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SUBJECTIVE RATINGS OF ANNOYANCE PRODUCED BY ROTARY-WING AIRCRAFT NOISE

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUBJECTIVE RATINGS OF ANNOYANCE PRODUCED BY ROTARY-WING AIRCRAFT NOISE

INTRODUCTION

Growing public concern about noise pollution, coupled with increasingly frequent passage of noise control legislation, has led to a demand for careful planning in aircraft operations. Army Aviation has not been immune to this requirement. In the Construction Criteria Manual No. 4270.1-M, published in 1972, the Department of Defense (DOD) set limits for noise at on-post housing construction sites and other sensitive land uses. The DOD Air Installation Compatibility Use Zone Program (AICUZ) of 1973 provided noise limits for off-post land use and noise impact. The latter document required coordination with local communities on the planning and use of land near air corridors. However, little information about far-field helicopter noise characteristics and annoyance caused by this type of noise has been available.

To answer this need, the US Army Construction Engineering Research Laboratory (CERL), Champaign, Illinois, and the US Army Aeromedical Research Laboratory (USAARL), Fort Rucker, Alabama, undertook to collect data on the far-field external noise produced by rotary-wing aircraft and to investigate the annoyance associated with it. This report contains the results of the annoyance evaluation part of that project.

The primary purpose of the subjective test conducted in this portion of the project was to quantify the annoyance caused by helicopter noise and to investigate the validity of applying the fixed-wing aircraft annoyance predictors to rotary-wing aircraft acoustic problems. Many studies concerned with the prediction of annoyance from various types of noises have been conducted (see Kryter, 1970). The general approach has been to attempt to find some means of transforming noise spectra and durations to a single number which predicts the annoyance to humans. Previous efforts have been concentrated primarily on finding some spectral weighting function by which the noises can be quantified into a single overall value on which to base the prediction and on determining "level correction factors" to better predict annoyance.

Most of the studies of annoyance from aircraft noise have concentrated on fixed-wing aircraft, particularly jets. As a result, relatively little information is available on how well these predictors predict the annoyance caused by rotary-wing aircraft. The results reported here provide information concerning four questions about the prediction of annoyance from rotary-wing aircraft. Which spectral weighting function is most appropriate in predicting annoyance? One of the most popular predictors -- Effective Perceived Noise Level (EPNL) -- has become a part of Federal Aviation Administration (FAA) Regulations, Part 36 (1969). Another popular predictor -- the A-Weighted Level (dBA) -- has been established as the basic unit of measurement by the Environmental Protection Agency (EPA) in the "Levels" document (1974). In addition to these two predictors, the "C-Weighting Network" as found on sound level meters was considered, along with the earlier EPNL and D_2-weighting functions formulated in Kryter (1970).

2. Is a "correction" factor for the impulsive "blade slap" of rotary-wing aircraft necessary? It has been suggested that rotary-wing aircraft are considered more annoying when they produce the periodic impulsive sound commonly referred to as "blade slap."

3. What type of integration should be used to best characterize an entire flyby? The EPNL measures require a temporal integration of the spectrally weighted acoustic energy. Other possibilities which were considered include the peak level, the weighted sum of the maximum level within each octave band, and the time average weighted level which is proportional to L_{eq}.

4. Do the fixed-wing aircraft annoyance predictors underestimate the annoyance of helicopters relative to fixed-wing aircraft? If so, how large a penalty is needed to correct for this underestimation?

METHOD AND INSTRUMENTATION

The general approach used in this study was to obtain subjective ratings of annoyance caused by a variety of rotary-wing aircraft performing a variety of maneuvers. These ratings were obtained on a non-interfering basis within the constraints of a test plan prepared by CERL (Schomer et al., 1974). The scheduling of aircraft and the types of maneuvers were determined in accordance with that test plan. Table I lists the aircraft rated during the study. (Annoyance ratings were not obtained during all measurement sessions scheduled by CERL.) Table II contains a list of the maneuvers which each aircraft performed during each set. The order in which the maneuvers were flown was varied from set to set. Occasionally, some maneuvers were repeated within a set. Figure 1 shows a schematic diagram of the

Table I

Types of Aircraft Used in Annoyance Ratings

C-47
CH-54
UH-1M
UH-1B
OH-58
TH-55
UH-1H
CH-47B
AH-1G

Table II

Maneuvers Flown by Each Aircraft During Annoyance Ratings

Maneuver	Direction	Altitude (AGL)
Level Flyover	S to N	300 Ft
Level Flyover	N to S	300 Ft
Nap-of-the-Earth	S to N	20-50 Ft
Nap-of-the-Earth	N to S	20-50 Ft
Ascent	S to N	275-600 Ft
Ascent	N to S	275-600 Ft
Descent	S to N	325-75 Ft
Descent	N to S	325-75 Ft
Left Turn	SE to SW	300 Ft
Left Turn	NW to NE	300 Ft
Right Turn	SW to SE	300 Ft
Right Turn	NE to NW	300 Ft

