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JUDGMENT TESTS OF FLYOVER NOISE FROM VARIOUS AIRCRAFT

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16. Abstract

An experiment was conducted at Wallops Station, Virginia, where judgments of the perceived noisiness of the flyover noises made by a variety of fixed-wing and helicopter aircraft were made by subjects seated outdoors and inside two houses. These judgments were related to a variety of physical units measured or calculated from spectral and temporal measures of the noises.

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SUMMARY

An experiment was conducted at Wallops Station, Virginia, where judgments of the perceived noisiness of the flyover noises made by a variety of fixed-wing and helicopter aircraft were made by subjects seated outdoors and inside two houses. These judgments were related to a variety of physical units measured or calculated from spectral and temporal measures of the noises.

Among other results it was found that:

1. So-called Effective units, calculated from sound measurements made over the duration of a noise, better predicted judged perceived noisiness than did so-called Maximum or Peak units of measurement.

2. Adjusting band spectra or overall weighted frequency levels to take into account the critical bandwidth of the ear, significantly improved the predictive ability of the units PNdB and dB(D).

3. So-called onset duration and tone corrections did not contribute significantly for these noises to the predictive accuracy of the various physical units used.

4. Because of the lesser attenuation by house structures of lower than higher frequencies, aircraft noise containing predominately low frequencies (typically propeller, reciprocating engine, and helicopter) were rated as relatively less acceptable to people indoors than to people outdoors, whereas the higher frequency jet aircraft noise was rated relatively more acceptable to people indoors than to people outdoors.

INTRODUCTION

The ever increasing use of aviation has led to an increased demand for the control of aviation noise near communities and for the design of quieter engines and operating procedures. To most efficiently and effectively control noise it is necessary to understand in as quantitative terms as possible the relations between the physical parameters of noise and man's reaction to them.

Over the past twenty to thirty years research has led to the development of a number of ways of measuring noise that purport to be correlated with how man's auditory system "measures" or responds to the noise. These methods run the gamut from simple peak sound level meter readings to spectral weightings of 1/3 octave band spectral measures taken every 0.5 sec during the duration of a noise occurrence.

Although the measurement procedures vary, the purpose and goal of all of these measures is to estimate or predict how "unwanted," "unacceptable," or "noisy" the sounds being measured will be perceived to be by people. This quantity or attribute has for convenience been labeled "perceived noisiness" or, sometimes, "annoyance."

Most of the psychological tests concerned with establishing the relations between perceived noisiness and the physical aspects of aircraft noise have been conducted in the laboratory with recordings of the noise, using relatively small groups of subjects and often a restricted variety of types of aircraft noises. A particular shortcoming of most previous laboratory and field tests of aircraft noise has been the lack of complete physical measures of the noise during the flyover cycle. In general only the peak or maximum levels reached by the noise have been noted or recorded. In view of the apparent importance of duration as well as spectrum of a sound upon its subjective noisiness, this has perhaps been a handicap to the proper interpretation of the relation between physical measurements and psychological judgments.

The present tests were designed to provide human subjects, listening conditions, types of aircraft noise, and physical measurements that would hopefully permit a valid examination of the ability to predict the judged acceptability of many different types of aircraft noise when heard in or outside houses. In addition, ancillary questions related to the reaction of house structures to the noise were to be investigated. The present report is concerned primarily with the relations between the psychological judgments made by the subjects located indoors and outdoors and physical measurements made from recordings of the noise from a microphone located outdoors near the subjects.

PROCEDURE

Test Location and Subjects

Two frame houses, one wood-and one brick-sided, and a large yard near one of the houses located in a residential area of Wallops Station, Virginia, were chosen as the test site. This station is an experimental facility operated by the National Aeronautics and Space Administration (NASA), and has a small airport and radar-radio control facilities suitable for the control of the operational aircraft made available for the study. The subjects were adults, primarily housewives, selected from communities in the local area. Table I gives some vital statistics for the subjects, and Figure 1 is a photograph of some of the subjects as seated for the tests. The subjects were screened by an audiometer and all found to have normal ($\pm$15 dB from audiometric zero) hearing. The subjects were paid $2 per hour and given careful instructions prior to, and during the tests as to the importance of the tests and nature of the task they were to perform.

FIGURE 1 PHOTOGRAPH SHOWING OUTDOOR SUBJECTS POSITIONED AT HOUSE K-13
(view looking west)

Table I

BIOGRAPHICAL DATA

Sex and Marital Status	Number of Persons	
Single male	0	
Married male	11	
Total male	11	
Single female	12	
Married female	73	
Total female	85	
Total male and female	96	
Male Occupations	**Number of Persons**	**Employed by NASA**
Retired	9	--
Other	2	1
Female Occupations	**Number of Persons**	**Husband Employed by NASA**
Housewife	74	16
Retired	5	--
Other	6	1
Age	**Average**	
Male	61.0 years	
Female	42.4	
Male and female	44.5	
Education	**Average***	
Male	10.3 years	
Female	11.4	
Male and female	11.3	
Time-in-Area	**Number of Persons living less than 6 years in area**	**Number of Persons living 6 or more years in area**
Male	4 (average 4.5 years in area)	7
Female	15 (average 2 years in area)	70
Male and Female	19 (average 2.5 years in area)	77
Residence	**Number of Persons**	
Wallops Station (on-base)	4	
Neighboring communities (up to 20 miles from Wallops Island)	92	

* High School graduates treated as having completed 12 years of study. The older residents generally spent 11 years in completing the high school requirements.

Experimental Design

Because of the very large number of aircraft tested, it was not possible to pair, for the judgments, each aircraft noise with each other aircraft noise. Instead, two of the aircraft were chosen to provide a standard or reference aircraft noise against which the noise from each of the other aircraft was judged when operating and if possible under landing and takeoff power conditions. The reference or standard aircraft chosen were the CV-880 with turbojet engines and the L-1049G (Super Constellation) propeller aircraft with reciprocating engines. Figure 2 is a schematic illustration of the flight paths followed by aircraft for the tests. As previously mentioned, the altitude of the operational conditions for each aircraft was carefully monitored and controlled for all flights.

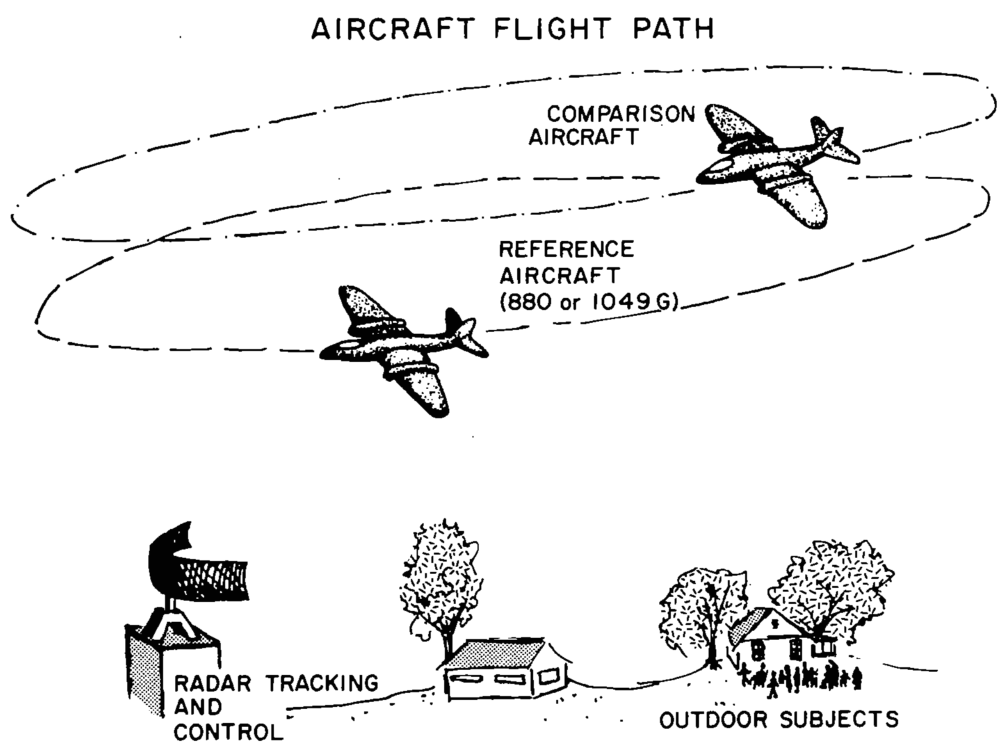

FIGURE 2 SCHEMATIC DIAGRAM OF AIRCRAFT FLIGHT PATHS AND LOCATION OF HOUSES AND SUBJECTS USED FOR AIRCRAFT NOISE JUDGMENT TESTS AT WALLOPS STATION, VIRGINIA

Table II shows the general design of the experiment and the operating conditions for the flights of the various aircraft. An attempt was made to operate the reference aircraft at an altitude that would be reasonable for that aircraft at about two to three miles from an airport. Table III shows by date the aircraft and mission pairs flown and the number of overflights accomplished.

Physical Measurements

All equipment for recording the airborne and structural borne noise from the aircraft was installed and operated by NASA. At the completion of the tests and after review and screening by NASA the recordings obtained from certain outdoor and indoor microphones were sent to Stanford Research Institute (SRI) for further analysis. In some cases it was necessary because of overload distortions in a few of the recordings to re-record at a later date noise from two of the aircraft flying under identical operational conditions as those present in the tests proper. These new recordings were substituted for original recordings.

At SRI the analog signals on the tape recordings were played through 1/3 octave band filters, and then digitized and stored in a computer. One concept of measurement being followed in our procedures is that the ear tends to average or integrate sound over about 0.5-sec intervals of time; therefore, to best predict from physical measures how a person will respond to noise we should measure the average, or the RMS level present, successive 0.5 secs of time. This 0.5-sec time averaging corresponds to that of a standard sound level meter set on slow meter action.

This was done by sampling once every half second the level in each 1/3 octave band filter, the output of which had been smoothed as though operating an RMS meter with a 0.5-sec time constant. However, the output wave from each filter band is not completely steady-state throughout any one 0.5-sec interval. The precise level obtained by the digital sampling procedure can accordingly be slightly different from one analysis of a recording to another separate analysis of the same recording because the analyses will not necessarily be perfectly synchronous with each other-- i.e., the 0.5-sec samples from one analysis may be shifted, say 100 msec from the exact time the successive 0.5-sec samples are taken on the second analysis.

Table II

WALLOPS ISLAND EXPERIMENTAL DESIGN FOR SUBJECTIVE JUDGMENTS

Standard Aircraft							Comparison Aircraft						
Standard Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers				Comparison Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers			
880	2.5(T.O.)	1400	97B	98A	99B	100A	990	1.95(T.O.)	1000	97A	98B	99A	100B
			101B	102A	103B	104A			1500	101A	102B	103A	104B
			105B	106A	107B	108A			2200	105A	106B	107A	108B
			195B	194A			990	1.3(Ldg)	250	195A	194B		
			196B	193A					500	196A	193B		
			109B	110A	111B	112A			700	109A	110B	111A	112B
			113B	114A	115B	116A			1100	113A	114B	115A	116B
			117B	118A	119B	120A			1800	117A	118B	119A	120B
880	2.1(T.O.)	1400	198B	197A			1049G	METO	350	198A	197B		
			169B	170A/370A	171B	172A			600	169A	170B/370B	171A	172B
			173B	174A	175B	176A			1000	173A	174B	175A	176B
			177B	178A	179B	180A			1500	177A	178B	179A	180B
880	2.0(T.O.)	1400	2B	1A			727	1.9(T.O.)	600	2A	1B		
			12B	3A					1000	12A	3B		
			6B	5A					1500	6A	5B		
			8B	7A			727	1.35(Ldg)	300	8A	7B		
			10B	9A	13B	14A			600	10A	9B	13A	14B
			4B	11A					1000	4A	11B		
			26B	25A			720	2.5(T.O.)	1500	26A	25B		
			28B	27A					2200	28A	27B		
			30B	29A					3000	30A	29B		
			32B	31A			720	1.65(Ldg)	250	32A	31B		
			34B	33A					400	34A	33B		
			36B	35A					800	36A	35B		

Table II (Continued)

Standard Aircraft							Comparison Aircraft						
Standard Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers				Comparison Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers			
880	2.0(T.O.)	1400	50B	49A			C-141	1.85(T.O.)	1000	50A	49B		
↓	↓	↓	52B	51A			↓	↓	1700	52A	51B		
			54B	53A					3000	54A	53B		
			56B	55A			C-141	1.24(Ldg)	250	56A	55B		
			58B	57A	61B	62A	↓	↓	500	58A	57B	61A	62B
			60B	59A					900	60A	59B		
			74B	73A			Jetstar	T.O.	800	74A	73B		
			76B	75A			↓	↓	1300	76A	75B		
			78B	77A					2000	78A	77B		
			158A	157A	164B	163A	F-106 (After-burner)		950	158A	157B	164A	163B
			160B	159A	166B	165A			1700	160A	159B	166A	165B
			162B	161A					3000	162A	161B		
			168B	167A					4000	168A	167B		
880	2.0(T.O.)	2200	137B	133A			CH-47	Cruise	250	137A	133B		
↓	↓	↓	136B	139A			↓	↓	450	136A	139B		
			138B	134A					750	138A	134B		
			142B	135A					1100	142A	135B		
			125B	121A			204B	Cruise	250	125A	121B		
			124B	127A	131B	128A	↓	↓	450	124A	127B	131A	128B
			126B	122A	132B	129A			750	126A	122B	132A	129B
			130B	123A					1100	130A	123B		
880	2.0(T.O.)	3000	80B				Jetstar	(Ldg)	250	80A			
↓	↓	↓	82B				↓	↓	500	82A			
			84B						900	84A			
1049G	METO	1000	20B	15A			727	1.35(Ldg)	400	20A	15B		
↓	↓	↓	22B	17A			↓	↓	700	22A	17B		
			19B	16A					1000	19A	16B		
			21B	18A					1500	21A	18B		

Table II (Concluded)

Standard Aircraft					Comparison Aircraft				
Standard Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers		Comparison Aircraft	EPR/Power	Local Altitude (feet)	Pair Numbers	
1049G	METO	1000	44B	39A	720	1.65(Ldg)	250	44A	39B
			46B	41A			400	46A	41B
			43B	40A			700	43A	40B
			45B	42A			1100	45A	42B
			70B	63A	C-141	1.24(Ldg)	300	70A	63B
			69B	64A			500	69A	64B
			67B	65A			900	67A	65B
			68B	66A			1300	68A	66B
1049G	METO	1300	202B	199A	204B	Cruise	250	202A	199B
			204B	206A			450	204A	206B
			203B	200A			750	203A	200B
			201B	205A			1100	201A	205B
			238B	231A	880	Landing	250	238A	231B
			237B	232A			400	237A	232B
			236B	233A			700	236A	233B
			235B	234A			1100	235A	234B
1049G	METO	1800	92B	87A/287A	Jetstar	Landing	250	92A	87B/287B
			94B	89A			400	94A	89B
			91B	88A			700	91A	88B
			93B	90A			1100	93A	90B
1049G	METO	3000	186B	181A	CV-7A	Cruise	250	186A	181B
			188B	183A			500	188A	183B
			185B	184A			800	185A	184B
			187B	182A			1300	187A	182B
1049G	METO	3000	227B	225A	CV-7A	Cruise	250	227A	225B
			230B	224A			500	230A	224B
(Loudness Experiment)			229B	226A			800	229A	226B
			228B	223A			1300	228A	223B

Table III

TABULATION OF OVERFLIGHTS FOR SUBJECTIVE JUDGMENTS DURING WALLOPS ISLAND EXPERIMENT

Date	Number of Pairs	Standard Aircraft*	Comparison Aircraft*	Mission Numbers	Time Sequence of Pairs†
31 Oct. 1967	24	880	990	97-120	98 102 106 118 114 110 109 113 117 105 101 97 111 115 119 120 116 112 100 104 108 107 103 99
1 Nov.	19 4 15	880 880	990 1049G	193-196, 169-180, 197,198,370	170 174 178 177 173 169 193 194 195 196 180 176 172 171 175 179 198 197 370
3 Nov.	20 8 12	1049G 880	204B 204B	199-206, 121-132	199 200 201 202 203 204 205 206 121 122 123 124 125 126 127 128 129 130 131 132
6 Nov.	22 8 14	1049G 880	727 727	15-22, 1-14	15 16 17 18 19 20 21 22 1 5 3 9 7 11 4 10 2 12 6 8 13 14
7 Nov.	20 8 12	1049G 880	720 720	39-46, 25-36	39 40 41 42 43 44 45 46 31 25 29 27 35 33 30 26 36 28 34 32
8 Nov.	22 8 14	1049G 880	C-141 C-141	63-70, 49-62	63 64 65 66 67 68 69 70 53 51 49 59 57 55 54 52 50 60 58 56 61 62
9 Nov.	18 9 9	1049G 880	Jetstar Jetstar	87-94,287, 73-78,80, 82,84	87 88 89 90 91 92 93 94 287 73 77 75 78 74 76 80 84 82
13 Nov.	12	880	F-106	157-168	157 159 161 162 160 158 163 165 167 168 166 164
14 Nov.	16 8 8	1049G 880	880 CH-47	231-238 133-139,142	231 234 232 233 235 237 236 238 133 134 135 136 137 138 142 139
15 Nov.	16	1049G	CV-7A	181-188, 223-230	181 182 183 184 185 186 187 188 223 224 225 226 227 228 229 230

Total Pairs	189

Total Overflights by Aircraft
(Two Overflights per pair)

880	132
1049G	80
990	28
727	22
C-141	22
720	20
204B	20
Jetstar	18
CV-7A	16
F-106	12
CH-47	8
	378

* See Table II for conditions

† An "A" overflight followed by a "B" overflight is implied for each mission

Notes: 1 Nov., 370 is a repeat of 170

3 Nov., 200B flown at 500 feet instead of scheduled 750 feet

9 Nov., 287 is a repeat of 87

To test this variability four separate analyses were made of the same two recordings of mission recordings obtained at Wallops Station. The total variability was, except for four isolated instances on individual bands, about 0.5 dB. We are looking into these four cases to see if some artifact possibly contributed to the variability. It is our belief that this sampling-time variability is not a significant factor of measurement, particularly in that its effects upon calculated units should be both slight and random.

From these digital signals samples taken every 0.5 sec, the 38 units shown in Table IV were calculated. The frequency weightings used for achieving the overall values of A, B, C, D_1, D_2, and D_3 are given in Table V and Figure 3. The band and overall levels were found as though a standard sound level meter set on slow scale had been used as the indicating instrument.

The PNdB-M, D_2, and D_3 units indicated on Table IV were derived during the course of these tests. Basically, PNdB-M differs from PNdB and D_2 differs from D_1 (the converse of the 40-noy contour, sometimes called "N" in the past) in that the band sound pressure levels or the weighting given to sound frequencies below about 355 Hz are adjusted to provide weights more proportional to the critical bandwidths of the ear over most of the audible frequency range; this procedure is discussed more fully in another report.[1]* D_3 has been proposed by Young and Peterson[2] as an appropriate frequency weighting for the evaluation of perceived noisiness of sounds. It is seen in Figure 3 that, when adjusted for overall level, it closely approximates the D_2 weighting.

The effect of this adjustment for "critical bands" on the frequency weighting for a sound level meter can be noted by a comparison of curve D_2 with D_1 in Figure 3. The effect of this proposed change on the calculation of PNdB is as follows:

Step 1. Determine the sound pressure level that occurs in each 1/3 or full octave band in each successive 0.5-sec interval of time.

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* Because of frequent referrals to authors by name and cross referencing of publications in tables, figures and text, referencing is accomplished in this report by means of superscript numbers and by authors' names.

