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THE SUBJECTIVE EVALUATION OF NOISE FROM LIGHT AIRCRAFT

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16. Abstract

A study was conducted in which subjects evaluated the sounds of a light aircraft and a motorcycle. Particular emphasis was placed on examining the duration of the sounds. Thirty subjects gave annoyance ratings to a total of 50 sounds, with peak levels between 65 and 85dB(A). It was found that aircraft and motorcycles have differing optimum duration corrections. The conventional duration correction used in the calculation of EPNL is far from being the optimum for light aircraft.

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THE SUBJECTIVE EVALUATION OF NOISE FROM LIGHT AIRCRAFT

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SUMMARY

The study was aimed at investigating the subjective evaluation of noise from light aircraft. Particular emphasis was placed on the duration of the noise. To highlight any source/spectral effects, a second source, a motorcycle, was included in the study. Sound recordings were made of a single-engined two-seater aircraft and a medium-sized two-stoke motorcycle over a wide range of source-receiver distances. This enabled a wide range of durations to be obtained. Using a numerical category scaling technique, thirty subjects gave annoyance ratings to a total of 50 tape recorded sounds. These had peak levels between 65 and 85 dB(A), and 10 dB(A) down duration of between 2 and 45 seconds. The subjective ratings were compared with the noises described in terms of the commonly used physical measuring units. Most of these measuring units were found to be equally good. The addition of a duration correction to any of these measuring units improved their predictive capabilities. The addition of a duration correction was of more benefit in explaining motorcycle annoyance than aircraft annoyance. The conventional duration correction, 10 log (10 dB-down duration) was found to be close to the optimum correction for the motorcycle noise; for aircraft the coefficient was found to be a number rather smaller than 10. The duration corrections of the

type "the time the sound exceeded x dB(A)" were found to be as good as the conventional 10 dB down duration correction.

INTRODUCTION

There have been many attempts in the past to relate the subjective reaction to various parameters associated with a sound. The first experiments were aimed at examining the relationship between the loudness of a sound and its frequency content and sound pressure level. Pure tones or narrow bands of noise were used (Ref. 1) and procedures were developed for finding the loudness of complex sounds (Refs. 2,3). The effect of the duration of a sound on loudness is rather unclear. Some investigations report that loudness grows with increasing duration up to a few tenths of a second and then remains constant (Ref. 4), while others report a decrease in loudness as the response time lengthens (Ref. 5). Still others report a noise level dependency; loudness increasing with increasing duration at high noise levels and decreasing with increasing duration at low noise levels (Ref. 6).

In the 1950's another acoustic concept, noisiness, was introduced into psychoacoustics by Kryter (Ref. 7). Research on noisiness proceeded in a similar way to the previous work on loudness. Procedures were developed for finding the noisiness of complex sounds, the resulting unit of measurement being the perceived noise decibel. This unit has been widely used for the quantification of aircraft noise. Since this unit (PNdB) was first introduced there have been many suggested modifications and variations.

The suggestion that the duration affected the noisiness of a sound was first put forward by Kryter and Pearsons (Ref. 8). Their proposed modification was a direct result of the Composite Noise Rating (CNR) concept advanced by Stevens and Pietrasanta (Ref. 9) in which basically they suggested that human response to noise (annoyance) was directly related to the frequency-weighted acoustical energy in the sound. According to this procedure, doubling the duration of a sound would have the same subjective effect as increasing its sound pressure level by 3dB. However, as Kryter and Pearsons pointed out in (Ref. 8) "what the exchange relation is between intensity level and duration with respect to noisiness has not been experimentally determined, and, of course, there is no real reason why man's auditory system needs to operate on an equal energy basis. . . ."

The duration correction that is most widely recognized is incorporated in the unit known as the effective perceived noise level (EPNdB). This correction is a function of the time that the noise level is within 10 PNdBT of the peak level. This unit, the EPNdB, has been chosen for aircraft certification purposes in the United State (Ref. 10).

Much of the research concerning the duration effect has produced conflicting results. For example, in (Ref. 11), Kryter et al., conclude that those measures with a duration correction do no better than simple peak level measures. In (Ref. 7) the opposite conclusion is reached. In (Ref. 12) it is reported that the inclusion of a duration correction gives better results. (Ref. 13) found that the addition of a duration correction to dB(A) gave results comparable to those using EPNdB.

Ref. 5 is a review of the research concerning the duration correction carried out prior to 1970. The reviewers claim that the duration correction is not observed unless the subjects in the experiment are specifically asked to rate the duration, i.e., a duration cue is given. Some of the previously quoted references do not support this conclusion. It worth remembering Kryter's warning given in Ref. 11 that "subjects tend to attend primarily to general spectral content and peak level." He recommends systematic variation of variables.

In 1971, Ollerhead (Ref. 14) carried out what is probably the most comprehensive research on the duration correction. He used a large number of flyover recordings from jets, turboprops, piston engined aircraft and helicopters. In all cases, Ollerhead found that the scales having a duration correction were superior to peak level scales. He also reported that there is apparently a different duration dependency for different kinds of noise sources.

In all of the research reported the sounds used have never included light aircraft. Also in cases where real aircraft rather than bands of noise have been used as the noise stimuli there has consistently been a problem in interpreting the results. For example, in Ollerhead's work (Ref. 14) it is clear that the "duration corrected" scales are superior to the "peak" scales, but the nature of the optimum correction cannot be satisfactorily determined. This is due to a rather high negative correlation between the peak level and duration of the sounds. This is a characteristic of all the research using real flyovers played at realistic levels. The result is that it is difficult to statistically separate these two factors.

In the project about to be described, recordings of single (piston) engined light aircraft with weights typically less than 1500 kg have been used in an experiment specifically designed to give maximum information about these two factors, duration and level. In addition, in order to investigate the possibility that different noise sources have different optimum duration corrections, a second source was included in the study, namely a motorcycle.

SYMBOLS

dB	Unit of sound pressure level, decibel, using reference pressure of 20 micro-Newtons per square meter.
PNL	perceived noise level, PNdB
EPNL	effective perceived noise leve, EPNdB
PNLT	tone corrected perceived noise level
OASPL	overall sound pressure level (unweighted)
dB_x	'x' dB-down duration of sound (seconds)
D	10 dB-down duration of sound (seconds)
T_x	time (in seconds) that sound was above 'x' dB(A)
dur	total audible duration (seconds)
SSV	subjective scale value
$\overline{SSV}$	subjective scale value averaged over all subjects
r	correlation coefficient
R	multiple correlation coefficient

EXPERIMENTAL APPROACH

The first design problem was to avoid confounding the duration and peak level of the sounds, i.e., to reduce the intercorrelation between these two factors. This was accomplished by the construction of Matrix 1 with five peak noise levels (L_1 - L_5) and five durations (D_1 - D_5). Five of each were chosen to give sufficient degrees of freedom for regression analysis. The numbers 1-25 represent all possible combinations of duration and level.

Matrix 1

	L_1	L_2	L_3	L_4	L_5
D_1	1	2	3	4	5
D_2	6	7	8	9	10
D_3	11	12	13	14	15
D_4	16	17	18	19	20
D_5	21	22	23	24	25

It would be advantageous if all subjects heard all twenty-five sounds. This would ideally be accomplished by the formation of two 25 x 25 balanced Latin squares. This would require fifty sessions, which is impractical.

