-0.701

EQUATION OF REG. LINE Y = 1.92 + 0.8816 X
 STANDARD ERROR OF ESTIMATE 5.03
 CORRELATION COEFFICIENT 0.717

0*EVALUATION OF PROTECTOR 3B*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

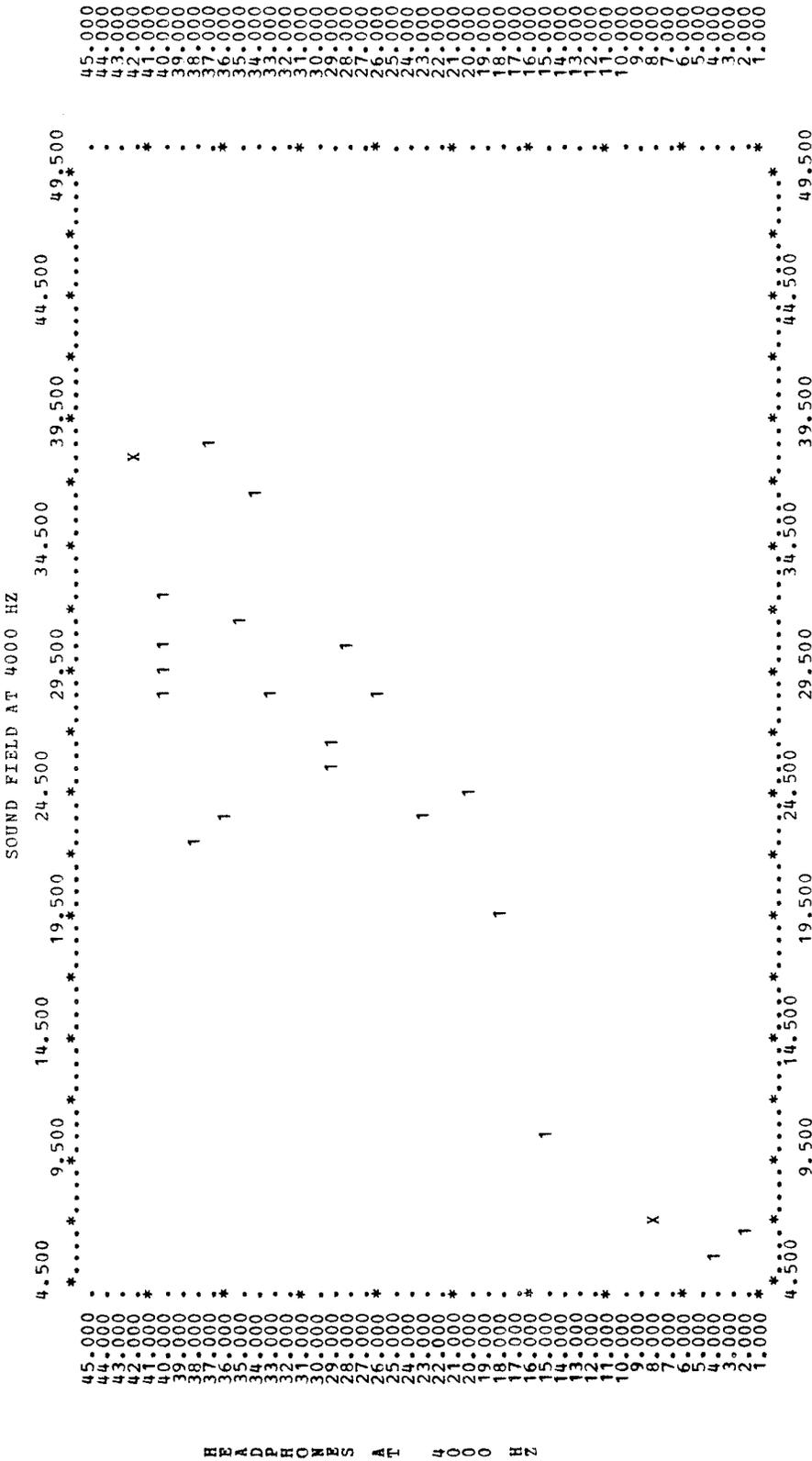
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	6	20	21.500	6.645	44.158	32.000	8.000	24.000	-0.429	-0.485
Y	15	20	22.950	8.217	67.524	36.000	5.000	31.000	-0.659	0.061

EQUATION OF REG. LINE Y = 1.85 + 0.9815 X

STANDARD ERROR OF ESTIMATE 5.41

CORRELATION COEFFICIENT 0.794

EVALUATION OF PROTECTOR 3B



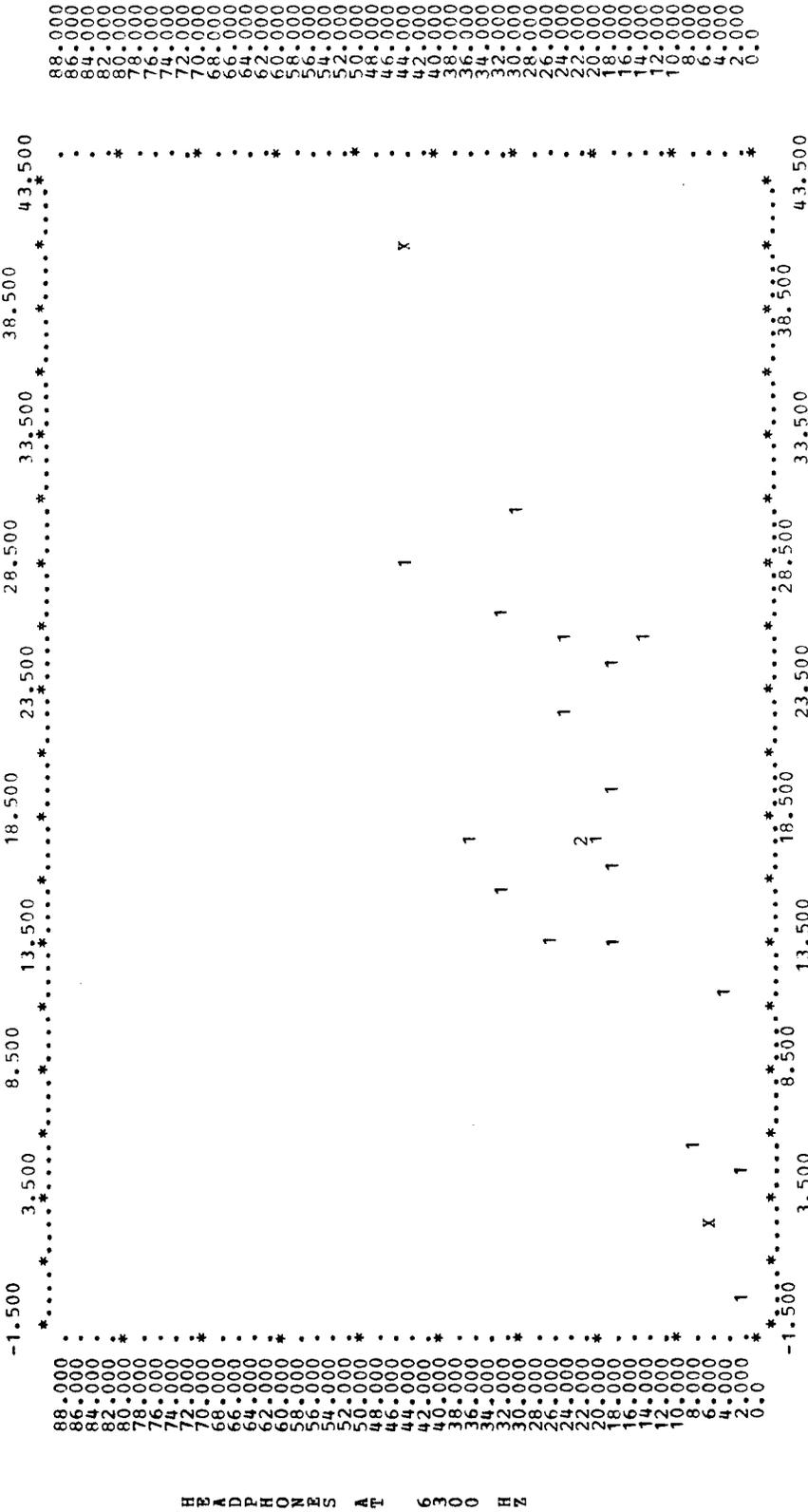
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	24.650	8.905	79.292	38.000	5.000	33.000	-0.950	0.282
Y	16	20	28.350	11.573	133.924	40.000	2.000	38.000	-0.978	0.019

EQUATION OF REG. LINE Y = 1.08 + 1.1061 X
 STANDARD ERROR OF ESTIMATE 6.58
 CORRELATION COEFFICIENT 0.851

0*EVALUATION OF PROTECTOR 3B*

SOUND FIELD AT 6300 HZ



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

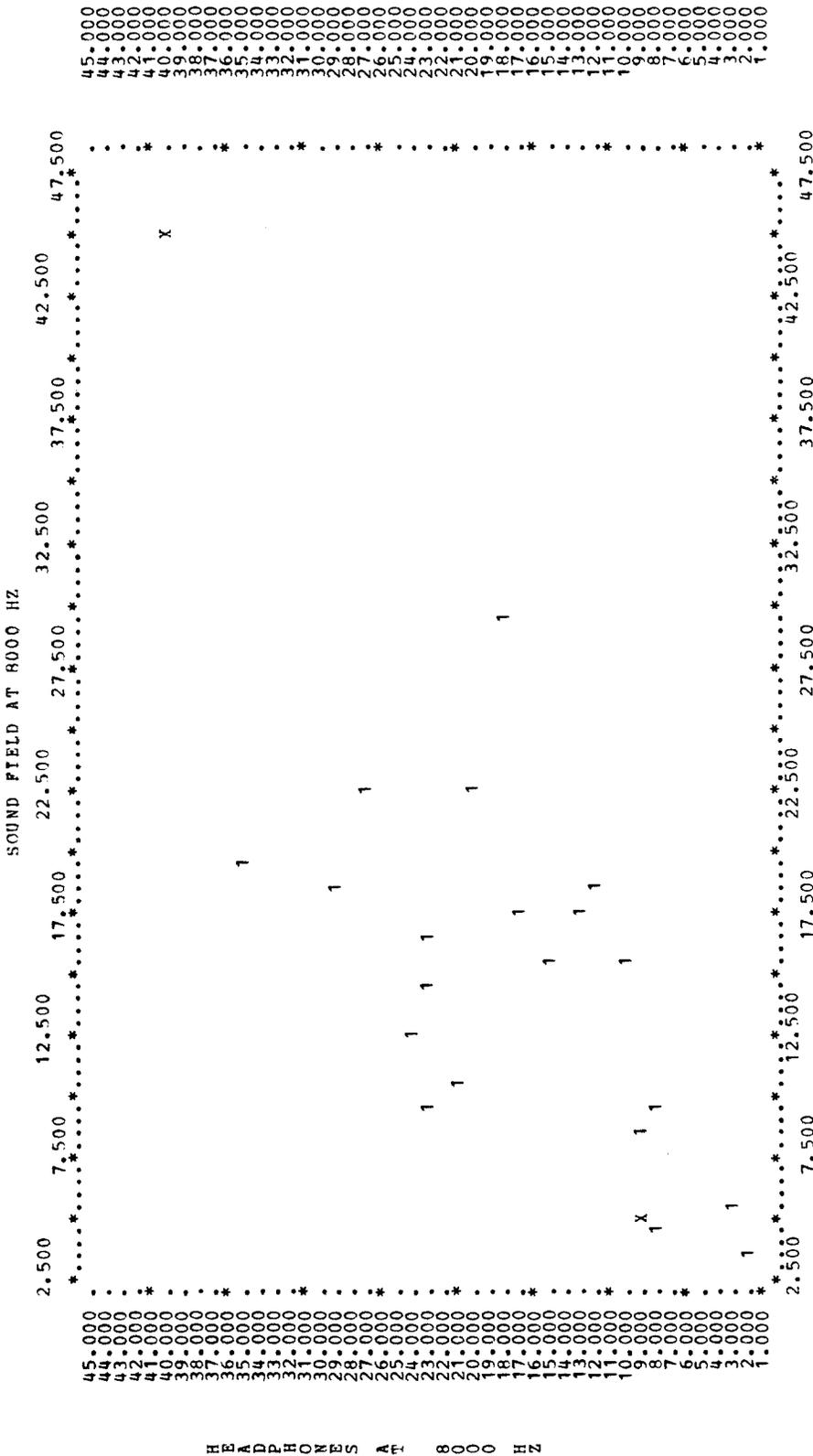
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	8	20	17.150	8.229	67.713	30.000	-1.000	31.000	-0.478	-0.343
Y	17	20	21.100	11.406	130.095	45.000	2.000	43.000	0.038	-0.380

EQUATION OF REG. LINE Y = 4.21 + 0.9846 X

STANDARD ERROR OF ESTIMATE 8.69

CORRELATION COEFFICIENT 0.710

0 EVALUATION OF PROTECTOR 3B*



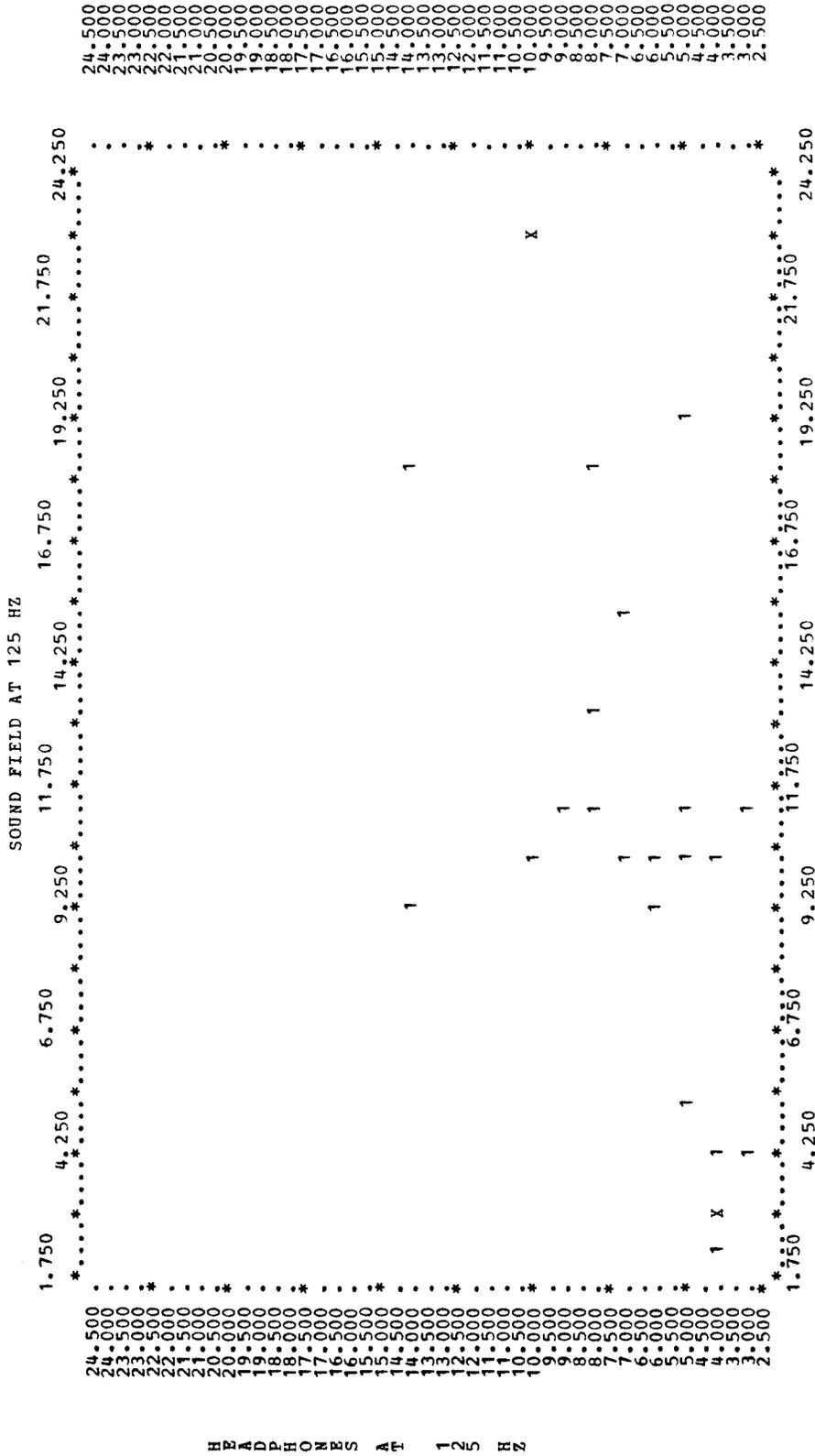
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	9	20	14.100	6.656	44.305	29.000	3.000	26.000	0.158	-0.354
Y	18	20	17.000	8.862	78.526	35.000	2.000	33.000	0.079	-0.737

EQUATION OF REG. LINE Y = 6.25 + 0.7627 X

STANDARD ERROR OF ESTIMATE 7.87

CORRELATION COEFFICIENT 0.573

O*EVALUATION OF PROTECTOR 4A*



HEADPHONES AT 125 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

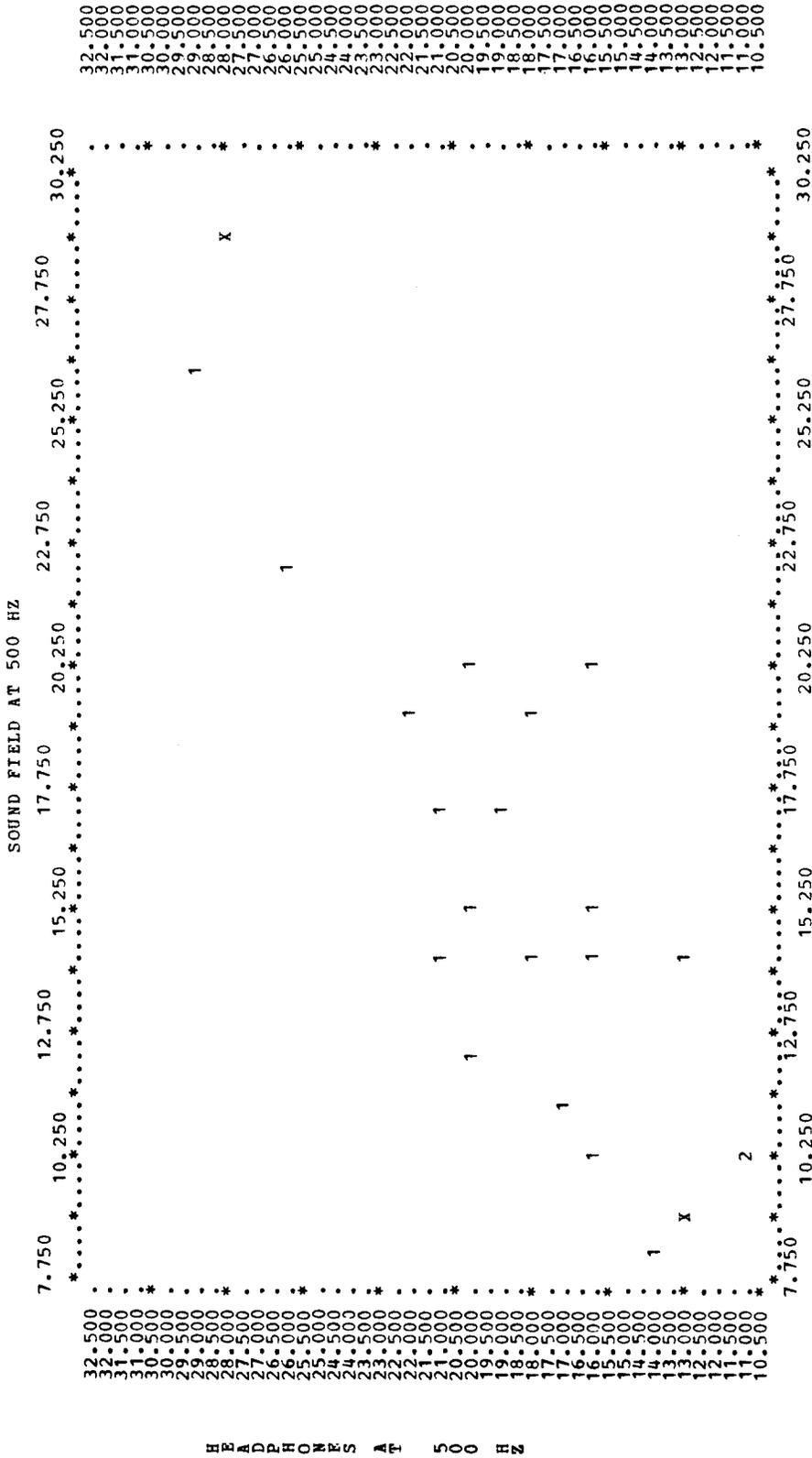
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKERNESS	KURTOSIS
X	1	20	10.500	4.617	21.316	19.000	2.000	17.000	0.125	-0.352
Y	10	20	6.750	3.160	9.987	14.000	3.000	11.000	1.067	0.486

EQUATION OF REG. LINE Y = 3.68 + 0.2926 X

STANDARD ERROR OF ESTIMATE 3.09

CORRELATION COEFFICIENT 0.427

0*EVALUATION OF PROTECTOR 4A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

