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APPLICATION OF MAGNITUDE ESTIMATION SCALING TO THE ASSESSMENT OF SUBJECTIVE LOUDNESS RESPONSE TO SIMULATED SONIC BOOMS

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APPLICATION OF MAGNITUDE ESTIMATION SCALING TO THE ASSESSMENT OF HUMAN SUBJECTIVE LOUDNESS RESPONSE TO SIMULATED SONIC BOOMS

SUMMARY

A laboratory study was conducted to (1) investigate the application of magnitude estimation scaling for evaluating the subjective loudness of sonic booms and (2) compare the relative merits of magnitude estimation and numerical category scaling for sonic boom loudness evaluation. The study was conducted in the NASA Langley Research Center's sonic boom simulator and used a total of 80 test subjects (48 for magnitude estimation and 32 for numerical category scaling). Results demonstrated that magnitude estimation was a practical and effective method for quantifying subjective loudness of sonic booms. When using magnitude estimation, the subjects made valid and consistent ratio judgments of sonic boom loudness irrespective of the frequency of presentation of the standard stimulus. Presentation of the standard as every fourth stimulus was preferred by the subjects and is recommended as the standard presentation frequency to be used in future tests.

INTRODUCTION

The aircraft community is considering the feasibility of developing a commercial high speed civil transport (HSCT). In order to be approved for supersonic flight overland, the sonic booms created by such an aircraft must not be objectionable to the general populace. This will require that the loudness and startle effects of sonic booms be kept to a minimum. In support of the HSCT effort, the NASA Langley Research Center is currently conducting experiments, using a new sonic boom simulator, to obtain human loudness response to a wide range of candidate sonic boom signatures. The goals of these efforts include identification of preferred signature shapes for minimum sonic boom loudness and development and validation of a sonic boom loudness prediction model.

A crucial element in any study involving sensation magnitudes (such as loudness) is the choice of a subjective rating method. Most previous studies (references 1,2, and 3, for example) of human subjective loudness response to sonic booms used paired-comparison scaling. This method is very simple and easy for subjects to understand and use, but is limited in the amount of information which can be obtained. In this method, subjects are presented a pair of stimuli and are asked to judge which member of the pair is the loudest. Thus, only relative loudness judgments can be made using paired-comparison, and no information related to the growth of loudness with the amplitude of a signal can be obtained. A recent study (reference 4) at NASA Langley Research Center utilized numerical category scaling to assess subjective loudness of sonic booms. This method provided considerably increased information on the growth of loudness but, as in the case of paired-comparison scaling, loudness scores could only be interpreted in a relative sense. In addition, the stimulus-response relationship using a category scale is inherently curvilinear due to the well-known "ceiling" or "flattening" of the sensation-response curve at the extreme ends of the scale. Thus, a numerical category scale does not possess either equal interval or ratio scale properties.

It would be desirable to obtain laboratory loudness judgments using a rating technique that minimizes the above limitations. Such a technique is available through application of the method of magnitude estimation. This method was used extensively by Stevens (reference 5) to define the psychophysical relationship between loudness sensation and sound level. The relationship was determined to be a power function which (by definition) is linear when expressed in terms of the logarithms of the magnitude estimates and acoustic pressure.

The magnitude estimation method requires subjects to make ratio judgments of loudness (relative to a standard stimulus having a specified loudness value) and eliminates the "ceiling" effect mentioned earlier. This method was also used successfully in research that led to the development of a ride comfort model for estimating passenger comfort within combined noise and vibration environments (reference 6).

The present study was conducted to investigate the general validity of magnitude estimation as a method for rating the loudness of sonic boom signatures and to assess the advantages and disadvantages of magnitude estimation scaling versus category scaling for sonic boom evaluation. Additional issues addressed included (a) investigation of the effect of the frequency of presentation of the standard stimulus on the ability of test subjects to make magnitude estimation judgments; (b) comparison of the relative accuracy of magnitude estimation versus category scaling; and (c) general assessment of the ability of untrained, naive test subjects to understand and apply magnitude estimation in the evaluation of impulsive-type sounds.

EXPERIMENTAL METHOD

Sonic Boom Simulator

The experimental apparatus used in this study was the Langley Research Center's sonic boom simulator, which is described in detail in reference 3. The simulator, shown in figure 1, is a man-rated, airtight, loudspeaker-driven booth capable of accurately reproducing user-specified sonic boom waveforms at peak sound pressure levels up to about 138-139 dB. Input waveforms were computer-generated and "predistorted" to compensate for the nonuniform frequency response characteristics of the booth. Predistortion was accomplished by use of a digital broadband equalization filter (see reference 7). Boom simulator construction details, performance capabilities, and operating procedures are given in reference 3.

Test Subjects

Eighty (80) test subjects obtained from a subject pool of local residents were used in this study. Ages of test subjects ranged from 18 years to 62 years. All subjects were paid for participating in this study and were required to undergo audiometric screening as a requirement for participation. Several of the subjects took part in an earlier category scaling study of sonic boom loudness in this laboratory, but none reported any prior experience with magnitude estimation.

Scaling Methods

Two scaling methods were used in this study, magnitude estimation and numerical category scaling. Forty-eight of the test subjects used magnitude estimation to evaluate the loudness of the boom signatures. The remaining 32 subjects used numerical category scaling.

The magnitude estimation method is summarized as follows: A sonic boom stimulus, designated as the standard, was presented to a subject. This standard was assigned a loudness value of 100 by the experimenter. The standard would then be followed by one or more comparison booms. It was the task of the subject to rate the loudness of each comparison stimulus as compared to the loudness of the standard. For example, if the subject felt that a comparison stimulus was twice as loud as the standard, then he/she would assign it a value of 200. If the comparison stmulus was judged to be only one-fourth as loud as the standard, then the subject would assign it a value of 25. The standard was repeated periodically throughout the test. (Note that the frequency of presentation of the standard was a test variable; see Experimental Design section for details). Thus, the loudness scale obtained by application of this method was a ratio scale. The instructions given to the subjects explaining how to use the magnitude estimation procedure are given in Appendix A. The magnitude estimation scoring sheets are shown in Appendix B.