Another design which is almost balanced is the following. Consider the following 5 x 5 Graeco-Latin Square:

Matrix 2

Aα	Bβ	Cγ	Dδ	Eε
Bδ	Cε	Dα	Eβ	Aγ
Cβ	Dγ	Eδ	Aε	Bα
Dε	Eα	Aβ	Bγ	Cδ
Eγ	Aδ	Bε	Cα	Dβ

It is clear that each combination of Roman and Greek letters occurs once, and that each row now contains all the Greek and Roman letters. The durations (D_1-D_5) were randomly assigned to the Roman letters (A-E) and the levels (L_1-L_5) were assigned to the Greek letters (α-ε). This gave the following:

Matrix 3

8	4	12	25	16
24	17	10	1	13
2	15	21	18	9
20	6	3	14	22
11	23	19	7	5

Examination of this matrix reveals that each row and column contains each duration and level, but the order of duration and level is not randomized.

Randomizing rows and columns using random number tables yielded the following:

Matrix 4

Tape	Order of Sounds				
1	2	9	18	15	21
2	24	13	1	17	10
3	11	5	7	23	19
4	8	16	25	4	12
5	20	22	14	6	3

Five tapes were thus formed. Each tape contained each duration and each level and the order or presentation was random.

Each subject heard each tape. The order of presentation of tapes is given by two 5 x 5 Latin squares.

Matrix 5

Subject Groups	Order of Tapes				
1	1	2	5	3	4
2	2	3	1	4	5
3	3	4	2	5	1
4	4	5	3	1	2
5	5	1	4	2	3
6	4	3	5	2	1
7	5	4	1	3	2
8	1	5	2	4	3
9	2	1	3	5	4
10	3	2	4	1	5

The order of tape presentation was therefore balanced such that each tape followed each other tape twice. Each group of subjects (1-10) heard five tapes, each containing five sounds giving twenty-five sounds per session.

The project used two noise sources, light aircraft and motorcycles. In order to balance the order of presentation of sources, the following matrix was formed.

Matrix 6

	Order of Presentation of Sources	
Subject Group 1-5	Aircraft	Motorcycle
6-10	Motorcycle	Aircraft

This experimental design required ten groups of subjects, twenty-five sounds per session and two sessions per group.

The required number of subjects was estimated in the following way. In order to be 95 percent confident that a measure on the subjective scale is within one-half of a unit of the true value, then $\frac{1}{2} = \frac{2\sigma}{\sqrt{n}}$. If we assume that the standard deviation, σ, is typically one unit, then the number of subjects, n, will be approximately sixteen. It was decided to use thirty subjects to give increased precision. Thus the experiment required thirty subjects, composed of ten groups of three and two sessions of twenty-five sounds each.

Sound Recordings

The light aircraft chosen for this program was a strutted, high wing, single engined aircraft weighing approximatly 700 kg. All recordings were made in a remote area where background noise levels were typically 35 dB(A). The equipment used consisted of a precision grade sound level meter and a high grade portable tape recorder. Recordings of a 250 cc two-stroke motorcycle with standard muffler were made under similar conditions.

Recordings were made in order to include as wide a range of sound durations as was practically possible. In order to minimize spectral variations the throttle settings for the aircraft and motorcycle were kept constant at all times. The aircraft altitudes varied from approximately 45 - 600 meters. The motorcycle pass-by distances were from a few meters to about 150 meters.

The best recordings were selected according to their signal to noise ratio and the widest achievable range of durations. The "10 dB(A) down" durations varied from 2 to 40 seconds. Copies of these master recordings were made using high grade amplifiers and tape recorders. Each recording was "faded" so that the noise rose from, and faded into the background noise without any sudden variations in intensity. In addition a small amount of high frequency filtering was used to reduce tape "hiss." The amplification was adjusted to give five recordings with peak levels of 65 - 85 dB(A) in five dB steps when played into the experimental chamber. Thus, for each noise source, twenty-five sounds consisting of five levels and five durations were formed as in Matrix 1.

Test Procedures

Of the thirty test subjects used in this experiment, half were female. The male age range was 19-30 with a median of 24 years. The female age range was 18-44 with a median of 27 years. The occupation of the subjects varied considerably, although there were a high number employed by the U.S. Air Force. Participation in the experiment was voluntary. The subjects were paid. Each subject was given an audiogram prior to the tests and no subject had a hearing loss greater than 15 dB at more than one frequency (I.S.O.).

The listening room used was the "exterior effects room" at NASA (Langley). This room is basically a modified lecture theater with a volume of approximately 360 m^3. It is a "live" room with a reverberation time of about 0.5 seconds at 1K Hz. It has speakers mounted in the walls and ceiling. These are studio quality two-way co-axial speakers with a frequency response from 20 - 20,000 Hz. Only the wall-mounted speakers in front of the subjects were used on this occasion.

The subjects were divided randomly into ten groups of three subjects each. They were seated in adjacent seats in the center of the listening room in front of a microphone which was used for monitoring the auditory stimuli.

The tapes were played using a high quality tape recorder and the room amplification and reproduction system. Calibration and the setting up of peak levels was carried out prior to the subjects entering the room. The subjects were given instructions describing the overall purpose of the program and detailed instructions can be seen in Appendices A and B. At the beginning of the tape there were a few flyovers or pass-bys designed to give the subjects an indication of the kinds of sounds that they were to judge. There were intervals of approximatly 6 seconds between sounds during which the number of the next sound was given.

The rating scale used in this experiment was a numerical category scale from 0 to 8 with the ends of the scale marked "not at all annoying" and "extremely annoying." (See Appendix B.). At the end of the first session, subjects were asked to take a rest break of 5 to 10 minutes. Each session lasted for approximately twenty-five minutes.

Acoustic Analysis of the Stimuli

The stimuli were monitored throughout the experimental program. The peak levels of the flyovers and pass-bys were nominally 65-85 dB(A) in 5 dB(A) steps. The actual levels heard by the subjects can be seen in Table 1. Also the standard deviations measured across the ten groups of subjects is given. It is clear that the sounds were presented to the subjects extremely uniformly.

In order to calculate the various physical scaling units it was necessary to obtain the one-third octave levels of the stimuli for each one-half second interval over the duration of the stimuli. This was accomplished by placing a microphone at the position of the test subjects and interfacing with a real-time analysis system which provided the one-third octave time histories in the range of 25 Hz to 10 kHz. Typical peak level spectra can be seen in Figure 1 and 2.

The stimuli were analyzed into the following composite and maximum frequency weighted units using the one-third octave time histories and the weights given in Reference 7: dB(A), dB(B), dB(C), dB(D_1), dB(D_2), dB(D_3), PNL, PNLT, EPNL, Stevens Mark VII, OASPL.

In addition various possible duration corrections were calculated. These were the "5, 10 and 20 dB down durations" (dB_5, dB_{10}, dB_{20}), i.e. the time (in seconds) that the signal was within 5, 10 or 20 dB of the peak level. Also, the durations of the kind "the time (in seconds) for which the signal exceeds certain references levels" were calculated. These reference levels were chosen to be 60, 70 and 80 dB(A). Also the "total audible duration" was measured when the sounds were played in the listening room. These durations can be seen in Table 2.

RESULTS

Preliminary Analysis

Thirty subjects judged twenty-five sounds from each of two sources. There were, hence, a total of 1500 subjective scale values (SSV's). The mean subjective scale value (SSV) was found for each of the sounds. The $\log_{10}$ of these mean values was plotted against the peak noise level (dB(A)) for each duration (labelled D_1-D_5) as shown in Figures 3 and 4. It is clear that these curves all have a similar gradient. The relationship between the SSV and the duration of the noise is not readily apparent. This aspect is investigated later. Using the method of least squares the "best" straight line was found for each of the curves in Figures 3 and 4. Assuming a relationship of the form $\log_{10}$ (SSV) = a (Peak dB(A)) + C it was found that:

Duration	Gradient (a)	Constant (C)	Correlation Coefficient	No. of dB per doubling of SSV
Aircraft				
D1	0.027	-1.87	0.607	11.1
D2	0.033	-2.05	0.541	9.1
D3	0.033	-2.07	0.690	9.1
D4	0.027	-1.61	0.528	11.1
D5	0.033	-2.02	0.728	9.1
Motorcycle				
D1	0.032	-2.00	0.721	9.4
D2	0.031	-1.86	0.689	9.7
D3	0.032	-2.11	0.716	9.4
D4	0.030	-1.65	0.682	10.0
D5	0.022	-1.05	0.685	13.7

It is clear that this agrees well with the frequently reported observation that the SSV doubles for each 10 dB increase in the peak noise level.

