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AURAL DETECTION OF SMALL PROPELLER-DRIVEN AIRCRAFT

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Background and Objectives:

The Federal Aviation Administration (FAA) has conducted numerous flight tests of small propeller-driven aircraft in support of developing aircraft noise regulations. Those tests typically measured ground-level noise resulting from high power/high RPM aircraft operation. However, there is also interest, at the opposite end of the power/RPM spectrum, in examining the aural detectability of a given aircraft operating at minimal flight conditions of low power and low RPM. Such information on "how quiet an aircraft can operate" is of interest to aircraft operators who may routinely and intensively operate small aircraft over noise-sensitive communities. At the request of the Federal Bureau of Investigation (FBI), the FAA in cooperation with the Department of Transportation's, Transportation Systems Center (TSC), the Department of the Navy, and the FBI's Aviation and Special Operations Unit conducted a flight test to characterize noise emissions from selected aircraft operating at minimal flight conditions. This report presents results from the flight test.

Specific objectives were to measure or determine, under minimal flight conditions, the:

(1) differences in noise emissions from selected aircraft models;

(2) difference in noise emissions between a 2-blade and a 3-blade propeller;

(3) dominant source of noise (i.e., propeller or engine exhaust);

(4) additional noise produced by increases in manifold pressure and flap settings.

Subsequent to the flight test, measurements of community noise were made for comparision to aircraft noise on an aircraft detectability basis. This report also presents a general discussion of community noise levels as well as a discussion of the influence of ground-reflected aircraft noise on aircraft detectability.

Test Aircraft

The following three fixed-wing aircraft were flight tested:

(1) Cessna 182RG equipped with a 2-blade propeller (82 inch diameter);

(2) Cessna 182RG equipped with a 3-blade propeller (79 inch diameter).

(3) Cessna 210 equipped with a 3-blade propeller (80 inch diameter).

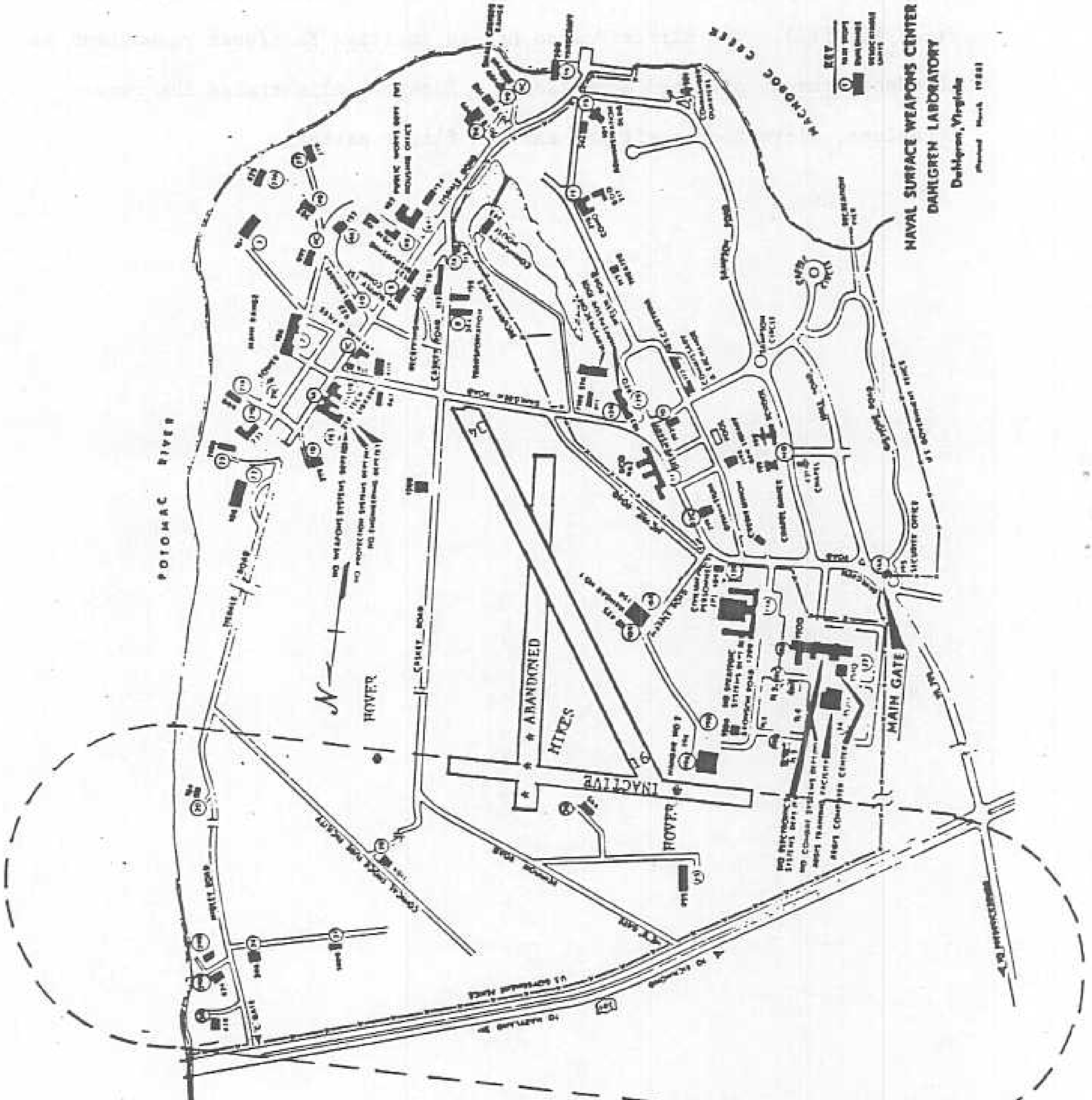
Cessna 182s are powered by Avco-Lycoming 0-540-J3C5D six cylinder engines.