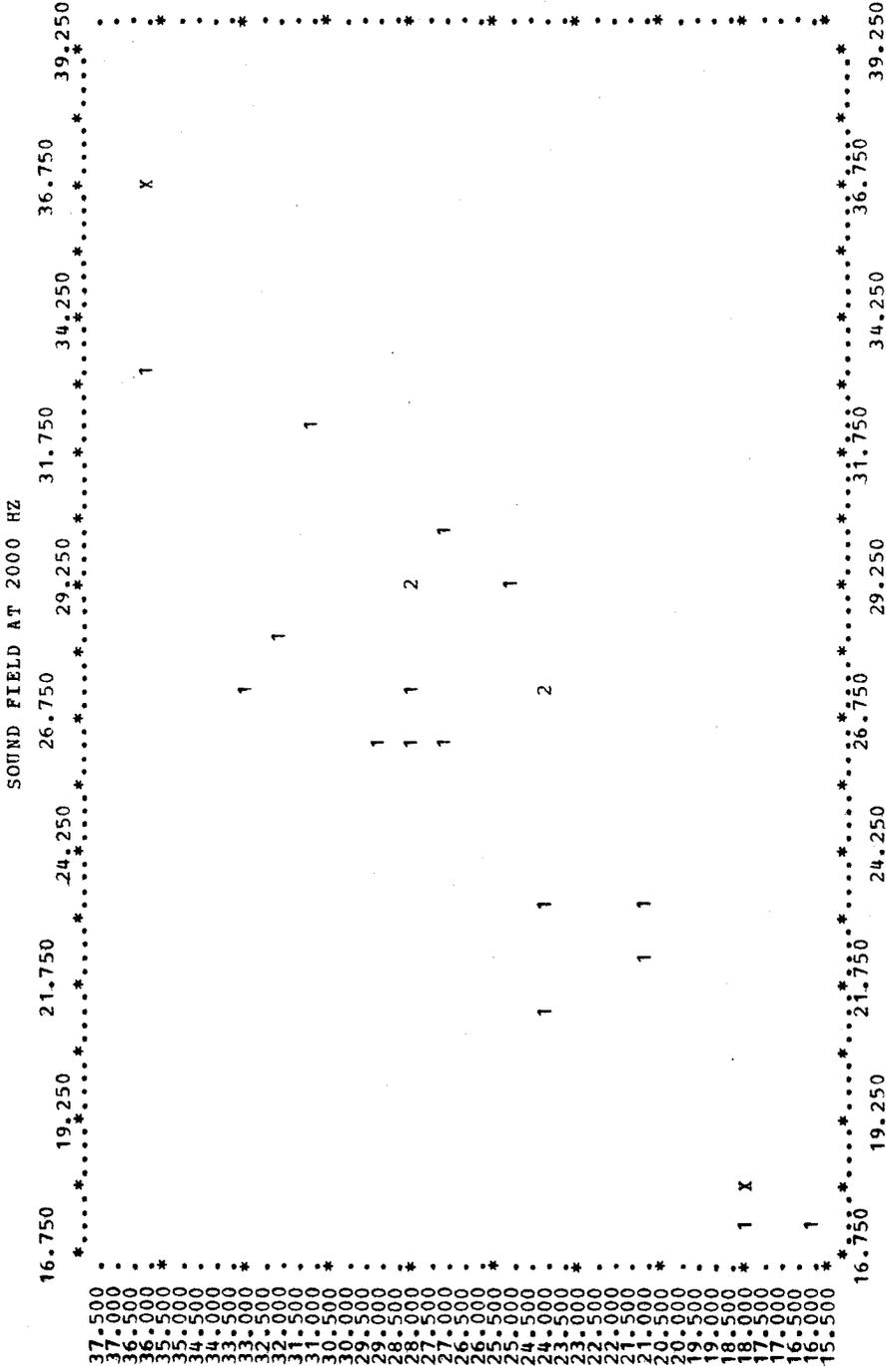
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	3	20	15.350	4.648	21.608	26.000	8.000	18.000	0.442	-0.390
Y	12	20	18.200	4.514	20.379	29.000	11.000	18.000	0.496	0.226

EQUATION OF REG. LINE Y = 6.62 + 0.7541 X

STANDARD ERROR OF ESTIMATE 3.08

CORRELATION COEFFICIENT 0.777

0*EVALUATION OF PROTECTOR 4A*

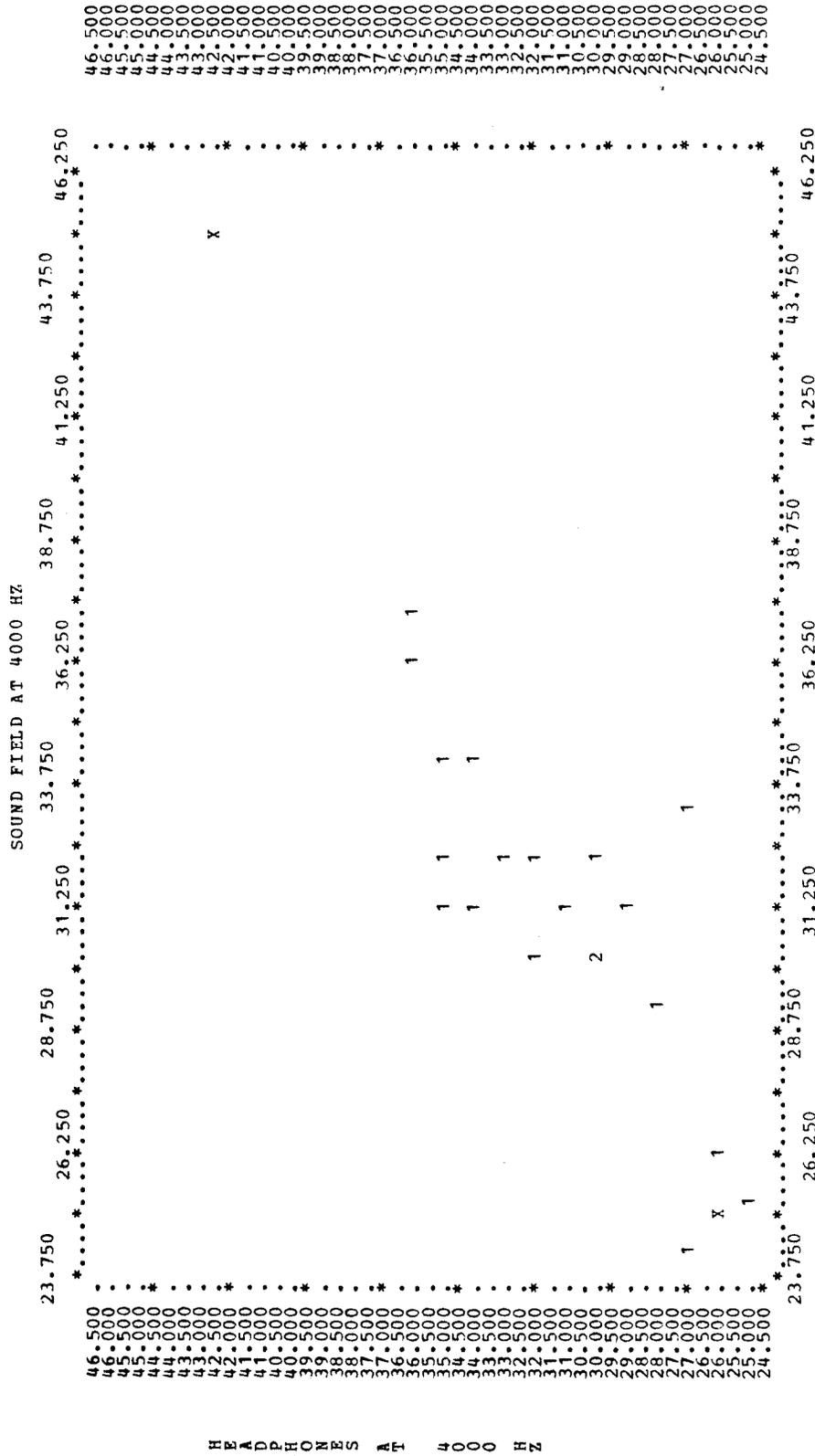


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	5	20	25.950	4.334	18.787	33.000	17.000	16.000	-0.618	-0.145
Y	14	20	26.200	4.959	24.590	36.000	16.000	20.000	-0.146	-0.248

EQUATION OF REG. LINE Y = 1.25 + 0.9615 X
 STANDARD ERROR OF ESTIMATE 2.91
 CORRELATION COEFFICIENT 0.840

0*EVALUATION OF PROTECTOR 4A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	31.000	3.277	10.737	37.000	24.000	13.000	-0.442	0.097
Y	16	20	31.250	3.477	12.092	36.000	25.000	11.000	-0.223	-1.174

EQUATION OF REG. LINE Y = 5.42 + 0.8333 X
 STANDARD ERROR OF ESTIMATE 2.33
 CORRELATION COEFFICIENT 0.785

0*EVALUATION OF PROTECTOR 4A*

SOUND FIELD AT 6300 HZ

HEADING	21.750	24.250	26.750	29.250	31.750	34.250	36.750	39.250	41.750	44.250
68.000	*	*	*	*	*	*	*	*	*	*
67.000	*	*	*	*	*	*	*	*	*	*
66.000	*	*	*	*	*	*	*	*	*	*
65.000	*	*	*	*	*	*	*	*	*	*
64.000	*	*	*	*	*	*	*	*	*	*
63.000	*	*	*	*	*	*	*	*	*	*
62.000	*	*	*	*	*	*	*	*	*	*
61.000	*	*	*	*	*	*	*	*	*	*
60.000	*	*	*	*	*	*	*	*	*	*
59.000	*	*	*	*	*	*	*	*	*	*
58.000	*	*	*	*	*	*	*	*	*	*
57.000	*	*	*	*	*	*	*	*	*	*
56.000	*	*	*	*	*	*	*	*	*	*
55.000	*	*	*	*	*	*	*	*	*	*
54.000	*	*	*	*	*	*	*	*	*	*
53.000	*	*	*	*	*	*	*	*	*	*
52.000	*	*	*	*	*	*	*	*	*	*
51.000	*	*	*	*	*	*	*	*	*	*
50.000	*	*	*	*	*	*	*	*	*	*
49.000	*	*	*	*	*	*	*	*	*	*
48.000	*	*	*	*	*	*	*	*	*	*
47.000	*	*	*	*	*	*	*	*	*	*
46.000	*	*	*	*	*	*	*	*	*	*
45.000	*	*	*	*	*	*	*	*	*	*
44.000	*	*	*	*	*	*	*	*	*	*
43.000	*	*	*	*	*	*	*	*	*	*
42.000	*	*	*	*	*	*	*	*	*	*
41.000	*	*	*	*	*	*	*	*	*	*
40.000	*	*	*	*	*	*	*	*	*	*
39.000	*	*	*	*	*	*	*	*	*	*
38.000	*	*	*	*	*	*	*	*	*	*
37.000	*	*	*	*	*	*	*	*	*	*
36.000	*	*	*	*	*	*	*	*	*	*
35.000	*	*	*	*	*	*	*	*	*	*
34.000	*	*	*	*	*	*	*	*	*	*
33.000	*	*	*	*	*	*	*	*	*	*
32.000	*	*	*	*	*	*	*	*	*	*
31.000	*	*	*	*	*	*	*	*	*	*
30.000	*	*	*	*	*	*	*	*	*	*
29.000	*	*	*	*	*	*	*	*	*	*
28.000	*	*	*	*	*	*	*	*	*	*
27.000	*	*	*	*	*	*	*	*	*	*
26.000	*	*	*	*	*	*	*	*	*	*
25.000	*	*	*	*	*	*	*	*	*	*
24.000	*	*	*	*	*	*	*	*	*	*

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	31.450	4.211	17.734	38.000	22.000	16.000	-0.328	-0.537
Y	17	20	35.500	6.220	38.684	47.000	25.000	22.000	0.251	-0.827

EQUATION OF REG. LINE Y = 9.60 + 0.8236 X

STANDARD ERROR OF ESTIMATE 5.59

CORRELATION COEFFICIENT 0.558

0*EVALUATION OF PROTECTOP 4A*

SOUND FIELD AT 8000 HZ

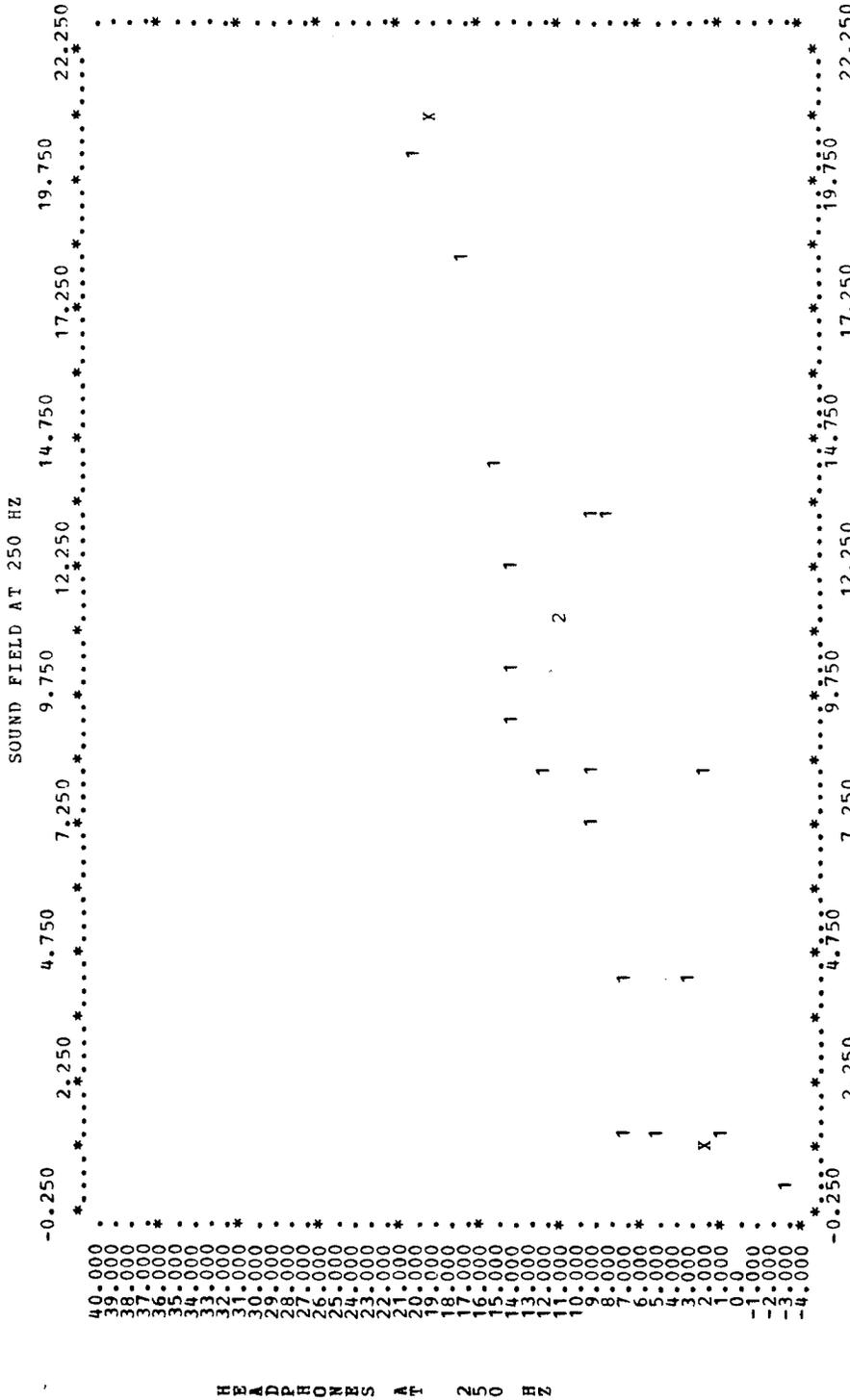
HEARD PHONES AT 8000 HZ	21.750	24.250	26.750	29.250	31.750	34.250	36.750	39.250	41.750	44.250
67.000	*	*	*	*	*	*	*	*	*	*
66.000	*	*	*	*	*	*	*	*	*	*
65.000	*	*	*	*	*	*	*	*	*	*
64.000	*	*	*	*	*	*	*	*	*	*
63.000	*	*	*	*	*	*	*	*	*	*
62.000	*	*	*	*	*	*	*	*	*	*
61.000	*	*	*	*	*	*	*	*	*	*
60.000	*	*	*	*	*	*	*	*	*	*
59.000	*	*	*	*	*	*	*	*	*	*
58.000	*	*	*	*	*	*	*	*	*	*
57.000	*	*	*	*	*	*	*	*	*	*
56.000	*	*	*	*	*	*	*	*	*	*
55.000	*	*	*	*	*	*	*	*	*	*
54.000	*	*	*	*	*	*	*	*	*	*
53.000	*	*	*	*	*	*	*	*	*	*
52.000	*	*	*	*	*	*	*	*	*	*
51.000	*	*	*	*	*	*	*	*	*	*
50.000	*	*	*	*	*	*	*	*	*	*
49.000	*	*	*	*	*	*	*	*	*	*
48.000	*	*	*	*	*	*	*	*	*	*
47.000	*	*	*	*	*	*	*	*	*	*
46.000	*	*	*	*	*	*	*	*	*	*
45.000	*	*	*	*	*	*	*	*	*	*
44.000	*	*	*	*	*	*	*	*	*	*
43.000	*	*	*	*	*	*	*	*	*	*
42.000	*	*	*	*	*	*	*	*	*	*
41.000	*	*	*	*	*	*	*	*	*	*
40.000	*	*	*	*	*	*	*	*	*	*
39.000	*	*	*	*	*	*	*	*	*	*
38.000	*	*	*	*	*	*	*	*	*	*
37.000	*	*	*	*	*	*	*	*	*	*
36.000	*	*	*	*	*	*	*	*	*	*
35.000	*	*	*	*	*	*	*	*	*	*
34.000	*	*	*	*	*	*	*	*	*	*
33.000	*	*	*	*	*	*	*	*	*	*
32.000	*	*	*	*	*	*	*	*	*	*
31.000	*	*	*	*	*	*	*	*	*	*
30.000	*	*	*	*	*	*	*	*	*	*
29.000	*	*	*	*	*	*	*	*	*	*
28.000	*	*	*	*	*	*	*	*	*	*
27.000	*	*	*	*	*	*	*	*	*	*
26.000	*	*	*	*	*	*	*	*	*	*
25.000	*	*	*	*	*	*	*	*	*	*
24.000	*	*	*	*	*	*	*	*	*	*
23.000	*	*	*	*	*	*	*	*	*	*

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	32.050	4.359	18.997	39.000	22.000	17.000	-0.332	-0.373
Y	18	20	36.250	5.937	35.250	48.000	24.000	24.000	0.226	-0.171

EQUATION OF REG. LINE Y = 10.61 + 0.8000 X
 STANDARD ERROR OF ESTIMATE 5.20
 CORRELATION COEFFICIENT 0.587

C*EVALUATION OF PROTECTOP 4B*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

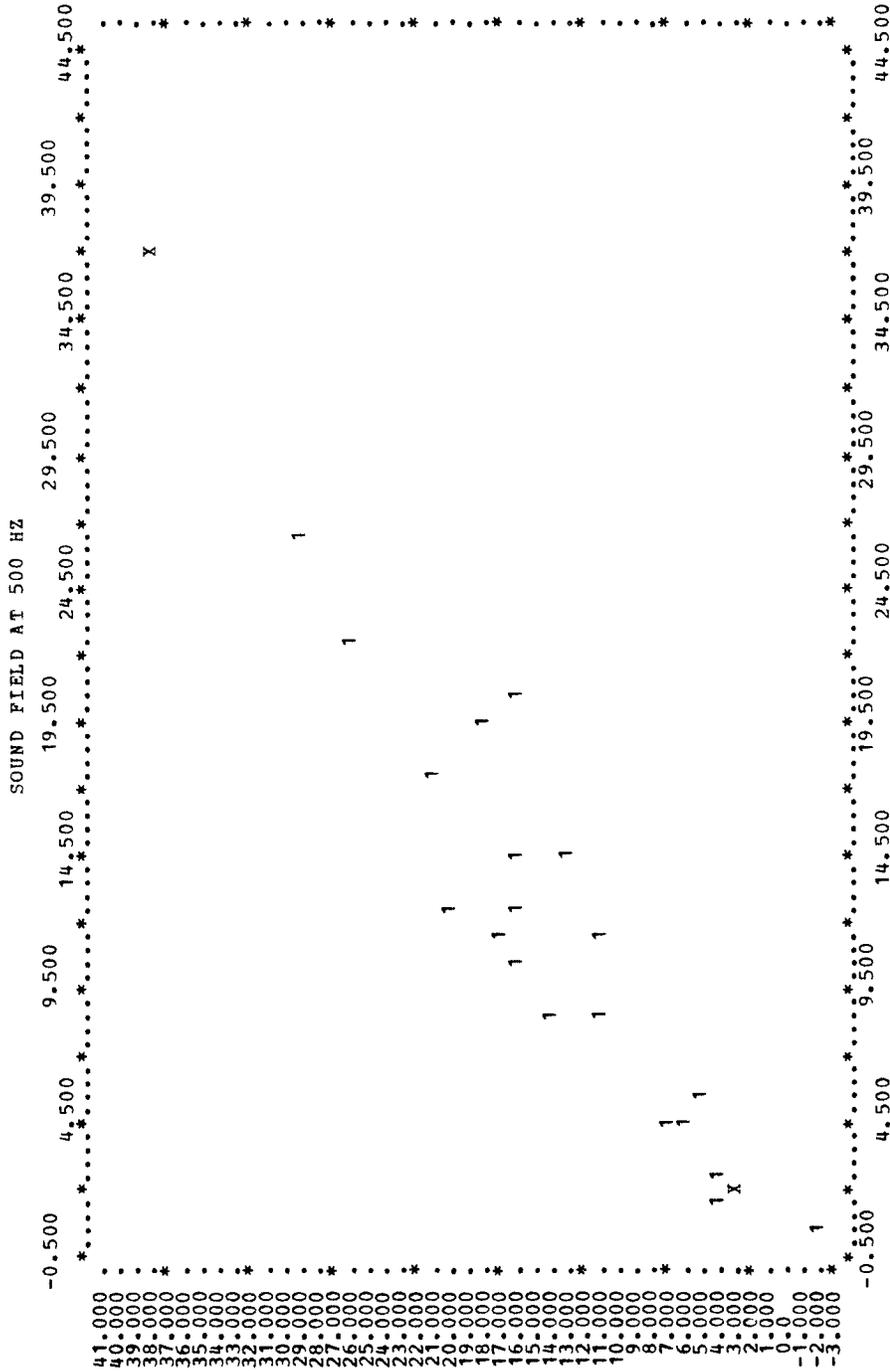
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	2	20	8.650	5.641	31.818	20.000	0.0	20.000	0.140	-0.659
Y	11	20	9.250	5.757	33.145	20.000	-3.000	23.000	-0.248	-0.404

