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A LABORATORY STUDY OF THE SUBJECTIVE RESPONSE TO HELICOPTER BLADE-SLAP NOISE

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SUMMARY

A laboratory study was conducted to investigate the subjective response to helicopter noise. The test stimuli were recorded during a recent field study and consisted of 16 sounds, each presented at 4 peak noise levels. Two helicopters and a fixed-wing aircraft were used. The impulsive characteristics of one helicopter were varied by operating at different rotor speeds, whereas the other helicopter, the noise of which was dominated by the tail rotor, displayed little variation in blade-slap noise. Thirty-two subjects made noisiness judgments on a continuous, 11-point, numerical scale.

Preliminary results indicate that an impulsiveness correction proposed by ISO and one based on A-weighted crest factor provide no significant improvement in the noisiness predictive ability of EPNL. For equal EPNL, the two categories of helicopter stimuli, one of which was far more impulsive than the other, showed no difference in judged noisiness. Examination of the physical characteristics of the sounds presented in the laboratory highlighted the difficulty of reproducing acoustical signals with high-crest factors.

INTRODUCTION

Studies which have examined noisiness or annoyance due to helicopter fly-over noise have produced conflicting results. Some have proposed that a correction be applied to account for the impulsive nature of helicopter noise (e.g., 1,2) whereas others have concluded that such a correction is unnecessary

(3,4). One study (5) proposed corrections for both the impulsiveness and the repetition rate of blade slap.

A recent study was conducted by Powell (6) which had two specific goals. The first was to determine if subjects in an outdoor situation consistently judge real helicopter flyover noises with high levels of impulsiveness noisier than similar flyover noises at the same EPNL but with lower levels of impulsiveness. The second was to determine if an impulsiveness correction proposed by the International Standard Organization (ISO) (ref. 7) significantly improves the predictive ability of EPNL for these same situations. Preliminary results indicated that no significant improvement in the predictive ability of EPNL was provided by either an ISO proposed or an A-weighted crest factor correction for impulsiveness.

The present study was conducted in a laboratory using recorded sounds selected from the stimuli utilized in the study by Powell (6). The primary purpose of the study was to determine if annoyance judgments made in the laboratory show agreement with those derived from the field study. Clearly, a laboratory environment enables greater control of the stimuli; in particular the peak noise levels may be adjusted to eliminate differences between aircraft types and flight conditions.

This report describes preliminary results from the laboratory study.

SYMBOLS AND ABBREVIATIONS

dB(A) - A-weighted sound pressure level, dB

SEL - sound exposure level, A-weighted sound pressure level with integrated duration correction, dB

dB(D) - D-weighted sound pressure level, dB dB(E) - E-weighted sound pressure level, dB

PNL - perceived noise level, PNdB

PNLT - tone-corrected perceived noise level, PNdB

EPNL - effective perceived noise level, EPNdB

$EPNL_1'$ - impulsiveness corrected effective perceived noise level using ISO method, EPNdB

$EPNL_2'$ - impulsiveness corrected effective perceived noise level using modified ISO method, EPNdB

$EPNL_3'$ - impulsiveness corrected perceived noise level using A-weighted sound pressure level method, EPNdB

SEL_1' - impulsiveness corrected sound exposure level using ISO method, dB

SEL_2' - impulsiveness corrected sound exposure level using modified ISO method, dB

SEL_3' - impulsiveness corrected sound exposure level using A-weighted sound pressure level method, dB

SSV - subjective scale value

ISO - International Standards Organization

EXPERIMENTAL DESIGN AND PROCEDURE

Test Sounds

The field study (6) used three types of aircraft consisting of two helicopters (Bell 204-B, Bell OH-58) and a fixed-wing aircraft (North American T-28). Under level flight conditions, the noise from the 204-B is far more impulsive than that associated with the OH-58. Each aircraft was flown at two altitudes (90 m and 270 m) and two angles of elevation and, in addition, the B204-B was flown with three rotor speeds (91 percent, 96 percent, and

100 percent of maximum certified rpm) in order to vary the degree of impulsiveness. For the purpose of selecting the sounds for the laboratory study, the B204-B recordings were grouped into two categories of impulsiveness based upon their ISO impulsiveness corrections. The laboratory test sounds represented each combination of aircraft type and flight condition and the selection was based upon the quality of the original recordings.

