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ATTENUATION OF AIRCRAFT NOISE BY WOOD-SIDED AND BRICK-VENEERED FRAME HOUSES

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16. Abstract

Aircraft noise attenuation characteristics were computed for two houses at Wallops Station, Virginia. These houses, one a wood-sided frame house and the other a brick-veneered frame house, were used as test houses in a study of the subjective evaluation of aircraft noise. Indoor and outdoor noise data used in this study were obtained by using a Convair CV-880 aircraft and a Lockheed 1049G aircraft as sound sources. Indoor noises were recorded using a pre-emphasis filter network which permitted improved recovery of low-intensity, high-frequency data in the indoor channels. Aircraft noise attenuation characteristics based on a 1/3 octave band frequency analysis were computed from recorded noise measurements for four interior locations in each house. The effect of house and room structures on externally generated aircraft noise as measured indoors was also expressed by tabulating the differences between outdoor and indoor noise levels in thirty-six standard noise measures. Attenuation characteristics were used to compute, from outdoor noise data, estimated indoor values of the thirty-six noise measures, and a comparison between estimated and actual values showed that the attenuation data are useful for indoor noise prediction purposes.

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CONTENTS

ILLUSTRATIONS

TABLES

SUMMARY

Aircraft noise attenuation characteristics were computed for two houses at Wallops Station, Virginia. These houses, one a wood-sided frame house and the other a brick-veneered frame house, were used as test houses in a study of the subjective evaluation of aircraft noise conducted in October and November of 1967. Indoor and outdoor noise data used in this study were obtained by using a Convair CV-880 aircraft and a Lockheed 1049G aircraft as sound sources. Indoor noises were recorded using a pre-emphasis filter network which permitted improved recovery of low-intensity, high-frequency data in the indoor channels. Aircraft noise attenuation characteristics based on a 1/3 octave band frequency analysis were computed from recorded noise measurements for four interior locations in each house. The effect of house and room structures on externally generated aircraft noise as measured indoors was also expressed by tabulating the differences between outdoor and indoor noise levels in thirty-six standard noise measures. Attenuation characteristics were used to compute, from outdoor noise data, estimated indoor values of the thirty-six noise measures, and a comparison between estimated and actual values showed that the attenuation data are useful for indoor noise prediction purposes. Comparison of the average house attenuation characteristics derived in this study and average characteristics reported in the literature indicates that the Wallops Station test houses are reasonably typical structures vis-a-vis their aircraft noise attenuation characteristics.

ATTENUATION OF AIRCRAFT NOISE BY WOOD-SIDED AND BRICK-VENEERED FRAME HOUSES

James R. Young

INTRODUCTION

During the months of October and November 1967 an experimental study of the subjective evaluation of various aircraft noises was conducted at Wallops Station, Virginia by NASA Langley Research Center and Stanford Research Institute.[1*] In the course of this experiment subjects were asked to judge the relative annoyance of different types of aircraft noises when heard indoors or outdoors.

Arrangements were made so that 30 subjects judged aircraft noises heard in house K-13, a one-story brick-veneer structure, and the remaining 30 indoor subjects judged noises heard in house H-11, a one-story wood-sided frame house. Both houses were completely furnished with carpets, drapes, and the normal complement of chairs, tables, sofas, etc., that would be found, on the average, in homes of these types. Space limitations prevented furnishing bedrooms with beds, but other normal bedroom furnishings were present. Four rooms in each house were occupied by subjects, a dining room, a living room, and two bedrooms. Floor plans and photographs which describe these two houses in detail appear in the appendix.

This report describes the aircraft noise attenuation characteristics of the two houses and the rooms within the houses which were occupied by test subjects during the psychoacoustic experiments. The primary information required to obtain these attenuation characteristics is a specification, for a given room or location in a house, of frequency-spectrum differences between a noise recorded or observed outside the house and the same noise observed inside the house. In general, the house structures attenuated low-frequency components of aircraft noise relatively less than high-frequency components. Because high-frequency spectrum components were so greatly attenuated as they propagated through the house structures, special pre-emphasis filtering of the indoor noise

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* Superscripts appearing in the text are reference numbers for the references listed at the end of this report.

signals was necessary in order to recover data from which attenuation characteristics could be calculated. Moreover, because these houses and, in fact all houses, are complex structures in their response to external acoustic stimulation, the noise attenuation characteristics of a house vary from room to room (and within rooms) and with the position of the external noise source. In this study these variables, position of measurement inside the house, and position of the external noise source were treated as follows:

(1) Measurements of indoor noise were made at locations in the houses where subjects were, or had been seated. The microphone was placed at approximately ear-level of seated subjects and equidistant from subjects arranged in a relatively small circle about the microphone.

(2) Aircraft were flown along a well-defined and constant flight track. Though the external noise source thus varied its position through the course of a single flyby, the pattern of source-movement was similar for the series of noise measurements consisting of many separate flybys.

Since the noise transmission or attenuation properties of a house as measured at some given interior point vary with the position of the external source, and since the source in this case moves in a certain pattern defined by the aircraft flight path and aircraft altitude and speed, it follows that the attenuation characteristic at this point cannot be described by a single curve or set of data points except in some average sense. For this work three different "average" characteristics were defined. One of these characteristics was superior to the others for the purpose of predicting certain useful physical measures of noise recorded in the test structures. No attempt was made in this study to define attenuation characteristics that permit the prediction of a complete noise-time history of an indoor noise.

When attenuation data for the individual rooms in a house are averaged, a composite "house attenuation" characteristic can be specified. This averaging was done for the two houses studied here, and the data were compared to some data previously published for structures in Boston, New York, Miami, and Los Angeles.[2] This comparison indicates that the test houses studied here are fairly typical of a broad population of structures insofar as noise attenuation is concerned. This fact is useful and reassuring in interpreting the psychological data derived from subjects seated in the Wallops Station houses during the aircraft noise evaluation experiment.

DATA COLLECTION AND ANALYSIS

General Description of Data Collection

The data used for this study of house attenuation were obtained December 11 and 12, 1968, at Wallops Station, Virginia. Two aircraft were used on these days to generate sounds similar to those used in the earlier psychoacoustic tests conducted in October and November of 1968. One aircraft, a four-engine propeller-driven Lockheed 1049G radar-surveillance airplane, was flown at approximately 1200 ft altitude and at METO power along a straight and level path passing directly over the two test houses in the manner of the earlier tests. A second aircraft, a four-engine CV-880 turbofan airplane, was flown at approximately 2000 ft altitude and at take-off power along the same flight track.

Data used to compute the attenuation characteristics of house K-13 were recorded December 11, 1968. A total of nine CV-880 flights and 16 1049G flights were recorded. On the following day, recording equipment and instruments were moved to house H-11 where 12 CV-880 flights and ten 1049G flights were recorded.

Data Recording and Instrumentation

Personnel under the direction of NASA Langley Research Center, Hampton, Virginia installed, calibrated, and operated the recording instruments at the test houses. This instrumentation consisted, basically, of two direct tape recorders with four recording channels in each instrument, six one-inch condenser microphones, and six sound level meters for ranging the analog noise data. A timing track with a centrally generated time code and voice annotation was recorded on one channel of each tape machine. For all flights of the CV-880 aircraft, each of the three data channels of one recording instrument, identified as Station No. 1, had installed a pre-emphasis filter network designed to flatten the noise spectrum expected inside the test houses. The network relative gain characteristic for one of these channel filters is shown in Figure 1. The three channels had nearly identical gain characteristics, differing from the median channel by less than 1 dB at any frequency between 50 Hz and 10,000 Hz.

At each of the two test houses, microphones were located both outside and inside. Two microphones, ranged 10 dB apart in gain, were located outside. At each house four microphones were located inside; one in the dining room (DR), one in the living room (LR), and one in each of two bedrooms (BR1 and BR2). All microphones were placed in the