EQUATION OF REG. LINE Y = 1.91 + 0.8482 X

STANDARD ERROR OF ESTIMATE 3.47

CORRELATION COEFFICIENT 0.831

0*EVALUATION OF PROTECTOR 4B*



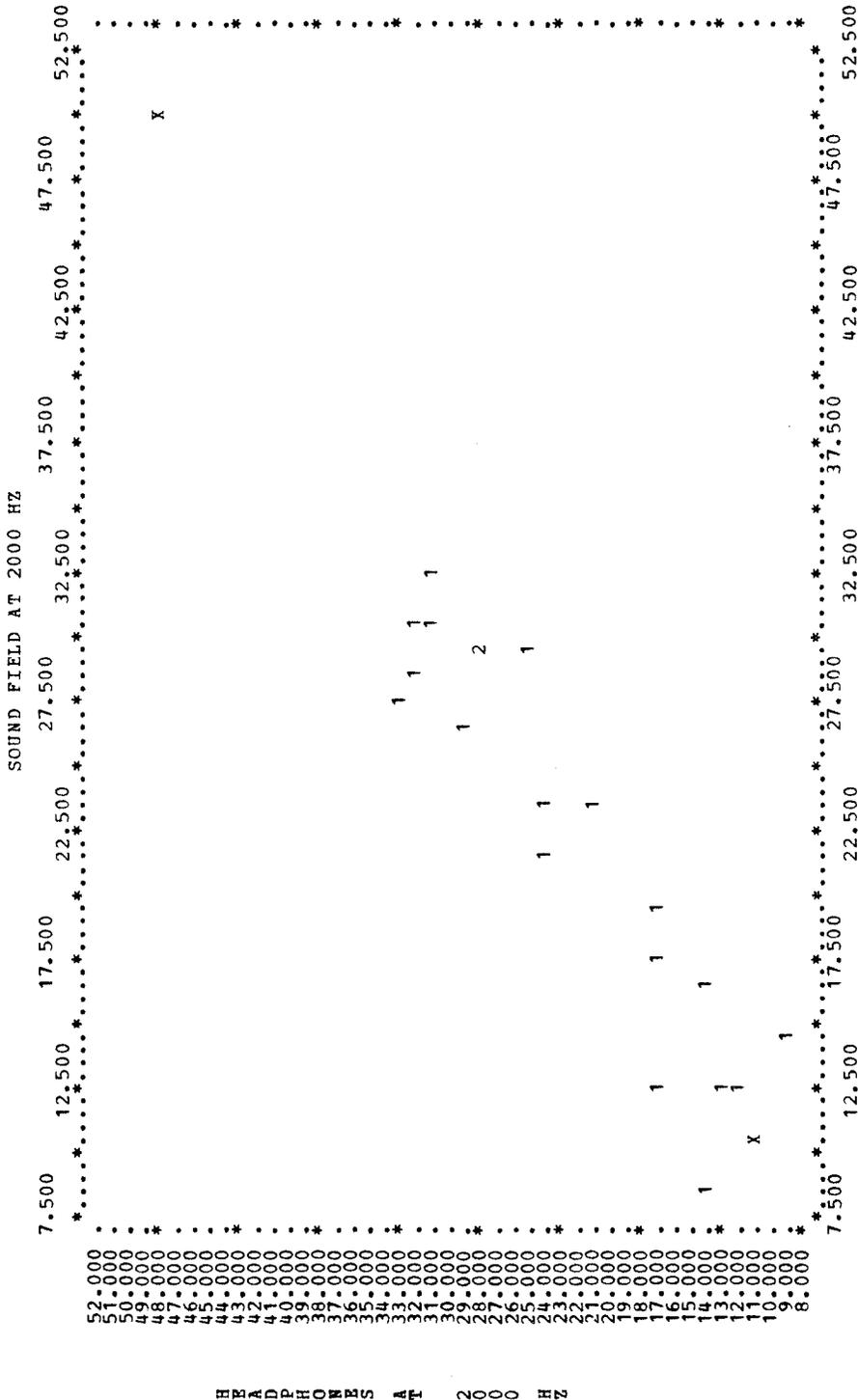
HEADPHONES ATTENUATION AT 500 HZ

** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKWENESS	KURTOSIS
X	3	20	11.000	7.262	52.737	26.000	0.0	26.000	0.310	-0.712
Y	12	20	13.400	7.803	60.884	29.000	-2.000	31.000	0.016	-0.429

EQUATION OF REG. LINE Y = 2.51 + 0.9900 X
 STANDARD ERROR OF ESTIMATE 3.28
 CORRELATION COEFFICIENT 0.921

0*EVALUATION OF PROTECTOR 4B*

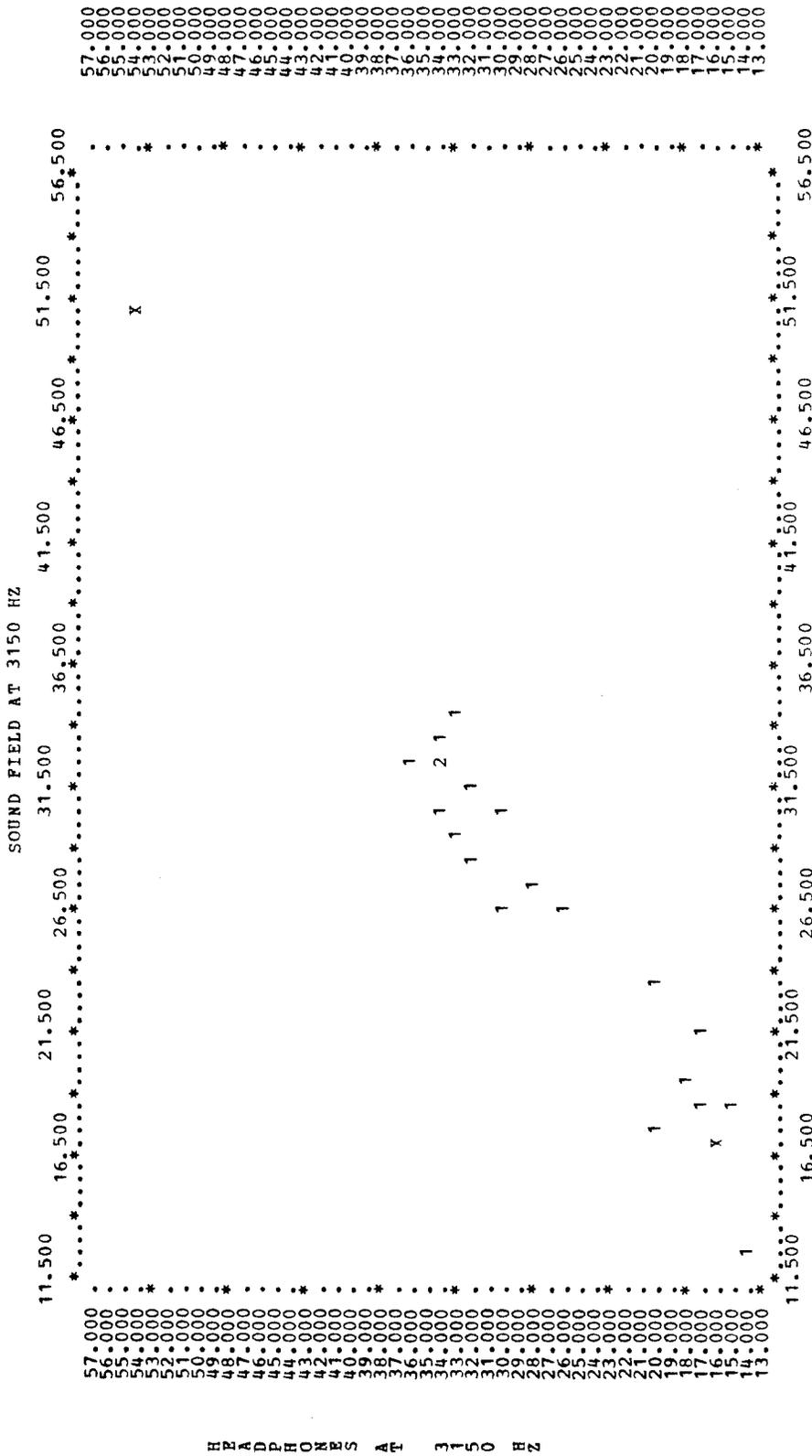


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	5	20	21.850	7.555	57.082	32.000	8.000	24.000	-0.335	-1.294
Y	14	20	22.550	7.844	61.524	33.000	9.000	24.000	-0.185	-1.396

EQUATION OF REG. LINE Y = 1.71 + 0.9540 X
 STANDARD ERROR OF ESTIMATE 3.35
 CORRELATION COEFFICIENT 0.919

0*EVALUATION OF PROTECTOR 4B*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

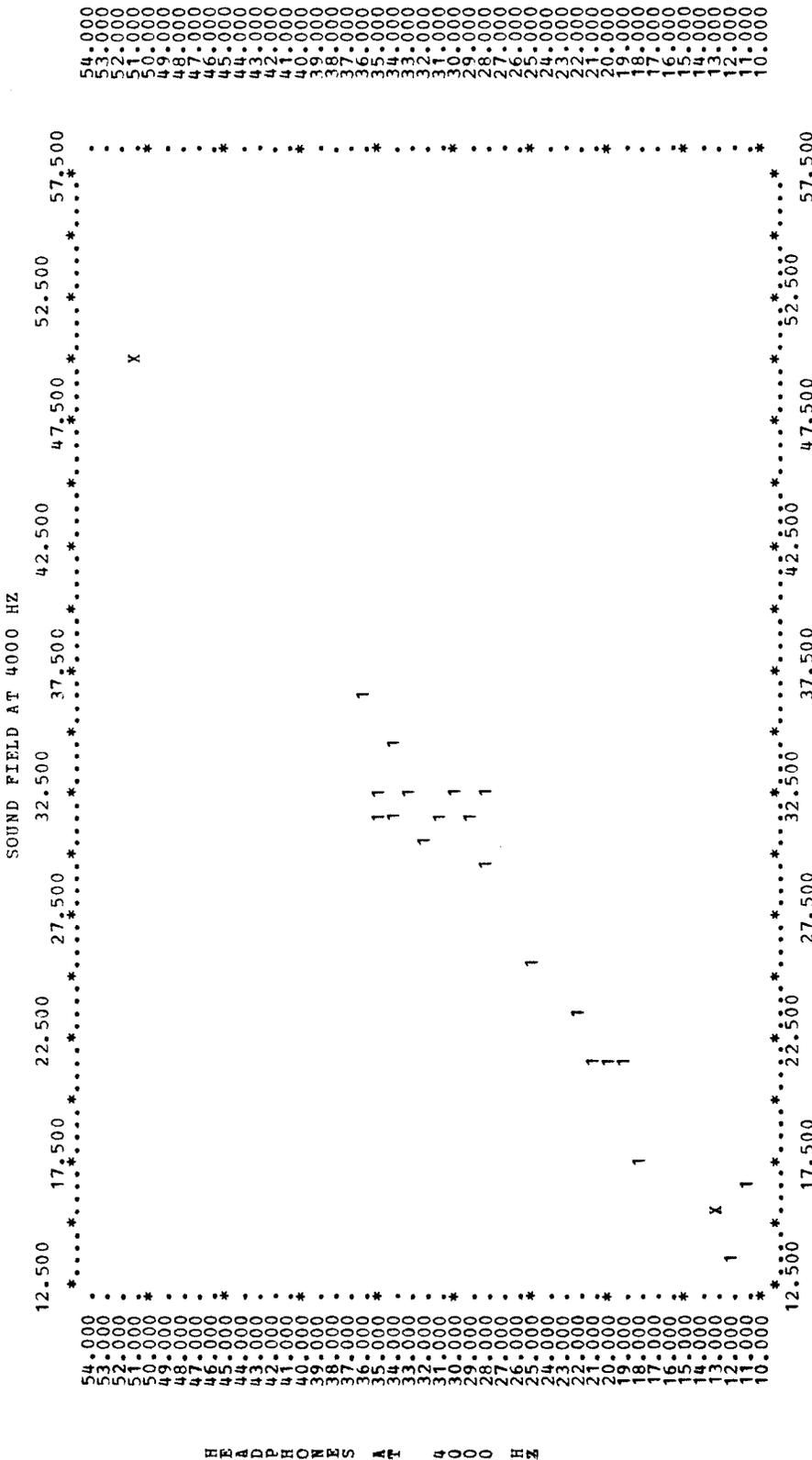
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	6	20	25.900	6.406	41.042	34.000	12.000	22.000	-0.609	-0.807
Y	15	20	26.850	7.645	58.450	36.000	14.000	22.000	-0.484	-1.406

EQUATION OF REG. LINE Y = -2.50 + 1.1332 X

STANDARD ERROR OF ESTIMATE 2.60

CORRELATION COEFFICIENT 0.950

O*EVALUATION OF PROTECTOR 4B*

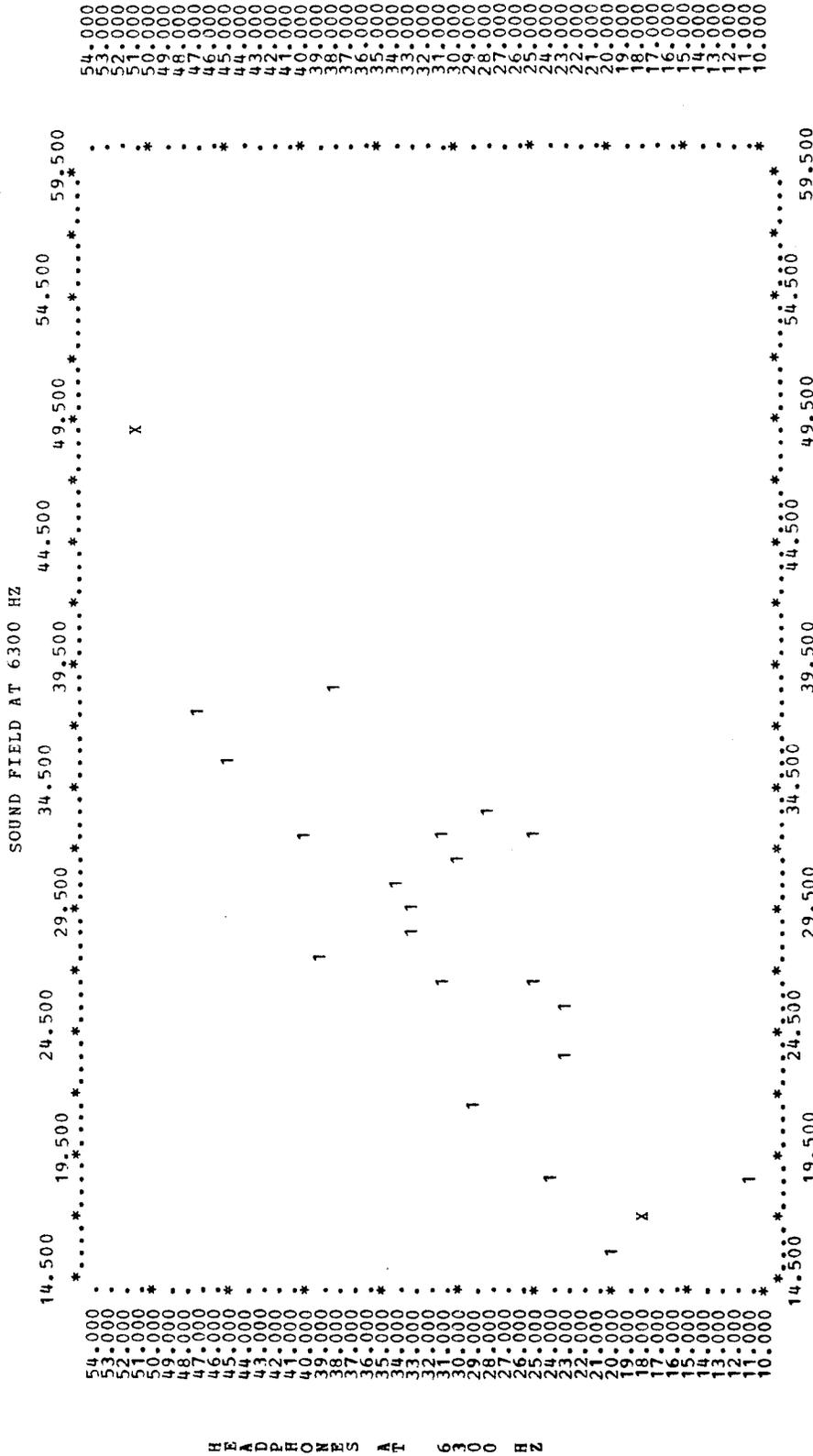


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	26.900	6.696	44.832	36.000	13.000	23.000	-0.661	-0.842
Y	16	20	26.650	7.734	59.818	36.000	11.000	25.000	-0.622	-0.760

EQUATION OF REG. LINE Y = -3.23 + 1.1109 X
 STANDARD ERROR OF ESTIMATE 2.29
 CORRELATION COEFFICIENT 0.962

0*EVALUATION OF PROTECTOR 4B*



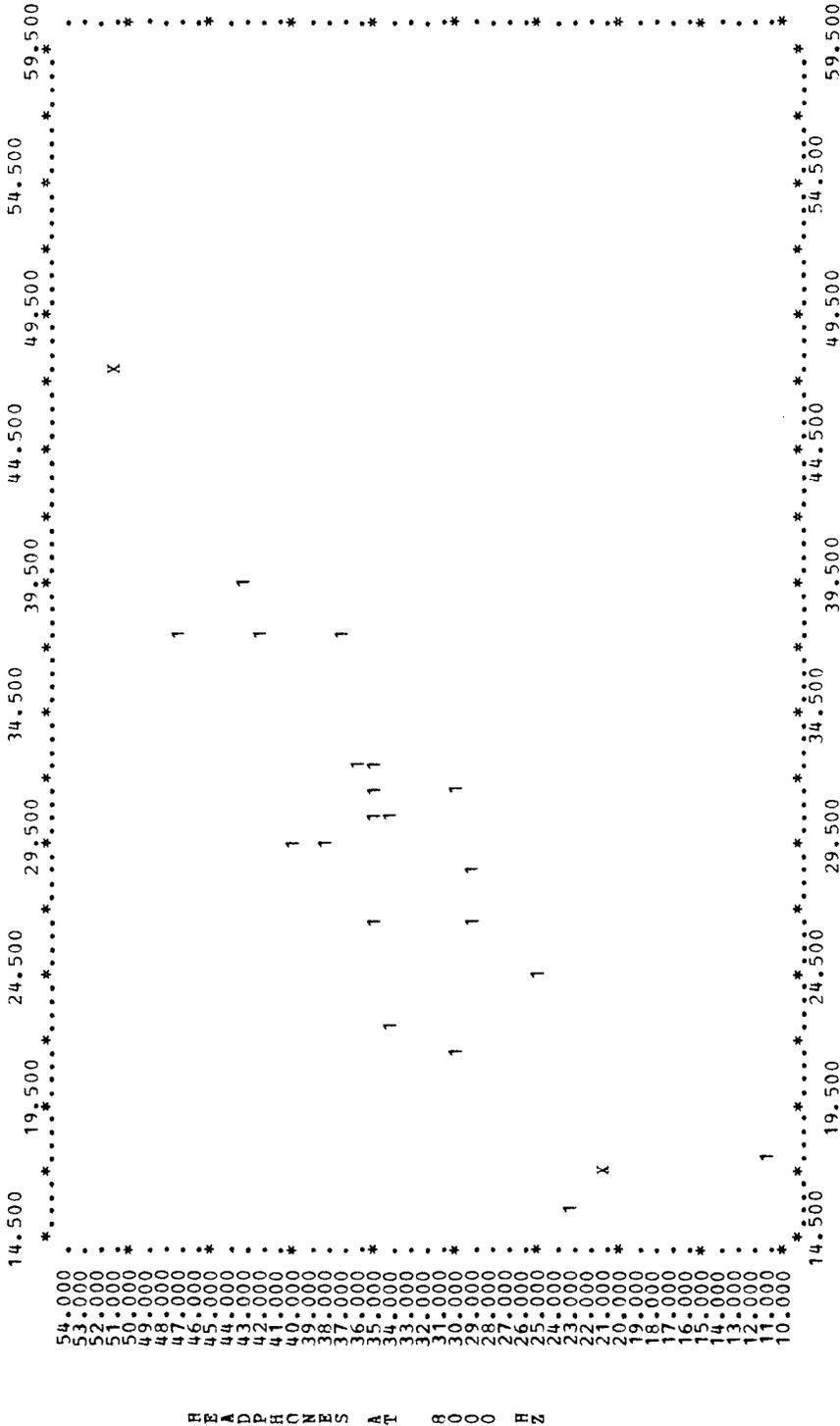
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	27.800	6.396	40.905	38.000	15.000	23.000	-0.375	-0.665
Y	17	20	30.450	8.709	75.840	47.000	11.000	36.000	-0.026	-0.094