Experimental Design

The experiment was based on a factorial design of the three factors; aircraft type, flight condition, and peak noise level. There were, in effect, four aircraft types (B204-B, high impulsiveness; B204-B, low impulsiveness; OH-58; T-28) and four flight conditions (two altitudes and two angles of elevation). Each of the sounds was presented at four peak noise levels (72, 78, 84, and 90 dB(A)), making a total of 64 test stimuli. These stimuli were assigned to four test sessions using orthogonal Latin squares, thus minimizing any order of presentation effects.

Test Procedure

The testing laboratory was the Exterior Effects Room at NASA's Langley Research Center. The sounds were presented by means of a single studio-quality coaxial loudspeaker positioned 1-1/2 meters in front of the seated subjects. Due to the impulsive nature of some of the sounds, it was considered necessary to minimize acoustic reflections from the walls of the room and to accomplish this the testing area was surrounded with sound absorbing panels (Figure 1).

Thirty-two subjects who were audiometrically screened were selected from a "pool" of residents local to the laboratory. Participation was voluntary and the subjects were paid. The instructions and response sheets (Appendix A) were, as far as possible, identical to those used in the field study. The subjects judged the "noisiness" of each aircraft event by placing a mark on a continuous numerical scale ranging from "0, Not Noisy at All" to "10, Extremely Noisy."

The test sounds were presented to one pair of subjects at a time, the order of presentation of sounds being varied for each of the 16 pairs of subjects.

ACOUSTICAL ANALYSES

The acoustical data were acquired with a microphone placed at the position occupied by the subjects, but with the subjects absent. The data were recorded on an FM tape recorder and then analyzed to provide 1/2-second, 1/3-octave band sound pressure levels which were used to calculate measures in terms of EPNL and other common noise rating scales. The noises were also analyzed to provide measures of impulsiveness.

One measure of impulsiveness is that proposed by the ISO which requires that the acoustical signal be A-weighted and sampled at 5 kHz. During each 0.5 second period of the signal, the sampled voltage, V_i, is used to calculate a correction factor, C_1, which is added to the tone-corrected perceived noise level, thus:

$$X = 10 \log \left[\frac{n \sum_{i=1}^{n} V_i^4}{\left(\sum_{i=1}^{n} V_i^2 \right)^2} - 1 \right]$$

$C_1 = 0.8\ (X-3)$

with the limits that

$0\text{dB} \le C_1 \le 5.5\text{dB}$

$PNLT_1' = PNLT + C_1$

The values of $PNLT_1'$ are then numerically integrated over the signal duration to provide an impulsiveness-corrected effective perceived noise level, $EPNL_1'$. A second impulsivensss correction was applied which was identical to that proposed by ISO except that the values of C_1 were allowed to exceed a value of 5.5dB. The corrected scale was designated $EPNL_2'$. These two correction procedures were also used to calculate SEL_1' and SEL_2' in which dB(A) values replaced those of PNLT in the formulas presented above. The final correction procedure required the computation of C_2 for each 1/2-second of the signal:

$$C_2 = L_A(\text{peak}) - L_A(\text{rms}) - 12 \text{ dB}$$

where L_A(peak) in the A-weighted peak sound pressure level and L_A(rms) is the root-mean-square A-weighted sound pressure level for the 0.5-second period. These corrections were applied to the 0.5-second PNLT and dB(A) values and integrated to provide the measures $EPNL_3'$ and SEL_3'.

RESULTS AND DISCUSSION

Effects of Noise Level and Aircraft Type on Noisiness

The mean subjective scale values (SSV) were calculated for each stimulus and are shown as a function of EPNL in Figure 2. The trend of the data is clearly linear, with apparently no large differences between the types of aircraft.