The numerical category scaling method used a continuous 11-point unipolar loudness scale. The scale was anchored at one end (scale value of 0) by the words **"NOT LOUD AT ALL"** and at the opposite end of the scale (scale value of 10) by the words **"EXTREMELY LOUD."** The instructions given to the subjects explaining how to use the numerical category scale are given in Appendix C. The rating scale is also shown in Appendix C.

Experimental Design

The sonic boom stimuli were symmetrical pressure time histories typical of the N-shaped waves of measured sonic booms. Rise times were 1,2,3,4,6, and 8 milliseconds with front and rear shock rise times equal for all signatures. The duration of all stimuli was 300 milliseconds. Each pressure time history was presented at five peak overpressure levels. The peak overpressure levels were selected such that each spanned approximately the same loudness range. Thus the peak overpressures varied from signature to signature. The actual peak overpressure values were determined from results of prior research conducted in the sonic boom simulator. Rise time and overpressure level were not factors of direct interest in this study since their effects have been documented in previous studies (references 1,2,3,and 4). They were included to provide a range of loudness sensations for evaluation and to provide data for comparing the accuracy of the two scaling methods.

The 30 boom signatures defined by the factorial combinations of rise time and level constituted the basic stimuli set. For the magnitude estimation tests, these were organized into three test sessions that differed with respect to the standard-comparison stimulus sequence used. The three standard-comparison sequences were: standard-comparison-standard (S-C-S); standard-three comparisons-standard (S-C-C-C-S); and standard-six comparisons-standard (S-C-C-C-C-C-C-S). These are referred to in the remainder of this paper as SEQA, SEQB, and SEQC, respectively. The standard stimulus used was selected from the stimuli set described above. It corresponded to the third overpressure level (0.89 psf) of the 3 millisecond rise time N-wave. Thus, during each magnitude estimation session, the standard stimulus was also presented as a comparison stimulus (unknown to the subjects). This provided a simple means for checking whether or not the subjects applied the method correctly or whether significant biases were introduced. For the numerical category scale tests, the subjects received only one session consisting of the 30 stimuli described above.

Boom presentation order within sessions was randomized and counterbalanced to minimize presentation order effects. Session presentation order was also randomized and counterbalanced for the magnitude estimation tests. To further minimize order effects one-half of the subjects in each test were presented the stimuli in reverse order.

Experimental Procedure

Subjects were delivered to the laboratory in groups of four, with one group in the morning and one group in the afternoon on any given day. Upon arrival at the laboratory each group was briefed on the overall purpose of the experiment, the test procedure to be followed, system safety features, and their rights as test subjects. A copy of these briefing remarks are given in Appendix D. The subjects were then given specific instructions related to the scaling method they were to use (see Appendices A or C). Those subjects who were to use magnitude estimation were given a simple line length estimation task to familiarize themselves with the general concept of magnitude estimation and to assess their understanding of the method and rating procedure. The line length task is shown in Appendix E.

At this point the subjects were taken individually from the waiting room to the sonic boom simulator. At the simulator the rating scale instructions were reviewed and the subject was asked to listen to several boom stimuli, played with the simulator door open, in order to become familiar with the type of sounds he/she would be asked to evaluate. At this point the subject was given a practice scoring sheet (appropriate to the scaling method been studied) and seated in the simulator with the door closed. A practice session was then conducted in which the subject rated a set of practice stimuli similar to those that would be used in the actual test session. Each session of the magnitude estimation tests and the single session of the category scale tests were all preceded by practice sessions. Upon completion of the practice session the practice scoring sheets were collected and any questions were answered. The actual test session was then conducted. After all subjects in the magnitude estimation tests had completed the first session they were then cycled through sessions 2 and 3.

DISCUSSION OF RESULTS

Arithmetic and Geometric Means

The primary metric used in this study to characterize the loudness of sonic booms was Perceived Level, PL. The procedure used to calculate this metric was based on Steven's Mark VII method (reference 8) and is described in detail in reference 9. The metric calculations were based upon microphone measurements of the boom pressure time histories made within the simulator. The subjective data were characterized by the arithmetic and geometric means of the magnitude estimations for each stimulus condition. These two means and the calculated PL values are given in Table 1 for each of the 30 simulated booms. The logarithms of the arithmetic and geometric means for each stimulus condition are plotted in figure 2 as a function of PL. Linear regression lines fit to the data for each mean are also shown. The linear relationships result from the fact that subjective loudness is expected to be a power function of the physical intensity of a sound. Such a power function is linear when expressed in terms of the logarithm of the subjective loudness and acoustic pressure. Since Perceived Level is proportional to the logarithm of acoustic pressure, the linear fit to the data in figure 2 was appropriate. Pearson correlation coefficients, r, calculated between the logarithms of both the arithmetic and geometric means and PL were $r = 0.9672$, ($p < 0.001$) for the arithmetic mean and $r = 0.9642$, ($p < 0.001$) for the geometric mean. These were not statistically different from one another. Thus, the high correlations between each mean and PL and the lack of statistical significance between the two indicate that either mean can be used as a measure of central tendency for magnitude estimates of sonic boom signature loudness. However, it is customary (see reference 10) to use geometric averaging with magnitude estimation since the distribution of the logarithms of the magnitude estimations is approximately normal. The remainder of this paper will therefore present the loudness responses in terms of the geometric mean.