Table IV

UNITS CALCULATED FROM PHYSICAL MEASURES FOR THE PREDICTION OF JUDGED PERCEIVED NOISINESS

Max	Peak	Effective	Estimated Effective	On-set Corrected
dB(A, B, C, D_1, D_2, D_3)	dB(D_2), PNdB, Phons	EdB(A, D_1, D_2, D_3)	EEPNdB,	EdB(A, D_1, D_2, D_3)$_o$
PNdB, $PNdB_{t_1}$, $PNdB_{t_2}$,		EPNdB, $EPNdB_{t_1}$, $EPNdB_{t_2}$,	$EEPNdB_{t_1}$,	$EPNdB_{t_1 o}$, $EPNdB_{t_1}M_o$,
PNdB-M, $PNdB_{t_1}M$, $PNdB_{t_2}M$,		EPNdB-M, $EPNdB_{t_1}M$, $EPNdB_{t_2}M$,	$EEPNdB_{t_2}$,	$EPNdB_{t_1}M_o$, $EPNdB_{t_2}M_o$
Phons			$EEPNdB_{t_1}M$	

Table V

CUT-OFF FREQUENCIES AND CENTER FREQUENCIES OF PREFERRED 1/3 OCTAVE BAND FILTERS, AND A, B, C, AND PROPOSED D FREQUENCY WEIGHTINGS FOR SOUND LEVEL METERS

Cut-Off Frequencies	Center Frequencies	dB(A)	dB(B)	dB(C)	dB(D_1)	dB(D_2)	dB(D_3)
(45-56) Hz	50 Hz	-30.2	-11.7	- 1.3	-12	-19	-26
(56-71)	63	-26.1	- 9.4	- 0.8	-11	-17	-24
(71-90)	80	-22.3	- 7.4	- 0.5	- 9	-14	-22
(90-112)	100	-19.1	- 5.7	- 0.3	- 7	-11	-20
(112-140)	125	-16.2	- 4.3	- 0.2	- 6	- 9	-18
(140-180)	160	-13.2	- 3.0	- 0.1	- 5	- 7	-16
(180-224)	200	-10.8	- 2.1	0.0	- 3	- 5	-14
(224-280)	250	- 8.0	- 1.4	0.0	- 2	- 3	-12
(280-355)	315	- 6.5	- 0.9	0.0	- 1	- 2	-10
(355-450)	400	- 4.8	- 0.6	0.0	0	0	- 8
(450-560)	500	- 3.3	- 0.3	0.0	0	0	- 6
(560-710)	630	- 1.9	- 0.2	0.0	0	0	- 4
(710-900)	800	- 0.8	- 0.1	0.0	0	0	- 2
(900-1120)	1000	0.0	0.0	0.0	0	0	0
(1120-1400)	1250	+ 0.5	- 0.1	- 0.1	+ 2	+ 2	+ 2
(1400-1800)	1600	+ 1.0	- 0.1	- 0.1	+ 6	+ 6	+ 3
(1800-2240)	2000	+ 1.2	- 0.2	- 0.2	+ 8	+ 8	+ 4
(2240-2800)	2500	+ 1.2	- 0.3	- 0.3	+10	+10	+ 4.5
(2800-3550)	3150	+ 1.2	- 0.5	- 0.5	+11	+11	+ 5
(3550-4500)	4000	+ 1.0	- 0.8	- 0.8	+11	+11	+ 5
(4500-5600)	5000	+ 0.5	- 1.3	- 1.3	+10	+10	+ 4.5
(5600-7100)	6300	- 0.2	- 2.0	- 2.0	+ 9	+ 9	+ 4
(7100-9000)	8000	- 1.1	- 3.0	- 3.0	+ 6	+ 6	+ 3
(9000-11,020)	10,000	- 2.5	- 4.3	- 4.3	+ 3	+ 3	0

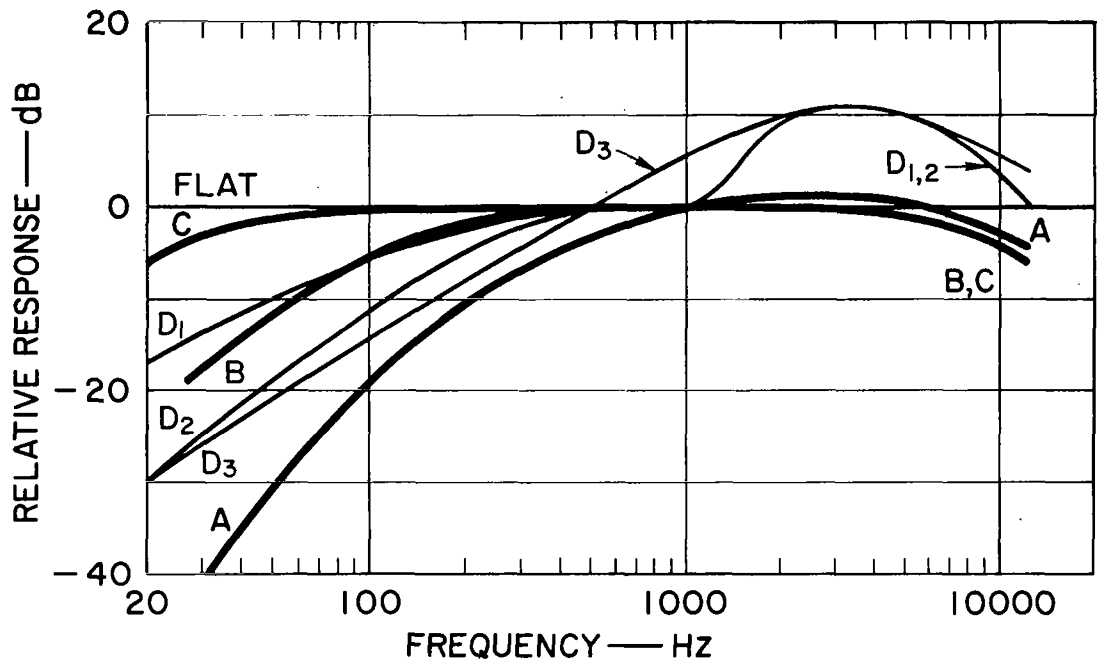

FIGURE 3 FREQUENCY WEIGHTINGS FOR SOUND LEVEL METER. Weightings A, B, and C are for loudness (S1.4, 1961, USASI, 10 E. 40th Street, New York, N.Y.). Weightings D_1, D_2, and D_3 have been proposed for annoyance or perceived noisiness. D_3, proposed by Young and Peterson,[3] is plotted 6 dB above its normal reference to show its close relation to D_2 at low and high frequencies.

Step 2. 1/3 Octave Bands. Add on a 10 $\log_{10}$ antilog basis the band levels of the 1/3 octave bands having the center frequencies of: (a) 50, 63, and 100 Hz and assign the result to the band center frequency having the greatest intensity; (b) 125, 160, and 200 Hz and assign the result to a band center frequency having the greatest intensity; (c) 250 and 315 Hz and assign the result to the band center frequency having the greatest intensity.

Note: If the greatest intensity in Step 2a, b, and c is present in more than one band within a step, assign the sum to the band with the highest frequency and a highest SPL in a, b, and c.

[Step 2. Full Octave Bands. Add on a 10 $\log_{10}$ antilog basis the band levels of the octave bands having the center frequencies of 63, and 125 Hz and assign the result to the band center frequency having the greatest intensity.

Note: If the intensity is the same in the two bands assign the sum to the center frequency of 125 Hz.]

Proceed to calculate PNdB in accordance with procedures given in Kryter and Pearsons,[4,5] ISO,[6] SAE,[7] or FAA[8] as appropriate. Phon (Stevens) was calculated according to ANSI* standard.[9,10]

The subscripts on certain PNdB units in Table IV of t_1 and t_2 refer to so-called tone correction procedures, t_1 being that proposed by Kryter and Pearsons[5] and t_2 that proposed by FAA.[11,12] It is proposed that consideration be given to standardizing procedures for tone corrections and the new procedure for asking allowances for critical bandwidth of the ear, and that the resulting unit be called PNdB, superseding previous PNdB units, just as in loudness scales improved phon units have superseded older, previous phon units. However, for the purposes of this paper, we will use both t_1 and t_2 subscripts, and PNdB and PNdB-M for purposes of identifying and distinguishing among the various units.

It has been proposed on the basis of laboratory findings of Nixon, von Gierke, and Rosinger,[13] that a correction to calculated EPNL is appropriate in accounting for the fact that although of equal duration, the period of noise intensity buildup is judged more annoying than the period of decreasing noise intensity. This has been labeled "onset correction" and its magnitude is found by referring to Figure 4. When the onset correction is used, the subscript 0 is added to the unit involved.

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* American National Standards Institute (ANSI), formerly named United States of America Standards Institute (USASI).

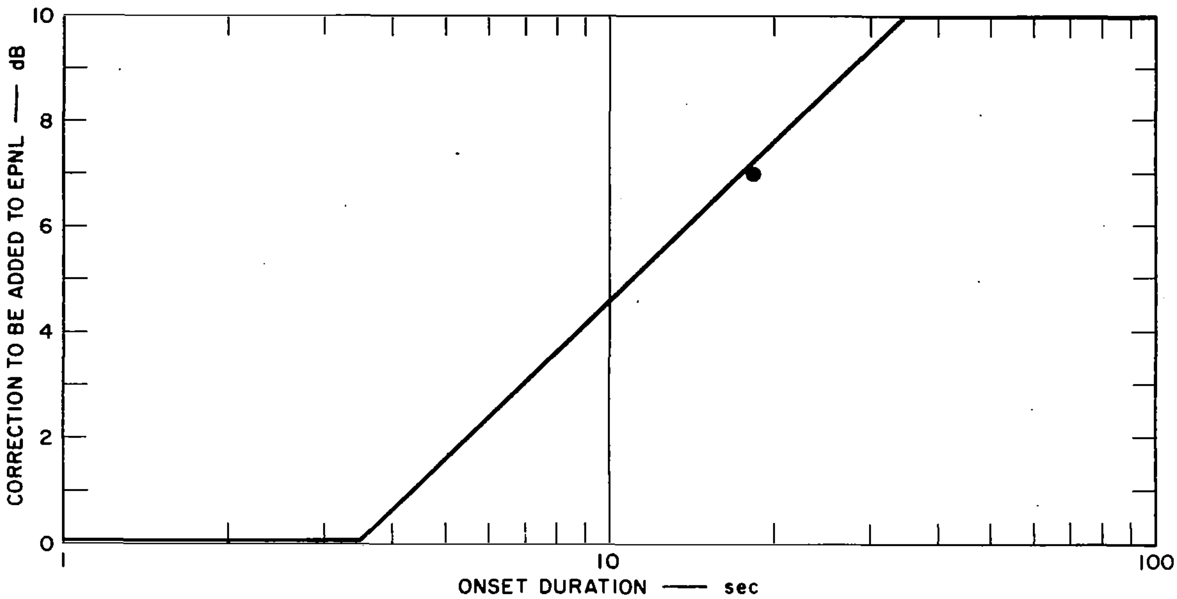

FIGURE 4 CORRECTION TO EPNL FOR CONTRIBUTION TO PERCEIVED NOISINESS OF ONSET DURATION OF NON-IMPULSIVE SOUNDS. The data plot is from Nixon, von Gierke, and Rosinger[14] plotted against a suggested standard onset duration of 3.5 secs.

The effective "E_8" units are the summed, on a power basis, one-half second values of the unit between the points of time the unit is within 10 of the maximum (max) level reached by that unit during a flyover minus a constant of 12.* The "EE_8" units are the max levels reached during a flyover, plus 10 $\log_{10}$ of the duration between the 10 dB downpoints (EE designating "Estimated Effective"); reference durations other than 8 sec can of course be used. For example, a reference duration of 16 sec, E_{16}PNdB, would be a constant 3 PNdB more than E_8.[15]

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* The constant of 12 arises from the use of 8 secs as a reference duration to be used with effective, integrated units; $12 = 10 \log_{10} (8/0.5)$ where 8 is the reference duration and 0.5 is the 0.5-sec time intervals between the noise measurements. Eight seconds is suggested as a reference duration because it is the nominal duration specified for a basic reference standard sound and because it is fairly representative of overflight durations near airports at least when measured to the 10 dB downpoints. This reference duration also provides a unit value that is roughly similar in magnitude to the Max PNL levels for these flights as now used for specifying aircraft noise level near airports; i.e., the 112 PNdB specified as maximum allowable levels for areas near New York City airports would be comparable on the average in that situation, for aircraft at approximately 2,000 feet altitude, to an E_8PNdB of 112.

Peak band levels are the highest band levels, as measured on a typical root-mean-square sound pressure level meter, present at any time during the occurrence of a sound. A PNdB (or Phon) calculated from these levels is sometimes called a Peak PNdB or Phon, sometimes a Composite PNdB or Phon. Maximum band levels are those band levels present at the period in time, usually some 0.5-sec period, when the unit for the successive such period reaches its highest value. These units are called Max PNdB or Max Phon. Measurements made over all frequencies, dB(A), dB(C), dB(D), are designated as Max E or EEdB(A), and so forth, as appropriate.

Psychological Measures

The fundamental task of the subjects was to mark on an answer sheet which of two aircraft sounds that were presented to them in a brief period of time, approximately within one to two minutes, did they consider to be the least acceptable if heard in or near their home 20 to 30 times per day. The instructions of "20-30 times per day" were given verbally to the subjects. The subjects also rated each noise on a scale running from completely acceptable to completely unacceptable. Copies of the instructions to the subjects and the questions they were required to answer after hearing each aircraft noise are in the Appendix.

The paired comparison tests are scored and interpreted as follows:

1. The percent of listeners in a group who preferred the reference aircraft noise when it appeared first in a given pair, and when it appeared in the second position with the same member of the pair, are averaged.

2. The percent obtained in step 1 is plotted against the level as measured by a given physical unit, of the comparison aircraft noise. Inasmuch as the level of the comparison noise was systematically varied, the percent of people, in general, who preferred the reference noise increased as the level of the comparison noise increased. An attempt was made to have the comparison noise vary over a range that caused the percent of people preferring the reference aircraft noise to change from near 0% to near 100%. Sample plots of the data are shown in Figure 5.

3. On each function such as those shown in Figure 5, a perpendicular is dropped to the abscissa from the point the 50% line crosses the curve drawn through the data points.

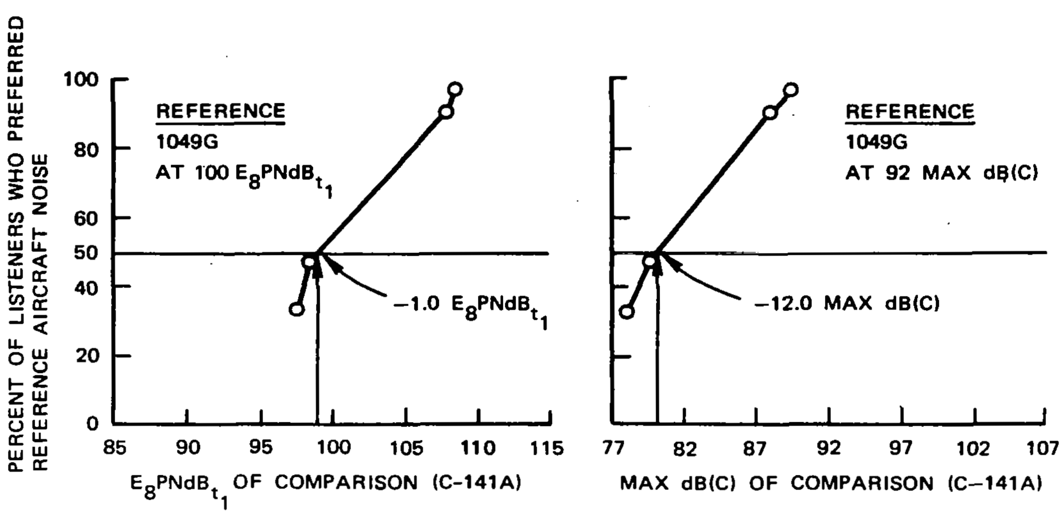

FIGURE 5 EXAMPLES OF PAIRED-COMPARISON JUDGMENTS OF SUBSONIC NOISE BY OUTDOOR LISTENERS AT WALLOPS STATION, VIRGINIA

4. The value obtained in step 3 is taken as the level for that unit of measurement required for the comparison noise if and when it is to be perceived as equal in unacceptability or noisiness to the reference aircraft noise.

5. The difference, if any, between the reference and comparison noises when judged equal is taken as the index of the ability of each of the physical units to properly indicate or predict the perceived noisiness of each pair of sounds. The physical units perfectly correlated with the psychological data would have a difference of 0 for each pair, i.e., when judged to be equal they are measured physically as being equal.

RESULTS AND DISCUSSION

Physical Measurements

Outdoor Measurements

Figure 6 shows peak and max 1/3 octave band spectra of representative overflights of the aircraft used in the tests. Also shown are the band levels present at the first 0.5-sec interval of time when the dB(C) level was 5 dB below the maximum dB(C) level reached by each noise.

It is to be noted in Figure 6 that the peak and max band levels are often not identical and that the shape of the band spectra changes somewhat from moment to moment, e.g., the relative shape of the spectra present at the 5 dB(C) downpoint sometimes differs from that present at its maximum level. These variations, which are audible to the listener, illustrate that some of the lack of precision with which one can predict judged perceived noisiness from physical measures of the noise is due perhaps as much to the general lack of accurate information about the noise, as it is to unreliability and individual differences among the listeners making judgments.

Some of the various units of measurements to be tested utilize not only the overall and 1/3 octave band levels taken over time but also information regarding so-called pure-tone or spectral complexity, total duration and on-set duration. Table VI gives representative total duration (between the 10 Max PNdB downpoints), onset duration, and tone corrections t_1 and t_2 of the aircraft noises involved in the judgment tests. The t_1 and t_2 values given in Table VI are those for Max PNdB; separate tone corrections were, of course, determined for the band spectra present during each 0.5-sec interval.

Comparison of Units of Measurement

Table VII presents the values of each of the 38 units of measurement for the noise from representative flights of each of the aircraft and operating power conditions used during the tests. It is perhaps of some interest to note in Table VII that, compared to Max PNdB, Max dB(A) is