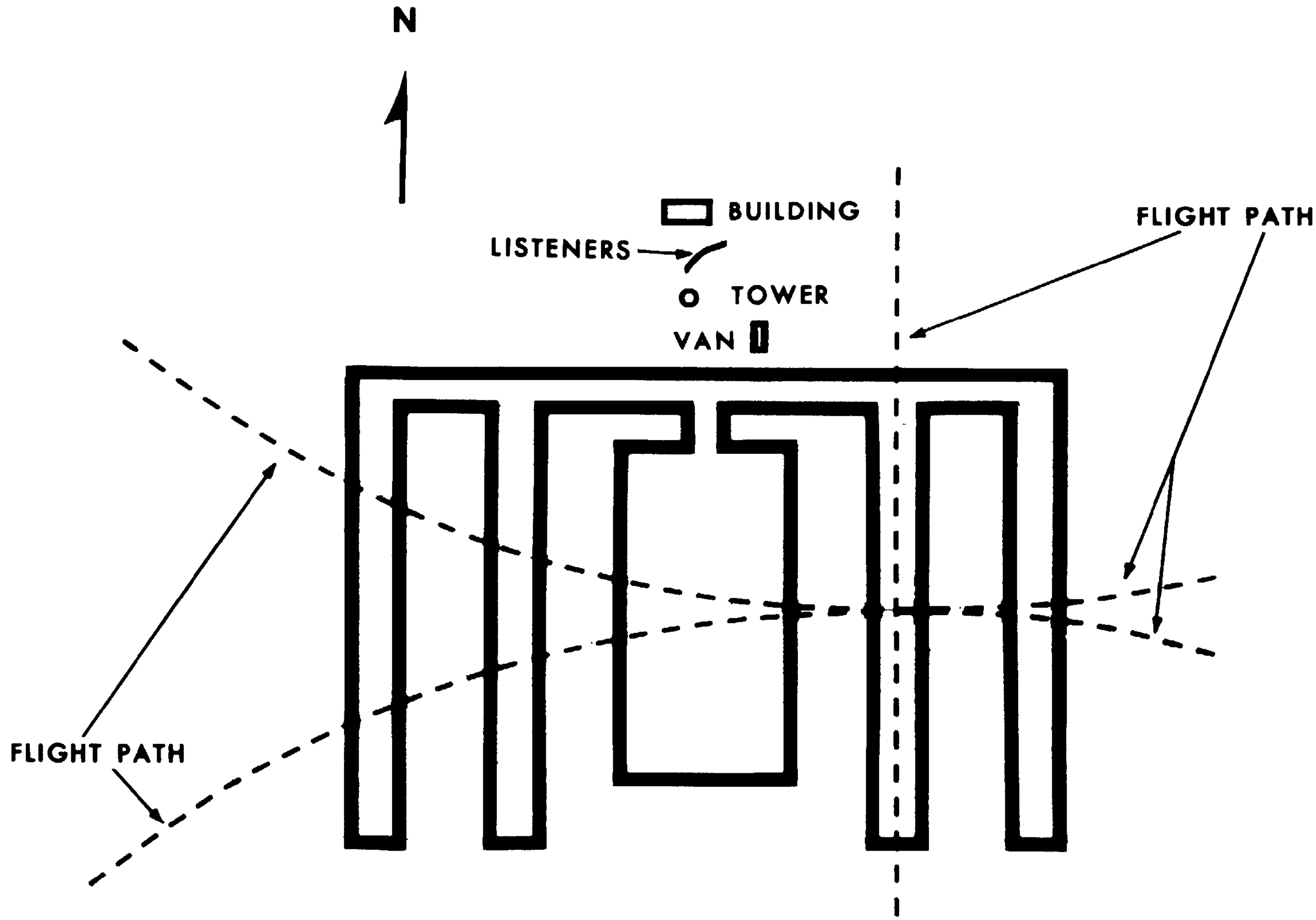

FIGURE 1. SCHEMATIC REPRESENTATION OF FLIGHT PATHS RELATIVE TO LISTENER LOCATION AT LOUISVILLE STAGE FIELD

stage field and the "theoretical" flight paths followed during the various maneuvers relative to the location of the observers rendering the ratings.

The observers were 25 adults hired on a part-time basis by CERL to serve as engineering assistants. The ages ranged from 18 to 46, with a median age of 22. Five of the observers were male and 20 female. All subjects were given an audiometric screening and found to have hearing levels within 20 dB of normal (ANSI 1969) for frequencies from 125 to 4000 Hz. Thirteen of the subjects were dependents of military or civilian personnel working at Fort Rucker, Alabama; twelve had no direct affiliation with the military installation.

The tests were conducted at a remote stage field in a rural area near Louisville, Alabama. There are no state or Federal highways within 15 miles of this field, and there was virtually no traffic on nearby county roads. There was no air traffic in the area except for the aircraft participating in the test. The observers were taken by bus from Fort Rucker, Alabama, to the test site each morning for a half-day listening session. During each half-day session, a complete set of maneuvers was scheduled to be flown by two different types of aircraft or by two aircraft of the same type.