EQUATION OF REG. LINE Y = 1.59 + 1.0381 X
 STANDARD ERROR OF ESTIMATE 6.10
 CORRELATION COEFFICIENT 0.762

0*EVALUATION OF PROTECTOR 4B*

SOUND FIELD AT 8000 HZ

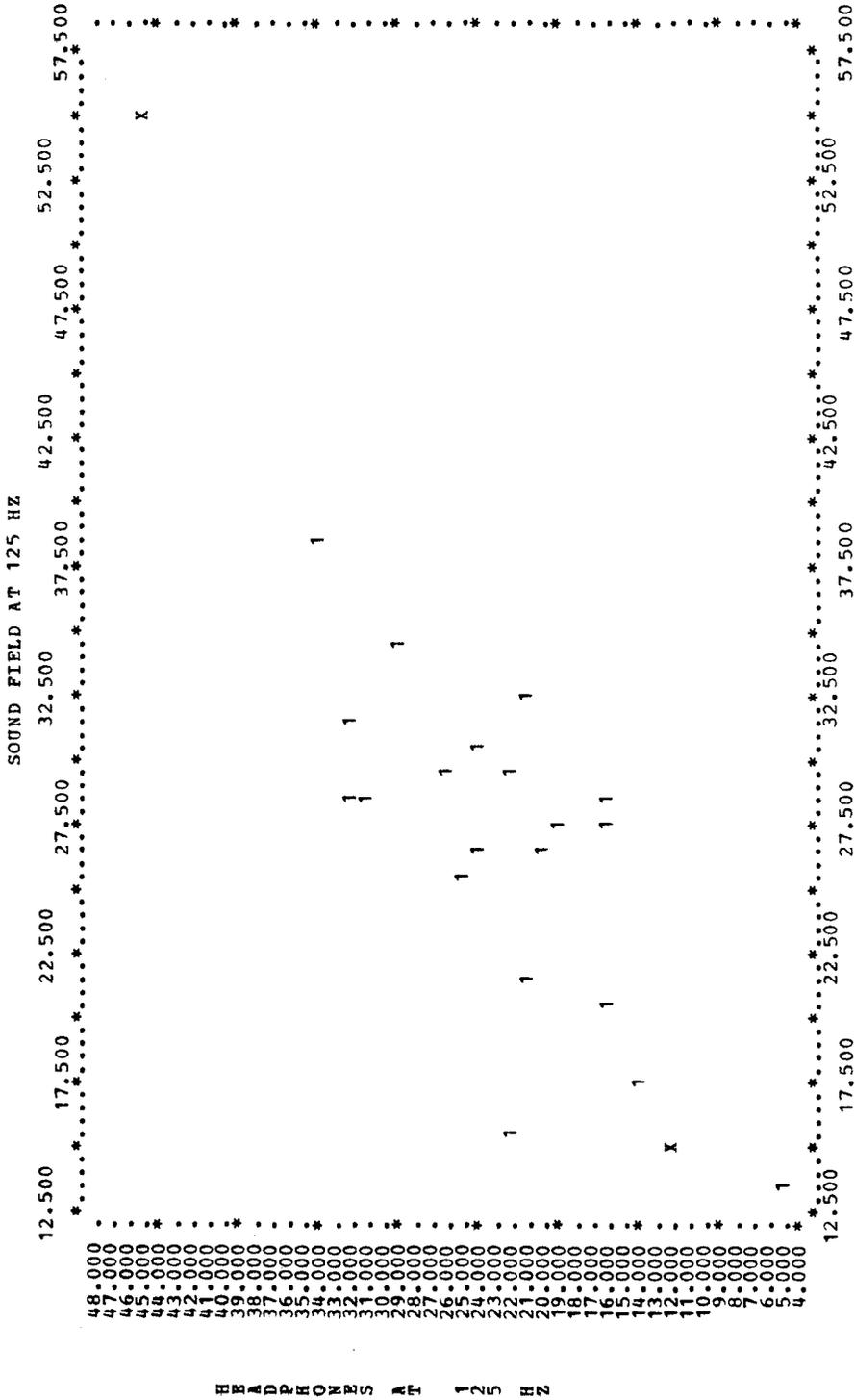


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	9	20	28.650	6.548	42.871	39.000	15.000	24.000	-0.393	-0.424
Y	18	20	33.400	7.910	62.568	47.000	11.000	36.000	-0.950	1.552

EQUATION OF REG. LINE Y = 5.06 + 0.9893 X
 STANDARD ERROR OF ESTIMATE 4.92
 CORRELATION COEFFICIENT 0.819

0*EVALUATION OF PROTECTOR 5A*



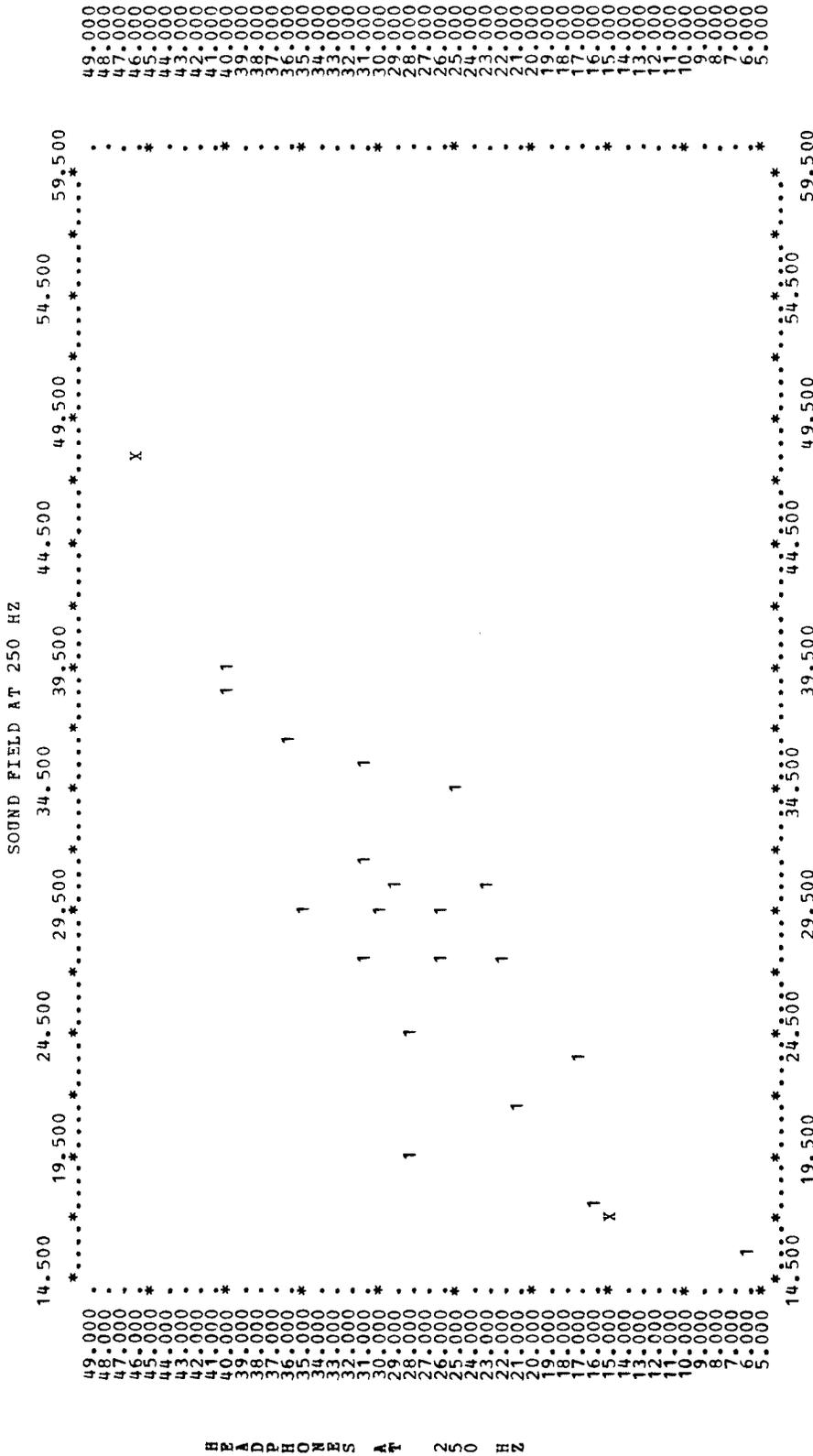
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKWENESS	KURTOSIS
X	1	20	26.200	6.279	39.432	38.000	13.000	25.000	-0.507	-0.129
Y	10	20	22.450	7.178	51.524	34.000	5.000	29.000	-0.369	0.027

EQUATION OF REG. LINE Y = 1.11 + 0.8145 X

STANDARD ERROR OF ESTIMATE 5.45

CORRELATION COEFFICIENT 0.713

0*EVALUATION OF PROTECTOR 5A*

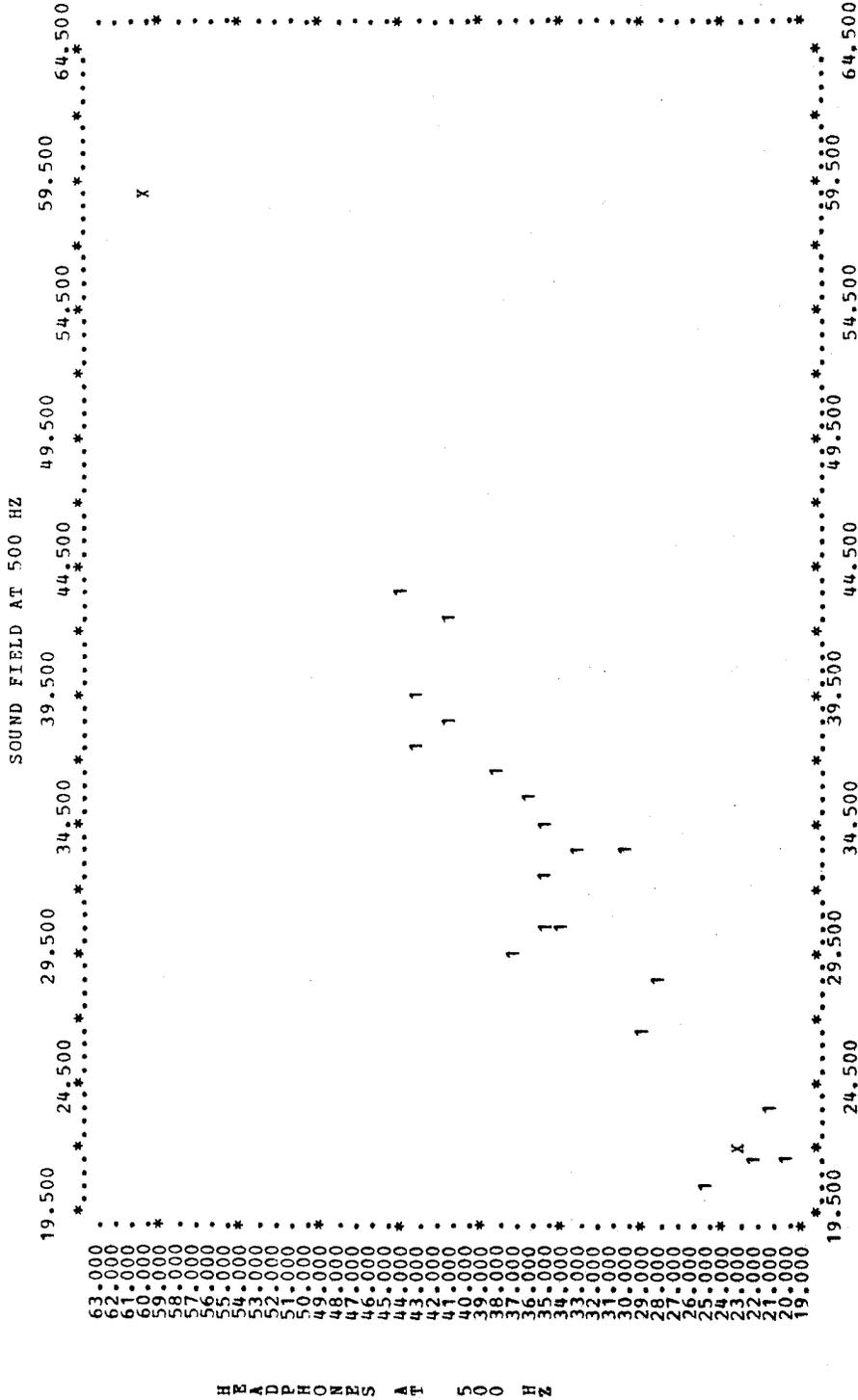


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	1	20	28.000	6.704	44.947	39.000	15.000	24.000	-0.241	-0.653
Y	2	20	27.050	8.243	67.945	40.000	6.000	34.000	-0.611	0.495

EQUATION OF REG. LINE Y = -0.95 + 1.0000 X
 STANDARD ERROR OF ESTIMATE 5.19
 CORRELATION COEFFICIENT 0.813

0*EVALUATION OF PROTECTOR 5A*

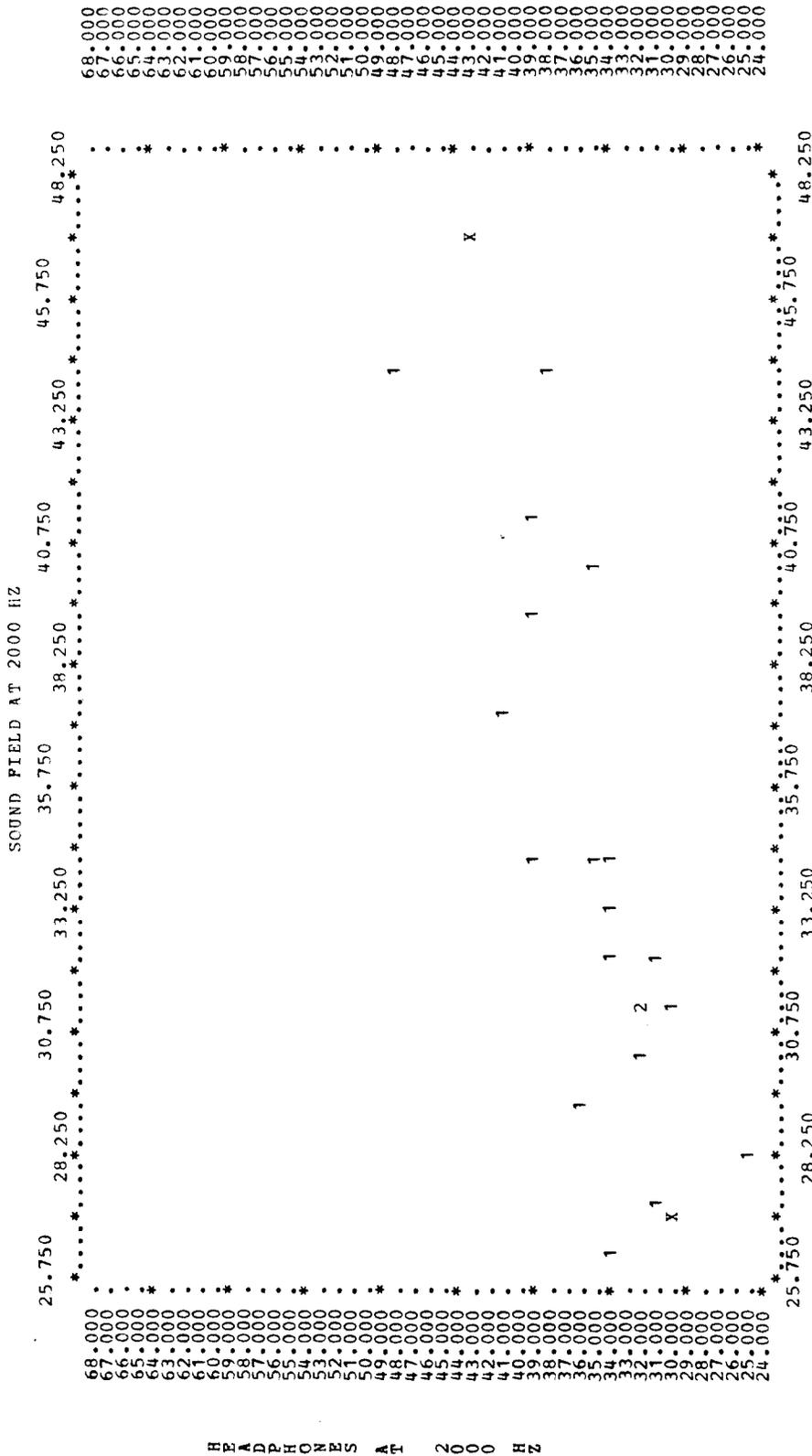


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	3	20	31.500	6.856	47.000	43.000	20.000	23.000	-0.165	-0.887
Y	12	20	33.500	7.452	55.526	44.000	20.000	24.000	-0.388	-0.894

EQUATION OF REG. LINE Y = 1.82 + 1.0056 X
 STANDARD ERROR OF ESTIMATE 3.06
 CORRELATION COEFFICIENT 0.925

0*EVALUATION OF PROTECTOR 5A*



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	5	20	33.850	5.354	28.661	44.000	26.000	18.000	0.562	-0.691
Y	14	20	34.950	4.872	23.734	48.000	25.000	23.000	0.636	1.166

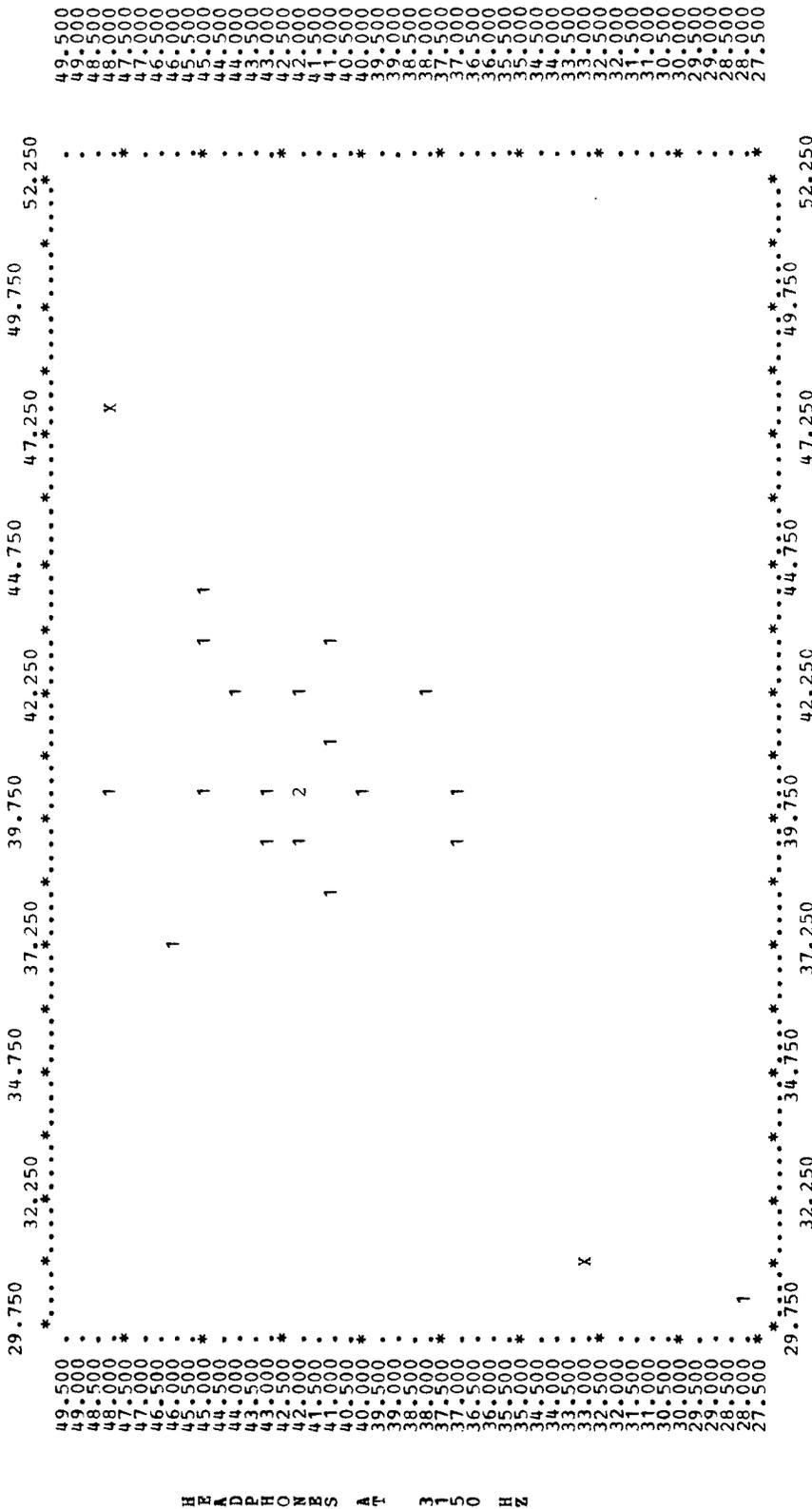
EQUATION OF REG. LINE Y = 11.77 + 0.6847 X