Analysis of Variance

Most of the analysis for this program was carried out using two statistical computer packages. The first (Ref. 15) is particularly good for multiple regression analysis, the other (Ref. 16) was used for the analysis of variance.

The experimental design has been described on page 5. Matrix 1 consisted of 25 sounds, five durations and five levels. Thirty subjects, rated each of the sounds. It was therefore possible to carry out an analysis of variance using the SSV's and Matrix 1. This result can be seen in Table 3. The mean squares were tested for significance using a pseudo F test (Ref. 17) assuming a model with two fixed variables and one random variable (subjects). It was found that all the mean squares, both main effects and interactions were significant at the 5% level. It is clear for both noise sources that the peak level of the noise does most to explain the variance of the SSV's. The duration and intersubject variability are of less importance. Further examination reveals that the duration of the noise appears to have a greater part in explaining the annoyance due to the motorcycle than the aircraft.

It was also possible to include the sex of the subjects in the analysis of variance. This can be seen in Table 4. It is clear that the sex of the subjects is not related to their perceived annoyance.

The second matrix which formed part of the experimental design was Matrix 5 which involves the order in which tapes were presented to the subjects. It was possible to carry out analyses of variance aimed at investigating both the tape order effect and the tape effect (differences between tapes) for each source (see Table 5). It was found that tape effects, tape order effects and all interactions were non-significant. "Subject groups" were found to be a significant variable. This simply reflects the inter-subject variability.

Regression Analysis

The data was investigated using regression analysis. In the first instance, the SSV's were regressed against the various physical scaling units. The correlation coefficients of each regression pair can be seen in Tables 6 and 7.

Correlation Coefficient (r)

SSV vs.

	dB(A)	OASPL	PNL	PNLT	EPNL	dB(B)	dB(C)	$dB(D_1)$	$dB(D_2)$	$dB(D_3)$
Aircraft	0.66	0.69	0.69	0.69	0.61	0.65	0.66	0.65	0.63	0.65
Motorcycle	0.67	0.56	0.67	0.64	0.58	0.65	0.57	0.66	0.67	0.65

It is apparent that all the correlation coefficients are significantly different from zero, and that the differences between them are all small. As always, the correlation between the rating units is high (see Tables 6 and 7).

The addition of a duration measure to the rating scale units was investigated. The first attempt was made using the conventional duration correction $10 \log_{10} D$ where D is the time (in seconds) during which the signal is within 5, 10 or 20 dB of the peak level. These are often known as the 5, 10 and 20 "dB down durations." The results of the regression analysis can be seen in Table 8. Typical results were:

	Correlation Coefficient (r)					
	SSV vs. dB(A) +			SSV vs. PNL +		
	10 log(dB_5)	10 log(dB_{10})	10 log(dB_{20})	10 log (dB_5)	10 log(dB_{10})	10 log(dB_{20})
Aircraft	.69	.68	.67	.67	.65	.64
Motorcycle	.73	.72	.74	.70	.71	.73

dB_x ≈ 'x' dB down duration

A difference of 0.05 between correlation coefficients respresents a statistically significant difference ($p = .05$). It is apparent that any improvement in the correlation coefficient caused by the addition of these duration corrections is significant for the motorcycle data but not for the aircraft data. This agrees with the conclusion from the analysis of variance that duration is more important in explaining the annoyance due to motorcycles than aircraft. Also it appears from these results that for aircraft the 5 dB down duration gives consistently, though not significantly, larger correlation coefficients, whereas for motorcycles the 20 dB down duration gives the largest correlation coefficients.

The assumption was made that the coefficient for $\log_{10} dB_x$ is 10. This need not be the case. The regressions were re-run with the durations as independent variables. The results can be seen in Table 7. Typical results were:

Aircraft

$$SSV = .26\ (PNL + 3.4\ \log\ (dB_5)) - 21.06 \qquad R = 0.706$$

$$= .26\ (PNL + 2.5\ \log\ (dB_{10})) - 21.08 \qquad R = 0.700$$

$$= .26\ (PNL + 2.1\ \log\ (dB_{20})) - 21.36 \qquad R = 0.697$$

Motorcycle:

$$SSV = .23\ (dB(A) + 7.0\ \log\ (dB_5)) - 14.65 \qquad R = 0.732$$

$$= .23\ (dB(A) + 8.5\ \log\ (dB_{10})) - 15.51 \qquad R = 0.724$$

$$= .23\ (dB(A) + 12.3\ \log(dB_{20})) - 17.10 \qquad R = 0.741$$

R = multiple correlation coefficient

Allowing the duration to be an independent variable gave a significant improvement for aircraft and an insignificant improvement for motorcycles. The reason is clearly that for aircraft the coefficient of the duration correction is much less than 10, whereas for motorcycles the coefficient of 10 is close to being the optimum. This is illustrated in Figures 5 and 6.

Regression was also run using the duration measures of the kind: the time the sound is above 'x' dB(A). The results can be seen in Table 8. It was found that these corrections are, in general, no better and no worse than the conventional 'x'-dB down corrections. All these forementioned regressions were re-run using the $\log_{10}$ of the SSV's. No improvement was found.

Various combinations of rating scale unit and duration measures were investigated and the following were found to be typical of the best combinations:

Aircraft

$$SSV = .26\ (PNL + 3.4 \log (dB_5)) - 21.06 \qquad R = 0.706$$

$$= .22\ (dB(A) + 6.05 \log (dB_5)) - 14.06 \qquad R = 0.696$$

$$= .25\ (PNLT + 3.65 \log (dB_5)) - 21.05 \qquad R = 0.702$$

$$= .28\ (dB(D_3) + 4.85 \log (dB_5)) - 18.42 \qquad R = 0.690$$

Motorcycle

$$SSV = 0.27\ (dB(D_3) + 14 \log (dB_{20})) -21.84 \qquad R = 0.766$$

$$= 0.21\ (dB(D_3) + 0.19\ (T_{60})) - 13.06 \qquad R = 0.758$$

$$= 0.25\ (dB(D_2) + 12.1 \log (dB_{20}) - 21.14 \qquad R = 0.752$$

$$= 0.20\ (dB(D_2) + 0.2\ (T_{60})) - 13.70 \qquad R = 0.749$$

T_{60} = time sound was above 60 dB(A) in seconds

In order that comparisons could be made with other studies, the mean of the SSV's was found for each sound. Similar regressions as before were carried out. Generally, the multiple correlation coefficients were increased to approximately 0.95. Once again, it was found that for aircraft the 5dB down duration gave consistently, though not significantly, larger correlation coefficients whereas for motorcycles the 20 dB down duration gave the largest correlation coefficients. These was one difference, however, between the analyses carried out on the raw data and those carried out on the means. In the case of the raw data, the correlation coefficients were higher for the motorcycle than for the aircraft. When the means were used, this condition was reversed. This emphasizes one of the hazards of using only the mean subjective judgements. Typical results were:

Aircraft

$$\overline{SSV} = 0.26\ (PNL + 3.3 \log (dB_5)) - 21.16 \qquad R = 0.968$$

$$= 0.22\ (dB(A) + 5.9 \log (dB_5)) - 14.13 \qquad R = 0.954$$

Motorcycle

$$\overline{SSV} = 0.18\ (dB(A) + .22\ T_{60}) - 10.96 \qquad R = 0.957$$

$$= 0.23\ (dB(A) + 12.8 \log (dB_{20})) - 17.17 \qquad R = 0.958$$

$\overline{SSV}$ = mean SSV
T_{60} = time (in seconds) sound exceeded 60 dB(A).