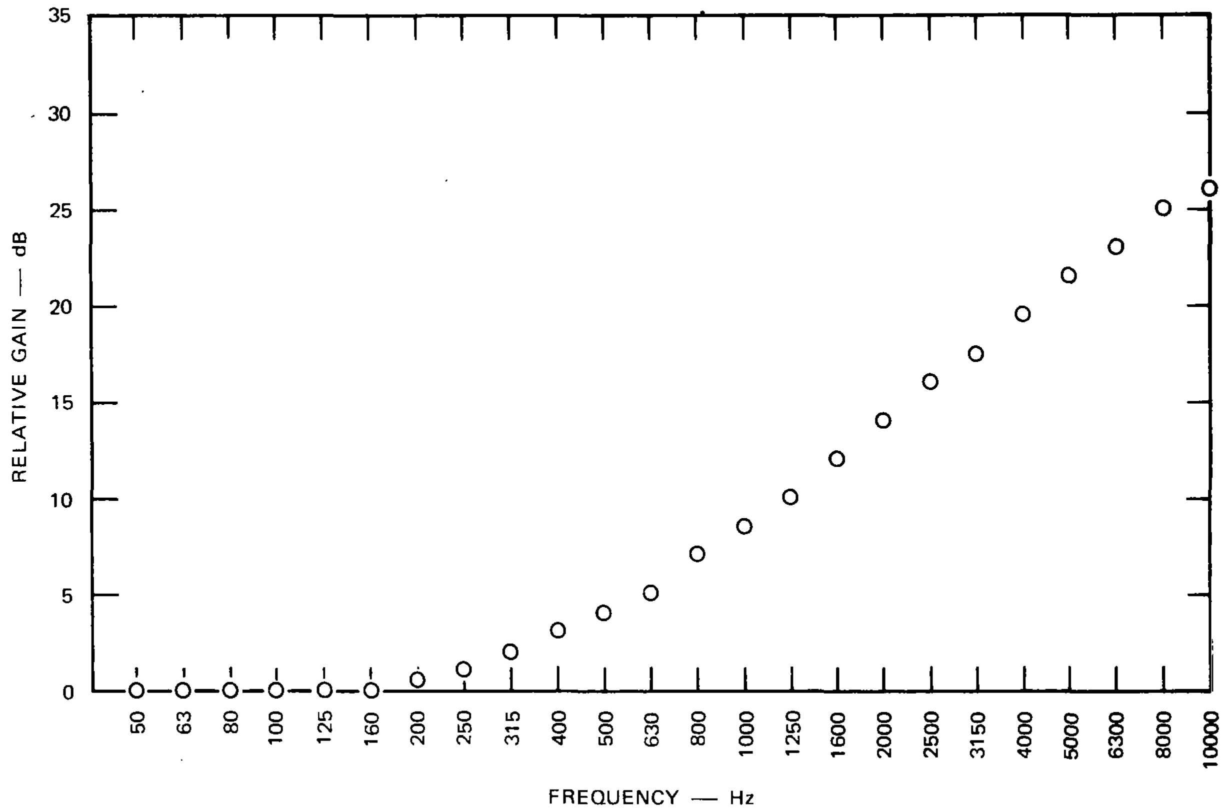

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FIGURE 1 TYPICAL PRE-EMPHASIS GAIN CHARACTERISTIC USED IN RECORDING CV-880 AIRCRAFT NOISE INDOORS locations designated in earlier psychoacoustic tests in order to measure as reliably as possible sounds heard by subjects seated in these areas, indoors and outdoors. Noise data at the two outside locations and in the dining room were recorded on one instrument, identified as Station No. 2, and noise data from the living rooms and bedrooms were recorded on the second instrument, Station No. 1.

Data Analysis

Data Selection.--Eight aircraft flights were selected from the total data set for complete analysis. Four flights were selected for each test house, two 1049G flights and two CV-880 flights. The selection of the specific flights to be used in subsequent analysis was based on the quality of data recorded both indoors and outdoors. Special considerations in this selection were: (1) good overall ranging of data in the available dynamic range of outdoor and indoor recording channels, and (2) adequate intensity of noise-signal components in the frequency range above 1000 Hz in indoor channels. It was found, as expected, that the 1049G aircraft noise spectrum was weighted toward frequencies below 500 Hz and that the CV-880 noise spectrum was weighted relatively more toward frequencies higher than 500 Hz. By using these two classes of disparate spectra, one would expect to find, in a combination of all data, reliable indoor data (data above the level of ambient and recording system noise) covering the widest possible frequency range.

1/3 Octave Band Analysis.--Forty noise events (five indoor and outdoor aircraft noises for each of eight selected flights) were analyzed by means of a parallel 24-channel 1/3 octave band filter bank covering the frequency range 50-10,000 Hz. Each filter output was passed through an envelope detector, smoothed in a manner comparable to that observed on a "slow" sound level meter, and sampled at 1/2-sec intervals. All 24 channels or frequency bands were sampled at virtually the same time (within approximately 10 msec) by a high-speed multiplexer/analog-to-digital converter, and the resulting digital data were stored on magnetic tapes which were used in subsequent data reduction processes.

Each aircraft flight analyzed in this manner yielded five digital records, a record corresponding to the aircraft noise recorded outside a test house and four digital records corresponding to the noises recorded inside the house at the four locations about which test subjects had been seated during the psychoacoustic experiments. The time code recorded on one channel of each analog tape was used to synchronize the data contained in these five digital records so that valid comparisons between indoor and outdoor noise intensities could be made at each sample time. The time error in synchronization using this method was within the range ±1 msec, and for these data this error was judged to be of no consequence.

Further Analysis of Digital Data.--House attenuation in a specified frequency band was defined as the difference between an outdoor noise intensity and a corresponding indoor noise intensity measured in that specific frequency band, instant-by-instant, or as the difference between maximum values of noise intensities measured outdoors and indoors in that band. Since 24 channels, or frequency bands, were used in the 1/3 octave band analysis, a complete house attenuation characteristic consisted of, at most, 24 sets of differences if attenuation were computed instant-by-instant or 24 single numbers if attenuation were computed by calculating only the differences between maximum frequency band values measured outdoors and indoors.

It became clear early in the study that some rule was needed to be used for rejecting data in frequency bands where the aircraft noise did not exceed, by a suitable margin, the level of ambient and system noise present on the analog tape. The rule used was this: the maximum intensity of noise data in any frequency band was required to exceed the level of data in that band at the beginning and end of a data record by 6 dB or more if the channel data were to be judged valid and useful. With this rule in mind, special care was taken during the 1/3 octave band analysis to provide adequate data at the beginning and end of each flight (nominally ambient data) so that valid comparisons between maximum values and "ambient" values could be computed.

After the data in each frequency band were tested to determine the presence or absence of useful data and if such data were present, the band data were smoothed digitally by a four-point smoothing process defined below:

$$S_j = \frac{8}{15} S_j + \frac{4}{15} S_{j-1} + \frac{2}{15} S_{j-2} + \frac{1}{15} S_{j-3} ,$$

where S_j is the jth time sample, S_{j-1} is the previous sample, etc. This process was used to stabilize difference estimates when two frequency bands (one from an outdoor recording and one from an indoor recording) were compared. The smoothing process has no significant effect upon mean values of differences and compensates, to some extent, for the fact that the 1/2-sec sampling rate in each channel is slightly too slow. After smoothing, each band was again tested by the 6-dB rule and data were rejected if the decision criterion was not satisfied. Testing after smoothing was an efficient method for eliminating data in records where spurious "noise spikes" occur. The effect of smoothing is illustrated in Figure 2, where 12 seconds of data in the 630-Hz frequency band are

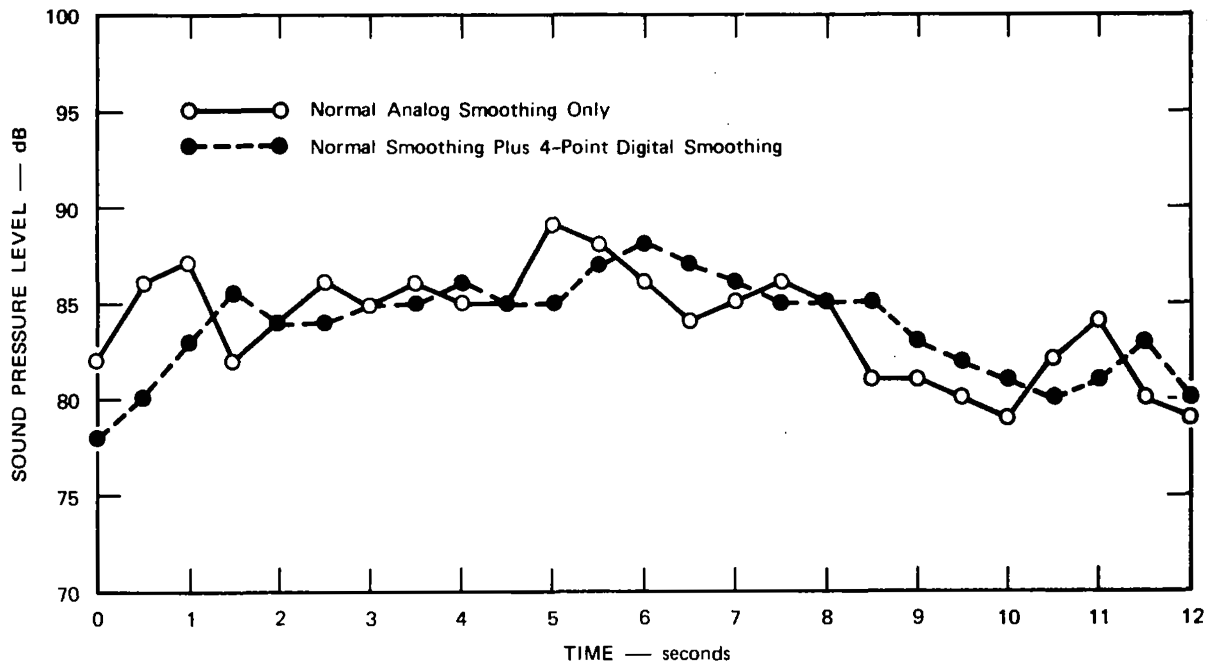

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FIGURE 2 A TYPICAL TIME HISTORY SHOWING THE EFFECT OF 4-POINT DIGITAL SMOOTHING ON A 630-Hz C.F. 1/3 OCTAVE BAND CHANNEL plotted. The major features of the unsmoothed time-history (open circles connected by a solid line) are preserved in the smoothed time-history (solid dots connected by a dashed line), but the scale of variation is reduced by about 2 dB in the smoothed curve relative to the unsmoothed curve.