STANDARD ERROR OF ESTIMATE 3.48

CORRELATION COEFFICIENT 0.752

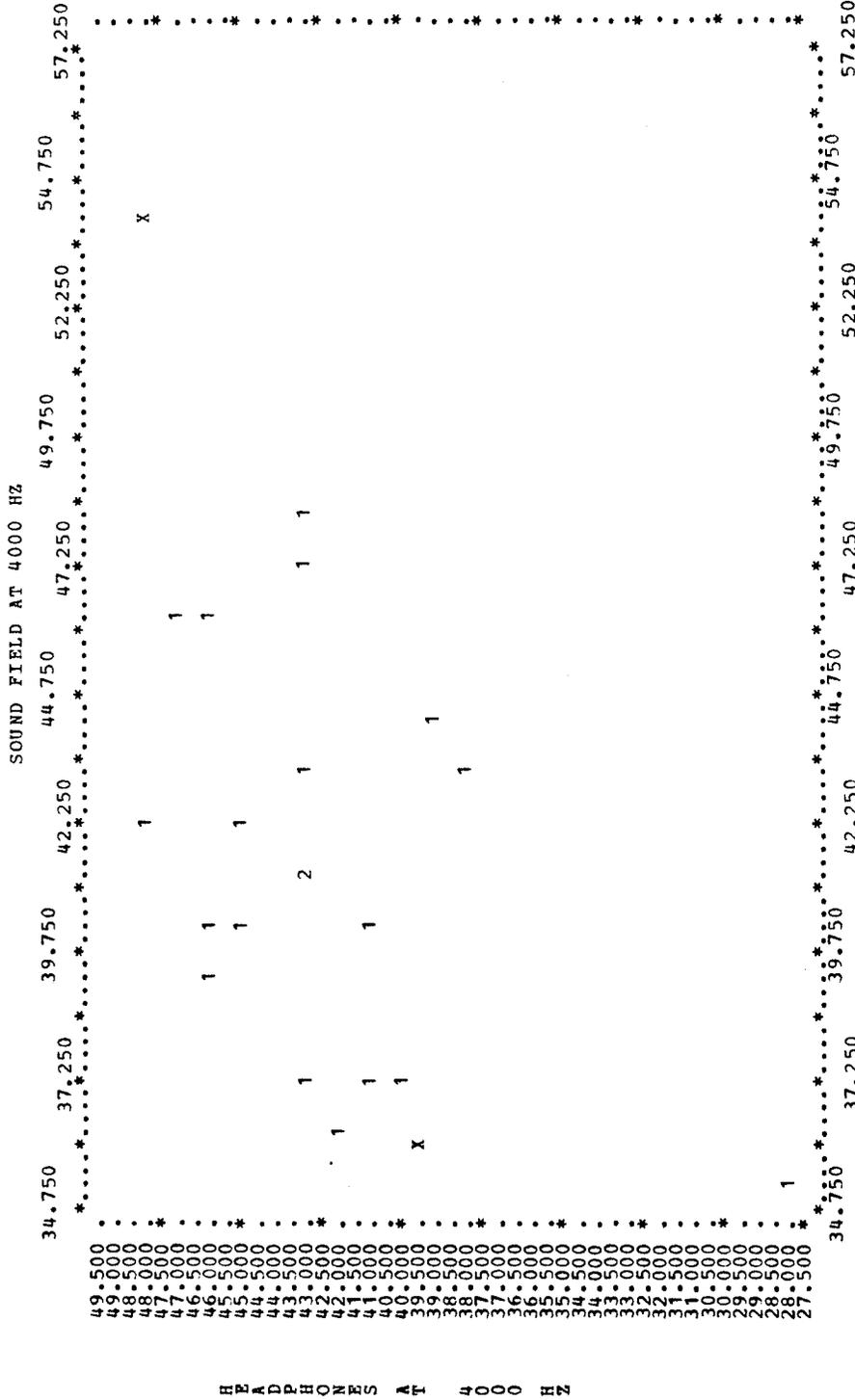
0*EVALUATION OF PROTECTOR 5A*

SOUND FIELD AT 3150 HZ



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

0*EVALUATION OF PROTECTOR 5A*

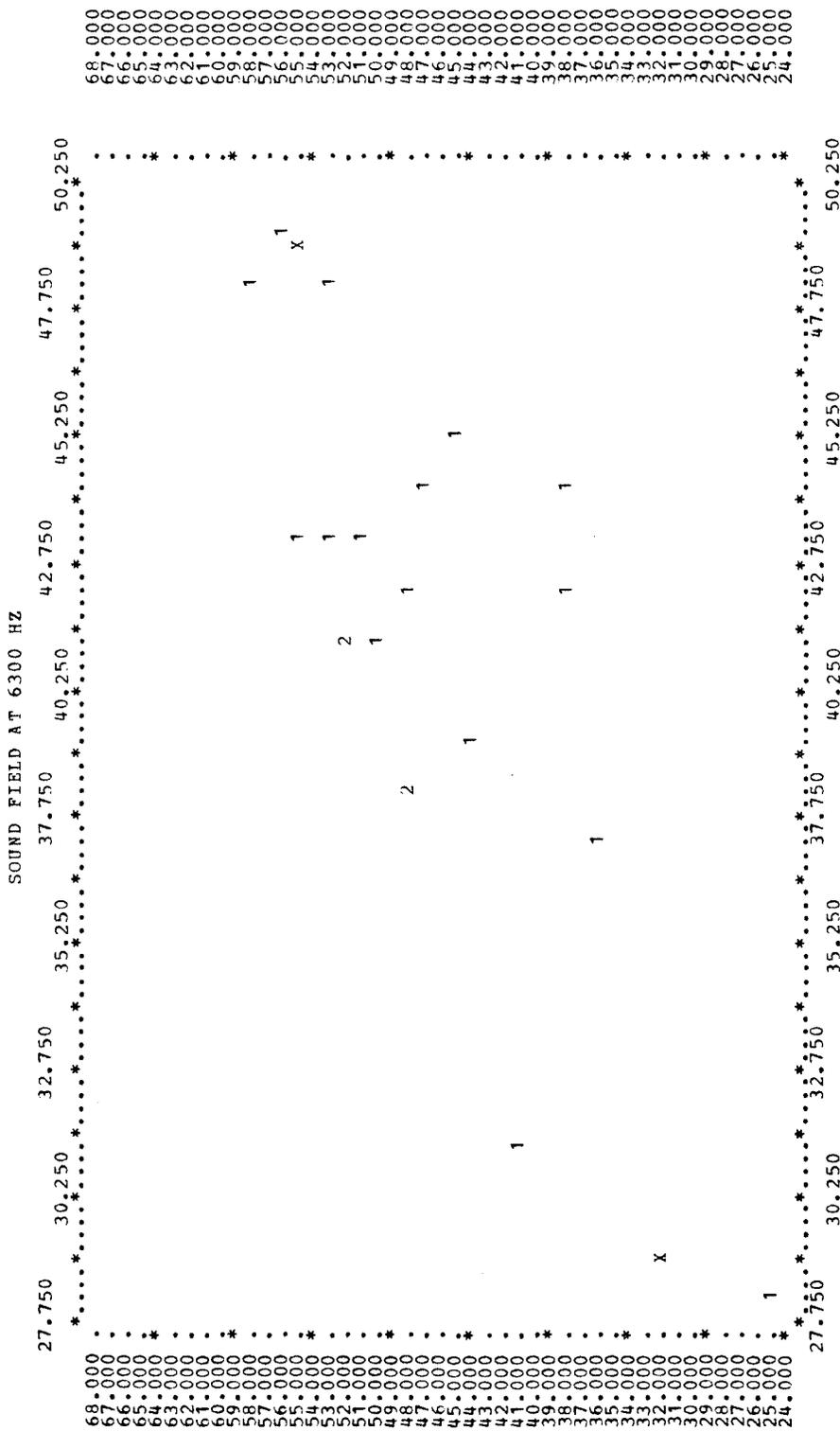


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	41.200	3.764	14.169	48.000	35.000	13.000	0.150	-0.906
Y	16	20	42.500	4.323	18.684	48.000	28.000	20.000	-1.863	4.406

EQUATION OF REG. LINE Y = 22.91 + 0.4755 X
 STANDARD ERROR OF ESTIMATE 4.26
 CORRELATION COEFFICIENT 0.414

0*EVALUATION OF PROTECTOR 5A*

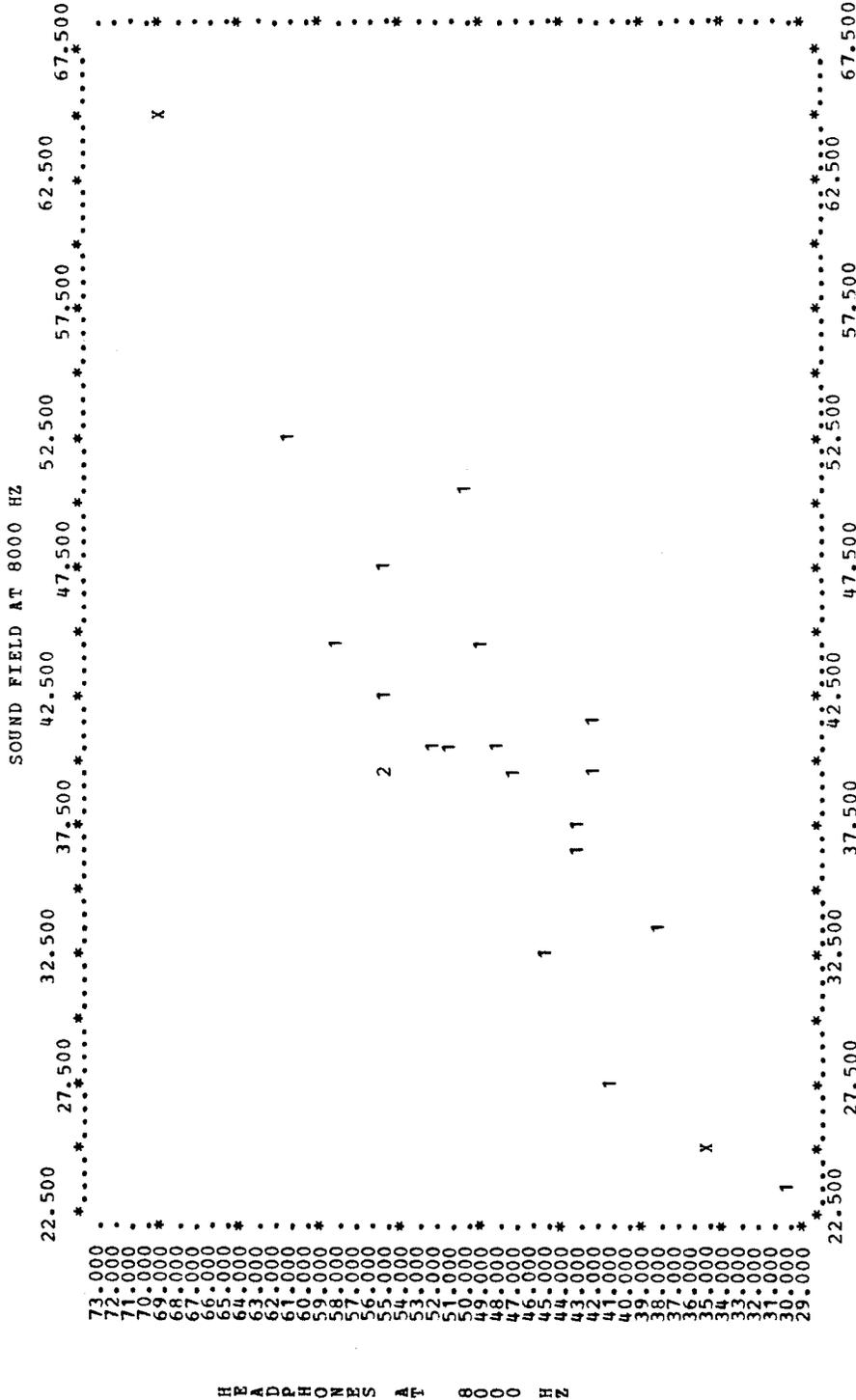


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	20	41.250	5.210	27.145	49.000	28.000	21.000	-0.904	0.800
Y	17	20	46.900	8.052	64.832	58.000	25.000	33.000	-1.031	0.807

EQUATION OF REG. LINE Y = 0.95 + 1.1139 X
 STANDARD ERROR OF ESTIMATE 6.04
 CORRELATION COEFFICIENT 0.721

0*EVALUATION OF PROTECTOR 5A*



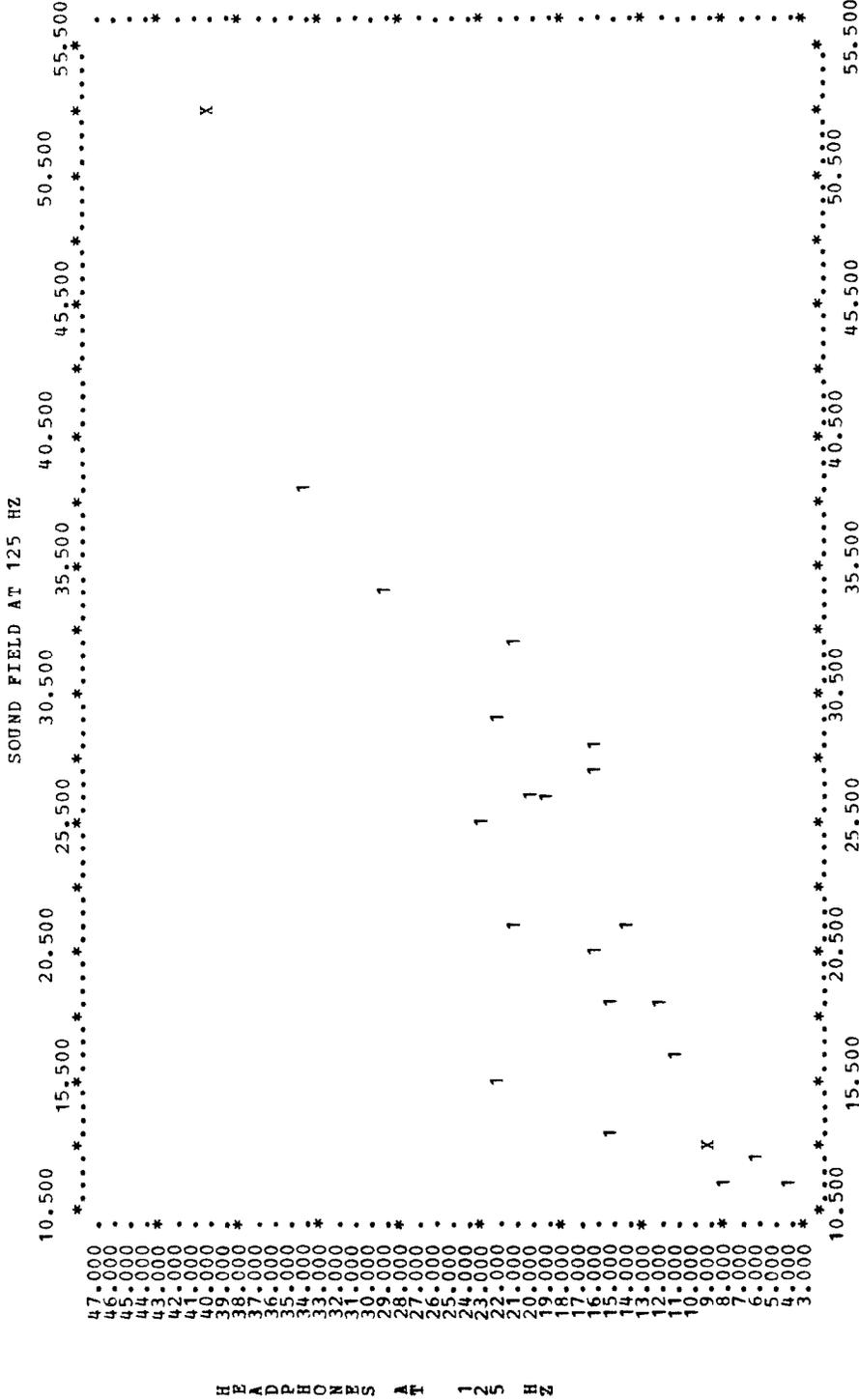
VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	9	20	39.200	6.948	48.274	52.000	23.000	29.000	-0.425	0.343
Y	18	20	48.000	7.609	57.895	61.000	30.000	31.000	-0.394	-0.193

EQUATION OF REG. LINE Y = 13.98 + 0.8679 X

STANDARD ERROR OF ESTIMATE 5.03

CORRELATION COEFFICIENT 0.792

0*EVALUATION OF PROTECTOR 5B*

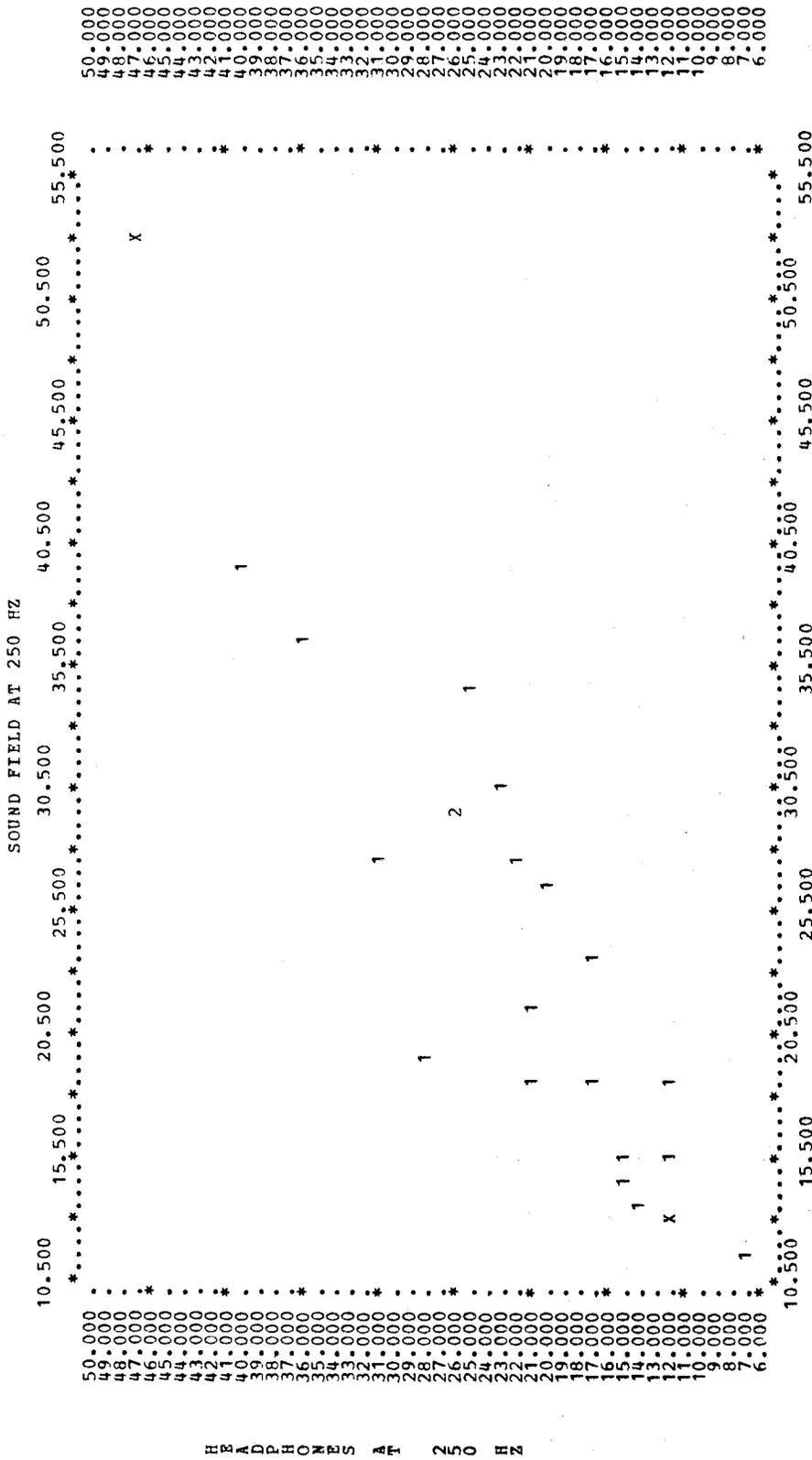


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	1	20	22.050	7.937	62.997	38.000	11.000	27.000	0.259	-0.895
Y	10	20	17.200	7.310	53.432	34.000	4.000	30.000	0.279	0.054

EQUATION OF REG. LINE Y = 0.29 + 0.7668 X
 STANDARD ERROR OF ESTIMATE 4.38
 CORRELATION COEFFICIENT 0.833

0*EVALUATION OF PROTECTOR 5b*

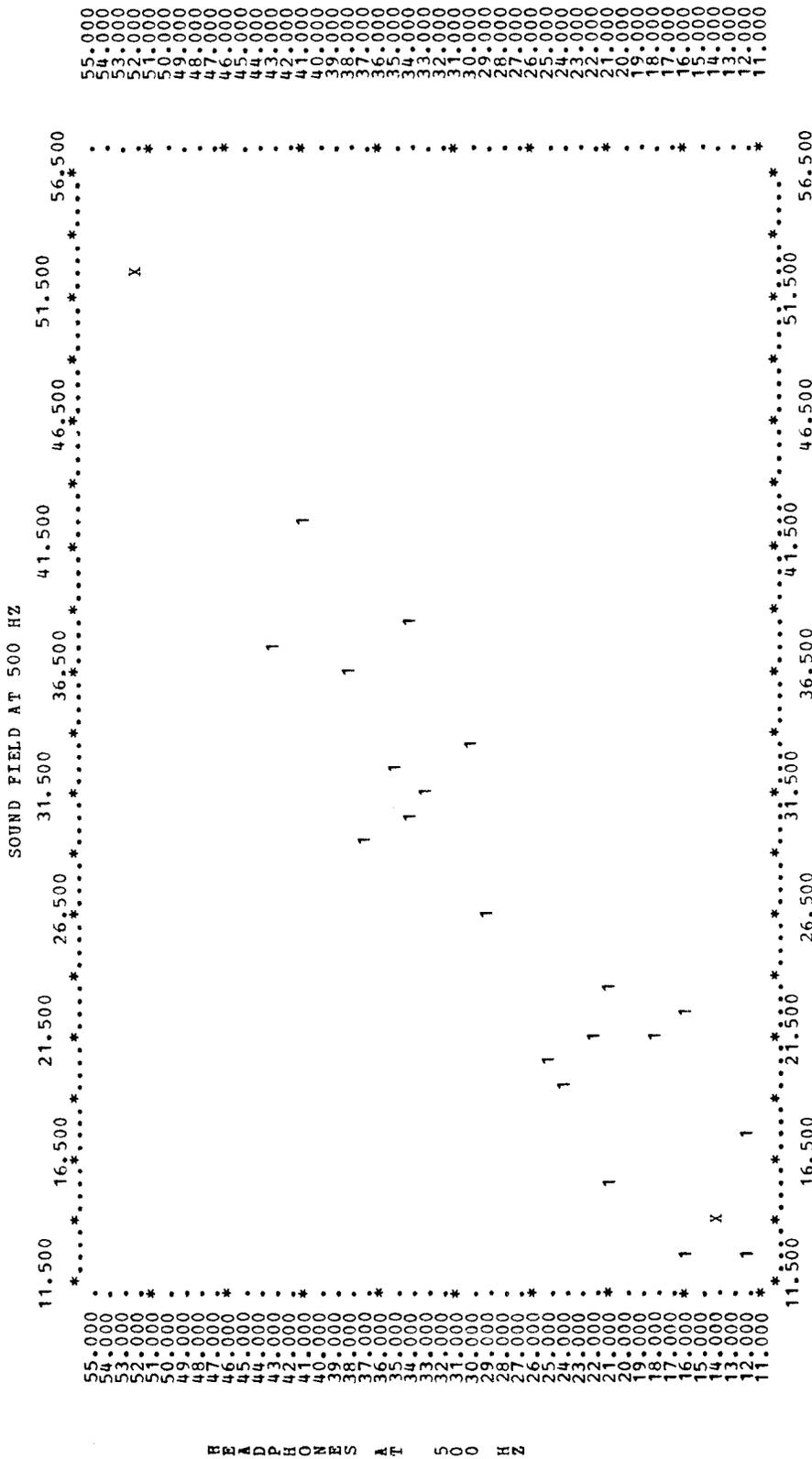


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	2	20	23.100	8.130	66.095	39.000	11.000	28.000	0.327	-0.963
Y	11	20	21.400	8.319	69.200	40.000	7.000	33.000	0.489	-0.197