CONCLUSIONS

An experiment was performed to investigate the annoyance of noise from a light aircraft with particular emphasis on the duration of the noise. To highlight possible noise source differences, a second source, a motorcycle, was included in the study. Thirty test subjects gave annoyance ratings to a total of 50 recorded sounds using a numerical category scaling technique. The following conclusions were found:

1. Most of the commonly used scaling units were equally good at predicting subjective response to both aircraft noise and motorcycle noise. Although there were significant differences in performance between some pairs of rating units, in all cases these differences were small.

2. The addition of a duration correction to any of the commonly used rating scale units helps explain annoyance. The benefit of this addition depends upon the rating scale unit and the duration correction that are employed.

   In general, the increase in the value of the correlation coefficient is statistically significant for motorcycles and marginally significant in the case of aircraft.

3. The conventional duration correction 10 $\log_{10}D$ is close to being the optimum correction for the motorcycle noise; for aircraft the coefficient should be a number rather smaller than 10.

4. The duration corrections of the type "the time the sound exceeded 'x' dB(A)" appear to be as good as the conventional 10 dB down duration correction.

5. For aircraft the 5 dB down duration produced consistently, though not significantly, larger correlation coefficients, whereas the motorcycles the 20 dB down duration produced the largest correlation coefficients.

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APPENDIX A

INSTRUCTIONS FOR SUBJECTS

We are asking you to help us solve a problem concerned with noise; how annoying are various kinds of sounds? First we will ask you to listen to some of the sounds you will be judging so you will have some familiarity with them.

The sounds you are to rate will be presented to you one at a time. We would like you to try to imagine that you are hearing these sounds while out of doors. Please consider both the peak noise level and the duration of the noise when making your judgments. Listen to all of the sound before making your judgment. Notice that on your answer sheet each sound has nine possible ratings. '0' is for no annoyance while '8' is for extremely annoying. You should place the sounds on the scale according to their degree of annoyance. For example, a sound causing a small amount of annoyance may be scored a '2' or a '3', a sound causing a high amount of annoyance may be scored a '6' or '7', and so on.

Your ratings should reflect only your own opinion of the noise, that is what we want.

APPENDIX B

ANSWER SHEET

NAME ______________________________ DATE ____________________

NOISE NUMBER	NOT AT ALL ANNOYING								EXTREMELY ANNOYING
1	0	1	2	3	4	5	6	7	8
2	0	1	2	3	4	5	6	7	8
3	0	1	2	3	4	5	6	7	8
4	0	1	2	3	4	5	6	7	8
5	0	1	2	3	4	5	6	7	8
1	0	1	2	3	4	5	6	7	8
2	0	1	2	3	4	5	6	7	8
3	0	1	2	3	4	5	6	7	8
4	0	1	2	3	4	5	6	7	8
5	0	1	2	3	4	5	6	7	8
1	0	1	2	3	4	5	6	7	8
2	0	1	2	3	4	5	6	7	8
3	0	1	2	3	4	5	6	7	8
4	0	1	2	3	4	5	6	7	8
5	0	1	2	3	4	5	6	7	8
1	0	1	2	3	4	5	6	7	8
2	0	1	2	3	4	5	6	7	8
3	0	1	2	3	4	5	6	7	8
4	0	1	2	3	4	5	6	7	8
5	0	1	2	3	4	5	6	7	8
1	0	1	2	3	4	5	6	7	8
2	0	1	2	3	4	5	6	7	8
3	0	1	2	3	4	5	6	7	8
4	0	1	2	3	4	5	6	7	8
5	0	1	2	3	4	5	6	7	8

Table 1 - Mean and (Standard Deviation) of Peak dB(A) Values of Experimental Sounds

Aircraft

	L_1	L_2	L_3	L_4	L_5
D_1	66.7 (0.46)	71.5 (0.50)	76.7 (0.46)	81.9 (0.30)	86.9 (0.30)
D_2	65.1 (0.30)	70.2 (0.52)	75.1 (0.28)	79.1 (0.64)	85.1 (0.30)
D_3	64.7 (0.64)	69.6 (0.66)	74.5 (0.67)	80.2 (0.52)	84.6 (0.66)
D_4	65.2 (0.52)	70.2 (0.51)	75.1 (0.30)	80.3 (0.54)	85.4 (0.42)
D_5	65.3 (0.44)	70.0 (0.45)	75.1 (0.30)	80.0 (0.77)	85.2 (0.52)

Motorcycles

	L_1	L_2	L_3	L_4	L_5
D_1	65.1 (0.30)	70.1 (0.28)	75.1 (0.30)	80.3 (0.54)	84.9 (0.54)
D_2	65.7 (0.64)	70.7 (0.64)	75.8 (0.87)	80.7 (0.64)	85.9 (0.54)
D_3	64.5 (0.67)	69.4 (0.80)	74.5 (0.67)	79.9 (0.54)	84.5 (0.67)
D_4	65.1 (0.30)	70.1 (0.31)	74.9 (0.54)	79.9 (0.54)	85.0 (0.30)
D_5	64.2 (0.60)	69.6 (0.66)	74.6 (0.66)	79.3 (0.56)	85.1 (0.30)

Each cell contains the peak dB(A) value for each sound averaged over the ten sessions and the standard deviation (in parentheses) of the peak level. L_1-L_5 and D_1-D_5 refer to the peak levels and durations (see Matrix 1).

Table 2 - Durations of the Sound Stimuli (Seconds)