Comparison-Standard Sequence Effects

The logarithms of the geometric means of the magnitude estimates of loudness are shown in figure 3 for each comparison-standard sequence. Also shown are the best fit linear regression lines for each standard-comparison sequence. These data show that the standard-comparison sequence effect was small. Application of dummy variable regression analysis indicated no significant difference due to sequence effect and no significant differences in the slopes of the regression lines. Thus, the obtained magnitude estimates of loudness were unaffected by the frequency of presentation of the standard for the three presentation sequences of this study. This implies that (a) the subjects were able to "remember" the standard equally well irrespective of whether it was presented as every other sound or as every seventh sound; or (b) the subjects made relative judgments on previous sounds heard more recently than the standard; or (c) a combination of both (a) and (b). When questioned after completion of the tests most subjects reported having more difficulty in remembering the standard for the SEQC session (S-C-C-C-C-C-C-S). Twenty-one of the subjects preferred SEQA (S-C-S), twenty preferred SEQB (S-C-C-C-S), and five preferred SEQC. (Two gave invalid responses.) It is apparent from the results that the subjects performed much better than they thought they did. This tendency of subjects to underestimate their performance on magnitude estimation tasks was also observed in the experimental testing leading to development of the ride quality model described in reference 6.

The fact that loudness ratings did not differ for the three standard-comparison sequences does not necessarily imply that the predictive accuracy of PL would also be independent of sequence effects. An overall indicator of the relative predictive accuracy of PL for each sequence is the degree of scatter about the respective regression lines of figure 3. The parameter which describes this scatter is the standard error of estimate of each regression line. Table 2 shows that only slight differences in the standard errors of estimate of the three sequences were observed. These differences were not considered to be of practical significance, indicating that accuracy was minimally affected by the frequency of presentation of the standard stimulus.

The results described above show that the subjects made consistent loudness discriminations, using loudness magnitude estimation, of the short duration impulsive sounds typical of sonic boom signatures. The lack of a significant standard-comparison sequence effect was a somewhat unexpected, but welcome, result. It indicates that future sonic boom labortory tests employing magnitude estimation procedures can be conducted more efficiently since the need to present the standard stimulus at frequent intervals is obviated.

Magnitude Estimation and Category Scaling Accuracy

It was of interest to also examine the relative accuracy of the magnitude estimation (ME) and numerical category scaling (NCS) methods. In this case, however, differences in the ranges of values for the two scale types (0 to 10 for NCS, unbounded for ME) did not permit meaningful comparison of the standard errors of estimate when determined in terms of actual rating scale units. To directly compare the accuracies of the two scale types, a modified calculation procedure was applied. It was further decided to calculate the accuracies of several metrics in addition to PL. These were: Zwicker loudness level (LLZ), A-weighted sound exposure level (L_{AE}), C-weighted sound exposure level (L_{CE}), and unweighted sound exposure level, (L_{UE}).

The modified procedure for comparing the two scaling methods involved, for each metric and rating scale combination, regression analysis with metric level as the dependent variable and rating as the independent variable. The resulting standard errors of estimate were in dB units of the particular metric being analyzed. They are listed in Table 3 and presented in figure 4 for each metric and scaling method. As shown in figure 4, the standard error of estimate for PL was slightly lower than those for LLZ and L_{AE}. The standard errors of estimate for L_{CE} and L_{UE} were significantly larger those of PL, LLZ, and L_{AE}, indicating that these two metrics were the least accurate estimators of loudness. Comparison between the standard errors of estimate for ME and NCS scaling for each metric indicated that they did not differ significantly, implying that the scales were equally precise in measuring subjective loudness.

Subject Performance in Magnitude Estimation Task

Recall that during the test the standard stimulus was also presented to the subjects (unknown to them) as a comparison stimulus. Since the standard was assigned a loudness value of 100 it would be expected, in the absence of significant biases in the loudness evaluations, that the comparison standard stimulus would also be assigned loudness values of approximately 100. Results showed that the arithmetic and geometric means of the loudness ratings for the comparison standard stimulus were 101.5 and 98.5 respectively. These values were in good agreement with the standard loudness value of 100, verifying that no significant biases in the loudness judgements were observed.

It is known (see reference 8, for example) that, for non-impulsive noises, a doubling of the perceived loudness magnitude in sones corresponds to an increase in Perceived Level (PL) of 9 dB when calculated using Steven's Mark VII method. It was of interest to examine whether the 9 dB per doubling of loudness also held for the impulsive noises used in this study. Using the slope of the linear regression lines relating the arithmetic and geometric means to PL it was determined that an increment of

9 dB in PL corresponded to subjective loudness response ratios of 2.05 and 2.11 respectively. The average of these two subjective loudness response ratios is 2.08. Thus the subjects' ME responses to the impulsive-type sonic boom stimuli were consistent with the 9 dB per doubling of loudness observed for non-impulsive noises. The slope of the regression line was also used to determine the power law exponent defining the relationship between loudness and PL for the present data. This exponent had a value of 0.365 which compares favorably with the power law exponent of 0.334 obtained from Steven's Mark VII method.

The above results show that the subjects used the ME scale properly and did, if fact, make valid ratio judgments of sonic boom loudness. They also demonstrate that application of the magnitude estimation method to the evaluation of sonic boom loudness produced results fully consistent with loudness results obtained for other noise sources.

CONCLUDING REMARKS

Results of this study demonstrate that magnitude estimation scaling is a practical and effective method for quantifying subjective loudness of sonic booms. The magnitude estimation data obtained were fully consistent with that reported in the literature for nonimpulsive-type sounds. Evidence for this was provided by the good agreement between the loudness power law exponent of the present study with that of Steven's Mark VII loudness calculation procedure. The subjects, as requested in the magnitude estimation test instructions, did make valid and consistent ratio judgments of sonic boom loudnesses. It was determined that magnitude estimation and numerical category scaling were equally precise. However, the ratio properties of the magnitude estimation scale render it more useful for describing and interpreting loudness results obtained from sonic boom subjective response studies.

The absence of a significant effect due to standard-comparison sequence spacing was a surprising result of this study. This implies that the standard need be presented only infrequently, which would certainly simplify the test procedure and improve test efficiency. Only a few subjects preferred having the standard presented as every seventh stimulus. The remainder were approximately equally divided in preference between having the standard presented as every other stimulus and as every fourth stimulus. Thus, it is felt that presenting the standard as every fourth stimulus is a reasonable compromise for future tests using magnitude estimation scaling.