Linear least-squares regression analyses of the subjective data were performed on noise levels in terms of EPNL and other descriptors. Table I presents the results of the regression analyses of SSV on EPNL for each aircraft type both separately and in combination. There was found to be no statistical difference ($p < 0.05$) between the slopes or intercepts of the regression lines for the three types of aircraft.

Correlation coefficients between the SSV's and several noise rating scales are given in Table II. All of the scales performed well for the various combinations of aircraft types. There was little difference in the performance of SEL and EPNL and in no case did the addition of an impulsiveness correction result in a statistically significant improvement.

Linear multiple regression analyses were conducted with EPNL, SEL, and their respective impulsiveness corrections as independent variables, and SSV as the dependent variable. Again, no significant improvement resulted from the addition of these measures of impulsiveness.

A Comparison of the Laboratory and Field Studies

In order to compare the two studies, an "equal noisiness level" was found for each sound used in the laboratory study. The EPNL value corresponding to the mean of the noisiness judgments of all the stimuli was calculated for each sound as illustrated in Figure 3. The "relative noisiness" of each sound was found by comparing the equal noisiness levels with the mean noisiness level calculated from Figure 2. These values and the relative noisiness levels derived in the field study are given in Table III. The relative noisiness judgments from the two studies are compared in Figure 4 in which it is observed that there is a statistically significant linear correlation ($r = 0.66$), indicating resonable agreement between judgments made in the two test environments.

The physical characteristics of the stimuli used in the two studies are compared in Table III, in which the effective ISO impulsiveness corrections are tabulated. Examination of these values gives an indication of the fidelity of the sound recording and reproduction system and is illustrated in Figure 5.

When the data for all the aircraft are considered, there is a significant linear correlation ($r = 0.85$) between the two sets of impulsiveness measures. However, for the B204-B data alone, the correlation coefficient ($r = 0.65$) is not statistically significant. The laboratory study used a studio-quality tape recorder, amplifier and loudspeaker, but despite this it is clear that reproducing audio signals with high crest factors presents considerable difficulty. It is interesting to note, however, that although the ISO corrections for the B204-B stimuli do not correlate significantly, the relative noisiness judgments for these stimuli do show a significant linear correlation ($r = 0.72$). This apparent contradiction may be due, in part, to phase changes caused by the loudspeaker, which, although affecting the measures of impulsiveness, are probably of little subjective importance.

The field study (6) indicated that for equal EPNL values, the OH-58 stimuli were generally judged more annoying than those of the B204-B. Although this trend was observed in the laboratory study, it was found to be not statistically significant. It should be noted, however, that this latter study did not include all the stimuli used in the field test.

CONCLUSIONS

A laboratory study was conducted to investigate subjective response to helicopter noise. The test sounds, from two helicopters and a fixed-wing aircraft, were recorded during a recent field study (6) which examined helicopter blade-slap noise. The degree of blade slap was varied for one of the helicopters by changes in rotor speed. The second helicopter, the noise of which was dominated by tail rotor noise, was operated under the same flight conditions but with little variation in impulsiveness.

Preliminary analyses indicate reasonable agreement between this laboratory study and the previous field study. The impulsiveness correction proposed by ISO and one based on A-weighted crest factor provided no significant improvement in the performance of EPNL. For equal EPNL, there were no differences in the noisiness judgments of the three types of aircraft. Examination of the physical characteristics of the noises presented in the laboratory indicated that reproducing acoustic signals with high crest factors presents considerable difficulty.