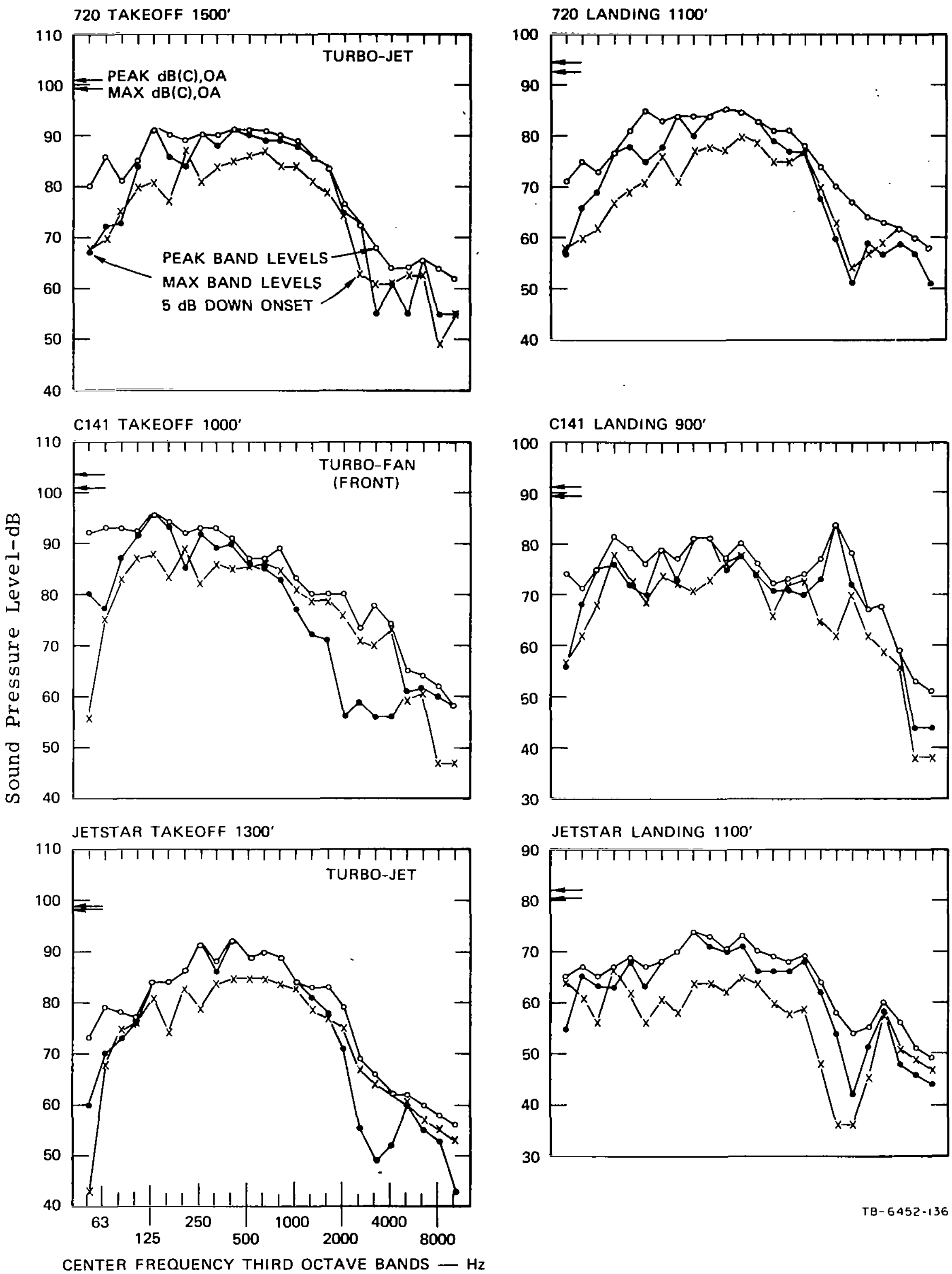

FIGURE 6 REPRESENTATIVE THIRD OCTAVE BAND SPECTRA FOR AIRCRAFT USED IN EXPERIMENT AT WALLOPS STATION

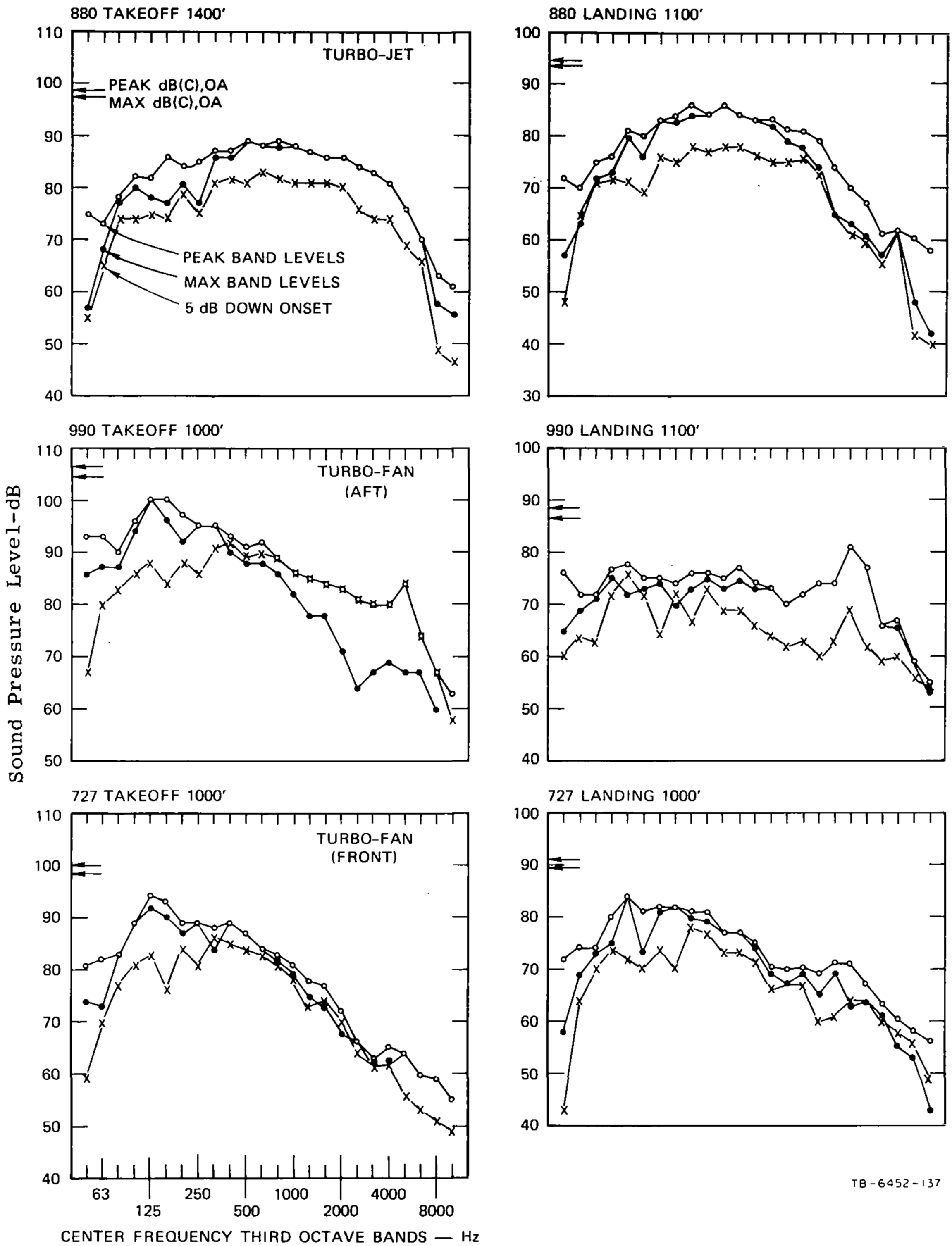

FIGURE 6 REPRESENTATIVE THIRD OCTAVE BAND SPECTRA FOR AIRCRAFT USED IN EXPERIMENT AT WALLOPS STATION Continued

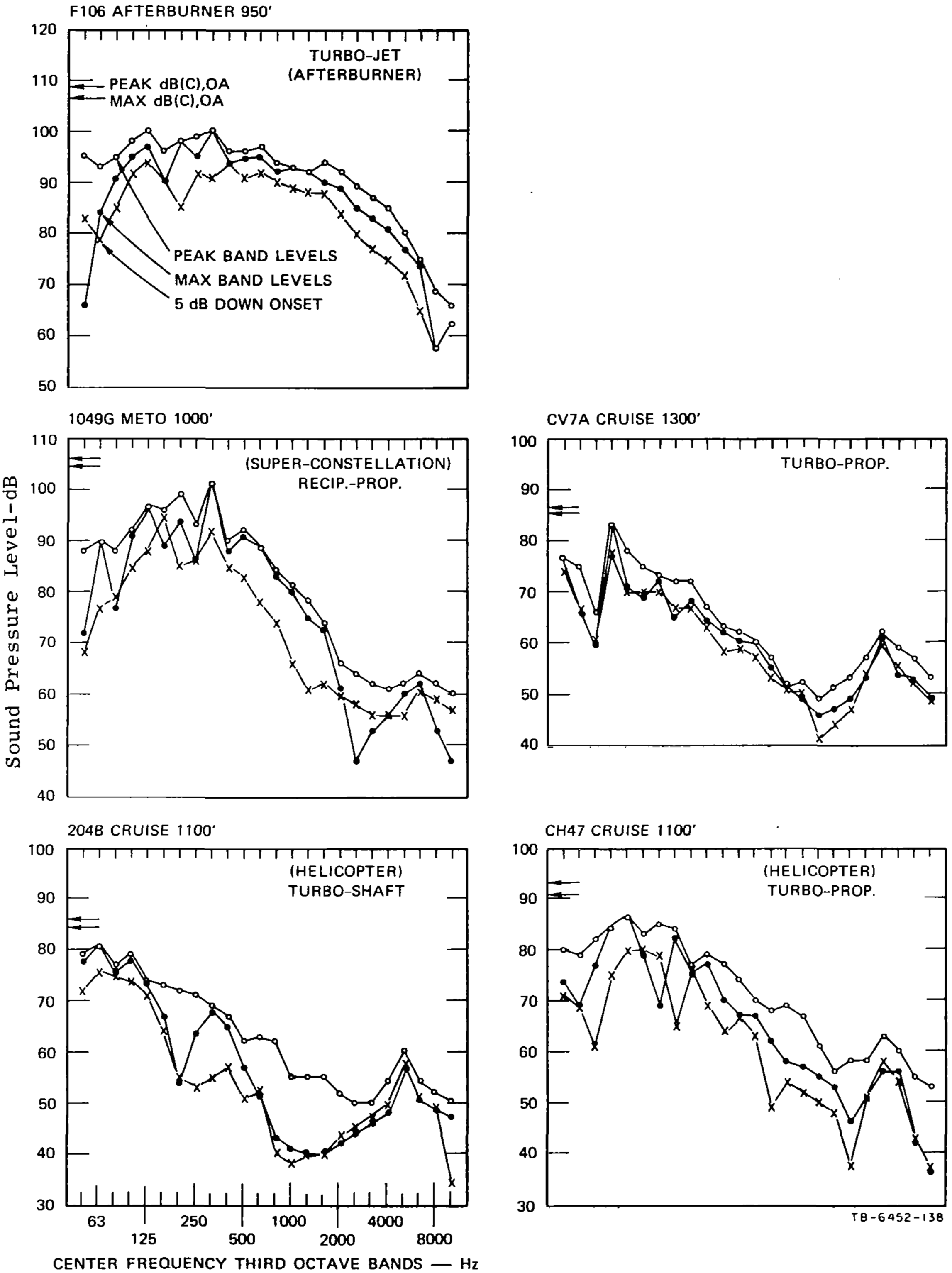

FIGURE 6 REPRESENTATIVE THIRD OCTAVE BAND SPECTRA FOR AIRCRAFT USED IN EXPERIMENT AT WALLOPS STATION Concluded

Table VI

TYPICAL PNL, TOTAL DURATION (BETWEEN 10 dB DOWN), ONSET DURATION (10 dB DOWN ONSET TO MAX), AND TONE CORRECTIONS t_1 AND t_2 FOR VARIOUS AIRCRAFT AND OPERATIONAL CONDITIONS USED DURING WALLOPS TESTS

Aircraft	EPR/Power	Altitude (feet)	Max PNdB	Average Duration* (secs)	Onset Duration (secs)	t_1	t_2
880	2.5 (TO)	1400	109.7	7.5		0.1	1.6
	2.1 (TO)	1400	106.9	8.0		0	3.0
	2.0 (TO)	1400	104.0	9.9	4.9	0.1	2.6
		2200	100.1	14.5	7.7	0.2	3.2
		3000	97.1	10.7	6.8	0.3	5.9
	Landing	250	116.1	2.8		0	0
		400	113.4	2.0		0	0.2
		700	107.3	3.8		0	1.0
		1100	101.4	8.5	3.8	0.2	1.1
990	Takeoff	1000	110.0	9.7	2.8	1.7	3.3
		1500	105.1	13.7		0.7	1.9
		2200	102.5	15.1		0.5	3.1
	Landing	250	115.6	3.0		4.3	3.0
		500	110.7	3.5	2.1	5.3	3.7
		700	106.1	4.5		4.2	3.8
		1100	100.9	4.3		4.6	4.2
		1800	93.6	7.8		4.8	4.5
727	Takeoff	600	112.5	4.8		0.5	3.1
		1000	108.7	8.9	4.9	0	1.5
		1500	104.9	9.0		0.5	2.0
	Landing	300	113.0	1.5		1.6	1.4
		400	110.9	1.5		0.2	2.0
		600	102.6	2.7		1.9	2.1
		700	101.7	3.0	1.3	2.0	3.9
		1000	96.7	5.0		1.7	3.4
		1500	90.1	8.5		0.8	4.3
720	Takeoff	1500	105.2	9.3		0.7	2.8
		2200	100.4	11.0	7.8	0	4.6
		3000	98.1	10.0		1.1	4.3
	Landing	250	116.8	2.5		0	1.2
		400	111.3	3.3		0.9	1.1
		700	105.8	4.8		0.1	2.1
		800	103.4	6.0	3.3	0	1.2
		1100	100.0	5.5		0.1	1.8
C-141	Takeoff	1000	106.1	9.5	3.8	2.1	3.5
		1700	100.2	11.0		0.2	5.0
		3000	96.0	9.5		0.5	5.4
	Landing	250	116.0	2.5		3.2	2.6
		300	114.5	2.5		4.5	3.9
		500	110.5	2.9		5.3	4.5
		900	101.8	4.3	3.3	5.6	5.3
		1300	97.0	4.8		6.6	5.4

Aircraft	EPR/Power	Altitude (feet)	Max PNdB	Average Duration* (secs)	Onset Duration (secs)	t_1	t_2
Jetstar	Takeoff	800	106.8	6.0	2.8	0	2.3
		1300	103.9	5.0		0.5	4.6
		2000	99.6	5.8		0.2	5.6
	Landing	250	104.6	1.7		0	1.1
		400	101.1	2.5	1.0	0.1	2.5
		500	98.6	3.0		0	4.6
		700	95.8	3.8		0	3.0
		900	91.2	4.5		0	3.8
		1100	89.5	5.3		0.8	4.5
F-106	After-Burner	950	116.2	5.2		0	2.3
		1700	110.8	7.7		0.1	2.4
		3000	105.5	11.3		1.0	4.2
		4000	99.2	11.8	5.0	0.8	6.7
1049G	Meto	350	116.0	3.3	1.5	0	2.6
		600	109.8	4.5		0.8	2.2
		1000	109.3	6.1	2.6	1.5	2.6
		1300	104.9	8.3	3.5	1.6	2.9
		1500	103.8	7.6		0.9	2.0
		1800	103.4	6.2	2.1	0.8	2.6
		3000	103.0	3.5	2.5	1.8	3.4
CV-7A	Cruise	250	97.8	3.8	1.8	0.4	3.6
		500	92.6	4.0		0.6	4.4
		800	89.8	5.5		0.2	4.7
		1300	87.7	6.5		0.5	4.2
204B	Cruise	250	94.5	19.8	16.5	0.7	3.6
		450	92.2	17.6		0.4	2.7
		750	86.7	27.0		0.6	4.6
		1100	83.5	23.9		1.5	5.0
CH-47	Cruise	250	106.3	3.8	2.3	0.3	1.7
		450	101.0	5.3		1.0	2.5
		750	97.3	6.0		0.5	2.3
		1100	95.3	9.0		0.7	4.8

* Max PNdB to 10 dB down.

Table VII

DURATION, ONSET DURATION AND VALUE OF 38 UNITS OF MEASUREMENT
FOR THE NOISE ON THE GROUND FROM REPRESENTATIVE FLIGHTS OF EACH OF THE AIRCRAFT
OPERATING AT THE INDICATED POWER SETTINGS AND ALTITUDES

Aircraft	Power	Altitude (feet)	Duration* (sec)	Onset† Duration (sec)	Max dB(A)	Max dB(B)	Max dB(C)	Max $dB(D_1)$	Max $dB(D_2)$	Max $dB(D_3)$	Max Phons	Max PNdB	Max PNdBM	Max $PNdB_{t_1}$	Max $PNdB_{t_1}M$	Max $PNdB_{t_2}$	Max $PNdB_{t_2}M$	Peak $dB(D_2)$	Peak Phons	Peak PNdB
880	Takeoff (2.5)	1400	9.5	5.5	98.9	99.9	100.4	103.4	103.4	99.7	106.7	109.7	108.9	109.7	108.9	111.4	110.6	104.3	107.7	110.8
880	Takeoff (2.1)	1400	9.5	4.4	95.6	96.8	97.3	100.7	100.7	96.6	103.5	106.9	106.2	106.9	106.2	109.9	109.2	101.5	104.9	108.2
880	Takeoff (2.0)	1400	10.5	5.8	94.7	96.4	97.1	97.9	97.5	94.5	101.5	104.1	103.1	104.2	103.2	106.6	105.6	98.6	102.7	105.2
990	Takeoff	1500	16.9	7.3	92.8	97.8	100.1	97.7	97.4	91.8	101.1	105.1	103.9	105.8	104.6	107.0	105.8	99.6	105.1	108.0
727	Takeoff	1500	9.3	5.5	92.3	97.7	100.3	97.4	96.2	90.9	102.3	104.9	103.4	105.3	103.8	106.9	105.4	97.7	103.7	106.3
720	Takeoff	1500	14.0	6.0	95.0	98.0	99.4	98.6	98.2	94.2	102.4	105.2	103.7	105.9	104.4	108.0	106.5	99.2	104.2	107.0
C141	Takeoff	1000	9.3	3.5	93.7	98.4	100.9	98.9	98.3	93.2	102.6	106.1	104.8	108.2	106.9	109.6	108.3	100.4	105.6	108.7
Jetstar	Takeoff	1300	7.0	4.3	94.0	97.7	98.7	97.9	97.7	92.5	100.9	103.9	102.9	104.4	103.4	108.5	107.5	98.5	102.6	105.5
F-106	Afterburner	1700	8.1	3.0	98.7	103.9	106.2	103.7	102.6	97.1	107.4	110.4	108.4	110.5	108.5	112.8	110.8	103.9	109.2	112.2
Jet Takeoff				Avg.	95.1	98.5	100.0	99.6	99.1	94.5	103.2	106.3	105.0	106.8	105.5	109.0	107.7	100.4	105.1	108.0
880	Landing	700	5.0	2.8	95.9	97.1	97.7	100.9	100.9	96.9	104.0	107.3	106.4	107.3	106.4	108.3	107.4	101.3	104.8	108.1
990	Landing	700	4.4	2.8	90.3	90.2	91.2	99.1	99.1	93.4	102.1	106.1	105.6	110.3	109.8	109.9	109.4	100.0	103.3	107.2
727	Landing	700	3.0	1.5	87.7	89.8	91.4	94.2	94.2	88.7	98.0	101.7	100.8	103.7	102.8	105.6	104.7	94.8	99.0	102.8
720	Landing	700	6.0	3.5	94.5	95.9	96.6	99.3	99.1	95.3	102.3	105.8	105.1	105.9	105.2	107.9	107.2	99.6	103.5	106.9
C141	Landing	900	2.5	2.0	87.6	87.7	88.6	95.5	95.5	90.3	97.8	101.8	101.3	107.4	106.9	107.1	106.6	96.8	99.6	103.5
Jetstar	Landing	700	6.5	4.3	84.4	85.7	86.4	88.9	88.8	85.0	93.1	95.8	95.0	95.8	95.0	98.8	98.0	89.4	94.1	96.5
Jet Landing				Avg.	90.1	92.7	92.0	96.3	96.3	91.6	99.6	103.1	102.4	105.1	104.4	106.3	105.6	97.0	100.7	104.2
CH47	Cruise	450	12.2	6.3	86.3	93.6	96.7	92.8	91.0	84.6	97.4	100.0	97.9	101.8	99.7	102.9	100.8	93.5	100.0	102.9
204B	Cruise	450	28.7	19.6	77.8	85.3	90.6	85.0	83.4	76.7	90.2	92.1	90.2	92.5	90.6	94.8	92.9	85.6	93.4	95.5
Helicopter Cruise				Avg.	82.1	89.5	93.7	88.9	87.2	80.7	93.8	96.1	94.1	97.2	95.2	98.9	96.9	89.6	96.7	89.5
CV7A	Cruise	500	11.8	4.8	77.0	85.6	89.8	85.0	82.4	75.9	90.5	92.6	90.9	93.2	91.5	97.0	95.3	84.2	92.6	94.7
Prop-Jet																				
1049G	Meto	1300	6.6	2.4	92.7	98.6	101.0	98.3	97.3	90.5	102.1	104.9	103.6	106.5	105.2	107.9	106.6	98.6	103.9	106.9
Prop-Recip.																				

* Time between levels that are 10 dB below max level.

† Time between first level preceding max level that is 10 dB below max level and moment max level occurs.

Table VII (Concluded)

	E_8dB(A)	E_8dB(A)$_o$	E_8dB(D_1)	E_8dB(D_1)$_o$	E_8dB(D_2)	E_8dB(D_2)$_o$	E_8dB(D_3)	E_8dB(D_3)$_o$	E_8 PNdB	E_8 PNdB M	E_8 PNdB M_o	E_8 PNdB$_{t_1}$	E_8 PNdB$_{t_1}$ M_o	E_8 PNdB$_{t_1}$ M	E_8 PNdB$_{t_1}$ M_o	E_8 PNdB$_{t_2}$	E_8 PNdB$_{t_2}$ M	E_8 PNdB$_{t_2}$ M_o	EE_8 PNdB	EE_8 PNdB$_{t_1}$	EE_8 PNdB$_{t_1}$ M	EE_8 PNdB$_{t_2}$
	95.7	97.7	101.0	103.0	100.4	102.4	95.6	97.6	107.4	106.5	108.5	107.7	109.7	106.8	108.8	108.1	107.2	109.2	110.9	110.9	110.0	111.6
	93.8	95.0	98.5	99.7	98.0	99.2	94.5	95.7	105.0	104.0	105.2	105.2	106.4	104.2	105.4	106.5	105.5	106.7	108.3	108.7	107.7	110.1
	90.5	92.7	94.0	96.2	95.0	97.2	91.5	93.7	100.4	99.3	101.5	100.7	102.9	99.6	101.8	102.3	101.2	103.4	104.3	104.6	103.5	106.1
	92.8	95.8	97.9	100.9	97.4	100.4	91.5	94.5	105.1	103.5	106.5	105.4	108.4	103.8	106.8	105.9	104.3	107.3	108.7	109.2	107.8	109.9
	90.1	92.1	95.2	97.2	94.2	96.2	88.3	90.3	101.8	100.4	102.4	102.1	104.1	100.7	102.7	104.6	103.2	105.4	105.6	106.0	104.5	108.2
	91.5	93.8	95.8	98.1	95.3	97.6	90.9	93.2	102.7	101.4	103.7	103.1	105.4	101.8	104.1	104.8	103.5	105.8	107.6	108.3	106.6	109.5
	91.0	91.5	96.7	97.2	95.4	95.9	89.7	90.2	103.6	102.1	102.6	104.5	105.0	103.0	103.5	106.0	104.5	105.0	108.0	108.9	107.6	110.2
	89.1	90.2	92.6	93.7	92.5	93.6	88.0	89.1	99.0	97.9	99.0	99.3	100.4	98.2	99.3	101.6	100.5	101.6	103.3	103.9	102.8	106.4
	96.2	96.2	100.8	100.8	99.6	99.6	94.3	94.3	107.7	106.1	106.1	108.0	108.0	106.4	106.4	108.7	107.1	107.1	111.4	111.5	109.2	112.2
Avg.	92.3	93.9	96.9	98.5	96.4	98.0	91.6	93.2	103.6	102.4	103.9	104.0	105.6	102.7	104.3	105.4	104.1	105.7	107.6	108.0	106.6	109.4
	90.2	90.2	94.7	94.7	94.6	94.6	90.6	90.6	101.4	100.5	100.5	101.7	101.7	100.8	100.8	102.1	101.2	101.2	104.8	105.3	104.4	105.7
	84.7	84.7	92.7	92.7	92.7	92.7	87.5	87.5	100.1	99.8	99.8	103.3	103.3	103.0	103.0	102.6	102.3	102.3	104.7	107.0	106.5	105.6
	81.5	81.5	87.5	87.5	87.1	87.1	81.4	81.4	94.7	93.6	93.6	96.1	96.1	95.0	95.0	97.5	96.4	96.4	97.8	99.5	98.6	100.8
	89.5	90.0	93.9	94.4	93.7	94.2	89.9	90.4	100.5	99.7	100.2	101.3	101.8	100.5	101.0	101.8	101.0	101.5	104.1	104.7	104.0	106.1
	81.9	81.9	89.0	89.0	88.9	88.9	83.6	83.6	95.9	95.4	95.4	100.0	100.0	99.5	99.5	100.0	99.5	99.5	98.8	102.6	102.1	103.1
	78.6	79.7	83.0	84.1	82.9	84.0	78.8	79.9	89.6	88.7	89.8	90.4	91.5	89.5	90.6	91.7	90.8	91.9	93.0	94.8	94.1	95.7
Avg.	84.4	84.7	90.2	90.4	90.0	90.3	85.3	85.6	97.1	96.3	96.6	98.8	99.1	98.1	98.3	99.3	98.6	98.8	100.6	102.2	101.6	102.9
	82.0	84.5	88.6	91.1	86.8	89.3	80.1	82.6	95.8	94.4	96.9	96.5	99.0	95.1	97.6	98.1	96.7	99.2	98.8	100.2	98.6	101.2
	77.6	83.9	85.6	91.9	83.2	89.5	76.8	83.1	92.2	90.6	96.9	92.4	105.3	90.8	97.1	93.3	91.7	98.0	96.5	96.7	94.9	96.7
Avg.	79.8	84.2	87.1	91.5	85.0	89.4	78.5	82.9	94.0	92.5	96.9	94.5	102.2	93.0	97.4	95.7	94.2	98.6	97.7	98.5	96.8	99.0
	73.5	75.0	80.7	82.2	81.2	82.7	75.6	77.1	88.3	87.7	89.2	89.8	91.3	89.2	90.7	90.6	90.0	91.5	92.8	95.3	95.6	94.9
	88.4	88.4	94.1	94.1	92.7	92.7	86.8	86.8	101.1	99.4	99.4	101.9	101.9	100.2	100.2	102.5	100.8	100.8	105.0	105.9	104.0	106.8

about 13 units less, dB(C) about six units less, etc. However, the differences found between any two units varies somewhat for different types of aircraft.

Indoor Measurements

It was planned to obtain physical measurements in each room where subjects were located, and to calculate from these measurements the units found for the noise present outdoors. Unfortunately this turned out to be impractical for primarily two reasons:

1. The dynamic range of the recording equipment, approximately 50 dB, was not sufficient to permit satisfactory recordings between the 10 dB downpoints for the noises whose spectra varied as much as 40 dB among various 1/3 octave bands, without some a priori and unavailable information regarding the sound attenuation characteristics of the houses; and

2. The inadvertent sounds made by the subjects were sufficient to interfere with the recording of some of the less intense frequency bands of some of the less intense flyover noises, particularly when at the 10 dB downpoints on the flyover cycle.

