AL-TR-1992-0093

ARMSTRONG LABORATORY

THE EFFECT OF ONSET RATE ON AIRCRAFT NOISE ANNOYANCE, VOLUME 1, LABORATORY EXPERIMENTS

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MAY 1992

FINAL REPORT FOR THE PERIOD JULY 1989 TO MAY 1992

AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

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TECHNICAL REVIEW AND APPROVAL
AL-TR-1992-0093

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This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1992

3. REPORT TYPE AND DATES COVERED
July 1989 thru May 1992 - Final

4. TITLE AND SUBTITLE
The Effect of Onset Rate on Aircraft Noise Annoyance
Volume 1: Laboratory Experiments

5. FUNDING NUMBERS
PE: 62202F
PR: 7231
TA: 34
WU: 11
F33615-89-C-0531

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
WR 91-19

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Occupational & Environmental Dir
Bioenvironmental Engineering Division
Human Systems Division
Air Force Systems Command
Wright-Patterson AFB OH 45433-6573

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL-TR-1992-0093

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
A laboratory study has been conducted to quantify the effect of onset rate on the annoyance of noise from aircraft operating on low-altitude military training routes (MTR). Using indoor and outdoor listening facilities, recordings of MTR sounds were presented to groups of participants. The recordings included actual sounds, plus sounds which had been modified to have particular onset rates and decay rates. Onset rates ranged from 1.3 to 152 dB/second. Sound exposure level of the stimuli varied from 65 to 95 dB indoors, and 80 to 110 dB outdoors. Participants recorded their annoyance on a nine-point scale. It was found that onset rates faster than 30 dB/second caused increased annoyance. The best fit to the data is an onset rate adjustment to SEL, which has the form of a linear relation on a dB versus log(rate) scale, from 0 dB at a rate of 30 dB/second to 11 dB at 150 dB/second. Below 30 dB/second, there is no adjustment, and data were not collected at higher rates. Stimulus duration and decay rate were found to have some effect, but these quantities are sufficiently well correlated with onset rate that a model based on onset rate alone is adequate. It was found that the direction of approach of the aircraft was not a major effect, but there is a substantial difference in annoyance between indoor and outdoor settings.

14. SUBJECT TERMS
Aircraft Noise
Noise
Psychoacoustics

15. NUMBER OF PAGES
133

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

P A G E   I N T E N T I O N A L L Y

L E F T   B L A N K

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ACKNOWLEDGMENTS

The authors would like to thank Dr. C. Stanley Harris and Mr. Jerry D. Speakman, of the U.S. Air Force Armstrong Laboratory, for their encouragement and guidance throughout this project. We also thank Mr. David McCurdy, of the Acoustics Division, NASA-Langley Research Center, for his tireless efforts to ensure that everything went right during the indoor test sessions.

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1.0 INTRODUCTION

1.1 Background

Military air tactics rely on increasing use of low-altitude penetration techniques. Training for this type of operation can take place in specially designated low-altitude military operating areas (MOAs) or along military training routes (MTRs). Environmental assessment of noise from these operations has become an important factor in the design of these special use airspaces. The noise environment is different from commonly studied situations such as airport or highway noise in urban/suburban areas, and it is not obvious that the usual analysis, in terms of Day-Night Average Level (L_{dn}), is appropriate. Individual events are loud (maximum levels in the 100 to 115 dB range*). Noise events are infrequent (typically an average of no more than three or four per day on the busiest routes) and occur at irregular, sporadic times.

A preliminary assessment of the noise environment under MTRs[1] suggested that key parameters affecting annoyance would be the high amplitude and short duration of individual events, the relatively few number of events, and the sporadic occurrence of flyovers. It was also speculated that Doppler shifts, strong sense of motion of the sound, and tactile vibration from low-frequency components of the noise might be factors. That study recommended field measurements of the noise environments and informal surveys of attitudes of residents along MTRs. A generic program for assessment of MTR noise was outlined, ranging from controlled laboratory tests of psychoacoustic parameters through attitudinal surveys of residents in their own homes.

Initial field studies were conducted along an MTR used by B-1, B-52, and FB-111 aircraft.[2] The results of that study included the following:

- Aircraft spectra were not dramatically different than those experienced around air bases, and motion effects (e.g., Doppler shifts) were not prominent.

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* A-weighted sound pressure level, re 20μPa. Unless otherwise specified, all sound levels (and sound level rates) in this report are A-weighted.

- Low-frequency noise, while present at relatively high levels, occurred at the same time as maximum audible sound, and so did not appear to be a dominant effect.

- The speed at which the aircraft approach, and the resultant high onset rate of noise, was a prominent effect. The high onset rate led to the most commonly reported observation by residents that they were most often annoyed because they were surprised by the aircraft.

- The high levels, brief durations, and sporadic occurrences were quite evident.

Concern about the suitability of L_{dn} to account for the few numbers of events, and for the obvious surprise factor associated with the high onset rate, led to the development of an interim noise metric[3] which would be supportable by the best available scientific knowledge at the time.

1.2 L_{dnmr}: The Interim Metric

A review was made of the available literature regarding the suitability of L_{dn} for sporadic events and the effect of high onset rate on annoyance.[3] The following conclusions were reached:

- In the absence of evidence that low-frequency vibration (for which C-weighting may be appropriate) is a dominant effect, A-weighting was considered to be the best accounting of spectral content.

- L_{dn} is the best available representation for the number of events, duration, and spectral content. Evidence was available that L_{dn} is valid even for one or two events per day,[4] although that study was for helicopters at lower sound levels. Based on typical route schedule variations, it was recommended that L_{dn} for routes be based on the busiest month of the year, hence L_{dnm}. This monthly averaging is an extension of the "average busy day" concept used for noise analysis around airbases.

- High onset rates were considered to be a real effect, causing increased annoyance. Based on data from a variety of sources (ranging from aircraft flyover noise to sonic booms) the onset rate correction illustrated in Figure 1 was developed.[3] This additive correction applied to Sound Exposure Level (SEL) yields SEL_r; applied to L_{dnm}, yields L_{dnmr}.

The L_{dnmr} metric was adopted as Air Force policy[5] to be used for assessment of community noise impact from MTRs. It was recognized in Reference 3 that, while L_{dnmr} was based on the best available data, much of the support is circumstantial. In the long term, it was considered essential to conduct formal psychoacoustic studies which would provide an adequate data base to support, refute, or revise, if necessary, this metric.

1.3 Context of Experiments

In Reference 1 a continuum of psycho/socioacoustic studies was outlined, ranging from laboratory studies of specific characteristics of noise, through field studies which can consist of attitudinal interviews. Three points along this continuum were identified as reasonable for establishing MTR noise impact. These are:

- Laboratory studies, which allow examination of the specific sound properties such as spectrum, onset rate, etc. Emphasis is on the sounds, which are presented at a fairly high rate: at least one every few minutes.

- Rented-house studies, which retain some of the characteristics of laboratory studies but are in a more realistic context. Sounds are presented at a more realistic rate (a few events per hour), and there is a transition from single-sound ratings to session-long (from an hour to a day) epoch ratings.

- Own-house studies, where the effect of noise on people is examined in their own homes. Emphasis is on epoch ratings and long-term annoyance/acceptability.

The current experiments represent laboratory studies. Emphasis is on assessing the validity of the onset rate correction. Attention is also given to

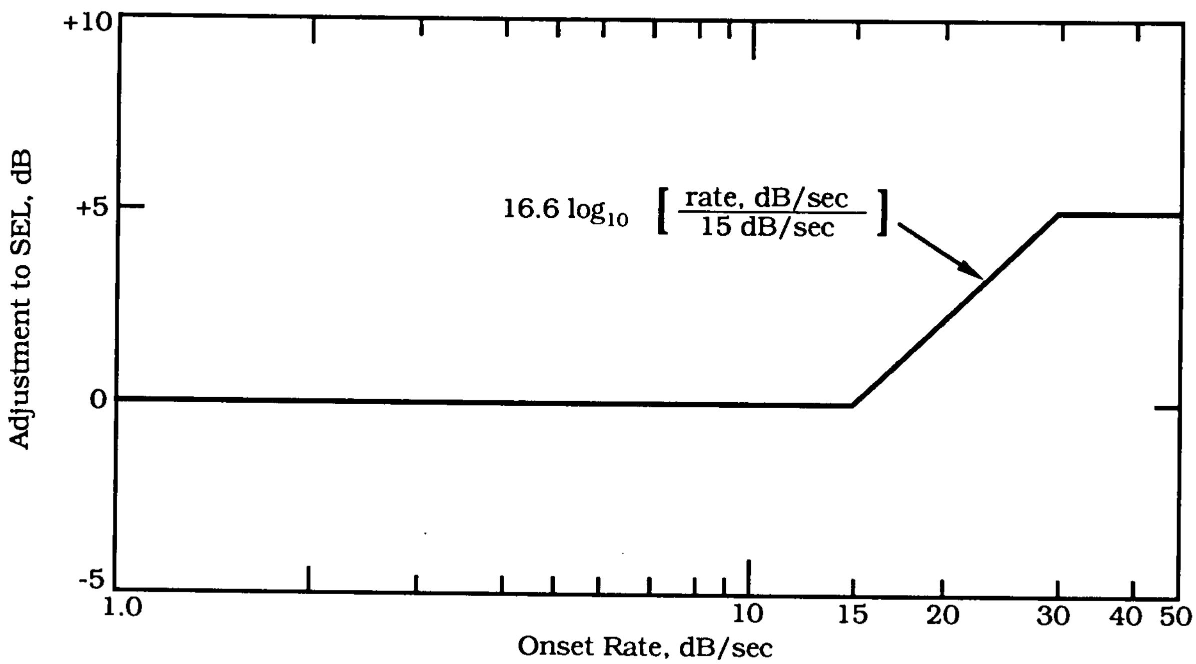

Figure 1. Recommended Adjustment to SEL for Onset Rate.[3]

spectral content, level, duration, and related sound parameters. These experiments were in parallel to laboratory experiments conducted by the Air Force[6] which have similar objectives. The current experiments and the Air Force experiments have been coordinated to the degree of ensuring consistency of general approach, hence providing compatible grounds for comparing results. They are otherwise independent of each other.

1.4 Overview of Experiments

The current study consisted of a set of three interlocking experiments: a kernel experiment, which was the primary experiment, a supporting experiment which examined the effect of onset rate in more detail, and a supporting independent variable experiment which was built around a regular matrix of key variables. The experiments were conducted under laboratory conditions (using two facilities: one indoors and one outdoors), with participants receiving 48 to 60 stimuli in a two-hour session.

The kernel experiment had the following features:

- Experiments were conducted, with the same participants, at both indoor and outdoor facilities.
- Stimuli were based on recordings of actual aircraft flyovers.
- Twelve aircraft sounds, at four levels each, were used as stimuli. The aircraft sounds included three military aircraft of differing spectral characteristics, each at several speeds (and corresponding onset rates), and one civil aircraft as a control. Onset rates ranged from approximately 1 to 150 dB per second.
- Stimuli were presented in random order, with random inter-stimulus intervals, so as to avoid anticipation by participants. Forty-eight stimuli were presented in each two-hour session.
- Participants rated each sound on a nine-point annoyance scale (described in Section 2.4.3) which was closely related to the seven-point scale used in Reference 6.

The onset rate experiment had the following features:

- Experiments were conducted only at the outdoor facility.
- The twelve original aircraft sounds from the kernel experiment were used, plus six modified sounds. The modified sounds were developed from original sounds, and had temporal shaping to achieve particular onset rates. The purpose of the modified sounds was to fill gaps in the onset rate sequence of the twelve original sounds.
- Each sound was played at three levels, for a total of 54 stimuli in the two-hour session.

The independent variable experiment had the following features:

- Experiments were conducted only at the outdoor facility.
- Twenty-four modified sounds were used. These were developed from three of the original kernel experiment sounds, with temporal shaping to achieve a regular matrix of six specific onset rates and four specific decay rates.
- Six of the original aircraft sounds were also used, to provide continuity with the other two experiments.
- Each of the 30 sounds was presented at two levels, for a total of 60 stimuli in the two-hour session.

In the above description, it should be noted that there were twelve <u>original sounds</u>, reproduced very much as they had been recorded from actual overflights. There were also a number of <u>modified sounds</u>, created by temporal shaping several of the original sounds. A <u>stimulus</u> was considered to be a particular sound played at a particular level.

Except for the stimuli, each of the three experiments was conducted in the same manner. Each session included six participants. Participants were occupied by reading magazines.

Data from these experiments were examined by analysis of variance (ANOVA) to establish the significance of major psychoacoustic and methodological variables. Regression analysis was then employed to establish a revised best-fit onset rate adjustment.

2.0 EXPERIMENTAL DESIGN

The experiments evolved from consideration of the key variables, the specific characteristics of MTR sounds, and the capabilities of available facilities. This section outlines the evolution of the experiments within these constraints. Section 2.1 outlines the objectives and general goals of the experiments. Section 2.2 describes the sounds used, which were based on available recordings, and how they were prepared for the experiment. Section 2.3 describes the facilities used. Section 2.4 contains detailed descriptions of the final experimental design.

2.1 Experimental Domain and Objectives

2.1.1 Major Experimental Variables

Most of the major acoustic variables governing the assessment of MTR noise impact were considered in the design of the experimental program. These major variables are:

1. Sound level of an individual flyover event.

2. Short-term temporal envelope of a given flyover event, i.e., duration, onset rate, dwell time, decay rate, envelope shape, etc.

3. Acoustic spectrum of an individual flyover event.

4. Listening environment differences in sound spectrum due to outdoor versus indoor listening conditions (sound attenuation of structures).

5. Identifiable other prominent noise sources, e.g., commercial aircraft, highways, railroads, farm machinery, etc.

6. Localization and directionality of the flyover event (interaural intensity and time differences, phase shifts, head shadow effects, etc.).

7. General background ambient noise in the vicinity of the flyover event.

8. Number of individual flyover events in a given time period.

9. Long-term temporal distribution of those individual flyover events, e.g., regular, irregular, random, sporadic, bunched, daytime, night-time, etc.

10. Short-term temporal changes in the acoustic spectrum associated with detailed operations,, e.g., engine thrust changes, afterburner cut-in, etc.

11. Secondary induced acoustic sources such as rattling objects indoors or echoes outdoors.

Variables 1 and 2 from the above list are considered to be the most significant, and are included in the current experiments as direct parameters. Note that variable 2 encompasses several parameters (including onset rate), which have some degree of interrelationship. Variables 3 and 4 are also considered to be significant, and are explicitly included. Variables 5 to 7 are accounted for by a limited consideration of possible effects in the selection of a single value for an important experimental parameter or condition. Variables 8 to 11 may be better studied by means of field experiments and surveys in the actual communities exposed to MTR noise, and are not addressed here.

A key philosophy in these experiments was to obtain data which would provide an empirical model for the noise impact of MTRs. This meant that acoustic parameters not explicitly varied should have values which correspond, as much as possible, to MTR conditions. The most certain way of accomplishing this would be to base sound stimuli on recordings of actual MTR aircraft flyovers.

In addition to the major acoustic variables enumerated above, the current experiments recognize non-acoustic variables that may have an important influence on the human response to MTR noise. Some of these important non-acoustic variables are:

1. Activity of the listener during the exposure to flyover noise and possible activity interference, e.g., reading, television viewing, conversation, sleeping, etc.

2. Demographics and life-style of the listening situation: urban versus suburban versus rural, farming versus non-farming (ranching, etc.).

3. Attitude of the listener toward military training operations, the occupation and income derivation of the listener as regards aircraft operations, and knowledge on the part of the listener of the purpose and expected nature of the MTR flights.

4. Previous noise exposure history of the respondent to aircraft, highway, railway, farm machinery, industrial, or other noise sources.

5. Noise tolerance of the individual and his/her tendency to complain about noise and other disturbances; also knowledge of to whom to complain.

6. Tolerance of the individual to startle and surprise reactions possibly related to arousal of the nervous system, as well as to the strength and lability of the orienting reflex.

7. Fear of aircraft crashes and other safety concerns, fear of crews taking unnecessary chances, and concern over pollution from the planes, e.g., fuel spills, etc.

8. Concern over the effects of the noise on wild and domestic animals, especially among farmers, ranchers, trappers, hunters, etc.

9. Fear of decreased property value, structural damage to the domicile or other buildings, interference with tourism or commerce, and other economic concerns.

10. Fear of adverse health effects from the noise exposure.

11. Positive or negative feelings toward MTR operations: "The sound of freedom", "excitement", etc., versus general opposition to the military.

Variables 1 to 6 from the above list are accounted for in the experiments by participant selection, task activity, and a post-experiment questionnaire. Variables 7 to 11 are better studied by means of field experiments and surveys, and are not addressed here.

2.1.2 Ranges of Onset Rates, Levels, and Spectra

As noted in Section 1.2, L_{dnmr} differs from L_{dn} primarily by an adjustment for onset rate. The experimental matrix must obviously include onset rate as a primary parameter. Figure 2 illustrates the range of interest.

The bottom portion of the figure was taken from Reference 2, and shows the data upon which the L_{dnmr} onset rate correction (Figure 1) is based. Shown at the top of the figure are the ranges of onset rates associated with various military aircraft under MTR conditions,[7] plus onset rates associated with civil aircraft during takeoff.[8] Indicated (downward arrows) in the center are six onset rates, at roughly equal logarithmic intervals, which cover the range of interest. The experiments were designed around this nominal set of onset rates.

Sounds with fast onset rates tend to have fast decay rates and also short durations. In the development of L_{dnmr}, it was considered that onset is the dominant parameter; decay would not be expected to contribute to surprise, and duration should be accounted for by SEL. However, the interrelationship between onset, decay, and duration is an obvious issue. Therefore, in addition to sound stimuli which had these parameters in their typical proportions, stimuli were used which had a fully balanced matrix of onset and decay rates.

Level is a key parameter in noise annoyance. Corrections for onset (or other parameters) are represented as effective changes to level. The appropriate measure of level for the current experiments is SEL. Maximum SELs of 115 dB occur on MTRs. A basic SEL matrix of 115, 105, 95, and 85 dB was used. Indoor stimuli were 20 dB lower, to represent the attenuation of a typical house. Indoor sounds were also shaped with a 2 dB per octave rolloff, representing the typical filtering effect of a house.[9]

Spectral content is an important characteristic of sound. The expectation is that A-weighting adequately addresses spectral effects. To test this hypothesis, a variation in spectral content is necessary. At a minimum, aircraft sounds must be selected which have "typical" spectral content, spectra weighted toward low frequencies, and spectra weighted toward high frequencies.

2.1.3 Considerations of Experimental Presentation

It was considered important that the stimuli be received in as realistic a manner as possible, preserving the way that they sound under natural conditions. The following elements were incorporated in the experiments:

- Sounds must be complete events, realistically rising out of and decaying into the ambient.
- Both indoor and outdoor presentations were required, with indoor sounds being attenuated and filtered versions of the outdoor sounds.
- Participants must be engaged in some moderately absorbing activity.
- Stimuli must be in stereo, with fade rate commensurate with aircraft speed. The direction of approach must be randomly varied from one presentation to the next.
- There must be adequately long inter-stimulus intervals, with random duration, so that participants would not develop a rhythm and anticipate sounds.
- Order of presentation of sounds must be random, and each participant must hear a different order in each session.
- All parameters which are not experimental variables (e.g., seating position) must be balanced.
- To avoid fatigue, each session would last no more than two hours, including a ten-minute break.
- Multiple participants per session were desired, so as to increase productivity. The facilities used (see Section 2.3) could accommodate up to six participants for each session.
- Each sound would be rated by the participants on a scale similar to the seven-point annoyance scale established by the Air Force.[6]

2.1.4 The Three Experiments

Consideration of the parameters outlined in Sections 2.1.1 through 2.1.3 lead to the concept of three interlocked experiments.

- The kernel experiment was primary. It used twelve real aircraft sounds at four levels each. Participants attended listening sessions both indoors and outdoors. Variables emphasized were level, onset rate, spectrum, and environment.

- The onset rate experiment was designed to specifically test onset rates. The twelve real sounds from the kernel experiment (which will be referred to as the "original" sounds) were supplemented with six modified sounds so as to provide greater onset rate resolution and to ensure that the six rates indicated in Figure 2 were represented. Three sound levels were used, and sessions were outdoors only.

- The independent variable experiment was designed to evaluate the separate effects of onset, decay, duration, and level. A matrix of original and modified sounds was used which covered the six onset rates indicated in Figure 2 and four decay rates. Two levels were used, and sessions were outdoors only.

These three experiments were formulated in the planning stages. The specific test matrices (presented in Section 2.4) were established based on available sound stimuli (discussed in Section 2.2) and the capabilities of the facilities (Section 2.3).

2.2 Sounds

2.2.1 Requirements and Selection

The sounds used were recordings of aircraft under actual MTR operating conditions. Because of the large dynamic range required to span from ambient to well over 100 dB, it was necessary to use recordings made under ideal conditions with high dynamic range instrumentation. Such measurements were made by the Air Force in 1988.[10] A number of aircraft were operated in dedicated flight tests

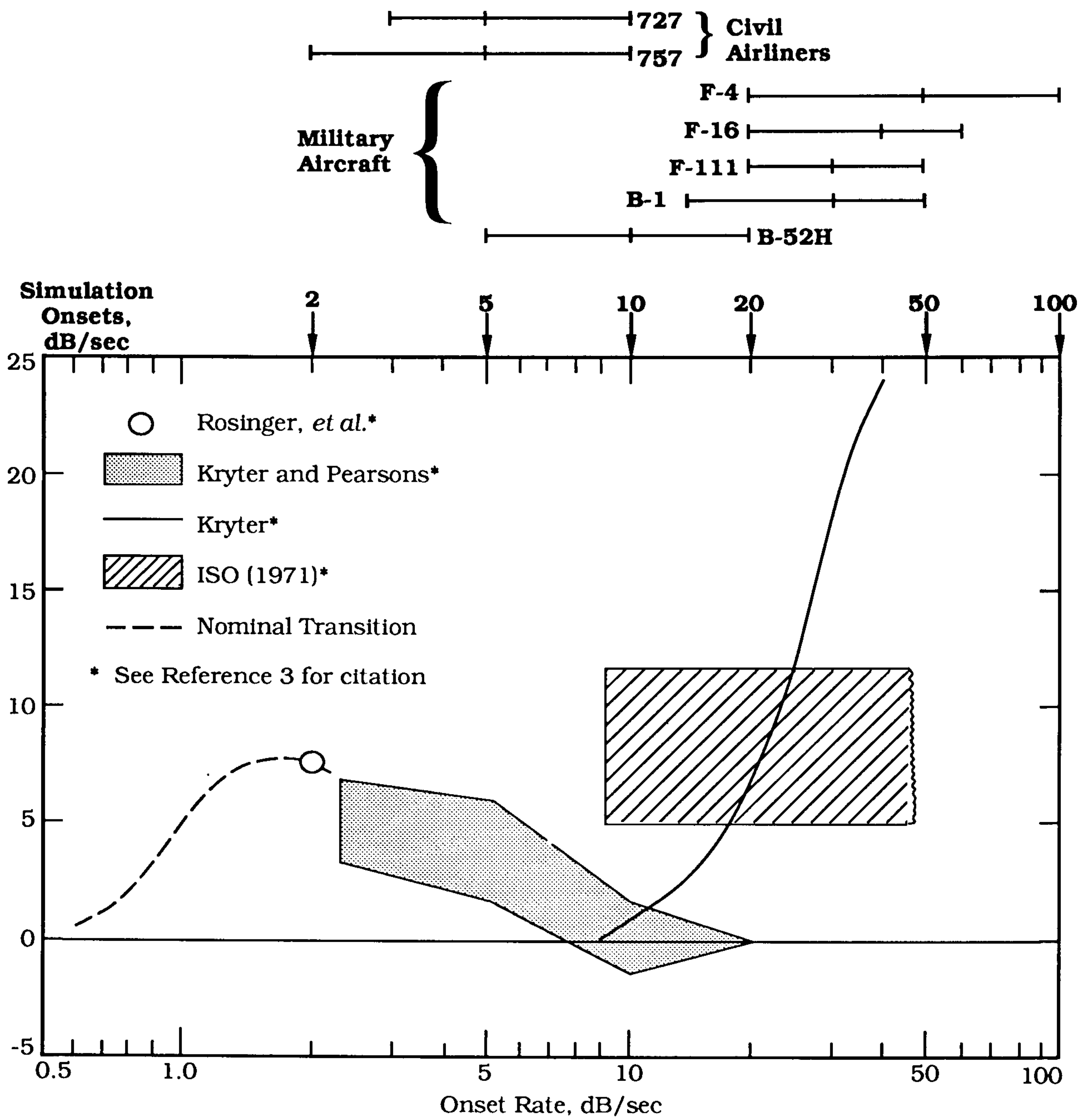

Figure 2. Basis for Current Onset Rate Correction,[3] and Onset Rate Ranges for Various Aircraft.

at MTR, and related, flight conditions. Noise at key locations (including undertrack) was recorded using the audio channels of a hi-fi stereo video cassette recorder. This system has a dynamic range in excess of 80 dB. Because of the dynamic range requirements, these recordings were the only available military aircraft sounds considered to be suitable.

An inventory of the recordings, consisting of flight parameters, SEL, maximum level, and onset rate, was reviewed. A number of candidate aircraft were identified on the basis of covering the onset rate domain and a range of spectral characteristics. The recordings were then auditioned to make a final selection. Key elements in the auditions were that the recordings be as clean as possible and that the selected sounds provided clear representation of various aircraft types and MTR flight parameters. Eleven military aircraft recordings were selected. The aircraft, test conditions, and acoustical properties as reported with the original data are summarized in Table 1. In addition to the A-weighted metrics SEL and L_{max}, the Equivalent Perceived Noise Level (EPNL) is shown. The specific reasons for the selections were:

- The B-1, FB-111, and F-4 represent high-speed combat aircraft with low, average, and high-frequency spectral characteristics. All are MTR users.

- The FB-111, as an "average" sounding aircraft, was selected in lieu of an F-15 or F-16, which are much more abundant MTR users. High-quality recordings of F-15 or F-16 over the desired range of conditions were, unfortunately, not available. Auditions of conventional recordings of these two aircraft types indicated that their spectral characteristics did not particularly emphasize high or low frequencies. The FB-111 was judged to have a very typical jet fighter sound, which an average person would have difficulty distinguishing from other common types.

- A B-52, a common MTR user, was desired. No adequate recordings were available for this aircraft. The KC-135 has similar engines, and therefore generally the same sound characteristics.

- A slow, medium, and fast recording was desired for each aircraft type, to provide independent variation of onset rate. Three recordings (slow, medium, and fast speed) were selected for each of B-1, FB-111, and F-4. The KC-135 (and the B-52, for which it is a surrogate) operates only at speeds considered to be slow and medium compared to the other aircraft,* so only two recordings (slow and medium) were selected for the KC-135.