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TABLE I. - REGRESSION ANALYSES OF SSV ON EPNL

Aircraft type	Number of stimuli	Intercept	Slope of EPNL	Standard error of slope	Correlation coefficient
B-204B	32	-21.44	0.27	0.013	0.967
OH-58	16	-19.77	0.26	0.015	0.976
T-28	16	-22.58	0.28	0.015	0.981
All Aircraft	64	-20.98	0.27	0.008	0.971

TABLE II. - CORRELATION COEFFICIENTS OF SSV AND VARIOUS NOISE RATING SCALES

Aircraft type	db(A)	db(D)	db(E)	PNL	PNLT	EPNL	$EPNL_1'$	$EPNL_2'$	$EPNL_3'$	SEL	SEL_1'	SEL_2'	SEL_3'
B-204B	.982	.960	.967	.973	.971	.967	.972	.972	.968	.976	.980	.979	.979
OH-58	.980	.97[illegible]	.974	.975	.976	.976	.978	.978	.972	.971	.974	.974	.973
B-204B/OH-58	.969	.965	.969	.973	.971	.968	.960	.958	.963	.973	.976	.974	.977
T-28	.845	.825	.777	.806	.841	.981	.975	.975	.980	.974	.965	.965	.969
All Aircraft	.912	.900	.907	.903	.908	.971	.962	.960	.967	.974	.972	.971	.975

TABLE III. - A COMPARISON OF THE LABORATORY AND FIELD DATA.

Aircraft type	Flight path	Laboratory study			Field study	
		Equal noisiness level, EPNdb	Relative noisiness, EPNdb	Effective ISO correction ($EPNL_1' - EPNL$)	Relative noisiness	Effective ISO correction
B-204B	90m/overhead	96.0	2.0	4.1	1.27	5.0
	90m/120m side	99.4	-1.4	3.0	0.53	4.5
(high	270m/overhead	97.8	0.2	2.5	-0.92	4.2
impulsiveness)	270m/370m side	99.4	-1.4	2.1	-0.97	3.7
B-204B	90	96.8	1.2	1.7	0.04	4.8
	90/120	98.1	-0.1	1.9	-0.54	3.5
(low	270	99.2	-1.2	2.7	-1.74	4.9
impulsiveness)	270/370	100.9	-2.9	1.6	-1.88	3.4
OH-58	90	96.4	1.6	0.9	0.65	1.3
	90/120	96.7	1.3	1.1	0.55	1.5
	270	97.8	0.2	1.0	-0.04	2.0
	270/370	98.3	-0.3	0.8	1.60	1.1
T-28	90	96.3	1.7	0.8	0.79	1.5
	90/120	97.6	0.4	1.0	0.38	2.8
	270	97.8	0.2	0.6	0.34	2.4
	270/370	99.0	-1.0	1.5	0.11	2.6