A rotary-wing aircraft, a Bell Helicopter 206, was also included in the flight test.

Location:

The test was conducted on the airfield of the Naval Surface Weapons Center at Dahlgren, Virginia. The airfield has one active runway (16/34; 4000 ft. X 150 ft.). The airfield also has an inactive East/West runway and an abandoned runway oriented North/South. Figure 1 illustrates the runway locations, microphone positions and the flight pattern.

FIGURE 1 FLIGHT TEST LOCATION



Test Plan:

All fixed-wing events (flybys) were level flyovers. Each aircraft flew the same set of test series listed in Table 1. A series is a set of replications of a given flight condition. The basic series (A, B, and C) were all flown eastbound at 300 feet AGL. Series A, the reference series, was flown at 16 inches manifold pressure, 1900 RPM, and 10 degrees flaps--operating variables previously identified as the most common minimal flight conditions for the 2-bladed 182. Series B was to test the noise impact of increasing manifold pressure by 2 inches. Series C tested the impact of increasing flaps from 10 degrees to 20 degrees. Series D and E were replications of the eastbound reference A series except at altitudes of 200 feet and 100 feet respectively. Series F, G, and H duplicated series A, D, and E in the opposite direction (westbound). Series D,E,F,G, and H were included in the event the basic test series (A,B, and C) did not provide adequate signal-to-noise ratio for analysis, and to verify the results of the sideline directivity analysis. Data from the A,B, and C series were found to be adequate and will be discussed in the following sections. Data from all series are presented in the appendixes.

Eastbound series were flown in a left-hand pattern as depicted in Figure 1. The south edge of the east/west runway was used as the flight track reference centerline. The runway edge (pavement/grass interface) functioned as a visual alignment cue for both the pilot and flight track observer on the ground. The observer radioed course corrections to the pilot if the aircraft deviated from the desired flight track. For those series flown westbound, the pattern was reversed using the same runway edge as the centerline.

Table 1. Target Test Plan

SERIES	DIRECTION	ALTITUDE (ft.)	MANIFOLD PRESSURE* (inches Hg)	RPM*	FLAPS (percent)
A	EAST	300	16	1900	10
B	EAST	300	18	1900	10
C	EAST	300	16	1900	20
D	EAST	200	16	1900	10
E	EAST	100	16	1900	10
F	WEST	300	16	1900	10
G	WEST	200	16	1900	10
H	WEST	100	16	1900	10

*Target RPM was 1900. However, in practice sufficient RPM and manifold pressure were used to maintain safe, level headway along the flight track.