One civil aircraft, the Boeing 727 at typical takeoff conditions (corresponding to the FAR Part 36 Takeoff Measurement Point), was included. This recording has been used by NASA as a control in psychoacoustic experiments (e.g., Reference 11), and provides a connection between the current study and extensive experience with civil aircraft noise. The 727 recording was a conventional direct tape recording with about 40 dB dynamic range. It was digitally edited (see Section 2.2.2) to obtain an effective 70 dB dynamic range.

The twelve sounds were transcribed from their original tapes to digital audio tape (DAT), which has a 90 dB dynamic range and a 48 kHz digitization rate. During this transcription, the gain was adjusted so that the maximum level of each sound fell just below the upper limit of the DAT's dynamic range. All subsequent processing was accomplished digitally. Processing consisted of four phases: editing of the sounds, modifications to provide specific onset and decay rates for the onset rate and independent variable experiments, preparation of stereo mixes with calibrated SEL values, and preparation of "session tapes" to be used during the experiments.

2.2.2 Editing of Sounds

All sounds were cleaned up in preparation for use, using a Dyaxis digital editor.[12] The Dyaxis system consists of a digital mixing board coupled to a microcomputer. The system used is capable of storing up to 30 minutes of digitized sound (at DAT resolution), and applying virtually any enveloping or other modifications to the sound. The system was located at a professional recording studio, and was operated by a skilled audio engineer.

* Maximum MTR speed for the B-52 is approximately 340 to 360 knots, versus 480 to 540 knots for the other three aircraft.

The Dyaxis system displays sounds as a time history of amplitude, much like an oscilloscope trace. Features of the sound which occur at a particular time can be accurately identified. This display does not, however, lend itself to precise measurement of envelope shapes. Accordingly, a B&K Type 2305 level recorder was added to the system. Quantification of slopes and other envelope properties were based on measurements from the level recorder charts.

Two types of clean-up edits were made to each sound. The first was to clean up the fade in and out at the beginning and end. This included fading out tape hiss from the original recordings so that it would fall below the expected laboratory ambient. The quality of the sound in this region was not considered to be as important as having smooth transitions; the sound must not suddenly switch on or off. The second clean-up edit was to adjust any anomalous features of the sound. For example, a number of the recordings of faster aircraft had an increase in level 30 to 40 seconds after the maximum. This corresponded to a point where the aircraft was several miles downtrack, the data collection run was essentially over, and climb-out was initiated. This type of adjustment was made such that the envelope in the modified region had a slope which matched that before and/or after the anomaly occurred.

It was noted earlier that the 727 recording had a dynamic range of 40 dB. This was artificially stretched to obtain a signal with a 70 dB dynamic range, with smooth transitions. To accomplish this at fade-in, about one second of sound near the original beginning was copied. It was spliced into a loop, with the splice blended over a short period so as to be inaudible. An envelope was applied to give the loop constant amplitude. The loop was then repeated enough times to provide the required total additional duration. This was then spliced to the beginning of the original sound, and an envelope applied to match the original onset rate. A similar process was applied at the end of the sound.

The properties of the edited original sounds, which differed slightly from the values in Table 1, are discussed in Section 2.2.4.

2.2.3 Modified Sounds

As described in Section 2.1.4, sounds were required which had particular onset and decay rates. These sounds were obtained by modification of FB-111

Table 1

Aircraft Noise Recordings Used as Source of Experimental Stimuli

Aircraft	Altitude (Feet)	Lateral Offset (Feet)	Speed (Knots)	SEL (dB)	L_{max} (dB)	EPNL (dB)	Onset Rate (dB/sec)
FB-111, Slow	960	36	160	97.5	90.9	100.4	2.5
FB-111, Med.	1,028	2	521	107.5	107.9	109.1	17.3
FB-111, Fast	228	70	524	118.1	121.8	121.2	53.9
B-1B, Slow	2,130	2,021	355	83.4	76.6	84.6	2.7
B-1B, Med.	1,053	35	580	109.6	110.1	110.6	17.4
B-1B, Fast	217	70	586	117.3	121.1	119.3	59.8
F-4D, Slow	1,126	60	179	102.2	95.6	104.9	5.2
F-4D, Med.	1,000	1	550	111.1	111.1	112.9	22.4
F-4D, Fast	108	54	597	122.9	128.0	126.4	108.9
KC-135A, Slow	937	43	137	110.9	102.0	112.9	2.5
KC-135A, Med.	152	2	147	120.8	118.5	126.0	10.6
727	1,300*	0*	160*	105.0	95.0	107.0	1.7

* Estimated from FAR Part 36 takeoff condition.

recordings. The FB-111 was used because of its role as the "typical" sounding aircraft. Required onset rates were 5, 10, 20, 30, 50, and 100 dB/second; required decay rates were 2, 5, 10, 20 and 30 dB/second. Each sound was made by selecting an FB-111 sound with the highest rates below the goals and applying constant slope envelopes to the onset and decay regions so as to obtain the desired rates. Table 2 lists the starting original sound for each of the 30 modified sounds. Most were made by modifying a single sound. Some, with onset and decay rate combinations far from any natural sounds, required splicing two sounds at the maximum. Table 2 indicates which sounds were spliced. The splices were carefully blended and were not apparent on listening to the sounds.

Thirty modified sounds were created. The final experimental design used 25 of these.

2.2.4 <u>Final Mix: Level Calibration and Stereo Mix</u>

The relative levels of the edited original and modified sounds were established by playing each DAT recording into an integrating sound level meter (Larson-Davis Model 700 Dosimeter), which gave the relative SEL and maximum level. (Both fast and slow maxima were obtained.) The sound with the lowest SEL was noted, and the amount by which each of the other sounds exceeded this was identified as a "cut" value. The following digital editing/mixing was then performed on each sound:

- It was reduced in amplitude by the cut amount.
- The sound was copied onto a second channel.
- A cross-fade was applied to the two channels, converting the monaural sound into stereo. Details of the cross-fade are described below.
- The sound was recorded on a master DAT. It was then attenuated by 10, 20, and 30 dB and re-recorded, yielding four levels, 10 dB apart, for each sound.

This process was applied to all sounds (twelve original, plus 30 modified), yielding a master stimulus library of 168 stereo stimuli (42 sounds at four levels

Table 2

Sources of Modified Sounds*

Onset Rate (dB/sec)	Decay Rate (dB/sec)				
	2	**5**	**10**	**20**	**30**
5	S	S	S	S	S
10	S	S	S	S	S
20	S	M	M	M	M
30	S	M	M	M	M
50	F/S	F/M	F/M	F	F
100	F/S	F/M	F/M	F	F

* S = FB-111, Slow
M = FB-111, Medium
F = FB-111, Fast

each). The levels were equated for SEL. The relative maximum levels were established by the difference between SEL and L_{max}, obtained during calibration.

The stereo fade consisted of applying constant slope envelopes to the two channels, as illustrated in Figure 3. The constant slope provided a reasonable approximation to actual fade from a moving aircraft. The approach time (time from onset to overhead point) was 0.7 times the pan time (time from onset to full value). This ensured that the sum of p^2 would match the original amplitude. When tested with constant amplitude white or pink noise, this fade envelope gave the sensation of a constant sound moving smoothly from one loudspeaker to the other.

The slope of the required fade envelope may readily be computed from the kinematics of the flyover. Envelopes for the twelve actual sounds were computed from the speeds and altitudes noted in Table 1, and were rounded off to the values shown in Table 3. Pan rates for the modified sounds were taken to be the same as for their original sources. For those modified sounds spliced from two original sounds, pan was based on the slower sound.

Table 3 summarizes the onset and decay rates, duration, pan time, and difference between L_{max} and SEL for the twelve original sounds. Two durations are shown. One is the time between 10 dB-down points. The other is the total duration of the recording, from initial fade in to final fade out. Two L_{max} − SEL values are shown, corresponding to slow L_{max} and fast L_{max}.

Note that some of the quantities in Table 3 differ from those in Table 1. This occurred for two reasons. First, cleaning up the sounds, and adjusting durations, changed some properties. Second, a slightly different method for obtaining onset rate was used. The nominal rates, given in Table 1, were obtained by an algorithm working on the highest 20 dB of digitized levels. The digitization analysis system included a fast (0.125 second) averaging detector for all sounds. The rates shown in Table 3 were based on measurement of slopes on the level recorder chart, using a wider range than just the highest 20 dB. When determining the slopes, the paper speed and writing speed of the level recorder were adjusted so that the measured slopes represented the signal, and not the time constant of the level recorder detector.

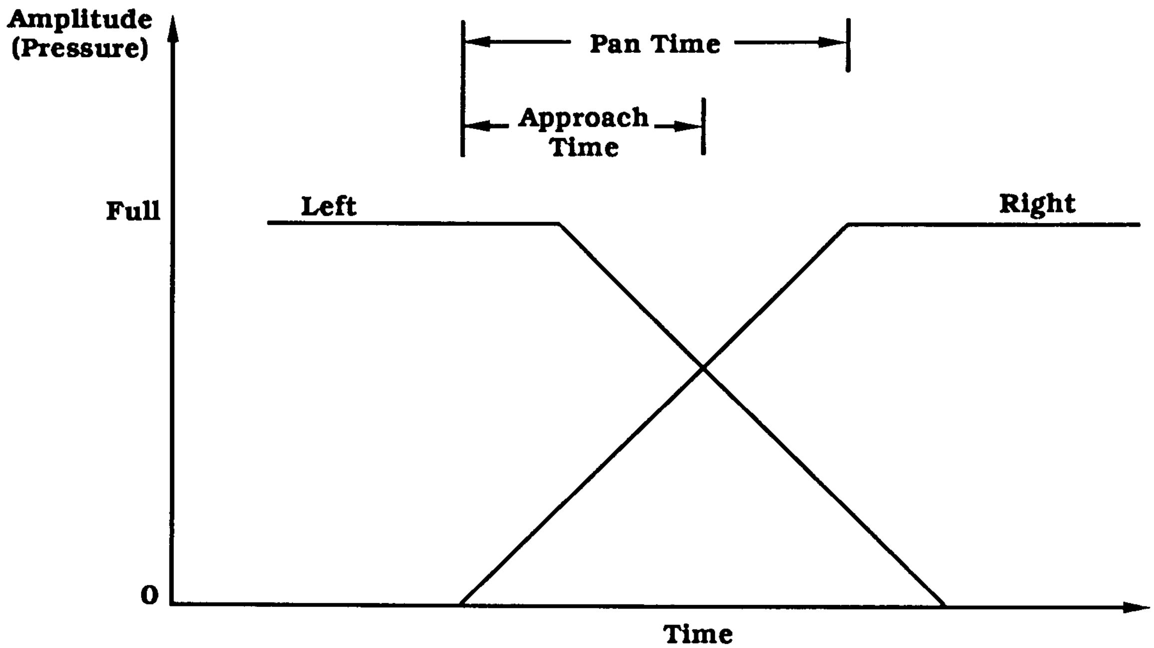

Figure 3. Stereo Fade Envelopes.

Table 3

Properties of Original Sounds, as Employed in Experiments*

Sound	Onset Rate (dB/sec)	Decay Rate (dB/sec)	10 dB-Down Duration (sec)	Total Duration (sec)	Pan Time (sec)	L_{max} - SEL (Slow)	L_{max} - SEL (Fast)
FB-111 Slow	1.7	1.2	15	65	10	-8	-5
FB-111 Med.	16	5.0	8	41	3	-3.5	1
FB-111 Fast	42	15	2.3	37	1	-1.5	4.5
B-1B Slow	1.9	1.1	14.3	75	10	-7	-6.5
B-1B Med.	18	7	6.8	54	3	-3	0.5
B-1B Fast	68	27	0.5	31	0.5	-1	5
F-4D Slow	2.4	3.1	8	65	10	-8	-4.5
F-4D Med.	22	7	2.4	66	3	-4	1.5
F-4D Fast	152	49	0.3	49	0.5	-1	6
KC-135A Slow	1.5	0.9	18	89	10	-10	-8.5
KC-135A Med.	6.5	6.0	3	45	2	-4	-2
727	1.3	1.1	18	105	15	-10	-9

* All twelve original sounds were used in the Kernel and Onset Rate experiments.
The three B-1B and three F-4D sounds were used in the Independent Variable experiment.

Table 4 shows the same information for the modified sounds used in the experiments. Table 4a shows duration, while 4b shows L_{max} – SEL. Empty spaces in Table 4 represent sounds which were not used in the final experimental matrices. When referring to the modified sounds, they are denoted by the onset and decay rates, e.g., 30/10 is the modified sound with a 30 dB/sec onset rate and 10 dB/sec decay rate..

2.2.5 Session Tapes

The sounds for each two-hour session were copied onto a single DAT, with sounds in the desired sequence and separated by the appropriate inter-stimulus intervals (ISI). The following procedure was followed:

- A list was made of the sounds which would be included in that session. Each list enumerated sounds and levels. There were three such lists, one for each of the experiments.

- A list of ISIs was prepared. Several ISIs were used for each experiment (see Section 2.4), and replicated enough times to have one per stimulus.

- A computer program was prepared which selected ISIs and stimuli, in random order, from each list. The sequencing began with an ISI, so that the first sound would occur a random time after start, and alternated between ISI and stimulus. Random selection continued until both lists were depleted. The program used the pseudo-random function RND in Microsoft GWBASIC, and used the system time as a seed to ensure a different sequence for each run.

- The random order program also generated a random list of directions to be used in varying approach direction during the experiments.

- Stimuli were digitally copied from the master tape to the session tape, separated by the ISIs, following the generated list.

Enough session tapes were prepared for each experiment so that no participant heard the same tape more than once.

Table 4

Properties of Modified Sounds*

(a) 10 dB-Down Duration (D_1) and Total Duration (D_2)

Onset Rate (dB/sec)	Decay Rate (dB/sec)									
	2		5		10		20		30	
	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2	D_1	D_2
5	7.0	65	4.0	65	3.0	65			2.3	65
10	6.0	65	3.0	65	2.0	65			1.3	65
20	5.5	65	2.5	41	1.5	41			0.8	41
30	5.3	65	2.3	41	1.3	41			0.7	41
50	5.2	48	2.2	43	1.2	43	0.7	36	0.5	36
100	5.1	48	2.1	43	1.1	43			0.4	36

(b) L_{max} – SEL (Δ_1 = slow, Δ_2 = fast)

Onset Rate (dB/sec)	Decay Rate (dB/sec)									
	2		5		10		20		30	
	Δ_1	Δ_2	Δ_1	Δ_2	Δ_1	Δ_2	Δ_1	Δ_2	Δ_1	Δ_2
5	-6.0	-4.5	-5.0	-3.0	-4.5	-2.0			-3.5	-0.5
10	-6.0	-3.0	-4.0	-1.0	-3.5	-0.5			-2.5	0.5
20	-6.0	-2.0	-3.5	1.0	-2.5	2.5			-2.0	3.5
30	-6.0	-2.0	-3.5	1.0	-2.0	3.0			-1.5	4.0
50	-6.0	-4.0	-3.5	1.0	-2.0	3.0	-1.5	4.5	-1.5	5.0
100	-6.0	-3.5	-3.5	1.0	-3.0	3.0			-1.5	5.0

* All 24 sounds at decay rates of 2, 5, 10, and 30 dB/sec used in Independent Variable experiment. The six shaded sounds were used in the Onset Rate experiment.

2.3 Facilities

2.3.1 Indoors: NASA–Langley Research Center

Indoor sessions were conducted in the exterior effects room at the NASA–Langley Research Center. This room is part of a set of facilities which have been developed at NASA–Langley for research on the effects of noise on humans.[13]

Figure 4 is a photograph of the exterior effects room. It is a 39-seat auditorium with speakers in the front and rear walls and the ceiling. The rear speakers and some of the ceiling speakers are visible in the photograph. Speakers may be operated in groups to simulate aircraft motion. For the current experiments, the front and rear wall speakers were used in a stereo mode to simulate aircraft approaching from either the front or the rear. Although this facility was originally intended for simulation of outdoor noise, its reverberation characteristics and the fact that it is physically indoors made it ideal for the indoor phase of the current study.

The six seats occupied in Figure 4 delimit the central part of the room over which the sound field is uniform. While there are ten seats within this 10-foot by 4-foot area, leaving four empty seats avoids crowding of participants. A monitor microphone is located in the center of this area, at a nominal participant ear height. The facility is man-rated for levels up to 95 dBA (slow), and the monitor microphone forms part of an automatic safety limiting system.

The sound system (other than speakers) is located in an adjacent control room. There is a closed circuit video monitoring system and a two-way intercom. These provide for monitoring of test sessions and provide safety for the participants.

Figure 5 shows the sound system configuration used. Stereo signals from the digital audio tape playback passed through a crossover switch box which was manually operated to select the direction of presentation according to the pre-determined random-order list. The signal then passes through a power limiter (part of the safety limiting system) and a pair of Hewlett Packard programmable attenuators. The signals are then equalized (2 dB per octave rolloff, as discussed in Section 2.1.2), amplified by the EER amplifiers, and sent to the speakers. The

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Figure 4. Indoor Test Facility: Exterior Effects Room at NASA-Langley Research Center.

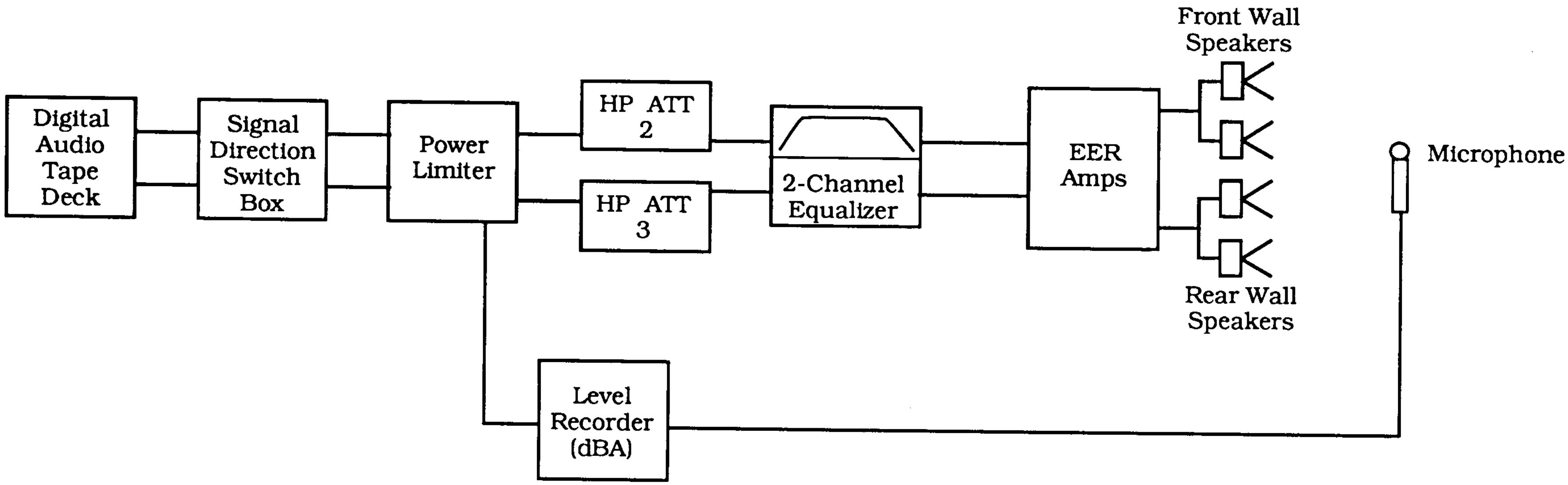

Figure 5. Sound System Configuration at NASA–Langley Research Center Acoustic Facility.

signal from the control microphone is applied to the power limiter, and is also recorded on a level recorder which documents sounds actually heard.

Not shown in Figure 5 is a separate system which provided, through the ceiling speakers, 45 dBA pink noise. This background noise was used to match the test conditions used in Reference 6.

2.3.2 Outdoors: Farmyard in Chuckatuck, VA

Outdoor sessions were conducted in a farmyard in Chuckatuck, Virginia. This area was rented for the purposes of this experiment, and was set up to replicate the functionality of the indoor facility, but in a rural outdoor setting. Figure 6 is a sketch of the arrangement. Figure 7 is a photograph of the facility, showing the participant area and the front speaker. Key features of the facility are:

- Six seating positions were provided, in a 12-foot by 6-foot area. This area, slightly larger than the seating area in the indoor facility, provided greater separation between participants, commensurate with the outdoor ambience. Parasols were affixed to each chair to provide protection from the sun.

- Speakers were placed 50 feet apart, and were elevated such that their centers were above seated head level.

- A small horse barn (not in use) served as a control room. Safety observation was from outside the barn (and out of sight of the participants as they sat facing forward) and videotaping was via a self-contained camcorder.

Figure 8 shows the sound system configuration used. It is schematically similar to that used for the indoor tests. Differences are the use of one large speaker per channel rather than two smaller ones, a bi-amplified system with electronic crossover, and no external limiting system. The bi-amplification system resulted from the particular speakers which were selected for their high efficiency and wide dispersion. Amplifiers were sized so that they could not deliver enough power to damage the speakers. No limiting system was required because the system could not deliver greater than 115 dBA, the limit set by safety

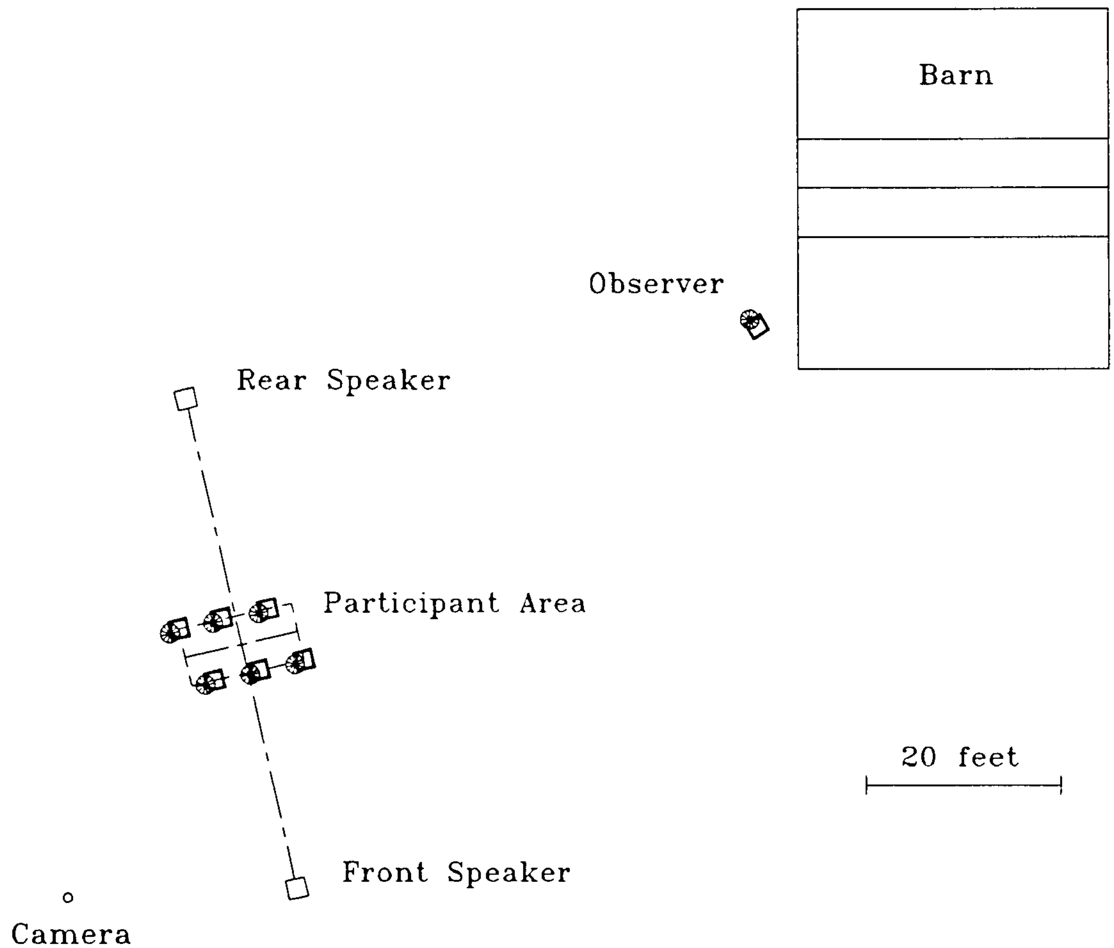

Figure 6. Layout of Outdoor Experimental Facility.

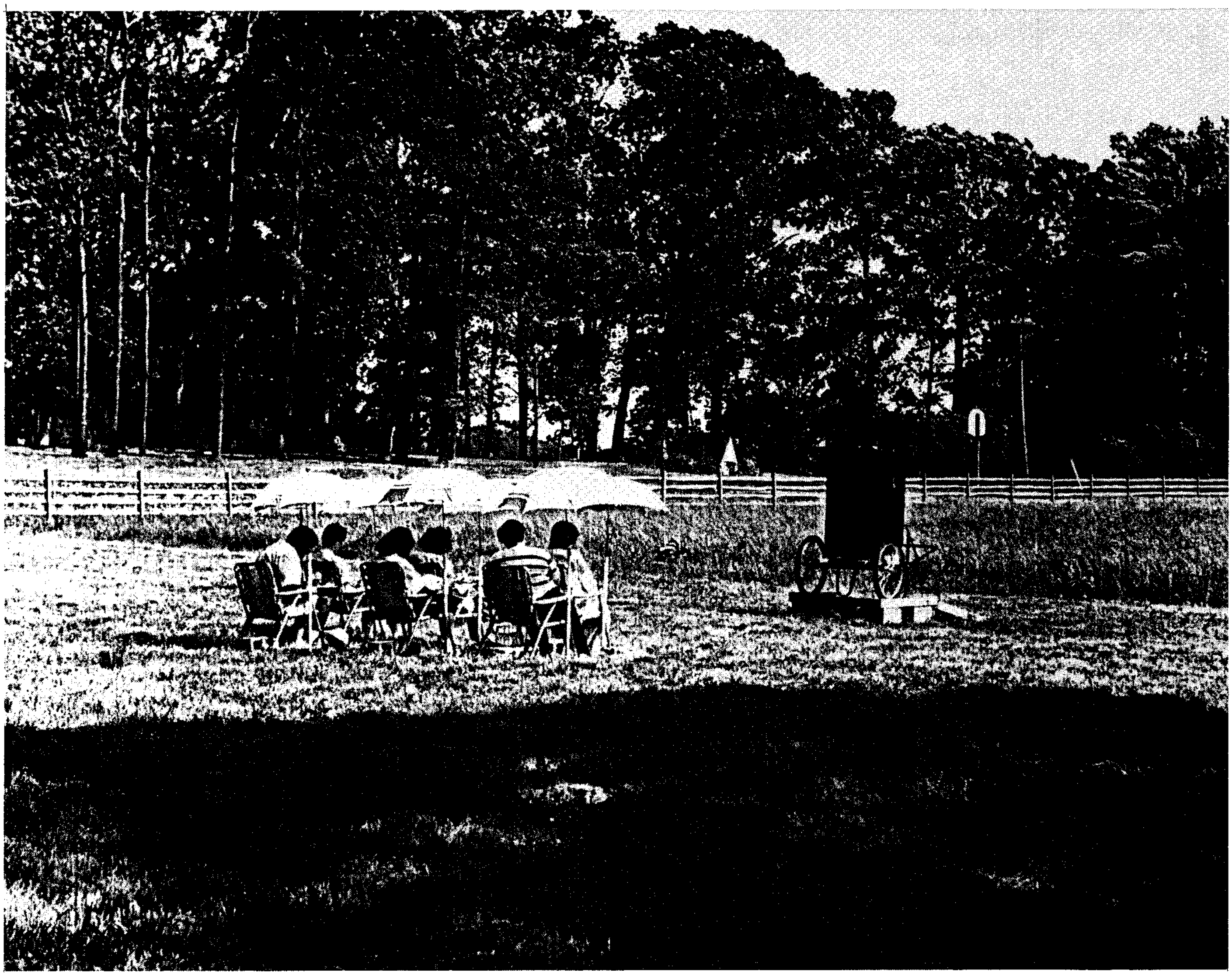

Figure 7. Outdoor Test Facility: Farmyard in Chuckatuck, Virginia.