The observers were instructed (see Appendix A for instructions to observers) to listen to the sound of a C-47 (DC-3) fixed-wing aircraft as it passed over and then rate each flyby of a rotary-wing aircraft relative to the C-47. During each half-day session, the C-47 made two passes over the field: one at the beginning of each set. (On three of the sets, the C-47 pass was omitted due to uncontrollable factors.) The C-47 always made a level flyover at an altitude of approximately 300 ft (AGL). The ratings were recorded on answer sheets with ratio scales marked for each maneuver (see Appendix B). The observers indicated their rating by marking through the scale at the point corresponding to their judgment of the relative annoyance of the rotary-wing aircraft. The scales were open-ended at both ends, and observers were allowed to use arbitrarily large or small ratings. These sheets were then scored, using "1" as an indication that the helicopter was equally as annoying as the C-47.

The instrumentation used to record the sound of each aircraft maneuver consisted of: a B&K type 4145 1-M. microphone, a B&K type 2619 cathode follower, a B&K type ZE0003 variable gain microphone amplifier, and an Ampex FR1300A seven-channel tape recorder. The microphone output was routed through two parallel microphone amplifiers and recorded on two separate tape channels at levels differing by 10 dB to insure adequate recording levels.

DATA ANALYSIS

The ratings recorded by each observer for the first 12 flybys in a set were converted to numerical ratios and entered on punched cards for computer analysis by a SEL System 85/86 computer. The Analog tape recordings were sampled by analog-to-digital conversion at 20,000 samples per second using a TD 1923 Time Series Analyzer. These time series were stored on digital tape for extraction of the blade slap parameters and for conversion to one-third-octave band levels, using Fast Fourier Transform techniques. The one-third-octave band level by .4-second time interval data were transferred to the SEL System 85/86 for final analysis. The results presented in the next section are all based on various comparisons of the subjective ratings and annoyance predictors computed from the one-third-octave band data and the blade slap parameters extracted by the TD 1923 Time Series Analyzer. Appendix C contains the computational formulas for various predictors.

RESULTS AND DISCUSSION

The one-third-octave band levels for each helicopter flyby were used to calculate 21 predictors of annoyance (see Appendix C). The ratios of these predictors to the same predictors calculated from the reference C-47 flyby were correlated with the subjects' responses. Table III contains the correlation coefficients between the various predictor ratios and the arithmetic means of all subject responses, the median of all subject responses, the geometric means of all subject responses, and the arithmetic mean of two subgroups of subject responses.

In general, the predictors based on A-weighted sound pressure levels, D_2-weighted sound pressure levels, and EPNL are most highly correlated with the average subjective annoyance ratings (arithmetic or geometric). Two subgroups of subjects were derived by looking at the correlation of individual observer responses with the 21 predictor ratios (see Appendix D). One group of observers ratings were more highly correlated with the A-weighted and D_2-weighted predictors than the B-weighted and C-weighted predictors (observers 2, 6, 9, 11, 13, 14, 16, 18, 20, 21, 22, 23, 25). These observers were placed into one subgroup and all other subjects formed the second subgroup. The ratings of Observer 3 did not correlate with any physical predictor of annoyance, and her data were excluded for all other analyses.

It has been suggested that helicopters be penalized in assessing their noisiness. The results of this study indicate that a small penalty may be necessary. Some insight into this penalty can be gained by examining the regression equation relating the log geometric mean relative subjective annoyance and the predicted relative annoyance based on the integrated A-weighted levels. Figure 2 shows the scatter

TABLE III

Product Moment Correlations Between Subjective Ratings and Twenty-One Predictors of Annoyance

	ARITHMETIC MEAN, ALL SUBJECTS	GEOMETRIC MEAN, ALL SUBJECTS	MEDIAN ALL SUBJECTS	ARITHMETIC MEAN SUBGROUP I	ARITHMETIC MEAN SUBGROUP II
INT. A	.84	.87	.83	.75	.76
AVE. A	.83	.82	.82	.83	.54
PEAK A	.83	.81	.81	.82	.55
MAX. A	.84	.84	.83	.80	.65
INT. B	.50	.55	.48	.32	.81
AVE. B	.70	.71	.67	.58	.76
PEAK B	.63	.65	.60	.49	.76
MAX. B	.70	.72	.67	.57	.79
INT. C	.38	.44	.37	.18	.78
AVE. C	.55	.59	.53	.37	.81
PEAK C	.59	.63	.58	.42	.82
MAX. C	.63	.68	.63	.47	.84
INT. D	.79	.83	.79	.67	.82
AVE. D	.85	.83	.83	.83	.59
PEAK D	.83	.81	.81	.79	.62
MAX. D	.85	.85	.84	.78	.71
IPNL K	.71	.76	.71	.56	.86
PPNL K	.81	.81	.78	.73	.71
EPNL K	.87	.87	.85	.83	.68
EPNL F	.72	.77	.71	.58	.86
PPNL F	.83	.82	.81	.78	.67

FIGURE 2 SCATTER DIAGRAM RELATING THE GEOMETRIC MEAN SUBJECTIVE ANNOYANCE RATINGS AND THE PREDICTED RELATIVE ANNOYANCE BASED ON INTEGRATED A-WEIGHTED SOUND PRESSURE LEVELS. DIFFERENT SYMBOLS REPRESENT DIFFERENT AIRCRAFT.