The Bell 206 helicopter was flown in 50 knot level flyovers at 300, 200, and 100 feet AGL along the same flight track as the fixed-wing aircraft. Hover tests at 500 feet AGL, and 1500 feet (approx. distances) from the microphones were also performed at the two locations along the flight track indicated in Figure 1. During each hover, noise levels were recorded while the nose of the helicopter was pointed at the microphones (0 degrees), and with the nose rotated in the upwind direction by 45 degrees and 90 degrees.

Instrumentation:

The acoustic signal from each flyover was recorded by Nagra magnetic tape recorders from subsequent laboratory analysis. Three microphones were deployed four feet above the abandoned north/south runway in a symetric linear array orthogonal to the flight track. The center microphone was positioned at the flight track, thus measuring the noise directly beneath the overflying aircraft. Each sideline was positioned 300 feet laterally from the flight track. A fourth ground-plane type microphone was located at the centerline site. The ground plane microphone measures the true acoustic signature from the aircraft; the elevated microphones measured the aircraft noise as influenced by ground surface reflections--consistent with a subject surveillance situation. Acoustic instruments and analysis procedures were consistent with FAA Federal Aviation Regulations aircraft noise certification procedures. All microphones were located on the abandoned runway resulting in an "acoustically hard" microphone installation. All acoustic data acquisition, reduction and analysis were performed by TSC's Noise Measurement and Assessment Facility.

Data Summary:

Summary results in maximum A-weighted sound levels for each aircraft are presented in Table 2. A complete acoustic data summary, time history listings, and narrowband spectra for the C182(2-blade), C182 (3-blade), C210, and Bell 206 are presented in Appendixes A, B, C, and D respectively. Table 3 presents an event log of each aircraft's operations. A discussion of these data follows in the next section.

Test day weather was clear and sunny with a temperature range of 40 to 55 degrees Fahrenheit. Winds were northwest at less than 10 knots resulting in a north to south crosswind component to the flight track.

Data Analysis:

The C182 (2-blade) was able to maintain steady headway along the flight track for the A "reference" series of 16 inches manifold pressure and 1900 RPM. The C182 (3-blade) and the C210 also attempted to fly the reference series (16"/1900 RPM), but in practice, these aircraft were flown with sufficient manifold pressure and RPM to safely maintain altitude, attitude, and remain on the desired flight track. For their respective A series, the C182 (3-blade) averaged roughly 17 inches manifold pressure and 2000 RPM, while the C210 ran 16 inches manifold pressure and 2100 RPM.

Table 2. Average dBA Values

	MICROPHONE POSITION*			
C182 (2-blade)	CL4	CLG	N. SIDE	S. SIDE
Series A (16"/1900)	73	76	69	70
B (18"/2100)	79	81	73	73
C (16"/1850)	74	77	68	69
C182 (3-blade)				
Series A (17"/2000)	76	79	71	72
B (18"/2100)	78	81	73	73
C (18"/2050)	77	80	72	73
C210 (3-blade)				
Series A (16"/2100)	79	82	74	74
B (18"/2100)	80	83	76	76
C (18"/2100)	80	83	75	76

* CL4 - centerline at 4 ft. elevation
CLG - centerline at ground level
N. SIDE - north side of flight track (300 ft.)
S. SIDE - south side of flgiht track (300 ft.)

Table 3a C182 (2-blade) Event Log

TIME	EVENT	DIRECTION	ALT.	M.P.	RPM	KIAS	FLAPS	REMARKS
0952	A1	EAST	300	16	1900	100	10	
0955	A2	EAST	300	16	1900	100	10	
0958	A3	EAST	300	16	1900	100	10	
1001	A4	EAST	300	16	1900	100	10	
1005	A5	EAST	300	16	1900	100	10	
1009	A6	EAST	300	16	1900	100	10	
1012	A7	EAST	300	16	1900	100	10	
1016	A8	EAST	300	16	1900	100	10	
1020	B9	EAST	300	18	2100	110	10	
1023	B10	EAST	300	18	2100	110	10	
1025	B11	EAST	300	18	2100	110	10	
1028	B12	EAST	300	18	2100	110	10	
1031	C13	EAST	300	17	1750	78	20	
1036	C14	EAST	300	16	1800	82	20	
1038	C15	EAST	300	NR	NR	NR	20	
1042	C16	EAST	300	NR	NR	NR	20	
1051	C17	EAST	300	16	NR	85	20	
1055	C18	EAST	300	16	1900	NR	20	
1058	D19	EAST	200	16	2000	100	10	
1101	E20	EAST	100	NR	NR	NR	10	
1104	F21	WEST	300	16	NR	NR	10	
1107	F22	WEST	300	NR	NR	NR	10	
1110	F23	WEST	300	NR	NR	NR	10	
1113	G24	WEST	200	16	2100	110	10	
1116	H25	WEST	100	NR	NR	NR	10	INVALID RUN
1120	H26	WEST	100	NR	NR	NR	10	