Attenuation data were computed by subtracting at corresponding time-sample points smoothed indoor frequency band data from the same smoothed outdoor band data. Figure 3 illustrates this process. On this figure are shown three time histories in the 630-Hz band. The upper curve is data from an outdoor recording; the middle curve is from a recording from the dining room microphone in house K-13; and the lower curve is the arithmetic difference point-by-point of the two curves lying above it. This set of curves is typical of sets derived using other frequency bands and other room locations. Of interest are the facts that "house attenuation" is not constant with time as plotted in Figure 3, and that maximum levels, indoors and outdoors, do not necessarily occur at the same time in the course of an aircraft flyby. Variable attenuation and the lack of synchronism of indoor and outdoor levels arise primarily from the nature of the measurement situation. First, the sound source (an aircraft) is moving relative to the measuring devices and the test houses, and second, the test houses and rooms within the houses are not equally vulnerable to noise penetration at all exposed surfaces and apertures, such as windows and doors. The combination of these two facts, a moving sound source and a nonuniform structure vis-a-vis directional noise attenuation, produces the patterns observed in Figure 3.

Though the relationships between indoor and outdoor noise are complicated, some simplifications can be introduced if the primary use of house attenuation characteristics is to predict maximum or peak indoor physical measures of noise using outdoor measures of noise compensated by octave band or 1/3 octave band attenuations. Clearly, it would be far more difficult, because of the facts mentioned above, to predict accurately the complete time-history of an indoor noise from the time-history of an outdoor noise.

Three measures of house attenuation were computed for each flyby. These measures were:

(1) Outdoor noise intensity for each frequency band minus indoor intensity for each corresponding band at the time (called AMAX) when the outdoor noise was maximum.

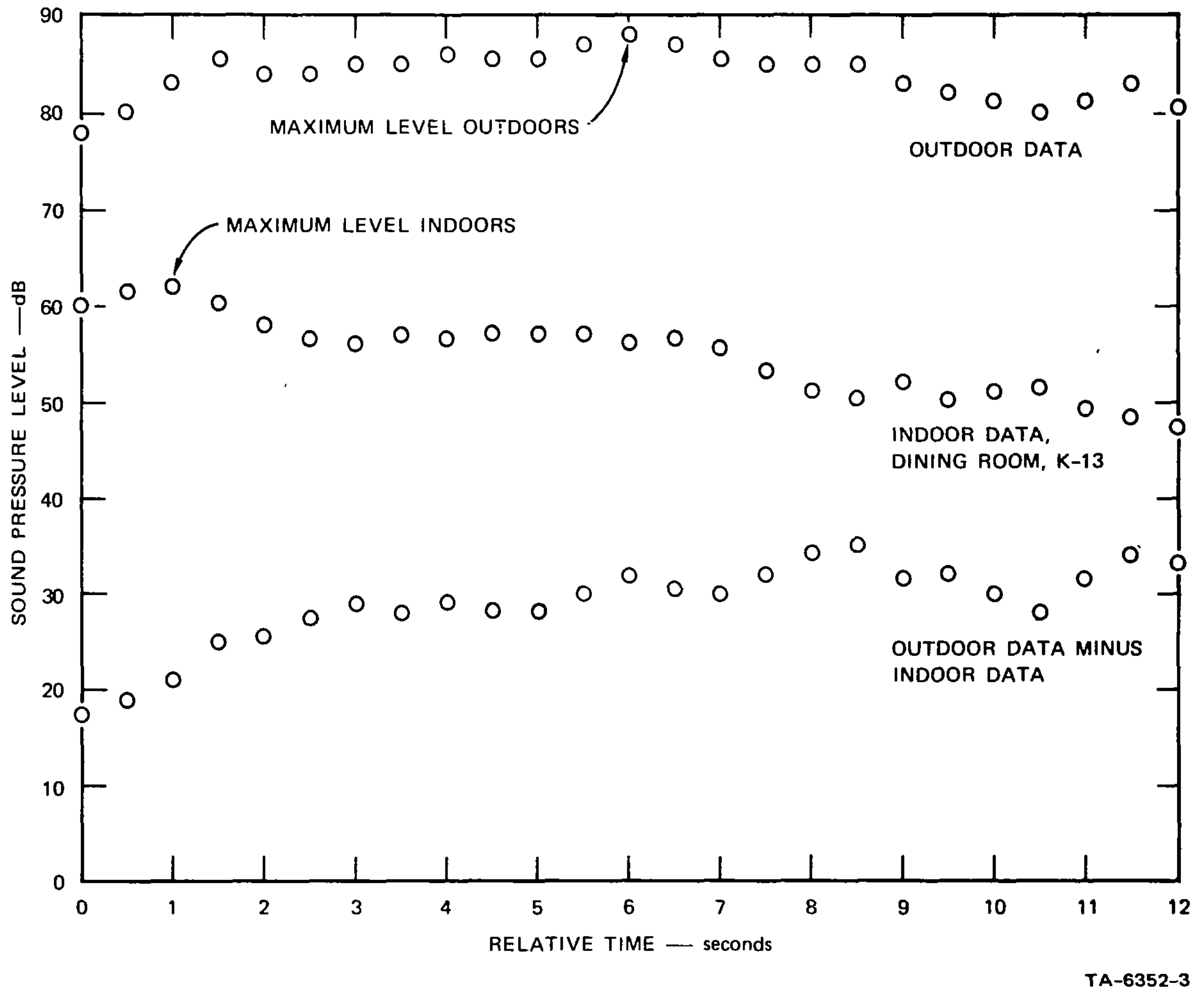

FIGURE 3 TYPICAL SMOOTHED TIME HISTORIES OF SOUND PRESSURE LEVELS IN 630-Hz 1/3 OCTAVE BAND FILTERS DURING CV-880 FLYBY

(2) Outdoor noise intensity for each frequency band minus indoor noise intensity for each corresponding band at the time (called BMAX) when the indoor noise was maximum.

(3) Maximum outdoor noise intensity for each band minus the maximum indoor noise intensity for each corresponding band.

Table I is a summary of the various attenuations for a typical flyby. These data pertain to a noise generated by the CV-880 aircraft recorded outside house K-13 and, simultaneously, in the dining room of that house. The table shows, for each 1/3 octave band (Band No. 1 is the 50-Hz band, Band No. 24 is the 10,000-Hz band), the frame number, or half-second interval (AMAX), in which the outdoor maximum intensity occurred, the frame number (BMAX) at which the indoor maximum occurred, and the differences between outdoor and indoor levels at AMAX and BMAX. Frame numbers start at 1 at the beginning of a noise event analysis and count upward as time through the event increases. A frame occurs each 1/2 second of the analysis time. Note that, in this case, no data are listed for bands 5, 21, 22, 23, and 24 because these bands (either outdoors or indoors, or both) failed to pass the 6-dB signal test.

In order to obtain the data used in this study, thirty-two such tables like Table I were computed, one table for each of eight locations indoors (four rooms in each of the two houses) and for each of four flights from which individual room data were collected. These tables were collated so that for each room, four estimates of attenuation were available. Average attenuations in each band were computed, and these average values were used for plotting house and room attenuation characteristics.

After attenuation characteristics for each room in the two test houses had been computed, thirty-six standard noise measures were computed for all analog data recorded indoors and out. The differences between indoor and outdoor noise, as expressed by these thirty-six measures, were tabulated. These differences and their statistics of dispersion are perhaps the best indicators of the "actual" difference between aircraft noises heard outdoors and indoors by subjects in the psychoacoustic tests.

A comparison between these "actual" physical noise measures and "predicted" noise measures was made possible by weighting outdoor data with the attenuation characteristic for each room to compute the predicted

Table I

TYPICAL SUMMARY OF ATTENUATION DATA FOR A CV-880 FLYBY

Data are for the dining room in house K-13

Band No.	AMAX frame No. when outdoor maximum occurs	BMAX frame No. when indoor maximum occurs	Attenuation at AMAX	Attenuation at BMAX	Attenuation using intensity at AMAX minus intensity at BMAX
1	121	116	20	15	18
2	117	107	25	14	21
3	100	93	28	7	23
4	100	93	29	8	24
6	111	97	31	17	22
7	104	93	20	11	19
8	107	92	27	2	18
9	103	92	27	7	20
10	107	95	32	21	27
11	106	95	33	20	29
12	106	96	32	21	26
13	106	95	33	21	28
14	100	95	34	19	27
15	100	95	35	21	28
16	99	95	34	21	26
17	99	95	33	21	26
18	101	95	36	23	29
19	102	95	43	23	32
20	100	95	60	37	48

values. Differences between the actual indoor noise measures and the predicted indoor noise measures were computed, averaged across all rooms in each house, and tabulated.

RESULTS

House attenuation defined on a 1/3 octave band basis by the difference between an outdoor band maximum and an indoor band maximum, without regard for when these maxima occur, during a given flyby, was found to be the best descriptor of the effect of the test house structures on externally generated aircraft noise measured inside the houses.

Adequate data were available in the 19 lower 1/3 octave bands to compute the average attenuation data shown in Figures 4 and 5 for houses K-13 and H-11, respectively. These figures illustrate the fact that there are room differences within each house. In Figure 6, data are shown which point out the differences between the two houses, K-13 a brick-veneer structure, and H-11 a wood-sided structure. In computing the data for Figure 6, attenuation characteristics of the four rooms in each house were averaged, and then these two house averages were plotted on the same ordinate and abscissa. Generally speaking, the brick-veneer structure is the better sound attenuator under the experimental conditions of this study.