However, a sufficient number of satisfactory recordings of each type of aircraft noise at their higher levels were obtained to permit the after-the-fact determination of attenuation properties of the two test houses with respect to each test room. The detailed results of the analysis of noise attenuation by the house structures is given in a separate report.[3]

Results of Paired-Comparison Judgment Tests

Outdoor Listeners

Table VIII gives the differences for each unit of measurement between the noise from the reference aircraft (CV-880) and that from the comparison aircraft when the two noises were deduced to be equally unacceptable to the listeners outdoors. Table IX gives similar information when the reference aircraft was the L-1049G, and, on the bottom of the table, for all pairs of judgments regardless of which reference aircraft was involved. Also given on Tables VIII and IX are the average difference, the average deviation (the averages of the differences without regard to whether a

Table VIII

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Outdoor Listeners | Outdoor Physical Measurements | Reference Aircraft: 880 at Takeoff Power

Comparison Aircraft		Reference Aircraft (880)			Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Peak	Peak	Peak	Max	Max
Type	Power	Altitude (feet)	Takeoff EPR	Avg. Peak PNdB	dB(A)	dB(B)	dB(C)	$dB(D_1)$	$dB(D_2)$	$dB(D_3)$	Phons	PNdB	$PNdB_{t_1}$	$PNdB_tM$	$PNdB_{t_2}$	$dB(D_2)$	Phons	PNdB	PNdB-M	$PNdB_{t_2}M$
990	Takeoff	1400	2.5	111.0	-3.0	+1.0	+3.0	-2.0	-1.5	-2.5	-1.0	-1.5	-0.5	+1.0	+2.0	-1.0	+1.0	+1.0	0	+3.5
727	Takeoff	1400	2.0	105.5	-1.0	+2.0	+4.5	+1.0	0.5	-1.5	+2.0	+2.5	+2.5	+1.0	+1.5	1.0	+2.0	+2.5	+1.0	0.0
720	Takeoff	1400	2.0	104.0	-2.5	-1.0	0	-2.0	-2.5	-2.5	-2.0	-1.5	-1.5	-2.0	0	-1.5	-1.0	-1.0	-2.0	-2.0
C141	Takeoff	1400	2.0	106.5	-5.5	-2.5	-0.5	-3.0	-3.5	-5.5	-3.0	-2.0	+0.5	0	-1.0	-2.5	-1.5	-0.5	-2.5	-1.5
Jetstar	Takeoff	1400	2.0	106.0	0	+1.5	+2.0	+0.5	0.5	0	+1.0	+1.0	+1.0	+1.0	+2.0	1.5	+1.5	+2.0	+1.0	+2.0
F106	Afterburner	1400	2.0	105.0	-3.0	0	+1.5	-2.0	-3.0	-5.0	-1.5	-2.0	-1.5	-2.0	+0.5	-2.0	-1.0	-1.0	-1.5	0.0
Jet TO vs. jet				Avg.	-2.5	+0.2	+1.8	-1.3	-1.6	-2.8	-0.8	0.6	+0.1	-0.2	+0.8	-0.8	+0.2	+0.5	-0.6	+0.3
				Avg. dev.	2.5	1.3	1.9	1.8	1.9	2.8	1.8	1.8	1.3	1.2	1.2	1.6	1.3	1.3	1.3	1.5
				Range	4.5	4.5	5.0	4.0	4.0	5.5	5.0	4.5	4.0	3.0	3.0	4.0	3.5	3.5	3.5	5.5
990	Landing	1400	2.5	113.0	-1.0	-3.0	-3.0	+3.5	3.5	+1.5	+3.0	+3.5	+8.0	+8.0	+5.5	3.5	+3.0	+3.0	+3.5	+5.5
727	Landing	1400	2.0	105.5	-2.5	-2.5	-2.0	+1.5	1.5	-1.0	+1.5	+2.5	+4.5	+4.5	+2.0	1.0	+1.0	+2.0	+2.5	+2.0
720	Landing	1400	2.0	103.5	-3.0	-3.5	-3.0	-2.0	-1.5	-2.0	-2.5	-1.0	-1.0	-1.5	-2.5	-2.0	-2.5	-1.5	-1.5	-2.5
C141	Landing	1400	2.0	106.0	-3.5	-5.0	-4.5	+1.0	1.5	-0.5	0	+1.5	+6.5	+7.0	+4.0	2.0	+0.5	+2.0	+2.0	+4.5
Jet landing vs. jet				Avg.	-2.5	-3.5	-3.1	+1.0	1.3	-0.5	+0.5	+1.6	+4.5	+4.5	+2.3	1.1	+0.5	+1.4	+1.6	+1.6
				Avg. dev.	2.5	3.5	3.1	2.0	2.0	1.3	1.8	2.1	5.0	5.3	3.5	2.1	1.8	2.1	1.6	2.4
				Range	2.5	2.5	2.5	5.5	5.0	3.5	5.5	4.5	9.0	9.5	8.0	5.5	5.5	4.5	5.0	8.0
Jet vs. jet				Avg.	-2.5	-1.3	-0.2	-0.4	-0.5	-1.9	-0.3	+0.3	+1.9	+1.7	+1.4	0	+0.3	+0.9	+0.1	+0.8
				Avg. dev.	2.5	2.2	2.4	1.9	2.0	2.2	1.8	1.9	2.8	2.8	2.1	1.8	1.5	1.6	1.4	1.8
				Range	4.5	7.0	9.0	6.5	7.0	7.0	6.0	5.5	9.5	10.0	8.0	6.0	5.5	4.5	5.5	8.0
1049G	METO	1400	2.1	108.5	+6.0	+11.0	+13.0	+7.5	5.0	+3.5	+10.0	+9.5	+10.0	+7.0	+8.5	4.5	+9.0	+8.5	+6.5	+5.5
CH47	Cruise	2200	2.0	100.5	+4.5	+9.5	+12.0	+8.5	8.0	+7.5	+ 8.5	+9.0	+10.0	+10.5	+7.5	6.5	+9.0	+9.5	+9.5	+8.0
All aircraft vs. 880 jet N = 12				Stand. dev.	3.3	5.0	5.6	3.8	3.5	3.6	4.2	4.0	4.4	4.3	3.3	2.8	3.7	3.5	3.5	3.4
				Avg.	-1.2	+0.6	+1.9	+1.0	0.7	-0.7	+1.3	+1.8	+3.3	+2.9	+2.5	0.9	+1.8	+2.3	+1.5	+2.1
				Avg. dev.	3.0	3.5	4.1	2.9	2.7	2.8	3.0	3.1	4.0	3.8	3.1	2.4	2.8	2.8	2.8	3.1
				Range	11.5	16.0	17.5	11.5	11.5	13.0	13.0	11.5	11.5	12.5	11.0	9.0	11.5	11.0	12.0	10.0

Table VIII (concluded)

E_8 dB(A)	E_8 dB(A)$_o$	E_8 dB(D_1)	E_8 dB(D_1)$_o$	E_8 dB(D_2)	E_8 dB(D_2)$_o$	E_8 dB(D_3)	E_8 dB(D_3)$_o$	E_8 PNdB	E_8 PNdB$_{t_1}$	E_8 PNdB$_{t_1o}$	E_8 PNdB$_{t_1}$M	E_8 PNdB$_{t_1}$M$_o$	E_8 PNdB-M	E_8 PNdB$_{t_2}$M	E_8 PNdB-M$_o$	E_8 EPNdB$_{t_2}$M$_o$	E_8 PNdB$_{t_2}$	EE_8 PNdB	EE_8 PNdB$_{t_1}$	EE_8 PNdB$_{t_1}$M	EE_8 PNdB$_{t_2}$
+0.5	-1.5	+0.5	-1.5	-0.5	-2.5	-2.5	-4.5	+1.0	+1.5	-0.5	0	-2.0	-0.5	+1.5	-2.5	-0.5	+3.0	+1.0	+1.5	+1.0	+3.5
-0.5	-0.5	+1.5	+1.5	0.5	0.5	-1.5	-1.5	+2.0	+2.0	+2.0	+1.5	+1.5	+1.5	+1.5	+1.5	+1.5	+2.0	+2.0	+2.0	+1.5	+1.5
-1.5	0	-1.0	+0.5	-1.0	0.5	-2.0	-0.5	-1.0	-0.5	+1.0	-0.5	+1.0	-1.0	+0.5	+0.5	+2.0	+0.5	-0.5	+0.5	-0.5	+1.0
-4.0	-5.0	-1.5	-2.5	-2.5	-3.5	-5.0	-6.0	-0.5	0	-1.0	-0.5	-1.5	-1.0	-0.5	-2.0	-1.5	0	+0.5	+0.5	+0.5	+0.5
0	-1.5	+1.0	-0.5	0.5	-1.0	0	-1.5	+1.0	+1.0	-0.5	+1.0	-0.5	+1.0	+1.0	-0.5	-0.5	+1.0	0	0	0	+0.5
-3.0	-1.5	-1.5	0	-2.5	-1.0	-4.5	-3.0	-2.0	-0.5	+1.0	0	+1.5	-1.5	+1.0	0.0	+2.5	+0.5	-1.5	+0.5	+0.5	+1.5
-1.4	-1.7	-0.2	-0.4	-0.9	-1.2	-2.6	-2.8	+0.1	+0.6	+0.3	+0.3	0	-0.3	+0.8	-0.5	+0.6	+1.2	+0.3	+0.8	+0.5	+1.4
1.6	1.7	1.2	1.1	1.3	1.5	2.6	2.8	1.3	0.9	1.0	0.6	1.3	1.1	1.3	1.2	1.4	1.2	0.9	0.8	0.7	1.4
4.5	5.0	3.0	4.0	3.0	4.0	5.0	5.5	4.0	2.5	3.0	2.0	3.5	3.0	2.0	3.0	4.0	3.0	3.5	2.0	2.0	3.0
-5.5	-7.0	-1.5	-3.0	-0.5	-2.0	-5.0	-6.5	-1.5	+1.5	0	+3.5	+2.0	+0.5	+2.5	-1.0	+1.0	+0.5	-1.0	0	+2.5	+1.0
-6.5	-8.0	-3.0	-4.5	-3.5	-5.0	-5.5	-7.0	-2.0	-1.0	-2.5	-1.0	-2.5	-2.0	+1.0	-3.5	-4.5	-3.0	-3.0	-1.5	-2.0	-4.0
-3.0	-4.0	-2.5	-3.5	-3.0	-4.0	-4.5	-5.5	-2.5	-2.0	-3.0	-2.5	-3.5	-3.0	-3.5	-4.0	-4.5	-3.0	-2.0	-1.5	-2.5	-3.5
-5.5	-5.5	-1.5	-1.5	-2.0	-2.0	-4.5	-4.5	-1.0	+3.0	+3.0	+3.5	+3.5	-0.5	-1.5	-0.5	+1.5	+1.0	-2.5	+2.0	+2.0	0
-5.1	-6.1	-2.1	-3.1	2.3	-3.3	-4.9	-5.9	-1.8	+0.4	-0.6	+0.9	-0.1	-1.2	-0.4	-2.3	-1.6	-1.1	-2.1	-0.3	0	-1.6
5.1	6.1	2.1	3.1	2.3	3.3	4.9	5.9	1.8	1.9	2.1	2.6	2.9	1.5	2.1	2.3	2.9	1.9	2.1	1.3	2.3	2.1
3.5	4.0	1.5	3.0	3.0	3.0	1.0	2.5	1.5	5.0	6.0	6.0	7.0	3.5	6.0	3.5	6.0	4.0	2.0	3.5	5.0	5.0
-2.9	-3.5	-1.0	-1.5	-1.5	-2.0	-3.5	-4.0	-0.7	+0.5	-0.1	+0.5	-0.1	-0.7	+0.4	-1.2	-0.3	+0.3	-0.7	+0.4	+0.3	+0.2
3.0	3.5	1.6	1.9	1.7	2.2	3.5	4.0	1.5	1.3	1.4	1.4	1.9	1.3	1.5	1.6	2.0	1.5	1.4	1.0	1.3	1.7
6.5	8.0	4.5	6.0	4.0	5.5	5.5	6.5	4.5	5.0	6.0	6.0	7.0	4.5	6.0	5.5	7.0	6.0	5.0	3.5	5.0	7.5
+1.5	-0.5	+2.5	+0.5	0.5	-1.5	-1.0	-3.0	+3.5	+4.5	+2.5	+2.5	+0.5	+1.5	+1.5	-0.5	-0.5	+3.5	+5.0	+5.0	+2.5	+4.5
+2.0	-2.0	+4.5	+0.5	3.5	-0.5	+1.0	-3.0	+5.5	+5.5	+1.5	+5.0	+1.0	+5.0	+4.0	+1.0	0.0	+4.5	+5.5	+5.5	+4.0	+4.0
2.9	2.7	2.2	1.9	2.0	1.8	2.1	2.1	2.5	2.3	1.9	2.2	2.1	2.1	2.0	1.7	2.3	2.3	2.7	2.2	1.9	2.6
-2.0	-3.1	-3.0	-1.2	-0.9	-1.8	-2.9	-3.9	+0.2	+1.3	+0.3	+1.0	+0.1	0.0	+0.8	1.0	0.3	+0.9	+0.3	+1.2	+0.8	+0.9
2.8	3.1	1.4	1.3	1.7	2.0	3.1	3.9	2.0	1.9	1.5	1.8	1.8	2.0	1.7	1.5	1.7	1.9	2.0	1.7	1.6	2.1
8.5	8.0	7.5	6.0	7.0	5.5	6.5	6.5	8.0	7.5	6.0	7.5	7.0	8.0	7.5	5.0	7.0	7.5	8.5	7.0	6.5	8.5

Table IX

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Outdoor Listeners | Outdoor Physical Measurements | Reference Aircraft: 1049G at METO Power

Comparison Aircraft: Type	Comparison Aircraft: Power	Reference Aircraft (1049G): Altitude (feet)	Reference Aircraft (1049G): Takeoff Power	Reference Aircraft (1049G): Avg. Peak PNdB		Max dB(A)	Max dB(B)	Max dB(C)	Max dB(D_1)	Max dB(D_2)	Max dB(D_3)	Max Phons	Max PNdB	Max PNdB$_{t_1}$	Max PNdB$_{t_1}$M	Max PNdB$_{t_2}$	Peak dB(D_2)	Peak Phons	Peak PNdB	Max PNdB-M	Max PNdB$_{t_2}$M
727	Landing	1000	METO	110.5		-6.0	-9.5	-10.5	-4.5	-3.0	-1.5	-6.5	-5.0	-4.5	-2.5	-3.5	-4.0	-7.0	-6.0	-3.0	-1.5
720	Landing	1000	METO	109.5		-7.0	-11.5	-13.0	-9.5	-8.0	-4.5	-9.5	-9.5	-11.0	-10.5	-10.5	-8.5	-9.5	-9.5	-9.0	-10.0
C141	Landing	1000	METO	111.0		-7.0	-13.5	-14.5	-5.0	-3.0	-1.5	-7.0	-5.5	-1.0	+0.5	-2.5	-3.5	-6.5	-5.0	-4.0	-1.0
Jetstar	Landing	1800	METO	107.0		-2.5	-6.0	-7.0	-2.0	-2.0	-0.5	-4.0	-3.5	-5.5	-4.5	-2.5	-1.0	-4.5	-4.0	-2.0	-1.5
Jet vs. 1049G					Avg.	-5.6	-10.1	-11.3	-5.3	-4.0	-2.0	-6.8	-5.9	-5.5	-4.3	-4.8	-4.3	-6.9	-6.1	-4.5	-3.5
					Avg. dev.	5.3	10.1	11.3	5.3	-4.0	2.0	6.8	5.9	5.5	4.5	4.8	-4.3	6.9	6.1	4.5	3.5
					Range	4.5	7.5	7.5	7.5	6.0	4.0	5.5	6.0	10.0	11.0	8.0	7.5	5.0	5.5	6.0	9.0
CV7A	Cruise	3000	METO	104.5		-5.5	-3.0	-1.0	-3.5	-4.0	-4.0	-2.0	-2.5	-3.5	-3.0	-2.5	-3.5	-2.0	-2.0	-2.0	-2.0
204B	Cruise	1300	METO	106.5		-8.5	-7.5	-2.5	-7.5	-7.5	-6.0	-5.5	-7.5	-7.0	-6.5	-7.0	-6.0	-4.0	-5.5	-7.0	-6.5
All aircraft vs. 1049G Prop. N = 6					Stand. dev.	2.0	3.8	5.5	2.7	2.5	2.1	2.6	2.6	3.4	3.8	3.3	2.6	2.6	2.5	2.9	3.7
					Avg.	-6.1	-8.5	-8.1	-5.3	-4.6	-3.0	-5.8	-5.6	-5.4	-4.4	-4.8	-4.4	-5.6	-5.3	-4.5	-3.8
					Avg. dev.	6.1	8.5	8.1	5.3	-4.6	3.0	5.8	5.6	5.4	4.6	4.8	-4.4	5.6	5.3	4.5	3.8
					Range	6.0	10.5	13.5	7.5	6.0	5.5	7.5	7.0	10.0	11.0	8.0	7.5	7.5	7.5	6.0	9.0
Comparison vs. either reference					Stand. dev.	3.7	6.3	7.3	4.6	4.0	3.3	5.0	5.0	5.8	5.4	4.8	3.7	4.9	4.8	4.5	4.5
					Avg.	-2.8	-2.4	-1.4	-1.1	-1.1	-1.5	-1.1	-0.7	+0.4	+0.5	+0.1	-0.9	-0.7	-0.2	-1.4	+0.1
					Avg. dev.	4.0	5.2	5.4	3.7	3.3	2.9	3.9	3.9	4.5	4.1	3.7	3.1	3.7	3.6	3.4	3.3
					Range	14.5	24.5	27.5	18.0	16.0	13.5	19.5	19.0	21.0	21.0	19.0	15.0	19.5	19.0	18.5	18.0

Row	E_8 dB(A)	E_8 dB(A)$_o$	E_8 dB(D_1)	E_8 dB(D_1)$_o$	E_8 dB(D_2)	E_8 dB(D_2)$_o$	E_8 dB(D_3)	E_8 dB(D_3)$_o$	E_8 PNdB	E_8 PNdB$_{t_1}$	E_8 PNdB$_{t_1 o}$	E_8 PNdB$_{t_1}$M	E_8 PNdB$_{t_1}$M$_o$	E_8 PNdB$_{t_2}$	E_8 PNdB-M	E_8 PNdB$_{t_2}$M	E_8 PNdB-M$_o$	E_8 PNdB$_{t_2}$M$_o$	EE_8 PNdB	EE_8 PNdB$_{t_1}$	EE_8 PNdB$_{t_1}$M	EE_8 PNdB$_{t_2}$
727	-9.0	-9.0	-8.5	-8.5	-4.5	-4.5	-6.5	-6.5	-8.5	-7.0	-7.0	-4.0	-4.0	-7.5	-5.5	-4.5	-5.5	-4.5	-8.5	-7.5	-4.0	-7.0
720	-5.0	-4.5	-6.5	-6.0	-5.5	-5.0	-3.0	-2.5	-6.5	-7.5	-7.0	-6.5	-6.0	-7.5	-5.5	-6.5	-5.0	-6.0	-8.5	-8.5	-7.5	-9.0
C141	-7.0	-7.0	-5.5	-5.5	-4.0	-4.0	-2.5	-2.5	-5.0	-1.5	-1.5	-1.0	-1.0	-3.0	-4.5	-2.5	-4.5	-2.5	-6.5	-2.5	-2.0	-4.0
Jetstar	-4.5	-4.5	-5.5	-5.5	-3.5	-3.5	-2.0	-2.0	-6.5	-6.5	-6.5	-5.5	-5.5	-7.5	-5.5	-6.5	-5.5	-6.5	-9.0	-8.0	-7.5	-8.5
Jet vs. 1049G Avg.	-6.4	-6.3	-6.5	-6.4	-4.4	-4.3	-3.5	-3.4	-6.6	-5.6	-5.5	-4.3	-4.1	-6.4	-5.3	-5.0	-5.1	-4.9	-8.1	-6.6	-5.3	-7.1
Jet vs. 1049G Avg. dev.	6.4	6.3	6.5	6.4	-4.4	4.3	3.5	3.4	6.6	5.6	5.5	4.3	4.1	6.4	5.3	5.0	5.1	4.9	8.1	6.6	5.3	7.1
Jet vs. 1049G Range	4.5	4.5	3.0	3.0	2.0	1.5	4.5	4.5	3.5	6.0	5.5	5.5	5.0	4.5	1.0	4.0	1.0	4.0	2.5	6.0	5.5	5.0
CV7A	-4.0	-2.5	-2.5	-1.0	-1.5	0	-1.5	0	-0.5	-2.5	-1.0	-2.0	-0.5	-2.0	0.0	-1.5	+1.5	-1.0	-1.5	-3.0	-1.5	-1.0
204B	-6.0	-1.5	-3.5	+1.0	-4.0	0.5	-3.5	+1.0	-3.5	-4.0	+0.5	-3.5	+1.0	-4.0	-3.0	-3.5	+1.5	+1.0	-4.0	-4.5	-3.5	-5.0
All aircraft Stand. dev.	1.9	2.8	2.1	3.5	1.4	2.3	1.8	2.6	2.8	2.5	3.4	2.1	2.9	2.5	2.2	1.8	3.4	2.9	3.0	2.7	2.6	3.0
All aircraft Avg.	-5.9	-4.8	-5.3	-4.3	-3.8	-2.8	-3.2	-2.1	-5.1	-4.8	-3.8	-3.8	-2.7	-5.3	-4.0	-4.2	-2.9	-3.3	-6.3	-5.7	-4.3	-5.8
All aircraft Avg. dev.	5.9	4.8	5.3	4.6	-3.8	2.9	3.2	2.4	5.1	4.8	3.9	3.8	3.0	-5.3	-4.0	-4.2	3.9	3.6	6.3	5.7	4.3	5.8
All aircraft Range	5.0	7.5	6.0	9.5	4.0	5.5	5.0	7.5	8.0	6.0	7.5	5.5	7.0	5.5	5.5	5.0	7.0	7.5	7.5	6.0	6.0	8.0
Comparison Stand. dev.	3.1	2.8	3.3	2.9	2.3	2.0	2.0	5.8	3.6	3.7	3.1	3.1	2.7	3.8	2.8	3.1	2.5	2.8	4.2	3.2	4.0	4.2
Comparison Avg.	-3.4	-3.7	-2.0	-2.2	-1.9	-2.1	-3.0	-3.3	-1.6	-0.7	-1.1	-0.6	-0.8	-1.2	-1.3	-0.9	-1.6	-1.3	-1.9	-1.1	-0.9	-1.3
Comparison Avg. dev.	3.8	3.7	2.7	2.4	2.4	2.3	3.1	3.4	3.0	2.9	2.3	2.5	2.2	3.0	2.7	2.5	2.3	2.3	3.4	4.2	2.5	3.3
Comparison Range	11.0	9.0	13.0	10.0	9.0	5.5	7.5	8.0	14.0	13.0	10.0	11.5	9.5	12.0	10.5	10.5	7.0	8.5	14.5	14.0	11.5	13.5

difference was positive or negative) and also, for the averages taken over all aircraft and operational conditions, the standard deviation of the differences.

A given difference can be directly interpreted to mean that the sound pressure level in dB between the given reference and comparison noise must be changed by an amount equal to the given difference, assuming no spectral changes are imposed, in order that the physical measurements would agree perfectly with the subjective judgments. For any one case a difference can be due to (1) a fundamental difference in the relative value ascribed to the spectral-temporal characteristics of noise by a unit of physical measurement and by the human listener, and (2) experimental error, either in the physical measurements and treatment of those data, and/or in subject unreliability.

More important than the average differences are perhaps the average deviation and standard deviation values. It is, of course, possible for the average difference taken over a wide variety of noises to be near zero and yet have a relatively large average and standard deviation if some of the differences are positive and some negative with respect to a given reference noise. The uncertainty in predicting the subjective judgments by means of a given unit of measurement is a function, then, of both the average difference and its average or standard deviation.

Relative Accuracy of the Units

Because of the high correlations between the physical units themselves--they are, after all, all based on at least some of the same band spectral measures--and the relatively small differences between some of the average differences and standard deviations, it is something of a problem to choose a meaningful way to select those units which might be considered significantly the better predictors of the subjective judgments. Because of this correlation factor, the standard error of a difference between the average accuracy of each of two units of measurement tends to be made small, whereas the small number of aircraft noises (12 in Table VIII and 6 in Table IX) tends to make the standard error a relatively insensitive measure, particularly for units such as dB(C) that have relatively large standard deviations. The standard error and its companion "t" statistic for the above reasons gave results when applied to the averages for the present data that were difficult to interpret.

A literature search was made for a procedure whereby one could evaluate the statistical significance of differences between the variability (standard deviations) in contrast to the average accuracy of the various units of measurement. Because the various units are not independent of each other, the standard so-called f test is not appropriate. Young and Peterson[2] employed, for comparing standard deviations of data similar to that at hand, a statistic called M which is somewhat like the t test; however, this statistic, as all others we were able to find, is not appropriate for comparing these standard deviation data because of their interdependence.