NR: not reported

Table 3b C-182(3-blade) Event Log

TIME	EVENT	DIRECTION	ALT.	M.P.	RPM	KIAS	FLAPS	REMARKS
1145	A1	EAST	300	17	1900	95	10	
1149	A3	EAST	300	16	1900	95	10	
1153	A5	EAST	300	17	2000	95	10	
1157	A7	EAST	300	17	2050	95	10	
1233	A9	EAST	300	17	2000	90	10	
1238	A11	EAST	300	17	2100	100	10	
1242	B13	EAST	300	18	2100	105	10	
1247	B15	EAST	300	18	2100	105	10	
1251	B17	EAST	300	18	2100	105	10	
1255	B19	EAST	300	18	2100	105	10	
1300	C21	EAST	300	18	2000	85	20	
1305	C23	EAST	300	18	2000	80	20	
1309	C25	EAST	300	18	2100	85	20	
1319	C27	EAST	300	18	2100	90	20	
1324	D29	EAST	200	16	1950	90	10	
1329	D31	EAST	200	16	2000	100	10	
1333	E33	EAST	100	16	2000	100	10	
1339	F35	WEST	300	16	2000	100	10	
1344	G37	WEST	200	16	2000	100	10	
1349	H39	WEST	100	16	2000	95	10	

Table 3C C210 Event Log

TIME	EVENT	DIRECTION	ALT.	M.P.	RPM	KIAS	FLAPS	REMARKS
1146	A2	EAST	300	NR	NR	NR	10	
1151	A4	EAST	300	16	2100	100	10	
1154	A6	EAST	300	16	2100	85	10	
1159	A8	EAST	300	16	2100	85	10	
1234	A10	EAST	300	16	2100	90	10	
1239	A12	EAST	300	16	2100	85	10	
1244	B14	EAST	300	18	2100	97	10	DRIFTED SOUTH
1248	B16	EAST	300	18	2100	100	10	
1252	B18	EAST	300	18	2100	100	10	
1256	B20	EAST	300	18	2100	100	10	
1302	C22	EAST	300	16	2100	80	20	DRIFTED SOUTH
1307	C24	EAST	300	18	2100	85	20	
1311	C26	EAST	300	18	2100	85	20	
1320	C28	EAST	300	18	2100	85	20	
1325	D30	EAST	200	16	2100	90	10	DRIFTED SOUTH
1329	D32	EAST	200	16	2100	85	10	
1335	E34	EAST	100	16	2100	95	10	
1340	F36	WEST	300	16	2100	95	10	
1345	G38	WEST	200	16	2100	95	10	
1350	H40	WEST	100	16	2100	95	10	

C182 (2-blade) versus C182(3-blade):

In a direct comparison between the C182 aircraft, the C182 (2-blade) was 2.0 to 2.5 dBA quieter in overall noise. This difference in noise levels can probably be accounted for by the slightly higher manifold pressure and RPM values for the C182 (3-blade). However, the test results indicate that at minimal flight conditions the 3-blade propeller does not offer any reduced-noise advantages compared to the 2-blade propeller. The reason for this is discussed in the next section.

Dominant Source of Noise:

The primary sources of noise from a general aviation fixed-wing small aircraft are the propeller and engine exhaust. At high RPM, propeller noise typically dominates the overall noise level produced by the aircraft. Thus, a "quieter" 3-blade propeller will reduce overall noise compared to a 2-blade propeller. However, as discussed below, the engine exhaust is the dominant source at the minimal flight conditions of 16 inches manifold pressure and 1900 RPM. AT very low RPM conditions, the choice of propeller will not affect overall sound levels.