Tables II and III present the measured differences in thirty-six physical noise measures between noise measured outside each test house and noise measured inside each test house at four microphone locations. The average differences are derived from four flybys, and sigma is a measure of the variability in the four difference values included in the computation of the average. The average differences in these tables express house attenuation insofar as the various noise measures differ between noise recorded outside and inside the test structures.

Table IV was constructed by comparing actual indoor noise measures and estimated values of the same indoor noise measures. Estimated values were compared to the actual values, flight-by-flight, and the differences averaged over all flights and all locations pertaining to each house. For example, an average difference of 1.0 in a specific table entry in Table IV indicates that the estimated value (computed using the house-room attenuation characteristic) was 1.0 dB less than that obtained by averaging actually measured indoor values. Sigma is a measure of the variation in these differences.

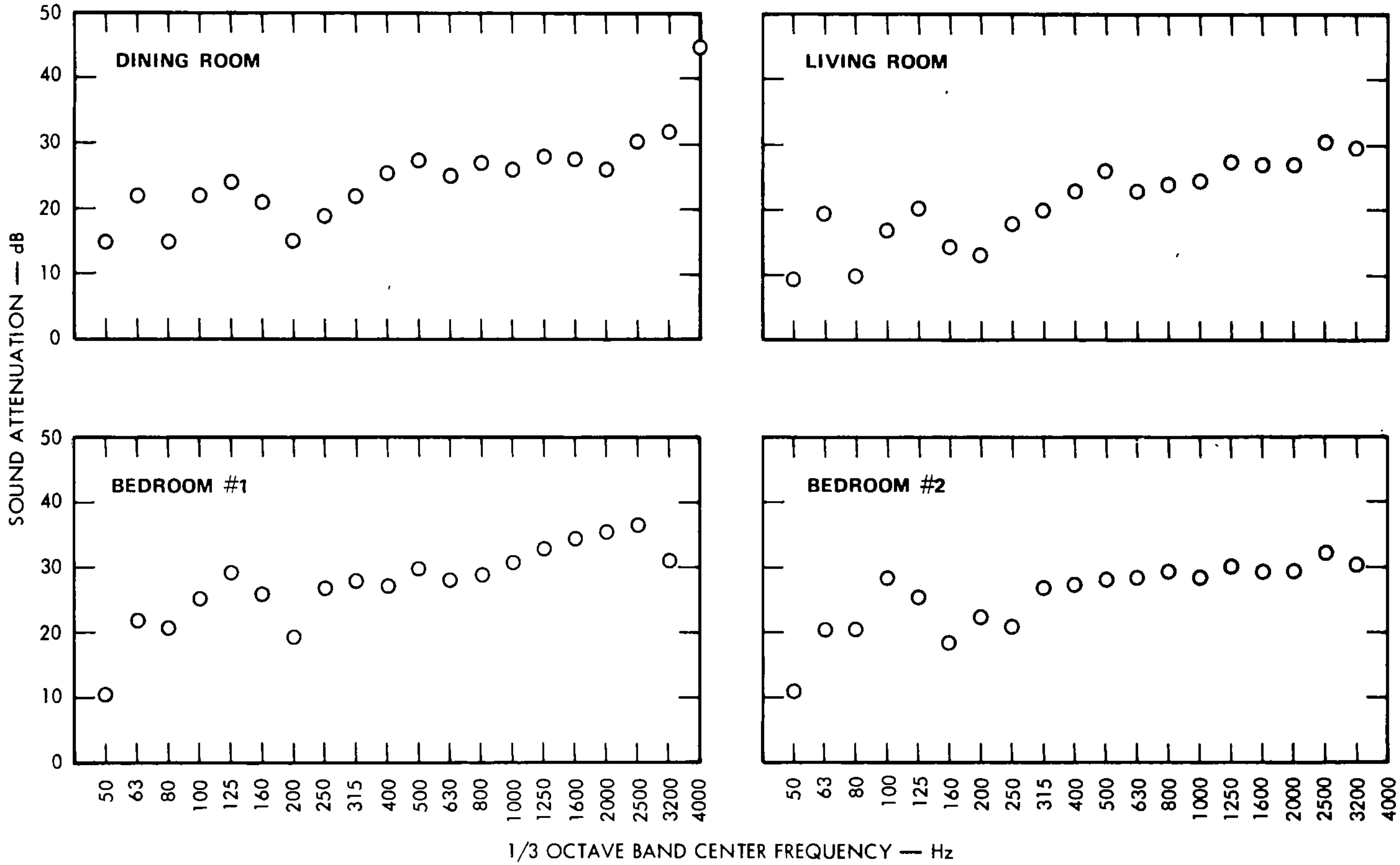

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FIGURE 4 SOUND ATTENUATION IN THE ROOMS OF HOUSE K-13 (Brick Veneer)

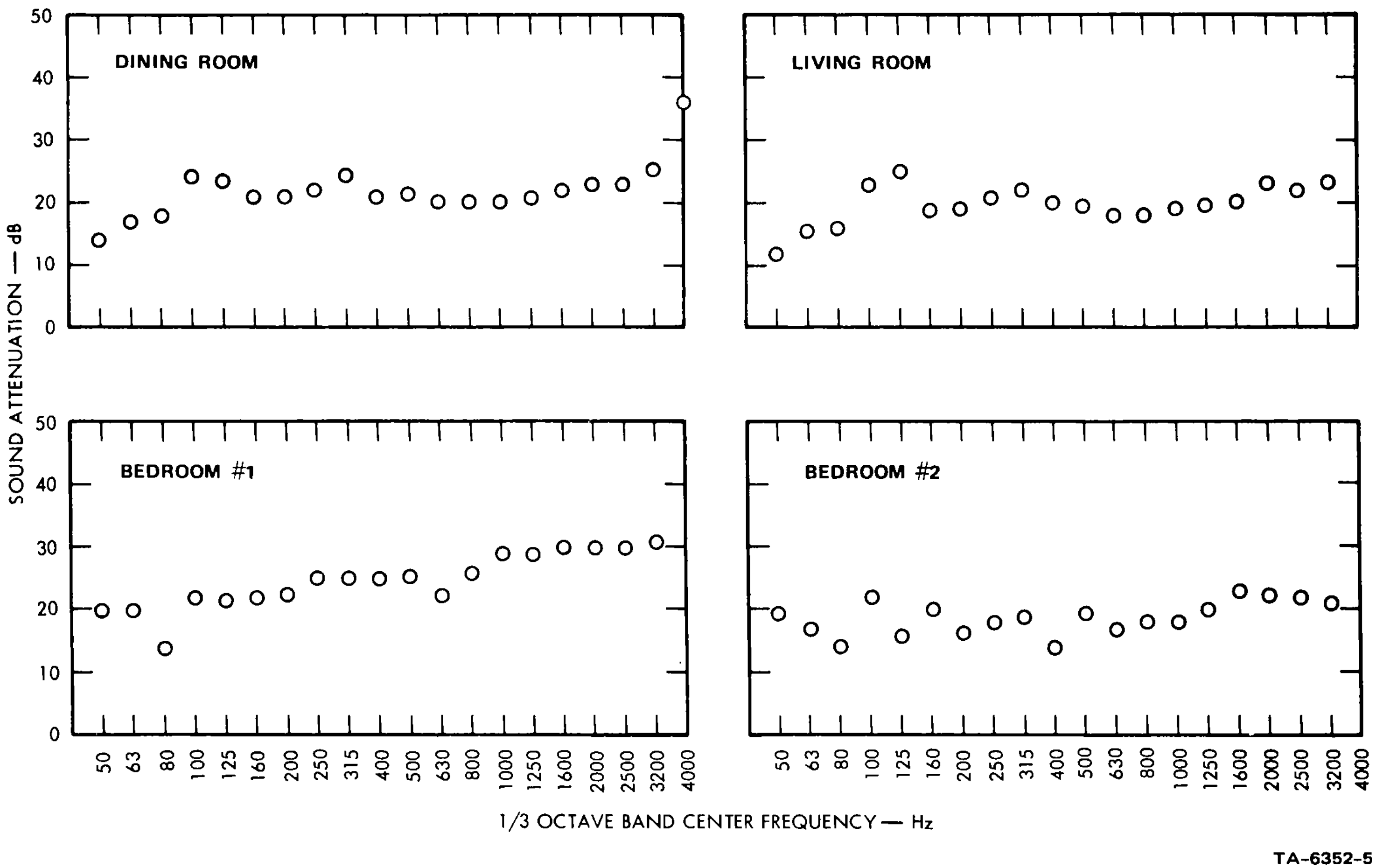


FIGURE 5 SOUND ATTENUATION IN HOUSE H-11 (Wood-Sided)