Rather than attempt to use statistical tests of significance of the average accuracy and variability in accuracy of the different units of measurement, we will use the following argument and procedure for this purpose. Let us presume that a person has taken physical measures of any aircraft noise chosen at random from those tested in this study and that these measures are, in turn, converted (or are made directly) into one of the 38 units given in Tables VIII and IX. One obvious question to be asked is which unit will be in closest agreement and how often, as the noises from different aircraft are evaluated with respect to the judged perceived noisiness of the aircraft sounds.

To answer this question we have tabulated in Table X the percentage of time the value of each of the 38 units of measurement would be within ± 2 and ± 4 "dB" units of the judged perceived noise level for any aircraft noises chosen at random from those tested. This percentage is the normal probability to be expected based on the number or portion of standard deviations of a given unit to be found between the average difference typical for that unit and the criterion of ± 2 or ± 4 units from exact agreement with subjective judgments. The general concept is illustrated in Figure 7.

Columns 3 and 4 of Table X can be interpreted as showing the percentage of times a given unit will have an "accuracy" in predicting judged perceived noisiness of ± 2 or ± 4 units of measurement (other difference criteria could of course be utilized). For example, Max dB(A), Max Phons, and Max PNdB are within ± 4 dB of the judged value about the same percentage time (57 to 60%) as EPNdB$_{t_1}$ M$_o$ is within about ± 2 (52%, ± 2.5 gives 63%). As with all statistics, the practical significance of the differences in the summary percentage figures, as well as the standard deviation values is a matter of judgment and the circumstances in which noise evaluations are to be made; however, an improvement of but ± 0.5 in "dB units" would represent a difference of about 20% in acoustical power and from a practical point of view would probably be significant.

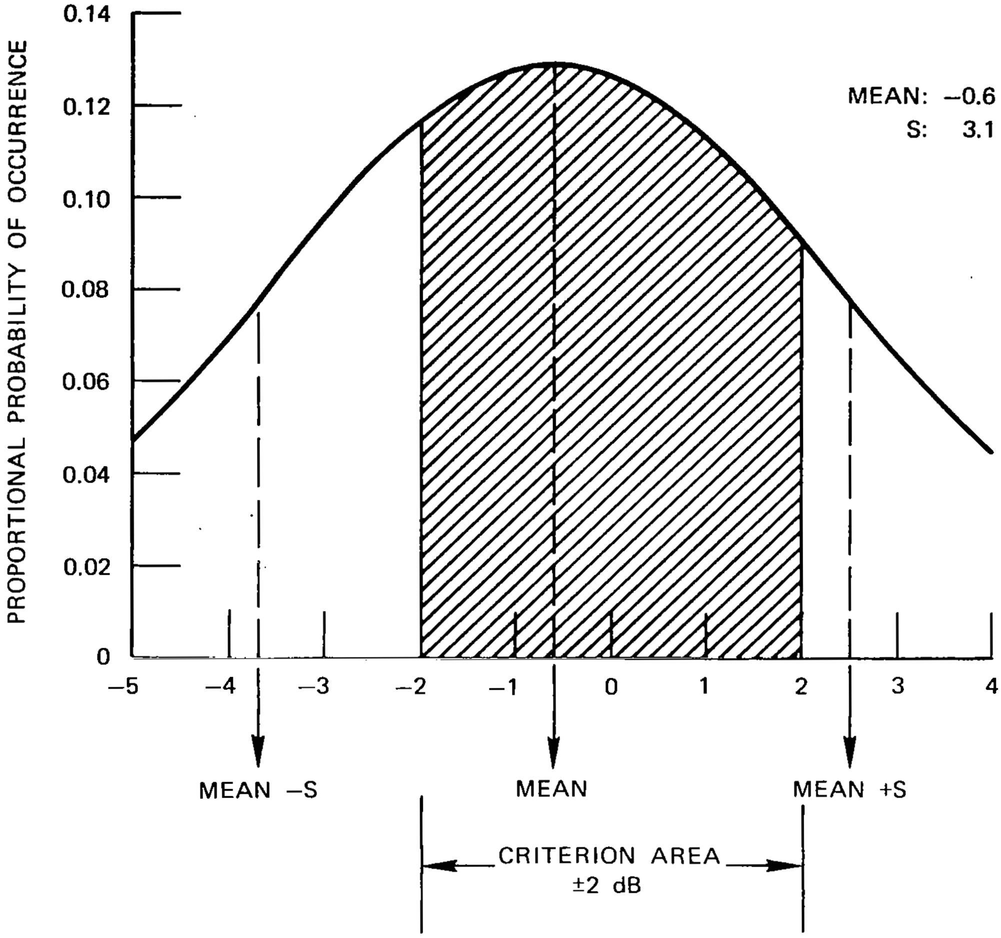

FIGURE 7 SCHEMATIC DIAGRAM SHOWING STATISTICAL METHOD USED FOR EVALUATING ACCURACY OF UNITS OF MEASUREMENT FOR ESTIMATING JUDGED PERCEIVED NOISINESS. Zero (0) on the scale is *true* subjective rating given by listeners; a -1 indicates that the physical measurement (PNdB, dB(D), Phon, etc.) underestimates the judged noisiness by a 1 "dB" unit, a +1 indicates an overestimation, etc. The curve is an example of the expected accuracy of a unit of measurement ($EPNdB_tM$) that has been found by test to have given average difference from judged noisiness and a given standard deviation of those differences.

Table X

AVERAGE DIFFERENCES AND STANDARD DEVIATIONS OF PHYSICAL NOISE MEASUREMENTS OF REFERENCE AND ALL COMPARISON AIRCRAFT NOISES WHEN JUDGED EQUALLY NOISY OR UNACCEPTABLE

Judgments and physical measurements made outdoors. Thirty-five listeners, 18 comparison aircraft (see Tables VIII and IX). Also shown are percentage of times the various units of noise measurement would agree with ±2 and ±4 units of judged equal perceived noisiness.

Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Rank (see Col. 5)	Measure	% Times Between -2 and +2	% Times Between -4 and +4	Average of Percentages (Col. 3 and 4)	Average Difference	Standard Deviation
1	$EPNdB_{t_1}M_o$	52	84	68	-0.8	2.7
2	$EdB(D_2)_o$	46	83	64.5	-2.1	2.0
3	EPNdB-M	48	80	64	-1.3	2.8
4	$EPNdB_{t_2}M_o$	48	80	64	-1.3	2.8
5	$EdB(D_2)$	47	81	64	-1.9	2.3
6	$EPNdB_{t_1}M$	47	79	63	-0.6	3.1
7	$EPNdB\text{-}M_o$	49	77	63	-1.6	2.5
8	$EPNdB_{t_2}M$	46	78	62	-0.9	3.1
9	$EPNdB_{t_1o}$	45	78	61.5	-1.1	3.1
10	$EEPNdB_{t_1}M$	45	77	61	-0.9	3.2
11	Max $dB(D_3)$	42	74	58	-1.4	3.3
12	$EPNdB_{t_1}$	41	71	56	-0.8	3.7
13	Peak $dB(D_2)$	40	71	55.5	-0.9	3.7
14	$EdB(D_1)_o$	40	71	55.5	-2.2	2.9
15	$EdB(D_1)$	39	70	54.5	-1.9	3.3
16	EPNdB	38	69	53.5	-1.6	3.6
17	$EPNdB_{t_2}$	38	68	53	-1.2	3.8
18	Max $dB(D_2)$	37	67	52	-1.1	4.0
19	$EEPNdB_{t_1}$	37	67	52	-1.1	4.0
20	$EEPNdB_{t_2}$	36	64	50	-1.3	4.2
21	$EdB(D_3)$	30	69	49.5	-3.0	2.0
22	Max $PNdB_{t_2}M$	34	63	48.5	0.1	4.5

Table X (concluded)

Col. 1 Rank (see Col. 5)	Col. 2 Measure	Col. 3 % Times Between -2 and +2	Col. 4 % Times Between -4 and +4	Col. 5 Average of Percentages (Col. 3 and 4)	Col. 6 Average Difference	Col. 7 Standard Deviation
23	Max dB(D_1)	33	61	47	-1.1	4.6
24	EEPNdB	33	61	47	-1.9	4.2
25	Max PNdB-M	32	60	46	-1.4	4.5
26	Max $PNdB_{t_2}$	33	59	46	0.1	4.8
27	Peak PNdB	32	60	46	-0.3	4.8
28	Max dB(A)	31	60	45.5	-2.8	3.7
29	Peak Phons	32	58	45	-0.7	4.9
30	$EdB(D_3)_o$	28	61	44.5	-3.3	2.4
31	Max PNdB	31	58	44.5	-0.7	5.0
32	Max Phons	31	57	44	-1.0	5.0
33	EdB(A)	29	57	43	-3.4	3.1
34	Max $PNdB_{t_1}M$	29	54	41.5	0.4	5.4
35	$EdB(A)_o$	25	54	39.5	-3.7	2.8
36	Max $PNdB_{t_1}$	27	51	39	0.3	5.8
37	Max dB(B)	24	46	35	-2.4	6.3
38	Max dB(C)	21	41	31	-1.4	7.3

Summary Evaluation of the Efficacy of the Various Units

Table XI attempts to bring together some of the data in Table X in a way that makes it possible to answer, within the context of the present experiment, questions concerning certain basic concepts and measurement techniques that might be followed in the measurement of noise. From Table XI it would appear that the following statements are justified:

1. There is no significant difference between Peak or Max Phon and Peak or Max PNdB; Peak units may possibly be slightly better than Max units.

2. PNdB-Ms modified to take into account critical bandwidth of the ear at low frequencies are significantly better on the average than the unmodified PNdBs.

3. Modifying also the overall frequency weighting (the 40-noy contour) to take into account the critical bandwidth of the ear at low frequencies provides a frequency weighting that is significantly better than D_1, D_3, or A.

4. Utilizing durational information (between the 10 PNL downpoints) by Estimated Effective (EE) units significantly improves the predictive accuracy of Max PNdBs and Effective (E) units are appreciably better than EE units.

5. The application of either t_1 or t_2 tone corrections gave inconsistent results with there being no significant improvement over non-tone-corrected units on the average.

6. The application of the so-called onset duration correction provided no consistent effect, with there being no improvement over non-onset duration corrected units on the average.

There are probably present in both the physical and judgment data errors that could have contributed some presumably small degree of spurious accuracy or inaccuracy to specific units of measurement in their prediction of the judgment data, particularly with respect to any individual pair of judged aircraft noise. Also, it is to be recognized that in spite of the number of types of aircraft noises involved, the present experiment provided a set of noises that were still fairly homogenous with respect to duration and spectral complexity. Some larger differences in the ability of the various units to predict judged perceived noisiness could well be found had there been present noises that

Table XI

SHOWING RELATION BETWEEN RESULTS WITH PHONS (Stevens) AND PNdB AND AVERAGE EFFECT OF VARIOUS MODIFICATIONS AND CORRECTIONS TO PNdB AND OVERALL FREQUENCY WEIGHTINGS

All score values are percentage of time a given unit of measurement would, for the 18 aircraft noises tested, fall within ±4 units of judged equal perceived noisiness. 35 listeners outdoors. Data taken from Table X.

Units Calculated from 1/3-Octave Band Spectra

Max Phons	57%	Max PNdB	58%	Max $PNdB_{t_1}$	51%	EPNdB	69%	$EPNdB_{t_1}$	71%	$EPNdB_o$	(69)*%	$EPNdB_{t_1 o}$	78%	EEPNdB	61%	$EEPNdB_{t_1}$	67%
Peak Phons	58			Max $PNdB_{t_2}$	59			$EPNdB_{t_2}$	68			$EPNdB_{t_2 o}$	(78)*			$EEPNdB_{t_2}$	64
Aver.	58																
Max PNdB	58	Max PNdB-M	60	Max $PNdB_{t_1}M$	54	EPNdB-M	80	$EPNdB_{t_1}M$	79	$EPNdB\text{-}M_o$	77	$EPNdB_{t_1}M_o$	84	EEPNdB-M	(70)*	$EEPNdB_{t_1}M$	77
Peak PNdB	60			Max $PNdB_{t_2}M$	63			$EPNdB_{t_2}M$	78			$EPNdB_{t_2}M_o$	80			$EEPNdB_{t_2}M$	(74)*
Aver.	59																
										*Estimated, not calculated							

Units Calculated from Overall Frequency Weightings

$dB(D_1)$		$dB(D_2)$		$dB(D_3)$		dB(A)	
Max $dB(D_1)$	61	Max $dB(D_2)$	67	Max $dB(D_3)$	74	Max dB(A)	60
$EdB(D_1)$	70	$EdB(D_2)$	81	$EdB(D_3)$	69	EdB(A)	57
$EdB(D_1)_o$	71	$EdB(D_2)_o$	83	$EdB(D_3)_o$	61	$EdB(A)_o$	54
Aver.	67	Aver.	77	Aver.	68	Aver.	57

Average Effect of Summation over Frequency Range (Freq. Weighting plus Stevens' Band Summation vs. Freq. Weighting plus Sound Energy Summation)

All PNdBs and PNdB-Ms except for tone-corrected units	68
All $PNdB_t$s and $PNdB_t$Ms	71
All $dB(D_1)$s and $dB(D_2)$s	72
Aver. Improvement $dB(D_1)$s and $dB(D_2)$s	
vs. PNdBs and PNdB-Ms	4% pts
vs. $PNdB_t$s and $PNdB_t$Ms	1% pts

Average Effect of Frequency Modification for Critical Bandwidth of the Ear (M, D_2)

All PNdBs	66	All $dB(D_1)$	67
All PNdB-Ms	73	All $dB(D_2)$	77
Aver. Improvement	7% pts	Aver. Improvement	10% pts

Average Effect of Duration (Max vs. Effective (E) and Estimated Effective (EE)

All Max PNdBs and PNdB-Ms	58	All Max $dB(D_1)$ and $dB(D_2)$	64
All EEPNdBs and PNdB-Ms	69	All $EdB(D_1)$ and $dB(D_2)$	76
All EPNdBs and PNdB-Ms	76	Aver. Improvement	12% pts
Aver. Improvement Re/ Max:	EE 11% pts: E 18% pts		

Average Effect of Onset Duration Correction (o)

All EPNdBs and PNdB-Ms no onset correction	74	$EdB(D_1)$ and $dB(D_2)$ no onset correction	76
All EPNdBs and PNdB-Ms with onset correction	78	$EdB(D_1)$ and $dB(D_2)$ with onset correction	77
Aver. Improvement	4% pts	Aver. Improvement	1% pts

Average Effect of Tone Corrections

All PNdBs - no tone corrections	68
All $PNdB_{t_1}$ - tone-corrected	70
All $PNdB_{t_2}$ - tone-corrected	71
Aver. Improvement, t_1	2% pt
Aver. Improvement, t_2	3% pts

differed more from each other. In particular, the real need for and validity, if any, of the so-called onset duration and possibly tone corrections were not adequately explored in these tests. Additional tests are probably required under more precisely controlled conditions and with more diverse noises to properly evaluate the advantages of pure-tone and onset duration corrections.

Indoor Paired Comparison Versus Outdoor Measurements

Typical aircraft noises are measured outdoors even though a considerable portion of the objections to the noise in real life is from people hearing the noise when indoors. Because of differential attenuation as a function of frequency of different parts of house structures, somewhat different noise spectra were present in the different rooms where subjects were located. Therefore, it would be unlikely that good predictions of indoor judgments from outdoor noise measurements would be achieved. However, as seen in Tables XII through XV and summarized in Table XVI, the average deviations between relative indoor judgments and relative units obtained from outdoor physical measurements are surprisingly small. Inasmuch as some of the relations shown in Tables XII through XVI are presumably to some unknown degree fortuitous because of unequal house attenuations, in our opinion it is not possible to draw with confidence any specific conclusions from these data. Also for these reasons, the relations between all of the 38 measurement units calculated for the outdoor spectra were not determined.

In general, it can be surmised that:

1. The relative perceived noisiness between the reference and comparison aircraft noises as heard indoors is predicted with reasonable accuracy by nearly all of the outdoor measurements.

2. PNdB, Phons, and D_1 for outdoor noise on the average better predict indoor than outdoor judgments because these units tend to overestimate the contribution to judged perceived noisiness of low frequency energy (below about 355 Hz) relative to high frequency energy when measured in third or octave bands. The less attenuation by the house structures of these lower compared to the higher frequencies tends to compensate for this overestimation made by these particular units on the basis of the outdoor spectra.

Table XII

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Indoor Listeners N-11   Outdoor Physical Measurements   Reference Aircraft: 880 at Takeoff Power

Comparison Aircraft: Type	Comparison Aircraft: Power	Reference Aircraft (880): Altitude (feet)	Takeoff EPR	Avg. Peak PNdB	Max dB(A)	Max dB(B)	Max dB(C)	Max $dB(D_1)$	Max $dB(D_2)$	Max $dB(D_3)$	Max Phons	Max PNdB	Max $PNdB_{t_1}$	Max $PNdB_{t_1}M$	Max $PNdB_{t_2}$	Peak $dB(D_2)$	Peak Phons	Peak PNdB	E dB(A)	E_8 $dB(A)_o$	E_8 $dB(D_1)$	E_8 $dB(D_1)_o$	E_8 $dB(D_2)$	E_8 $dB(D_2)_o$	E_8 $dB(D_3)$	E_8 $dB(D_3)_o$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1o}$	E_8 $PNdB_{t_1}M$	E_8 $PNdB_{t_1}M_o$	E_8 $PNdB_{t_2}$	EE_8 PNdB	EE_8 $PNdB_{t_1}$	EE_8 $PNdB_{t_1}M$	EE_8 $PNdB_{t_2}$
990	Takeoff	1400	2.5	111.0	-6.0	-2.0	0	-6.0	-9.0	-8.0	-5.0	-4.5	-4.0	-4.5	-5.0	-8.0	-3.0	-3.0	-2.0	-4.0	-2.0	-4.0	-6.5	-8.5	-5.0	-7.0	-1.5	-1.5	-3.5	-2.0	-4.0	-1.5	-1.5	-1.0	-1.0	-1.5
727	Takeoff	1400	2.0	105.5	-2.5	+1.0	+3.0	-1.0	-4.0	-4.0	+0.5	+0.5	+1.0	+0.5	0	-3.5	+0.5	+1.0	-1.0	-1.0	+1.0	+1.0	-3.5	-3.5	-3.0	-3.0	+1.0	+1.0	+1.0	+1.0	+1.0	+1.5	+1.0	+1.0	+0.5	+1.5
720	Takeoff	1400	2.0	104.0	-0.5	+1.0	+1.5	0	-1.0	-1.0	0	0	0	0	+1.0	-0.5	+0.5	+0.5	-0.5	+1.0	+0.5	+2.0	-0.5	+1.0	-0.5	+1.0	+0.5	+1.0	+2.5	+0.5	+2.0	+1.5	+1.0	+1.5	+0.5	+2.0
C141	Takeoff	1400	3.0	106.5	-7.5	-3.5	-1.0	-5.5	-9.0	-9.0	-5.5	-5.0	-5.0	-5.0	-2.0	-7.5	-2.5	-2.5	-3.5	-4.5	-1.5	-2.5	-5.5	-6.5	-5.0	-8.0	-1.0	-0.5	-1.5	-1.0	-2.0	-0.5	-1.5	-1.0	-1.5	-0.5
Jetstar	Takeoff	1400	2.0	106.0	+1.0	+2.5	+2.5	+1.5	+2.0	+1.0	+2.0	+2.0	+2.0	+2.0	+3.0	+2.5	+3.0	+3.0	+1.5	0	+2.0	+0.5	+1.5	0	+1.5	0	+2.5	+2.5	+1.0	+2.5	+1.0	+2.5	+0.5	+0.5	+1.0	+1.5
F106	Afterburner	1400	2.0	105.0	-2.0	+1.0	+2.0	-1.5	-5.5	-4.5	-1.0	-2.0	-1.0	-2.0	+1.5	-4.5	-0.5	-1.0	-3.0	-1.5	-2.5	-1.0	-3.0	-1.5	-4.5	-3.0	-0.5	+0.5	+2.0	+0.5	+2.0	0	+0.5	+2.0	+1.5	+1.0
Jet TO vs. jet				Avg.	-2.9	0	+1.3	-2.1	-4.4	-4.3	-1.5	-1.5	-1.2	-1.5	-0.3	-3.6	-0.3	-0.3	-1.4	-1.7	-0.4	-0.6	-2.9	-3.2	-2.8	-3.0	+0.2	+0.5	+0.3	+0.3	0	+0.6	0	+0.5	+0.2	+0.7
				Avg. dev.	3.3	1.8	1.7	2.6	5.1	4.6	2.3	2.3	2.2	2.3	2.1	4.4	1.7	1.8	1.9	2.0	1.6	1.8	3.4	3.5	3.3	3.3	1.2	1.2	1.9	1.3	2.0	1.3	1.0	1.2	1.0	1.3
				Range	8.5	8.0	4.0	7.5	11.0	10.0	7.5	7.0	7.0	7.0	8.0	10.5	6.0	6.0	5.0	5.5	4.5	6.0	8.0	9.5	6.5	8.0	4.0	4.0	6.0	4.5	6.0	4.0	2.5	3.0	3.0	3.5
990	Landing	1400	2.5	113.0	-2.0	-3.5	-3.5	+2.5	+3.0	+0.5	+2.5	+2.0	+7.5	+8.0	+4.5	+4.0	+2.5	+2.5	-5.0	-6.5	-1.5	-3.0	-3.5	-5.0	-5.5	-7.0	-1.0	+2.5	+1.0	+3.0	+1.5	+1.0	-1.0	+1.0	+1.5	+1.0
727	Landing	1400	2.0	105.5	-4.5	-3.5	-3.0	-1.0	-0.5	-3.0	-1.0	+0.5	+2.0	+2.5	0	-0.5	-1.0	+0.5	-7.0	-8.5	-4.0	-5.5	-5.0	-6.5	-7.5	-9.0	-3.0	-2.0	-3.5	-2.0	-3.5	-3.5	-4.0	-3.0	-3.0	-4.5
720	Landing	1400	2.0	103.5	-1.0	-1.5	-1.0	0	+0.5	0	-0.5	+0.5	+0.5	+0.5	-0.5	0	-0.5	+0.5	-1.0	-2.0	-0.5	-1.5	-1.0	-2.0	-1.5	-2.5	-0.5	-0.5	-1.5	-0.5	-1.5	-1.0	-1.0	-0.5	-0.5	-1.5
C141	Landing	1400	2.0	106.0	-2.5	-4.0	-3.5	+2.0	+3.0	+0.5	+1.0	+2.5	+7.5	+8.0	+5.0	+3.5	+1.5	+3.0	-4.5	-4.5	-0.5	-0.5	-1.5	-1.5	-4.0	-4.0	0	+3.5	+3.5	+4.5	+4.5	+2.0	-1.5	+2.0	+3.0	+1.0
Jet landing vs. jet				Avg.	-2.5	-3.1	-2.8	+0.9	+1.5	-0.5	+0.5	+1.4	+4.4	+4.8	+2.3	+1.8	+0.6	+1.6	-4.4	-5.4	-1.6	-2.6	-2.8	-3.8	-4.6	-5.6	-1.1	+0.9	-0.1	+1.3	+0.3	-0.4	-1.9	-0.1	+0.3	-1.0
				Avg. dev.	2.5	3.1	2.8	1.4	1.8	1.0	1.3	1.4	4.4	4.8	2.5	2.0	1.4	1.6	4.4	5.4	1.6	2.6	2.8	3.8	4.6	5.6	1.1	2.1	2.4	2.5	2.8	1.9	1.9	1.6	2.0	2.0
				Range	3.5	2.5	2.5	3.5	3.5	3.5	3.5	2.0	7.0	7.5	5.5	4.5	3.5	2.5	6.0	6.5	3.5	5.0	4.0	5.0	6.0	6.5	3.0	5.5	7.0	6.5	8.0	5.5	3.0	5.0	6.0	5.5
Jet vs. jet				Avg	-2.8	-1.8	-0.3	-0.9	-2.1	-2.8	-0.7	-0.4	+1.0	+1.0	+0.8	-1.5	+0.1	+0.5	-2.6	-3.2	-0.9	-1.5	-2.9	-3.4	-3.5	-4.1	-0.4	+0.7	+0.1	+0.7	+0.1	+0.2	-0.8	+0.3	+0.2	0
				Avg. dev.	3.0	2.4	2.1	2.1	3.8	3.2	1.9	2.0	3.1	3.3	2.3	3.5	1.6	1.8	2.9	3.4	1.6	2.2	3.2	3.6	3.8	4.3	1.2	1.6	2.1	1.8	2.3	1.5	1.4	1.4	1.4	1.6
				Range	8.5	6.5	6.5	8.5	12.0	10.0	8.0	7.5	12.5	13.0	10.0	12.0	6.0	6.0	8.5	9.5	6.0	7.5	8.0	9.5	9.0	10.0	5.5	5.5	7.0	6.5	8.5	6.0	5.0	5.0	6.0	6.5
1049G	METO	1400	2.1	108.5	-5.5	+3.5	+2.0	-4.5	-11.0	-9.0	0	-4.0	-2.5	-3.5	-1.5	-10.5	0	-3.5	-8.5	-10.5	-7.5	-9.5	-14.0	-16.0	-15.5	-17.5	-7.5	-7.0	-9.0	-6.5	-8.5	-4.0	-6.5	-6.0	-7.0	-3.5
CH47	Cruise	2200	2.0	100.5	-4.5	-0.5	+2.5	-1.5	-4.0	-5.0	-1.0	-0.5	0	-0.5	-1.5	-3.0	+0.5	+0.5	-8.0	-12.0	-3.0	-7.0	-6.5	-10.5	-9.0	-13.0	-2.5	-2.5	-6.5	-3.0	-7.0	-3.0	-3.0	-3.0	-3.0	-3.5
All aircraft vs. 880 jet N = 12				Avg.	-3.2	-1.3	+0.1	-1.3	-3.0	-3.5	-0.7	-0.7	+0.6	+0.5	+0.4	-2.4	+0.1	-0.2	-3.5	-4.5	-1.6	-2.6	-4.1	-5.0	-5.0	-6.0	-1.2	-0.2	-1.2	-0.2	-1.2	-0.4	-1.5	-0.5	-0.7	-0.6
				Avg. dev.	3.3	2.3	2.1	2.3	4.4	3.8	1.7	2.0	2.8	3.1	2.2	4.0	1.4	1.8	3.8	4.7	2.2	3.2	4.4	5.2	5.2	6.1	1.8	2.1	3.0	2.3	3.2	1.8	2.0	1.9	2.0	1.9
				Range	8.5	7.5	6.5	8.5	14.0	10.0	8.0	7.5	12.5	13.0	10.0	14.5	6.0	6.5	10.0	13.0	9.5	11.5	15.5	17.0	17.0	18.5	10.0	10.5	12.5	11.0	13.0	6.5	7.5	8.0	10.0	6.5