Based upon the results of this study it is recommended that, whenever possible, future laboratory study of sonic boom loudness effects should use magnitude estimation scaling. Its demonstrated validity, precision, and ratio properties are considered worth the additional complexity involved in setting up and conducting sonic boom subjective response tests.

Table 1.- Arithmetic and geometric means, standard deviations and PL levels for magnitude estimation test. Geometric mean data are given in logarithmic units.

Rise Time, msec	Level	Arithmetic Mean	Arithmetic Standard Deviation	Geometric Mean	Geometric Standard Deviation	PL, dB
1	1	75.51	26.40	1.845	0.1823	87.93
	2	94.49	31.23	1.945	0.1804	90.38
	3	129.20	32.91	2.095	0.1262	92.94
	4	161.08	38.96	2.197	0.1022	95.53
	5	183.54	45.89	2.250	0.1138	98.19
2	1	76.65	24.42	1.859	0.1562	87.79
	2	92.77	20.51	1.954	0.1137	90.33
	3	115.82	23.54	2.055	0.0882	92.90
	4	130.43	31.32	2.102	0.1110	95.50
	5	178.82	38.61	2.242	0.0954	98.16
3	1	72.92	22.71	1.832	0.1838	87.61
	2	91.08	22.20	1.945	0.1171	90.08
	3	101.53	21.29	1.994	0.1194	92.67
	4	125.14	31.52	2.083	0.1163	95.33
	5	158.90	38.32	2.188	0.1073	97.95
4	1	76.58	25.59	1.853	0.1833	88.07
	2	87.30	22.83	1.920	0.1515	90.63
	3	104.10	26.17	2.001	0.1293	93.19
	4	139.13	34.87	2.129	0.1189	95.90
	5	157.29	35.42	2.186	0.0995	98.67
5	1	74.45	25.30	1.840	0.1801	87.63
	2	77.36	26.19	1.855	0.1902	90.18
	3	105.69	29.51	2.004	0.1412	92.91
	4	139.00	34.17	2.130	0.1112	95.77
	5	173.11	43.61	2.224	0.1164	98.71
6	1	66.75	25.94	1.781	0.2142	87.84
	2	82.75	25.49	1.893	0.1578	90.50
	3	108.59	28.72	2.020	0.1223	93.29
	4	136.85	38.57	2.116	0.1444	96.24
	5	179.06	43.85	2.240	0.1098	99.17

Table 2.- Standard Error of Estimate for Each Standard Presentation Sequence. Standard Errors of Estimate Are in Logarithmic Units.

Sequence	Standard Error of Estimate
A	0.0389
B	0.0369
C	0.0381

Table 3.- Standard Errors of Estimate for Each Scaling Method and Loudness Metric. Standard Errors of Estimate Are in dB Units.

METRIC, dB	STANDARD ERROR OF ESTIMATE, dB	
	MAGNITUDE ESTIMATION	CATEGORY SCALE
PL	1.0155	0.9447
L_{AE}	1.2880	1.2804
L_{CE}	2.8985	2.8293
L_{UE}	3.5166	3.4341
LLZ	1.2064	1.1320

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Appendix A.- Magnitude Estimation Instructions

Specific Instructions

Each of you will take part in three separate tests. The procedure will be as follows: (1) you will be taken individually to the simulator, (2) at the simulator you will be given specific instructions for the current test, (3) you will listen to sounds similar to those you will be asked to rate, (4) we will then conduct a practice rating session, and (5) the actual test will be conducted. You will then return to the waiting room while the other members of your group complete the same test. The above procedure will be repeated for the remaining tests.

During each test we will play a series of sonic booms over the loudspeakers in the door of the simulator. The first boom that you hear, which will be repeated throughout each session, is the boom you will use as a basis for judging how loud other booms are. It is called the standard boom and will be preceded by a short tone each time it is played. Your task will be to tell us how loud or soft the other booms seem as compared to the standard boom. You will be provided a scoring sheet for use in making your evaluations. The rating sheet will indicate when a standard boom will be played to refresh your memory.

The rating scale will work in the following manner. The standard boom will be assigned a loudness score of 100, thus you <u>will not</u> write down a score for the standard. It will be your task to assign loudness scores to other booms in order to indicate how much louder or softer they are compared to the standard. It is important for you to always try to compare the loudness of the other booms to the standard. If you feel that the other boom is twice as loud as the standard, write down "200" in the blank provided for that boom. If it seems to be half as loud as the standard, write down a score of "50". To aid in understanding the scoring method, pretend that you are listening to music over a stereo system with the volume set at 100. If you want the music to be only half as loud, then you would turn the volume control from 100 to 50. If you wanted to double the loudness, you would turn the volume control to 200. Essentially, we will be playing the standard at a volume of 100, and you will be telling us at what volume setting you think we are playing the other booms. Try to rate each boom independently of your other ratings. Only a short time will be provided between comparisons, so write down your first impression; there is no need to spend a lot of thought on making precise ratings. Also, do not worry about consistency between ratings, rate each boom as it compares to the standard by itself. There are no right or wrong answers since we are interested in how the booms sound to you.