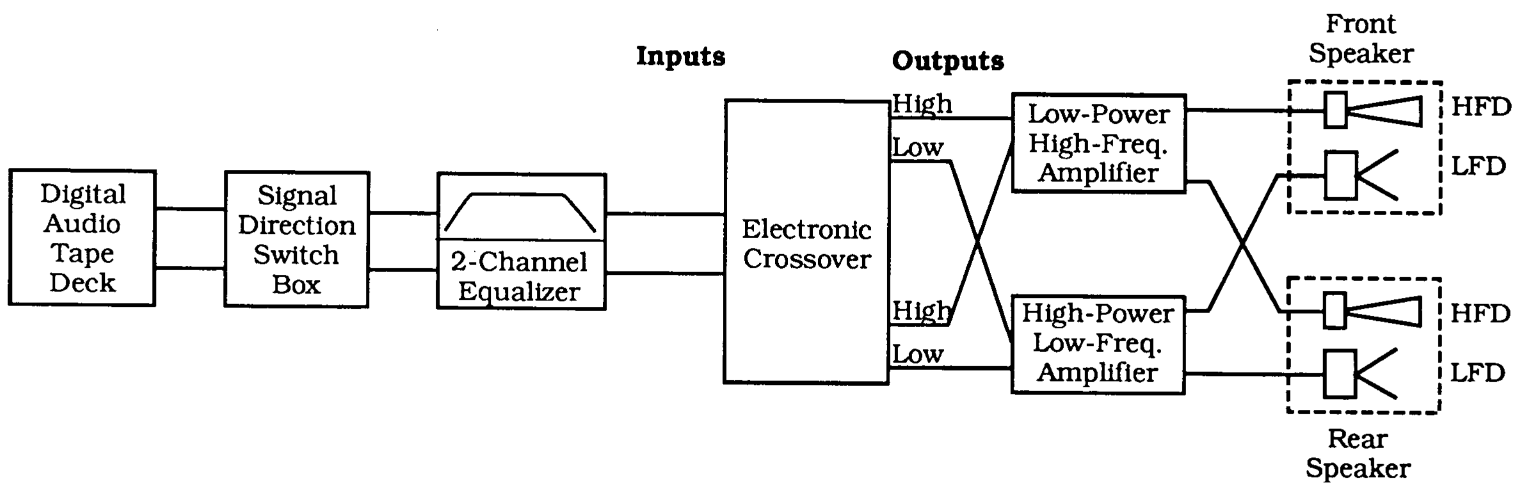

Figure 8. Sound System Configuration at Wyle Outdoor Facility.

protocols for these tests. The system was equalized for flat frequency response at participant ear locations, commensurate with outdoor playback of the original outdoor recordings.

The sound system delivered a uniform sound field over the seating area, comparable to that indoors. The maximum level fell somewhat short of the design goal. While SEL of 115 dB could be obtained for the slower sounds, it was found that the faster sounds (which had high peak levels) would be clipped by as much as 6 dB. Moving the speakers to 25 feet apart would allow the design levels without significant clipping, and maintained uniformity over the seating area. However, that resulted in the speakers being within 10 feet of the participants, at which distance they formed a looming presence which spoiled the outdoor ambience. Accordingly, the 50-foot spacing was retained and the amplifier gain reduced by 4 dB. Some of the faster sounds were still clipped slightly. This remaining clipping reduced SEL and L_{max} (which was accounted for in the analysis by working with actual measured levels), but did not distort the signals other than near the peak region. The onset, decay, and duration were not affected.

2.4 Final Design

2.4.1 Scope of Experiments

The final set of experiments consisted of kernel (K), onset rate (OR), and independent variable (IV). The kernel experiment was conducted both indoors and outdoors; these are denoted K1 and K2. OR and IV were conducted outdoors only. Each participant was assigned to one of the three experiments, and attended two sessions for each location. Kernel participants thus attended four sessions (two indoors and two outdoors), while OR and IV participants attended two sessions (both outdoors). The two sessions at each location used the same stimuli (albeit in different order) and were designed as a consistency check. Sessions were conducted in groups of six participants. Table 5 summarizes the number of participants planned for each experiment and the number of sessions and their locations.

Table 5

Numbers of Participants and Sessions

Experiment	Number of Participants*	Sessions
Kernel (K1, K2)	36 (32)	4**
Onset Rate (OR)	24 (22)	2
Independent Variable (IV)	24 (22)	2

* Design goal. Numbers in parentheses indicate minimum required.

** Two indoors (K1) and two outdoors (K2).

2.4.2 Stimulus Matrices

Stimuli are defined by the sound name (as used in Tables 1 through 4) and the nominal SEL. Four levels were available at each location. Outdoors, the design levels were 85, 95, 105, and 115 dB. Indoors, they were 65, 75, 85, and 95 dB. As will be described in Section 3.3, actual sound levels obtained differed somewhat from the design levels.

The kernel experiment used the twelve original sounds, as given in Table 3. The onset rate experiment also used the twelve original sounds, plus six modified sounds: one at each onset rate. Table 6 lists the onset rate experiment sounds, in order of increasing onset rate. The Independent Variable experiment used six of the original sounds (three B-1B and three F-4D) plus 24 modified sounds. The modified sounds consisted of all six onset rates and four decay rates: 2, 5, 10, and 30 dB per second (Table 2, without the 20 dB/sec decay rate column).

To accommodate the full duration of the sounds, with reasonable ISIs, no more than 60 sounds could be used per session. Accordingly, the K, OR, and IV experiments used 4, 3, and 2 levels, respectively. These are summarized in Table 7. The levels in Table 7 are design goals. Actual sound levels obtained during the experiments differed somewhat, and are discussed in Section 3.3.

Inter-stimulus intervals (ISIs) used in the experiments are summarized in Table 8. Shown, for each experiment, are the number used of each ISI duration.

Table 6
Sounds Employed in the Onset Rate Experiment, In Order of Onset Rate

Sound	Onset Rate, dB/sec	Decay Rate, dB/sec
727	1.3	1.1
KC-135A, Slow	1.5	0.9
FB-111A, Slow	1.7	1.2
B-1B, Slow	1.9	1.1
F-4D, Slow	2.4	3.1
5/2	5.0	2.0
KC-135A, Medium	6.5	6.0
10/5	10	5.0
FB-111A, Medium	16	5.0
B-1B, Medium	18	7.0
20/5	20	5.0
F-4D, Medium	22	7.0
30/10	30	10.0
FB-111A, Fast	42	15.0
50/20	50	20.0
B-1B, Fast	68	27.0
100/30	100	30.0
F-4D, Fast	152	49.0

Table 7
Sound Levels Planned for Experiments

Experiment	Design* SEL, dB					
	65	75	85	95	105	115
Kernel, Indoors (K1)	•	•	•	•		
Kernel, Outdoors (K2)			•	•	•	•
Onset Rate (OR)				•	•	•
Independent Variable (IV)				•		•

* See Section 3.3 and Table 11 for actual levels obtained.

Table 8
Distribution of Inter-Stimulus Intervals

Experiment	ISI, Seconds				
	30	45	60	75	90
Kernel, (K1, K2)	8	8	16	8	8
Onset Rate (OR)	13	14	14	13	0
Independent Variable (IV)	15	15	15	15	0

2.4.3 Annoyance Response Scale

For consistency with other experiments, the seven-point annoyance scale developed by Harris[6] was used as the basis for the current scale. This consists of the following verbal annoyance ratings:

1. Minimally
2. Slightly
3. Fairly
4. Moderately
5. Decidedly
6. Highly
7. Extremely

This scale had been previously well validated,[6] and it was intended to use it in its original form. During pre-pilot and pilot testing of the current experiments, however, it was observed that there was a tendency for responses to be compressed at the top or bottom of the scale. This compression occurred even when participants had been trained with example sounds at both extremes. It was therefore decided to expand the numeric range of the scale to include 0 and 8, without additional verbal designations. This preserved the original scale, but allowed participants extra room if they judged a sound to be particularly extreme.

Figure 9 shows the participant response sheet for the kernel experiment. Response sheets for the other two experiments were similar, but had entries for the appropriate numbers of responses. A five-response sheet for training sessions was also prepared.

2.4.4 Task Activity

To keep the participants moderately occupied during the experiments, they were given magazines of their choice to read. Table 9 contains lists of the magazines provided at each site. The use of this single task indoors and outdoors provided consistency across locations.

ANNOYANCE RATING RESPONSE FORM (K)

Name ______________________ Participant #________ Date ________ Time ________

Location ______________________ Session ______________ Seat ______________

INSTRUCTIONS: Rate the annoyance of each airplane sound according to the scale portrayed below: THE SOUND WAS:

0	1	2	3	4	5	6	7	8
	Minimally	Slightly	Fairly	Moderately	Decidedly	Highly	Extremely	

ANNOYING.

In making your annoyance ratings, please pay attention to the words which form the basis for the scale. Then, for each airplane sound, write the whole-number digit ("1", "2", "5", etc.) that corresponds to the word that best describes your annoyance response. You may use any number from "0" to "8", but only numbers "1" to "7" have words associated with them. Use numbers "0" and "8" when your rating falls outside the range of the words. Remember, your judgment should be based upon the words, so refer back to these words as often as you need during the session to make sure you are making the judgments correctly.

Sound #	Rating	Sound #	Rating	Sound #	Rating
1	________	17	________	33	________
2	________	18	________	34	________
3	________	19	________	35	________
4	________	20	________	36	________
5	________	21	________	37	________
6	________	22	________	38	________
7	________	23	________	39	________
8	________	24	________	40	________
9	________	25	________	41	________
10	________	26	________	42	________
11	________	27	________	43	________
12	________	28	________	44	________
13	________	29	________	45	________
14	________	30	________	46	________
15	________	31	________	47	________
16	________	32	________	48	________

Figure 9. Annoyance Response Form.

Table 9

Magazines Used for Task Activity

Indoors	Outdoors
Redbook, May	*Hot Rod*, May
Longevity, June	*Peterson's Handguns*, April
Vogue, May	*Working Woman*, May
True Story, June	*Popular Mechanics*, November 1989
McCall's, May	*Sports Illustrated*, May 14, 1990
Motor Trend, June	*Better Homes and Gardens*, May
Wooden Boat, June	*People*, May 14, 1990
People, May 14	*New Woman*, May
Time, May 14	*House and Garden*, May
Essence, May	*Time*, June 11, May 14
Newsweek, May 14	*McCall's*, May
Good Housekeeping, May	*Self*, June
Mademoiselle, June	*Family Circle*, August 9
	Redbook, May
	Greenpeace, Nov/Dec, July/Aug
	Southern Living, May
	Harper's, May
	Sports Illustrated, May 23
	Ladies' Home Journal, May
	Newsweek, June 11, May 14
	PC Computing, May
	Ebony, May
	Cosmopolitan, May
	US, May 14
	Smithsonian, May
	Popular Science, May

2.4.5 Questionnaire

A questionnaire was prepared for administration to each participant at the completion of all sessions. This questionnaire obtained corroborative information on some of the acoustic variables addressed in the experiment as well as information on some of the potential non-acoustic variables noted in Section 2.1.1. The questionnaire is presented in Appendix A.

3.0 EXPERIMENTAL PROCEDURES

3.1 Participants

Participants were recruited from the Hampton Roads area of Virginia, and represented suburban and rural residents. Ages were 18 to 65. Within each experiment, half were male and half were female. At least half had never previously participated in a noise experiment; the remainder had participated in no more than one noise experiment. All had normal hearing, as determined by audiometric measurements resulting in hearing thresholds within 20 dB of ISO threshold.[14]

Five participants originally recruited for the kernel experiment either did not appear or dropped out before completing all sessions. Three additional participants were recruited to replace those who did not appear or who missed the first session; one of those dropped out. Three make-up sessions were scheduled to finish out the sequence for replacements or those who missed one session but were available to continue. A total of 33 participants completed the kernel experiment. Of these, 27 were original participants who stayed with their group.

The onset rate and independent variable experiments were completed by 23 participants each. All onset rate participants stayed with their original groups. Two independent variable participants could not attend their second session and were given a make-up; the remaining 21 stayed with their original groups.

3.2 Procedures

Hearing tests (before and after each session) and administrative details were handled at a location in Hampton, VA, adjacent to NASA–Langley. Basic instructions were given at the time of the pre-session hearing test. Participants were then driven to the appropriate test facility. They were allowed to examine score sheets and a written copy of the instructions during the ride. A copy of those instructions and the consent form are presented in Appendix B. At the test facility, the participants were given a final briefing. The briefing was read to them from an appropriate "greeting", which is presented in Appendix B. During the first session for each participant, they were given a five-stimulus training session. The training session stimuli are listed in Table 10; these included stimuli which were expected to be the most and least annoying. After completion of the full test session, they were returned to the administrative site for post-session hearing testing and payment. In addition to payment for each session, kernel participants were given a bonus upon completion of all four sessions.

Table 10

Training Session Stimuli

Sound	Level* (dB)	Approach Direction
B-1B, Medium	-20	Front
KC-135, Medium	-30	Back
F-4D, Fast	0	Back
FB-111A, Slow	-30	Front
B-1B, Medium	0	Back

* Relative to maximum at each facility.

Participants were organized into groups of six, the seating capacity of each facility. Groups were nominally kept together throughout each experiment. The order in which kernel participants attended indoor and outdoor sessions was balanced, so that each had a different sequence. Seats were rotated from session to session, so that each participant would sit in both the front and back rows and would not have the same neighbors every time.

In accordance with standard ethical procedures, participants were free to quit the experiment at any time, without prejudice, and had the right to order the experiment stopped at any time.

To ensure quick response in such an event, or should any other problem arise, participants were observed during all sessions. Indoors, visual observation was via a video monitor in the control room. Outdoors, observation was via an experimenter sitting outside, in the position indicated in Figure 6. At both locations participants were aurally observed via the intercom system.

All sessions were videotaped for reference purposes. No incidents occurred which required analysis of these tapes.

One session anomaly occurred during the onset rate experiment. A sudden rainstorm ended the session after 49 of the 54 stimuli had been played. The group was brought back for a make-up session, and the final 15 stimuli replayed. Scores for the ten duplicated stimuli agreed extremely well between the two sessions. The sessions were therefore combined, with the 49 stimuli from the original session and the final five from the make-up treated as if they had been presented in the same session.

3.3 Sound System Operation

As described in Section 2.2.5, stimuli for each session were pre-set on a session tape. The tape was played continuously during each half of the session (i.e., before and after the break). After each six sounds, an announcement of the next number sound was made over the intercom. This prevented participants who got their responses out of sequence from remaining so for very long.

Both sound systems were calibrated and equalized prior to the experiments. Gain was adjusted prior to each session, and calibration was periodically checked.

An independent measurement was made of the sounds actually heard by the participants during each session. The measurement position was at the control microphone. Most sessions were measured on a Larson-Davis Model 700, which documented the SEL and slow maximum level. Selected sessions were recorded on DAT, so as to provide an analog record of "as-heard" sounds. The measurements made during the sessions were analyzed to establish the sound levels actually produced; data analysis was performed with respect to these actual levels. There was some session-to-session variation in sound system gain. System gain indoors was generally maintained within ±1 dB. System gain outdoors was generally within ±3 dB.

As discussed in Section 2.3, <u>actual</u> playback levels (i.e., the level actually occurring for each presentation of each stimulus) varied from the <u>design</u> levels presented in Table 7. Table 11 summarizes the <u>nominal</u> levels actually obtained for each design level. These represent the average across all sounds and all sessions.

Table 11

Nominal SEL Obtained for Each Design Level*

Facility	Design SEL, dB					
	65	75	85	95	105	115
Indoor	66	76	86	96	--	--
Outdoor	--	--	81	91	101	109

* Average across all sounds at each design level.

Also as discussed in Section 2.3, the 2 dB/octave filter caused sound-to-sound variation in the A-weighted levels indoors. Table 12 shows the average SEL and L_{max} for each K1 sound at the design level of 95 dB (nominal level of 96 dB). The values in Table 12 are averages across all indoor sessions.

Table 12

Average SEL and Slow L_{max} for Kernel Sounds, Indoors (K1), for 95 dB Design (96 dB Nominal) SEL Stimuli

Sound	SEL (dB)	Slow L_{max} (dB)
FB-111 Slow	98	90
FB-111 Med.	95	91.5
FB-111 Fast	95	93.5
B-1B Slow	99	92
B-1B Med.	96	93
B-1B Fast	96	95
F-4D Slow	95	87
F-4D Med.	95	91
F-4D Fast	94	93
KC-135A Slow	96	86
KC-135A Med.	96	92
727	100	90

Sound-to-sound variations occurred outdoors, but generally (after allowance for session-to-session variations) by no more than 1 dB from nominal. A complete matrix of average levels, sound-to-sound variations, and session-to-session variations was prepared. This was maintained in digital form, and has been delivered separately. This matrix was utilized in data analysis and provided the actual level heard by each participant in each session.

3.4 Data Qualification and Logging

As data were collected, response scores were entered into a computerized data base. Each session was maintained as a separate file. Stimulus presentation orders were incorporated into this data base so that each response score could be properly correlated with the stimulus presentation. Scatterplots were generated after each session, using a different symbol for each sound. It was noted that the response score versus level (either SEL or L_{max}) had a generally monotonic increasing trend, and that the faster sounds tended to elicit higher responses. Obvious deviations from these patterns were noted, and participant response sheets were reviewed to ensure that transcription errors had not occurred. Each response sheet was also reviewed for sequence errors, and corrected when an apparent error was corroborated by missing entries or marks made by the participant. There were 11 missing scores, out of a total of 11,580 participant presentations.

Following completion of all sessions, the database was expanded to include the specific sound properties presented in Tables 3, 4, 11, and 12, the direction of presentation, and the session-to-session level differences. The database is hosted on an MS–DOS-based personal computer, and consists of the file for each of the 44 sessions, plus a set of Fortran programs which incorporate the presentation orders and stimulus properties. This system provides access to the data in two ways:

- A "master data file" generated for external use. This is an ASCII file containing one line for each of the 11,580 participant scores. Contained on each line is all information pertaining to the participant (ID code, group, seat, score, etc.) and to the stimulus (nominal and actual sound properties, direction, etc.). This arrangement is suitable for analysis by standard packaged statistical software. ANOVAs presented in Section 4 were performed in this manner.

- A Fortran-based analysis system. The session files have been indexed and compressed into a single binary file. A header program is provided which accesses this file, and provides documented indexing to the properties of the stimuli. These properties are incorporated as data items in the code. Analysis is then accomplished by subroutines called from the header program. Regression analyses presented in Section 4 were accomplished from this system.

The complete data set, in both of these PC-based forms, has been delivered to the Air Force.

4.0 RESULTS AND DISCUSSION

Analysis of experimental results was undertaken in four stages:

1. Analysis of Variance (ANOVA) of all experiments. This established the significance of onset rate and level.

2. Single linear regressions of annoyance score with respect to level. These established that the effect of level is linear, and yielded a decibel equivalent for the response scale.

3. Curve fits of the effect of onset rate, for the purpose of establishing general non-linear trends.

4. Multiple regressions of annoyance score with respect to level and onset rate. The regression employed a linear model for level, as established in Stage 2, and a non-linear model for onset rate, as suggested by Stage 3.

The analysis concentrated on level and onset rate as the primary psychoacoustic variables. Secondary variables considered were decay rate, direction of presentation, and spectral characteristics. Methodological variables discussed in Sections 2 and 3 were accounted for by counterbalancing in the experimental design, and no evidence was seen that this was not successful.

The ANOVAs considered sound levels to be categorical, at the nominal values presented in Table 11. The implications of the difference between nominal levels and actual levels are discussed during the linear regressions and onset rate curve fitting. All regressions use actual presented sound levels.

Each of these analysis stages is discussed in the Sections 4.1 (ANOVAs), 4.2 (single regressions and curve fits), and 4.3 (multiple regressions), below. Supplementary analyses, including an analysis of the questionnaire, are presented in Appendix C. A significance level of 0.05 was employed in all statistical tests.

4.1 Analysis of Variance

The design of the experiments allowed repeated-measure analysis of the major variables. It was found (see Appendix C) that direction of approach was not significant. The dependent variable was therefore taken to be the average of each participant's front-to-back and back-to-front response scores for the same nominal flyover. The use of averages filled in the missing scores. (There were 11 missing scores out of 11,580 responses. No participant missed both presentations of any one stimulus.)

Two-way ANOVAs (variables SEL, dB, and onset rate, dB/sec) were calculated for the four experiments: K1 (kernel indoors), K2 (kernel outdoors), OR (onset rate), and IV (independent variable). Additionally, the OR and IV experiments, which used both original and modified sounds, were each divided into two parts: P1 (original sounds) and P2 (modified sounds). The P1 division allowed comparison of common sounds across all four experiments. The P2 division allowed a three-way ANOVA of IV P2, with decay rate as the third variable, commensurate with the counterbalanced design illustrated in Table 4.

The results of the two-way ANOVAs for original-sound experiments are summarized in Table 13. Sound level was significant in all experiments. Onset rate was also always significant. Interactions were significant for the kernel experiment and OR P1, all of which were comprised of the twelve original sounds.

Table 13

Summary Results for All Two-Way ANOVAs

Experiment	**Sound Level (A)**	**Onset Rate (B)**	**A x B**
K1	$p < 0.01$	$p < 0.01$	$p < 0.01$
K2	$p < 0.01$	$p < 0.01$	$p < 0.01$
OR	$p < 0.01$	$p < 0.01$	NS
OR P1	$p < 0.01$	$p < 0.01$	$p < 0.01$
OR P2	$p < 0.01$	$p < 0.01$	NS
IV P1	$p < 0.01$	$p < 0.05$	NS

Tables 14 through 17 present the ANOVAs for the four original-sound experiments. Included on each table are the means and standard deviations for the variables and interactions among the variables. The differences between means were evaluated using a Tukey test for determining "least significant difference" at the 0.05 level. The least significant differences are indicated for each variable and interaction. The means were significantly different among all sound levels in all experiments. Significant effects were also found for the onset rate in

Table 14

ANOVA For Indoor Kernel Experiment (K1)

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level	3	4,011.98	1,337.33	1,145.61	0.01
Onset Rate	11	354.09	32.19	27.58	0.01
Interaction	33	62.16	1.88	1.61	0.01
Residual	1,536	1,793.05	1.17		
TOTAL	1,583	6,221.29			

(b) Means and Standard Deviations for Sound Level (N = 396)

Sound Level	Mean	Standard Deviation
66 dB	1.73	1.01
76 dB	2.93	1.33
86 dB	4.40	1.27
96 dB	5.98	1.09

Mean Difference of 0.20 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 132)

Onset Rate (dB/sec)	Mean	Standard Deviation
1.3	3.65	1.93
1.5	3.53	1.80
1.7	3.50	1.74
1.9	3.46	1.87
2.4	3.41	1.90
6.5	4.05	2.00
16.0	3.45	1.78
18.0	3.24	1.86
22.0	3.56	1.97
42.0	4.06	2.12
68.0	4.23	2.08
152.0	5.00	2.07

Mean Difference of 0.43 Significant at 0.05 Level

(d) Interaction of Sound Level and Onset Rate (N = 33 Per Mean)

Onset Rate (dB/sec)	Sound Level (dB)			
	66	76	86	96
1.3	1.59	2.88	4.21	5.92
1.5	1.71	2.74	3.91	5.74
1.7	1.74	2.86	3.79	5.59
1.9	1.78	2.42	3.80	5.91
2.4	1.56	2.62	3.82	5.65
6.5	1.74	3.17	4.88	6.42
16.0	1.56	2.68	4.20	5.35
18.0	1.24	2.48	3.91	5.35
22.0	1.53	2.47	4.38	5.86
42.0	1.67	3.08	4.86	6.62
68.0	1.95	3.32	5.18	6.46
152.0	2.80	4.45	5.88	6.86

Mean Difference of 1.05 Significant at 0.05 Level

Table 15

ANOVA For Outdoor Kernel Experiment (K2)

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level	3	4,164.15	1,388.05	1,381.36	0.01
Onset Rate	11	512.63	46.60	46.38	0.01
Interaction	33	84.15	2.55	2.54	0.01
Residual	1,536	1,543.44	1.005		
TOTAL	1,583	6,304.37			

(b) Means and Standard Deviations for Sound Level (N = 396)

Sound Level	Mean	Standard Deviation
81 dB	2.22	1.19
91 dB	3.72	1.33
101 dB	5.24	1.19
109 dB	6.54	0.90

Mean Difference of 0.18 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 132)

Onset Rate (dB/sec)	Mean	Standard Deviation
1.3	4.23	1.92
1.5	4.24	1.97
1.7	4.23	1.87
1.9	3.80	1.92
2.4	4.03	1.84
6.5	4.94	2.02
16.0	4.08	1.98
18.0	3.73	1.82
22.0	4.30	1.89
42.0	4.83	2.04
68.0	5.02	1.97
152.0	5.77	1.79

Mean Difference of 0.40 Significant at 0.05 Level

(d) Interaction of Sound Level and Onset Rate (N = 33 Per Mean)

Onset Rate (dB/sec)	Sound Level (dB)			
	81	91	101	109
1.3	2.15	3.48	4.92	6.36
1.5	2.06	3.30	5.02	6.59
1.7	2.15	3.45	4.85	6.47
1.9	1.77	2.91	4.33	6.17
2.4	2.10	3.15	4.62	6.24
6.5	2.35	4.41	6.02	7.00
16.0	1.77	3.18	5.14	6.24
18.0	1.79	2.92	4.28	5.92
22.0	2.01	3.48	5.29	6.41
42.0	2.42	4.08	5.73	7.11
68.0	2.58	4.48	6.02	6.98
152.0	3.52	5.77	6.73	7.08

Mean Difference of 0.98 Significant at 0.05 Level

Table 16

ANOVA For Onset Rate (OR) Experiment (Part 1)

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level	2	1,628.63	814.32	709.35	0.01
Onset Rate	11	214.22	19.47	16.96	0.01
Interaction	22	38.96	1.77	1.54	0.05
Residual	792	909.20	1.148		
TOTAL	827	2,791.01			

(b) Means and Standard Deviations for Sound Level (N = 396)

Sound Level	Mean	Standard Deviation
91 dB	2.76	1.24
101 dB	4.54	1.24
109 dB	6.20	1.07

Mean Difference of 0.18 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 69)

Onset Rate (dB/sec)	Mean	Standard Deviation
1.3	4.25	1.78
1.5	4.43	1.83
1.7	4.58	1.79
1.9	3.95	1.92
2.4	4.03	1.85
6.5	5.31	1.73
16.0	4.12	1.79
18.0	3.71	1.61
22.0	4.54	1.46
42.0	4.90	1.90
68.0	4.77	1.81
152.0	5.42	1.80

Mean Difference of 0.60 Significant at 0.05 Level

(d) Interaction of Sound Level and Onset Rate (N = 23 Per Mean)

Onset Rate (dB/sec)	Sound Level (dB)		
	91	101	109
1.3	2.72	4.17	5.85
1.5	2.76	4.15	6.37
1.7	2.78	4.48	6.48
1.9	2.20	3.61	6.04
2.4	2.06	4.17	5.84
6.5	3.43	5.48	7.02
16.0	2.46	4.02	5.89
18.0	2.17	3.74	5.22
22.0	3.17	4.61	5.83
42.0	2.67	5.35	6.67
68.0	3.06	5.00	6.23
152.0	3.67	5.65	6.93

Mean Difference of 1.21 Significant at 0.05 Level

Table 17

ANOVA and Means for IV P1 Experiment

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level	1	662.16	662.16	441.25	0.01
Onset Rate	5	101.91	20.38	13.58	0.01
Interaction	5	9.25	1.85	1.23	NS
Residual	264	396.17	1.5006		
TOTAL	275	1,169.49			

(b) Means and Standard Deviations for Sound Level (N = 138)

Sound Level	Mean	Standard Deviation
91 dB	2.90	1.47
109 dB	6.00	1.24

Mean Difference of 0.29 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 132)

Onset Rate (dB/sec)	Mean	Standard Deviation
1.9	3.85	1.87
2.4	4.01	1.90
18.0	4.00	1.86
22.0	4.32	1.97
68.0	4.99	2.08
152.0	5.52	2.07

Mean Difference of 0.73 Significant at 0.05 Level

all experiments. The effect of onset rate is illustrated in Table 18. Table 18 shows, for experiments K1, K2, and OR P1 (the three with all twelve original sounds), the differences between means for all pairs of onset rates. Significant differences are highlighted. This table shows a significant onset rate effect at onset rates of 42 dB/sec and higher. Note that there is a gap between 22 and 42 dB/sec, so the threshold of onset rate effect is somewhere in that range.