Figure I. Testing laboratory

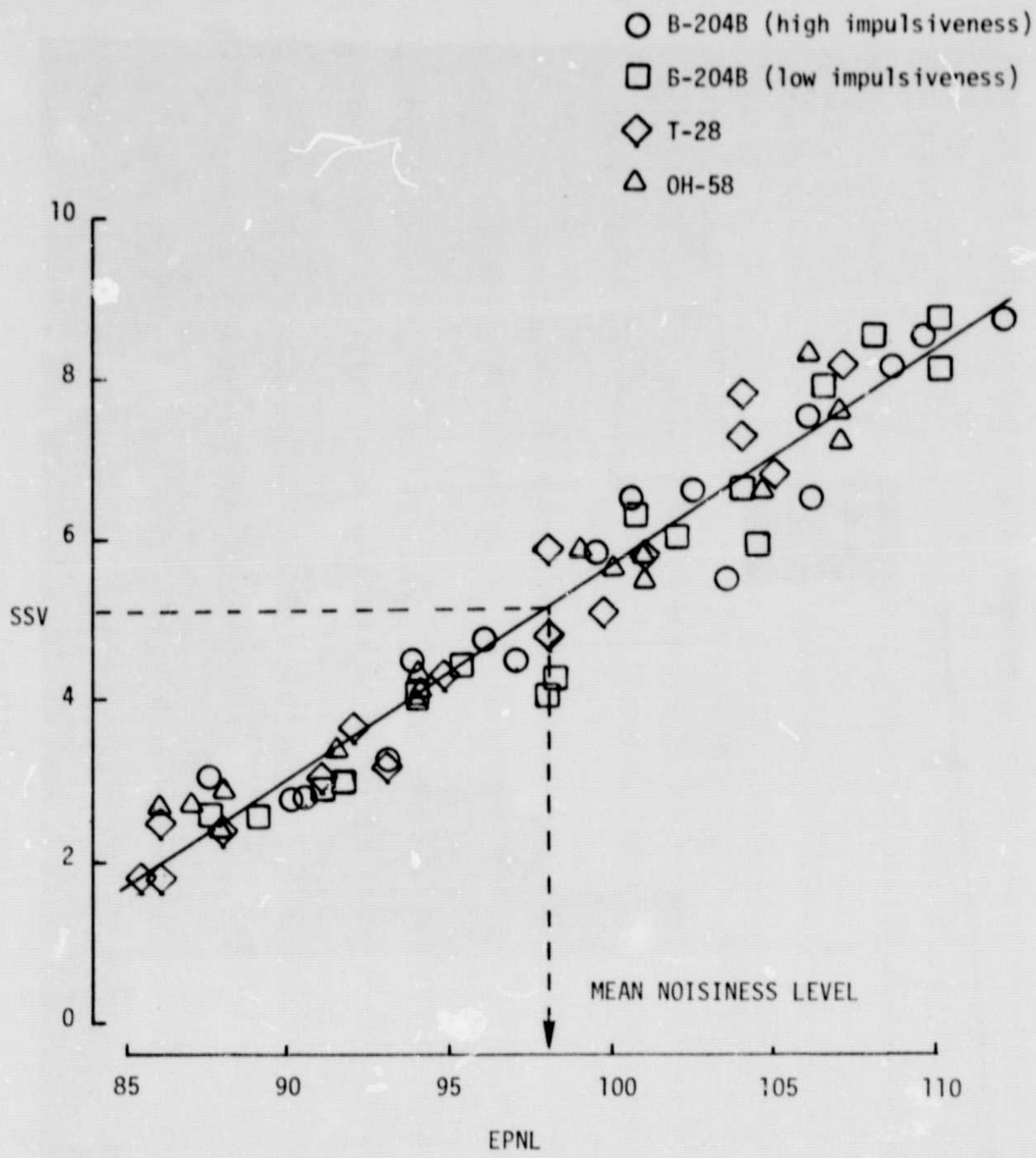

Figure 2. The relationship between mean subjective noisiness judgements and EPNL of test stimuli.