Appendix B.- Scoring Sheets for Magnitude Estimation Task

(a) SEQA

Subject #: ________ ID #: ________ Date: ________

SONIC BOOM RATING SHEET

S=100
1. ________

S=100
2. ________

S=100
3. ________

S=100
4. ________

S=100
5. ________

S=100
6. ________

S=100
7. ________

S=100
8. ________

S=100
9. ________

S=100
10. ________

S=100
11. ________

S=100
12. ________

S=100
13. ________

S=100
14. ________

S=100
15. ________

S=100
16. ________

S=100
17. ________

S=100
18. ________

S=100
19. ________

S=100
20. ________

S=100
21. ________

S=100
22. ________

S=100
23. ________

S=100
24. ________

S=100
25. ________

S=100
26. ________

S=100
27. ________

S=100
28. ________

S=100
29. ________

S=100
30. ________

Appendix B.- Continued

(b) SEQB

Subject #: ____________ ID #: ____________ Date: ____________

SONIC BOOM RATING SHEET

S=100

1. ________
2. ________
3. ________

S=100

4. ________
5. ________
6. ________

S=100

7. ________
8. ________
9. ________

S=100

10. ________
11. ________
12. ________

S=100

13. ________
14. ________
15. ________

S=100

16. ________
17. ________
18. ________

S=100

19. ________
20. ________
21. ________

S=100

22. ________
23. ________
24. ________

S=100

25. ________
26. ________
27. ________

S=100

28. ________
29. ________
30. ________

S=100

Appendix B.- Concluded.

(c) SEQC

Subject #: ____________ ID #: ____________ Date: ____________

SONIC BOOM RATING SHEET

S=100

1. ________
2. ________
3. ________
4. ________
5. ________
6. ________

S=100

7. ________
8. ________
9. ________
10. ________
11. ________
12. ________

S=100

13. ________
14. ________
15. ________
16. ________
17. ________
18. ________

S=100

19. ________
20. ________
21. ________
22. ________
23. ________
24. ________

S=100

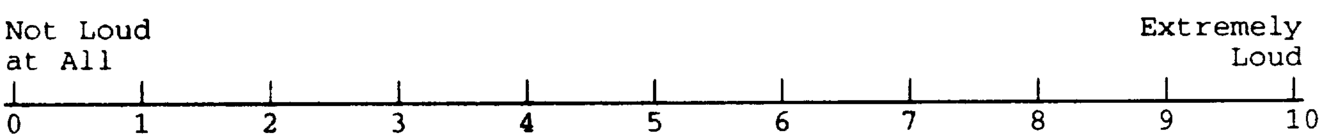
25. ________
26. ________
27. ________
28. ________
29. ________
30. ________

Appendix C.- Instructions for Numerical Category Scaling

Instructions

This experiment is intended to assist us in understanding the way people respond to various sounds produced by aircraft. To do this we are going to ask you to judge how **LOUD** some of these aircraft sounds are.

The experiment consists of one session containing 30 sounds. Before this session you will be given three rating sheets containing rating scales similar to the one shown below.



After each sound there will be a few seconds of silence. During this interval please indicate how loud you judge the sound to be by placing a slash mark at a point along the scale. The point at which the slash mark crosses the line will be used to indicate your rating. If you judge a sound to be only slightly loud, then place your slash mark close to the **NOT LOUD AT ALL** end of the scale. Similarly, if you judge a sound to be very loud, then place your slash mark closer to the **EXTREMELY LOUD** end of the scale. A moderately loud judgment should be marked somewhere in the middle portion of the scale. You may place your slash marks anywhere along the scale; that is, you may place them on, near, or between numbers. In any case, **PLEASE MAKE ONLY ONE SLASH MARK** on each scale (there is one scale for each sound you will judge). There are no right or wrong answers; we are only interested in your opinion of each sound.

Before entering the test booth you will listen to six sounds similar to those that you will be asked to judge. You will not rate these sounds. They are only intended to give you a feel for the range of sounds that you will hear. You will then be given a practice rating sheet, placed in the booth, and nine practice sounds will be presented. You will record your loudness judgments of the practice sounds on the practice scoring sheet. After the practice session we will answer any questions that you may have. We will then proceed with the actual test.

Thank you for your participation and help in conducting this experiment.

Appendix D.- General Briefing Remarks

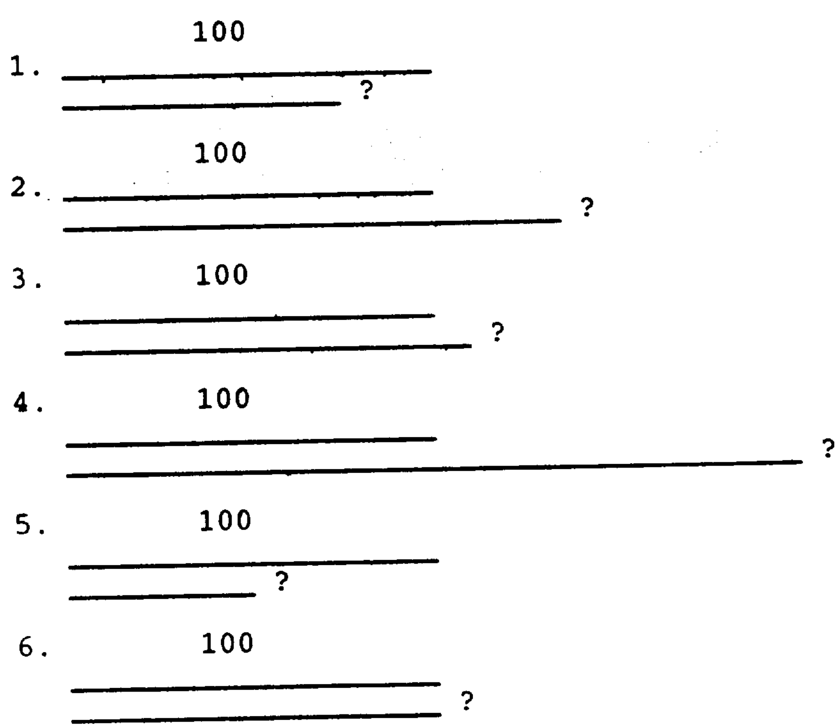
GENERAL INSTRUCTIONS

You have volunteered to participate in a research program designed to evaluate various sounds that may be produced by certain aircraft. Our purpose is to study people's impressions of these sounds. To do this we have built a simulator which can create sounds similar to those produced by some aircraft. The simulator provides no risk to participants. It meets stringent safety requirements and cannot produce noises which are harmful. It contains safety features which will automatically shut the system down if it does not perform properly.