EQUATION OF REG. LINE Y = 1.05 + 0.8809 X
 STANDARD ERROR OF ESTIMATE 4.58
 CORRELATION COEFFICIENT 0.861

0*EVALUATION OF PROTECTOR 5B*

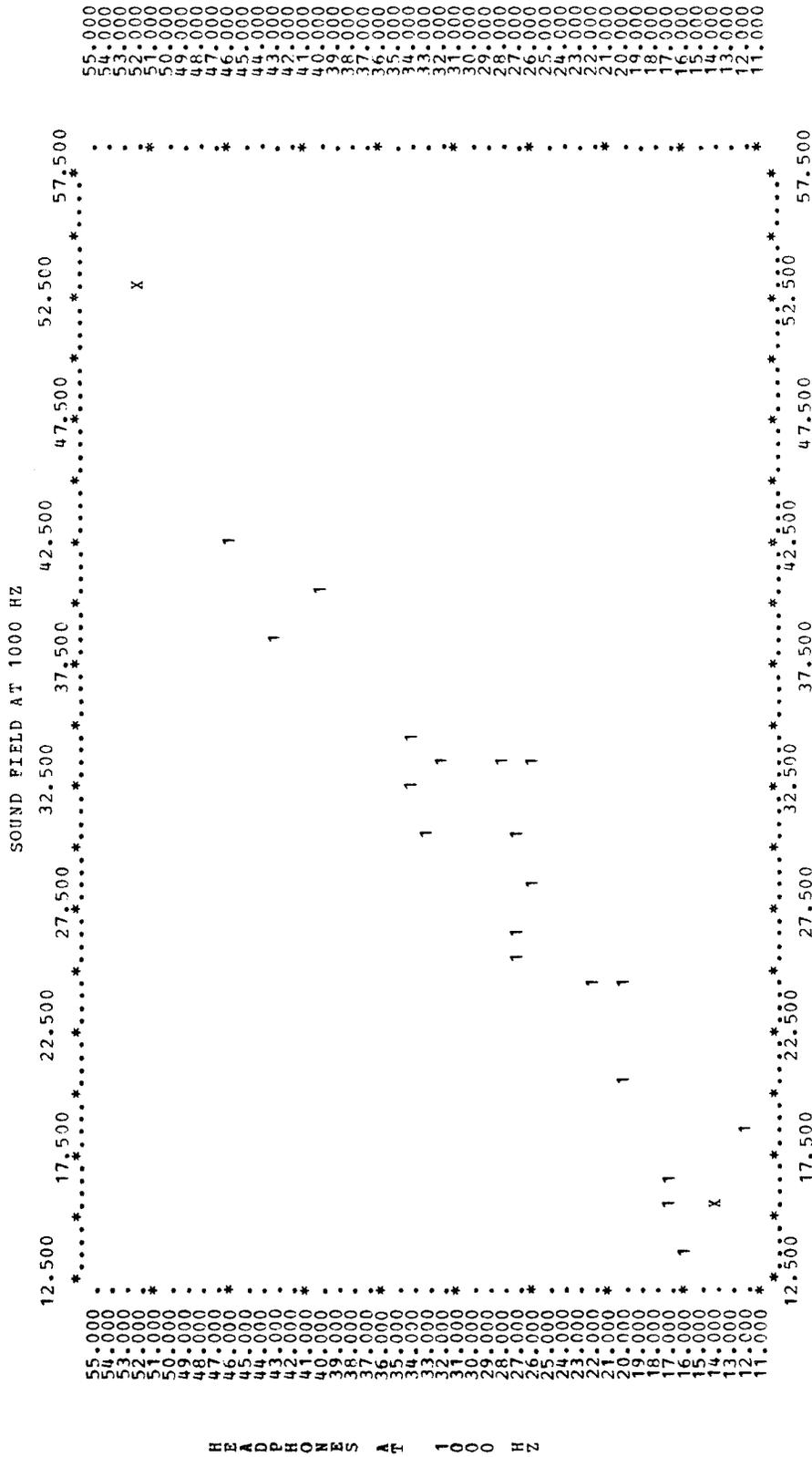


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	3	20	25.800	8.912	79.432	42.000	12.000	30.000	0.106	-1.071
Y	12	20	27.050	9.644	92.997	43.000	12.000	31.000	-0.023	-1.211

EQUATION OF REG. LINE Y = 1.73 + 0.9814 X
 STANDARD ERROR OF ESTIMATE 4.40
 CORRELATION COEFFICIENT 0.907

0*EVALUATION OF PROTECTOR 5B*



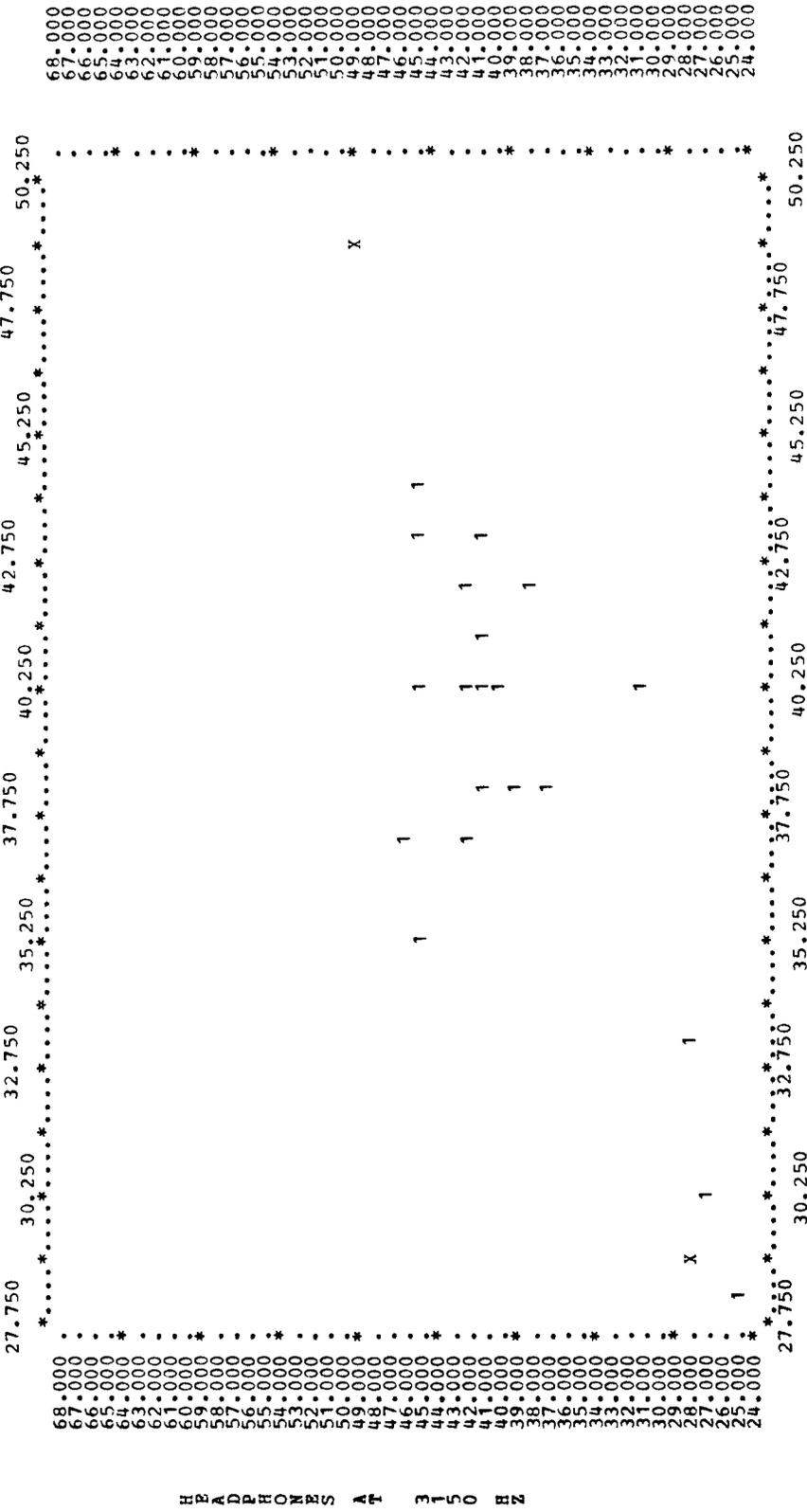
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE.

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	4	20	27.700	8.336	69.484	42.000	13.000	29.000	-0.153	-0.882
Y	13	20	27.350	9.218	84.976	46.000	12.000	34.000	0.342	-0.593

EQUATION OF REG. LINE Y = -1.19 + 1.0302 X
 STANDARD ERROR OF ESTIMATE 3.63
 CORRELATION COEFFICIENT 0.932

0*EVALUATION OF PROTECTOR 5B*

SOUND FIELD AT 3150 HZ

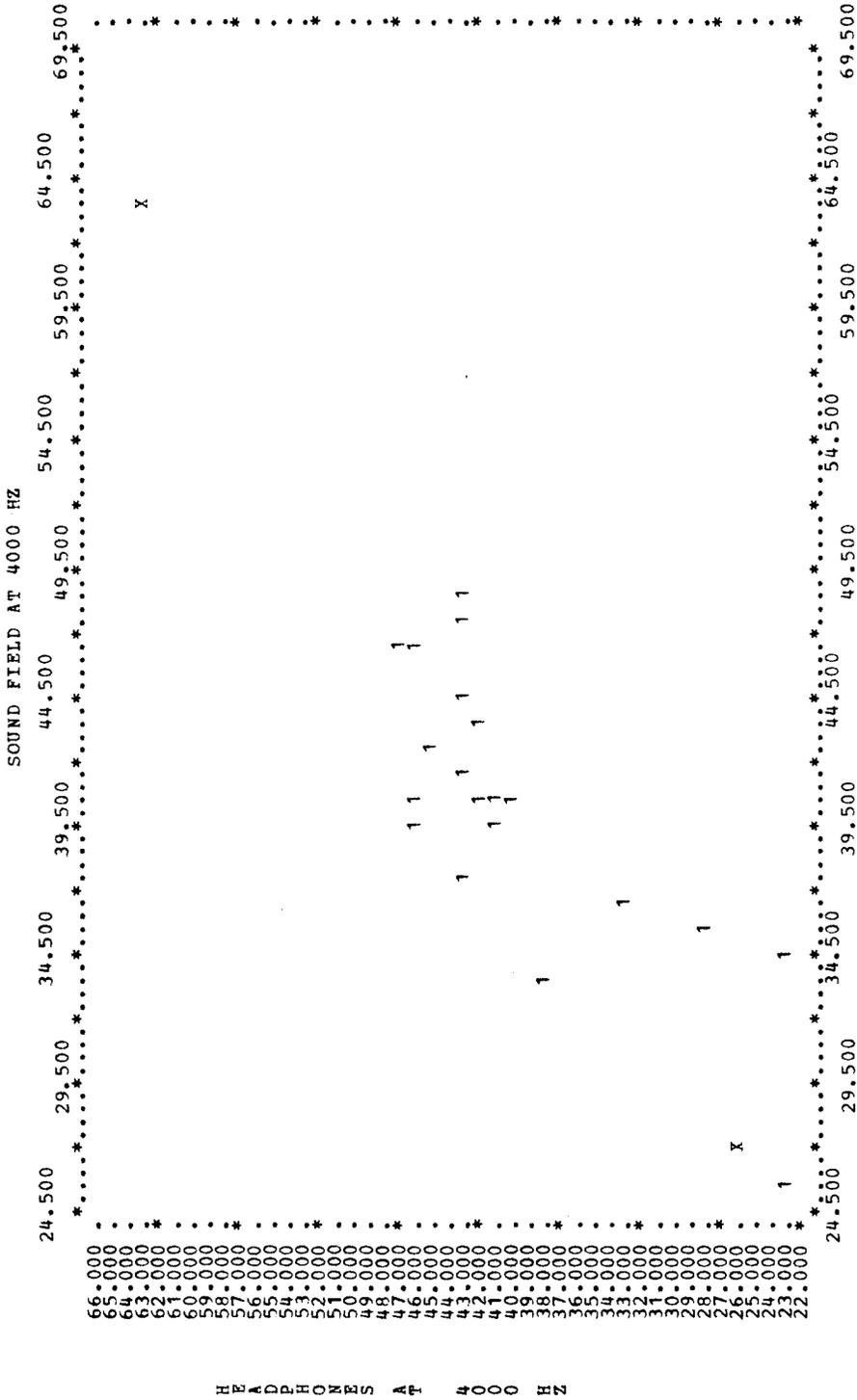


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	6	20	38.450	4.249	18.050	44.000	28.000	16.000	-1.035	0.444
Y	15	20	39.050	6.353	40.366	46.000	25.000	21.000	-1.078	-0.048

EQUATION OF REG. LINE Y = -1.37 + 1.0513 X
 STANDARD ERROR OF ESTIMATE 4.89
 CORRELATION COEFFICIENT 0.703

0*EVALUATION OF PROTECTOR 5B*



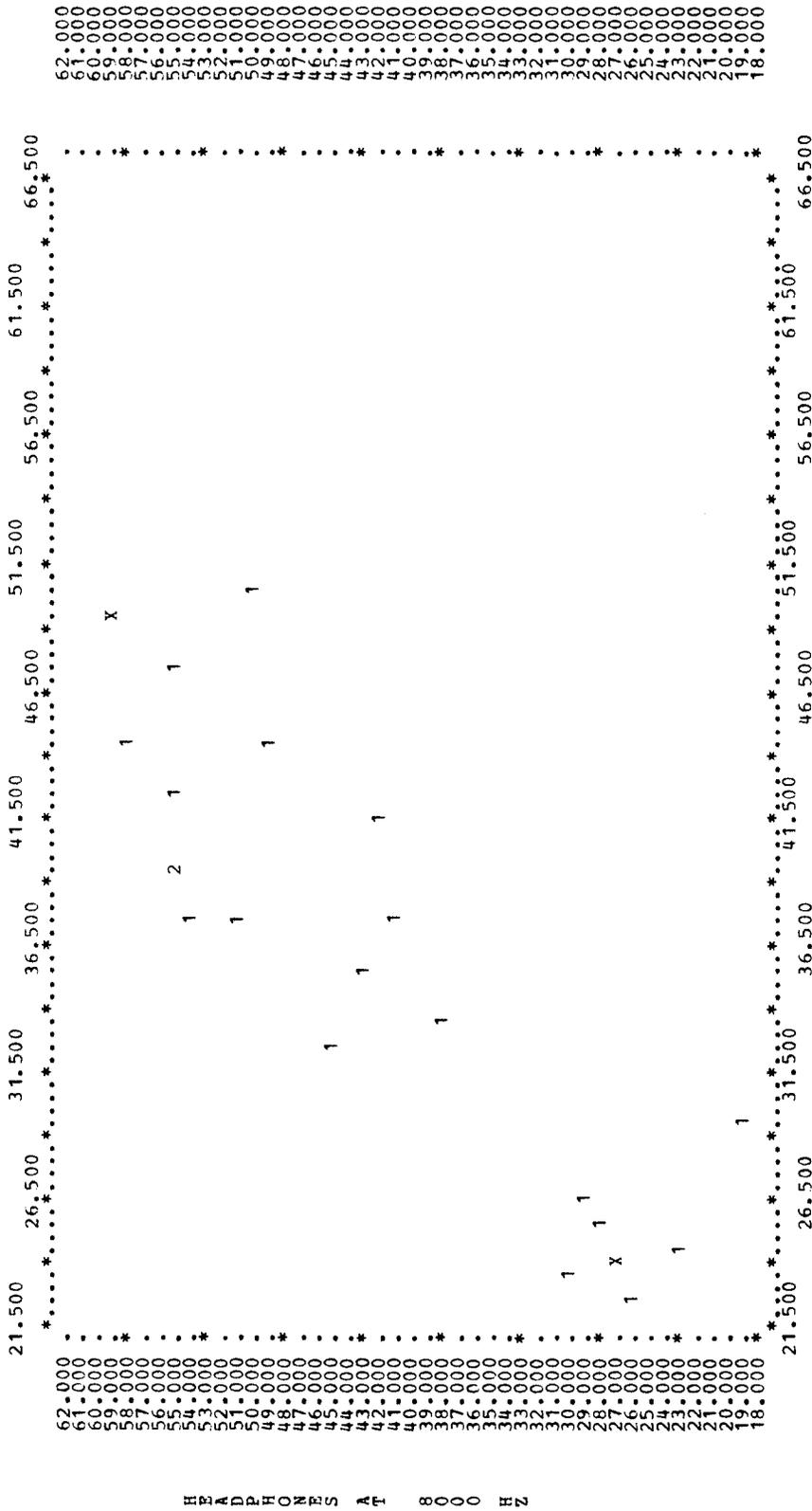
** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	20	39.750	5.505	30.303	48.000	25.000	23.000	-0.755	0.752
Y	16	20	39.800	7.295	53.221	47.000	23.000	24.000	-1.395	0.702

EQUATION OF REG. LINE Y = -1.35 + 1.0352 X
 STANDARD ERROR OF ESTIMATE 4.93
 CORRELATION COEFFICIENT 0.781

EVALUATION OF PROTECTOR 5B

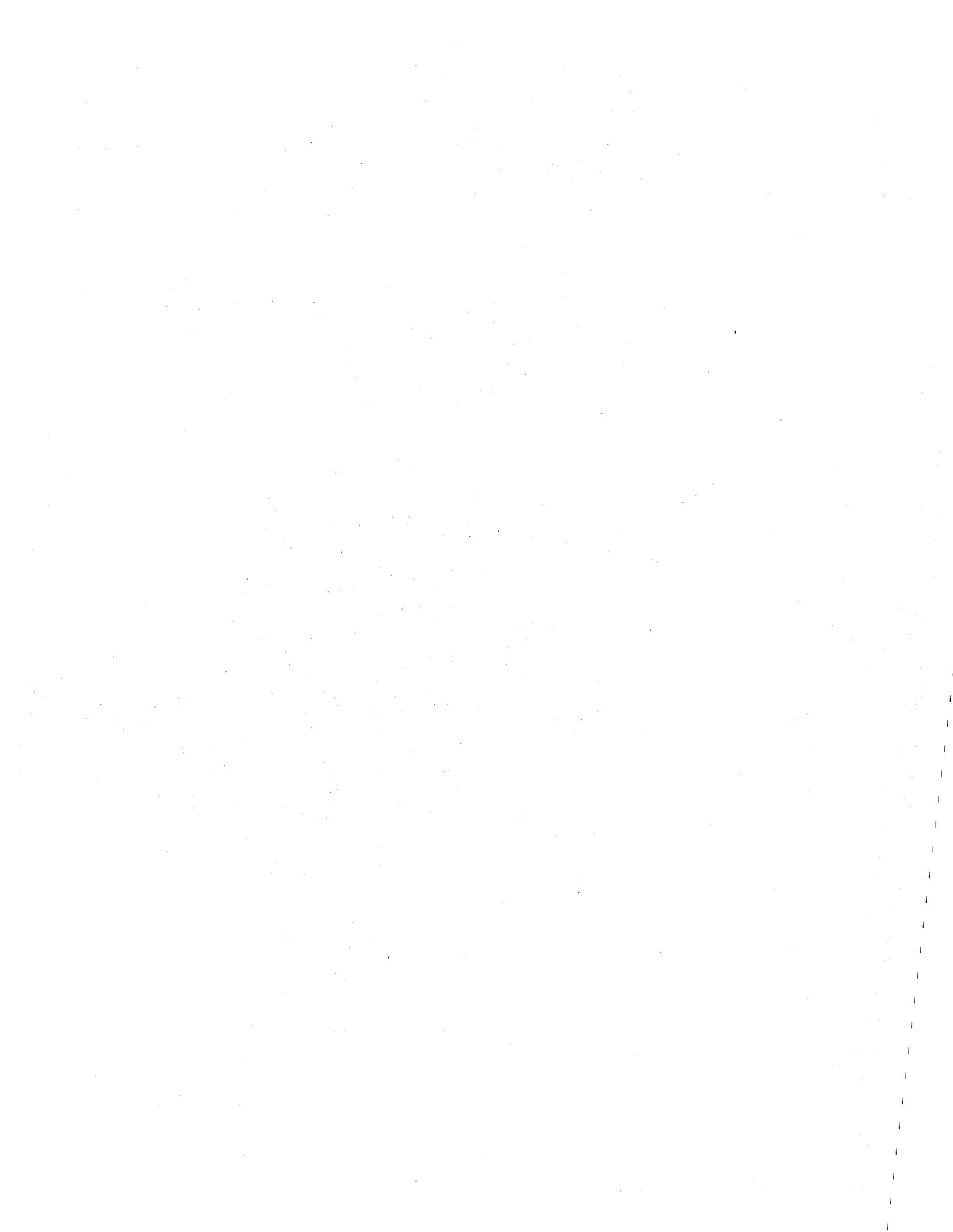
SOUND FIELD AT 8000 HZ



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	9	20	35.300	8.342	69.590	50.000	22.000	28.000	-0.107	-1.040
Y	18	20	42.300	12.461	155.274	58.000	19.000	39.000	-0.455	-1.173