Two anomalies are seen in Tables 14 through 18. The first is that the mean scores for the onset rate of 6.5 dB/sec (the medium KC-135) are noticeably higher than for surrounding sounds. The reason for this was apparent upon listening to the sound: there is a pronounced whistle which is clearly heard at higher levels. The A-weighted level is not significantly affected by this whistle. However, it should be recalled from Table 1 that EPNL for this aircraft is 5.2 dB higher than SEL, significantly higher than the average 2.5 for all the military aircraft. EPNL accounts for the effect of tonality on annoyance, and the difference between EPNL and SEL can be taken as a measure of this effect. It will be shown later that most of the anomaly associated with this sound can be attributed to: (a) tonality, as quantified by EPNL, and (b) differences between the nominal SEL and the actual levels presented during the experiment.

The second anomaly is the stimulus at 18 dB/sec (the medium B-1B). This stimulus was less annoying than surrounding ones. Sound from this aircraft had considerably more low-frequency content than the others, making it potentially less annoying because of the lack of high frequencies. Referring to Table 1, this aircraft had EPNL – SEL difference of 1 dB, the lowest value of all the military aircraft. As with the KC-135, much of the anomaly for the B-1B can be shown to be associated with tonality (in this case, the lack of tonality) and differences between nominal and actual levels.

The anomalous properties of the medium KC-135 and medium B-1B raise the concern that the ANOVAs may have been unduly influenced by these two aircraft. To test this possibility, the two-way ANOVAs were computed for only the other ten aircraft. The results were the same as for the original ANOVAs, with level, onset rate, and interactions remaining significant. These two aircraft thus did not distort the overall results. The ANOVAs of the partial data sets are not presented here.

Table 18

Differences Between Means at Various Onset Rates

(a) Indoor Kernel Experiment (K1)

	1.3	1.50	1.70	1.90	2.40	6.50	16.00	18.00	22.00	42.00	68.00	152.00
1.3		-0.12	-0.15	-0.19	-0.24	0.40	-0.20	-0.41	-0.09	0.41	**0.58**	**1.35**
1.5			-0.03	-0.07	-0.12	**0.52**	-0.08	-0.29	0.03	**0.53**	**0.70**	**1.47**
1.7				-0.04	-0.09	**0.55**	-0.05	-0.26	0.06	**0.56**	**0.73**	**1.50**
1.9					-0.05	**0.59**	-0.01	-0.22	0.10	**0.60**	**0.77**	**1.54**
2.4						**0.64**	0.04	-0.17	0.15	**0.65**	**0.82**	**1.59**
6.5							-0.60	-0.81	-0.49	0.01	0.18	**0.95**
16.0								-0.21	0.11	**0.61**	**0.78**	**1.55**
18.0									032	**0.82**	**0.99**	**1.76**
22.0										**0.50**	**0.67**	**1.44**
42.0											0.17	**0.94**
68.0												**0.77**

Mean difference of 0.43 significant at 0.05 level

(b) Outdoor Kernel Experiment (K2)

	1.3	1.50	1.70	1.90	2.40	6.50	16.00	18.00	22.00	42.00	68.00	152.00
1.3		0.01	0.00	-0.43	-0.20	**0.71**	-0.15	-0.50	0.07	**0.60**	**0.79**	**1.54**
1.5			-0.01	-0.44	-0.21	**0.70**	-0.16	-0.51	0.06	**0.59**	**0.78**	**1.53**
1.7				-0.43	-0.20	**0.71**	-0.15	-0.50	0.07	**0.60**	**0.79**	**1.54**
1.9					0.23	**1.14**	0.28	-0.07	**0.50**	**1.03**	**1.22**	**1.97**
2.4						**0.91**	0.05	-0.30	0.27	**0.80**	**0.99**	**1.74**
6.5							-0.86	-1.21	-0.64	-0.11	0.08	**0.83**
16.0								-0.35	0.22	**0.75**	**0.94**	**1.69**
18.0									**0.57**	**1.10**	**1.29**	**2.04**
22.0										**0.53**	**0.72**	**1.47**
42.0											0.19	**0.94**
68.0												**0.75**

Mean difference of 0.40 significant at 0.05 level

(c) Onset Rate Experiment, Original Sounds (OR P1)

	1.3	1.50	1.70	1.90	2.40	6.50	16.00	18.00	22.00	42.00	68.00	152.00
1.3		0.18	0.33	-0.30	-0.22	**1.06**	-0.13	-0.54	0.29	**0.65**	0.52	**1.17**
1.5			0.15	-0.48	-0.40	**0.88**	-0.31	-0.72	0.11	0.47	0.34	**0.99**
1.7				-0.63	-0.55	**0.73**	-0.46	-0.87	-0.04	0.32	0.19	**0.84**
1.9					0.08	**1.36**	0.17	-0.24	0.59	**0.95**	**0.82**	**1.47**
2.4						**1.28**	0.09	-0.32	0.51	**0.87**	**0.74**	**1.39**
6.5							-1.19	-1.60	-0.77	-0.41	-0.54	0.11
16.0								-0.41	0.42	**0.78**	0.65	**1.30**
18.0									0.83	**1.19**	**1.06**	**1.71**
22.0										0.36	0.23	**0.88**
42.0											-0.13	0.52
68.0												**0.65**

Mean difference of 0.60 significant at 0.05 level

The full OR experiment included modified sounds to fill gaps in the onset rate sequence of the original sounds. Table 19 presents the ANOVAs for the OR experiment. The results are similar to those for OR P1, Table 16. Table 20 is a matrix of significant differences for the OR experiment. It is similar to the OR P1 matrix in Table 18(c). The additional rates suggest that the onset rate effect occurs above 30 dB/sec.

The three-way ANOVA for IV P2 (the balanced matrix of modified sounds) is presented in Table 21. All three variables (sound level, onset rate, and decay rate) were found to be significant, although sound level and onset rate were more significant than decay rate. Significant interactions existed between sound level and onset rate, and between onset rate and decay rate. Interactions were not significant between sound level and decay rate, nor between all three variables.

An onset rate effect, consistent with the other experiments, is seen in Table 21. The means at onset rates of 50 and 100 dB/sec are not significantly different from each other, but are significantly different than those for the three lower onset rates, which are in turn not significantly different from each other. The overall means for onset rate are not particularly orderly, with mean increasing somewhat at lower onset rate. If the interaction between sound level and onset rate is examined, it is seen that there is a clear onset rate effect at the higher sound level (109 dB), while differences are not significant at the lower sound level (91 dB). This non-linear effect of sound level was not clearly exhibited in the other experiments (although all exhibited interaction between level and onset rate), and may be an artifact of the presentation of this experiment. This point will be discussed further in the regression analysis.

The effect of decay rate was found to be significant at the 0.05 level. However, the difference between means was significant (exactly matching the Tukey test least significant difference) between only one pair of decays: 10 and 30 dB/sec. Differences between all other pair combinations were not significant. Similarly, interactions between onset and decay were significant, but differences between means were not particularly larger than the Tukey test least significant difference. This is in contrast to the effects of level and onset rate, which were significant at the 0.01 level and exhibited clear differences. While decay rate does

Table 19

ANOVA For OR Experiment

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level	2	2,436.63	1,218.32	1,077.43	0.01
Onset Rate	17	272.26	16.02	14.16	0.01
Interaction	34	48.40	1.42	1.26	NS
Residual	1,188	1,343.35	1.13		
TOTAL	1,241	4,100.65			

(b) Means and Standard Deviations for Sound Level (N = 414)

Sound Level	Mean	Standard Deviation
91 dB	2.72	1.25
101 dB	4.54	1.19
109 dB	6.15	1.02

Mean Difference of 0.17 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 69)

Onset Rate (dB/sec)	Mean	Standard Deviation
1.3	4.25	1.78
1.5	4.43	1.83
1.7	4.58	1.79
1.9	3.95	1.92
2.4	4.03	1.85
5.0	4.22	1.72
6.5	5.31	1.73
10.0	4.41	1.67
16.0	4.12	1.79
18.0	3.71	1.61
20.0	3.95	1.76
22.0	4.54	1.46
30.0	4.10	1.75
42.0	4.90	1.90
50.0	4.69	1.85
68.0	4.77	1.81
100.0	5.03	1.76
152.0	5.42	1.80

Mean Difference of 1.05 Significant at 0.05 Level

(d) Interaction of Sound Level and Onset Rate (N = 33 Per Mean)

Onset Rate (dB/sec)	Sound Level (dB)		
	91	101	109
1.3	2.72	4.17	5.85
1.5	2.76	4.15	6.37
1.7	2.78	4.48	6.48
1.9	2.20	3.61	6.04
2.4	2.06	4.17	5.84
5.0	2.48	4.20	6.00
6.5	3.43	5.48	7.02
10.0	2.61	4.52	6.11
16.0	2.46	4.02	5.89
18.0	2.17	3.74	5.22
20.0	2.15	3.91	5.78
22.0	3.17	4.61	5.83
30.0	2.17	4.43	5.69
42.0	2.67	5.35	6.67
50.0	2.84	4.93	6.28
68.0	3.06	5.00	6.23
100.0	3.47	5.24	6.37
152.0	3.67	5.65	6.93

Mean Difference of 1.26 Significant at 0.05 Level

Table 20

Differences Between Means at Various Onset Rates, OR Experiment

	1.3	1.50	1.70	1.90	2.40	5.00	6.50	10.00	16.00	18.00	20.00	22.00	30.00	42.00	50.00	68.00	100.00	152.00
1.3		0.18	0.33	-0.30	-0.22	-0.03	**1.06**	0.16	-0.13	-0.54	-0.30	0.29	-0.15	**0.65**	0.42	0.52	**0.78**	**1.17**
1.5			0.15	-0.48	-0.40	-0.21	**0.88**	-0.02	-0.31	-0.72	-0.48	0.11	-0.33	0.47	0.24	0.34	0.60	**0.99**
1.7				-0.63	-0.55	-0.36	**0.73**	-0.17	-0.46	-0.87	-0.63	-0.04	-0.48	0.32	0.09	0.19	0.45	**0.84**
1.9					0.08	0.27	**1.36**	0.46	0.17	-0.24	0.00	0.59	0.15	**0.95**	**0.72**	**0.82**	**1.08**	**1.47**
2.4						0.19	**1.28**	0.38	0.09	-0.32	-0.08	0.51	0.07	**0.87**	**0.64**	**0.74**	**1.00**	**1.39**
5.0							**1.09**	0.19	-0.10	-0.51	-0.27	0.32	-0.12	**0.68**	0.45	0.55	**0.81**	**1.20**
6.5								-0.90	-1.19	-1.60	-1.36	-0.77	-1.21	-0.41	-0.64	-0.54	-0.28	0.11
0.0									-0.29	-0.70	-0.46	0.13	-0.31	0.49	0.26	0.36	0.62	**1.01**
16.0										-0.41	-0.17	0.42	-0.02	**0.78**	0.55	**0.65**	**0.91**	**1.30**
18.0											0.24	**0.83**	0.39	**1.19**	**0.96**	**1.06**	**1.32**	**1.71**
20.0												0.59	0.15	**0.95**	0.72	**0.82**	**1.08**	**1.47**
22.0													-0.44	0.36	0.13	0.23	0.49	**0.88**
30.0														**0.80**	0.57	0.67	**0.93**	**1.32**
42.0															-0.23	-0.13	0.13	0.52
50.0																0.10	0.36	**0.75**
68.0																	0.26	**0.65**
100.0																		0.39

Mean difference of 0.63 significant at 0.05 level

Table 21

ANOVA for Independent Variable Experiment, Modified Sounds (IV P2)

(a) ANOVA

Source	Degrees of Freedom	Sum of Squares	Mean Sum of Squares	F	P
Sound Level (A)	1	2,874.77	2,874.77	2,268.91	0.01
Onset Rate (B)	5	38.82	7.76	6.13	0.01
Decay Rate (C)	3	10.81	3.60	2.84	0.05
A x B	5	24.98	5.00	3.94	0.01
A x C	3	2.84	0.95	0.75	NS
B x C	15	35.86	2.39	1.89	0.05
A x B x C	15	23.69	1.58	1.25	NS
Residual	1,056	1,337.98	1.267024		
TOTAL	1,103	4,349.74			

(b) Means and Standard Deviations for Sound Level (N = 552)

Sound Level	Mean	Standard Deviation
91 dB	2.88	1.23
109 dB	6.11	1.08

Mean Difference of 0.13 Significant at 0.05 Level

(c) Means and Standard Deviations for Onset Rate (N = 184)

Onset Rate (dB/sec)	Mean	Standard Deviation
5	4.44	1.88
10	4.40	1.84
20	4.37	1.89
30	4.29	1.93
50	4.65	2.16
100	4.84	2.15

Mean Difference of 0.33
Significant at 0.05 Level

(d) Means and Standard Deviations for Decay Rate (N = 276)

Onset Rate (dB/sec)	Mean	Standard Deviation
5	4.47	2.04
10	4.44	1.98
20	4.41	1.96
30	4.66	1.97

Mean Difference of 0.25
Significant at 0.05 Level

(e) Sound Level x Onset Rate (N = 92)

Onset Rate (dB/sec)	Sound Level (dB)	
	91	109
5	2.91	5.98
10	2.93	5.86
20	2.85	5.86
30	2.76	5.82
50	2.78	6.52
100	3.07	6.60

Mean Difference of 0.54
Significant at 0.05 Level

(f) Onset Rate x Decay Rate (N = 46)

Onset Rate (dB/sec)	Decay Rate			
	2	5	10	30
5	4.40	4.58	4.25	4.55
10	4.22	4.20	4.18	4.92
20	4.25	4.24	4.44	4.53
30	4.70	4.22	4.31	3.93
50	4.55	4.60	4.55	4.89
100	4.72	4.75	4.73	5.15

Mean Difference of 0.85
Significant at 0.05 Level

appear to be an effect, it is smaller than either level or onset rate, and the current data does not exhibit a clear enough trend so as to derive a meaningful model. Also, it is expected that, since onset and decay rates are closely related on real MTR sounds, an onset rate correction derived from K1, K2, OR, and IV P1 will implicitly account for decay rate.

4.2 Single Regressions and Curve Fits

The ANOVAs have shown that there are significant effects due to level and onset rate. The level effect is dominant, with significant differences between all levels. An effect due to onset rate occurs for faster sounds, with the effect beginning between 30 and 42 dB/sec. The trends for onset rate, however, tend to have some irregularities.

A potential cause of irregularities seen in the onset rate trends is that the ANOVAs assume that each sound was presented at the nominal level. Sound levels varied during the experiments, by amounts that could confound the onset rate effect. Two sounds also had particular tonal characteristics such that their effective levels, when expressed as EPNL (which accounts for tonality), differ from their representation in SEL.

The appropriate analysis for quantitative assessment of the effect of actual levels and onset rate is multiple regression; the question of tone is addressed by performing regressions with EPNL rather than SEL. These analyses are performed in Section 4.3. It is enlightening, however, to first perform single regression analyses of the data, and to examine them by simple curve fits. These analyses provide insight as to the physical characteristics of the results, and also provide hypotheses for the functional form of the regression models.

4.2.1 Linear Regressions With Respect to Level

A total of 37 sounds (12 original and 25 modified), played at various levels, were used in these experiments. This stimulus set embodies four psychoacoustic variables: level, onset rate, decay rate, and spectral content.* Differences in the last three variables are obtained across the sounds. Within a given sound, the only independent variable is level. It is therefore meaningful to perform single regressions of the response scores to each of the sounds.

Least square fits were made to each sound used in each experiment. There are 72 such regressions: 12 each in K1 and K2, 18 in OR, and 30 in IV. The regressions are of the form:

$$\text{Score} = A + B \ \text{SEL}$$

Tables 22 through 24 contain the regression parameters. Shown in each table are the sound name, the coefficients A and B, the standard error of estimate of the slope (σ_B), the standard error of estimate of the annoyance score in the center of the data domain (σ_M), the correlation coefficient (R), and estimated scores (i.e., scores predicted by the regression formulae) at each of the indicated levels. The levels at which scores are estimated are rounded (to the nearest 5 dB) values of those in Table 11. For the indoor tests, the levels correspond to the design matrix in Table 7. For outdoor tests, scores are estimated at levels 5 dB below the design matrix.** Shown at the bottom at each table are the average and standard deviation of the estimated score at each level. These standard deviations are an indication of how well the noise metric accounts for sound-to-sound variations; the ANOVAs presented in Section 4.1 provide statistical corroboration of the effects depicted.

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* One can consider, rather than "spectral content", a "sound characteristic" variable which embodies all properties other than the first three variables. This would include spectrum, detailed temporal characteristics, and any other qualities that distinguish one aircraft sound from another. Recognizing that spectrum is considered to be the dominant quality in the annoyance of sounds of otherwise equal level, we assume that this last variable is predominantly spectrum. It should be noted that this quantity is not directly represented by a simple parameter (as are level, onset, and decay), but can be parameterized by derived quantities such as EPNL or tone correction. On a practical basis, only EPNL was considered in this study.

** The levels chosen for estimation were somewhat arbitrary. Rounding to the nearest 5 dB was a useful convenience. It was decided to use rounded nominal levels, rather than the design levels, to avoid undue extrapolation.

Table 22

Linear Regressions and Estimated Scores, Kernel Experiment

a. Indoors (K1)

Sound	A	B	SigmaB	SigmaM	R	Estimated Score 65 dB	75 dB	85 dB	95 dB
FB-111 Slow	-7.529	0.133	0.0067	0.0748	0.776	1.095	2.421	3.748	5.074
FB-111 Med	-6.210	0.122	0.0067	0.0797	0.747	1.699	2.916	4.133	5.349
FB-111 Fast	-8.722	0.161	0.0066	0.0771	0.831	1.715	3.321	4.927	6.533
B-1B Slow	-8.247	0.139	0.0068	0.0762	0.785	0.775	2.163	3.551	4.939
B-1B Med	-7.824	0.136	0.0072	0.0809	0.760	1.020	2.381	3.742	5.102
B-1B Fast	-7.821	0.150	0.0072	0.0839	0.787	1.901	3.397	4.892	6.388
F-4D Slow	-7.398	0.135	0.0073	0.0823	0.751	1.347	2.692	4.037	5.382
F-4D Med	-7.867	0.144	0.0068	0.0786	0.795	1.468	2.904	4.340	5.776
F-4D Fast	-5.784	0.136	0.0088	0.0996	0.690	3.056	4.416	5.776	7.136
KC-135 Slow	-6.621	0.124	0.0069	0.0775	0.745	1.462	2.705	3.948	5.192
KC-135 Med	-7.835	0.148	0.0059	0.0704	0.840	1.785	3.264	4.744	6.224
727	-7.276	0.130	0.0065	0.0797	0.778	1.177	2.477	3.777	5.078
					Average:	1.542	2.921	4.301	5.681
					Std. Deviation:	0.561	0.588	0.632	0.689

b. Outdoors (K2)

Sound	A	B	SigmaB	SigmaM	R	Estimated Score 80 dB	90 dB	100 dB	110 dB
FB-111 Slow	-10.776	0.1556	0.0071	0.0780	0.805	1.671	3.227	4.783	6.339
FB-111 Med	-10.832	0.1561	0.0067	0.0737	0.821	1.655	3.216	4.776	6.337
FB-111 Fast	-11.456	0.1704	0.0078	0.0809	0.802	2.178	3.882	5.586	7.290
B-1B Slow	-11.117	0.1531	0.0075	0.0796	0.785	1.134	2.665	4.196	5.727
B-1B Med	-10.317	0.1464	0.0073	0.0780	0.777	1.397	2.862	4.326	5.790
B-1B Fast	-10.158	0.1596	0.0076	0.0790	0.790	2.611	4.208	5.804	7.400
F-4D Slow	-10.034	0.1464	0.0073	0.0767	0.779	1.676	3.140	4.604	6.067
F-4D Med	-10.711	0.1566	0.0065	0.0695	0.829	1.819	3.386	4.952	6.518
F-4D Fast	-6.7848	0.1338	0.0085	0.0855	0.698	3.921	5.259	6.597	7.936
KC-135 Slow	-9.7596	0.1464	0.0072	0.0785	0.784	1.950	3.414	4.878	6.341
KC-135 Med	-10.068	0.1571	0.0074	0.0809	0.796	2.496	4.066	5.637	7.207
727	-10.376	0.1485	0.0078	0.0830	0.763	1.502	2.987	4.471	5.956
					Average:	2.001	3.526	5.051	6.576
					Std. Deviation:	0.711	0.691	0.681	0.682

Table 23

Linear Regressions and Estimated Scores, OR

Sound	A	B	SigmaB	SigmaM	R	Estimated Score 90 dB	100 dB	110 dB
FB-111 Slow	-12.678	0.169	0.0133	0.1117	0.735	2.508	4.195	5.883
FB-111 Med	-12.014	0.161	0.0145	0.1210	0.690	2.455	4.063	5.670
FB-111 Fast	-15.520	0.205	0.0138	0.1061	0.787	2.895	4.942	6.988
B-1B Slow	-15.681	0.193	0.0153	0.1181	0.734	1.676	3.604	5.533
B-1B Med	-11.004	0.147	0.0137	0.1110	0.676	2.222	3.692	5.162
B-1B Fast	-11.548	0.164	0.0173	0.1270	0.631	3.217	4.857	6.498
F-4D Slow	-15.327	0.192	0.0135	0.1038	0.774	1.971	3.892	5.814
F-4D Med	-8.182	0.127	0.0132	0.1064	0.638	3.250	4.521	5.791
F-4D Fast	-12.587	0.184	0.0167	0.1166	0.686	3.930	5.765	7.600
KC-135 Slow	-13.563	0.180	0.0116	0.0971	0.800	2.663	4.466	6.269
KC-135 Med	-12.494	0.178	0.0121	0.0979	0.783	3.511	5.290	7.068
727	-11.323	0.151	0.0179	0.1376	0.588	2.309	3.824	5.338
5/2	-12.966	0.172	0.0129	0.1047	0.751	2.487	4.203	5.920
10/5	-12.801	0.174	0.0132	0.1018	0.749	2.881	4.624	6.366
20/5	-13.823	0.177	0.0124	0.0999	0.776	2.146	3.920	5.694
30/10	-14.688	0.186	0.0141	0.1042	0.749	2.048	3.907	5.767
50/20	-14.213	0.189	0.0177	0.1238	0.674	2.777	4.665	6.553
100/30	-11.106	0.162	0.0191	0.1270	0.587	3.446	5.063	6.680
					Average:	2.688	4.416	6.144
					Std. Deviation:	0.587	0.583	0.634

Table 24

Linear Regressions and Estimated Scores, IV

Sound	A	B	SigmaB	SigmaM	R	Estimated Score 90 dB	110 dB
B-1B Slow	-12.575	0.158	0.0179	0.1620	0.681	1.657	4.820
B-1B Med	-13.669	0.173	0.0152	0.1451	0.767	1.869	5.321
B-1B Fast	-16.130	0.208	0.0173	0.1472	0.786	2.627	6.795
F-4D Slow	-13.605	0.171	0.0175	0.1580	0.719	1.786	5.207
F-4D Med	-13.950	0.179	0.0146	0.1389	0.790	2.122	5.693
F-4D Fast	-9.770	0.153	0.0194	0.1561	0.639	4.023	7.088
5/2	-11.788	0.158	0.0152	0.1446	0.740	2.458	5.624
5/5	-11.559	0.158	0.0163	0.1550	0.715	2.639	5.793
5/10	-11.760	0.160	0.0139	0.1323	0.772	2.604	5.797
5/30	-12.085	0.164	0.0154	0.1464	0.748	2.701	5.986
10/2	-14.422	0.183	0.0161	0.1450	0.768	2.050	5.710
10/5	-8.899	0.131	0.0156	0.1407	0.662	2.853	5.464
10/10	-12.823	0.169	0.0157	0.1416	0.750	2.355	5.728
10/30	-11.562	0.164	0.0165	0.1491	0.722	3.160	6.432
20/2	-11.681	0.156	0.0188	0.1604	0.657	2.337	5.452
20/5	-15.644	0.194	0.0139	0.1325	0.827	1.851	5.739
20/10	-11.674	0.157	0.0134	0.1206	0.778	2.441	5.578
20/30	-11.858	0.159	0.0168	0.1516	0.707	2.494	5.684
30/2	-14.365	0.187	0.0160	0.1444	0.777	2.489	6.234
30/5	-12.159	0.161	0.0162	0.1465	0.722	2.322	5.540
30/10	-11.494	0.154	0.0178	0.1602	0.674	2.349	5.425
30/30	-13.883	0.173	0.0145	0.1312	0.783	1.719	5.186
50/2	-18.876	0.232	0.0138	0.1245	0.871	2.038	6.685
50/5	-17.262	0.215	0.0152	0.1375	0.830	2.067	6.363
50/10	-16.702	0.211	0.0143	0.1289	0.841	2.280	6.498
50/30	-14.029	0.188	0.0193	0.1546	0.717	2.867	6.622
100/2	-16.650	0.212	0.0161	0.1449	0.812	2.431	6.672
100/5	-13.510	0.180	0.0189	0.1610	0.709	2.706	6.310
100/10	-16.374	0.210	0.0185	0.1581	0.767	2.555	6.761
100/30	-18.972	0.238	0.0169	0.1272	0.830	2.465	7.229
					Average:	2.411	5.981
					Std. Deviation:	0.464	0.606

The following elements of Tables 22 through 24 are of particular interest:

- The slope, B, provides the relation between annoyance score and level. Were there no interaction between level and other variables, B would always be the same. Table 25 summarizes the slopes, both in terms of the properties of B and as a dB per rating point conversion. For outdoor listening, the conversion is about 6 dB per point.