You will enter the simulator, sit in the chair, and make yourself comfortable. The door will be closed and you will hear a series of sounds. These sounds represent those you could occasionally hear during your routine daily activities. Your task will be to evaluate these sounds using a method that we will explain later. Make yourself as comfortable and relaxed as possible while the test is being conducted. You will at all times be in two-way communication with the test conductor, and you will be monitored by the overhead TV camera. You may terminate the test at any time and for any reason in either of two ways: (1) by voice communication with the test conductor or (2) by exiting the simulator.

Appendix E.- Line Task

IN EACH OF THE FOLLOWING PAIRS OF LINES, DECIDE HOW LONG THE SECOND LINE IS COMPARED TO THE FIRST ONE. THE FIRST LINE HAS A LENGTH OF 100.



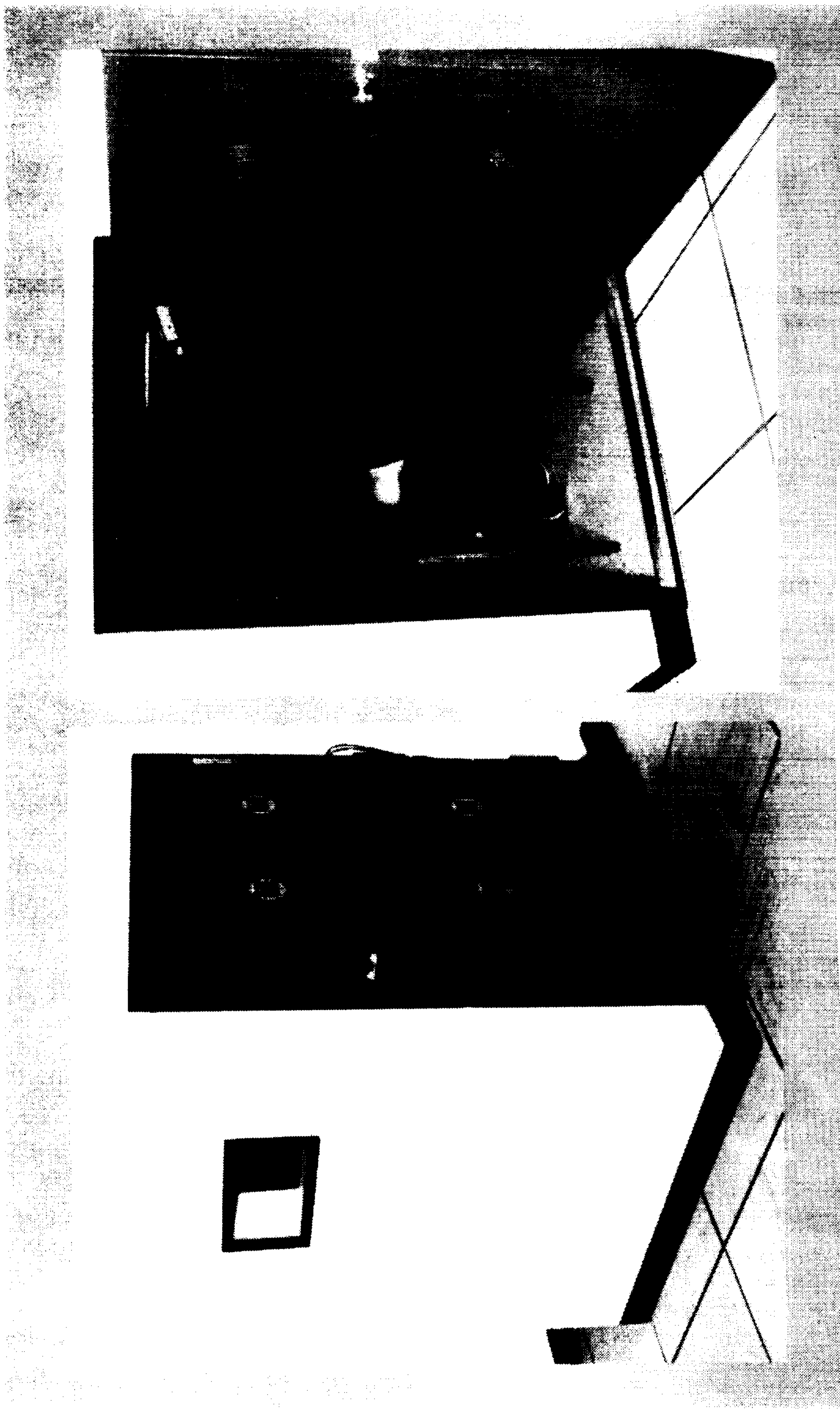


Figure 1.- Sonic Boom Simulator.