Table XIII

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Indoor Listeners H-11 Outdoor Physical Measurements Reference Aircraft: 1049G at METO Power

Comparison Aircraft		Reference Aircraft (1049G)			Max dB(A)	Max dB(B)	Max dB(C)	Max dB(D_1)	Max dB(D_2)	Max dB(D_3)	Max Phons	Max PNdB	Max $PNdB_{t_1}$	Max $PNdB_{t_1M}$	Max $PNdB_{t_2}$	Peak dB(D_2)	Peak Phons	Peak PNdB
Type	Power	Altitude (feet)	Takeoff Power	Avg. Peak PNdB														
880	Landing	1300	METO	105.0	-1.0	-5.5	-7.0	-3.0	+2.0	+1.5	-2.5	-2.5	-4.0	-4.0	-4.5	+2.0	-3.0	-3.0
727	Landing	1000	METO	110.5	+2.5	-3.0	-4.5	+4.5	+12.0	+7.5	+4.0	+5.0	+3.5	+1.5	+4.5	+10.5	+3.0	+4.0
720	Landing	1000	METO	109.5	+3.5	-1.5	-3.5	+2.5	+9.0	+7.0	+1.5	+2.0	+1.0	+2.0	+2.5	+7.5	+1.0	+2.0
C141	Landing	1000	METO	111.0	+0.5	-7.0	-9.0	+3.0	+10.0	+6.0	+2.0	+2.5	+6.0	+7.5	+4.0	+9.5	+1.0	+2.0
Jetstar	Landing	1800	METO	107.0	-2.5	-6.0	-7.0	-2.0	+1.0	-0.5	-4.0	-3.5	-5.5	-1.5	-2.5	+1.0	-4.5	-4.0
Jet vs. 1049G				Avg.	+0.6	-4.6	-6.2	+1.0	+6.8	+4.3	+0.2	+0.7	+0.2	-1.1	+0.8	+6.1	+0.5	+0.2
				Avg. dev.	2.0	4.6	6.2	3.0	6.8	4.5	2.8	3.1	4.0	4.5	3.6	6.1	2.5	3.0
				Range	6.0	5.5	5.5	7.5	11.0	8.0	8.0	8.5	11.5	12.0	9.0	9.5	7.5	8.0
CV7A	Cruise	3000	METO	104.5														
204B	Cruise	1300	METO	106.5	-9.0	-8.0	-3.0	-8.0	-5.0	-6.5	-6.5	-7.0	-7.0	-7.0	-7.0	-4.5	-4.5	-5.0
All aircraft vs. 1049G Prop. N = 6				Avg.	-1.0	-5.2	-5.7	-0.5	+4.8	+2.5	-0.9	-0.6	-1.0	-0.3	-0.5	+4.3	-1.2	-0.7
				Avg. dev.	3.2	5.2	5.7	3.8	6.5	4.8	3.4	3.8	4.5	4.9	4.2	5.8	2.8	3.3
				Range	12.5	6.5	6.0	12.5	17.0	14.0	10.5	12.0	13.0	14.5	11.5	15.0	7.5	9.0
Comparison vs. either reference				Avg.	-2.5	-2.6	-1.8	-1.0	-0.4	-1.5	-0.8	-0.7	+0.1	+0.2	+0.1	-0.2	-0.3	-0.1
				Avg. dev.	3.3	3.3	3.3	2.8	5.1	4.1	2.3	2.6	3.4	3.7	2.9	4.6	1.9	2.3
				Range	12.5	11.5	12.0	12.5	23.0	16.5	10.5	12.0	14.5	15.0	12.0	21.0	7.5	9.0

Comparison Aircraft		Reference Aircraft (1049G)			E_8 dB(A)	E_8 $dB(A)_o$	E_8 dB(D_1)	E_8 $dB(D_1)_o$	E_8 dB(D_2)	E_8 $dB(D_2)_o$	E_8 dB(D_3)	E_8 $dB(D_3)_o$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1o}$	E_8 $PNdB_{t_1M}$	E_8 $PNdB_{t_1M_o}$	E_8 $PNdB_{t_2}$	EE_8 PNdB	EE_8 $PNdB_{t_1}$	EE_8 $PNdB_{t_1M}$	EE_8 $PNdB_{t_2}$
Type	Power	Altitude (feet)	Takeoff Power	Avg. Peak PNdB																		
880	Landing	1300	METO	105.0	0	0	-1.5	-1.5	+2.5	+2.5	+1.5	+1.5	-2.0	-2.5	-2.5	-2.0	-2.0	-3.0	-2.5	-3.5	-2.5	-4.0
727	Landing	1000	METO	110.5	-1.5	-1.5	+0.5	+0.5	+2.5	+2.5	-0.5	-0.5	+1.5	+0.5	+0.5	+1.5	+1.5	+0.5	0	-0.5	+0.5	-0.5
720	Landing	1000	METO	109.5	+4.0	+4.5	+3.0	+3.5	+4.5	+5.0	+3.0	+3.5	+3.0	+2.5	+3.0	+3.5	+4.0	+2.5	+2.0	+2.0	+3.5	+2.5
C141	Landing	1000	METO	111.0	-1.5	-1.5	+1.5	+1.5	+4.5	+4.5	+1.5	+1.5	+1.0	+5.0	+5.0	+6.0	+6.0	+3.0	0	+4.5	+6.0	+2.0
Jetstar	Landing	1800	METO	107.0	-4.5	-4.5	-5.5	-5.5	-0.5	-0.5	-2.0	-2.0	-6.5	-6.5	-6.5	-5.5	-5.5	-7.5	-9.0	-8.0	-7.5	-8.5
Jet vs. 1049G				Avg.	-0.7	-0.6	-0.4	-0.3	+2.7	+2.8	+0.7	+0.8	-0.6	-0.2	-0.1	+0.7	+0.8	-0.9	-1.9	-1.1	0	-1.7
				Avg. dev.	2.3	2.4	2.4	2.5	2.9	3.0	1.7	1.8	2.8	3.4	3.5	3.7	3.8	3.3	2.7	3.7	4.0	3.5
				Range	8.5	9.0	8.5	9.0	5.0	5.5	5.0	5.5	9.5	11.5	11.3	11.5	11.5	10.5	11.0	12.5	13.5	11.0
CV7A	Cruise	3000	METO	104.5																		
204B	Cruise	1300	METO	106.5	-6.0	-1.5	-3.5	+1.0	-2.0	+2.5	-4.0	+0.5	-3.5	-4.0	+0.5	-4.0	+0.5	-4.5	-3.5	-3.5	-4.0	-5.5
All aircraft vs. 1049G Prop. N = 6				Avg.	-1.6	-0.8	-0.9	-0.1	+1.9	+2.8	-0.1	+0.8	-1.1	-0.8	0	-0.1	+0.8	-1.5	-2.2	-1.5	-0.7	-2.3
				Avg. dev.	2.9	2.3	2.6	2.3	2.8	2.9	2.1	1.6	2.9	3.5	3.0	3.8	3.3	3.5	2.8	3.7	4.0	3.8
				Range	10.0	9.0	8.5	9.0	6.5	5.5	7.0	5.5	9.5	11.5	11.5	11.5	11.5	10.5	11.0	12.5	13.5	11.0
Comparison vs. either reference				Avg.	-2.9	-3.3	-1.4	-1.8	-2.1	-2.4	-3.4	-3.7	-1.2	-0.4	-0.8	-0.2	-0.5	-0.8	-1.7	-0.8	-0.7	-1.2
				Avg. dev.	3.5	3.9	2.3	2.9	3.9	4.4	4.2	4.6	2.2	2.6	3.0	2.8	3.2	2.4	2.3	2.5	2.7	2.5
				Range	12.5	16.5	10.5	13.0	18.5	21.0	18.5	21.0	10.5	12.0	14.0	12.5	14.5	10.5	11.0	12.5	13.5	11.0

Table XIV

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Indoor Listeners K-13 Outdoor Physical Measurements Reference Aircraft: 880 at Takeoff Power

Comparison Aircraft Type	Comparison Aircraft Power	Reference Aircraft (880) Altitude (feet)	Reference Aircraft (880) Takeoff EPR	Reference Aircraft (880) Avg. Peak PNdB	Max dB(A)	Max dB(B)	Max dB(C)	Max $dB(D_1)$	Max $dB(D_2)$	Max $dB(D_3)$	Max Phons	Max PNdB	Max $PNdB_{t_1}$	Max $PNdB_{t_1}M$	Max $PNdB_{t_2}$	Peak $dB(D_2)$	Peak Phons	Peak PNdB
990	Takeoff	1400	2.5	111.0	-6.0	-2.0	0	-6.0	-9.0	-8.0	-5.0	-4.5	-4.0	-4.5	-5.0	-8.0	-3.0	-3.0
727	Takeoff	1400	2.0	105.5	-3.0	+0.5	+2.5	-1.5	-4.5	-4.5	0	0	+0.5	0	-0.5	-4.0	0	+0.5
720	Takeoff	1400	2.0	104.0	-3.0	-2.0	-1.0	-3.0	-3.5	-3.5	-2.5	-2.5	-2.5	-2.5	-0.5	-3.0	-1.5	-1.5
C141	Takeoff	1400	2.0	106.5	-10.0	-6.0	-4.0	-8.0	-12.0	-11.5	-8.0	-7.5	-7.5	-7.5	-5.0	-10.5	-5.5	-5.0
Jetstar	Takeoff	1400	2.0	106.0	-0.5	+1.5	+2.0	+0.5	-1.5	-1.0	0	+1.0	+1.5	+1.5	+2.5	-1.0	+0.5	+1.5
F106	Afterburner	1400	2.0	105.0	-3.5	-0.5	+0.5	-3.0	-7.0	-6.0	-2.5	-3.5	-2.5	-3.5	0	-6.0	-2.0	-2.5
	Jet TO vs. 880			Avg.	-4.3	-1.4	0	-3.5	-6.3	-5.8	-3.0	-2.8	-2.4	-2.8	-1.4	-5.4	-1.9	-1.7
				Avg. dev.	4.3	2.1	1.7	3.7	6.3	5.8	3.0	3.2	3.1	3.3	2.3	5.4	2.1	2.3
				Range	9.5	7.5	6.5	8.5	10.5	10.5	5.5	8.5	9.0	9.0	7.5	9.5	6.0	6.5
990	Landing	1400	2.5	113.0	-2.0	-3.5	-3.5	+2.5	+3.0	+0.5	+2.5	+2.0	+7.5	+8.0	+4.5	+4.0	+2.5	+2.5
727	Landing	1400	2.0	105.5	-4.5	-3.5	-3.0	-1.0	-0.5	-3.0	-1.0	+0.5	+2.0	-2.5	0	-0.5	-1.0	+0.5
720	Landing	1400	2.0	103.5	-2.5	-3.0	-3.0	-1.5	-1.0	-2.0	-2.0	-1.0	-1.0	-1.0	-2.0	-1.5	-2.5	-1.0
C141	Landing	1400	2.0	108.0	-2.5	-4.0	-3.5	+2.0	+3.0	+0.5	+1.0	+2.5	+7.5	+8.0	+5.0	+3.5	+1.5	+3.0
	Jet landing vs. 880			Avg.	-2.9	-3.5	-3.3	+0.5	+1.1	-1.0	+0.1	+1.0	+4.0	+4.4	+1.9	+1.4	+0.1	+1.3
				Avg. dev.	2.9	3.5	3.3	1.8	1.9	1.5	1.6	1.5	4.5	4.9	2.9	2.4	1.9	1.8
				Range	2.5	1.0	0.5	4.0	4.0	3.5	4.5	3.5	8.5	9.0	7.0	5.5	5.0	4.0
	Jet vs. 880			Avg.	-3.8	-2.3	-1.3	-1.9	-3.3	-3.9	-1.8	-1.3	+0.2	+0.1	-0.1	-2.7	-1.1	-0.5
				Avg. dev.	3.8	2.7	2.3	2.9	4.5	4.1	2.5	2.5	3.7	3.9	2.5	4.2	2.0	2.1
				Range	9.5	7.5	6.5	10.5	15.0	12.0	10.5	10.0	15.0	15.5	10.0	14.5	8.0	8.0
1049G	METO	1400	2.1	108.5	-4.0	+5.0	+3.5	-3.0	-9.5	-7.5	+1.5	-2.5	-1.0	-2.0	0	-9.0	+1.5	-2.0
CH47	Cruise	2200	2.0	100.5	-4.0	0	+3.0	-1.0	-3.5	-4.5	-0.5	0	+0.5	0	-1.0	-3.0	+0.5	+1.0
	All aircraft vs. 880 Jet N = 12			Avg.	-3.8	-1.5	-0.5	-1.9	-3.8	-4.3	-1.4	-1.3	+0.1	-0.1	-0.2	-3.3	-0.8	-0.5
				Avg. dev.	3.8	2.7	2.5	2.8	4.8	4.4	2.3	2.3	3.2	3.4	2.2	4.5	1.8	2.0
				Range	9.5	11.0	7.5	10.5	15.0	12.0	10.5	10.0	15.0	15.5	10.0	14.5	8.0	8.0

Comparison Aircraft Type	Comparison Aircraft Power	Reference Aircraft (880) Altitude (feet)	Reference Aircraft (880) Takeoff EPR	Reference Aircraft (880) Avg. Peak PNdB	E_8 dB(A)	E_8 $dB(A)_o$	E_8 $dB(D_1)$	E_8 $dB(D_1)_o$	E_8 $dB(D_2)$	E_8 $dB(D_2)_o$	E_8 $dB(D_3)$	E_8 $dB(D_3)_o$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1o}$	E_8 $PNdB_{t_1}M$	E_8 $PNdB_{t_1}M_o$	E_8 $PNdB_{t_2}$	EE_8 PNdB	EE_8 $PNdB_{t_1}$	EE_8 $PNdB_{t_1}M$	EE_8 $PNdB_{t_2}$
990	Takeoff	1400	2.5	111.0	-2.0	-4.0	-2.0	-4.0	-6.5	-8.5	-5.0	-7.0	-1.5	-1.5	-3.5	-2.0	-4.0	-1.5	-1.5	-1.0	-1.0	-1.5
727	Takeoff	1400	2.0	105.5	-1.5	-1.5	+0.5	+0.5	-4.0	-4.0	-3.5	-3.5	+0.5	+0.5	+0.5	+0.5	+0.5	+1.0	+0.5	+0.5	0	+1.0
720	Takeoff	1400	2.0	104.0	-2.0	-0.5	-1.5	0	-2.5	-1.0	-2.5	-1.0	-1.0	-0.5	+1.0	-1.0	+0.5	0	-1.0	-0.5	-1.0	+0.5
C141	Takeoff	1400	2.0	106.5	-6.0	-7.0	-4.0	-5.0	-7.0	-8.0	-7.5	-8.5	-3.5	-3.0	-4.0	-3.5	-4.5	-3.0	-4.0	-4.0	-4.0	-3.0
Jetstar	Takeoff	1400	2.0	106.0	-1.0	-2.5	-0.5	-2.0	-1.5	-3.0	-1.5	-3.0	-0.5	-0.5	-2.0	-0.5	-2.0	0	0	+0.5	+0.5	0
F106	Afterburner	1400	2.0	105.0	-4.5	-3.0	-4.0	-2.5	-4.5	-3.0	-6.0	-4.5	-2.0	-1.0	+0.5	-1.0	+0.5	-1.5	-1.0	+0.5	0	-0.5
	Jet TO vs. 880			Avg.	-2.8	-3.1	-1.9	-2.2	-4.3	-4.6	-4.3	-4.6	-1.3	-1.0	-1.3	-1.3	-1.5	-0.8	-1.2	-0.7	-0.9	-0.6
				Avg. dev.	2.8	3.1	2.1	2.3	4.3	4.6	4.3	4.6	1.5	1.2	1.9	1.4	2.0	1.2	1.3	1.2	1.1	1.1
				Range	5.0	6.5	4.5	5.5	5.5	7.5	6.0	7.5	4.0	3.5	5.0	4.0	5.0	4.0	4.5	4.5	4.5	4.0
990	Landing	1400	2.5	113.0	-5.0	-6.5	-1.5	-3.0	-3.5	-5.0	-5.5	-7.0	-1.0	+2.5	+1.0	+3.0	+1.5	+1.0	-1.0	+1.0	+1.5	+1.0
727	Landing	1400	2.0	105.5	-7.0	-8.5	-4.0	-5.5	-5.0	-6.5	-7.5	-9.0	-3.0	-2.0	-3.5	-2.0	-3.5	-3.5	-4.0	-3.0	-3.0	-4.5
720	Landing	1400	2.0	103.5	-2.0	-4.0	-2.0	-3.0	-2.5	-3.5	-3.0	-4.0	-2.0	-2.0	-3.0	-2.0	-3.0	-2.5	-2.5	-2.0	-2.0	-3.0
C141	Landing	1400	2.0	108.0	-4.5	-4.5	-0.5	-0.5	-1.5	-1.5	-4.0	-4.0	0	+3.5	+3.5	+4.5	+4.5	+2.0	-1.5	+2.0	+3.0	+1.0
	Jet landing vs. 880			Avg.	-4.9	-5.9	-2.0	-3.0	-3.1	-4.1	-5.0	-6.0	-1.5	+0.5	-0.5	+0.9	-0.1	-0.8	-2.3	-0.5	-0.1	-1.4
				Avg. dev.	4.9	5.9	2.0	3.0	3.1	4.1	5.0	6.0	1.5	2.5	2.8	2.9	3.1	2.3	2.3	2.0	2.4	2.4
				Range	4.0	4.5	3.5	5.0	3.5	5.0	4.5	5.0	3.0	5.5	7.0	6.5	8.0	5.5	3.0	5.0	6.0	5.5
	Jet vs. 880			Avg.	-3.7	-4.2	-2.0	-2.5	-3.9	-4.4	-4.6	-5.2	-1.4	-0.4	-1.0	-0.4	-1.0	-0.8	-1.6	-0.6	-0.8	-0.9
				Avg. dev.	3.7	4.2	2.1	2.6	3.9	4.4	4.6	5.2	1.5	1.7	2.3	2.0	2.5	1.6	1.7	1.5	1.6	1.6
				Range	6.0	8.0	4.5	6.0	5.5	7.5	6.0	8.0	4.0	6.5	7.5	8.0	9.0	5.5	4.5	4.5	7.0	5.5
1049G	METO	1400	2.1	108.5	-7.0	-9.0	-6.0	-8.0	-12.5	-14.5	-14.0	-16.0	-6.0	-5.5	-7.5	-6.0	-8.0	-2.5	-5.0	-4.5	-5.5	-2.0
CH47	Cruise	2200	2.0	100.5	-7.5	-11.5	-3.0	-7.0	-6.0	-10.0	-8.5	-12.5	-2.5	-2.5	-6.5	-2.5	-6.5	-2.5	-3.0	-2.5	-3.0	-3.0
	All aircraft vs. 880 Jet N = 12			Avg.	-4.3	-5.2	-2.4	-3.3	-4.8	-5.7	-5.7	-6.7	-1.9	-1.0	-2.0	-1.0	-2.0	-1.1	-2.0	-1.1	-1.2	-1.2
				Avg. dev.	4.3	5.2	2.5	3.4	4.8	5.7	5.7	6.7	2.0	2.1	3.1	2.4	3.3	1.8	2.1	1.8	2.0	1.8
				Range	6.5	11.0	6.5	8.5	11.0	13.5	12.5	15.0	6.5	9.0	11.0	10.5	12.5	5.5	5.5	6.5	8.5	5.5