- The average estimated scores and standard deviations correspond to the sound level means and standard deviations presented with the ANOVAs (part b of Tables 14 through 17, 19, and 21), and are the values expected to have occurred if all stimuli had been presented at the levels employed in Tables 22 through 24. Note that the averages are similar to those with the ANOVAs, while the standard deviations are somewhat smaller because the presentation level variability has been corrected for and participant variability has been averaged out.

- The standard errors of estimate, σ_B and σ_M, are of interest because they establish the confidence intervals of the mean. σ_B should be noted when employing the average slopes from Table 25. σ_M is the standard error of estimate at the average SEL; the standard error σ_E at other SEL is given by the relation $\sigma_E^2 = \sigma_M^2 + \sigma_B^2 \text{ (SEL} - \text{SEL}_{avg})$.

- The correlation coefficients, R, are not of particular interest because their deviation from 1.0 is primarily associated with the participant-to-participant variability of annoyance scores. The y-intercept, A, is also not of particular interest.

Table 25

Properties of Regression Slope, B, for Four Experiments, and Relation Between Level and Annoyance Rating

Experiment	Average	Sigma	Min.	Max.	dB/Rating Point (Average)
K1	0.138	0.011	0.122	0.161	7.2
K2	0.152	0.009	0.134	0.170	6.6
OR	0.173	0.019	0.127	0.205	5.8
IV	0.178	0.026	0.131	0.238	5.6

Figure 10 shows a typical plot of the regression analysis for one sound: the 727 in the K1 experiment. The plot is annotated with properties of the sound and the regression quantities from Table 22; also indicated for convenience is the estimated score at 90 dB. Three types of data are plotted:

- The average and standard deviation of each cluster of data associated with the four nominal presentation levels. A round data point is presented which represents the average of the actual presented sound levels and the average of the annoyance scores, at each nominal level. Attached to the cluster average are one standard deviation error bars in both level and annoyance score.

- The linear regression, shown as a straight solid line.

- The 95 percent confidence interval for the mean (2 σ_E, as described above) associated with the regression. This is the pair of broken curves above and below the regression line.

Figure 10 shows that a linear model is a good representation of the effect of level. First, the cluster averages are close to the regression, within the confidence interval of the mean. Second, the standard deviations of annoyance scores at each cluster are of comparable magnitude, indicating homogeneity of variance with regard to level.

Another feature seen in the regressions is that the standard error of estimate, when interpreted in terms of annoyance score and corresponding sound level (at 6 dB per annoyance point) is fairly small. For K1 and K2, where σ_M is typically 0.08 or less, the 95 percent confidence interval of the mean is about 1 dB. For OR, the interval is about 1.3 dB, and for IV (which generally exhibited the greatest variability) the confidence interval is still less than 2 dB. This result provides validation of the designed sample size for the experiments.

Not all of the regressions were as well behaved as seen in Figure 10. Figure 11 shows one of the worst cases, the fast F-4D in the K2 experiment. The cluster averages do not follow the regression line well, but have a clear concave appearance. The score variability (vertical error bars) is large at the lower two levels but decreases at the higher levels. Note also that the slope is somewhat lower than average. These three features suggest a potential methodological

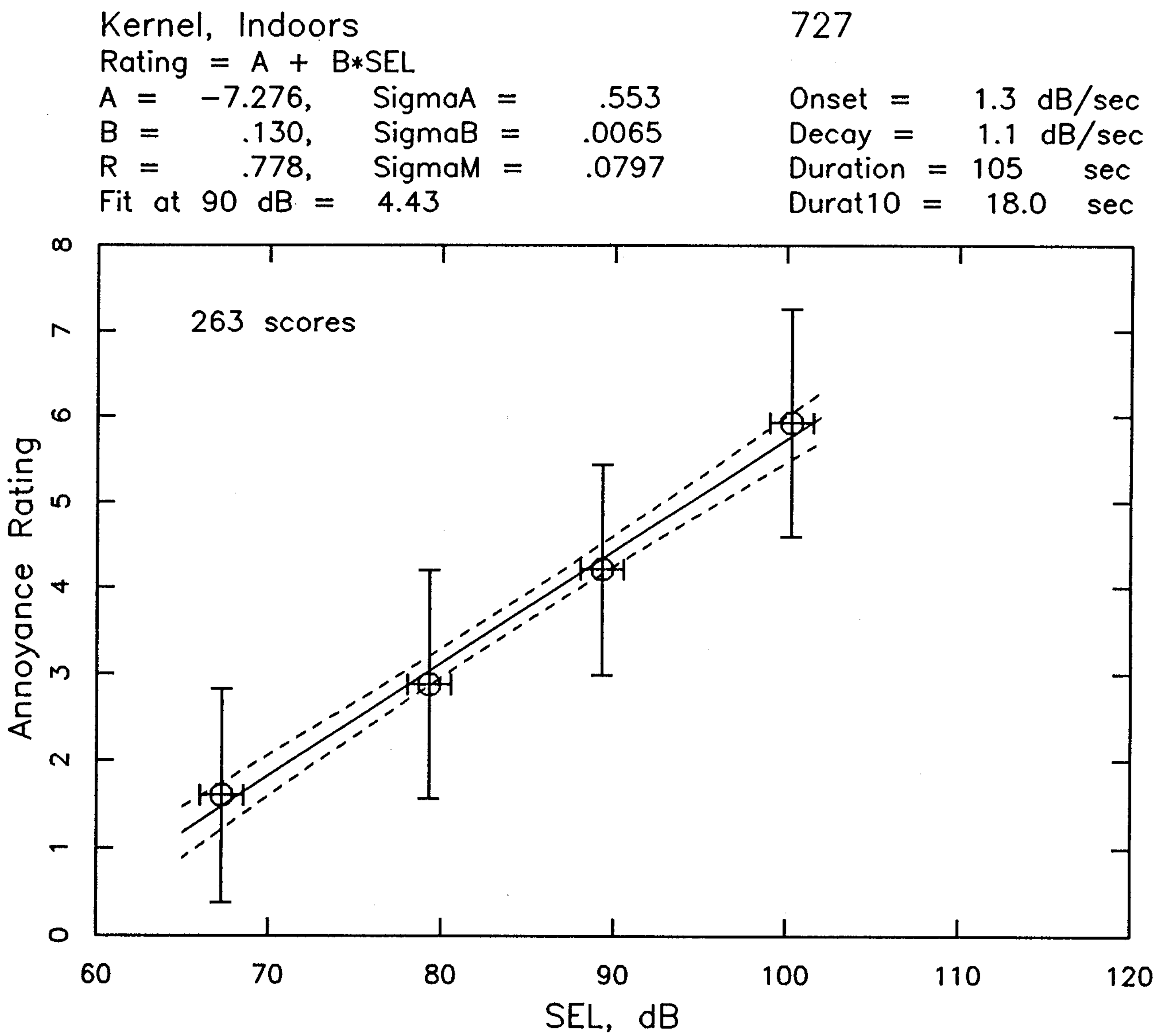

Figure 10. Linear Regression, 727, K1.

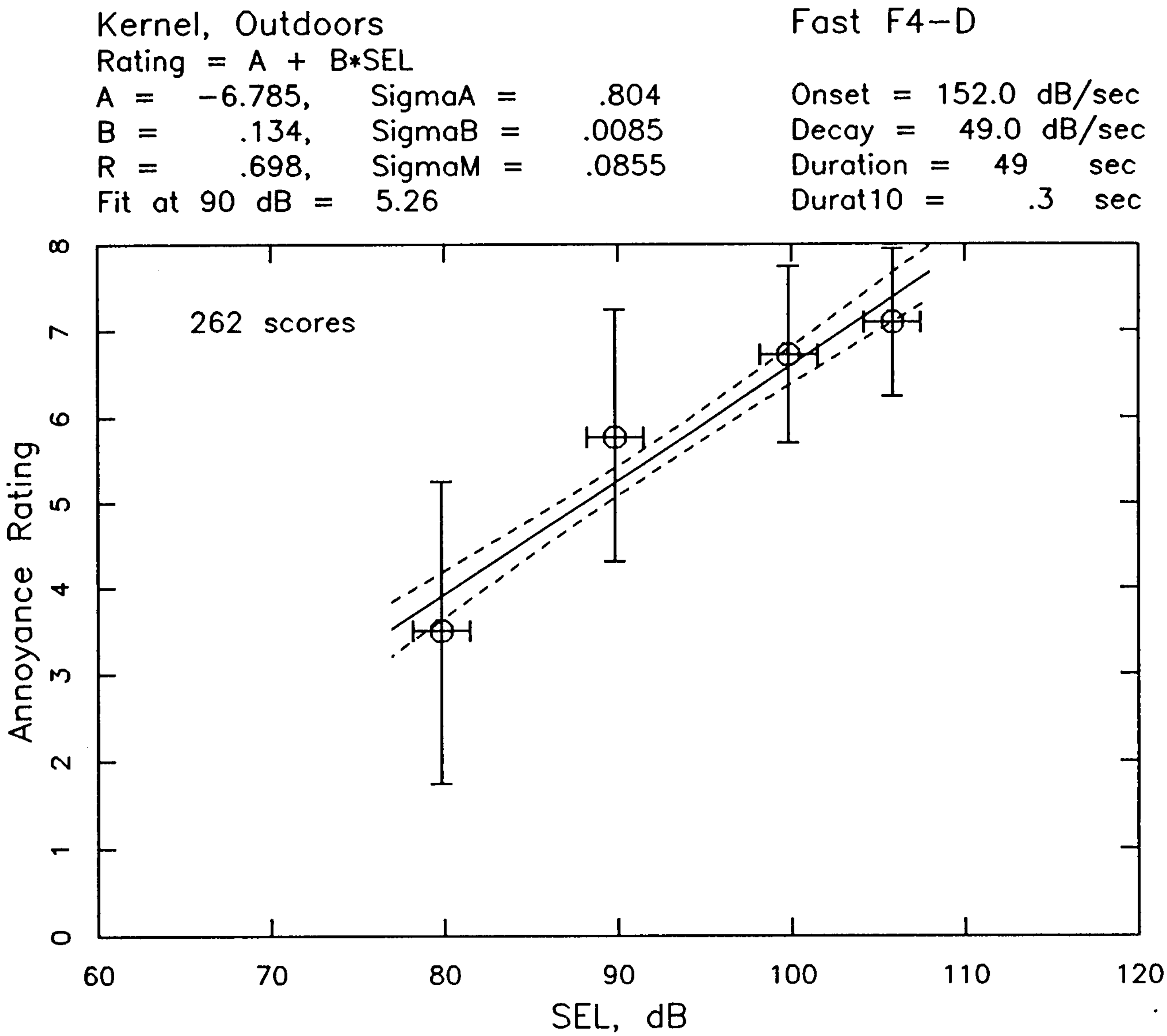

Figure 11. Linear Regression, Fast F-4D, K2.

artifact: that the participants ran out of room at the top of the scale, and the scores were compressed.

The potential that participants ran out of room at either end of the scale was evaluated for the experiment as a whole by examining the frequency of use of each rating in the kernel experiment. Figure 12 shows the frequency distributions. The greatest number of 8s that occurred was for the case exhibited in Figure 11, the highest level of the fastest onset rates in K2. Approximately 32 percent of the ratings at this condition were 8. Similarly, the greatest number of zeroes occurred for a low onset rate (2.4 dB/sec) at the lowest level (66 dB) in K1. Some compression appears to have occurred at these extremes, but even here the majority of scores was not the extreme value, so it is clear that mean annoyance ratings were still free to vary. Figure 12 shows that there was, in fact, a tendency to underuse the extremes (0 and 8) of the scale. Considering this low frequency of use of 0 and 8, it is clear that compression was not a problem for the experiment as a whole. In retrospect, it is difficult to conclude whether the expansion of the seven-point scale to nine points (which was based on qualitative examination of pre-pilot test data similar to Figure 11) was actually necessary.

4.2.2 Effect of Onset Rate

The effect of onset rate is illustrated in Figure 13, which shows the average annoyance ratings, from Table 19(c), for the onset rate experiment. The trends seen in Figure 13 are as discussed in Section 4.1: there is a clear onset rate effect above 30 dB/sec, and there is some irregularity among the sounds at lower onset rates. The sound at 6.5 dB/sec (the KC-135, which had tonal characteristics) stands out. In Section 4.1 it was suggested that some irregularities in the averages may be due to presentation-to-presentation variations in stimulus level, and that some were associated with spectral characteristics not adequately addressed by A-weighting.

Figure 14 addresses the question of nominal levels versus actual presentation levels. Shown are the predicted scores at 100 dB from the single linear regressions, Table 23. There are some differences, but these are small compared to the major features of the data. The use of nominal levels rather than actual levels does not pose a problem, although actual levels will be used in all regressions. Note that Figure 13 (representing ratings averaged over all three levels

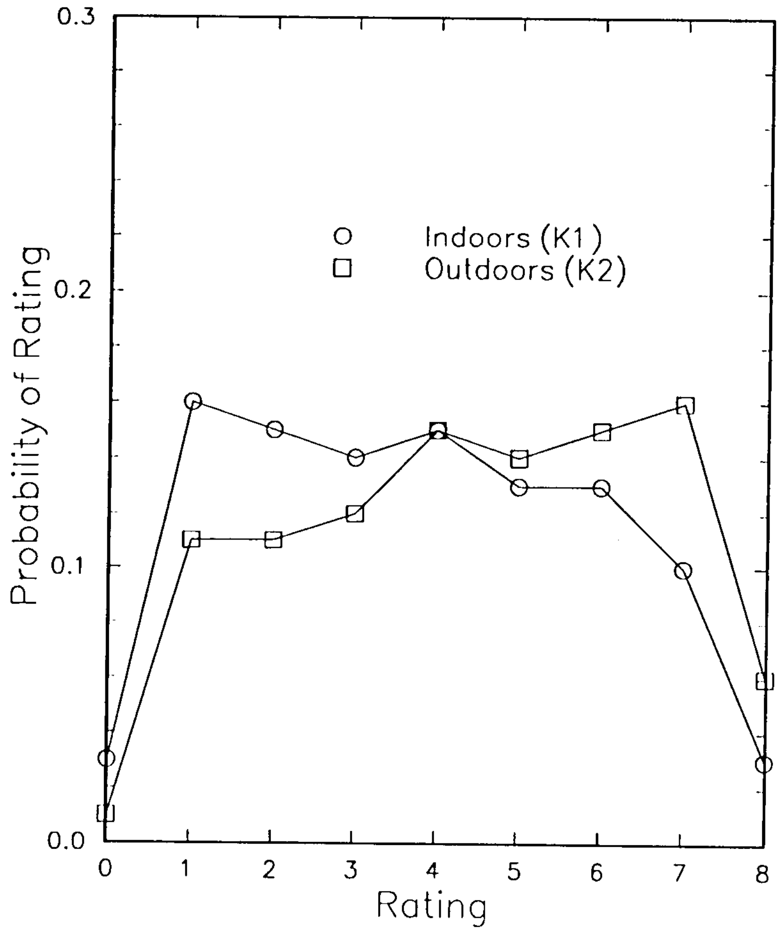

Figure 12. Distribution of Annoyance Ratings for Kernel Indoor (K1) and Outdoor (K2) Experiments.

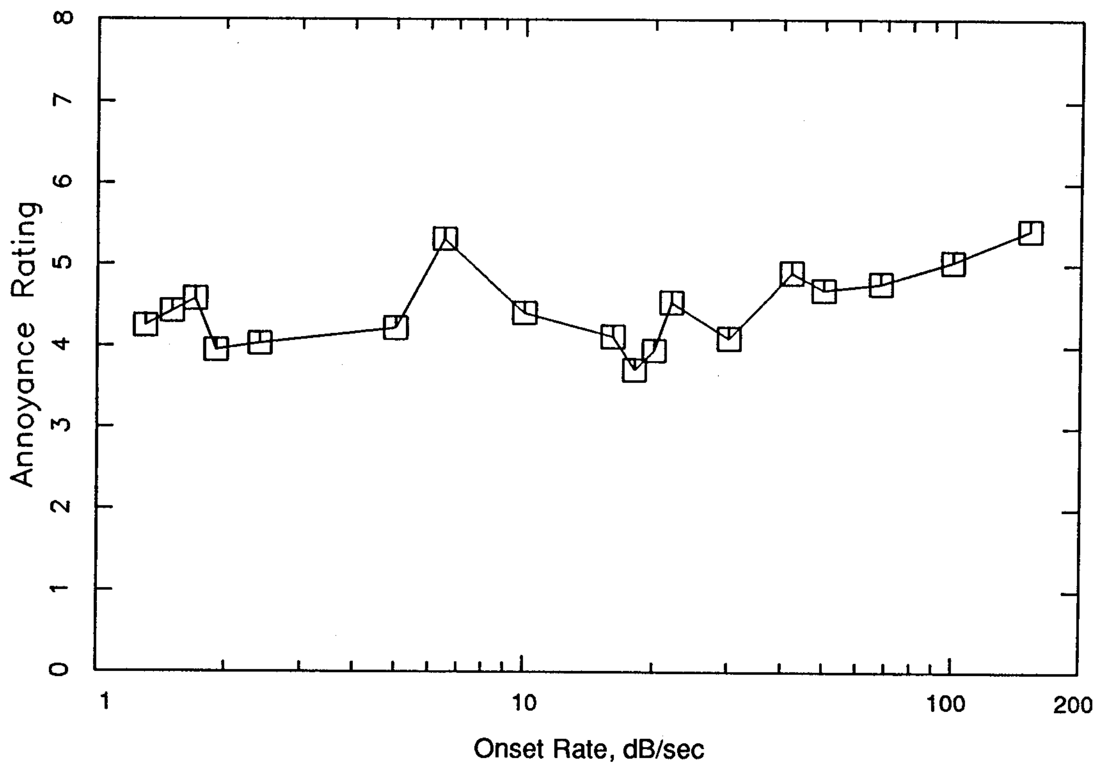

Figure 13. Effect of Onset Rate: OR Experiment, Average Scores.

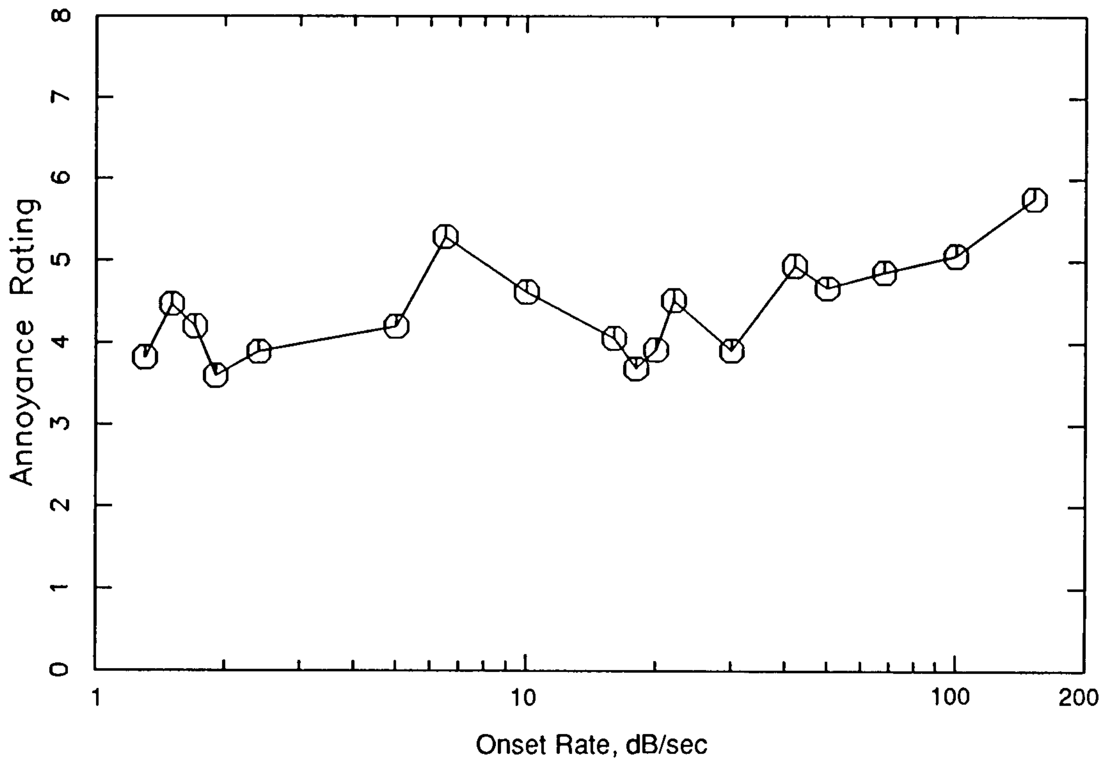

Figure 14. Effect of Onset Rate: OR Experiment,
Regression-Adjusted Scores at SEL = 100 dB.

used in the OR experiment) and Figure 14 (representing ratings at the middle of the three levels) very nearly overlay. Data for each level are similar to those for the middle level or the averages, an indication that interaction between level and onset rate is weaker than either effect by itself.

The question of spectral content has been examined by fitting regressions based on EPNL, which incorporates tone correction, rather than SEL. Figure 15 shows the result at EPNL of 100 dB. The curve is about half a point lower than the curves in Figures 13 and 14, because of the average 3 dB difference between SEL and EPNL. Major characteristics of the curve are similar. However, two features are clearly apparent. First, the sound at 6.5 dB/sec, while higher than surrounding sounds, no longer stands out as dramatically as in the SEL analysis. Second, irregularities in the trends at other rates (in particular, data at the slowest four or five onset rates) are reduced. The significance of tone correction will be addressed in Section 4.2.3, within the context of sound metrics.

Figures 13 and 14 are typical of plots of rating versus onset rate for most of the data, either at one level or averaged across levels. Figures 16 and 17 are similar plots for the kernel experiment indoors (K1) and outdoors (K2). The following features may be seen in Figures 13 through 17:

- Below about 20 dB/sec, the data do not exhibit a strong trend with onset rate, and are irregular. This is the region where the Tukey test indicated differences were not significant.

- Above about 20 dB/sec, the data have a consistent monotonically increasing trend. This trend does not level off, so there does not appear to be an upper plateau (as seen in Figure 1) for the kernel and onset rate data.

- All of the curves have similar shapes, indicating little interaction between onset rate and level.

- There is an obvious difference in score, at a given level, between K1 and K2. There is thus a significant difference between indoor and outdoor settings, with sound of a given level being perceived as more annoying indoors than outdoors.

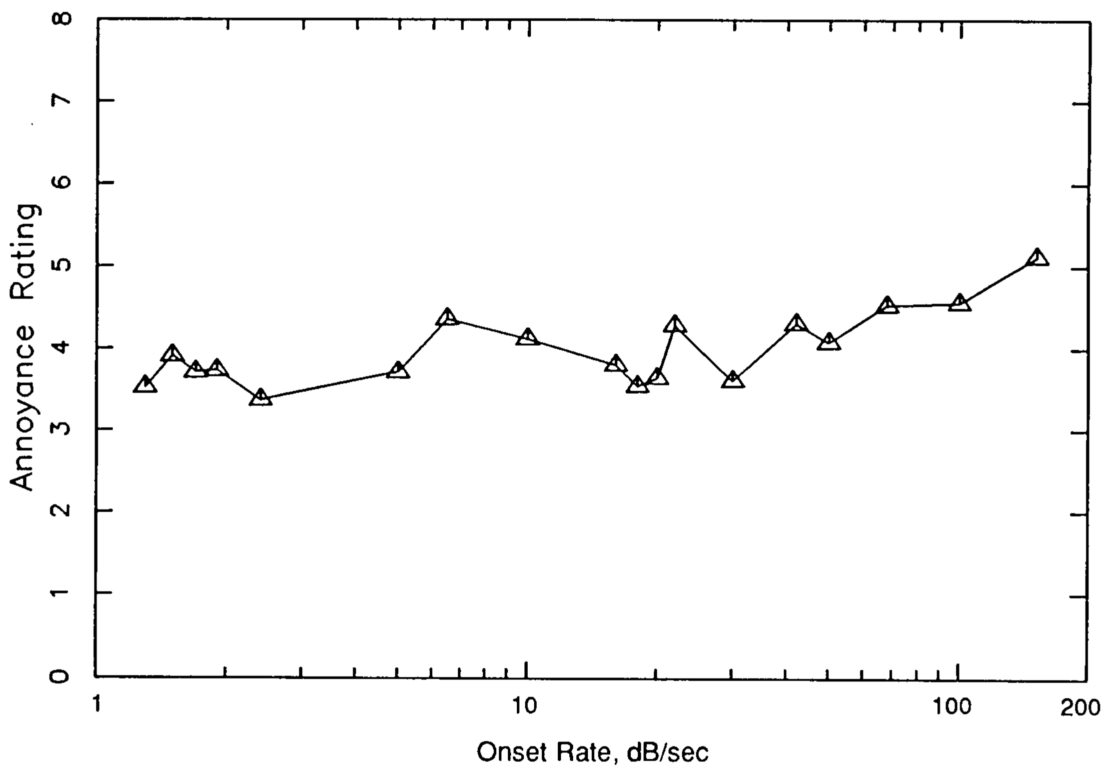

Figure 15. Effect of Onset Rate: OR Experiment,
Regression-Adjusted Scores at EPNL = 100 dB.