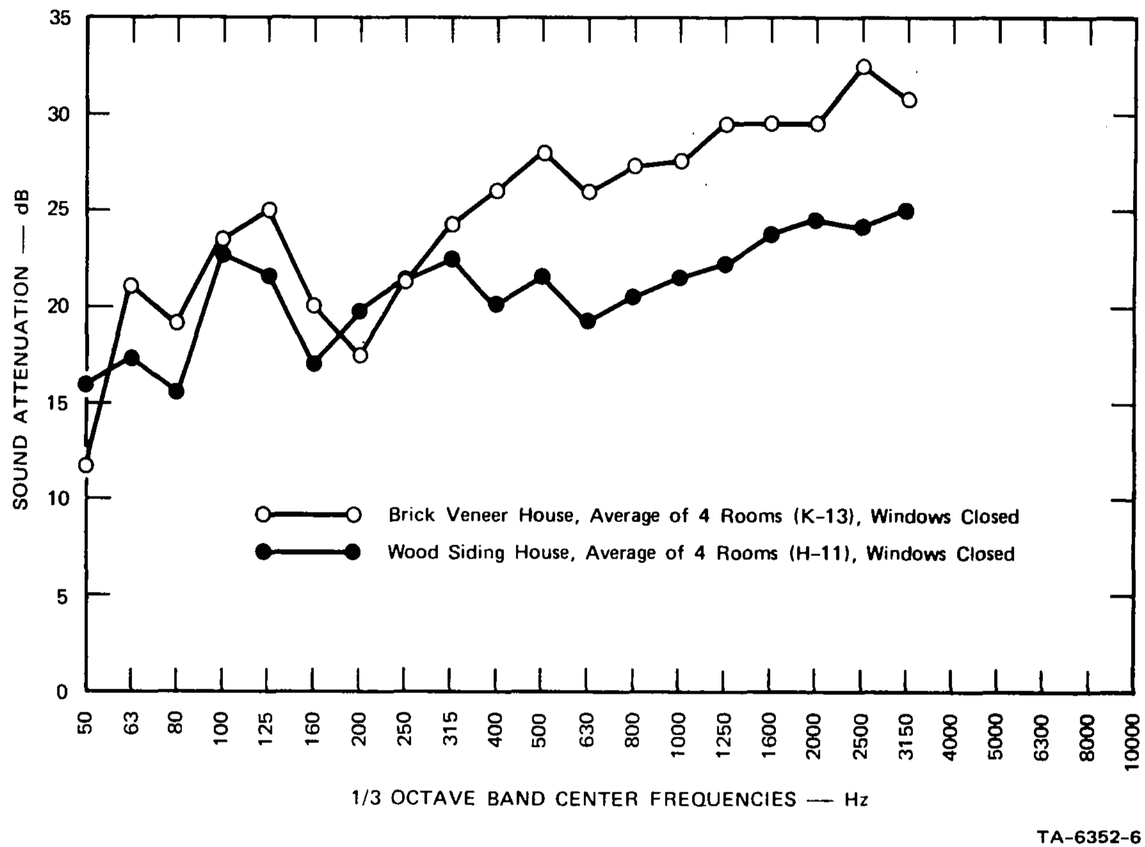


FIGURE 6 AVERAGE AIRCRAFT NOISE ATTENUATION OF TWO HOUSES AT WALLOPS STATION, VA.

Table II

ATTENUATION OF A BRICK-VENEER HOUSE AS MEASURED AT FOUR INDOOR LOCATIONS
Attenuation is expressed by average differences between various outdoor and indoor physical noise measures. Averages and standard deviations are based on data from four aircraft flybys.

ACTUAL ATTENUATION K-13 DR

MEASURE	MAXIMUM MEASURE STATISTICS AV DIFF	SIGMA	PEAK MEASURE STATISTICS AV DIFF	SIGMA	INTEGRAL MEASURE STATISTICS AV DIFF	SIGMA
A	23.2	3.1	22.6	3.0	24.5	3.3
C	20.8	3.2	20.3	2.8	22.0	2.5
D1	21.8	3.6	21.2	3.3	23.1	3.3
D2	22.4	3.3	21.7	3.1	23.6	3.3
D3	23.6	3.1	23.1	3.2	25.3	3.5
PHN	20.6	2.3	20.3	2.3	21.8	2.1
PN	22.6	3.7	22.1	3.7	24.6	3.7
PN1	21.7	3.9	21.9	4.1	23.9	4.2
PN2	21.9	3.5	21.1	2.2	23.9	3.1
PNM	22.4	3.6	21.5	3.4	24.2	3.4
PNM1	21.2	4.2	21.3	3.7	23.8	4.4
PNM2	21.7	3.2	20.5	1.8	23.4	2.8

ACTUAL ATTENUATION K-13 LR

MEASURE	MAXIMUM MEASURE STATISTICS AV DIFF	SIGMA	PEAK MEASURE STATISTICS AV DIFF	SIGMA	INTEGRAL MEASURE STATISTICS AV DIFF	SIGMA
A	21.6	4.0	20.9	4.5	22.7	4.8
C	19.5	4.2	18.7	4.3	20.1	4.0
D1	20.7	4.7	19.7	4.7	21.4	4.8
D2	21.1	4.4	20.1	4.6	21.8	4.7
D3	22.2	4.1	21.5	4.7	23.4	5.0
PHN	19.0	3.2	18.6	3.5	19.3	2.8
PN	21.0	5.1	20.2	5.1	22.4	5.0
PN1	20.1	4.9	19.9	4.8	21.3	4.9
PN2	20.1	6.2	18.8	4.2	21.0	5.7
PNM	20.8	4.8	19.9	4.5	22.1	4.7
PNM1	19.5	4.9	19.6	4.4	21.1	4.8
PNM2	19.8	5.8	18.6	3.5	20.7	5.4

ACTUAL ATTENUATION K-13 BR1

MEASURE	MAXIMUM MEASURE STATISTICS AV DIFF	SIGMA	PEAK MEASURE STATISTICS AV DIFF	SIGMA	INTEGRAL MEASURE STATISTICS AV DIFF	SIGMA
A	27.6	2.2	27.1	2.6	27.9	1.8
C	25.5	2.3	24.7	3.0	25.5	2.0
D1	26.4	2.8	26.1	3.3	26.9	2.2
D2	27.0	2.5	26.6	3.2	27.4	2.1
D3	28.3	2.6	27.7	2.9	28.0	2.3
PHN	24.2	2.0	23.8	2.5	23.9	2.0
PN	27.4	3.8	26.8	4.6	28.3	3.2
PN1	26.1	3.4	26.0	4.7	27.5	3.1
PN2	27.2	5.5	26.6	4.2	27.8	4.6
PNM	26.9	3.5	26.7	4.2	27.8	3.1
PNM1	25.4	3.7	25.6	4.3	27.2	2.9
PNM2	26.9	5.1	26.4	3.7	27.3	4.6

ACTUAL ATTENUATION K-13 BR2

MEASURE	MAXIMUM MEASURE STATISTICS AV DIFF	SIGMA	PEAK MEASURE STATISTICS AV DIFF	SIGMA	INTEGRAL MEASURE STATISTICS AV DIFF	SIGMA
A	26.0	1.1	25.6	1.1	26.5	1.9
C	23.3	1.7	22.9	2.0	24.2	2.4
D1	24.6	1.5	24.4	1.8	25.4	2.4
D2	25.2	1.2	24.9	1.6	25.9	2.2
D3	26.6	1.4	26.3	1.6	26.6	2.5
PHN	22.8	.8	22.8	1.1	22.8	2.3
PN	25.4	1.6	25.4	2.3	26.8	3.3
PN1	24.6	1.2	24.7	1.8	26.2	3.1
PN2	25.1	2.9	24.3	2.0	25.8	4.7
PNM	25.8	1.5	25.4	2.2	26.4	3.2
PNM1	24.5	1.4	24.7	1.4	26.1	3.2
PNM2	25.3	2.7	24.3	2.0	25.5	4.7

Table III

ATTENUATION OF A WOOD-SIDED HOUSE AS MEASURED AT FOUR INDOOR LOCATIONS
Attenuation is expressed by average differences between various outdoor and indoor physical noise measures. Averages and standard deviations are based on data from four aircraft flybys.

ACTUAL ATTENUATION H-11 DR

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	20.6	.8	A	20.7	.7	A	22.5	.8
C	21.6	.4	C	20.7	1.0	C	22.3	.9
D1	21.1	.7	D1	21.1	.6	D1	22.7	.7
D2	20.9	1.1	D2	21.0	.7	D2	22.7	.8
D3	20.4	.8	D3	20.6	.7	D3	22.5	.7
PHN	19.9	.9	PHN	19.6	.4	PHN	20.9	.3
PN	22.3	.6	PN	22.0	.7	PN	24.2	1.0
PN1	22.6	.8	PN1	22.2	.6	PN1	24.2	1.1
PN2	21.5	.8	PN2	21.3	.9	PN2	23.6	.5
PNM	21.8	.6	PNM	21.7	.7	PNM	24.1	.8
PNM1	22.5	1.0	PNM1	21.9	.8	PNM1	24.1	.9
PNM2	21.1	1.0	PNM2	21.1	1.0	PNM2	23.4	.5

ACTUAL ATTENUATION H-11 LR

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	19.1	1.3	A	19.1	1.1	A	21.0	.4
C	19.5	.8	C	19.3	.5	C	20.8	.2
D1	19.6	1.1	D1	19.6	.9	D1	21.2	.3
D2	19.4	1.4	D2	19.5	1.2	D2	21.1	.5
D3	18.9	1.3	D3	19.0	1.0	D3	21.0	.3
PHN	18.5	1.6	PHN	18.5	1.3	PHN	19.3	.6
PN	20.7	1.1	PN	20.5	1.1	PN	22.4	.4
PN1	20.9	.5	PN1	20.7	.7	PN1	22.5	.4
PN2	20.4	1.8	PN2	20.1	1.7	PN2	22.2	.9
PNM	20.3	1.0	PNM	20.1	1.2	PNM	22.3	.3
PNM1	21.0	.5	PNM1	20.3	.7	PNM1	22.3	.5
PNM2	19.9	1.7	PNM2	19.7	1.8	PNM2	22.0	.9