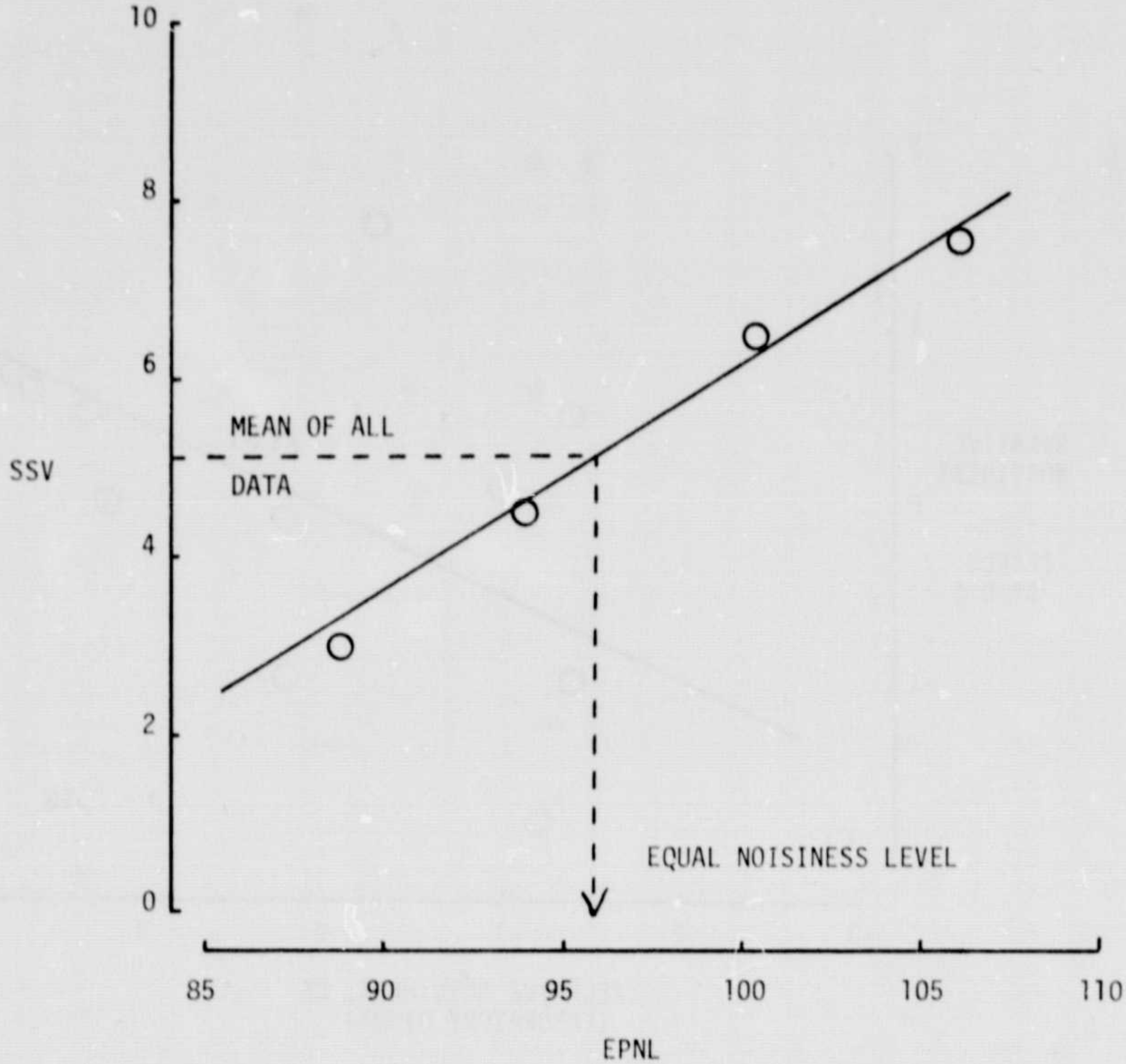

Figure 3. Derivation of equal noisiness level for a stimulus presented at four peak levels.