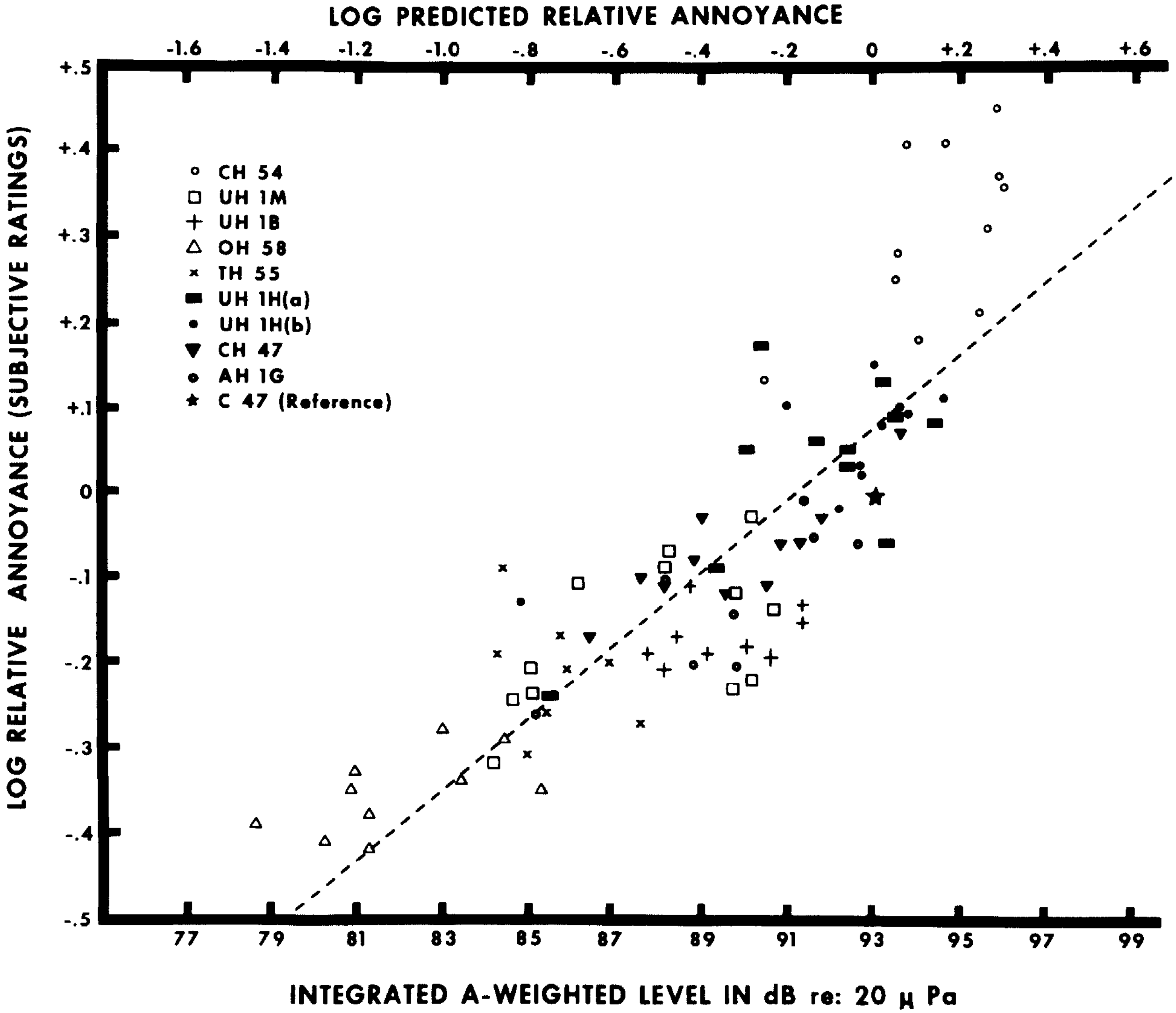

diagram of these two variables. The regression equation for these data is $y = .084 + .42x$. This regression line does not pass through the point corresponding to equal subjective rating at equal integrated A-weighted level; it is displaced to the left. Thus, at the same integrated A-weighted level, the helicopters were rated as relatively more annoying than the C-47. Adding 2 dB to the helicopter levels as a penalty would shift this line so that when the helicopters are rated equally as annoying as the C-47, the corrected A-weighted level would predict equivalence. This would suggest a penalty of only 2 dB.