A procedure called narrowband frequency spectroscopy is available for separating and thus assessing the relative contribution of exhaust and propeller noise on overall noise levels. A narrowband spectrum presents noise levels as a function of narrow discrete frequency bands. Figure 2a illustrates a typical unweighted narrowband spectrum from a propeller-driven small airplane operating at high RPM. The airplane depicted, a Piper Lance, is similar to the Cessna 182 (2-blade) tested in that the Lance is also powered by a six-cylinder engine driving a 2-blade propeller. Exhaust and propeller components are readily identifiable in the spectrum. The"fundamental" exhaust frequency, in hertz, for a six-cylinder engine is calculated by dividing RPM by 20. The fundamental frequency for 2-blade and 3-blade propellers are RPM/30 and RPM/20 respectively. "Harmonics," which are consecutive integer multiples of the fundamental frequency, are clearly evident in the Lance spectrum. The spectrum also shows that propeller harmonics, as opposed to exhaust harmonics, dominate the overall spectrum. The A-weighted spectrum in Figure 2b indicates that mid-range harmonics dominate the A-weighted total noise level.

The same Lance aircraft operated at 55 percent power and 2140 RPM shows a distinctly different spectrum as illustrated in Figure 3. Although the fundamental exhaust and propeller noise levels are only slightly less than the higher power/RPM spectrum, the mid-range and higher harmonics are drastically reduced resulting in a 17 dBA difference between the spectra. The 55 percent/2140 RPM Lance spectrum is moderately dominated by exhaust noise. Thus it can be anticipated that the C182 (2-blade) spectrum at 1900 RPM may be even further dominated by exhaust noise.

FIGURE 2a EXAMPLE NARROWBAND SPECTRA (high power & rpm)

(ref. 2)