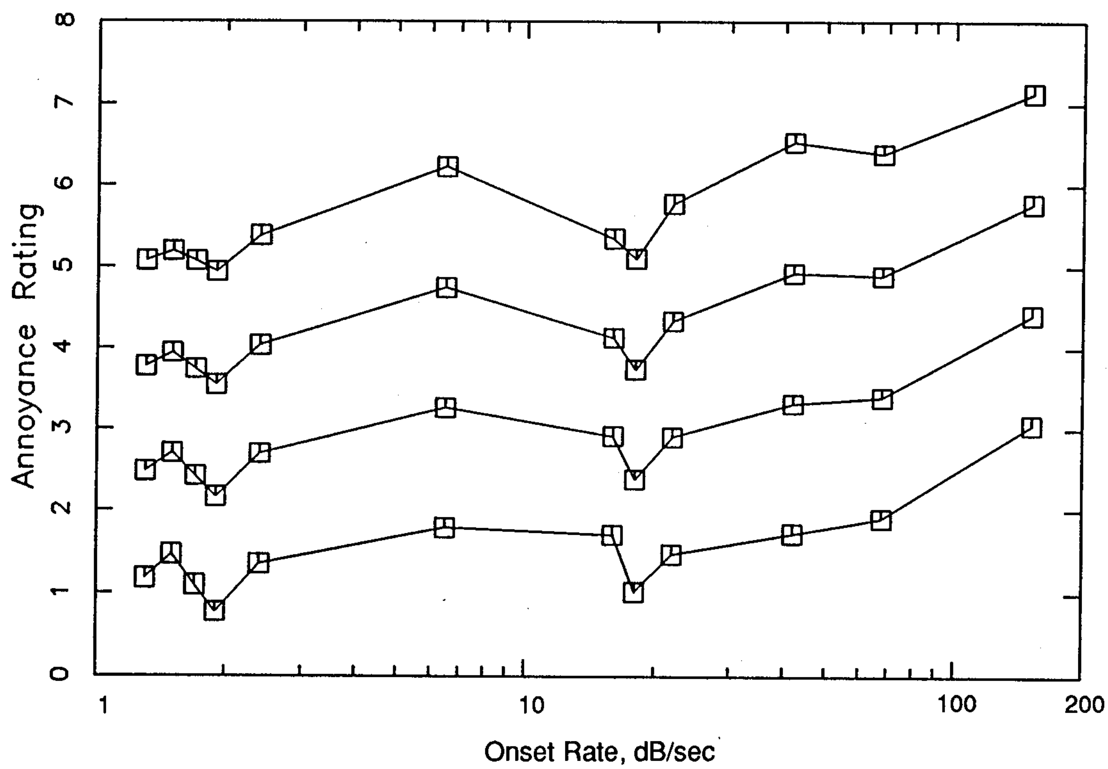

Figure 16. Effect of Onset Rate: K1 Experiment,
Regression-Adjusted Scores at SEL = 65, 75, 85, 95 dB.

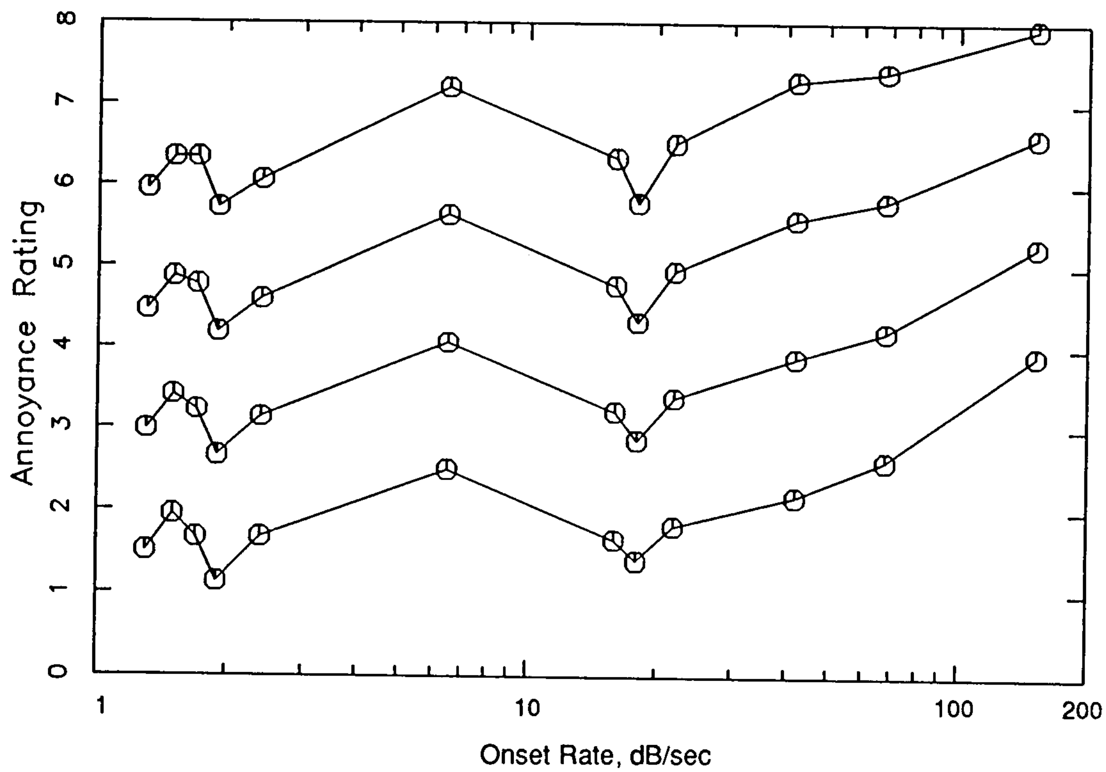

Figure 17. Effect of Onset Rate: K2 Experiment, Regression-Adjusted Scores at SEL = 80, 90, 100, 110 dB.

The indication of little interaction between onset rate and level is not consistent with the ANOVAs, which showed significant interaction. Note that Figures 16 and 17 show level-adjusted scores, while the ANOVAs used actual scores regardless of variations in presentation level. Figures 18 and 19 show the actual average scores at the nominal levels, equivalent to the averages presented in Section 4.1. These are considerably less orderly than Figures 16 and 17, with the curves having different shapes at different levels. It appears that the interaction detected in the ANOVAs may be, at least in part, an artifact of the session-to-session sound level variations.

Irregularities in Figures 13 through 17 arise because of aircraft-to-aircraft differences. Most of the experiments are not balanced, owing to the use of real aircraft sounds. One experiment, IV P2, has a balanced design, with the specific intent of exploring the effects of level, onset rate, and decay rate. This balance has been exploited in Section 4.1, where a three-way ANOVA was performed.

IV P2, it may be recalled, has 24 modified sounds (all derived from one aircraft type), with a balanced matrix of six decay rates and four decay rates. These sounds were presented at two levels. An unbalanced aspect of this experiment is that duration varies. However, one subset stands out as a clean test of onset rate alone: the sounds at the slowest decay rate, 2 dB/sec. The decay rate is fixed across these six sounds, and duration is dominated by the decay rate, so it does not vary.

Figure 20 shows annoyance rating versus onset rate for the six modified IV sounds at 2 dB/sec, at levels (SEL) of 90 and 110 dB. The data at 110 dB closely resemble Figure 1 (including an upper plateau), except that the break points of the ramp section are at 20 and 50 dB/sec, and the maximum increase is about 6 dB. At 90 dB, the data are flat, suggesting that onset rate contributes to annoyance only at higher sound levels.

To gain a more complete understanding of the parametric interrelationship between onset and decay, Figure 21 is a plot of all 24 IV modified sounds. The format is identical to Figure 20, except that there are four data lines at each level rather than just one. The results show the following trends:

- At 110 dB, the 5 and 10 dB/sec decay sounds exhibit onset rate trends similar to the 2 dB/sec decay sound. One difference is that the

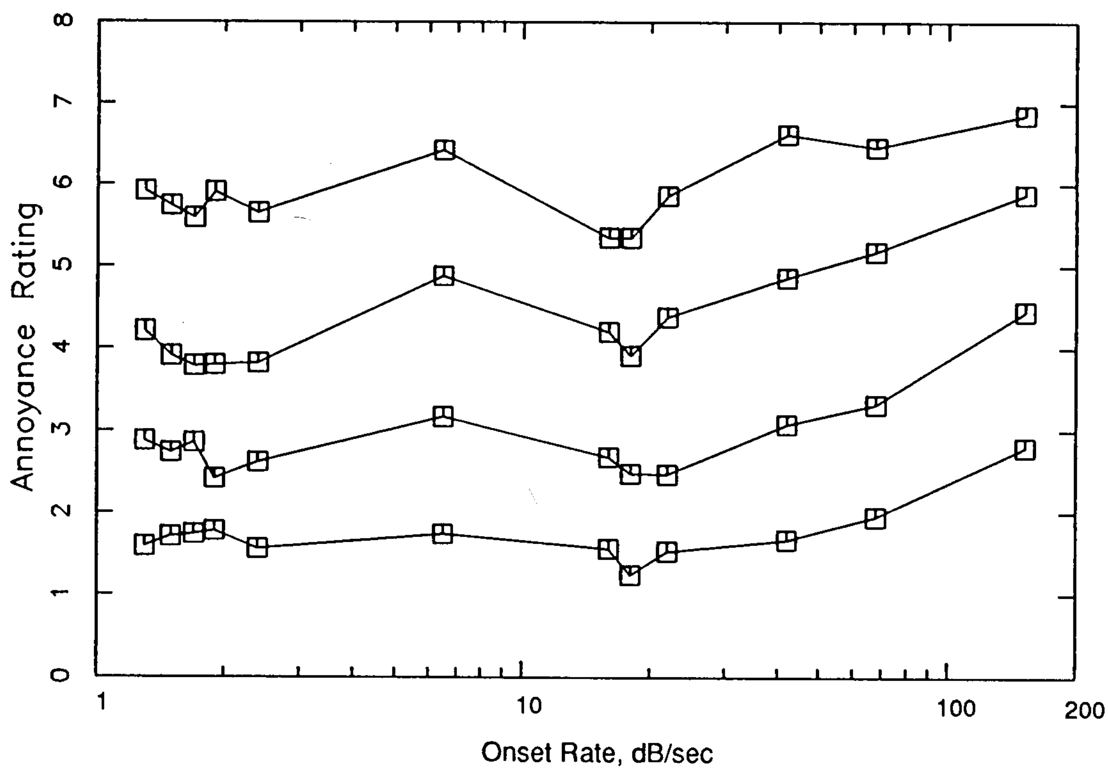

Figure 18. Effect of Onset Rate: K1 Experiment,
Average Scores at Nominal SEL = 66, 76, 86, 96 dB.

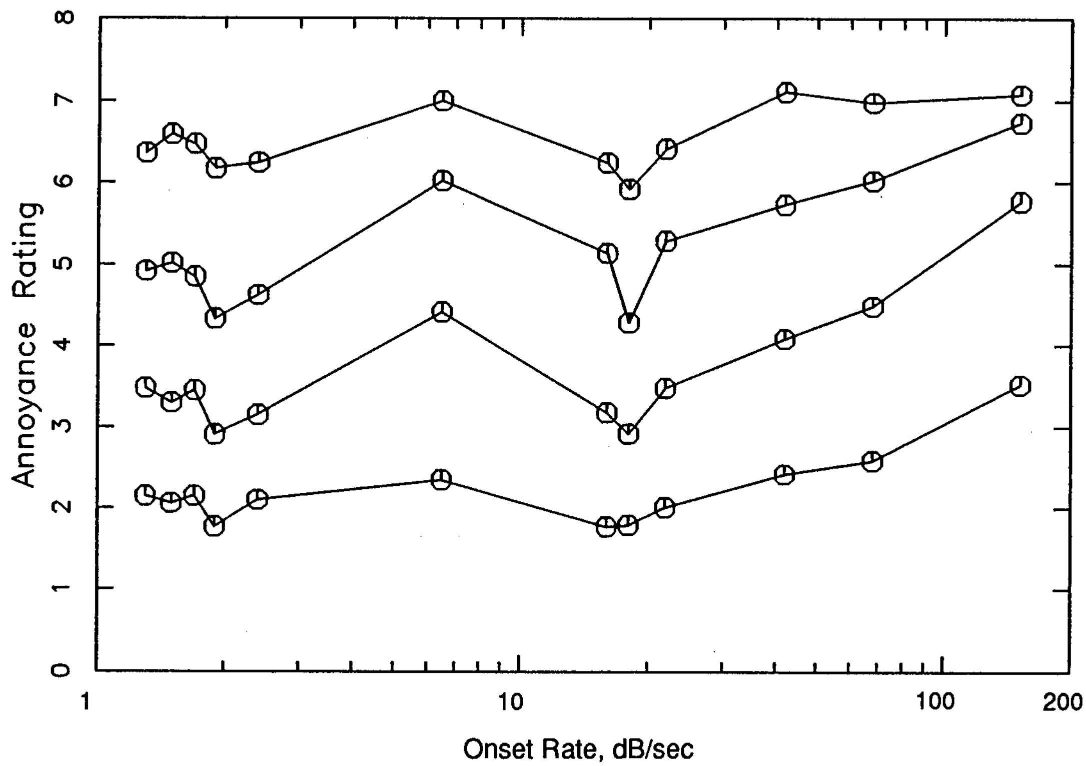

Figure 19. Effect of Onset Rate: K1 Experiment,
Average Scores at Nominal SEL = 81, 91, 101, 109 dB.

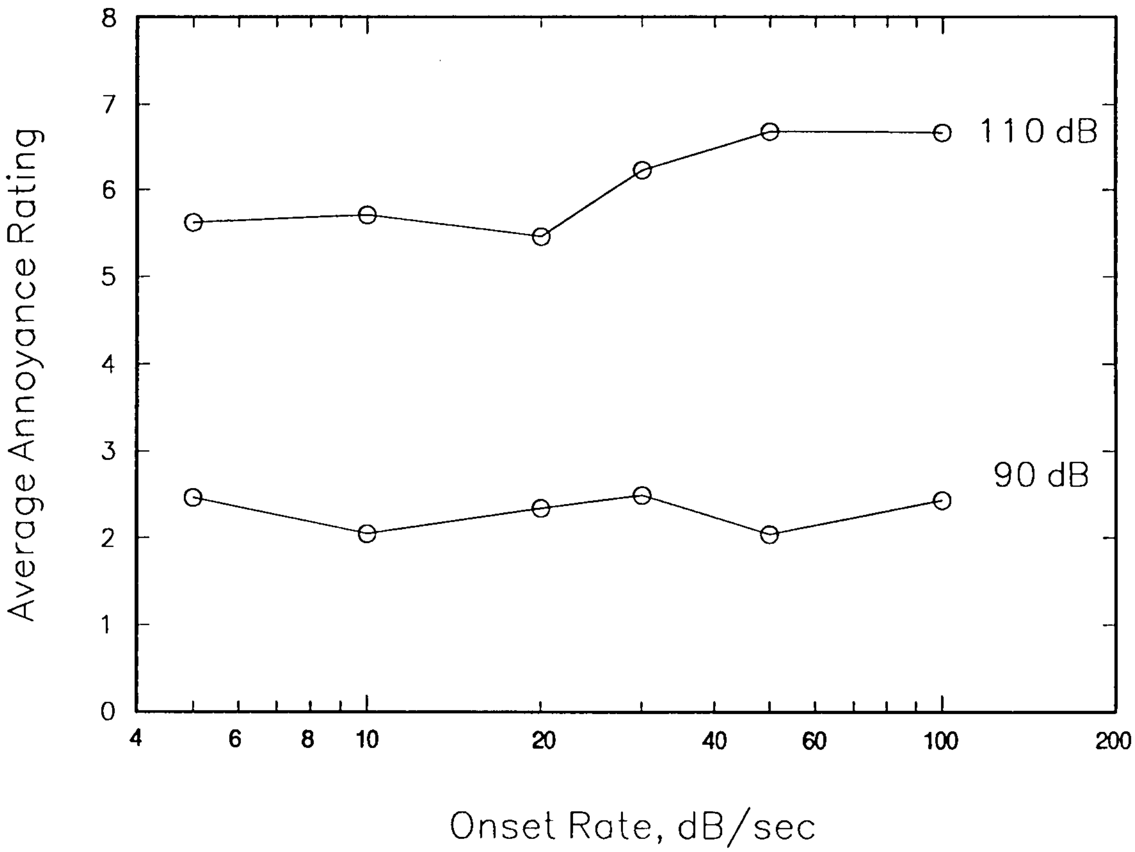

Figure 20. Effect of Onset Rate on Annoyance, IV, Modified Sounds, 2 dB/Second Decay.

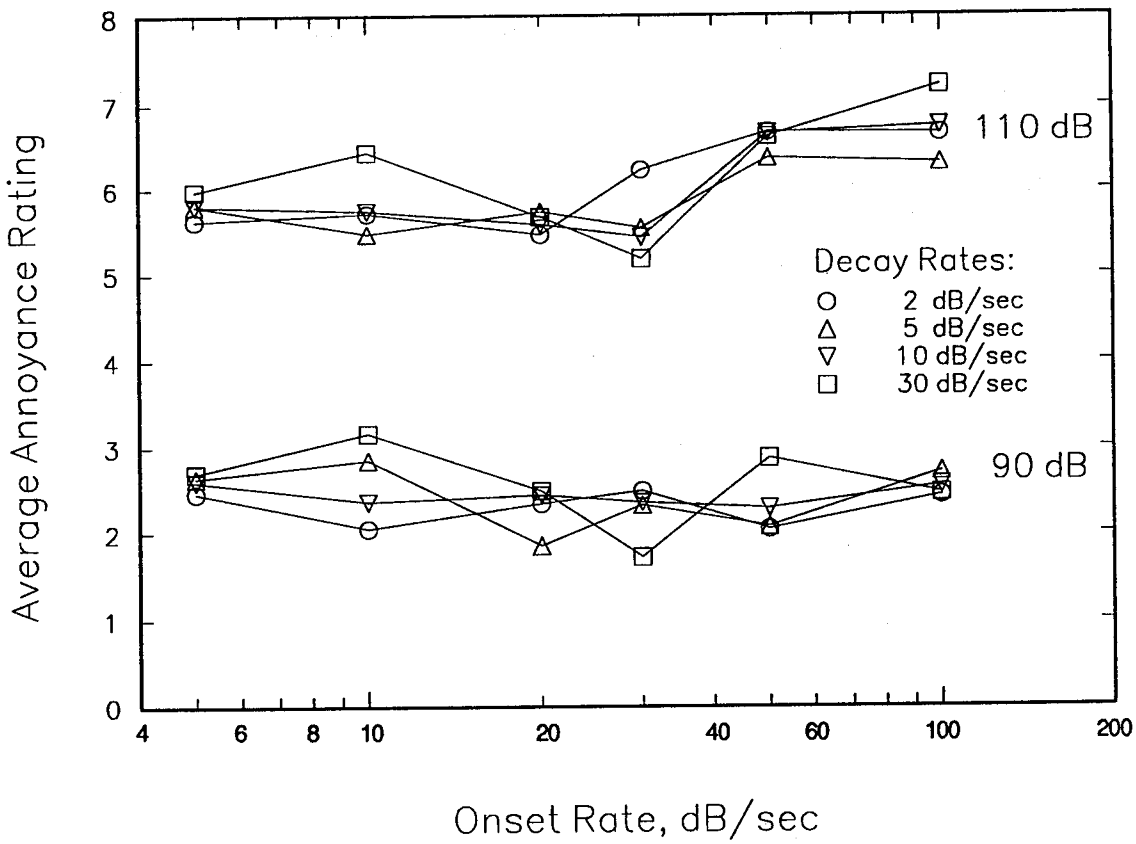

Figure 21. Effect of Onset and Decay Rates on Annoyance, IV, All Modified Sounds.

beginning of the onset rate adjustment is at 30 dB/sec rather than 20 dB/sec. These two sounds exhibit inconsistent behavior with regard to decay rate: the set of 2, 5, and 10 dB/sec decay sounds do not exhibit consistent monotonic behavior at any given onset rate.

- The 30 dB/sec decay sound, at 110 dB, exhibits wide swings. It was observed that this decay, particularly in conjunction with slower onset rates, resulted in very unnatural sounds. The impression given by a slow onset and a fast decay was often that the sound system had shut off just as the aircraft reached its peak. The inconsistent behavior of these fast decay sounds may be attributable to their unfamiliarity to the participants.

- At 90 dB, the sounds do not form any coherent pattern. The difference between the scores at 90 and 110 dB may be seen in Tables 24 and 25. The slopes associated with IV exhibit a wider variation than any of the other experiments. The non-linearity inherent in Figure 21 is probably not real, but is an artifact of wide variance in the 90 dB data.

The IV experiment included only two sound levels, 20 dB apart. With half the sounds at full level, it also produced the most stimulus overload for the participants. It is felt that good results were obtained at the higher levels, at least for all except the unnatural 5/30 through 30/30 sounds. The 20 dB drop to the lower level probably outweighed other effects. This is consistent with the generally higher slopes and greater variability seen in Table 24 than in Tables 22 and 23. Considering the monotonically increasing trend of the OR, K1, and K2 experiments (Figures 13, 16, and 17, respectively), the plateau seen in Figures 20 and 21 may be due to stimulus overload.

Those IV data which are well behaved show a consistent trend with onset rate and a much weaker dependence on decay rate. This is consistent with the ANOVA results, which showed decay to be significant but accounting for less variance than level or onset rate. The analysis may therefore proceed to optimization of an onset rate dominant model, as discussed in Section 4.1.

4.2.3 Preliminary Evaluation of Metrics

The ultimate goal of this research is to establish a metric which accurately reflects the annoyance of MTR operations. In Section 4.3, a model which accounts for level and onset rate is derived from the current data, using multiple regression. It is of interest to perform preliminary analysis of the benefit of various metrics and adjustments, within the simplified context of this section. Some analysis of this type has already been presented – in particular, the use of EPNL in Figure 15.

Single regression analyses, similar to those presented in Tables 22 through 24, have been performed for the following metrics:

- SEL_T, an obvious candidate.

- L_{max}, both slow and fast. There is a recurrent question in community noise analysis as to whether transient sounds are best represented by maximum levels or integrated metrics.

- EPNL, which appears to resolve some of the outlying data points associated with two of the experimental sounds.

- The combination of all metrics (except SEL_T) with the SEL_T onset rate adjustment.

These analyses have been applied to K2, the outdoor kernel experiment. The results are presented in Table 26. Shown, for each metric, are the standard deviations associated with the predicted annoyance rating at each of the levels in Table 22(b). These standard deviations quantify the sound-to-sound variations, accounting for actual presented levels and averaging out participant variation. The values shown for SEL are taken from Table 22(b). Recalling the 6.6 dB per rating point relation for the K2 experiment (Table 25), the SEL standard deviations correspond to 4.5 to 4.7 dB. The results for the other metrics are:

- SEL_T yields a noticeable improvement, reducing the standard deviation to 3.2 to 3.8 dB. This is the best result of any of the metrics tested, except for the combination of EPNL and onset rate correction.

- Slow L_{max} does not work as well as SEL. Fast L_{max} offers some improvement, but not as much as SEL_T and it is not consistent across all four levels.

Table 26

Standard Deviations of Predicted Annoyance Ratings,*
Sounds Quantified by Various Metrics, Experiment K2

Metric	Level			
	80 dB	**90 dB**	**100 dB**	**110 dB**
SEL	0.71	0.69	0.68	0.68
SEL_r	0.57	0.53	0.51	0.49
L_{max} (slow)	0.82	0.81	0.81	0.82
L_{max} (slow) + Rate Adj.	0.79	0.77	0.76	0.76
L_{max} (fast)	0.65	0.61	0.57	0.54
L_{max} (fast) + Rate Adj.	0.82	0.78	0.74	0.71
EPNL	0.64	0.61	0.60	0.60
EPNL + Rate Adj.	0.49	0.44	0.39	0.37

* Multiply by 6.6 for decibel equivalent.

- Combining either L_{max} with onset rate yields results not as good as SEL.

- EPNL yields some improvement over SEL, reducing the standard deviation to 4 to 4.2 dB. This is consistent with the differences seen between Figures 14 and 15, where improvements occurred with some sounds. The benefit of this tone correction is about half the benefit of the onset rate adjustment.

- The combination of EPNL and the onset rate correction yields standard deviations of 2.4 to 3.1 dB. The improvement is very nearly the sum of the benefit (relative to SEL) of the single effects of onset rate and tone correction.

These results show that an onset rate adjustment can improve predictions of annoyance. Sound level is better represented by total energy metrics (e.g., SEL or EPNL) than maximum levels. The tone correction included in EPNL offers improvement over SEL, but only by half as much as the onset rate adjustment embodied in SEL_r. The effects of onset rate and tone correction appear to be additive, so it is reasonable to address each separately. Because onset rate appears to be a larger effect than tonality, and because SEL and L_{dn} are currently employed much more widely than EPNL and Noise Exposure Forecast, the remaining analysis will consider only adjustments to SEL.