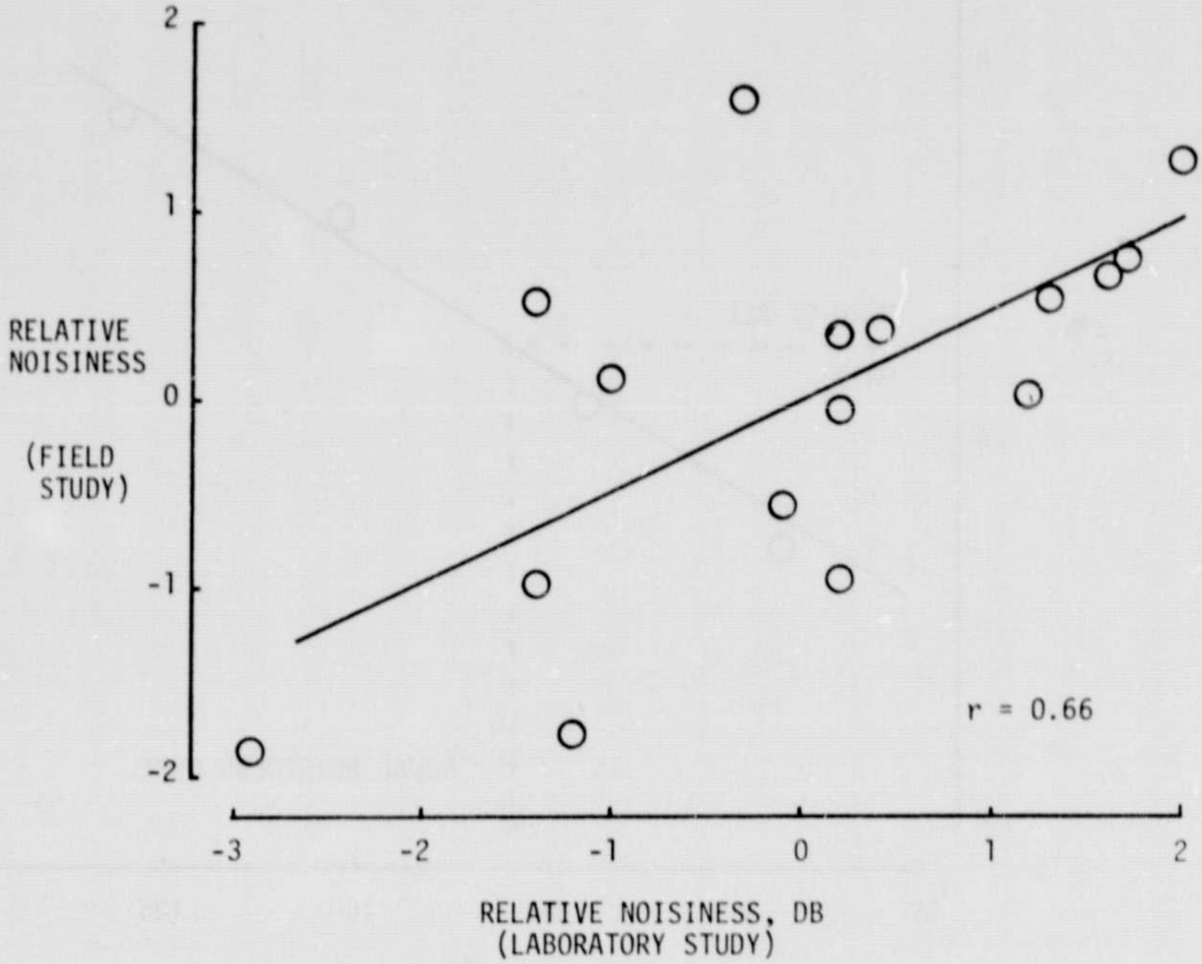

Figure 4. A comparison of the relative noisiness of the stimuli for the laboratory and field studies.