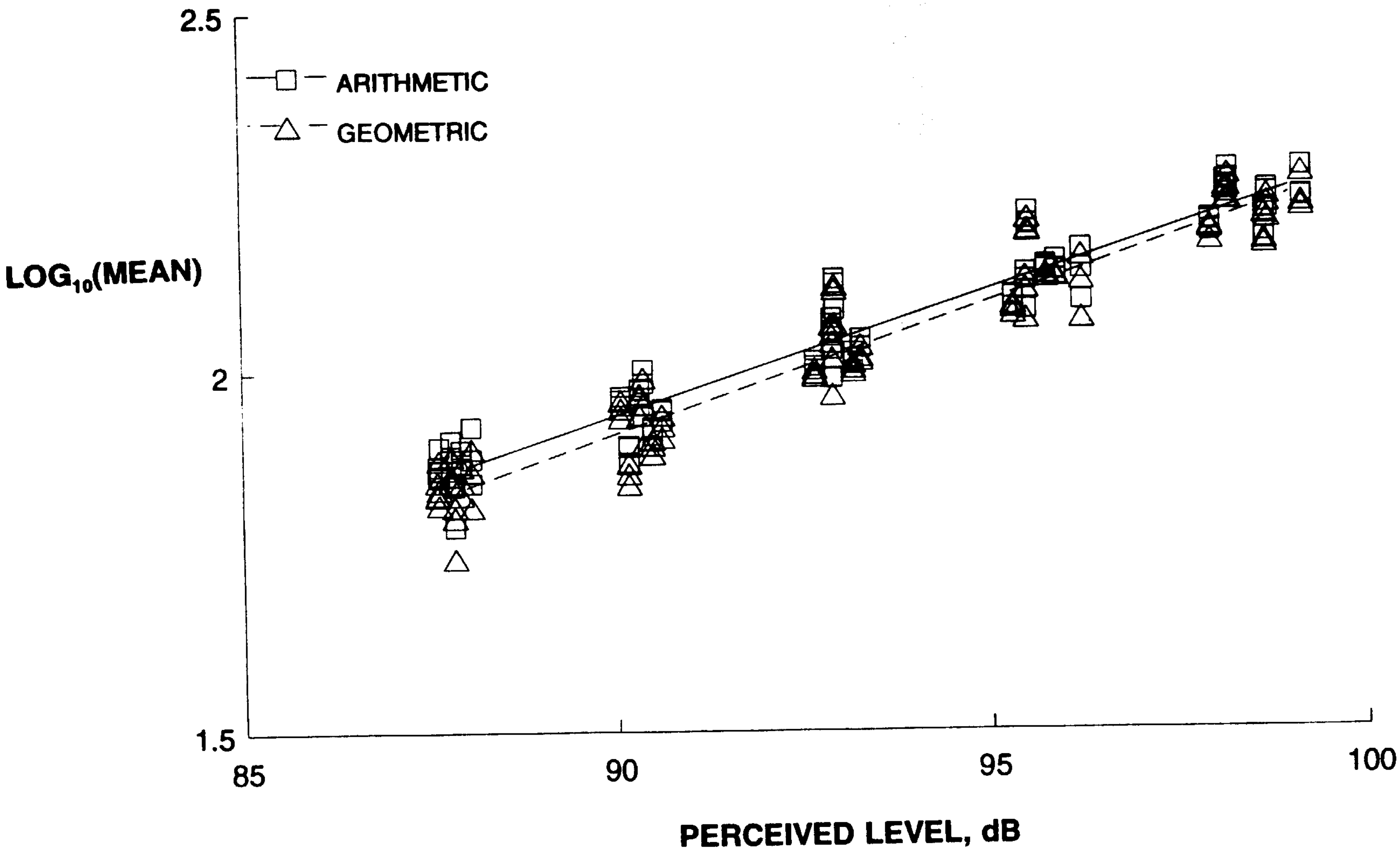


Figure 2.- Logarithms of the arithmetic and geometric means of loudness ratings as a function of Perceived Level (Steven's Mark VII).