Table XV

DIFFERENCES IN UNIT VALUES (COMPARISON AIRCRAFT MINUS REFERENCE AIRCRAFT)
WHERE 50% OF THE LISTENERS PREFER THE COMPARISON AIRCRAFT AND 50% PREFER THE REFERENCE AIRCRAFT

Indoor Listeners K-13 | Outdoor Physical Measurements | Reference Aircraft: 1049G at METO Power

Comparison Aircraft		Reference Aircraft (1049G)			Max dB(A)	Max dB(B)	Max dB(C)	Max $dB(D_1)$	Max $dB(D_2)$	Max $dB(D_3)$	Max Phons	Max PNdB	Max $PNdB_{t_1}$	Max $PNdB_{t_1}M$	Max $PNdB_{t_2}$	Peak $dB(D_2)$	Peak Phons	Peak PNdB
Type	Power	Altitude (feet)	Takeoff Power	Avg. Peak PNdB														
880	Landing	1300	METO	105.0	-2.0	-6.0	-7.5	-4.0	+1.5	+0.5	-3.5	-3.5	-5.0	-5.0	-5.0	+1.0	-4.0	-4.0
727	Landing	1000	METO	110.5	+1.0	-4.5	-6.0	+3.0	+10.5	+6.0	+2.5	+3.5	+2.0	+3.0	+3.0	+9.0	+1.5	+2.5
720	Landing	1000	METO	109.5	0	-5.0	-7.0	-1.5	+5.0	+3.5	-2.0	-1.5	-3.0	-2.0	-1.5	+4.0	-2.5	-2.0
C141	Landing	1000	METO	111.0	-0.5	-7.5	-10.0	+2.0	+9.0	+5.0	+1.0	+1.5	+5.5	+6.0	+3.5	+9.0	+0.5	+1.0
Jetstar	Landing	1800	METO	107.0	-2.5	-6.0	-7.0	-2.0	+1.0	-0.5	-4.0	-3.5	-5.5	-4.5	-2.5	+1.0	-4.5	-4.0
Jet vs. 1049G				Avg.	-0.8	-5.8	-7.5	-0.5	+5.4	+2.9	-1.2	-0.7	-1.2	-0.5	-0.5	+4.8	-1.8	-1.3
				Avg. dev.	1.2	5.8	7.5	2.5	5.4	3.1	2.6	2.7	4.2	4.1	3.1	4.8	2.6	2.7
				Range	3.5	3.0	4.0	7.0	9.5	6.5	6.5	7.0	11.0	11.0	8.5	8.0	6.0	6.5
CV7A	Cruise	3000	METO	104.5	Insufficient data													
204B	Cruise	1300	METO	106.5	-8.0	-7.0	-2.0	-7.0	-4.0	-5.5	-5.5	-6.0	-6.0	-6.0	-6.0	-3.5	-3.5	-4.0
All aircraft vs. 1049G Prop. N = 6				Avg.	-2.0	-6.0	-6.6	-1.6	+3.8	+1.5	-1.9	-1.6	-2.0	-1.4	-1.4	+3.4	-2.1	-1.8
				Avg. dev.	2.3	6.0	6.6	3.3	5.2	3.5	3.1	3.3	4.5	4.4	3.6	4.6	2.8	2.9
				Range	9.0	3.0	8.0	10.0	14.5	11.5	8.0	9.5	11.5	12.0	9.5	12.5	6.0	6.5
Comparison vs. either reference				Avg.	-3.2	-3.0	-2.5	-1.8	-1.3	-2.4	-1.6	-1.4	-0.6	-0.5	-0.3	-1.1	-1.2	-0.9
				Avg. dev.	3.3	3.8	3.9	3.0	4.9	4.1	2.6	2.6	3.6	3.7	2.7	4.5	2.1	2.3
				Range	11.0	12.5	13.5	11.0	22.5	17.5	10.5	11.0	15.0	15.5	11.0	19.5	8.0	8.0

Comparison Aircraft		Reference Aircraft (1049G)			E_8 dB(A)	E_8 $dB(A)_o$	E_8 $dB(D_1)$	E_8 $dB(D_1)_o$	E_8 $dB(D_2)$	E_8 $dB(D_2)_o$	E_8 $dB(D_3)$	E_8 $dB(D_3)_o$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1oc}$	E_8 $PNdB_{t_1}M$	E_8 $PNdB_{t_1}M_o$	E_8 $PNdB_{t_2}$	E_8 PNdB	E_8 $PNdB_{t_1}$	E_8 $PNdB_{t_1}M$	E_8 $PNdB_{t_2}$
Type	Power	Altitude (feet)	Takeoff Power	Avg. Peak PNdB																		
800	Landing	1300	METO	105.0	-0.5	-0.5	-2.5	-2.5	+1.5	+1.5	+1.0	+1.0	-2.5	-3.0	-3.0	-2.5	-2.5	-3.5	-3.5	-4.0	-3.5	-5.0
727	Landing	1000	METO	110.5	-3.0	-3.0	-1.0	-1.0	+1.0	+1.0	-2.0	-2.0	0	-1.0	-1.0	0	0	-1.0	-1.5	-2.0	-1.0	-2.0
720	Landing	1000	METO	109.5	0	+0.5	-1.0	-0.5	+0.5	+1.0	-0.5	0	-1.0	-1.0	-0.5	0	+0.5	-1.5	-1.5	-2.0	-0.5	-1.5
C141	Landing	1000	METO	111.0	-2.5	-2.5	+0.5	+0.5	+3.5	+3.5	+0.5	+0.5	0	+4.0	+4.0	+5.5	+5.5	+2.0	-1.0	+3.5	+5.5	+1.5
Jetstar	Landing	1800	METO	107.0	-4.5	-4.5	-5.5	-5.5	-0.5	-0.5	-2.0	-2.0	-6.5	-6.5	-6.5	-5.5	-5.5	-7.5	-9.0	-8.0	-7.5	-8.5
Jet vs. 1049G				Avg.	-2.1	-2.0	-1.9	-1.8	+1.2	+1.3	-0.6	-0.5	-2.0	-1.5	-1.4	-0.5	-0.4	-2.3	-3.3	-2.5	-1.4	-3.1
				Avg. dev.	2.1	2.2	2.1	2.0	1.4	1.5	1.2	1.1	2.0	3.1	3.0	2.7	2.8	3.1	3.3	3.6	3.6	3.7
				Range	4.5	5.0	6.0	6.0	4.0	4.0	3.0	3.0	6.5	10.5	10.5	11.0	11.0	9.5	8.0	11.5	13.0	10.0
CV7A	Cruise	3000	METO	104.5																		
204B	Cruise	1300	METO	106.5	-5.0	-0.5	-2.5	+2.0	-1.0	+3.5	-3.0	+1.5	-2.5	-3.0	+1.5	-3.0	+1.5	-3.5	-2.5	-2.5	-3.0	-4.5
All aircraft vs. 1049G Prop. N = 6				Avg.	-2.6	-1.8	-2.0	-1.2	+0.8	+1.7	-1.0	-0.2	-2.1	-1.8	-0.9	-0.9	-0.1	-2.5	-3.2	-2.5	-1.7	-3.3
				Avg. dev.	2.6	1.9	2.2	2.0	1.3	1.8	1.5	1.2	2.1	3.1	2.8	2.8	2.6	3.2	3.2	3.7	3.5	3.8
				Range	5.0	5.0	6.0	7.5	4.5	4.0	4.0	3.5	6.5	10.5	10.5	11.0	11.0	9.5	8.0	11.5	13.0	10.0
Comparison vs. either reference				Avg.	-3.7	-4.1	-2.3	-2.6	-2.9	-3.2	-4.1	-4.5	-2.0	-1.3	-1.6	-1.0	-1.4	-1.6	-2.4	-1.6	-1.4	-1.9
				Avg. dev.	3.7	4.1	2.4	2.9	3.6	4.4	4.3	4.9	2.0	2.4	3.0	2.5	3.1	2.3	2.5	2.4	2.5	2.5
				Range	7.5	12.0	6.5	10.0	16.0	18.0	15.0	17.5	7.0	10.5	11.5	11.5	13.5	9.5	9.5	11.5	13.0	10.0

Table XVI

SUMMARY OF AVERAGE DEVIATION FOR THE VARIOUS MEASUREMENT UNITS TAKEN OUTDOORS
BETWEEN REFERENCE AND COMPARISON AIRCRAFT NOISES
WHEN JUDGED EQUALLY UNACCEPTABLE BY SUBJECTS INDOORS. (Averages taken from Tables XII, XIII, XIV, and IV)

Reference Aircraft	House	Table	Max dB(A)	Max dB(B)	Max dB(C)	Max dB(D_1)	Max dB(D_2)	Max dB(D_3)	Max Phons	Max PNdB	Max PNdB$_{t_1}$	Max PNdB$_{t_1}$ M	Max PNdB$_{t_2}$	Peak dB(D_2)	Peak Phons	Peak PNdB
880	H-11	XII	3.3	2.3	2.1	2.3	4.4	3.8	1.7	2.0	2.8	3.1	2.2	4.0	1.4	1.8
1049G	H-11	XIII	3.2	5.2	5.7	3.8	6.5	4.8	3.4	3.8	4.5	4.9	4.2	5.8	2.8	3.3
880	K-13	XIV	3.8	2.7	2.5	2.8	4.8	4.4	2.3	2.3	3.2	3.4	2.2	4.5	1.8	2.0
1049G	K-13	XV	2.3	6.0	6.6	3.3	5.2	3.5	3.1	3.3	4.5	4.4	3.6	4.6	2.8	2.9
Aver. of Aver. Deviations			3.3	3.5	3.6	2.9	5.0	4.1	2.4	2.6	3.5	3.7	2.8	4.6	2.0	2.3

E_8 dB(A)	E_8 dB(A)$_o$	E_8 dB(D_1)	E_8 dB(D_1)$_o$	E_8 dB(D_2)	E_8 dB(D_2)$_o$	E_8 dB(D_3)	E_8 dB(D_3)$_o$	E_8 PNdB	E_8 PNdB$_{t_1}$	E_8 PNdB$_{t_1 o}$	E_8 PNdB$_{t_1}$ M	E_8 PNdB$_{t_1}$ M$_o$	E_8 PNdB$_{t_2}$	EE_8 PNdB	EE_8 PNdB$_{t_1}$	EE_8 PNdB$_{t_1}$ M	EE_8 PNdB$_{t_2}$
3.8	4.7	2.2	3.2	4.4	5.2	5.2	6.1	1.8	2.1	3.0	2.3	3.2	1.8	2.0	1.9	2.0	1.9
2.9	2.3	2.6	2.3	2.8	2.9	2.1	1.6	2.9	3.5	3.0	3.8	3.3	3.5	2.8	3.7	4.0	3.8
4.3	5.2	2.5	3.4	4.8	5.7	5.7	6.7	2.0	2.1	3.1	2.4	3.3	1.8	2.1	1.8	2.0	1.8
2.6	1.9	2.2	2.0	1.3	1.8	1.5	1.2	2.1	3.1	2.8	2.8	2.6	3.2	3.2	3.7	3.5	3.8
3.6	4.0	2.4	2.9	3.8	4.4	4.2	4.7	2.1	2.5	3.0	2.7	3.2	2.3	2.4	2.5	2.6	2.5

Results of Rating Scales

As previously mentioned, the subjects rated each noise after its occurence on a rating scale ranging from very acceptable (0) to very unacceptable (100). These data are of interest because (a) they provide a basis for direct comparison of the judged perceived noisiness of the aircraft noises as heard in different environments, e.g., different rooms indoors; and (b) these absolute judgments made indoors and outdoors of the unacceptability of an aircraft noise can be compared with somewhat similar ratings obtained in other studies.

Room Differences

The plots given in Figure 8 represent an attempt to determine the possible effect of room differences upon rated acceptability of aircraft noises of different spectra; the noise of the 990 can be classified as predominately high-, that of the F-104 as mid-, and that of the CH-47 as low-frequency (see Figure 6). It is seen that for all the rooms the lower the frequency content of the noise the greater is rated unacceptability for a given $EPNdB_{t_1}$ M value as measured outdoors. This is as would be expected, inasmuch as house structures typically attenuate the higher frequencies more than the lower. Indeed, it is possible that very intense frequencies near 10-30 Hz or so could cause non-linear house vibrations.

One possible explanation for the room differences shown in Figure 8 could be that the different groups of subjects in the test rooms respond differently to noises of different spectra. In view of the relatively small number, four to seven subjects in any one room, such group differences are very possible. However, the differences in sound attenuation characteristics afforded these different rooms by the houses is also a likely and partial explanation. Unfortunately, the small number of subjects in any one room and the design of the study (non-rotation of subjects among rooms) make it impractical to demonstrate with any validity the exact effects of room differences in sound attenuation upon the subjective ratings. Figure 9, taken from a report by Young,[3] illustrates the average attenuation of aircraft noise afforded by different rooms of the two test houses.

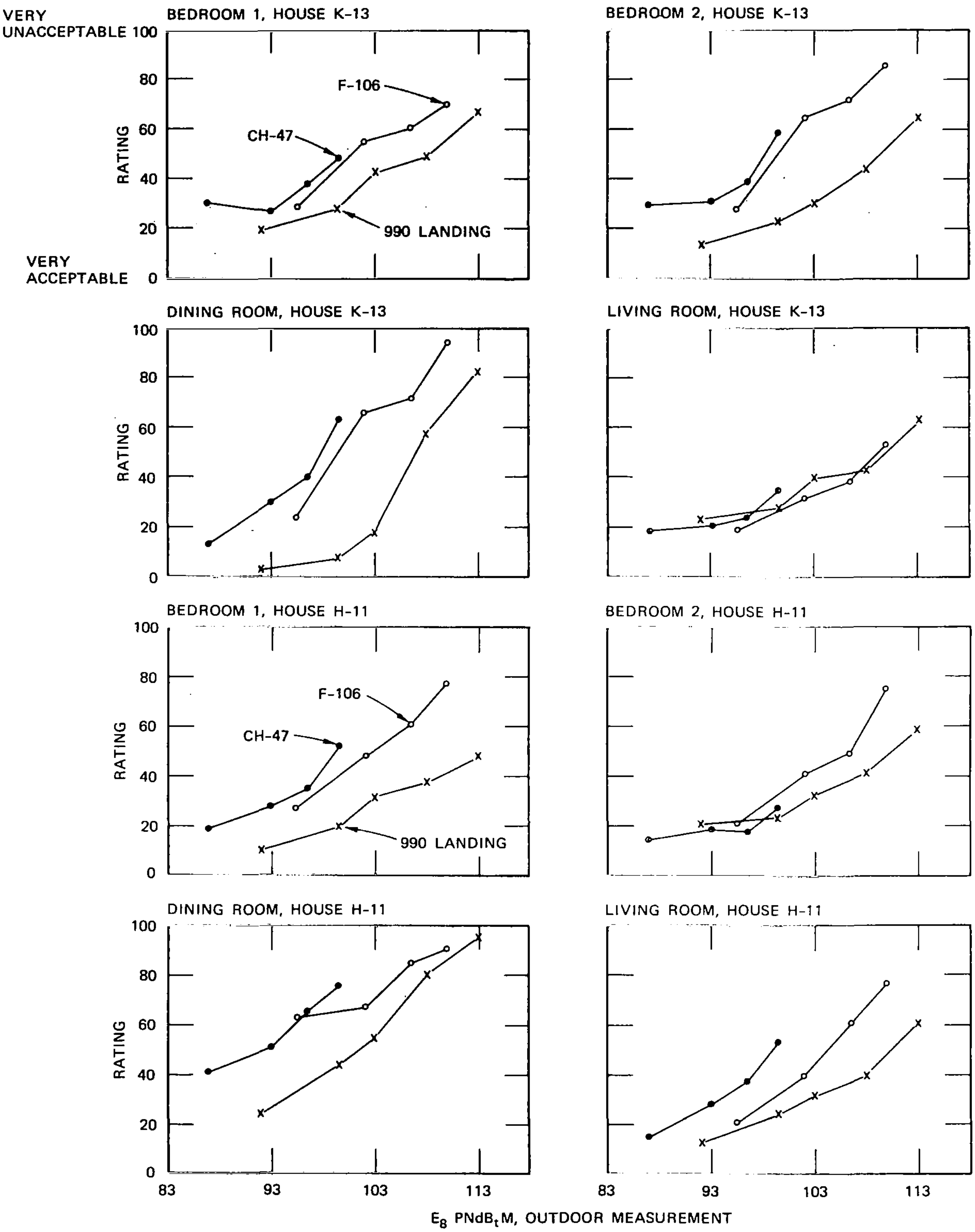

FIGURE 8 INDOOR RATINGS FOR EIGHT ROOMS VERSUS E_8PNdB_tM. The aircraft were selected to show room variations among rooms in their relative isolation from low- (CH-47), mid- (F-106), and high-frequency (990) noise.

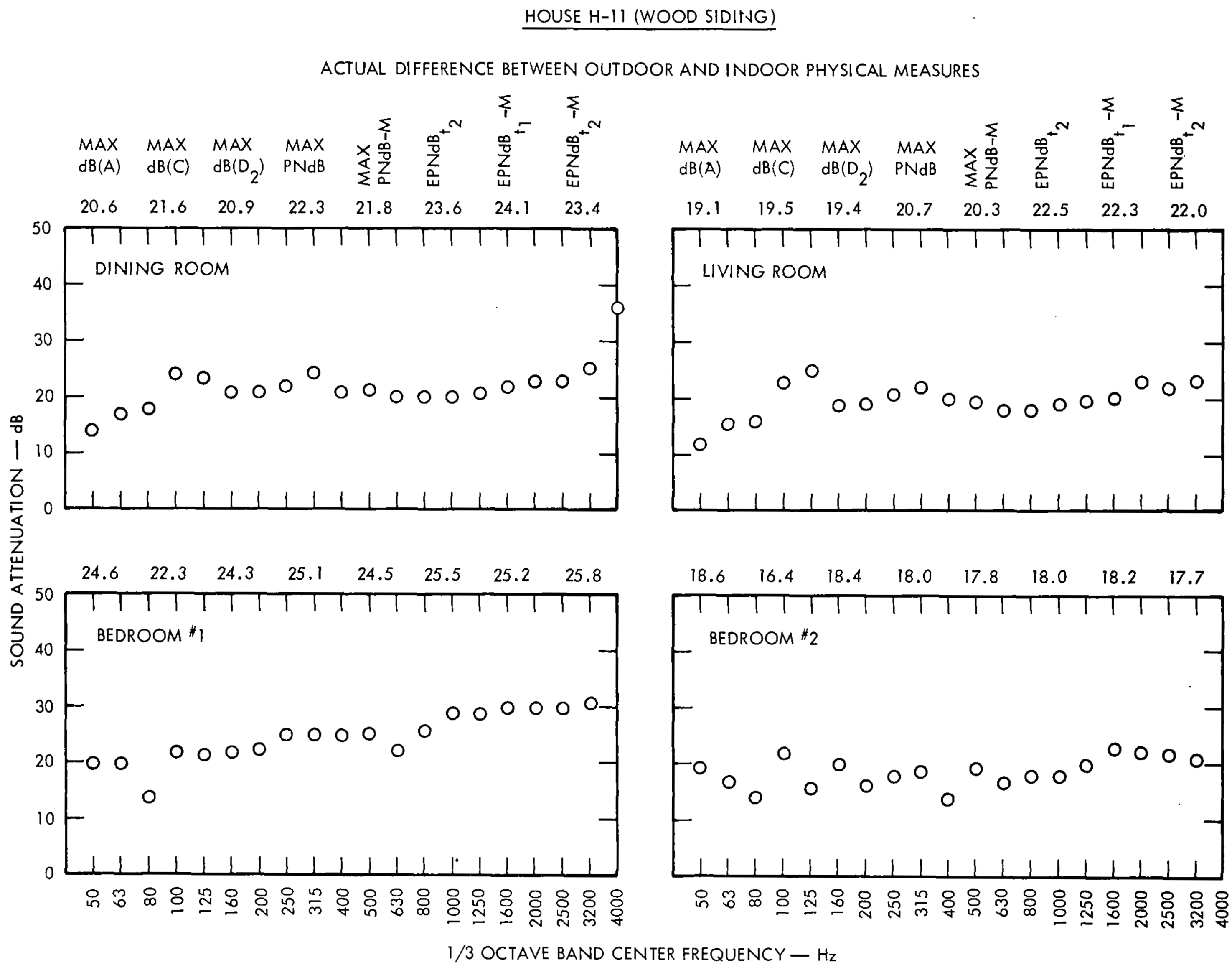

FIGURE 9 SOUND ATTENUATION (level outdoors minus level indoors) CHARACTERISTICS OF FOUR ROOMS IN A WOOD-SIDED HOUSE (H-11) AND IN A BRICK-VENEER HOUSE (K-13). Windows and doors closed. Based on an average of four aircraft flyover noises.[3]