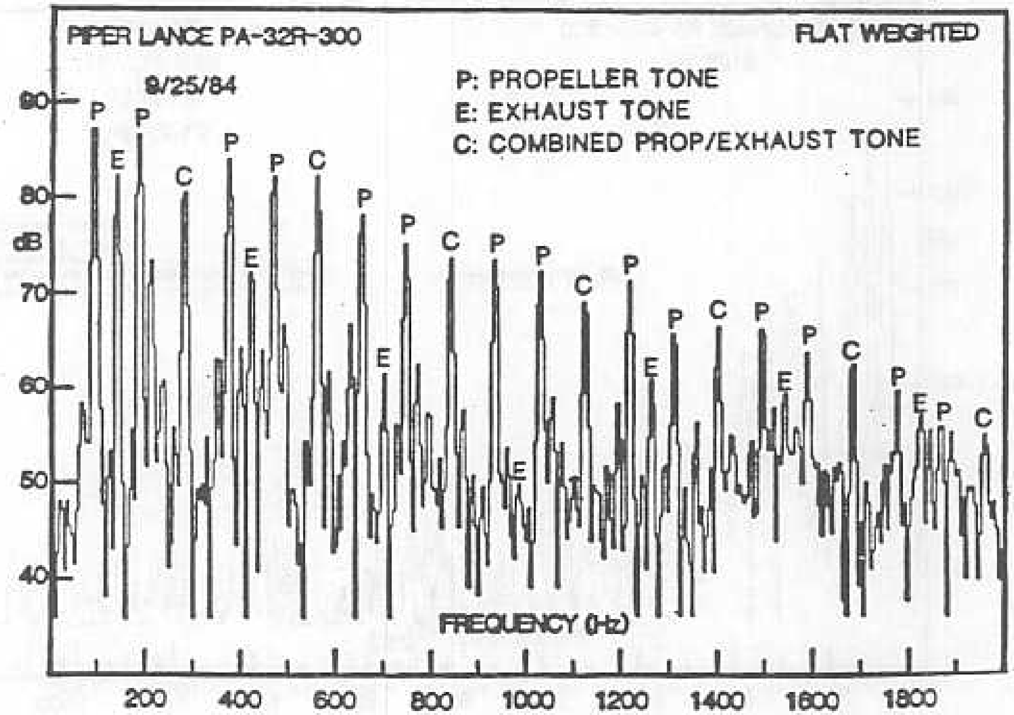


FIGURE 2b ABOVE SPECTRUM W/A-WEIGHTING

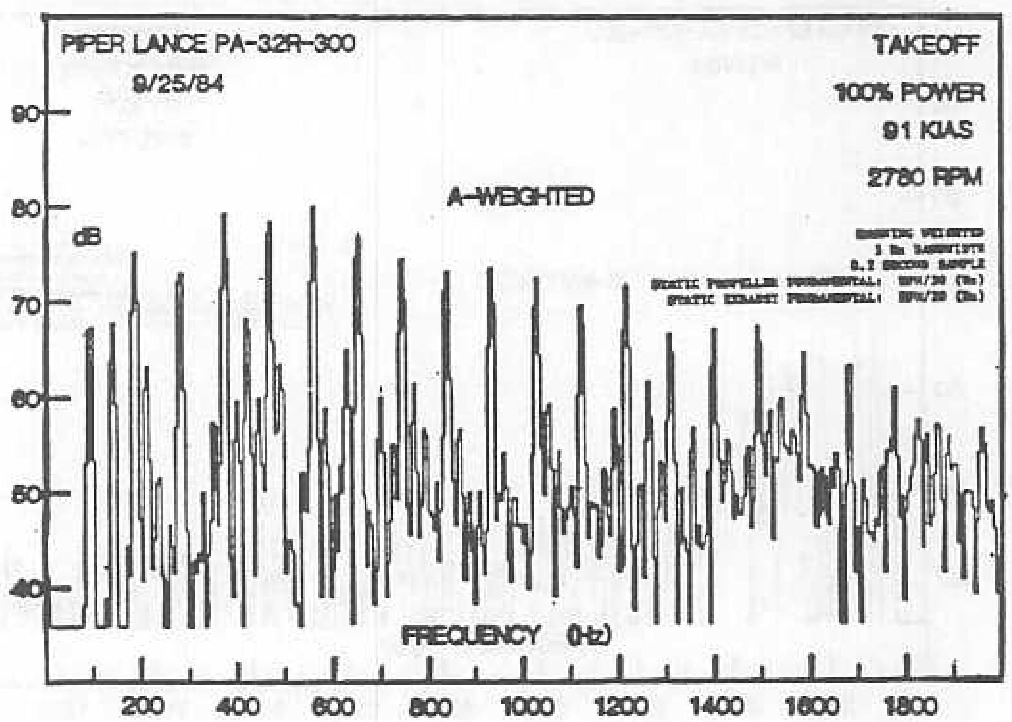


FIGURE 3a EXAMPLE NARROWBAND SPECTRA (low power & rpm)

(ref. 2)