Aircraft								Motorcycle							
Stimulus Number	5dB down duration	10dB down duration	20dB down duration	Time above 80 dB(A)	Time above 70 dB(A)	Time above 60 dB(A)	Total "audible" duration	Stimulus Number	5dB down duration	10dB down duration	20dB down duration	Time above 80 dB(A)	Time above 70 dB(A)	Time above 60 dB(A)	Total "audible" duration
1	1.25	1.75	5.00	0	0	1.25	7.00	1	2.50	6.00	17.50	0	0	2.50	16.00
2	1.25	1.75	5.00	0	0	1.75	7.50	2	2.50	6.00	17.50	0	0	6.00	24.00
3	1.25	1.75	5.00	0	1.25	3.50	9.00	3	2.50	6.00	17.50	0	2.50	12.00	25.00
4	1.25	1.75	5.00	0	1.75	5.00	11.00	4	2.50	6.00	17.50	0	6.00	17.50	31.00
5	1.25	1.75	5.00	1.25	3.50	6.25	10.00	5	2.50	6.00	17.50	2.50	12.00	25.00	30.00
6	3.75	6.25	11.50	0	0	3.75	12.00	6	3.75	7.50	14.00	0	0	3.75	9.00
7	3.75	6.25	11.50	0	0	6.25	16.00	7	3.75	7.50	14.00	0	0	7.50	12.00
8	3.75	6.25	11.50	0	3.75	8.75	18.00	8	3.75	7.50	14.00	0	3.75	11.00	12.00
9	3.75	6.25	11.50	0	6.25	11.50	19.50	9	3.75	7.50	14.00	0	7.50	4.00	14.00
10	3.75	6.25	11.50	3.75	8.75	20.00	19.00	10	3.75	7.50	14.00	3.75	11.00	15.50	14.00
11	2.50	10.00	32.50	0	0	2.50	32.00	11	6.00	13.75	18.00	0	0	6.00	14.00
12	2.50	10.00	32.50	0	0	10.00	26.00	12	6.00	13.75	18.00	0	0	13.75	13.00
13	2.50	10.00	32.50	0	2.50	21.00	36.00	13	6.00	13.75	18.00	0	6.00	16.00	17.00
14	2.50	10.00	32.50	0	10.00	32.50	45.00	14	6.00	13.75	18.00	0	13.75	18.00	20.00
15	2.50	10.00	32.50	2.50	21.00	35.00	58.00	15	6.00	13.75	18.00	6.00	16.00	20.00	22.00
16	9.50	14.00	58.00	0	0	9.50	44.00	16	20.00	27.00	42.00	0	0	20.00	27.00
17	9.50	14.00	58.00	0	0	14.00	39.00	17	20.00	27.00	42.00	0	0	27.00	30.00
18	9.50	14.00	58.00	0	9.50	36.00	65.00	18	20.00	27.00	42.00	0	20.00	34.00	30.00
19	9.50	14.00	58.00	0	14.00	58.00	63.00	19	20.00	27.00	42.00	0	27.00	42.00	32.00
20	9.50	14.00	58.00	9.50	36	80.00	78.00	20	20.00	27.00	42.00	20.00	34.00	46.00	34.00
21	18.50	40.00	85.00	0	0	18.50	61.00	21	35.00	45.00	70.00	0	0	35.00	43.00
22	18.50	40.00	85.00	0	0	40.00	64.00	22	35.00	45.00	70.00	0	0	45.00	48.00
23	18.50	40.00	85.00	0	18.50	40.00	66.00	23	35.00	45.00	70.00	0	35.00	60.00	50.00
24	18.50	40.00	85.00	0	40.00	85.00	85.00	24	35.00	45.00	70.00	0	45.00	70.00	50.00
25	18.50	40.00	85.00	18.50	80.00	90.00	75.00	25	35.00	45.00	70.00	35.00	67.00	70.00	55.00

The stimulus numbers refer to Matrix 1.

Table 3 - Analysis of Variance of Matrix 1

	Source of Variation		Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio**
Aircraft	1.	Subjects	29	1072.05	36.97	33.90*
	2.	Durations	4	373.38	93.34	26.70*
	3.	Levels	4	1929.79	482.45	150.0*
		1 x 2	116	257.02	2.22	2.04*
		1 x 3	116	223.80	1.93	1.77*
		2 x 3	16	37.91	2.37	2.18*
		Residual Error	464	503.68	1.09	
		Total	749	4397.65		
Motorcycle						
	1.	Subjects	29	764.38	26.36	24.80*
	2.	Durations	4	623.68	155.92	51.50*
	3.	Levels	4	1979.03	494.76	151.0 *
		1 x 2	116	238.87	2.06	1.94*
		1 x 3	116	267.93	2.31	2.18*
		2 x 3	16	32.56	2.03	1.92*
		Residual Error	464	491.67	1.06	
		Total	749	4398.13		

*Significant at 5% level
**Pseudo F-test

Table 4 - Analysis of Variance of Matrix 1 Including Sex of Respondents

	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio**
<u>Aircraft</u>	1. Sex	1	51.74	51.74	0.98
	2. Subjects (within sex)	14	281.23	20.09	20.09*
	3. Duration	4	373.38	93.34	42.23*
	4. Level	4	1929.79	482.45	339.50*
	1 x 2	14	739.07	52.79	52.79*
	1 x 3	4	17.99	4.50	2.20
	1 x 4	4	10.09	2.52	1.05
	2 x 3	56	124.14	2.21	2.21*
	2 x 4	56	79.53	1.42	1.42*
	3 x 4	16	37.91	2.37	2.02*
	1 x 2 x 3	56	114.88	2.05	2.05*
	1 x 2 x 4	56	134.19	2.40	2.40*
	1 x 3 x 4	16	15.40	0.96	0.96
	2 x 3 x 4	224	264.17	1.17	1.17
	Residual Error	224	224.10	1.00	
	Total	749	4397.65		

**Pseudo F-test
*Significant at 5% level

Table 4 (continued)

	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F-Ratio**
Motorcycle					
	1. Sex	1	4.18	4.18	0.11
	2. Subjects (within sex)	14	238.50	17.08	17.08*
	3. Duration	4	623.68	155.92	70.90*
	4. Level	4	1979.03	494.76	230.00*
	1 x 2	14	521.70	37.26	37.26*
	1 x 3	4	6.57	1.64	0.84
	1 x 4	4	22.18	5.54	2.47*
	2 x 3	56	122.95	2.20	2.20*
	2 x 4	56	120.21	2.15	2.15*
	3 x 4	16	32.56	2.03	1.81*
	1 x 2 x 3	56	109.35	1.95	1.95*
	1 x 2 x 4	56	125.94	2.24	2.24*
	1 x 3 x 4	16	18.21	1.14	1.14
	2 x 3 x 4	224	250.20	1.12	1.12
	Residual Error	224	223.26	1.00	
	Total	749	4398.13		

**Pseudo F-Test
*Significant at 5% level

Table 5 - Analysis of Variance of Tape and Tape Order Effects

	Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F-Ratio**
Aircraft	1. Subject Groups	9	111.70	12.41	9.64*
	2. Tapes	4	0.983	0.24	0.47
	1 x 2	36	18.40	0.511	0.40
	Within replicates	100	129.09	1.29	
	Total	149	260.17		
	1. Subject Groups	9	111.70	12.41	9.64*
	2. Tape Order	4	3.70	0.92	2.08
	1 x 2	36	15.68	0.44	0.34
	Within replicates	100	129.09	1.29	
	Total	149	260.17		
Motorcycle					
	1. Subject Groups	9	100.84	11.20	15.57*
	2. Tapes	4	0.73	0.18	0.46
	1 x 2	36	14.21	0.39	0.54
	Within replicates	100	72.40	0.72	
	Total	149	188.19		
	1. Subject Groups	9	100.84	11.20	15.57*
	2. Tape Order	4	0.35	0.09	0.22
	1 x 2	36	14.60	0.41	0.57
	Within replicates	100	7.24	0.72	
	Total	149	188.19		

*Significant at 5% level
**Pseudo F-Test

Table 6 - Matrix of Correlation Coefficients for Aircraft

	SSV	AGE	SEX	dB(A)	OASPL	PNL	PNLT	EPNL	dB(B)	dB(C)	dB(D_1)	dB(D_2)	dB(D_3)	MK.7
SSV	1.0													
AGE	-.08	1.0												
SEX	N/A	N/A	1.0											
dB(A)	.66	.00	.00	1.0										
OASPL	.69	.00	.00	.95	1.0									
PNL	.69	.00	.00	.97	.99	1.0								
PNLT	.69	.00	.00	.97	.98	1.0	1.0							
EPNL	.61	.00	.00	.77	.93	.88	.87	1.0						
dB(B)	.65	.00	.00	.96	.99	.97	.99	.90	1.0					
dB(C)	.66	.00	.00	.95	.99	.99	.98	.91	.99	1.0				
dB(D_1)	.65	.00	.00	.96	.99	.99	.99	.87	1.0	1.0	1.0			
dB(D_2)	.63	.00	.00	.99	.96	.99	.99	.83	.99	.98	.99	1.0		
dB(D_3)	.65	.00	.00	.98	.96	.99	.99	.83	.98	.97	.98	.99	1.0	
MK. 7	.66	.00	.00	.97	.98	1.0	.99	.87	.99	.99	.99	.99	.99	1.0