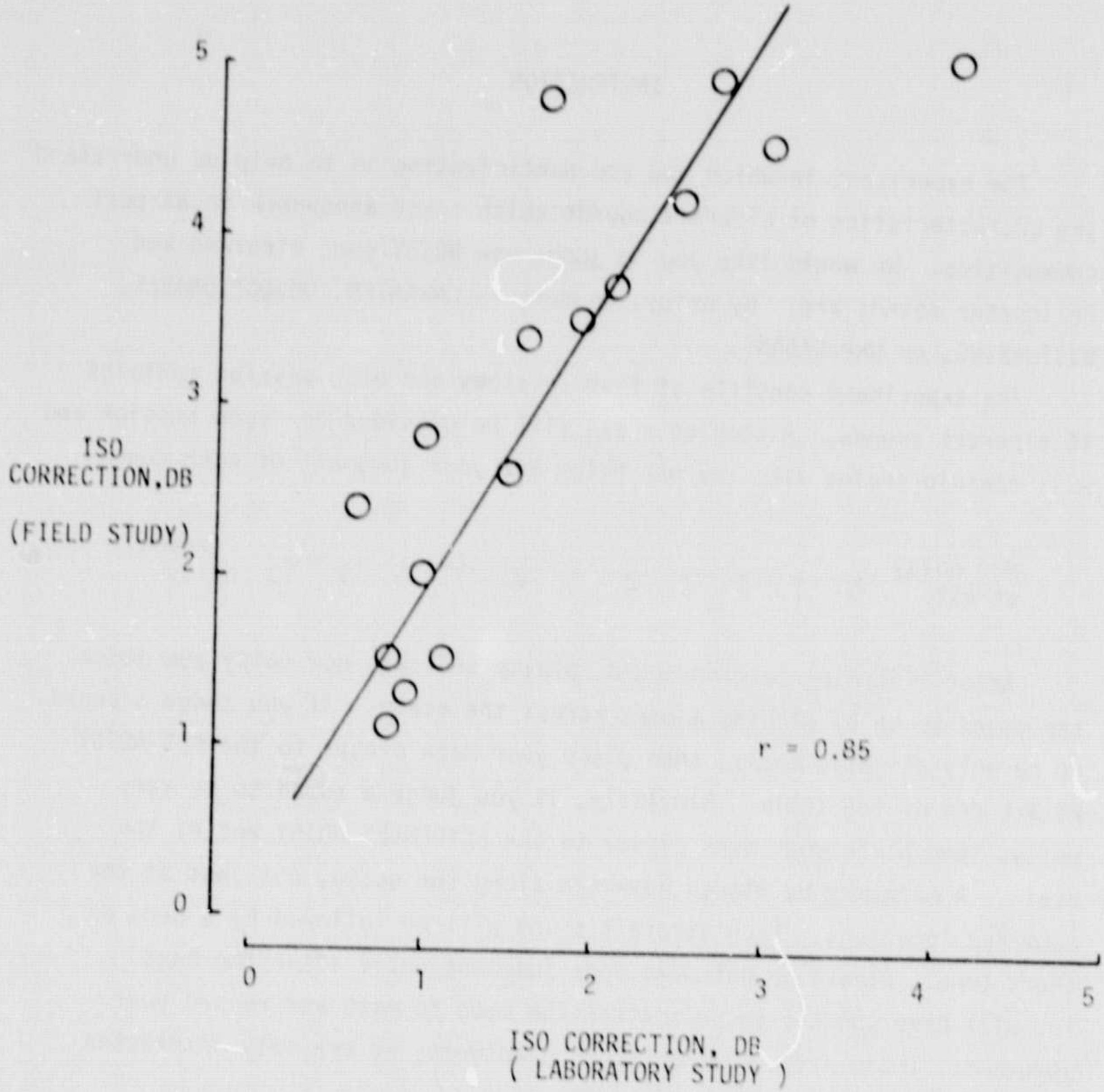

Figure 5. A comparison of the ISO impulsiveness corrections for the laboratory and field stimuli.

APPENDIX A. Instructions and scoring sheets.

INSTRUCTIONS

The experiment in which you are participating is to help us understand the characteristics of aircraft sounds which cause annoyance in airport communities. We would like you to judge how NOISY some airplane and helicopter sounds are. By noisy, we mean -- UNWANTED, OBJECTIONABLE, DISTURBING, or UNPLEASANT.

The experiment consists of four sessions and each session contains 16 aircraft sounds. A scoring sheet will be provided for each session and will contain scales like the one below for your judgment of each sound:

Not noisy at all	0	1	2	3	4	5	6	7	8	9	10	Extremely noisy

After listening to each sound, please indicate how noisy you judge the sound to be by placing a mark across the scale. If you judge a sound to be only slightly noisy, then place your mark closer to the NOT NOISY AT ALL end of the scale. Similarly, if you judge a sound to be very noisy, then place your mark closer to the EXTREMELY NOISY end of the scale. A mark may be placed anywhere along the scale, not just at the numbered locations. Each aircraft sound will be followed by a beep or short tone. Please do not make your judgment until after the beep. You will have about 5 seconds after the beep to make and record your judgment. There are no right or wrong answers; we are only interested in your judgment of each sound.

Thank you for your help in conducting the experiment.

RATING SHEET

Subject ____________________ Session ____________________ Page 1

Sound			
1	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
2	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
3	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
4	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
5	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
6	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
7	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
8	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
9	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
10	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy
11	Not Noisy at all	0 1 2 3 4 5 6 7 8 9 10	Extremely Noisy