4.3 Multiple Regression

The analysis of the previous sections has shown that a linear relation exists between level and annoyance, and that a non-linear relation, similar in character to that shown in Figure 1, exists between onset rate and annoyance. These relationships are embodied in the following model:

$$\text{Annoyance Rating} = A + B \bullet \text{SEL} + \begin{cases} 0\,, & R<R_1 \\ \Delta L \dfrac{\log_{10} R/R_1}{\log_{10} R_2/R_1}\,, & R_1 < R < R_2 \\ \Delta L\,, & R<R_1 \end{cases}$$

where R is the onset rate, dB/sec. The first two terms of this model are as in the single linear regressions of Section 4.2.1, and the final term is a generalization of the interim metric rate correction, and is shown in Figure 22. It is a ramp (linear on a log scale) between lower and upper break points R_1 and R_2, with a lower plateau of 0 and an upper plateau of ΔL.*

Least-square regression fits have been made to this model, for the four experiments and subsets. Best-fit values were obtained for the five parameters A, B, R_1, R_2, and ΔL. For optimization of the non-linear onset rate portion of the model, a grid search scheme was employed. This search used a 5 dB/sec granularity in R_1 and R_2, and a 1 dB granularity in ΔL.

The fitting scheme recognized features of the data which were established in the previous analysis. A minimum value of 20 dB/sec was considered for R_1, based on the result in Section 4.1 that differences were not significant below that value. For the kernel and onset rate experiments, where the data clearly do not exhibit an upper plateau, R_2 was taken to be 150 dB/sec, approximately the highest onset rate employed. There may or may not be a plateau above this value, but the fit must recognize the domain of the data.

Table 27 shows the result of the multiple regression fits. Fits were made to five data sets: the four experiments, plus the IV P2 subset. Seven sets of parameters R_1, R_2, and ΔL are shown. These correspond to SEL, SEL_T, best fits (least squares) to each of the five data sets (K1 and K2 had the same best fit), and a best fit to the 110 dB curve in Figure 18 (IV P2, 2 dB/sec decay, 110 dB). Shown in the table are the values of R_1, R_2, and ΔL, plus the standard deviation of the fit. This standard deviation was computed from the residual sum-of-squares and the degrees of freedom. In addition to the standard deviation for each data set, the combined standard deviation for K1, K2, and OR is shown. At the bottom of the chart is the decibel per annoyance rating conversion factor for each data set, at the optimized condition.

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* The salient feature of the onset portion of this model is three parameters defining an upper plateau and the transition range. The three-segment model has been chosen for computational convenience. If a continuous function is beneficial, any convenient matching function (e.g., logistic curve or hyperbolic tangent) could be substituted. A direct analogy exists between three-segment community annoyance curves used in the 1970s[15] and the smooth functional form of the Schultz curve.[16]

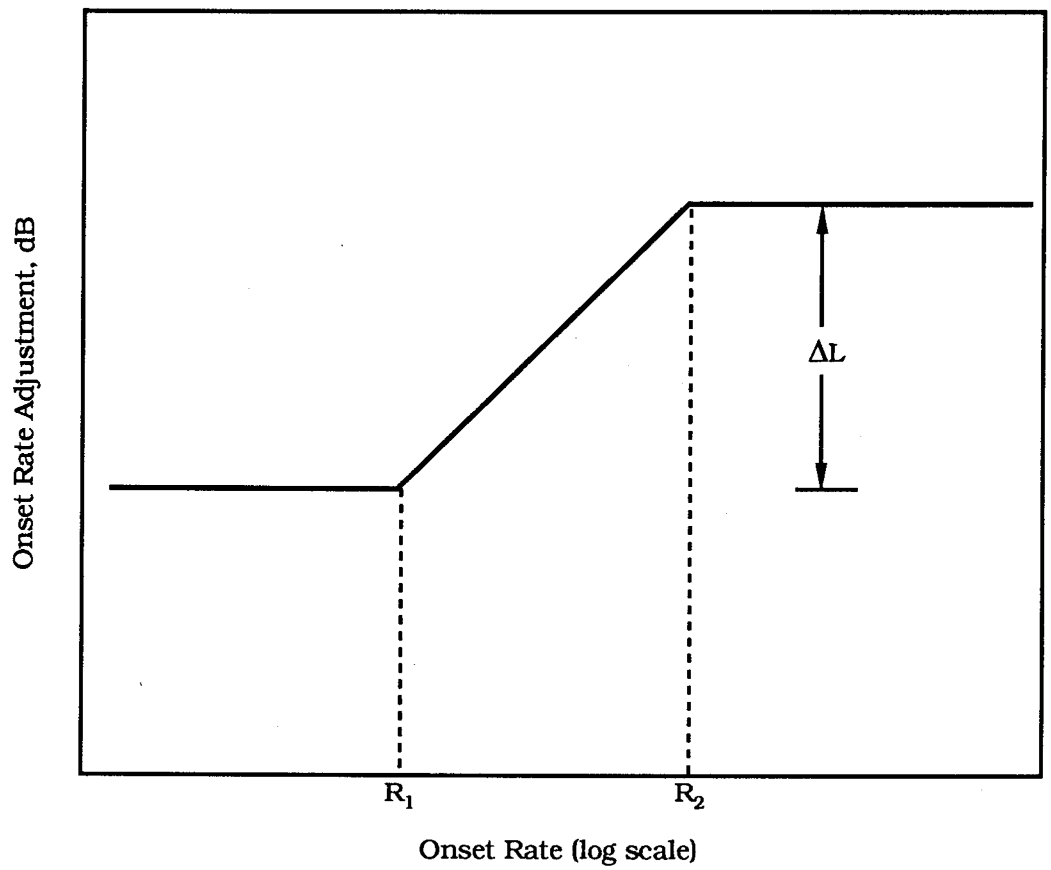

Figure 22. Three-Parameter Onset Rate Adjustment Model.

The standard deviations in Table 27 are larger than those presented in Sections 4.1 and 4.2 because they include deviations from the model (not included in Section 4.1) and variability associated with the participants (not included in Section 4.2).

It is seen in Table 27 that SEL_T provides a definite improvement over SEL. Other models offer further improvement. Because of the irregularities seen in the IV experiment, the best fit should be based on the Kernel and Onset Rate experiments. Referring to the combined K1–K2–OR best fit, the optimum onset adjustment is R_1 = 20 dB/sec, R_2 = 150 dB/sec, and ΔL = 13 dB. This is the best fit to K1 and K2. The next best fit is R_1 = 30 dB/sec, R_2 = 150 dB/sec, and ΔL = 9 dB, which is the best fit to OR.

Discussion in Section 4.1 suggests that the threshold of the onset rate effect is around 30 dB/sec. Fixing R_1 at this value, and keeping R_2 at 150 dB/sec, there is only one free parameter in the onset adjustment: ΔL. Table 28 shows standard deviations for various values of ΔL. The best fit, based on aggregate K1–K2–OR fit, is ΔL of 11 or 12 dB. The value of ΔL = 11 dB is a better choice, since it also yields a better fit to IV and IV P2. It is possible to consider various trades between the separate experiments, but these would change the model by no more than one or two decibels, an amount which is not of practical consequence.

The best fit onset rate adjustment to the current experiments thus has break points of 30 and 150 dB/sec and a maximum increase of 11 dB. The issue of whether there is a plateau above 150 dB, or whether the adjustment continues to increase at higher rates, cannot be addressed in the current study since the fastest sound employed had an onset rate of 152 dB/sec. For the sake of conceptual consistency with the three-segment model, a plateau is considered to exist above 150 dB/sec. The issue of a correction above this rate is of little practical significance, since actual MTR operations do not involve flight parameters which cause onset rates to even approach this value.

Table 27

Standard Deviations of Optimized Fit of Various Onset Rate Models to Each Experiment*

Model Parameters			Standard Deviations of Fit For Each Experiment					
R_1	R_2	ΔL	K1	K2	OR	IV	IV P2	K1 + K2 + OR
--	--	0[a]	1.441	1.450	1.442	1.481	1.431	1.444
15	30	5[b]	1.374	1.373	1.415	1.474	1.460	1.387
20	150	13	1.338	1.320	1.401	1.475	1.476	1.353
30	150	9	1.352	1.337	1.379	1.437	1.423	1.356
30	150	7	1.364	1.353	1.381	1.433	1.413	1.366
30	70	4	1.385	1.378	1.392	1.438	1.409	1.385
20	60	6[c]	1.362	1.352	1.390	1.446	1.431	1.368
dB/Rating Point			7.4	6.6	5.9	5.7	5.6	

a. SEL, no onset rate adjustment.

b. SEL_r, interim metric adjustment.

c. Best fit to IV P2, 110 dB, 2 dB/sec decay (upper curve of Figure 20).

* Standard deviations of rating scores based on sum of squares and degrees of freedom. Shaded values indicate the experiment for which each set of parameters was optimized.

Table 28

Standard Deviations for Fit of Onset Rate Model With R_1 = 30 dB/sec and R_2 = 150 dB/sec

ΔL	K1	K2	OR	IV	IV P2	K1 + K2 + OR
7	1.364	1.353	1.381	1.433	1.413	1.366
8	1.358	1.344	1.379	1.434	1.417	1.360
9	1.352	1.337	1.379	1.433	1.423	1.356
10	1.348	1.332	1.380	1.441	1.430	1.353
11	1.345	1.328	1.383	1.448	1.438	1.352*
12	1.343	1.325	1.388	1.455	1.448	1.352
13	1.342	1.324	1.394	1.464	1.458	1.354

* Overall best fit (see text).

5.0 CONCLUSIONS

Experiments have been conducted to evaluate the effect of onset rate on the annoyance due to noise from low-altitude, high-speed military aircraft operations on MTRs. The specific objective of these experiments was to validate, refute, or improve the onset rate adjustment contained in L_{dnmr}. The following conclusions have been reached:

- Onset rate is a genuine effect which must be accounted for.

- Decay rate and/or duration may have independent effects on annoyance. However, for typical MTR sounds, they are sufficiently correlated with onset rate that onset rate may be taken to be the single significant parameter.

- SEL_r, which embodies the current onset rate correction, was found to be a better predictor of annoyance than SEL. The original onset rate correction embodied in the current Air Force methodology in SEL_r is 0 dB below 15 dB/sec and 5 dB above 30 dB/sec, with a log (rate) transition between.

- A revised onset rate correction can be defined, based on the data collected in the current experiments, which predicts annoyance more accurately than does SEL_r. The best fit from these data is a correction of 0 dB below 30 dB/sec and 11 dB at 150 dB/sec, with a log (rate) transition between.

This final result is sufficiently clear that, taken by itself, a revision to SEL_r would be appropriate, although the change should not result in significantly different assessment findings for most MTR operational scenarios. In view of the experiments reported in Reference 6, and other ongoing Air Force studies, any new onset rate correction recommendation should ultimately be based on review of the results of all of these studies. It must be recalled that onset rate is only one aspect of MTR noise; the low numbers of flights and their sporadic scheduling are also issues. Given that the current experiments provide good support for SEL_r, refinement at this time is not urgent. It would therefore be prudent to wait for the outcome of studies directed at longer term epoch ratings, and make a single recommendation for a better metric when these studies have been completed.

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APPENDIX A

Post-Experiment Questionnaire

Post-Experiment Questionnaire

Name: ______________________________ Participant #__________

Date: __________________ Time __________

1. For the entire experiment, as a whole, how would you rate the overall group of all the airplane sounds that you heard? Use the same scale that you used to rate the individual sounds.

   Overall Rating: ________

2. Did any of the types of sounds stand out as being particularly less annoying than the others?

   Yes ___ No ___ If yes, which ones? Describe in words ________________

   ____

   Please describe why you thought that they were less annoying:

   ____

3. Did any of the types of sounds stand out as being particularly more annoying than the others?

   Yes ___ No ___ If yes, which ones? Describe in words ________________

   ____

   Please describe why you thought that they were more annoying:

   ____

4. How do you think the sounds affected the reading task that you were doing?

   Check one: Not at all _____ Somewhat _____

   Minimally _____ Considerably _____

   Please describe any effects that you experienced:

   ____

5. Did you ever lose your place during the experiment? Yes ___ No ___

   If yes, when and why do you think this happened? ______________________

   ____

 Participant #________

6. Please rank the following qualities of the airplane sounds that you heard as to their importance in contributing to your annoyance judgments. Put a number "1" after the quality that annoyed you the most. Put a number "2" after the next most annoying quality. By a process of elimination, put a "3" next to the third most annoying, and so on, until you have ranked all six items, with number "6" being the least annoying. Make sure all blanks are filled in; use each number only once, but use all six numbers.

Quality	*Rank*
How long the sound lasts (duration)	_____
How strong the peak sound is (intensity)	_____
How fast the sound comes on (onset rate)	_____
How much whine the sound has (tonality)	_____
How low and rumbly the sound is (low frequency)	_____
How slow the sound fades away (decay rate)	_____

7. What is your present occupation? ______________________________

   Are there any loud noises in your present occupation? Yes ___ No ___

   If yes, what kind of noises? ______________________________

   Were there any loud noises in any previous occupation (including the military)?

   Yes ___ No ___

   If yes, what was that occupation? ______________________________

   What were the noises? ______________________________

8. Have you ever been a pilot? Yes ___ No ___

   Have you ever worked with or near airplanes? Yes ___ No ___

   If yes, in what capacity? ______________________________

   Did you ever wear hearing protectors against aircraft noise? Yes ___ No ___

Participant #__________

9. Have you ever flown in an airplane? Yes ___ No ___

   If yes, on the average, how often have you flown? Check one:

   a. A few times in your life _____
   b. Once every few years _____
   c. Once a year _____
   d. A few times a year _____
   e. Once a month _____

10. Have you ever lived near an airport or near aircraft operations?

    Yes ___ No ___

    If yes, have you ever been annoyed by the noise? Yes ___ No ___

    Explain briefly ____

11. Have you ever been exposed to unusually high levels of any of the following noises? Check all that apply:

    a. Railroad noise _____
    b. Traffic noise _____
    c. Industrial noise _____
    d. Aircraft noise _____
    e. Truck noise _____
    f. Outdoor machinery noise _____
    g. Shipboard noise _____

12. How would you rate the overall experiment? ______________________

    ____

    ____

13. How might the experiment be improved? __________________________

    ____

    ____

14. Do you have any other comments? _______________________________

    ____

    ____

APPENDIX B

Participant Instructions

FIRST INSTRUCTIONS FOR INDOOR EXPERIMENT (K)

Welcome. In this part of the experiment you will be listening to aircraft sounds in the NASA-Langley listening auditorium. Please sit in your marked seat. Each two-hour experimental session will be divided into two listening periods of about 50 minutes duration, with a short break between. During each 50-minute listening period you will hear 24 aircraft sounds while you read a magazine. You should rate the annoyance of each aircraft sound on the Annoyance Rating Response Form in front of you.

You will rate sounds 1 through 24 during the first 50-minute period and sounds 25 through 48 during the second period. The experimenter will periodically tell you which sound will come next so that you can keep your place. If you lose your place, draw a horizontal line at the place where you think you got out of step and continue in the proper order. Please try not to lose your place.

Make sure that you rate every aircraft sound after the peak or loudest part has occurred, but we suggest that you wait until the sound has begun to recede or fade before you make your judgment. Now read your Annoyance Rating Response Form carefully, if you have not already done so. The experimenter will tell you how to fill in the top of your Annoyance Rating Response Form and offer you a selection of magazines to read.

There are a few rules that you must follow during this part of the experiment. No smoking is permitted in the listening auditorium at any time. During the actual listening sessions, no talking is permitted. Besides rating the aircraft sounds, your main task will be to read a magazine of your choice. Please choose some long articles to read, rather than just browsing and turning the pages. You may take more than one magazine with you to your seat if you wish.

During the session, both video and audio monitoring will be employed for your safety. The experimenter will be able to see you and hear you at all times. In addition, each listening session will be recorded on video tape in order to keep a permanent record. These video tapes will be used exclusively for scientific and archival purposes. They will not be broadcast or shown to the public. As with all personal data collected during this study, these video tapes will be kept confidential.

You have the right to stop the experiment at any time by loudly saying "STOP". However, unless it is absolutely necessary, we ask you not to stop the experiment, but rather to simply get up and leave the auditorium if you feel that you cannot continue. Your decision to stop or quit will in no way prejudice you for future experiments, and you will be paid for your participation up to that point. During the break, the experimenter will be present to show you the bathrooms, lounge, and vending areas.

You are free to talk among yourselves and with the staff during the breaks, but please do not discuss your opinions, judgments, impressions, or feelings about the experiment or about any of the sounds with anyone else who is in the experiment or may be in the experiment. Since you never know who may be in the experiment, for a period of about two months, we would appreciate your not discussing the details of the experiment with anyone except immediate family members who are not in the experiment.

At the end of your four experimental sessions, you will fill out a Post-Experiment Questionnaire concerning your overall impressions of the experiment. This questionnaire is not invasive and does not contain any personal or embarrassing questions. At the beginning of each experimental session, you will be required to sign some consent forms. These have been devised for your safety and protection.

Before the first 50-minute listening session, you will have a brief Practice Session containing only five sounds. This Practice Session is to acquaint you with the types and range of aircraft sounds that you are likely to hear during the experiment and to familiarize you with the response form and procedures. Fill out the form and rate these five practice sounds as you would for the main experiment. You will be given feedback on how well you are doing in following the instructions and procedures. Then we will begin the main experiment. If you have any questions, either now or at any time during the breaks, please ask.

FIRST INSTRUCTIONS FOR OUTDOOR EXPERIMENT (K)

Welcome. In this part of the experiment you will be listening to aircraft sounds in an open pasture. Please sit in your marked seat. Each two-hour experimental session will be divided into two listening periods of about 50 minutes duration, with a short break between. During each 50-minute listening period you will hear 24 aircraft sounds while you read a magazine. You should rate the annoyance of each aircraft sound on the Annoyance Rating Response Form in front of you.

You will rate sounds 1 through 24 during the first 50-minute period and sounds 25 through 48 during the second period. The experimenter will periodically tell you which sound will come next so that you can keep your place. If you lose your place, draw a horizontal line at the place where you think you got out of step and continue in the proper order. Please try not to lose your place. Occasionally, you may hear the sounds from real aircraft flying overhead. Please ignore those sounds.

Make sure that you rate every aircraft sound after the peak or loudest part has occurred, but we suggest that you wait until the sound has begun to recede or fade before you make your judgment. Now read your Annoyance Rating Response Form carefully, if you have not already done so. The experimenter will tell you how to fill in the top of your Annoyance Rating Response Form and offer you a selection of magazines to read.

There are a few rules that you must follow during this part of the experiment. During the actual listening sessions, no smoking or talking is permitted. Besides rating the aircraft sounds, your main task will be to read a magazine of your choice. Please choose some long articles to read, rather than just browsing and turning the pages. You may take more than one magazine with you to your seat if you wish.

During the session, both video and audio monitoring will be employed for your safety. The experimenter will be able to see you and hear you at all times. In addition, each listening session will be recorded on video tape in order to keep a permanent record. These video tapes will be used exclusively for scientific and archival purposes. They will not be broadcast or shown to the public. As with all

personal data collected during this study, these video tapes will be kept confidential.

You have the right to stop the experiment at any time by loudly saying "STOP". However, unless it is absolutely necessary, we ask you not to stop the experiment, but rather to simply get up and leave the auditorium if you feel that you cannot continue. Your decision to stop or quit will in no way prejudice you for future experiments, and you will be paid for your participation up to that point. During the break, the experimenter will show you the bathroom and where you can get soft drinks. Please do not enter the barn or house.

You are free to talk among yourselves and with the staff during the breaks, but please do not discuss your opinions, judgments, impressions, or feelings about the experiment or about any of the sounds with anyone else who is in the experiment or may be in the experiment. Since you never know who may be in the experiment, for a period of about two months, we would appreciate your not discussing the details of the experiment with anyone except immediate family members who are not in the experiment.

At the end of your four experimental sessions, you will fill out a Post-Experiment Questionnaire concerning your overall impressions of the experiment. This questionnaire is not invasive and does not contain any personal or embarrassing questions. At the beginning of the experiment, you will be required to sign a consent form. This form has been devised for your safety and protection.

Before the first 50-minute listening session, you will have a brief Practice Session containing only five sounds. This Practice Session is to acquaint you with the types and range of aircraft sounds that you are likely to hear during the experiment and to familiarize you with the response form and procedures. Fill out the form and rate these five practice sounds as you would for the main experiment. You will be given feedback on how well you are doing in following the instructions and procedures. Then we will begin the main experiment. If you have any questions, either now or at any time during the breaks, please ask.

Second Instructions for Indoor [Outdoor] Experiment (K)

This part of the experiment is very similar to the one you participated in outdoors [indoors] in the pasture [Langley listening auditorium], only this time you will listed to a series of aircraft sounds in the NASA-Langley listening auditorium [an outdoor pasture]. Please sit in your marked seat. As before, each two-hour experimental session will be divided into two 50-minute listening periods with 24 sounds each. You will read magazines and rate the annoyance of the aircraft sounds as before. No smoking is permitted in the listening auditorium at any time [pasture during listening periods]. The same rules for talking apply as before. Likewise, audio and video monitoring and video tape recording will be employed as before. You may stop the experiment at any time. During the break the experimenter will show you the [bathroom.] bathrooms, lounge, and vending area. As before, you will first have a brief Practice Session. If you have any questions, please ask.

Second Instructions for Indoor Experiment (K)

This part of the experiment is very similar to the one you participated in outdoors in the pasture, only this time you will listed to a series of aircraft sounds in the NASA-Langley listening auditorium. Please sit in your marked seat. As before, each two-hour experimental session will be divided into two 50-minute listening periods with 24 sounds each. You will read magazines and rate the annoyance of the aircraft sounds as before. No smoking is permitted in the listening auditorium at any time. The same rules for talking apply as before. Likewise, audio and video monitoring and video tape recording will be employed as before. You may stop the experiment at any time. During the break the experimenter will show you the bathrooms, lounge, and vending area. As before, you will first have a brief Practice Session. If you have any questions, please ask.

Second Instructions for Outdoor Experiment (K)

This part of the experiment is very similar to the one you participated in indoors in the Langley listening auditorium, only this time you will listen to a series of aircraft sounds in our outdoor pasture. Please sit in your marked seat. As before, each two-hour experimental session will be divided into two 50-minute listening periods with 24 sounds each. You will read magazines and rate the annoyance of the aircraft sounds as before. No smoking is permitted in the pasture during listening periods. The same rules for talking apply as before. Likewise, audio and video monitoring and video tape recording will be employed as before. You may stop or quit the experiment at any time. During the break the experimenter will show you the bathroom and soda cooler. As before, you will first have a brief Practice Session. If you have any questions, please ask.

Third Instructions for Indoor Experiment (K)

This part of the experiment will be identical to the last session conducted in the NASA-Langley listening room. Here is a brief reminder of some important rules:

- No smoking in the room at any time.
- No talking during the listening period.
- There will be audio and video monitoring.
- You may stop or quit at any time.

Third Instructions for Indoor Experiment (K)

This part of the experiment will be identical to the last session conducted in the NASA-Langley listening room. Here is a brief reminder of some important rules:

- No smoking in the room at any time.
- No talking during the listening period.
- There will be audio and video monitoring.
- You may stop or quit at any time.

INSTRUCTIONS FOR OUTDOOR EXPERIMENT (I)

Welcome. In this part of the experiment you will be listening to aircraft sounds in an open pasture. Please sit in your marked seat. Each two-hour experimental session will be divided into two listening periods of about 50 minutes duration, with a short break between. During each 50-minute listening period you will hear 30 aircraft sounds while you read a magazine. You should rate the annoyance of each aircraft sound on the Annoyance Rating Response Form in front of you.

You will rate sounds 1 through 30 during the first 50-minute period and sounds 31 through 60 during the second period. The experimenter will periodically tell you which sound will come next so that you can keep your place. If you lose your place, draw a horizontal line at the place where you think you got out of step and continue in the proper order. Please try not to lose your place. Occasionally, you may hear the sounds from real aircraft flying overhead. Please ignore those sounds.

Make sure that you rate every aircraft sound after the peak or loudest part has occurred, but we suggest that you wait until the sound has begun to recede or fade before you make your judgment. Now read your Annoyance Rating Response Form carefully, if you have not already done so. The experimenter will tell you how to fill in the top of your Annoyance Rating Response Form and offer you a selection of magazines to read.

There are a few rules that you must follow during this part of the experiment. During the actual listening sessions, no smoking or talking is permitted. Besides rating the aircraft sounds, your main task will be to read a magazine of your choice. Please choose some long articles to read, rather than just browsing and turning the pages. You may take more than one magazine with you to your seat if you wish.

During the session, both video and audio monitoring will be employed for your safety. The experimenter will be able to see you and hear you at all times. In addition, each listening session will be recorded on video tape in order to keep a permanent record. These video tapes will be used exclusively for scientific and archival purposes. They will not be broadcast or shown to the public. As with all

personal data collected during this study, these video tapes will be kept confidential.

You have the right to stop the experiment at any time by loudly saying "STOP". However, unless it is absolutely necessary, we ask you not to stop the experiment, but rather to simply get up and leave the auditorium if you feel that you cannot continue. Your decision to stop or quit will in no way prejudice you for future experiments, and you will be paid for your participation up to that point. During the break, the experimenter will show you the bathroom and where you can get soft drinks. Please do not enter the barn or house.

You are free to talk among yourselves and with the staff during the breaks, but please do not discuss your opinions, judgments, impressions, or feelings about the experiment or about any of the sounds with anyone else who is in the experiment or may be in the experiment. Since you never know who may be in the experiment, for a period of about two months, we would appreciate your not discussing the details of the experiment with anyone except immediate family members who are not in the experiment.

At the end of your four experimental sessions, you will fill out a Post-Experiment Questionnaire concerning your overall impressions of the experiment. This questionnaire is not invasive and does not contain any personal or embarrassing questions. At the beginning of the experiment, you will be required to sign a consent form. This form has been devised for your safety and protection.

Before the first 50-minute listening session, you will have a brief Practice Session containing only five sounds. This Practice Session is to acquaint you with the types and range of aircraft sounds that you are likely to hear during the experiment and to familiarize you with the response form and procedures. Fill out the form and rate these five practice sounds as you would for the main experiment. You will be given feedback on how well you are doing in following the instructions and procedures. Then we will begin the main experiment. If you have any questions, either now or at any time during the breaks, please ask.

INSTRUCTIONS FOR OUTDOOR EXPERIMENT (O)

Welcome. In this part of the experiment you will be listening to aircraft sounds in an open pasture. Please sit in your marked seat. Each two-hour experimental session will be divided into two listening periods of about 50 minutes duration, with a short break between. During each 50-minute listening period you will hear 27 aircraft sounds while you read a magazine. You should rate the annoyance of each aircraft sound on the Annoyance Rating Response Form in front of you.

You will rate sounds 1 through 27 during the first 50-minute period and sounds 28 through 54 during the second period. The experimenter will periodically tell you which sound will come next so that you can keep your place. If you lose your place, draw a horizontal line at the place where you think you got out of step and continue in the proper order. Please try not to lose your place. Occasionally, you may hear the sounds from real aircraft flying overhead. Please ignore those sounds.