Consideration of the slope of this regression line indicates that the subjective annoyance doubles for every 7-dB increase in noise level. The sensitivity factor calculated as described by Young (1976) is 7.16 dB, a rate of growth somewhat greater than the 10 dB reported by Young (1976) for fixed-wing aircraft. However, the limited range of helicopter noise levels (less than 20 dB) should be considered in interpreting this slope difference. It can also be seen in Figure 2 that the A-weighted levels for each type of aircraft tended to cluster together. The total range of levels is largely accounted for by differences in aircraft. This limitation on the data resulted from attempts to optimize the flight patterns for physical measurements instead of psychophysical scaling.

Since the range of helicopter types used in this study spans the largest to the smallest, it was hoped that any differences in the predictive power of the various predictors would be evident. Since, in general, there seemed to be little difference in how well several measures correlated to the subjective ratings, the question of correlation among the predictors arose. If the predictors correlate highly, then their correlations to the criterion variable must be similar. Table IV contains the intercorrelation matrix for the predictors used in the subject correlations of Table III. It is apparent that the A-weighted, D_2-weighted and PNL predictors are all highly correlated. This correlation is further evidence that the predictive powers of these measures provide little basis upon which to choose between them.

The preceding analysis omitted any specific correction for blade slap of the helicopters. Several attempts were made to find a blade slap characteristic on which to base a correction. None of these proved to be very promising. The first measure examined was the ratio of peak instantaneous pressure to RMS pressure. The aircraft with maximum blade slap (UH-1H) and the aircraft with mimimum slap (C-47) exhibited little difference in this measure.

TABLE IV

Product Moment Correlations Between Twenty-One Predictors of Annoyance

	INT. A	AVE. A	PEAK A	MAX. A	INT. B	AVE. B	PEAK B	MAX. B
INT. A	1.0	.80	.78	.86	.74	.75	.72	.80
AVE. A	.80	1.0	.97	.97	.44	.79	.73	.78
PEAK A	.78	.97	1.0	.97	.46	.81	.78	.81
MAX. A	.86	.97	.97	1.0	.56	.83	.81	.86
INT. B	.74	.44	.46	.56	1.0	.79	.79	.82
AVE. B	.75	.79	.81	.83	.79	1.0	.97	.97
PEAK B	.72	.73	.78	.81	.79	.97	1.0	.98
MAX. B	.80	.78	.81	.86	.82	.97	.98	1.0
INT. C	.62	.30	.32	.43	.98	.71	.73	.75
AVE. C	.69	.51	.53	.61	.91	.89	.88	.88
PEAK C	.71	.56	.59	.66	.88	.89	.91	.90
MAX. C	.76	.62	.64	.72	.88	.91	.91	.94
INT. D	.96	.75	.75	.84	.86	.81	.79	.86
AVE. D	.78	.97	.96	.94	.48	.85	.79	.82
PEAK D	.76	.94	.98	.95	.52	.87	.85	.86
MAX. D	.84	.94	.96	.98	.62	.89	.87	.91
IPNL K	.91	.66	.66	.76	.93	.81	.81	.86
PPNL K	.76	.90	.93	.92	.60	.91	.91	.91
EPNL K	.88	.76	.75	.81	.63	.69	.63	.73
EPNL F	.91	.66	.66	.76	.93	.82	.81	.87
PPNL F	.76	.92	.95	.93	.57	.91	.88	.89

TABLE IV (Cont)

	INT. C	AVE. C	PEAK C	MAX. C	INT. D	AVE. D	PEAK D	MAX. D
INT. A	.62	.69	.71	.76	.96	.78	.76	.84
AVE. A	.30	.51	.56	.62	.75	.97	.94	.94
PEAK A	.32	.53	.59	.64	.75	.96	.98	.96
MAX. A	.43	.61	.66	.72	.84	.94	.95	.98
INT. B	.98	.91	.88	.88	.86	.48	.52	.62
AVE. B	.71	.89	.89	.91	.81	.85	.87	.89
PEAK B	.73	.88	.91	.91	.79	.79	.85	.87
MAX. B	.75	.88	.90	.94	.86	.82	.86	.91
INT. C	1.0	.91	.87	.86	.76	.34	.40	.49
AVE. C	.91	1.0	.97	.97	.80	.57	.61	.68
PEAK C	.87	.97	1.0	.98	.80	.62	.67	.72
MAX. C	.86	.97	.98	1.0	.85	.67	.71	.78
INT. D	.76	.80	.80	.85	1.0	.74	.75	.84
AVE. D	.34	.57	.62	.67	.74	1.0	.97	.96
PEAK D	.40	.61	.67	.71	.75	.97	1.0	.97
MAX. D	.49	.68	.72	.78	.84	.96	.97	1.0
IPNL K	.86	.86	.86	.89	.97	.66	.68	.78
PPNL K	.50	.71	.78	.79	.77	.94	.97	.96
EPNL K	.52	.61	.64	.69	.87	.74	.73	.79
EPNL F	.87	.86	.87	.90	.98	.67	.69	.78
PPNL F	.46	.69	.75	.77	.76	.96	.98	.96