ACTUAL ATTENUATION H-11 BR1

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	24.6	2.4	A	24.3	1.9	A	25.0	.9
C	22.3	1.7	C	21.7	.8	C	22.6	.6
D1	23.6	2.4	D1	23.4	1.8	D1	24.2	1.0
D2	24.3	2.7	D2	24.0	2.0	D2	24.8	1.0
D3	25.3	2.4	D3	24.8	2.0	D3	25.3	1.1
PHN	22.4	2.5	PHN	22.1	1.9	PHN	22.0	.8
PN	25.1	2.6	PN	24.5	2.1	PN	26.3	.7
PN1	24.3	2.7	PN1	23.9	2.8	PN1	25.5	.5
PN2	25.0	2.6	PN2	24.5	2.2	PN2	25.7	1.5
PNM	24.5	2.2	PNM	24.3	2.1	PNM	26.1	.6
PNM1	23.7	2.0	PNM1	23.5	3.4	PNM1	25.2	.6
PNM2	24.4	2.3	PNM2	24.4	2.1	PNM2	25.8	.8

ACTUAL ATTENUATION H-11 BR2

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	18.6	3.7	A	17.3	2.6	A	18.2	1.6
C	16.4	3.2	C	16.2	1.8	C	17.8	.9
D1	17.6	3.4	D1	17.0	2.1	D1	18.2	1.2
D2	18.4	3.9	D2	17.6	2.6	D2	18.5	1.6
D3	19.1	2.9	D3	17.7	2.1	D3	18.3	1.6
PHN	15.7	3.5	PHN	16.1	2.5	PHN	16.8	1.5
PN	18.0	3.4	PN	17.3	2.2	PN	19.1	1.2
PN1	17.0	3.7	PN1	17.1	2.2	PN1	18.6	1.6
PN2	17.3	3.2	PN2	16.9	2.9	PN2	18.0	1.1
PNM	17.8	3.2	PNM	17.2	2.8	PNM	18.8	1.4
PNM1	17.6	3.6	PNM1	16.9	2.5	PNM1	18.2	1.8
PNM2	17.0	3.1	PNM2	16.7	3.5	PNM2	17.7	1.5

Table IV

AVERAGE DIFFERENCES BETWEEN HOUSE ATTENUATIONS LISTED IN TABLES II AND III
AND ATTENUATIONS COMPUTED BY APPLYING SPECTRAL ATTENUATION DATA SHOWN IN FIGURES 4 AND 5
TO OUTDOOR NOISES

DIFFERENCE BETWEEN ACTUAL AND ESTIMATED ATTENUATIONS IN K-13

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	.6	1.5	A	1.1	1.8	A	-0.4	1.7
C	.3	1.6	C	.6	1.9	C	-1.0	1.3
D1	.8	1.9	D1	1.1	1.9	D1	-0.5	1.5
D2	.8	1.7	D2	1.2	1.8	D2	-0.3	1.7
D3	.8	1.3	D3	1.1	1.7	D3	-0.3	1.8
PHN	1.7	1.7	PHN	1.6	1.9	PHN	.8	1.3
PN	1.7	2.3	PN	1.6	2.4	PN	.4	2.1
PN1	1.6	2.9	PN1	2.0	2.6	PN1	.4	2.3
PN2	1.9	2.9	PN2	1.4	2.7	PN2	.6	3.2
PNM	1.7	2.2	PNM	1.7	2.0	PNM	.5	2.1
PNM1	2.1	3.2	PNM1	2.2	2.5	PNM1	.3	2.4
PNM2	1.8	2.9	PNM2	1.6	2.4	PNM2	.7	3.2

DIFFERENCES BETWEEN ACTUAL AND ESTIMATED ATTENUATIONS IN H-11

MAXIMUM MEASURE STATISTICS			PEAK MEASURE STATISTICS			INTEGRAL MEASURE STATISTICS		
MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA	MEASURE	AV DIFF	SIGMA
A	.3	2.2	A	.7	1.6	A	-0.8	1.3
C	.5	1.8	C	.9	1.2	C	-0.4	1.1
D1	.6	1.9	D1	.8	1.4	D1	-0.6	1.2
D2	.5	2.3	D2	.7	1.7	D2	-0.7	1.3
D3	.4	2.1	D3	.7	1.5	D3	-0.7	1.3
PHN	.5	1.5	PHN	.8	1.1	PHN	-0.1	1.1
PN	.5	1.9	PN	.8	1.5	PN	-0.4	1.1
PN1	.7	2.1	PN1	.8	1.8	PN1	-0.5	1.2
PN2	.6	2.0	PN2	.8	1.9	PN2	-0.1	1.4
PNM	.8	1.8	PNM	1.0	1.5	PNM	-0.4	1.1
PNM1	.6	2.1	PNM1	1.0	2.0	PNM1	-0.4	1.3
PNM2	.9	1.9	PNM2	.9	2.0	PNM2	-0.2	1.4

Terms and symbols appearing in these tables are interpreted as follows:

K-13: a brick-veneer house structure at Wallops Station, Virginia

H-11: a wood-sided house structure at Wallops Station, Virginia

DR: dining room

LR: living room

BR1: bedroom No. 1

BR2: bedroom No. 2

Maximum measure: a value of a physical noise measure which was actually achieved during a flyby and which is greater than or equal to all other values assumed by the measure during that flyby.

Peak measure: a value of a physical noise measure computed on a 1/3 octave band spectrum constructed by selecting, for each frequency band, the maximum sound pressure level measured in that band without regard for the time at which the maximum occurred.

Integral measure: a value of a physical noise measure computed by arithmetically integrating on a power basis the 1/2-second sample values of the measure. The integration is calculated over values within 10 dB of the maximum value assumed by the measure.

<u>Physical Noise Measure Observations</u>

A: "A"-weighted sound pressure level (SPL)

C: "C"-weighted SPL

D1: "D1"-weighted SPL[3]

D2: "D2"-weighted SPL[3]

D3: "D3"-weighted SPL[3]

PHN: Stevens' phons, a measure of subjective loudness

PN: Perceived noise level in dB (PNdB)

PN1: Perceived noise level in dB with the Kryter-Pearsons pure-tone correction

PN2: Perceived noise level in dB with the current standard FAA tone correction

PNM: Modified perceived noise level in dB[3]

PNM1: Modified perceived noise level in dB with the Kryter-Pearsons pure-tone correction

PNM2: Modified perceived noise level in dB with the current standard FAA tone correction

CONCLUDING REMARKS

Two methods were employed to describe and evaluate the sound attenuation properties of two houses at Wallops Station, Virginia:

(1) Aircraft noises recorded simultaneously outdoors and indoors were compared spectrographically in 1/3 octave bands. Differences between outdoor and indoor frequency spectra were used in a particular way to establish house- or room-attenuation curves or characteristics. Specifically, house- or room-attenuation was computed using the following definition: For a given pair of noises recorded simultaneously outdoors and indoors at a given point, house-room attenuation in a frequency band is the maximum sound pressure level achieved in that band in the outdoor data minus the maximum level achieved in that band in the indoor data without regard for when these maxima occur during the noises.

(2) Thirty-six standard measures of noise including maximum, peak, and integrated measures were computed on simultaneously recorded aircraft noise, indoors and outdoors. The differences between these physical measures of indoor and outdoor noise were also used to describe the sound attenuation properties of the test houses.

A house-room attenuation characteristic or curve is useful insofar as it can be used to predict specific physical measures of noise occurring indoors. These physical measures, such as dB(A), dB(C), PNdB, etc., are time-varying quantities during the course of an aircraft flyby. However, for many purposes (such as predicting subjective response to noise) some single value of one of these measures is useful; such a value might be a peak value, a maximum value, or the integral of time-varying values over some given time. The definition of attenuation stated above was constructed to permit computation, or estimation, of single values of noise measures; it does not permit an accurate prediction of the time-varying pattern that noise measures follow during a flyby. Our definition is a very simple model of a quite complicated process, and it is but one of several plausible models. Therefore, it was necessary to test the merits of this definition and other definitions by (1) using derived attenuation characteristics as modifiers of outdoor spectra to produce a quasi-indoor spectra, (2) computing appropriate (estimated) physical measures of noise on the quasi-indoor spectra, and (3) comparing these estimated physical noise measures to actual noise measures computed on real indoor noise data. One expects, and indeed finds, that the simplicity of our model, or definition, is an inherent limitation in trying to achieve an exact comparison between estimated and actual physical measures.

The comparison of actual and estimated physical noise measures shows that the house and room attenuation characteristics tend to underestimate house sound attenuation in maximum, peak, and integral noise measures. Estimates of integral measures are quite close to actual measures; the integral measures are, on the average, overestimated in data for house H-11. A summary of these averages across the three classes of physical measures and for the two houses is shown in Table V.

The data in Table V could be used to adjust, for either or both houses, attenuation characteristics so that closer agreement can be obtained between actual and estimated physical measures if one were concerned only with one class of measures. For example, by uniformly increasing the value of each frequency band attenuation by 1.3 to 1.4 dB, indoor maximum and peak measures for K-13 could be computed from outdoor data with essentially no error when twelve measures are averaged together. Or by reference to Table IV, more specific corrections of the attenuation characteristics could be obtained for a given physical measure.