EQUATION OF REG. LINE Y = -2.32 + 1.2640 X
 STANDARD ERROR OF ESTIMATE 7.19
 CORRELATION COEFFICIENT 0.846

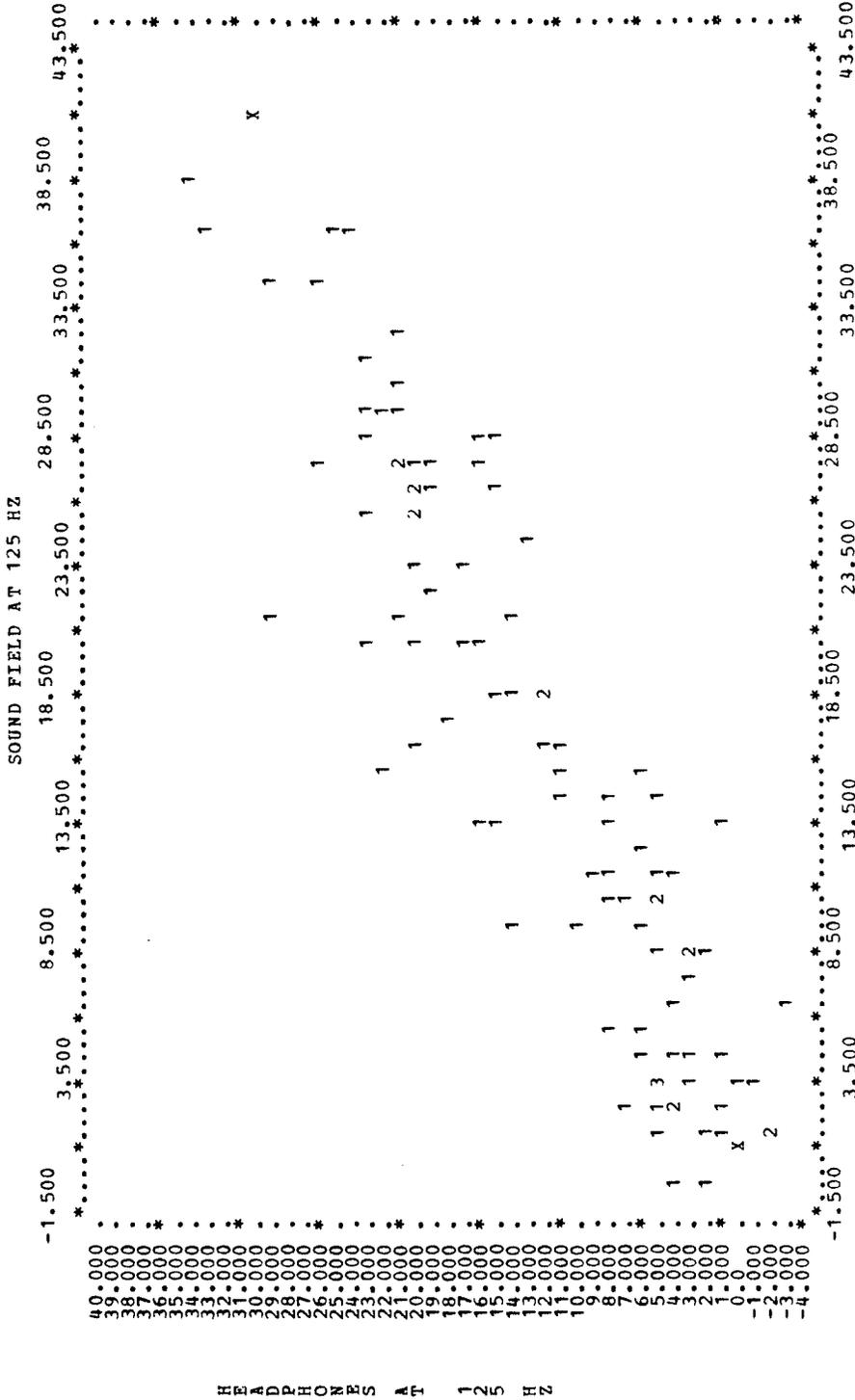


APPENDIX B

SCATTERPLOTS AND COMPUTED RESULTS FOR THE REGRESSION ANALYSES LUMPED ACROSS DATA

The nine sets of scatterplots and computed results that follow are for the regression analyses lumped across data for five models of earplugs that compares values of earplug noise attenuation data measured with the EAL field-method headphones and the ASA/ANSI standard (diffuse sound field) method. Analysis results are presented for each of the nine test signals (one-third-octave bands) that were measured under conditions of retest fit on twenty different subjects for each earplug.

EVALUATION OF FIELD TEST METHOD

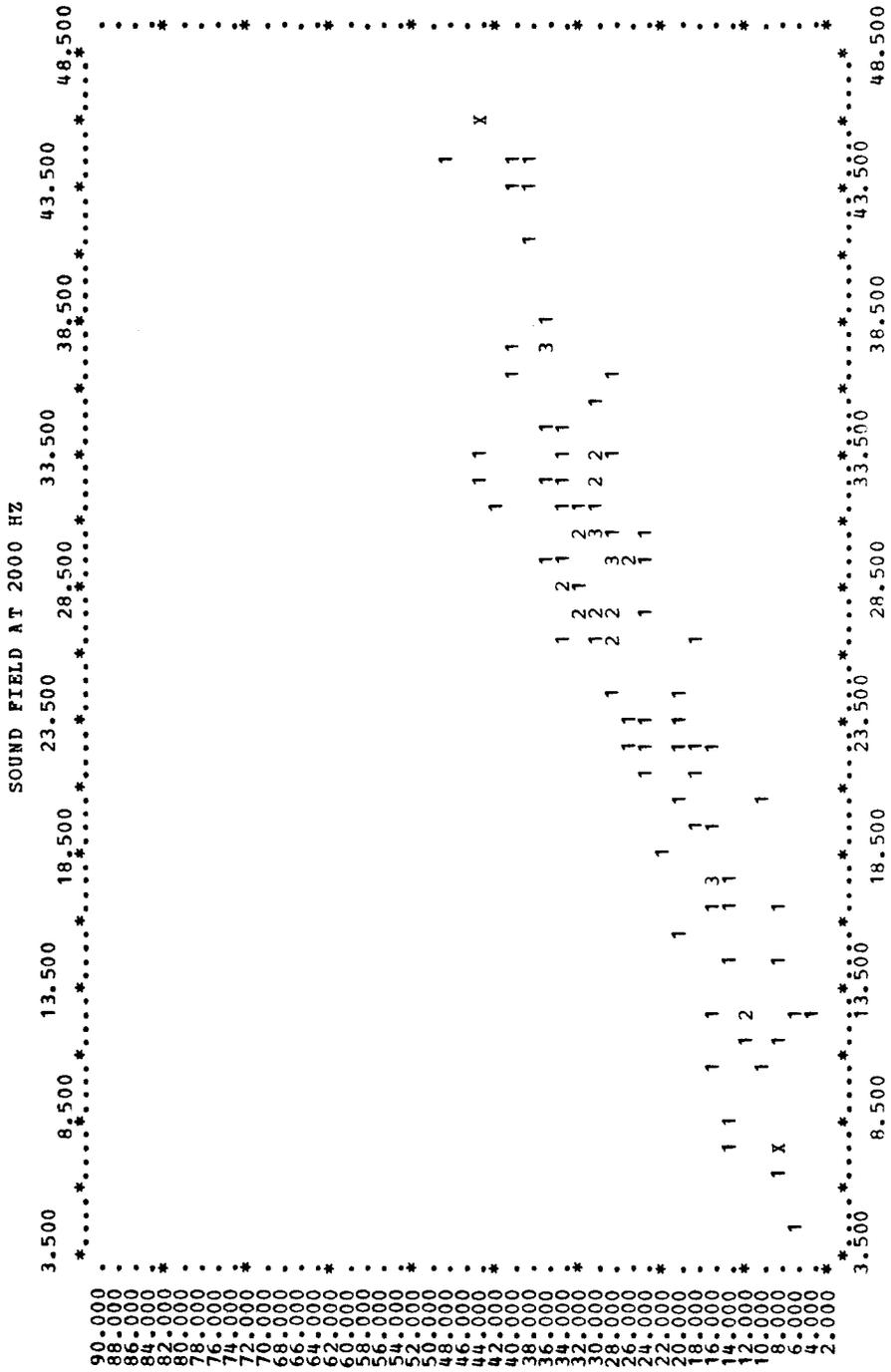


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	1	100	15.610	10.620	112.786	38.000	-1.000	39.000	0.229	-1.096
Y	10	100	12.220	8.803	77.486	34.000	-3.000	37.000	0.300	-0.903

EQUATION OF REG. LINE Y = 0.53 + 0.7487 X
 STANDARD ERROR OF ESTIMATE 3.80
 CORRELATION COEFFICIENT 0.903

EVALUATION OF FIELD TEST METHOD

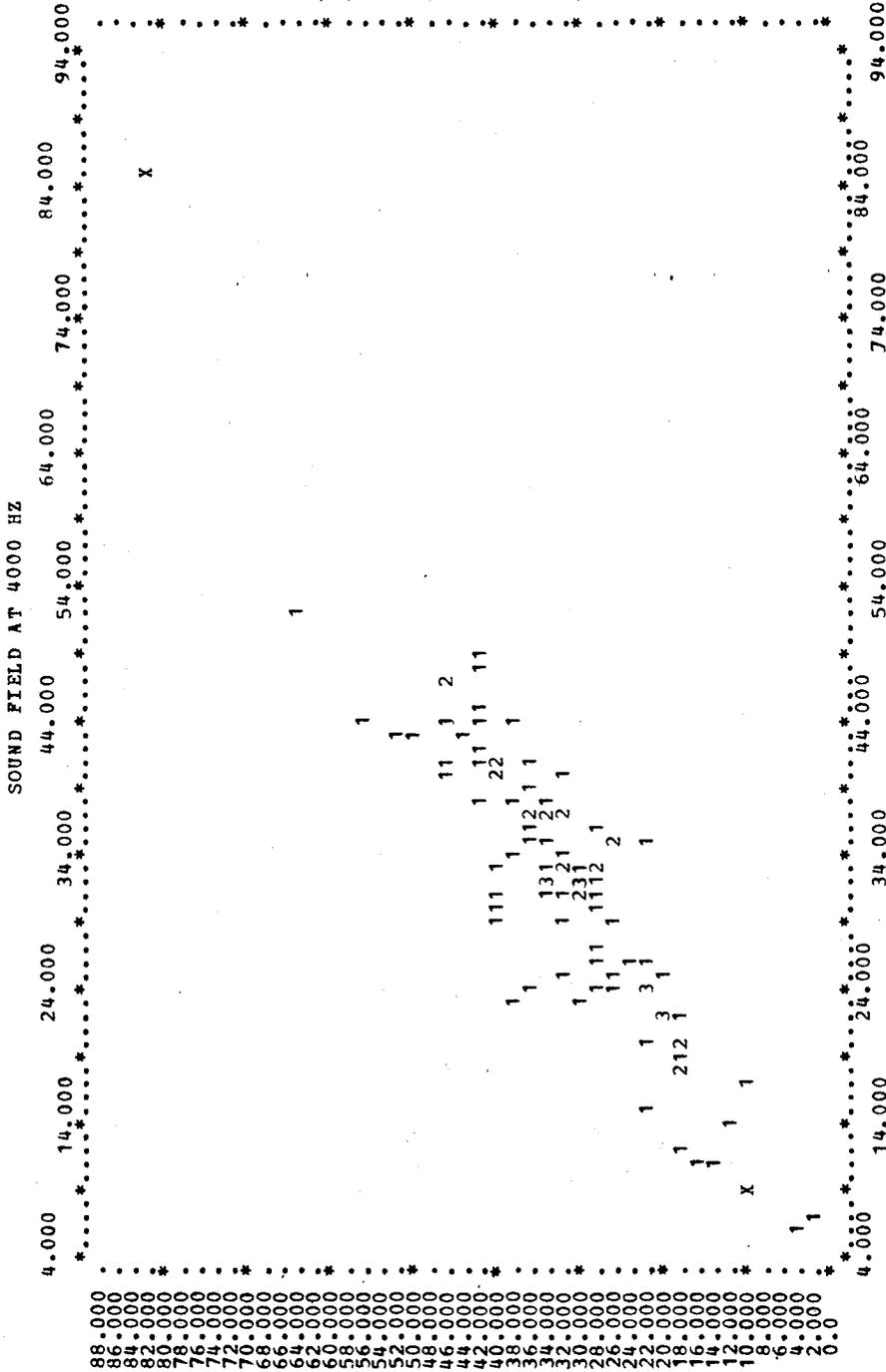


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
Y	5	100	25.650	9.250	85.563	44.000	4.000	40.000	-0.239	-0.466
Y	14	100	26.270	9.965	99.311	48.000	4.000	44.000	-0.275	-0.717

EQUATION OF REG. LINE $Y = 1.29 + 0.9740 X$
 STANDARD ERROR OF ESTIMATE 4.28
 CORRELATION COEFFICIENT 0.904

EVALUATION OF FIELD TEST METHOD



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	7	100	30.440	9.699	94.067	51.000	5.000	46.000	-0.490	-0.197
Y	16	100	31.830	10.597	112.304	64.000	2.000	62.000	-0.076	0.503

EQUATION OF REG. LINE Y = 2.41 + 0.9664 X

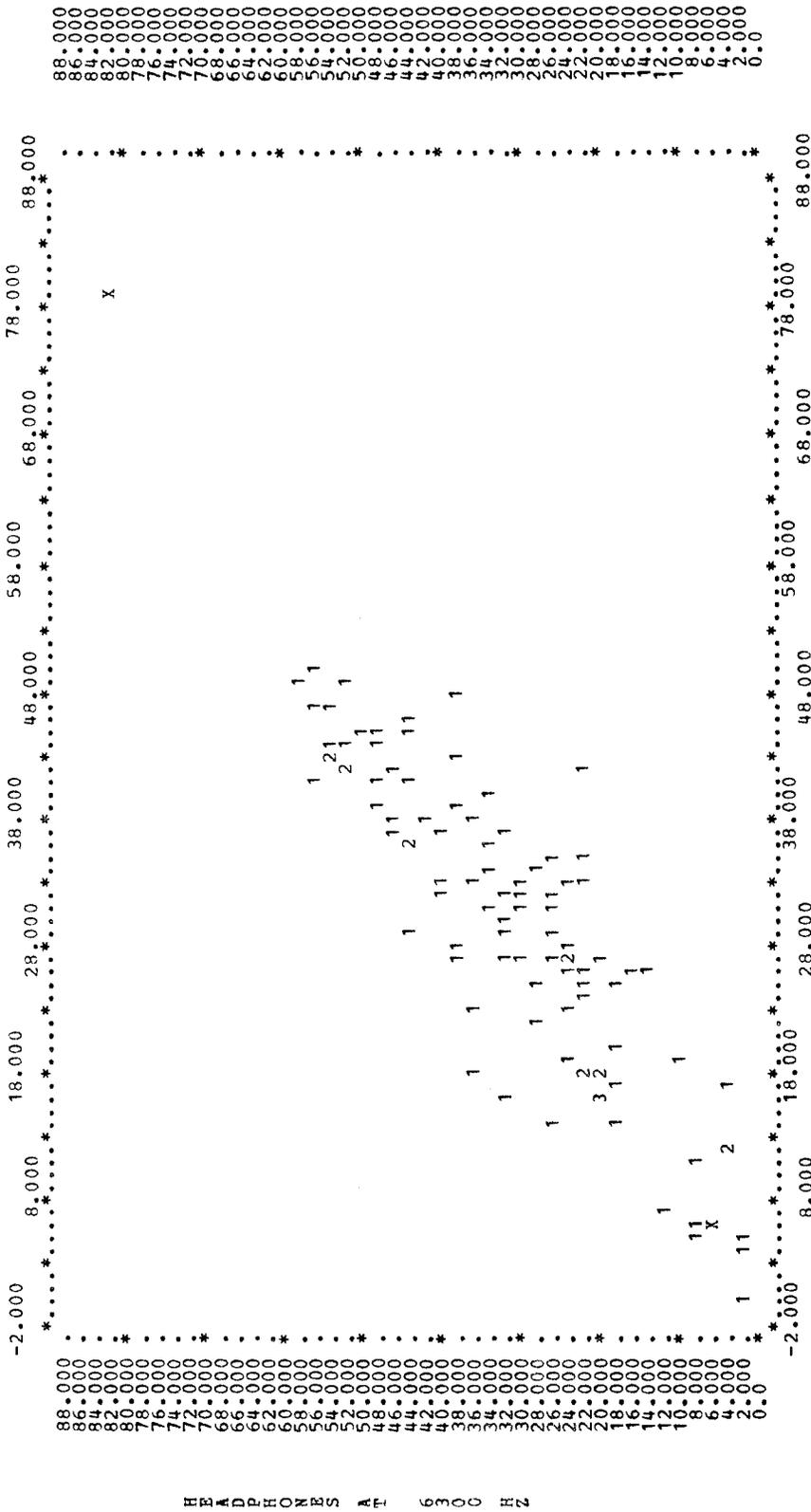
STANDARD ERROR OF ESTIMATE 4.97

CORRELATION COEFFICIENT 0.884

HEADPHONE LEVEL AT 4000 HZ

EVALUATION OF FIELD TEST METHOD

SOUND FIELD AT 6300 HZ

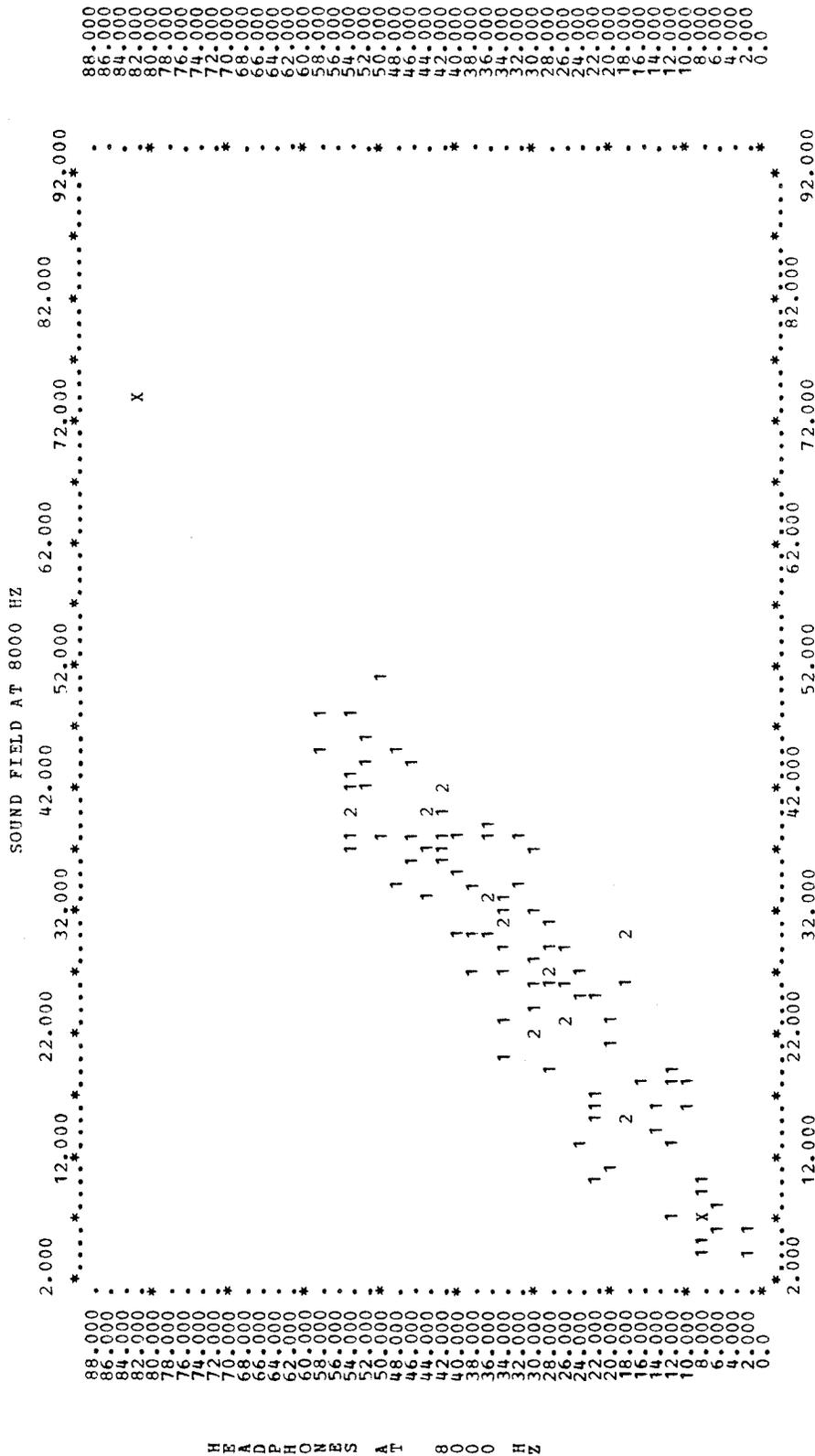


** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKENNESS	KURTOSIS
X	8	100	28.670	11.841	140.203	49.000	-1.000	50.000	-0.374	-0.563
Y	17	100	31.540	14.432	208.292	58.000	2.000	56.000	-0.066	-0.727

EQUATION OF REG. LINE Y = 1.24 + 1.0568 X
 STANDARD ERROR OF ESTIMATE 7.23
 CORRELATION COEFFICIENT 0.867

EVALUATION OF FIELD TEST METHOD



** NOTE - THE X'S ARE TWO POINTS ON THE REGRESSION LINE

VARIABLE	VAR. NO.	N	MEAN	S. D.	VARIANCE	MAX	MIN	RANGE	SKEWNESS	KURTOSIS
X	9	100	27.100	11.625	135.141	50.000	3.000	47.000	-0.296	-0.763
Y	18	100	31.930	14.399	207.319	59.000	2.000	57.000	-0.082	-0.822

EQUATION OF REG. LINE Y = 1.42 + 1.1259 X
 STANDARD ERROR OF ESTIMATE 6.03
 CORRELATION COEFFICIENT 0.909

APPENDIX C

FURTHER DISCUSSION OF TEST IMPLEMENTATION AND TREATMENT OF DATA

T. L. Henderson, National Institute for Occupational Safety and Health,
Cincinnati, Ohio

The ANSI* and EAL methods for evaluating ear plug performance are quite similar in experimental practice: a subject (person) undergoes threshold tests at 9 audiometric frequencies both with and without the ear plugs in place. The threshold shifts at each frequency constitute the results of the individual "test." This procedure is then repeated several times with several different subjects, for a total of N individual tests. The test data are analyzed, and the mean value and standard deviation (both in decibels) are reported at each frequency. (This entire process, incorporating N separate tests, is termed an "evaluation" in the discussions that follow.) The difference between the two methods is that the ANSI method requires a large, extremely quiet, moderately reverberant test chamber with a diffuse-field speaker system; whereas the EAL method requires only a small, adequately quiet audiometric test room and a set of specially constructed headphones.