TABLE IV (Cont)

	IPNL K	PPNL K	EPNL K	EPNL F	PPNL F
INT. A	.91	.76	.88	.91	.76
AVE. A	.66	.90	.76	.66	.92
PEAK A	.66	.93	.75	.66	.95
MAX. A	.76	.92	.81	.76	.93
INT. B	.93	.60	.63	.93	.57
AVE. B	.81	.91	.69	.82	.91
PEAK B	.81	.91	.63	.81	.88
MAX. B	.86	.91	.73	.87	.89
INT. C	.86	.50	.52	.87	.46
AVE. C	.86	.71	.61	.86	.69
PEAK C	.86	.78	.64	.87	.75
MAX. C	.89	.79	.69	.90	.77
INT. D	.97	.77	.87	.98	.76
AVE. D	.66	.94	.74	.67	.96
PEAK D	.68	.97	.73	.69	.98
MAX. D	.78	.96	.79	.78	.96
IPNL K	1.0	.73	.80	.99	.71
PPNL K	.73	1.0	.71	.73	.98
EPNL K	.80	.71	1.0	.81	.72
EPNL F	.99	.73	.81	1.0	.72
PPNL F	.71	.98	.72	.72	1.0

Next, a measure based on the ratio of peak instantaneous pressure to the RMS level between peaks was examined. This gave a clearer distinction between aircraft producing a large amount of blade slap and those with less slap. However, difficulty in selecting the time frame for the RMS computation between peaks and the inherently complicated nature of the calculation argued against the utility of such a measure.

Finally, it was noted that the blade slap was represented in the narrow band spectrum of the noise as a harmonic series with the blade's passing frequency as the fundamental frequency. The spectra of samples with large amounts of blade slap indicated that most of the harmonically related energy was below 250 Hz. It was also noted that the aircraft with blade slap showed relatively more energy in the extremely low-frequency one-third-octave bands than in the midrange frequencies. The reverse was true when blade slap was minimal. This observation suggested that a simple measure using the ratio of the energy below 250 Hz to the energy at high frequencies might characterize the amount of blade slap. This calculation was used as a correction factor in conjunction with all the predictors previously discussed; it reduced the correlation between each of the predictors and the subjective ratings.

The final analysis of the data was an attempt to determine whether a better spectral weighting function could be found. For this purpose, the weighting coefficient for each one-third-octave band was estimated using a numerical method based on several criteria of goodness of fit (maximum correlation, minimum squared difference, etc.) between annoyance predicted by the integrated, weighted band levels and and subjective rating. This procedure yielded weighting functions which predicted the subjective rating very accurately ($r > .99$). However, the empirical weighting functions were not very satisfactory in other respects. These functions have some frequency bands positive weights and some negative weights. Furthermore, whether a particular band was given positive or negative weight was idiosyncratic to the data being fit. This indicated that while a better weighting function could be obtained for predicting the subjective annoyance of this experiment, it would not be likely to have any generality for predicting annoyance in other situations.

CONCLUSIONS

The results reported here indicate that there is little difference between the predictive power of A-weighting, D_2-weighting, or EPNL measures. The integrated, A-weighted levels, which are used as the predictors in the EPA's L_{DN} calculations, seem to predict the subjective annoyance of helicopters about as well as any of the measures. The high correlation among these predictors of annoyance makes any attempt to show the superiority of one over another unlikely to succeed. These conclusions are based on the average of a group of subjects. It should be noted that there were individuals whose ratings of annoyance were more consistent with C-weighted and B-weighted levels.

No correction for blade slap was found which improves the prediction of annoyance. However, a small (2 dB) penalty for helicopters was indicated by the results. The 2 dB value is probably of little practical significance considering the variability of subject data and the discriminatory capability of an individual subject.

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APPENDIX A

INSTRUCTIONS FOR MAGNITUDE ESTIMATION JUDGMENTS OF NOISINESS

The purpose of the tests to be conducted is to determine the relative acceptability and tolerability of noises and various types of helicopters and helicopter maneuverings to people when in or near their home. You may like or dislike any of the noises you hear, but we want you to judge the noises relative to a reference noise.

You will be asked to listen to the sounds of aircraft flying over. You are to judge how disturbing or unacceptable the sounds would be if heard regularly, as a matter of course, in your home. We would like for you to make judgments of the noises you will hear as though you were listening to these noises near your home when engaged in typical everyday activities such as reading, conversing with friends, members of the family, etc. It is important that you keep this in mind and attempt to judge each of the noises you will hear as though you were near your home and engaged in similar activites for each of the exposures. It is also important that you judge how the noise would affect you in its totality from its beginning to end as an overall noise occurrence if you were near your home.