*N/A - not applicable

Table 7 - Matrix of Correlation Coefficients for Motorcycles

	SSV	AGE	SEX	dB(A)	OASPL	PNL	PNLT	EPNL	dB(B)	dB(C)	dB(D_1)	dB(D_2)	dB(D_3)	MK.7
SSV	1.0													
AGE	-.07	1.0												
SEX	N/A	N/A	1.0											
dB(A)	.67	.00	.00	1.0										
OASPL	.56	.00	.00	.89	1.0									
PNL	.67	.00	.00	.99	.89	1.0								
PNLT	.64	.00	.00	.97	.85	.99	1.0							
EPNL	.58	.00	.00	.83	.80	.83	.80	1.0						
dB(B)	.65	.00	.00	.97	.95	.97	.94	.90	1.0					
dB(C)	.57	.00	.00	.90	.98	.91	.89	.84	.98	1.0				
dB(D_1)	.66	.00	.00	.99	.91	.99	.98	.88	.98	.93	1.0			
dB(D_2)	.67	.00	.00	.99	.87	.99	.99	.83	.96	.89	.99	1.0		
dB(D_3)	.65	.00	.00	.97	.79	.96	.97	.69	.90	.81	.96	.98	1.0	
MK.7	.67	.00	.00	.99	.89	.99	.98	.83	.97	.90	.99	.99	.97	1.0

*N/A - not applicable

Table 8 - Regression Results

Aircraft Dependent Variable	Independent Variable(s)	Correlation Coefficient	Motorcycle Dependent Variable	Independent Variables	Correlation Coefficient
SSV	(PNL+10 log dB_5)	.670	SSV	(PNL+10 log dB_5)	.701
	(PNL+10 log dB_{10})	.650		(PNL+10 log dB_{10})	.705
	(PNL+10 log dB_{20})	.640		(PNL+10 log dB_{20})	.734
	(PNL+10 log T_{80})	.690		(PNL+10 log T_{80})	.661
	(PNL+10 log T_{70})	.695		(PNL+10 log T_{70})	.700
	(PNL+10 log T_{60})	.682		(PNL+10 log T_{60})	.714
	(PNL+10 log (dur))	.671		(PNL+10 log(dur))	.718
	(dB(A) +10 log dB_5)	.685		(dB(A) + 10 log dB_5)	.726
	(dB(A) +10 log dB_{10})	.680		(dB(A) + 10 log dB_{10})	.723
	(dB(A) +10 log dB_{20})	.666		(dB(A) + 10 log dB_{20})	.739
	(dB(A) +10 log T_{80})	.670		(dB(A) + 10 log T_{80})	.664
	(dB(A) +10 log T_{70})	.692		(dB(A) + 10 log T_{70})	.701
	(dB(A) +10 log (dur))	.684		(dB(A) + 10 log (dur))	.719
	PNL, log dB_5	.706		PNL, log dB_5	.721
	PNL, log dB_{10}	.700		PNL, log dB_{10}	.713
	PNL, log dB_{20}	.697		PNL, log dB_{20}	.734
	PNL, T_{80}	.697		PNL, T_{80}	.683
	PNL, T_{70}	.699		PNL, T_{70}	.718
	PNL, T_{60}	.698		PNL, T_{60}	.740
	dB(A), log dB_5	.696		dB(A), log dB_5	.732
	dB(A), log dB_{10}	.696		dB(A), log dB_{10}	.724
	dB(A), log dB_{20}	.688		dB(A), log dB_{20}	.741
	dB(A), T_{80}	.668		dB(A), T_{80}	.680
	dB(A), T_{70}	.682		dB(A), T_{70}	.713
	dB(A), T_{60}	.683		dB(A), T_{60}	.741
	dB(A), log T_{80}	.671		dB(A), log T_{80}	.677
	dB(A), log T_{70}	.692		dB(A), log T_{70}	.700
	dB(A), log T_{60}	.692		dB(A), log T_{60}	.724
	log dB_5, EPNL	.615		log dB_{20}, EPNL	.613
	log dB_5, OASPL	.702		log dB_{20}, OASPL	.613

Table 8 (continued)

Dependent Variable	Independent Variable(s)	Correlation Coefficient	Dependent Variable	Independent Variable(s)	Correlation Coefficient
SSV	log dB_5, dB(B)	.674	SSV	log dB_{20},dB(B)	.696
	log dB_5, dB(C)	.673		log dB_{20},dB(C)	.624
	log dB_5, dB(D_1)	.676		log dB_{20},dB(D_1)	.735
	log dB_5, dB(D_2)	.673		log dB_{20},dB(D_2)	.752
	log dB_5, dB(D_3)	.690		log dB_{20},dB(D_3)	.766
	log dB_5, MK.7	.688		log dB_{20},MK.7	.745
	T70, dB(B)	.668		T_{60}, OASPL	.652
	T_{70}, dB(C)	.671		T_{60}, EPNL	.593
	T_{70}, dB(D_1)	.668		T_{60}, dB(B)	.709
	T_{70}, dB(D_2)	.675		T_{60}, dB(C)	.661
	T_{70}, OASPL	.702		T_{60}, dB(D_1)	.736
	T_{70}, EPNL	.625		T_{60}, dB(D_2)	.749
	T_{70}, dB(D_3)	.672		T_{60}, dB(D_3)	.758
	T_{70}, MK.7	.674		T_{60}, MK.7	.747
log (SSV)	dB(A), log dB_5	.689	log(SSV)	dB(A), log dB_5	.705
log (SSV)	dB(A), log dB_{10}	.689	log(SSV)	dB(A), log dB_{10}	.697
log (SSV)	dB(A), log dB_{20}	.681	log(SSV)	dB(A), log dB_{20}	.716
log (SSV)	PNL, T_{80}	.682	log(SSV)	PNL, T_{80}	.648
log (SSV)	PNL, T_{70}	.686	log(SSV)	PNL, T_{70}	.677
log (SSV)	PNL, T_{60}	.688	log(SSV)	PNL, T_{60}	.711
$\overline{SSV}$	dB(A)	.902	$\overline{SSV}$	dB(A)	.870
$\overline{SSV}$	PNL	.947	$\overline{SSV}$	PNL	.867
$\overline{SSV}$	dB(D_3)	.925	$\overline{SSV}$	dB(D_3)	.838
$\overline{SSV}$	MK.7	.938	$\overline{SSV}$	MK.7	.871
$\overline{SSV}$	EPNL	.913	$\overline{SSV}$	EPNL	.853
log $\overline{SSV}$	dB(A)	.857	log $\overline{SSV}$	dB(A)	.831
log $\overline{SSV}$	dB(D_3)	.879	log $\overline{SSV}$	dB(D_3)	.790
log $\overline{SSV}$	MK.7	.895	log $\overline{SSV}$	MK.7	.811
$\overline{SSV}$	dB(A), log dB_5	.954	$\overline{SSV}$	dB(A), log dB_5	.946
$\overline{SSV}$	dB(A), log dB_{10}	.954	$\overline{SSV}$	dB(A), log dB_{10}	.935
$\overline{SSV}$	dB(A), log dB_{20}	.944	$\overline{SSV}$	dB(A), log dB_{20}	.958
$\overline{SSV}$	PNL, log dB_5	.968	$\overline{SSV}$	PNL, log dB_5	.931
$\overline{SSV}$	PNL, log dB_{10}	.960	$\overline{SSV}$	PNL, log dB_{10}	.921
$\overline{SSV}$	PNL, log dB_{20}	.956	$\overline{SSV}$	PNL, log dB_{20}	.949

SSV= subjective scale value. $\overline{SSV}$ = average subjective scale value dB_x = 'x' dB down duration
T_x = Time for which signal exceeds 'x' dB(A).