The development of the EAL method was directed and funded by NIOSH with one goal in mind: to enable subsequent research evaluation of performance of ear plugs on-site under actual industrial working conditions. If it were practical to transport a large, portable, soundproof reverberation chamber to the worksite, then the ANSI method would be quite satisfactory. The obvious impossibility of such an undertaking provided the stimulus for development of a practical alternative.

It is intended that the EAL method will be implemented in an audiometric test van, which will be driven to various worksites. Workers who regularly use ear plugs will be escorted to the van for testing. Precautions will be taken to ensure that the workers do not tamper with their earplugs between the time they are approached at their work stations and the time of the test, and to assure that ear plug usage is not biased in any way by the workers' anticipation of the tests.

The aim of the research will be to find out how earplug performance (both mean attenuation and standard deviation) depends upon the following factors:

- A. Differing company policies or programs for use of ear plugs, including procedures for fit and/or selection of plugs,
- B. Differences among various types of ear plug designs,

* For brevity we shall use the label ANSI here instead of ASA/ANSI as used in the main text of this report.

- C. Day-to-day or hour-to-hour variations in performance on the same worker,
- D. Influence of the noise level on the meticulousness of ear plug use, thus indirectly upon ear plug performance, and
- E. The effect of working conditions (heat, humidity, physical exertion, etc.).

Ear plug performance will, of course, need to be evaluated under a variety of circumstances. For each set of specified conditions (i.e., controlled parameters) an evaluation consisting of a total of N separate tests will be conducted, reporting average attenuation and standard deviation. For example, one such evaluation might consist of testing each of fifty workers once (N = 50), with all the workers wearing foam plugs of several different brands. Later one might test 35 workers wearing individually molded ear inserts, and compare results.

The size of N clearly affects the accuracy of the results (i.e., the residual random error due to non-infinite sample size). The discussion that follows will show how accuracy depends upon N, and will be equally applicable to either the ANSI or EAL methods. Audiometric frequency is not specified; one may assume that the formulas can be applied to each frequency.

Accuracy vs. N*

Let $Z_1, Z_2, Z_3, \dots, Z_n$ denote the N measurements of ear plug attenuation that constitute the raw data for the evaluation. Then the sample mean and sample standard deviation are defined as follows:

Sample mean: $m = (\sum Z_i) / N$

Sample standard deviation: $s = [(\sum Z_i^2 - (\sum Z_i)^2 / N) / (N - 1)]^{1/2}$

The quantities m and s are estimates of the "true" (population) mean and standard deviation. As N becomes large, these estimates become more accurate and converge to the true values. For finite N it is possible to define tolerance limits or "confidence intervals" around the estimates, which will contain the true parameters with a Q% probability.

For the mean, the confidence interval is centered about the estimate, m, as follows:

The Q% confidence interval for the mean is

$$m \pm (k \times s),$$

where k is a constant that depends upon N and upon Q, the percent confidence.

* See Dixon, W. J., and F. K. Massey. Introduction to Statistical Analysis. McGraw-Hill, Inc., 3rd Ed., 1969, p. 80 ff., and p. 102 ff.

The following table gives values of k for several values of N and Q.

N \ Q	80%	90%	95%	98%
5	0.69	0.95	1.24	1.68
10	0.44	0.58	0.71	0.89
20	0.30	0.39	0.47	0.57
30	0.24	0.31	0.37	0.45

Table C-1: Values of k

Example: Suppose 20 tests at 4000 Hz yield a mean attenuation of 32.1 dB with a standard deviation of 6.4 dB. Then with 90% confidence the true mean lies within $32.1 \pm (0.39 \times 6.4)$ dB i.e., between 29.6 dB and 34.6 dB.

For the standard deviation, the confidence interval is not symmetrically spaced around s:

The Q% confidence interval for the standard deviation is

$$s - (g_1 \times s) \quad \text{to} \quad s + (g_2 \times s)$$

where g_1 and g_2 depend upon N and Q, and are tabulated as follows:

N \ Q	80%	90%	95%	98%
5	0.28, 0.94	0.35, 1.37	0.40, 1.87	0.45, 2.68
10	0.22, 0.47	0.27, 0.65	0.31, 0.83	0.36, 1.08
20	0.16, 0.28	0.21, 0.37	0.24, 0.46	0.27, 0.58
30	0.14, 0.21	0.18, 0.28	0.20, 0.34	0.24, 0.43

Table C-2: Values of g_1 , g_2

Example: Using the same example as before, $N = 20$, $m = 32.1$ dB, $s = 6.4$ dB. Then with 90% confidence the true standard deviation lies between $6.4 - (0.21 \times 6.4)$ and $6.4 + (0.37 \times 6.4)$, i.e., between 5.1 dB and 8.8 dB.

It is interesting to note that the range of uncertainty (i.e., the confidence interval) is somewhat wider for the mean attenuation than for the standard deviation.

A few qualifying remarks should be made regarding the confidence intervals formulas.

1. Normal statistics are assumed. In actual practice the threshold shifts may not exactly be normally distributed but they are certainly close enough for a good approximation.

2. It is assumed that all N samples are statistically, and uniformly, independent. If the N tests are performed on less than N persons (i.e., some or all persons are tested more than once) then this independence condition is not strictly satisfied. However, the confidence intervals given here are probably good enough provided the number of persons is not less than 10, as specified by the ANSI standard.

3. Caution must be exercised when viewing confidence intervals for several frequencies. If it so happens that the true mean falls outside the interval at 4000 Hz, then the chances of this happening at 3150 Hz are increased; i.e., the "confidence levels" at the various frequencies cannot be regarded as independent probabilities.

Comparison of the EAL and ANSI methods

With either method the end product of an evaluation consists of a mean attenuation level and standard deviation (at each frequency). The ANSI method is obviously the preferred one, because it is institutionally sanctioned, and because it employs a superior testing scheme. (It is more appropriate, acoustically). Since the EAL method is intended as an alternative, several important questions ought to be addressed:

1. For a given N, how accurate is the EAL method as an estimator of what the ANSI method would have produced using the same test subjects?

Or, even more pertinent:

2. For a given finite N, how accurate is the EAL method as an estimator of what the ANSI method would have produced for $N \rightarrow \infty$; i.e., as an estimator of the "true" value?

3. What corrections can be applied to improve the accuracy of the EAL method?

The logical approach to answer these questions is to do a regression analysis of the results from several representative ear plug evaluations using the EAL method versus those obtained using the ANSI method. Specifically this means a regression analysis of means vs. means and of standard deviations vs. standard deviations! (Recall that the results of the EAL or ANSI evaluations are average measures of N tests, not individual results of tests.) Although this sounds unorthodox, it is actually quite legitimate. It is not important that the "outputs" happen to be sample means and sample standard deviations. They can be treated just like any other results of an experiment. Furthermore they can be treated separately since it is a well known fact in statistics that sample means and sample standard deviations are statistically independent.

Appendix A of this report has listed results, using both the ANSI and EAL methods, of evaluations of five separate models of ear plugs. The "retest-fit" data are most appropriate for our use here since they represent a mixture of conditions of deliberately poor fit and good fit, perhaps similar

to what might be found at the worksite. Furthermore, the five ear plug types provide a sufficient variety to reflect the probable array of categories of ear plugs to be studied in future research projects. Using these data from Appendix A, a simple linear regression analysis was performed for the five data points, at each frequency. Figure C-1 shows the scatterplots and regression lines for the mean-vs.-mean analysis, and Figure C-2 shows the results for the standard deviation-vs.-standard deviation analysis. The regression lines represent regression of X on Y, not Y on X. This has been done so that the regression line will provide an estimate of the ANSI results in terms of the EAL results. The point labeled "#" in the scatter plot represents the composite results of Appendix B, i.e., where all ear plug data are lumped together. This point is intended for information only and was not incorporated into the regression analysis.

The equations for estimating ANSI results from EAL results are tabulated in Tables C-3 and C-4, together with the correlation coefficient (r), and the standard error of the estimate (S.D.E.).

It is clear from the scatter plots that the mean attenuation figures resulting from the two methods are very well correlated, and it is possible to accurately estimate the ANSI results from the EAL results, particularly if the regression equations of Table C-3 are used. For the standard deviation scatter plots the picture is not quite so good, but the correlations are still adequate. Actually the absolute errors are very small when one takes account of the plotting scale.

Treatment of Data: Summary

Making Corrections to EAL Data

When research evaluations of earplugs are performed using the EAL method, the data should be corrected as follows:

$$\text{Estimated ANSI Result} = \alpha \times (\text{EAL Result}) + \beta,$$

Where the appropriate α 's and β 's are obtained from Tables C-3 and C-4.

Error Tolerance due use of Substitute (EAL) Method*

Let "Y" denote the EAL result which might be either a mean or a standard deviation, let "X" denote the result which would have been obtained if the ANSI method had been used, and let " \hat{X} " denote the corrected EAL result, i.e., $\hat{X} = \alpha Y + \beta$. Then we can be 90% confident that the following tolerance interval will be satisfied for at least 90% of all future ear plug evaluations:

$$X \text{ lies in the following interval: } \dagger \quad \hat{X} \pm (3.74) \times (\text{S.D.E.}) \times (1 + \epsilon^2)$$

Where S.D.E. is the standard error of the estimate obtained from Table C-3 or C-4, and ϵ is defined as follows:

* See Dixon and Massey, p. 199.

† This expression represents a 90%/90% tolerance interval based on epsilon being small so that higher orders of epsilon may be neglected (see bottom of p. 199 in Dixon and Massey).

$$\epsilon = h_1 \times Y - h_2$$

Table C-5 contains values of h_1 and h_2 . Most of the time ϵ will be close enough to zero that the tolerance interval around \bar{X} is approximately $\pm (3.74) \times (\text{S.D.E.})$

For most frequencies the size of the tolerance interval will range between $\pm 2\frac{1}{2}$ dB and $\pm 5\frac{1}{2}$ dB. The frequency 4000 Hz seems to be the worst, and the tolerance interval is thus larger.

Note: Strictly speaking the above tolerances are valid only for $N = 20$. However one may expect them to hold just as well or better for any $N > 20$.

Error Tolerance due to Non-infinite Sample Size

The tolerance limits described above only account for differences between the ANSI and EAL methods which exist even when N is very large. The limitation in accuracy due to a small N are inherent in both methods, and the tolerance limit described in the previous section entitled "Accuracy vs. N " still apply. These tolerances can simply be added to those described above, although this approach is perhaps unnecessarily conservative.

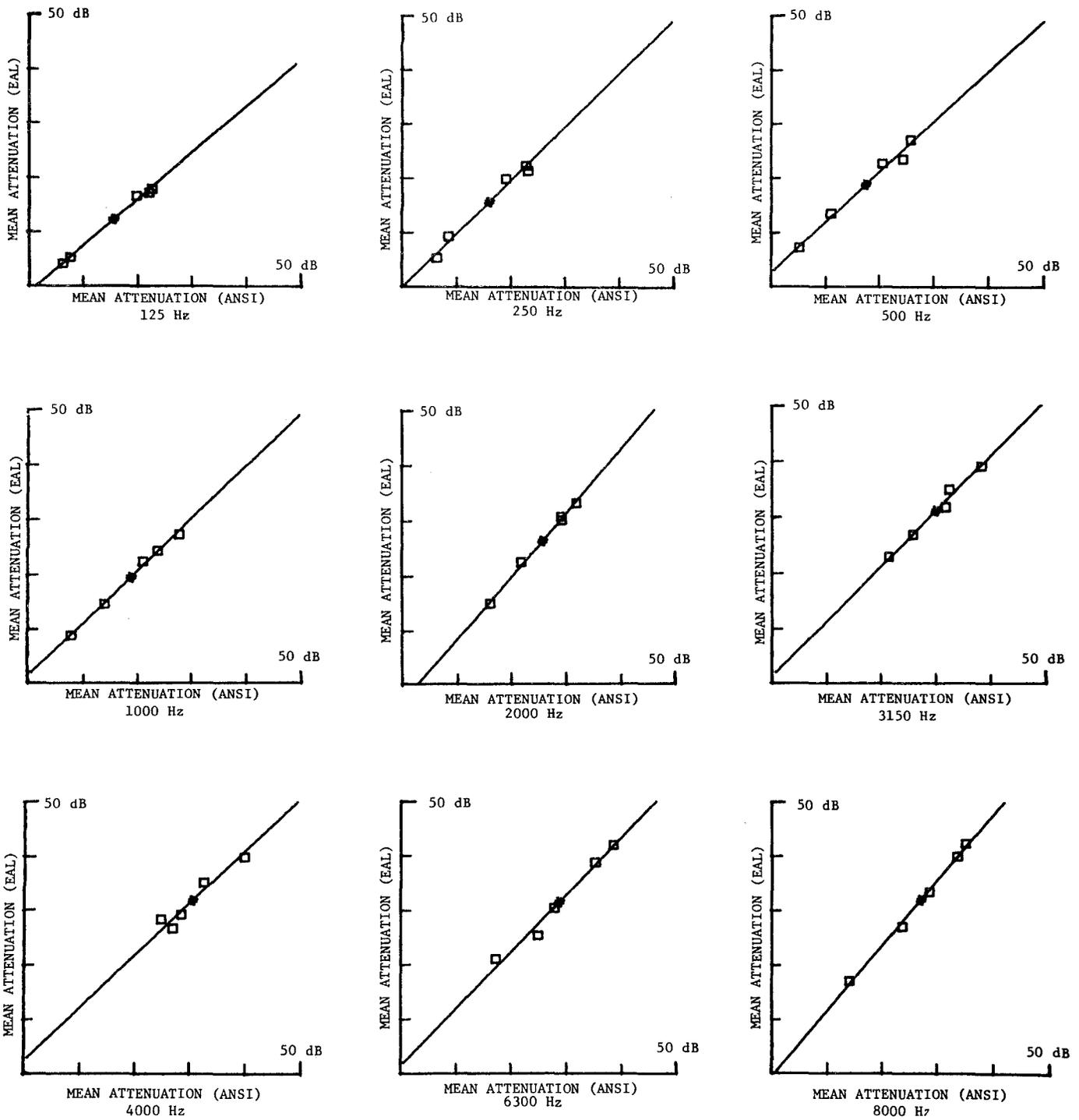


Figure C-1. Comparison of Mean Attenuations for EAL - vs. - ANSI Methods

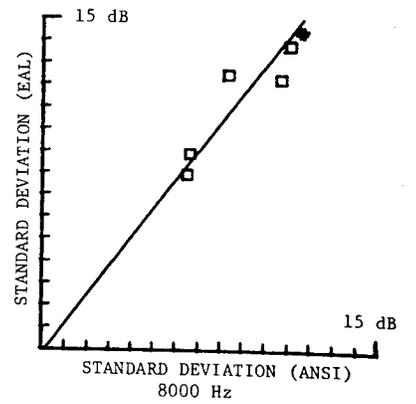
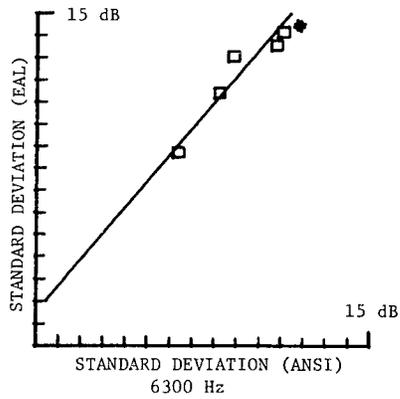
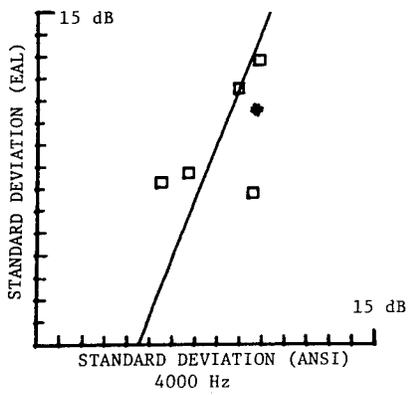
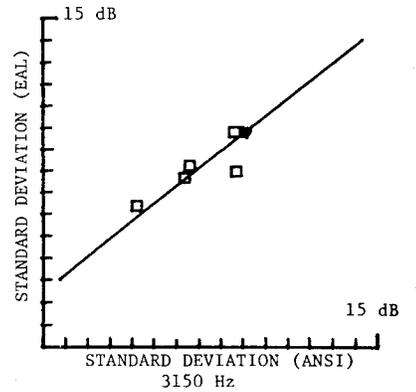
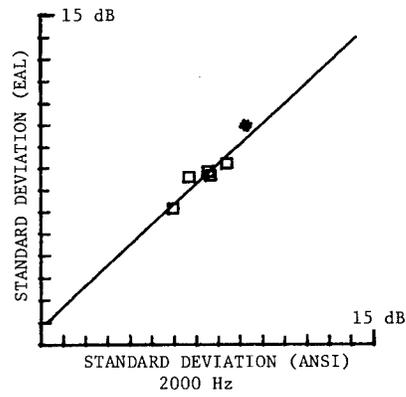
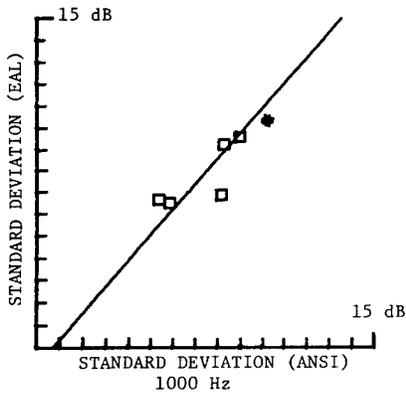
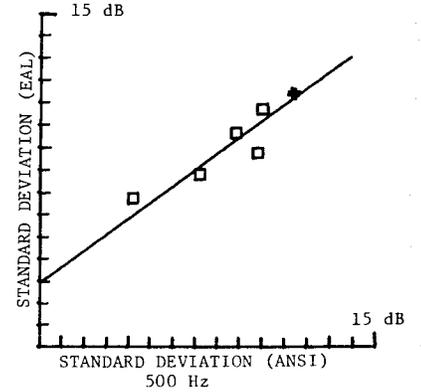
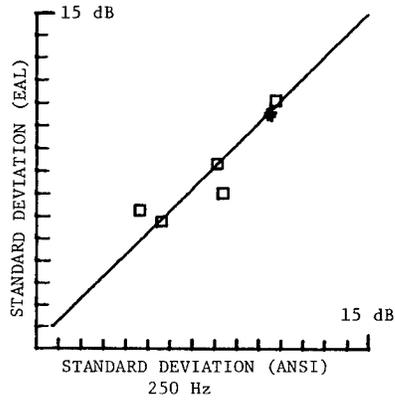
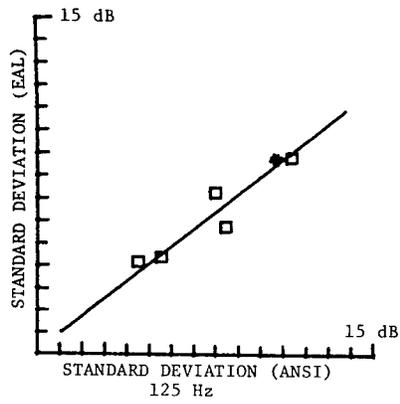


Figure C-2. Comparison of Standard Deviations for EAL - vs. - ANSI Methods

Frequency	α	β	r	S.D.E.
125 Hz.	1.17	1.37	0.997	0.75
250 Hz.	1.00	0.26	0.990	1.27
500 Hz.	1.07	-2.76	0.991	1.35
1000 Hz.	1.04	-1.54	0.997	0.67
2000 Hz.	0.87	2.74	0.998	0.49
3150 Hz.	1.02	-1.52	0.990	1.07
4000 Hz.	1.03	-2.50	0.957	1.98
6300 Hz.	0.95	-1.41	0.989	1.46
8000 Hz.	0.83	0.46	0.998	0.61

$$\text{MEAN (ANSI)} \approx \alpha \times \text{MEAN (EAL)} + \beta$$

TABLE C-3: ESTIMATING ANSI MEANS IN TERMS OF EAL MEANS

Frequency	α	β	r	S.D.E.
125 Hz.	1.27	-0.23	0.939	1.06
250 Hz.	1.02	-0.31	0.901	1.21
500 Hz.	1.38	-3.96	0.881	1.32
1000 Hz.	0.86	0.71	0.795	1.13
2000 Hz.	1.07	-0.79	0.896	0.49
3150 Hz.	1.24	-2.98	0.820	1.23
4000 Hz.	0.38	4.53	0.559	1.82
6300 Hz.	0.84	-1.20	0.950	0.70
8000 Hz.	0.77	0.17	0.901	1.108

$$\text{STD. DEV. (ANSI)} \approx \alpha \times \text{STD. DEV. (EAL)} + \beta$$

TABLE C-4: ESTIMATING ANSI STANDARD DEVIATIONS IN TERMS OF EAL STANDARD DEVIATIONS

Frequency	For Means		For Standard Deviations	
	h_1	h_2	h_1	h_2
125 Hz.	0.051	12.2	0.18	6.1
250 Hz.	0.045	15.7	0.16	7.7
500 Hz.	0.048	18.8	0.23	8.7
1000 Hz.	0.047	19.5	0.24	7.8
2000 Hz.	0.047	26.3	0.45	7.5
3150 Hz.	0.055	31.1	0.29	8.0
4000 Hz.	0.064	31.8	0.13	9.2
6300 Hz.	0.040	31.5	0.16	12.2
8000 Hz.	0.034	31.9	0.14	11.1

TABLE C-5: PARAMETERS FOR COMPUTING TOLERANCE LIMITS