The first sound you will listen to is a standard or reference sound made by a C-47. All other sounds will be judged relative to this standard. Thus, you will give the standard sound a rating of "10" or a ratio of "1". Remember your job is to rate each of the other sounds relative to this standard. The first line on your answer sheet is for rating the C-47. Listen carefully to its sound and fix it in your mind. Give this sound a mid-scale rating. Then on each succeeding sound determine how much more or less annoying you would find it and mark the appropriate scale (marking to the left is less objectionable, to the right is more objectionable). For example, if the second sound is half as objectionable, mark "5" or a ratio of "1/2" on line 2. If you find it twice as objectionable, mark "20" or a ratio of "2" on line 2. Remember it is your subjective impression that is important. There are no right or wrong answers, nor do we expect there to be, necesssarily, agreement among the subjects. We expect people to differ. It is your opinion alone that is desired, but keep in mind, again, that you are to judge, relative to the reference noise, how each of the succeeding noises would affect you if you were exposed to it when near your home and engaged in typical everyday activities.

APPENDIX B

NAME: ______________ TIME: ______________ DATE: ______________

AIRCRAFT TYPE: ______________ TAPE NO: ______________

SEQUENCE CODE: ______________ SET NO: ______________

```
           .63   1.25   2.5    5    10    20    40    80    160
1.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
2.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
3.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
4.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
5.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
6.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
7.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___

           .63   1.25   2.5    5    10    20    40    80    160
8.   -+------+------+------+------+------+------+------+------+------+------+--
     ___   1/16   1/8   1/4   1/2    1     2     4     8     16     ___
```

NOTE: Original answer sheet had 10 response lines per page.

APPENDIX C

DEFINITIONS

x_{ij} : j^{th} one-third octave band level at the i^{th} .4-second time bin (numbers proportional to power; not in dB).

a_j : A-weighting coefficient for the j^{th} one-third octave band.

b_j : B-weighting coefficient for the j^{th} one-third octave band.

c_j : C-weighting coefficient for the j^{th} one-third octave band.

d_j : D_2-weighting coefficient for the j^{th} one-third octave band.

N : number of .4-second time intervals which are within 10 dB of the peak weighted level.

FORMULAS

PEAK A $= \max [\sum_j a_j x_{ij}]$ where the maximum is calculated with respect to i.

MAX A $= \sum_j a_j \max [x_{ij}]$ where the maximum is calculated with respect to i.

INT A $= \sum_i \sum_j a_j x_{ij}$ i is summed over all intervals within 10 dB of PEAK A

AVE A $= (1/N) \sum_i \sum_j a_j x_{ij}$ i is summed over all intervals within 10 dB of PEAK A

PEAK B $= \max [\sum_j b_j x_{ij}]$ where the maximum is calculated with respect to i.

MAX B $= \sum_j b_j \max [x_{ij}]$ where the maximum is calculated with respect to i.

INT B $= \sum_i \sum_j b_j x_{ij}$ i is summed over all intervals within 10 dB of PEAK A

AVE B $= (1/N) \sum_i \sum_j b_j x_{ij}$ i is summed over all intervals within 10 dB of PEAK A

PEAK C $= \max [\sum_j c_j x_{ij}]$ where the maximum is calculated with respect to i.

MAX C	$= \sum_j c_j \max [x_{ij}]$	where the maximum is calculated with respect to i.
INT C	$= \sum_i \sum_j c_j x_{ij}$	i is summed over all intervals within 10 dB of PEAK A
AVE C	$= (1/N) \sum_i \sum_j c_j x_{ij}$	i is summed over all intervals within 10 dB of PEAK A.
PEAK D	$= \max [\sum_j d_j x_{ij}]$	where the maximum is calculated with respect to i.
MAX D	$= \sum_j d_j \max [x_{ij}]$	where the maximum is calculated with respect to i.
INT D	$= \sum_i \sum_j d_j x_{ij}$	i is summed over all intervals within 10 dB of PEAK A.
AVE D	$= (1/N) \sum_i \sum_j d_j x_{ij}$	i is summed over all intervals within 10 dB of PEAK A
PPNL K	=	peak PNL calculated by formulas given in Kryter (1970)
IPNL K	=	integrated PNL calculated by formulas given in Kryter (1970)
ENPL K*	=	effective PNL calculated by formulas given in Kryter (1970).
PPNL F	=	peak PNL calculated by formulas given in FAA Noise Standards (1969) and corresponds to PNLTM in that document.

*While tone correction procedures are involved in these calculations, the tone correction was found to be zero for all aircraft flyby data used in this study.