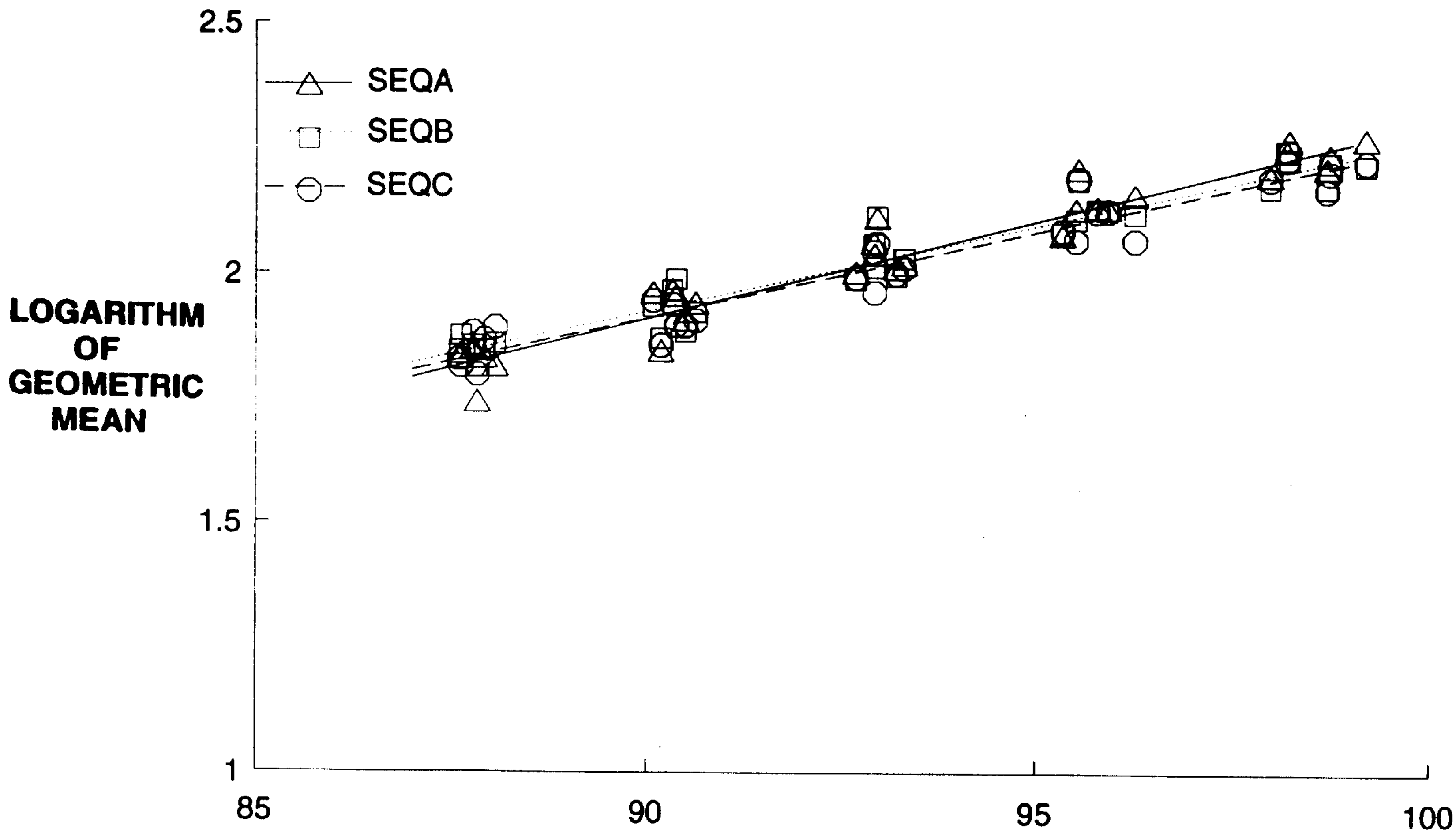


Figure 3.- Logarithm of geometric means of loudness responses for each standard-comparison sequence.

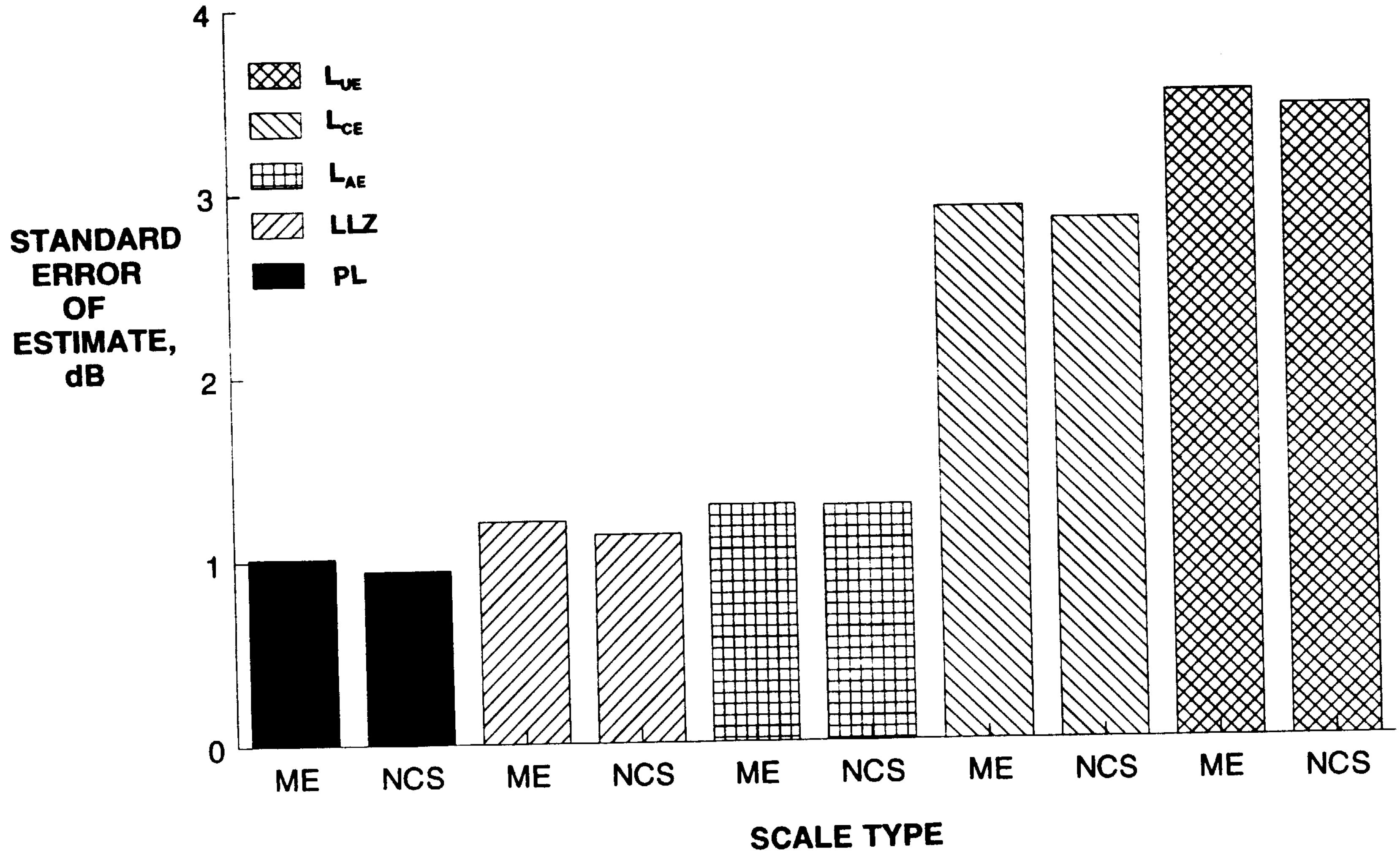


Figure 4.- Standard error of estimate (in dB units) for each scale type and for metrics PL, L_{AE}, L_{CE}, L_{UE}, and LLZ.

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13. ABSTRACT *(Maximum 200 words)*

A laboratory study was conducted to (1) investigate the application of magnitude estimation scaling for evaluating the subjective loudness of sonic booms and (2) compare the relative merits of magnitude estimation and numerical category scaling for sonic boom loudness evaluation. The study was conducted in the NASA Langley Research Center's sonic boom simulator and used a total of 80 test subjects (48 for magnitude estimation and 32 for numerical category scaling). Results demonstrated that magnitude estimation was a practical and effective method for quantifying subjective loudness of sonic booms. When using magnitude estimation, the subjects made valid and consistent ratio judgments of sonic boom loudness irrespective of the frequency of presentation of the standard stimulus. Presentation of the standard as every fourth stimulus was preferred by the subjects and is recommended as the standard presentation frequency to be used in future tests.

14. SUBJECT TERMS
Sonic Boom; Subjective Response; Loudness; Simulator; Shaped Boom; Minimized Boom

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