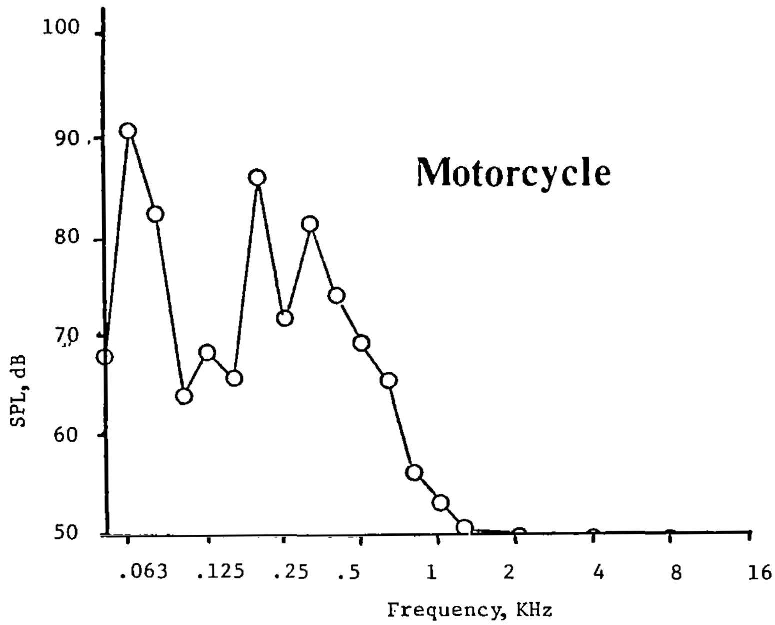


Figure 1. Maximum one-third-octave band spectrum of an aircraft stimulus.

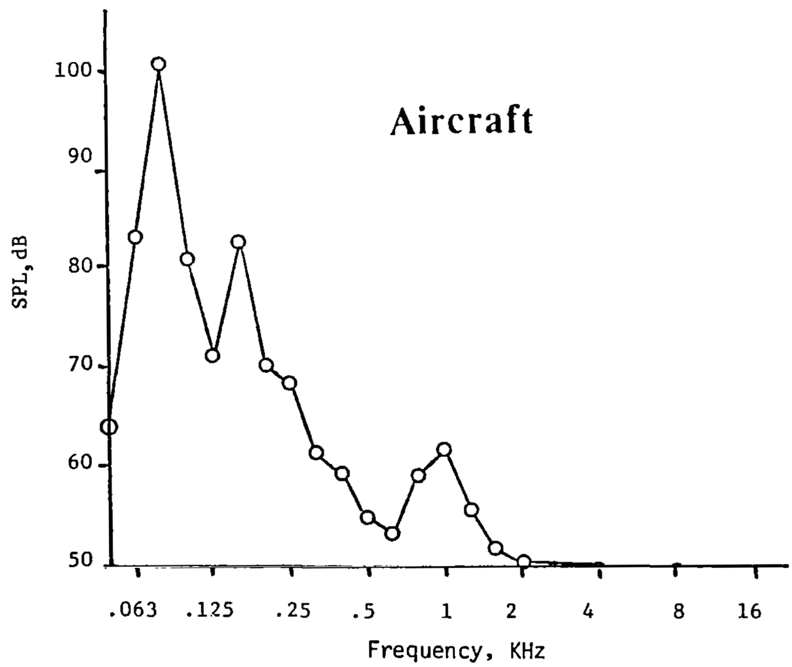


Figure 2. Maximum one-third-octave band spectrum of a motorcycle stimulus.

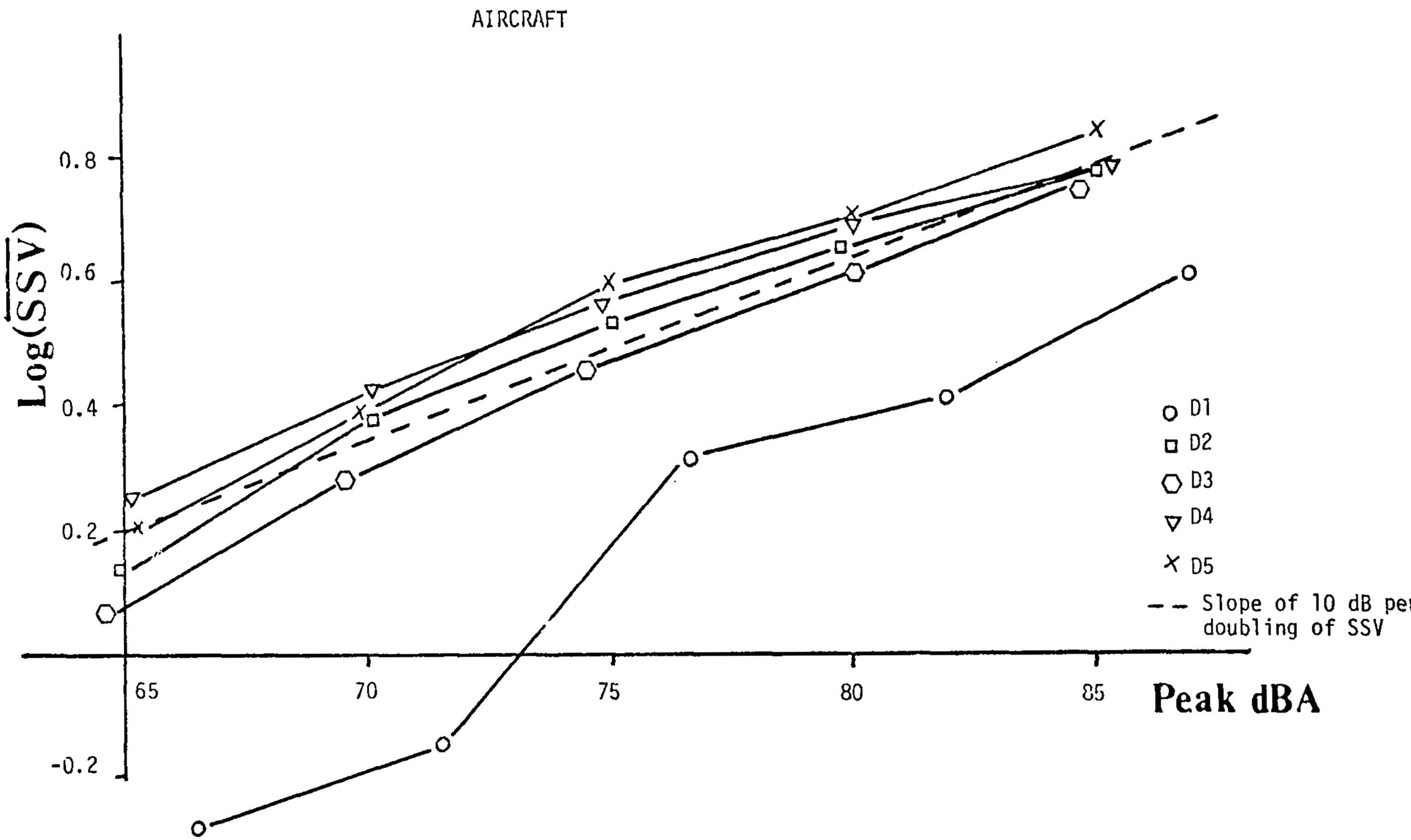


Figure 3. The log of the mean subjective scale value plotted against the peak noise level for each duration of the aircraft sounds.