APPENDIX D

PRODUCT MEAN CORRELATIONS BETWEEN INDIVIDUAL SUBJECTIVE RATINGS AND TWENTY-ONE PREDICTORS OF ANNOYANCE

	S1	S2	S3	S4	S5	S6	S7	S8
INT. A	.46	.73	.05	.71	.76	.73	.78	.54
AVE. A	.37	.80	.14	.48	.62	.65	.74	.39
PEAK A	.34	.78	.12	.47	.63	.62	.72	.42
MAX. A	.41	.76	.11	.57	.69	.66	.74	.50
INT. B	.42	.28	.01	.60	.75	.34	.68	.77
AVE. B	.44	.53	.02	.57	.78	.44	.61	.72
PEAK B	.40	.44	.04	.56	.76	.38	.56	.73
MAX. B	.46	.51	.05	.61	.79	.46	.61	.73
INT. C	.39	.14	-.01	.56	.69	.23	.54	.76
AVE. C	.46	.33	-.02	.61	.75	.34	.62	.80
PEAK C	.45	.38	-.00	.65	.78	.38	.63	.77
MAX. C	.49	.42	.01	.66	.79	.42	.62	.78
INT. D	.49	.64	.03	.71	.80	.66	.79	.66
AVE. D	.40	.78	.14	.53	.67	.63	.73	.45
PEAK D	.40	.74	.13	.54	.68	.58	.71	.50
MAX. D	.47	.73	.13	.62	.74	.64	.74	.58
IPNL K	.49	.51	.05	.72	.81	.56	.77	.73
PPNL K	.43	.67	.11	.59	.76	.57	.71	.59
EPNL K	.39	.76	.03	.63	.69	.68	.80	.50
EPNL F	.50	.53	.04	.70	.81	.56	.77	.73
PPNL F	.43	.72	.10	.56	.73	.57	.71	.56

	S9	S10	S11	S12	S13	S14	S15	S16
INT. A	.63	.67	.39	.63	.51	.45	.41	.69
AVE. A	.80	.60	.41	.52	.58	.44	.40	.72
PEAK A	.81	.61	.35	.53	.56	.46	.41	.72
MAX. A	.76	.67	.36	.59	.53	.45	.41	.71
INT. B	.24	.76	.91	.57	.06	.17	.37	.34
AVE. B	.58	.63	.21	.62	.29	.25	.33	.55
PEAK B	.49	.64	.12	.60	.20	.22	.31	.48
MAX. B	.54	.71	.17	.63	.25	.26	.36	.54
INT. C	.10	.76	-.00	.52	-.06	.09	.26	.23
AVE. C	.32	.81	.08	.60	.09	.17	.29	.40
PEAK C	.36	.78	.09	.62	.13	.20	.29	.44
MAX. C	.41	.82	.12	.63	.16	.22	.33	.48
INT. D	.55	.72	.35	.66	.41	.40	.44	.63
AVE. D	.83	.56	.42	.58	.57	.43	.41	.73
PEAK D	.80	.59	.34	.58	.51	.44	.40	.71
MAX. D	,76	.66	.37	.65	.49	.43	.41	.70
IPNL K	.44	.78	.29	.67	.29	.32	.43	.54
PPNL K	.73	.59	.30	.65	.45	.40	.37	.66
EPNL K	.72	.58	.45	.58	.63	.53	.48	.75
EPNL F	.46	.76	.29	.67	.31	.34	.41	.55
PPNL F	.79	.59	.33	.63	.49	.40	.37	.71

	S17	S18	S19	S20	S21	S22	S23	S24
INT. A	.38	.60	.79	.66	.62	.73	.73	.78
AVE. A	.36	.66	.63	.78	.82	.77	.76	.65
PEAK A	.29	.66	.62	.79	.79	.75	.73	.63
MAX. A	.37	.65	.69	.74	.76	.75	.74	.68
INT. B	.46	.38	.62	.25	.32	.37	.32	.78
AVE. B	.31	.58	.65	.53	.69	.57	.53	.61
PEAK B	.28	.53	.61	.46	.61	.50	.44	.54
MAX. B	.36	.58	.67	.51	.63	.58	.53	.64
INT. C	.46	.30	.54	.11	.22	.25	.18	.72
AVE. C	.38	.44	.61	.29	.44	.42	.36	.73
PEAK C	.33	.49	.62	.35	.51	.44	.39	.66
MAX. C	.40	.53	.64	.39	.51	.51	.45	.71
INT. D	.43	.58	.77	.58	.57	.68	.65	.79
AVE. D	.30	.69	.63	.78	.84	.76	.75	.66
PEAK D	.27	.66	.62	.75	.81	.73	.70	.63
MAX. D	.35	.67	.69	.71	.77	.74	.71	.70
IPNL K	.48	.53	.74	.45	.48	.59	.54	.79
PPNL K	.27	.66	.62	.68	.80	.69	.64	.63
EPNL K	.32	.63	.72	.77	.68	.78	.82	.72
EPNL F	.43	.55	.74	.48	.50	.60	.55	.79
PPNL F	.27	.70	.64	.73	.82	.72	.69	.64

	S25
INT. A	.82
AVE. A	.82
PEAK A	.79
MAX. A	.80
INT. B	.41
AVE. B	.58
PEAK B	.51
MAX. B	.59
INT. C	.28
AVE. C	.42
PEAK C	.48
MAX. B	.52
INT. D	.74
AVE. D	.78
PEAK D	.74
MAX. D	.76
IPNL K	.64
PPNL K	.70
EPNL K	.84
EPNL F	.66
PPNL F	.74