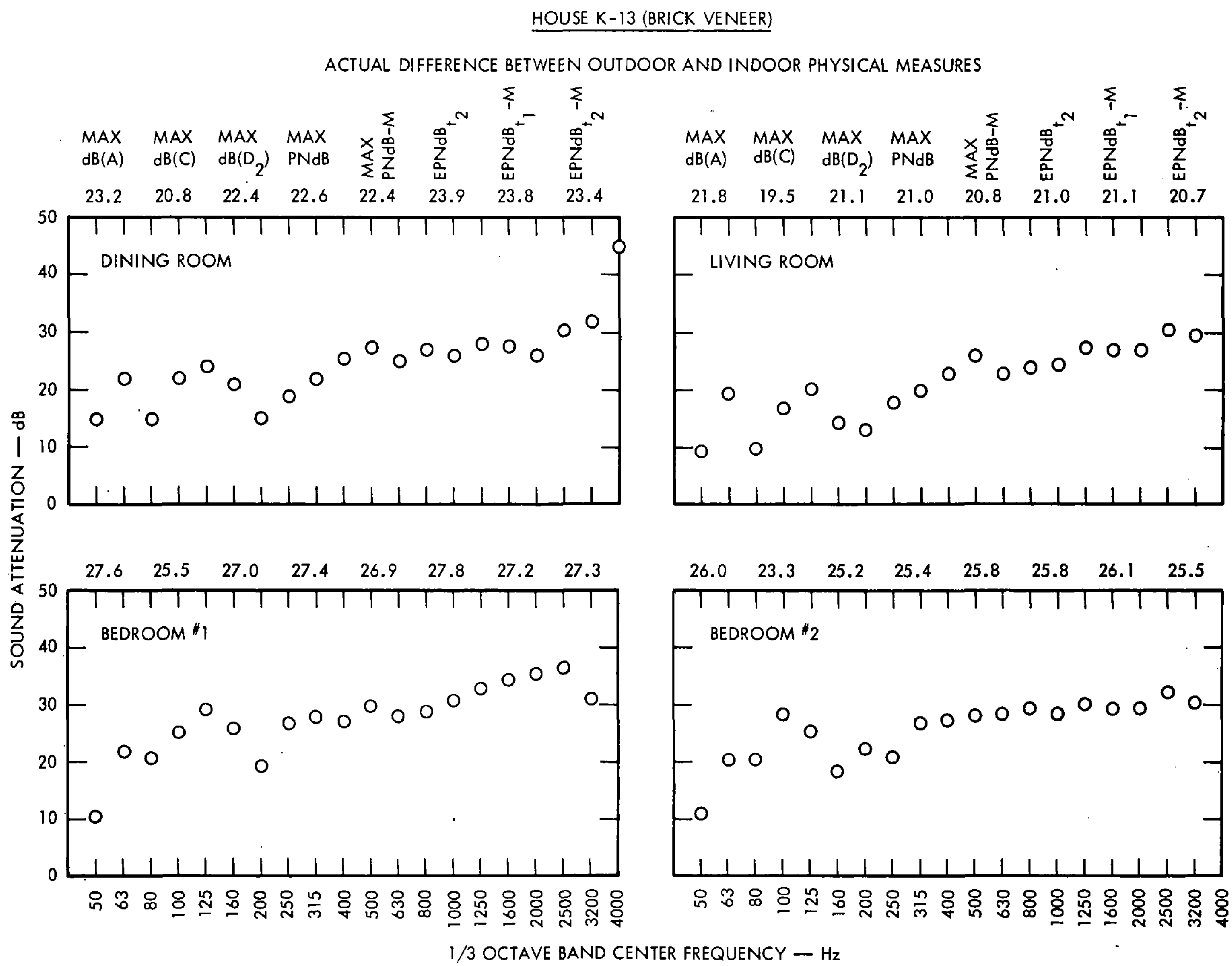

FIGURE 9 SOUND ATTENUATION (level outdoors minus level indoors) CHARACTERISTICS OF FOUR ROOMS IN A WOOD-SIDED HOUSE (H-11) AND IN A BRICK-VENEER HOUSE (K-13). Windows and doors closed. Based on an average of four aircraft flyover noises.[3] Concluded

Outdoor Versus Indoor Ratings

Figure 10 presents the average ratings given by the various aircraft noises when at different levels of intensity, given in $EPNdB_{t_1}M$. These functions, extrapolated when necessary, provided the summary tabulations of Table XVII where it is seen that the listeners indoors on the average rated the noises from the jet aircraft as more acceptable, i.e., would tolerate more intense levels, than did the listeners outdoors by an amount equivalent to an average difference in level of about 3 dB. On the other hand, the noises from the L-1049G and CH-47, which are predominately low frequency, are less acceptable indoors than outdoors by an amount equivalent to 3 dB. These results are obviously in agreement with the 6 to 10 dB lesser attenuation by the houses of low frequency compared with high frequency sounds.

Inasmuch as appreciable attenuation (20 PNdB or so) of even the noise from the CH-47 and L-1049G is imposed by the house structures, it must be presumed that people when indoors subjectively require or desire less intense noise for equal acceptability than when outdoors. These data are consistent with data obtained on rating scales in similar previous studies as shown in Figure 11. In order to place the present data on a more comparable basis with the various studies, Max PNdB rather than $E_8PNdB_{t_1}M$ values are plotted on Figure 11. Max PNdB and E_8PNdB (or $E_8P\,dB_{t_1}M$) are usually nearly equal in magnitude for jet aircraft at an altitude of about 2000 feet following takeoff.

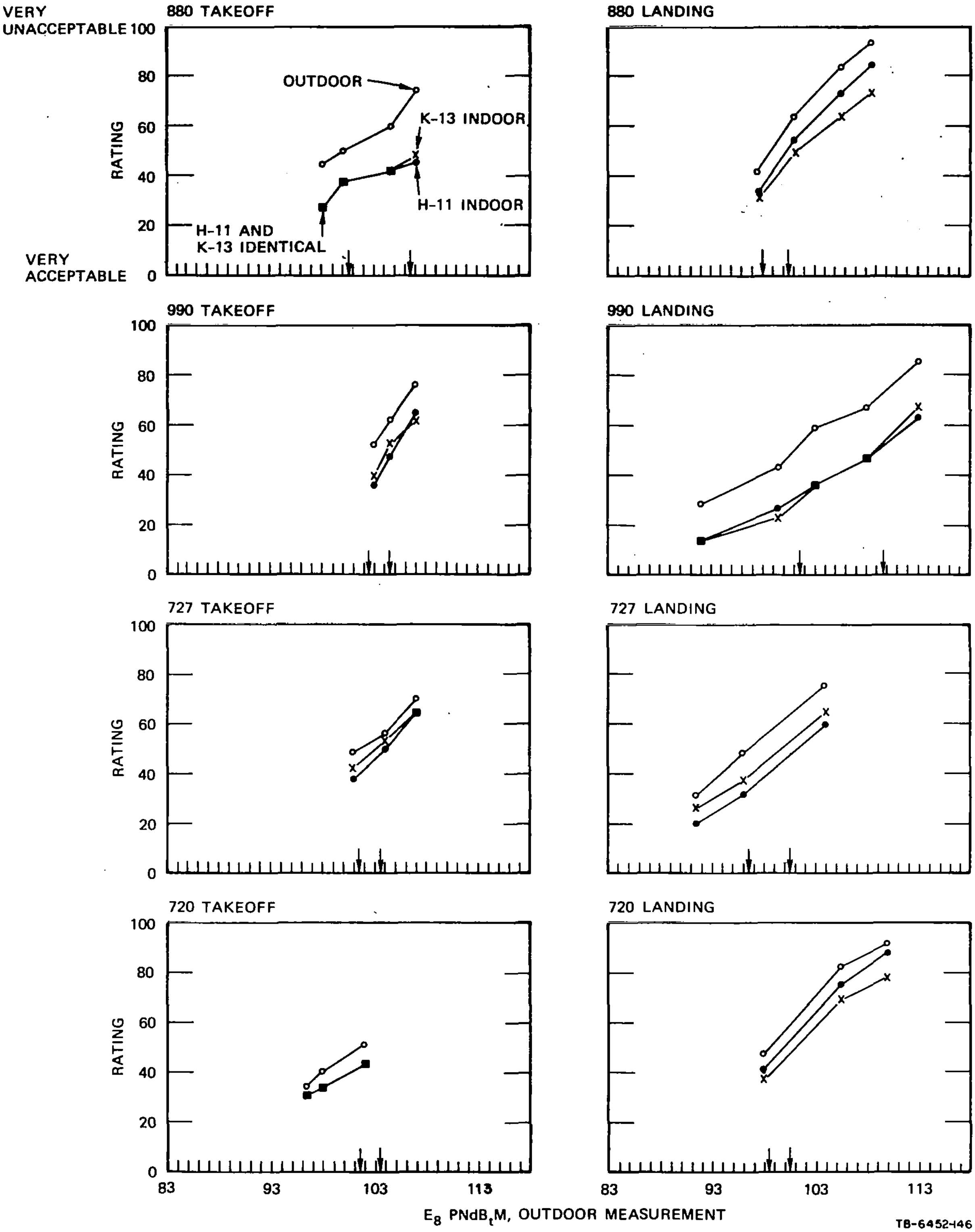

FIGURE 10 OUTDOOR RATINGS AND INDOOR RATINGS (2 Houses) VERSUS E_8PNdB_tM MEASURED OUTDOORS FOR AIRCRAFT USED DURING THE EXPERIMENT AT WALLOPS STATION

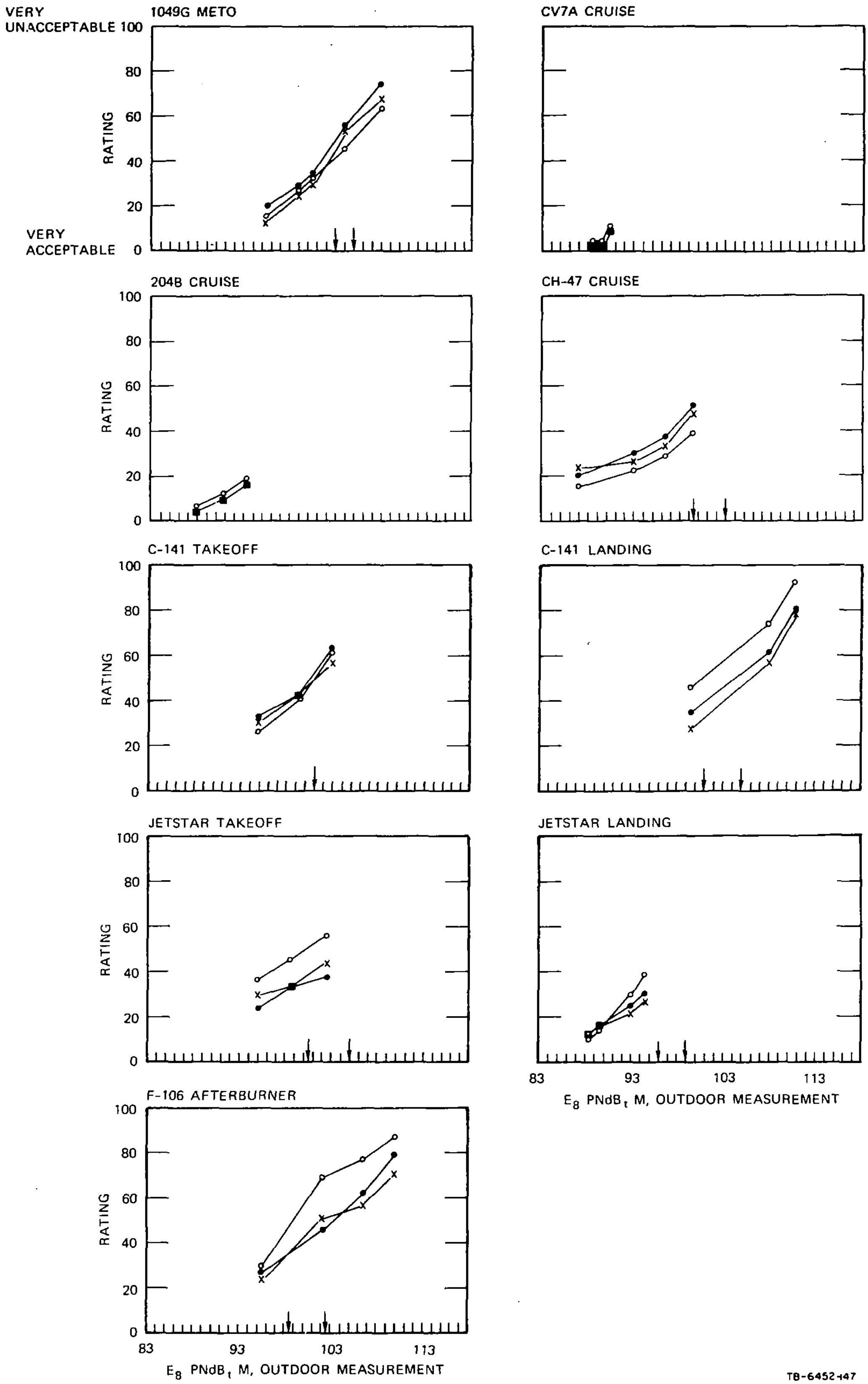

FIGURE 10 OUTDOOR RATINGS AND INDOOR RATINGS (2 Houses) VERSUS E_8PNdB_tM MEASURED OUTDOORS FOR AIRCRAFT USED DURING THE EXPERIMENT AT WALLOPS STATION Concluded

Table XVII

VALUE OF E_8PNdB_tM WHERE LISTENERS RATE AIRCRAFT AS 50 (MIDWAY BETWEEN VERY ACCEPTABLE AND VERY UNACCEPTABLE)

Aircraft	Power	Outdoor Listeners	Indoor Listeners	Difference
880	Takeoff	100.5	106.5	6.0
990	Takeoff	102.5	104.5	2.0
727	Takeoff	101.5	103.5	2.0
720	Takeoff	101.5	103.5	2.0
C-141	Takeoff	101.0	101.0	0.0
Jetstar	Takeoff	100.5	105.0	4.5
F-106	Afterburner	98.5	102.5	4.0
880	Landing	98.0	100.5	2.5
990	Landing	101.5	109.5	8.0
727	Landing	96.5	100.5	4.0
720	Landing	98.5	100.5	2.0
C-141	Landing	101.0	105.0	4.0
Jetstar	Landing	96.0	99.0	3.0
1049G	METO	105.0	103.0	-2.0
CH-47	Cruise	103.0	99.5	-3.5

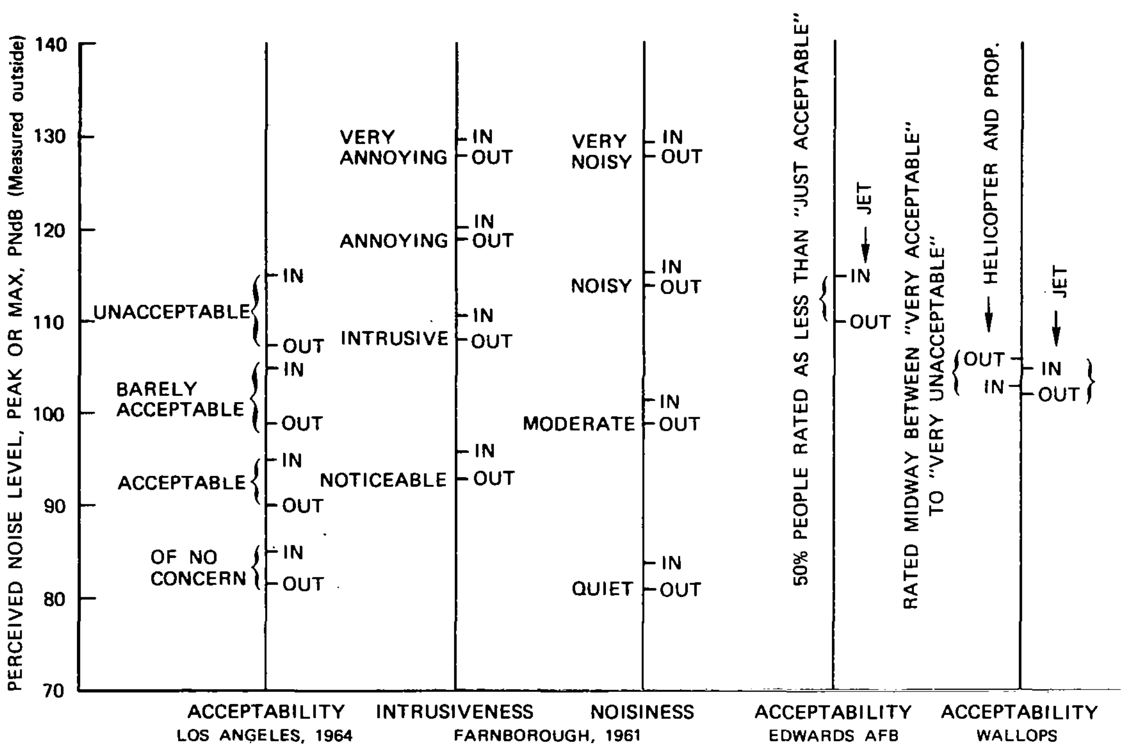

FIGURE 11 COMPARISON BETWEEN PERCEIVED NOISE LEVEL OF AIRCRAFT FLYOVERS AND CATEGORY SCALES OF ACCEPTABILITY, INTRUSIVENESS, AND NOISINESS. Subjects were from civilian communities with the exception of those at Edwards Air Force Base.[12,16,17]

CONCLUSIONS

It is concluded that:

1. Effective PNL in EPNdB-M, with or without tone or onset corrections (78% to 84% points) and EdB(D_2) (89% points) were the most accurate means used for estimating from physical measurements the judged perceived noisiness of a wide variety of aircraft noises.

2. An integration of 0.5-sec intervals of overall sound pressure level weighted in accordance with D_2 may provide as accurate or even more accurate means of predicting judged perceived noisiness than 1/3 octave band spectra adjusted for critical bandwidth of the ear and summed in accordance with the band procedure used for Phons (Stevens) and PNdB.

3. Onset duration and tone corrections (t_1 or t_2) did not on the average contribute significantly to the predictive accuracy of the various physical units of measurement. However, the possibility of experimental error and the relative homogeniety of the noises involved suggests that further tests designed to evaluate more specifically the possible contribution of these two factors to perceived noisiness are in order.

4. The noise of a jet aircraft at approximately 2,000 feet altitude following takeoff, heard outdoors on the ground and having a PNL of about 102 E_8PNdB, E_8PNdB-M, Max PNdB, Max PNdB-M [or E_8dB(D_2) or Max dB(D_2) of about 97] will be rated as midway between "very acceptable" and "very unacceptable."

5. To the degree that the two test houses are representative of house structures, listeners indoors will rate high frequency jet aircraft noises as an average of 3 dB or so more acceptable than listeners outdoors, but listeners indoors will rate low frequency aircraft noises as 3 dB or so less acceptable than listeners outdoors. For an average over all types of aircraft noise it would thus appear that about the same rating of unacceptability will be given the noise by listeners indoors as by listeners outdoors.

6. There will be large differences in the perceived noisiness of the sound from an aircraft overflight as judged by groups of listeners located in different rooms in a house. These differences in sound spectra are the result of differential attenuation of sound afforded to the different rooms.

7. Except for underestimating somewhat the perceived noisiness of low frequency noise relative to high frequency noise, physical measurements made outdoors can be used to approximately predict judgments made indoors of the perceived noisiness of sounds generated outdoors.

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Appendix

AIRCRAFT NOISE JUDGMENT TESTS

The aircraft noises you will hear will be of the intensity that can or will normally occur at or near communities in the vicinity of airports.

There is nothing secret or classified about these tests. However, we ask that you do not attempt to give opinions about the results of the tests inasmuch as the results will not be analyzed nor understood until the study is completed and all data are given proper consideration. Also, you should not discuss, in particular, your reactions to these sounds with your fellow observers inasmuch as we want your own opinions, and we expect people to differ in their judgments. There are no right or wrong answers.

These tests are being conducted by the National Aeronautics and Space Administration with the help of Stanford Research Institute; they are part of the program of research on the effects of noise from aircraft and means of reducing this noise. Your conscientious participation in the program is greatly appreciated. Any requests for additional information should be addressed to: Public Information Officer, National Aeronautics and Space Administration, Wallops Station, Wallops Island, Virginia 23337.

LAST NAME	INITIAL	LOCATION	DATE

Circle A if first sound is more acceptable.
Circle B if second sound is more acceptable.

1.	A	B
2.	A	B
3.	A	B
4.	A	B
5.	A	B
6.	A	B
7.	A	B
8.	A	B
9.	A	B
10.	A	B
11.	A	B
12.	A	B
13.	A	B
14.	A	B
15.	A	B
16.	A	B
17.	A	B
18.	A	B
19.	A	B
20.	A	B

INSTRUCTIONS:

The primary purpose of the tests being conducted is to determine, if possible, how people feel about the relative acceptability of one type or level of aircraft noise when compared with a second type or level of aircraft noise.

You will hear a series of sounds from aircraft. The sounds will occur in "pairs" and your task is to judge which sound in each pair you think would be more acceptable to you if heard in or near your home during the day and/or evening when you are engaged in typical, awake activities.

After you have heard each pair of sounds, please quickly decide which of the two you feel would be more acceptable to you. If you think the second sound of a pair would be more acceptable, circle B for that particular pair. If you think the first sound in the pair would be more acceptable to you than the second, circle A.

Please concentrate on the judgment at hand and give an answer even though the two sounds may seem approximately equal in acceptability to you. If you feel that there is absolutely no real difference in terms of acceptability of the two sounds, please circle either A or B, giving the best guess you can, and put a question mark after that pair.

There are no "right" or "wrong" answers, nor do we expect people to agree with each other. We are interested in how you feel about the sounds and how people differ in their judgments of the acceptability of these aircraft sounds.

An announcement will be made before each pair of sounds is to occur. The sounds of a pair may be separated in time by several minutes; usually, however, they will occur within a single minute. During this period, we ask that you be quiet and attentive. Give us your best judgement and imagine, if you will, that you are listening to these sounds in or near your own home.

LAST NAME	INITIAL	LOCATION	DATE

For each aircraft noise enter a number in the appropriate blank according to the following procedure:

Imagine a noise from an aircraft flying overhead that is weak enough to be completely acceptable to you if heard in your home at any time of the day or night; this noise would be assigned the number "1." Now imagine a noise from an aircraft flying overhead that is so intense it would be considered completely unacceptable to you if heard in your home at any time of the day or night; this noise would be assigned the number "100."

For each aircraft noise that is a part of the test, please assign a number between 1 and 100 in the appropriate blank to the right of the page. For example, if the noise of the A part of the fifth pair seems to be halfway between being acceptable and unacceptable, then the number "50" might be written in the blank to the right of No. 5 in the A column.

Try to assign to each aircraft noise a number that indicates its relative acceptability to you on the scale 1 to 100. In other words, estimate the magnitude of an "acceptable-unacceptable value" for each aircraft noise.

Pair	A	B
1	____	____
2	____	____
3	____	____
4	____	____
5	____	____
6	____	____
7	____	____
8	____	____
9	____	____
10	____	____
11	____	____
12	____	____
13	____	____
14	____	____
15	____	____
16	____	____
17	____	____
18	____	____
19	____	____
20	____	____

NAME:

LAST NAME

FIRST NAME

MIDDLE INITIAL

SOCIAL SECURITY NUMBER: ___ — __ — ____

MARITAL STATUS (Circle One): M Married S Not Married

SEX (Circle One): M Male F Female

AGE:

OCCUPATION: ______________________________

If Female and married, husband's occupation ______________

EDUCATION: ______________ (Enter number of years completed)

TIME IN AREA TO THE NEAREST YEAR (Circle One):

L	1	2	3	4	5	6
Less than 6 Months	1 yr.	2 yrs.	3 yrs.	4 yrs.	5 yrs.	6 yrs. or more

ADDRESS: ______________________________

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NASA-Langley, 1970 —— 2 CR-1635