The simplified definition of house attenuation (stated in method 1 above) used to compute these tabular data is a useful definition in an average sense. It does produce consistently different results, however, between integral measures and the others, as can be seen in Tables IV and V.

Table V

AVERAGES OF DIFFERENCES BETWEEN ACTUAL AND ESTIMATED PHYSICAL MEASURES INDOORS FOR TWO TEST HOUSES
Data are for four rooms in each house.

House	Maximum Measures (12)	Peak Measures (12)	Integrated Measures (12)
K-13	+ 1.3 dB	+ 1.4 dB	+ 0.1 dB
H-11	+ 0.6 dB	+ 0.8 dB	- 0.4 dB

In Figure 7 the house attenuation characteristics determined in this study are plotted on the same ordinate with some average house attenuation data obtained from SAE Committee A-21 in document AIR 1081[2]. These latter data were compiled from measurements made in Boston and New York (18 rooms), Los Angeles (4 rooms), and Miami (8 rooms). House K-13 data are probably closer to this average curve than are data from H-11. All data for K-13 and H-11 lie within the range of measurements reported in AIR 1081 for houses in Boston, New York, and Miami. In some sense, then, one can conclude that the houses used for the psychological tests at Wallops Station, Virginia are "typical" houses in that their attenuation characteristics are not markedly different from those expected, on the average, or as reported in the SAE document.

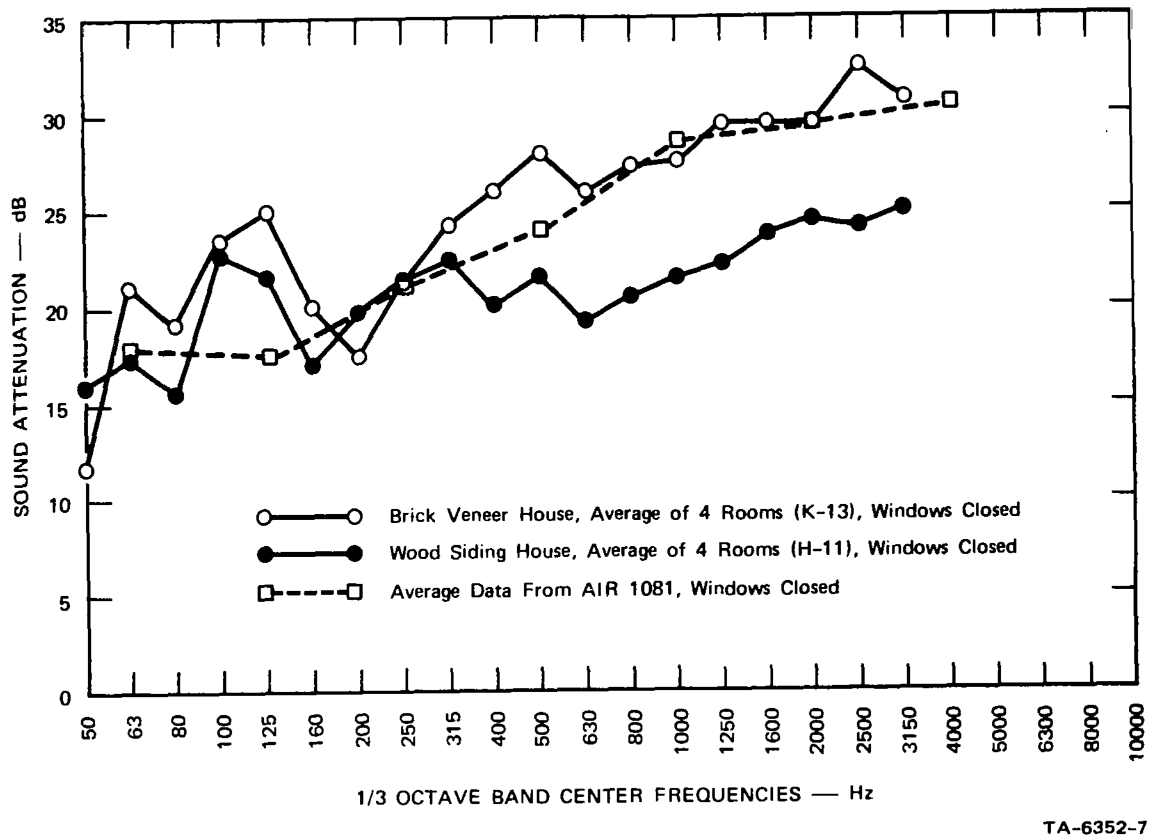
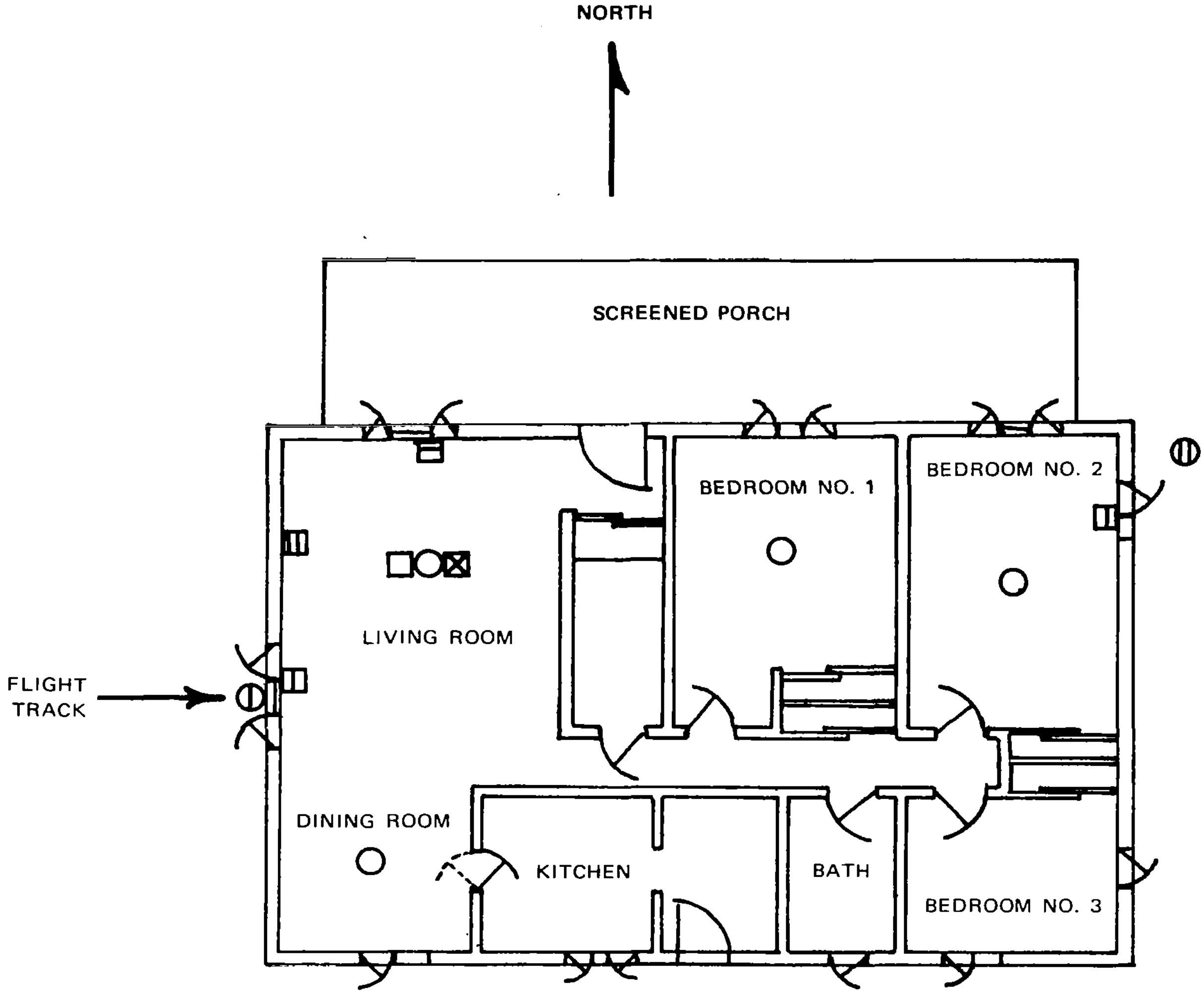


FIGURE 7 AVERAGE AIRCRAFT NOISE ATTENUATION OF TWO HOUSES AT WALLOPS STATION, VA. Compared to average data from SAE Document AIR 1081.

Appendix

FLOOR PLANS AND INTERIOR PHOTOGRAPHS OF HOUSES K-13 AND H-11 AT WALLOPS STATION, VIRGINIA

The drawings and photographs in the appendix (Figures A-1 and A-2) describe the test houses and measurement instrumentation used in the aircraft noise evaluation studies conducted in October and November of 1967[1]. The microphone locations shown by open circles in Figure A-1(a) and (b) were the locations used again in December 1968 for the measurement of indoor aircraft noise. These measurements were used to calculate house and room attenuations reported in this study.