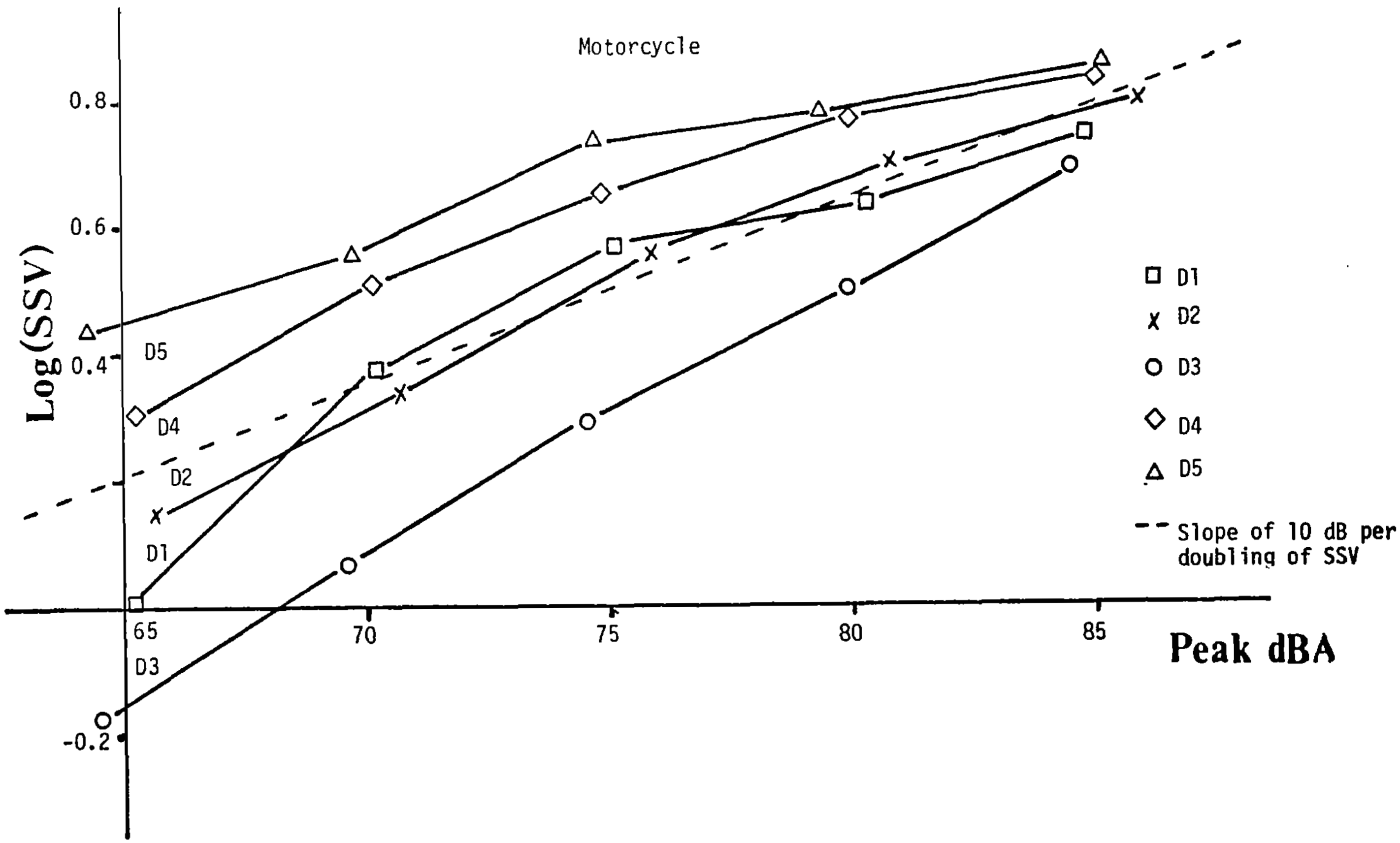
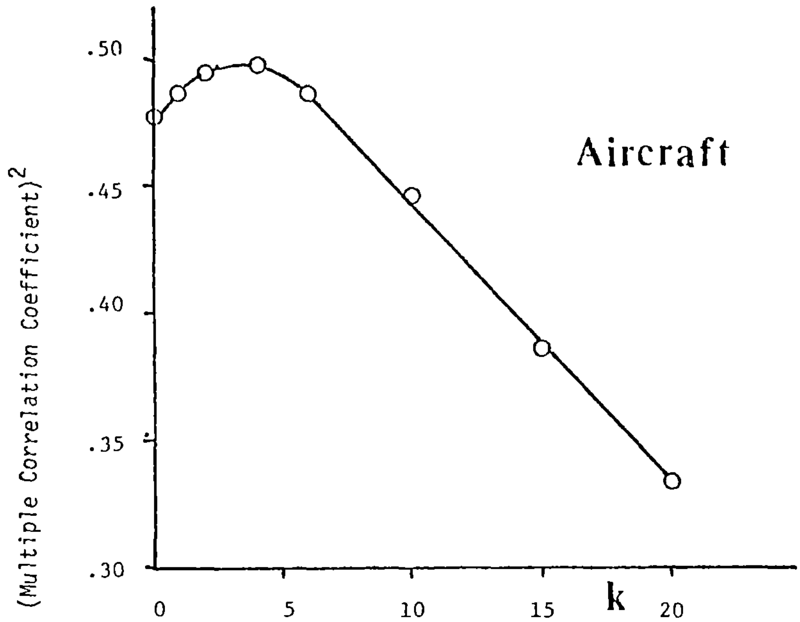
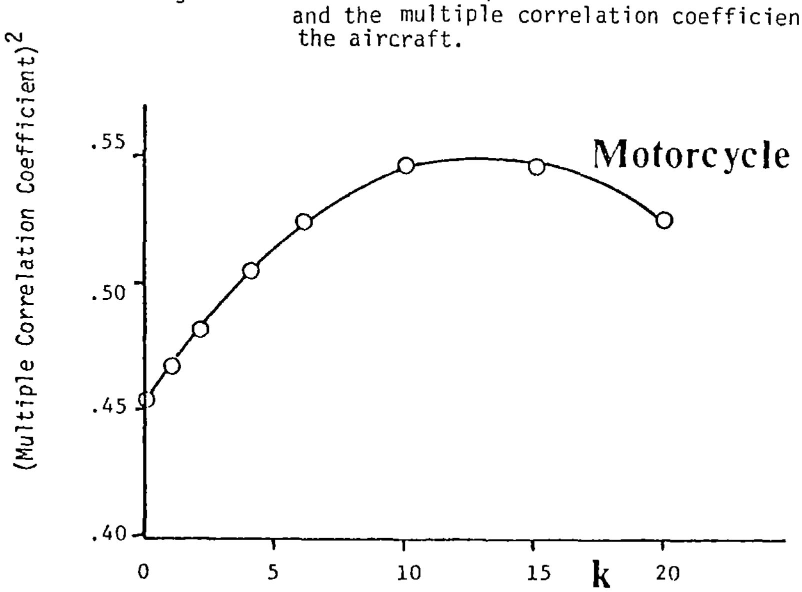


Figure 4. The log of the mean subjective scale value plotted against the peak noise level for each duration of the motorcycle sounds.



SSV = PNL + K log D_5 where D_5 = 5 dB down duration.

Figure 5. The relationship between the duration correction and the multiple correlation coefficient (R) for the aircraft.



SSV = dB(A) + K log D_{20} D_{20} = 20 dB down duration.

Figure 6. The relationship between the duration correction and the multiple correlation coefficient (R) for the motorcycle.

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