Make sure that you rate every aircraft sound after the peak or loudest part has occurred, but we suggest that you wait until the sound has begun to recede or fade before you make your judgment. Now read your Annoyance Rating Response Form carefully, if you have not already done so. The experimenter will tell you how to fill in the top of your Annoyance Rating Response Form and offer you a selection of magazines to read.

There are a few rules that you must follow during this part of the experiment. During the actual listening sessions, no smoking or talking is permitted. Besides rating the aircraft sounds, your main task will be to read a magazine of your choice. Please choose some long articles to read, rather than just browsing and turning the pages. You may take more than one magazine with you to your seat if you wish.

During the session, both video and audio monitoring will be employed for your safety. The experimenter will be able to see you and hear you at all times. In addition, each listening session will be recorded on video tape in order to keep a permanent record. These video tapes will be used exclusively for scientific and archival purposes. They will not be broadcast or shown to the public. As with all

personal data collected during this study, these video tapes will be kept confidential.

You have the right to stop the experiment at any time by loudly saying "STOP". However, unless it is absolutely necessary, we ask you not to stop the experiment, but rather to simply get up and leave the auditorium if you feel that you cannot continue. Your decision to stop or quit will in no way prejudice you for future experiments, and you will be paid for your participation up to that point. During the break, the experimenter will show you the bathroom and where you can get soft drinks. Please do not enter the barn or house.

You are free to talk among yourselves and with the staff during the breaks, but please do not discuss your opinions, judgments, impressions, or feelings about the experiment or about any of the sounds with anyone else who is in the experiment or may be in the experiment. Since you never know who may be in the experiment, for a period of about two months, we would appreciate your not discussing the details of the experiment with anyone except immediate family members who are not in the experiment.

At the end of your four experimental sessions, you will fill out a Post-Experiment Questionnaire concerning your overall impressions of the experiment. This questionnaire is not invasive and does not contain any personal or embarrassing questions. At the beginning of the experiment, you will be required to sign a consent form. This form has been devised for your safety and protection.

Before the first 50-minute listening session, you will have a brief Practice Session containing only five sounds. This Practice Session is to acquaint you with the types and range of aircraft sounds that you are likely to hear during the experiment and to familiarize you with the response form and procedures. Fill out the form and rate these five practice sounds as you would for the main experiment. You will be given feedback on how well you are doing in following the instructions and procedures. Then we will begin the main experiment. If you have any questions, either now or at any time during the breaks, please ask.

GREETING (Indoors)

Welcome to the NASA–Langley listening auditorium. This is just a reminder of some of the highlights from the Instructions that you have already read.

- Please sign and hand in your Voluntary Consent form now.
- We will begin with a Practice Session consisting of five sounds.
- You should read articles from your magazine and rate each aircraft sound.
- Be sure to rate each sound and try not to lose your place.
- Always pay attention to the words that form the basis of the annoyance scale.
- Are there any questions?
- Begin the Practice Session now.

GREETING (Outdoors)

Welcome to our open pasture. This is just a reminder of some of the highlights from the Instructions that you have already read.

- We will begin with a Practice Session consisting of five sounds.
- You should read articles from your magazine and rate each aircraft sound.
- Be sure to rate each sound and try not to lose your place.
- Always pay attention to the words that form the basis of the annoyance scale.
- Are there any questions?
- Begin the Practice Session now.

Informed Consent Form

For Aircraft Noise Listening Experiment (K)

You are invited to participate in a study of the human response to certain kinds of aircraft sounds. We hope to learn the best way to measure these aircraft sounds so as to reflect the individual and community response to such noise sources. This will help the government and communities to determine the impact of aircraft operations on the local population. You have been selected as a possible participant in this study because you have normal hearing, you are between 18 and 55 years of age, and you live in the area where the study is being conducted.

If you decide to participate, we (Kenneth Plotkin, Kevin Bradley, John Molino, John Farbry, Linda Langley, and Katrin Helbing), the experimenters, will present you with reproduced aircraft sounds and ask for your response to these sounds. You will listen to these sounds in groups of six people seated in (1) a small listening auditorium at the NASA-Langley Research Center, and (2) a small open field in a rural area. You will listen to tape-recorded and simulated aircraft takeoff and flyby sounds. These sounds will be reproduced for you by a system of loudspeakers and you will be requested to rate the annoyance of these sounds according to scales and questionnaires. You will listen to these sounds during two-hour-long listening sessions (including short breaks). You will hear anywhere between 60 and 128 such sounds during a single two-hour session. You will participate in four such sessions. All of your participation will be completed within a four- to six-week period.

Any potential risks to you as a participant in this experiment are minimal. Some of the aircraft flyby sounds that you will hear may be quite loud, but they will be very brief. They may be unpleasant or annoying, but they cannot damage your hearing. The average two-hour sound level will not exceed 80 to 84 dBA. The Occupational Health and Safety Administration (OSHA) limit for two (2) hours of exposure per workday is 100 dBA. The Air Force Regulation 161-35 limit for two (2) hours of exposure per workday is 92 dBA. Thus the risk of hearing damage may be considered to be minimal to negligible. Other natural risks such as tripping, falling, or slipping are also minimal, no more than would be normally associated with entering or exiting a building or an open field area, or engaging in simple activities while listening to sounds. Your entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and if you desire further information you may contact Dr. Kenneth J. Plotkin at 703/892-6700.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Only group average data or individual data identified by means of a code will be published or released. All videotapes will be kept as confidential material. Only the experimenters named above will have access to confidential information which could be identified with you. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 USC 552a, and its implementing regulations.

For your participation in this experiment you shall be entitled to payment of $144 as follows: $22 for each of two sessions in the NASA auditorium, $40 for each of two sessions in the open field, plus a $20 bonus for completing all four sessions. In the event that you revoke your consent or your participation is terminated for any other reason, you shall be entitled to receive payment on a pro-rata basis for the portion completed.

By signing this form in the space provided below, you are certifying the validity of the following statements: The decision to participate in this research is completely voluntary on your part. No one has coerced or intimidated you into participating in this program. You are participating because you want to. The experimenter has adequately answered any and all questions you have about this study, your participation, and the procedures involved. You understand that Dr. Kenneth J. Plotkin at 703/892-6700 will be available to answer any questions concerning procedures throughout this study. You understand that if significant new findings develop during the course of this research which may relate to your decision to continue participation, you will be informed. You further understand that you may withdraw this consent at any time and discontinue further participation in this study without prejudice to your entitlements. You also understand that the medical monitor of this study may terminate your participation in this study if he or she feels this to be in your best interest.

You will be given a copy of this form to keep.

Date: ____________________ Time: ______________ AM PM

Participant Print Name: ______________________________

Signature: ______________________________

Social Security Number: ______________________________

Experimenter Print Name: Kenneth J. Plotkin

Signature: ______________________________

Witness Print Name: ______________________________

Signature: ______________________________

Informed Consent Form

For Aircraft Noise Listening Experiment (O, I)

You are invited to participate in a study of the human response to certain kinds of aircraft sounds. We hope to learn the best way to measure these aircraft sounds so as to reflect the individual and community response to such noise sources. This will help the government and communities to determine the impact of aircraft operations on the local population. You have been selected as a possible participant in this study because you have normal hearing, you are between 18 and 55 years of age, and you live in the area where the study is being conducted.

If you decide to participate, we (Kenneth Plotkin, Kevin Bradley, John Molino, John Farbry, Linda Langley, and Katrin Helbing), the experimenters, will present you with reproduced aircraft sounds and ask for your response to these sounds. You will listen to these sounds in groups of six people seated in a small open field in a rural area. You will listen to tape-recorded and simulated aircraft takeoff and flyby sounds. These sounds will be reproduced for you by a system of loudspeakers and you will be requested to rate the annoyance of these sounds according to scales and questionnaires. You will listen to these sounds during two-hour-long listening sessions (including short breaks). You will hear anywhere between 60 and 128 such sounds during a single two-hour session. You will participate in two such sessions. All of your participation will be completed within a four- to six-week period.

Any potential risks to you as a participant in this experiment are minimal. Some of the aircraft flyby sounds that you will hear may be quite loud, but they will be very brief. They may be unpleasant or annoying, but they cannot damage your hearing. The average two-hour sound level will not exceed 80 to 84 dBA. The Occupational Health and Safety Administration (OSHA) limit for two (2) hours of exposure per workday is 100 dBA. The Air Force Regulation 161-35 limit for two (2) hours of exposure per workday is 92 dBA. Thus the risk of hearing damage may be considered to be minimal to negligible. Other natural risks such as tripping, falling, or slipping are also minimal, no more than would be normally associated with entering or exiting a building or an open field area, or engaging in simple activities while listening to sounds. Your entitlement to medical care or compensation in the event of injury are governed by federal laws and regulations, and if you desire further information you may contact Dr. Kenneth J. Plotkin at 703/892-6700.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. Only group average data or individual data identified by means of a code will be published or released. All videotapes will be kept as confidential material. Only the experimenters named above will have access to confidential information which could be identified with you. Records of your participation in this study may only be disclosed according to federal law, including the Federal Privacy Act, 5 USC 552a, and its implementing regulations.

For your participation in this experiment you shall be entitled to payment of $80 as follows: $40 for each of the two sessions. In the event that you revoke your consent or your participation is terminated for any other reason, you shall be entitled to receive payment on a pro-rata basis for the portion completed.

By signing this form in the space provided below, you are certifying the validity of the following statements: The decision to participate in this research is completely voluntary on your part. No one has coerced or intimidated you into participating in this program. You are participating because you want to. The experimenter has adequately answered any and all questions you have about this study, your participation, and the procedures involved. You understand that Dr. Kenneth J. Plotkin at 703/892-6700 will be available to answer any questions concerning procedures throughout this study. You understand that if significant new findings develop during the course of this research which may relate to your decision to continue participation, you will be informed. You further understand that you may withdraw this consent at any time and discontinue further participation in this study without prejudice to your entitlements. You also understand that the medical monitor of this study may terminate your participation in this study if he or she feels this to be in your best interest.

You will be given a copy of this form to keep.

Date: ____________________ Time: ______________ AM PM

Participant Print Name: ____

Signature: ____

Social Security Number: ____________________________

Experimenter Print Name: ____________________________________

Signature: ____

Witness Print Name: ____

Signature: ____

APPENDIX C

Additional Analyses

C.1 Effect of Presentation Order and Direction

In the current experiments, each participant heard each stimulus twice, once in each of two sessions. It is important, for methodological validity, that there not be a significant difference between the first and second presentations. Sounds were also presented in random direction, from either the front or the rear. The validity of the current results is not affected by differences (if any) between presentation direction, since direction was balanced. The effect of direction is of interest, however, because previous experiments have used only a single direction. If direction is not significant, then future experiments can be simplified by not having to change direction.

Differences between first and second presentation, and front or rear approach direction, have been tested by means of t-tests applied to the data partitioned across level. These are presented in Table C1. Shown are the average annoyance rating, at each level, for front and rear presentation and for first and second presentation, the differences, and the value of t . For the difference to be significant at the 0.05 level, t must exceed 1.96. Ideally, all t values would be below this threshold. A number of t values exceed 1.96, indicating a statistically significant difference. These are highlighted.

The following features may be seen in Table C1:

- Presentation order was not significant for the OR or IV experiments, nor for the two higher levels of K1.

- Presentation order was always significant in experiment K2. It was found, however, that there was a consistent difference in sound system amplification between the first and second presentation in this experiment. This accounts for much of the difference.

- Direction of approach was significant in about half the cases, but without a clear pattern as to when.

Table C1

t-Test For Direction and Repeat

a. K1, N = 396

	65 dB	**75 dB**	**85 dB**	**95 dB**
Average Score, Front	1.536	2.878	4.219	5.560
Average Score, Rear	1.713	3.023	4.333	5.644
Difference	0.177	0.145	0.114	0.084
t	**2.08**	1.70	1.34	0.98
Average Score, First	1.479	2.839	4.200	5.560
Average Score, Second	1.753	3.051	4.349	5.647
Difference	0.274	0.212	0.149	0.087
t	**3.21**	**2.49**	1.75	1.02

b. K2, N = 396

	80 dB	**90 dB**	**100 dB**	**110 dB**
Average Score, Front	1.939	3.454	4.970	6.485
Average Score, Rear	2.223	3.660	5.096	6.532
Difference	0.284	0.206	0.126	0.047
t	**3.33**	2.42	1.48	0.55
Average Score, First	1.928	3.660	4.906	6.395
Average Score, Second	2.271	3.417	5.153	6.594
Difference	0.343	0.243	0.247	0.199
t	**4.02**	**2.85**	**2.90**	**2.33**

Table C1 (Continued)

c. OR, N = 414

	90 dB	100 dB	110 dB
Average Score, Front	2.762	4.332	5.902
Average Score, Rear	2.777	4.500	6.224
Difference	0.015	0.168	0.322
t	0.18	**2.01**	**3.80**
Average Score, First	2.730	4.415	6.100
Average Score, Second	2.796	4.417	6.038
Difference	0.066	0.042	0.062
t	0.79	0.50	0.74

d. IV, N = 690

	90 dB	110 dB
Average Score, Front	2.398	5.878
Average Score, Rear	2.551	5.978
Difference	0.153	0.100
t	**2.37**	1.55
Average Score, First	2.489	5.914
Average Score, Second	2.447	5.942
Difference	0.042	0.028
t	0.65	0.43

The largest differences in Table C1, when converted from rating scores to sound level (using the factors at the bottom of Table 27) are about 2 dB. This difference is small compared to the magnitude of the onset rate effect.

It is concluded that a statistically significant difference did occur between a number of front–rear and first–second presentations. The largest consistent difference, first–second presentation in K2, was apparently due to a difference in presented sound level. The largest differences are about 2 dB, which is not of great practical significance.

C.2 Results of Post-Experiment Questionnaire

The results of the Post-Experiment Questionnaire are given at the end of this appendix, where a copy of the questionnaire has been filled in with summary responses from the 79 research participants who completed the questionnaire. These summary responses are discussed below.

The overall rating for the entire group of aircraft flyover sounds as a whole averaged between "moderately" and "decidedly" annoying, closer to "decidedly" (4.88 average on a scale of 0 to 8 across 79 responses). This average rating from the questionnaire may be compared with the grand mean of 4.17 for all the individual annoyance ratings observed in all four experiments. The difference is 0.71 annoyance unit. The general overall correspondence between these ratings confirms that people are able to integrate annoyance ratings for individual flyover events to form an overall or epoch-based annoyance rating concerning a number of acoustic events heard during a specified period. This is an important methodological finding for future planned experiments where such epoch-based judgments will play an important role. The bias toward somewhat higher annoyance ratings from the questionnaire is an empirical finding to be evaluated in future studies. It may be that people tend to remember the worst flyover events the most, and thus the integrated epoch ratings will be greater than the average of the individual flyover ratings made immediately after each event. In any case, the absolute magnitude of the overall annoyance experience indicates that MTR noise could be a significant environmental issue in some communities.

The majority of the participants found that certain types of sounds stood out as being particularly less or more annoying than other sounds. Thus considerable variability might be expected around this average for individual annoyance judgments, as indeed was observed in the individual annoyance ratings obtained from the four experiments. This is quantified in the analysis in Section 4. Nevertheless, despite this variability, both the quantitative data and the questionnaire results revealed important distinctions among the various acoustic stimuli.

About 76 percent of the participants (60 out of 79) said that there were some sound events which they found to be less annoying than others. The events which seemed to be least annoying were the ones of short duration, or quick events (24 responses). The main reason was that these sounds were over quickly and did not need to be tolerated as long (17 responses). This judgment was contradicted by an almost equal number (23) who considered quick or sudden sounds to be most annoying.

Eleven of the participants found that the longer events were less annoying, since they were often quieter and less startling than other events. Events which were quiet were found to be the second least annoying (16 responses). These sounds tended to be less harsh to the listeners and were not disruptive to their reading. Low-frequency sounds also were rated more favorably (10 responses), as were far away sounds (8 responses). Far-away sounds would tend to be dominated by low frequencies, since the high frequencies are absorbed to a greater extent by the atmosphere. Thus the finding that low-frequency sounds were generally lower in annoyance corroborates examination of tone correction in Sections 4.2.2 and 4.2.3.

About 91 percent of the participants (72 out of 79) identified certain flyover sounds as more annoying than other sounds. Flyover events which were loud were the most annoying (26 responses), followed closely by events which were quick or sudden (23 responses). These results were in accordance with the strong roles played by sound level and onset rate in the quantitative data obtained from the four experiments. In contrast, however, slow events were also found by some to be more annoying than other events (14 responses). The complaint about these slow events was that they "drag on" and had to be endured for a longer period of time. This tendency agrees with the possible increase in annoyance for sounds with relatively slow onset rates (between 1 and 6 dB/second) initially suggested in Figure 2. To a certain extent, such an increase was associated with the anomalous sound onset rate of 6.5 dB/second. High-frequency sounds were also annoying (15 responses), as were ones which were not constant (13 responses). The former finding is in accord with the results for spectral content. The latter finding represents an interesting indication that time-varying envelope effects or modulations may be important variables to track in future experiments. The low-frequency rumble found in the B-1B flyover could possibly be an example of where a time-varying modulation may enhance the annoyance of the sound.

The reason many participants disliked particular flyover events, especially the loud, quick, or high-frequency ones, was because they were startling (21 responses) and also distracting (8 responses). Many events were very annoying simply because they were extremely loud (15), slow (16), or the frequency was high (7). Some of these sounds caused actual physical discomfort, such as pain or tingling in the ears, or vibrations (6 responses).

"Quick" was given as an answer for both the less and more annoying questions. A possible reason for this inconsistency may be a problem in defining the word "quick". It could mean that the sound was over quickly and therefore not annoying, or that the noise came on quickly and startled the individual. This possible inconsistency in definition may be responsible for some confounding of results in the present questionnaire. Nonetheless, the questionnaire results do reflect many of the patterns observed in the annoyance ratings made to individual flyover events. In particular, they confirm the strong effects of stimulus sound level, onset rate, and duration found in the quantitative results, as well as some of the weaker effects of acoustic spectrum (aircraft type) and decay rate.

When asked to rank certain sound qualities as to their annoyance factor ("1" as most annoying, "6" as least annoying), the intensity of the sound was ranked as most annoying (2.09), followed by the onset rate (2.95) and duration of the event (3.19). Tonality (3.48) and the low frequency of the sound (3.66) were less annoying, and the decay rate (4.84) was least annoying. In general, this relative ranking of sound characteristics as to the annoyance produced reflects the overall results for the corresponding psychoacoustic variables obtained from the analyses of variance performance on the quantitative data.

Most participants were either somewhat (38) or minimally (32) affected by the sounds during the reading task. Three participants were not affected at all, while 6 were considerably affected. The most prevalent complaint by the participants that were affected was that the sounds were distracting and caused them to lose their place in their reading (17). This emphasizes the importance of the listener's activity in determinations of noise annoyance. The distraction of the sounds tended to interfere with ongoing behavior (variable 1 in the list of non-acoustic variables found in Section 2.1.1). A few of the participants (13) were affected in general by feeling nervous or jumpy during the experiment. Here the questionnaire revealed indications of possible physiological responses relating to startle and arousal in the nervous system (number 6 of the non-acoustic variables). Physical discomfort, such as head or ear aches, was mentioned by 5 people. Three participants were able to block the sounds out after listening to them for a while (habituation).

Many of the participants (29) lost their place at some point during the experiment. Some participants interpreted the question as referring to getting lost on the rating scale (15), while others thought it meant getting lost in their reading task (15). Those participants who lost their place on the rating form for the most part reported that it was due to being engrossed in the article they were reading (9). Others thought that they missed a flyover event because it was barely audible (4) or for other reasons (2). Other participants lost their place in the article or misread because they were startled by a flyover event, or because it caused them to lose their concentration. These results once again emphasize the importance of activity interference as a possible determinant of noise annoyance.

The present occupations of the research participants were varied: student (12), homemaker (11), professional (10), sales (10), laborer (7), waitress (5), unemployed (7), other (20), and 3 people did not answer. Thus the demographics of the sample of participants (variable 2 in the list of non-acoustic effects) indicated a spread of occupational backgrounds. It also indicated that none of the participants derived their income directly from the Air Force, minimizing the risks of special knowledge, expectations, or biases (non-acoustic variable number 3). Many participants (31) reported loud noises in their present occupations. These loud noises included: airplanes (8), machinery (6), and human noises (5). Twenty-five people reported working around loud noises in their previous occupations. These people described the same types of noises as were mentioned under their present occupations. Thus previous noise exposure (non-acoustic variable number 4) represented a reasonable past history, with less than half of the respondents reporting loud noises in present or previous occupations.

Out of the 79 participants, only two are or were previously pilots. Fourteen of the respondents have worked with or near airplanes either with NASA (3), at Langley (4), as aircraft crews (5), or other (4). Fourteen respondents have previously worn hearing protectors against aircraft noise. Thus only two out of 79 respondents were pilots, and only 14 ever worked with airplanes. This confirms the adequacy of the sample demographics (non-acoustic variable number 2) and listener attitude (non-acoustic variable number 3) factors as concerns the present sample of research participants. Sixty-one of the participants have flown in an airplane before. Of these 61 people, 19 have flown a few times in their lives, 14 fly once every few years, 13 fly a few times a year, 8 fly once a year, and 7 fly once a month.

Forty-nine participants have lived near an airport or near aircraft operations. Sixty-seven percent of these people have been annoyed by the noise. The takeoff and landing of the planes were identified as being annoying (8), as were sounds which caused activity interference (13), such as disruption while talking on the telephone. Six people reported that they had gotten used to the noise from nearby airports. In addition, 45 people out of the sample of 79 respondents have been exposed to unusually high levels of noises such as railroad, traffic, industrial noises, etc. (non-acoustic variable number 4). Although this previous noise exposure history is somewhat high, it is not unusual for the geographic locale of the respondent sample.

In rating the overall experiment, 62 participants responded positively, such as "good, interesting, fun, well designed", etc. The three negative responses included "hot, loud/annoying, and time consuming." Suggestions to improve the experiment included: improve the physical test area (15), improve the experimental design (18), and fine as is (12).

Post-Experiment Questionnaire

Name: ____________________ Participant # N=79

Date: 5/21/90 to 6/18/90 Time ________

1. For the entire experiment, as a whole, how would you rate the overall group of all the airplane sounds that you heard? Use the same scale that you used to rate the individual sounds.

   Overall Rating: 4.88

2. Did any of the types of sounds stand out as being particularly less annoying than the others? No answer 1

   Yes 60 No 16 If yes, which ones? Describe in words Quick - 24, Quiet - 16

   Slow-11, Low frequency-10, Far away-8, Constant-5, Other-10, No answer-18.

   Please describe why you thought that they were less annoying: Quick-17, Quiet-13,

   Not distracting-6, Not startling-5, Far away-4, Other-10, No answer-23

3. Did any of the types of sounds stand out as being particularly more annoying than the others? No answer-1

   Yes 72 No 6 If yes, which ones? Describe in words Loud-26, Quick-23,

   High frequency-15, Not constant-13, Slow-14, Not far away-3,

   Other-11, No answer-11.

   Please describe why you thought that they were more annoying:

   Startling-21, Slow-16, Loud-15, Distracting-8, High frequency-7,

   Physical discomfort-6, Not far away-5, Quick-3, Other-7,

   No answer-15.

4. How do you think the sounds affected the reading task that you were doing?

   Check one: Not at all 3 Somewhat 38

   Minimally 32 Considerably 6

   Please describe any effects that you experienced:

   Distracting-17, Startling-13, Physical discomfort-5, Grown accustomed-3, None-3, Other-6, No answer-29.

5. Did you ever lose your place during the experiment? Yes 29 No 50

   If yes, when and why do you think this happened? Rating form: Engrossed in article-9, sound barely audible-4, Other-2. No answer-51.

   Reading: Misread article-15.

Participant #________

6. Please rank the following qualities of the airplane sounds that you heard as to their importance in contributing to your annoyance judgments. Put a number "1" after the quality that annoyed you the most. Put a number "2" after the next most annoying quality. By a process of elimination, put a "3" next to the third most annoying, and so on, until you have ranked all six items, with number "6" being the least annoying. Make sure all blanks are filled in; use each number only once, but use all six numbers.

Quality	*Rank*
How long the sound lasts (duration)	3.19
How strong the peak sound is (intensity)	2.09
How fast the sound comes on (onset rate)	2.95
How much whine the sound has (tonality)	3.48
How low and rumbly the sound is (low frequency)	3.66
How slow the sound fades away (decay rate)	4.84

7. What is your present occupation? Student-12, Homemaker-11, Professional-10, Sales-10, Laborer-7, Waitress-5, Unemployed-7, Other-20, No answer-3.

Are there any loud noises in your present occupation? Yes 31 No 43 No ans.-5

If yes, what kind of noises? Airplane-8, Machinery-6, Human-5, Other-8, No answer-48.

Were there any loud noises in any previous occupation (including the military)?

Yes 25 No 51 No answer-3

If yes, what was that occupation? Laborer-9, Military-6, Professional-6, Other-4, No answer-53.

What were the noises? Machniery-14, Airplane-5, Other-9, No answer-53.

8. Have you ever been a pilot? Yes 2 No 77

Have you ever worked with or near airplanes? Yes 14 No 59 No answer-6

If yes, in what capacity? NASA-3, Langley AFB-4, Aircraft crew-5, Other-4, No answer-62.

Did you ever wear hearing protectors against aircraft noise? Yes 14 No 58 No answer-7

Participant #_________

9. Have you ever flown in an airplane? Yes 61 No 18

   If yes, on the average, how often have you flown? Check one:

   a. A few times in your life 19
   b. Once every few years 14
   c. Once a year 8
   d. A few times a year 13
   e. Once a month 7

   No answer 18

10. Have you ever lived near an airport or near aircraft operations?

    Yes 49 No 30

    If yes, have you ever been annoyed by the noise? Yes 33 No 17 No answer-29

    Explain briefly Activity interference-13, Take-off/landing-8, Live/work near airport/base-8, Grown accustomed-6, Other-3, No answer-41.

11. Have you ever been exposed to unusually high levels of any of the following noises? Check all that apply:

a. Railroad noise	21	e. Truck noise	19
b. Traffic noise	29	f. Outdoor machinery noise	21
c. Industrial noise	18	g. Shipboard noise	8
d. Aircraft noise	30	No answer	24

12. How would you rate the overall experiment? Positive (well designed, good, interesting, etc.)-62, Negative (hot, loud, time consuming)-3, Other-20.

13. How might the experiment be improved? Improve design-18, Improve test area-15, Fine as is-12, Other-13, No answer-23.

14. Do you have any other comments? Positive (liked working with people, interested in being in another experiment, excellent,etc.)-13, Other-7, No answer-59.