(a) K-13

MICROPHONE LOCATIONS:

- ○ Standing ear level (suspended from ceiling)
- ⊗ Standing ear level (stand mounted, movable)
- ⦶ Outdoor, roof mounted
- ⦶ Outdoor, standing ear level (in subject group)

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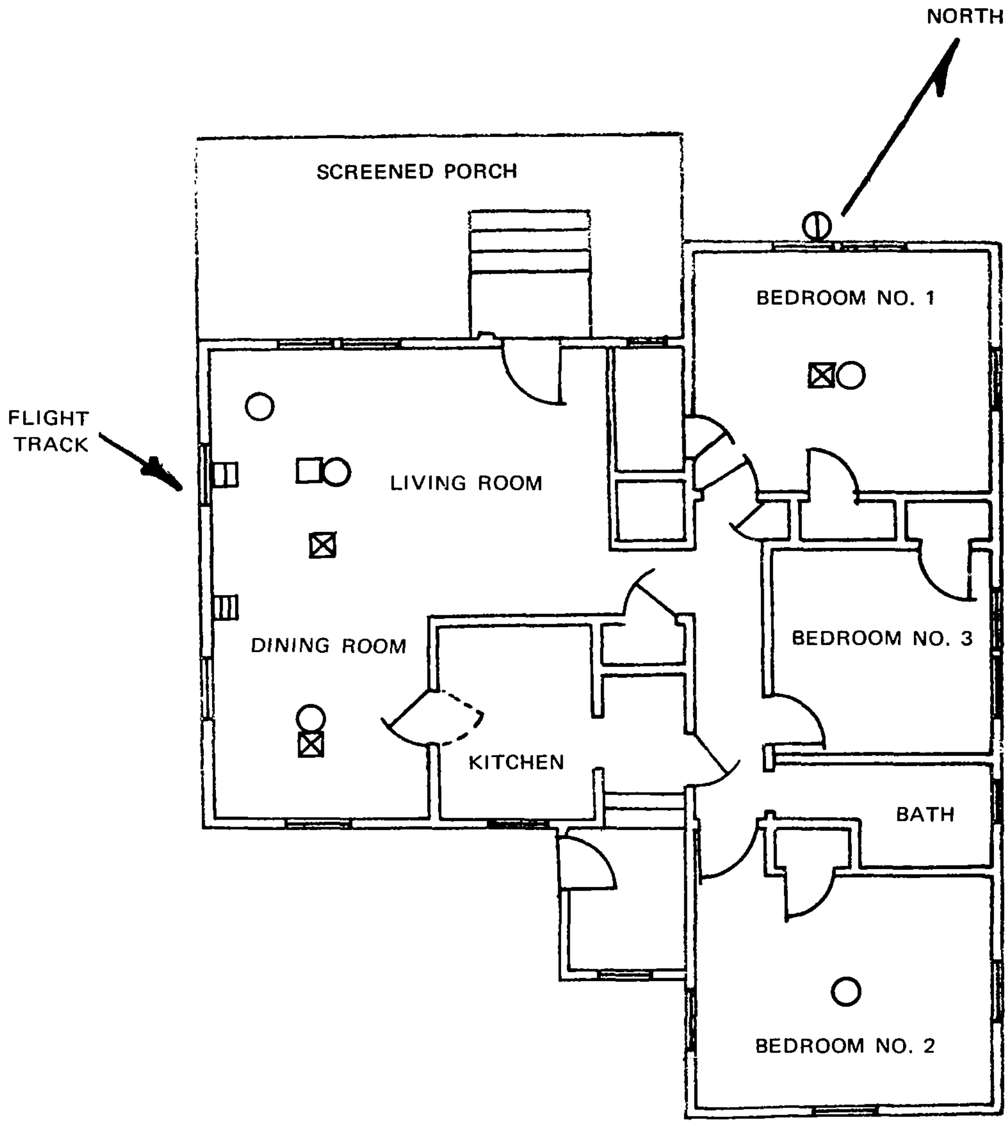
FIGURE A-1 TRANSDUCER LOCATIONS



(b) H-11

ACCELEROMETER LOCATIONS

- ☐ Ceiling mounted
- ☒ Floor mounted
- ◫ Window mounted
- ▥ Wall mounted

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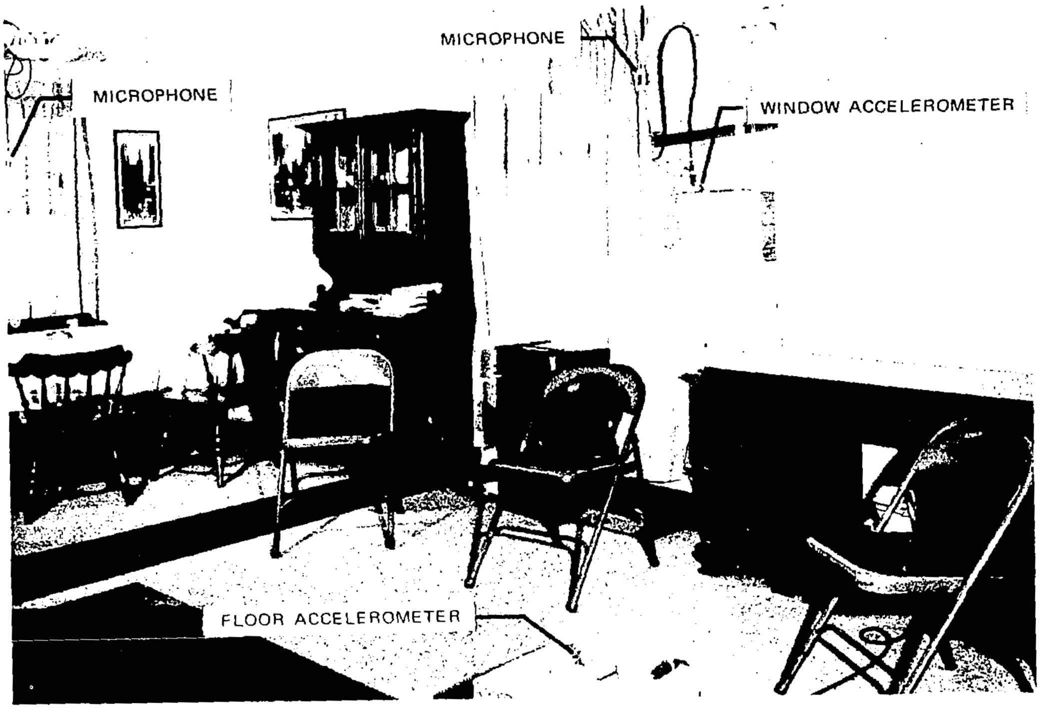
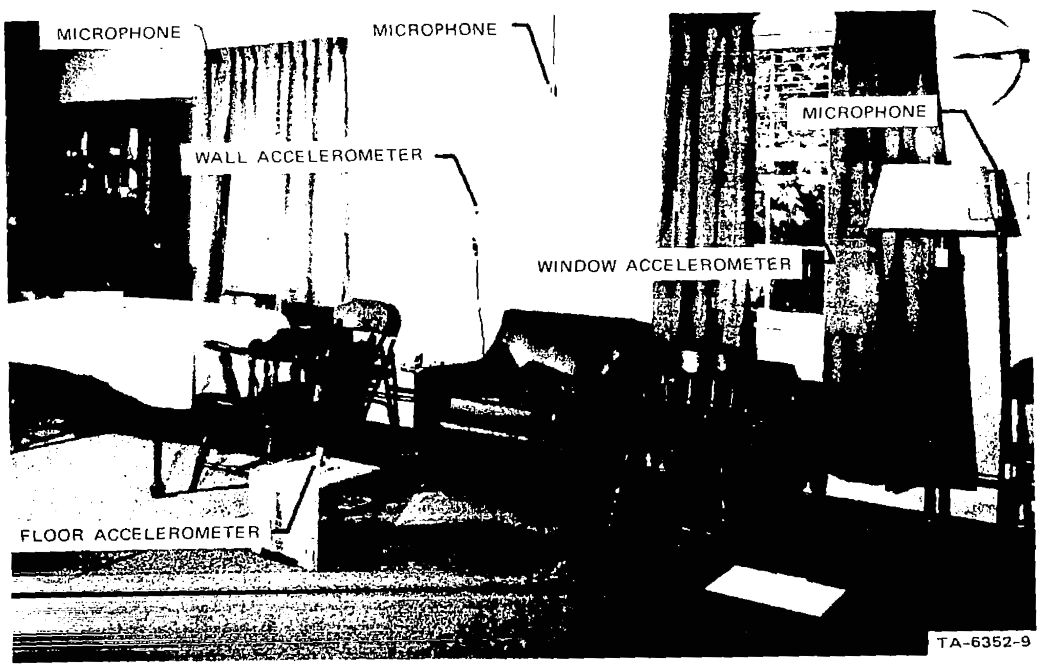
FIGURE A-1 TRANSDUCER LOCATIONS Concluded



(a) K-13, VIEW OF WEST WALL



(b) H-11, VIEW OF NORTH-WEST WALL

FIGURE A-2 PHOTOGRAPH SHOWING LIVING ROOMS OF TEST HOUSES

REFERENCES

1. Kryter, K. D., P. J. Johnson, and J. R. Young. Judgment Tests of Flyover Noise from Various Aircraft. Stanford Research Institute, NASA CR-1635 (1970).

2. Society of Automotive Engineers, AIR 1081. Recent House Noise Attenuation Data and an Average House Noise Attenuation Curve. Society of Automotive Engineers, Inc., New York, N.Y. (1969).

3. Kryter, K. D. Possible Modifications to the Calculation of Perceived Noisiness. Stanford Research Institute, NASA CR-1636 (1970).