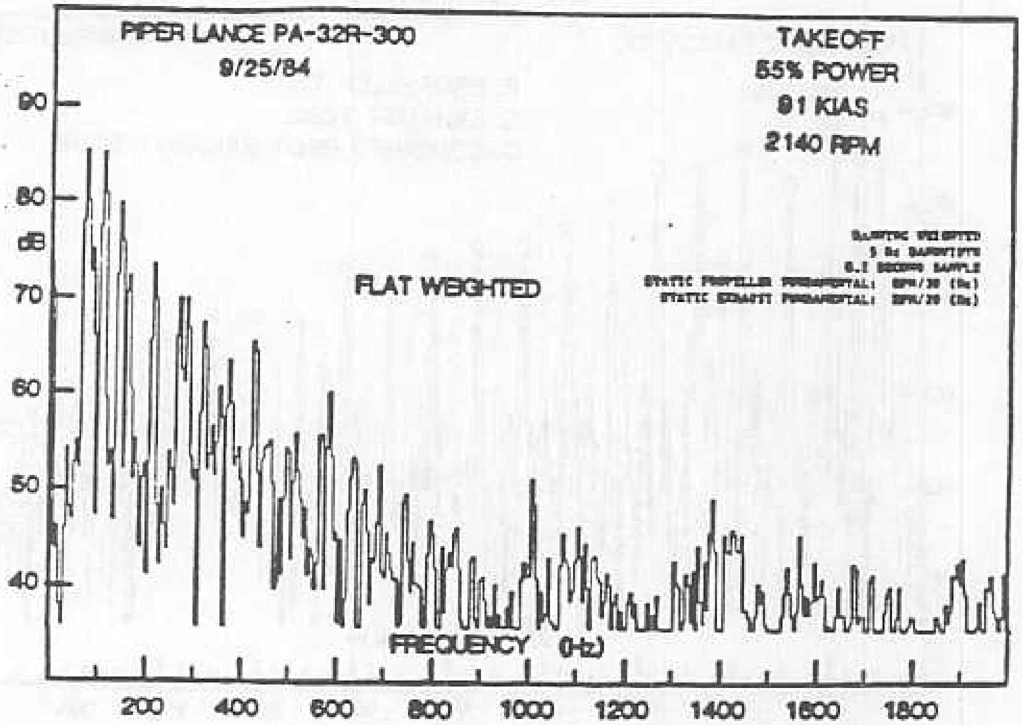


FIGURE 3b ABOVE SPECTRUM W/A-WEIGHTING

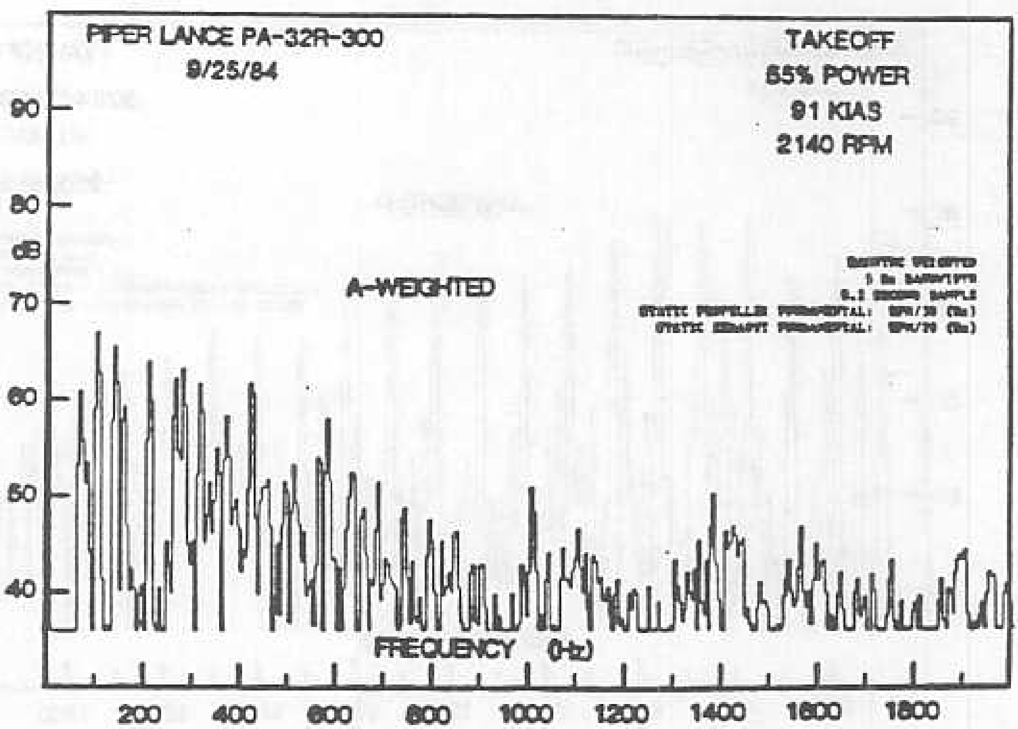


Figure 4 is a C182 (2-blade) narrowband spectrum from the ground centerline microphone of event A3 of the November 1986 Dahlgren test. It is immediately evident that engine exhaust substantially dominates the spectrum. The first several exhaust and propeller harmonics from each of the A series events were averaged into the composite spectra shown in Figure 5. As shown in Figure 5b, even with A-weighting the fundamental exhaust tone is the dominant discrete tone. Overall, there is approximately 14 dB difference between total exhaust noise and total propeller noise.

Extrapolated Aircraft Noise Levels:

During the Dahlgren test the aircraft were flown at an unrepresentatively low altitude to provide sufficient signal-to-noise ratio for the acoustic analysis. However, the measurements can be extrapolated to greater distances using fundamental acoustics formula. Given the test altitude of 300 feet AGL and sideline microphones positioned 300 feet lateral from the flight track, the slant range from aircraft to sideline microphone is 424 feet at a 45 degree "look down" angle. The formula for adjusting (algebraically added to) a known noise level at a known source-to-receptor distance to a different propagation distance is as follows:

$$20 \times \log_{10} (\text{present distance/desired distance})$$

FIGURE 4 EXAMPLE C182 (2-BLADE) NARROWBAND SPECTRUM

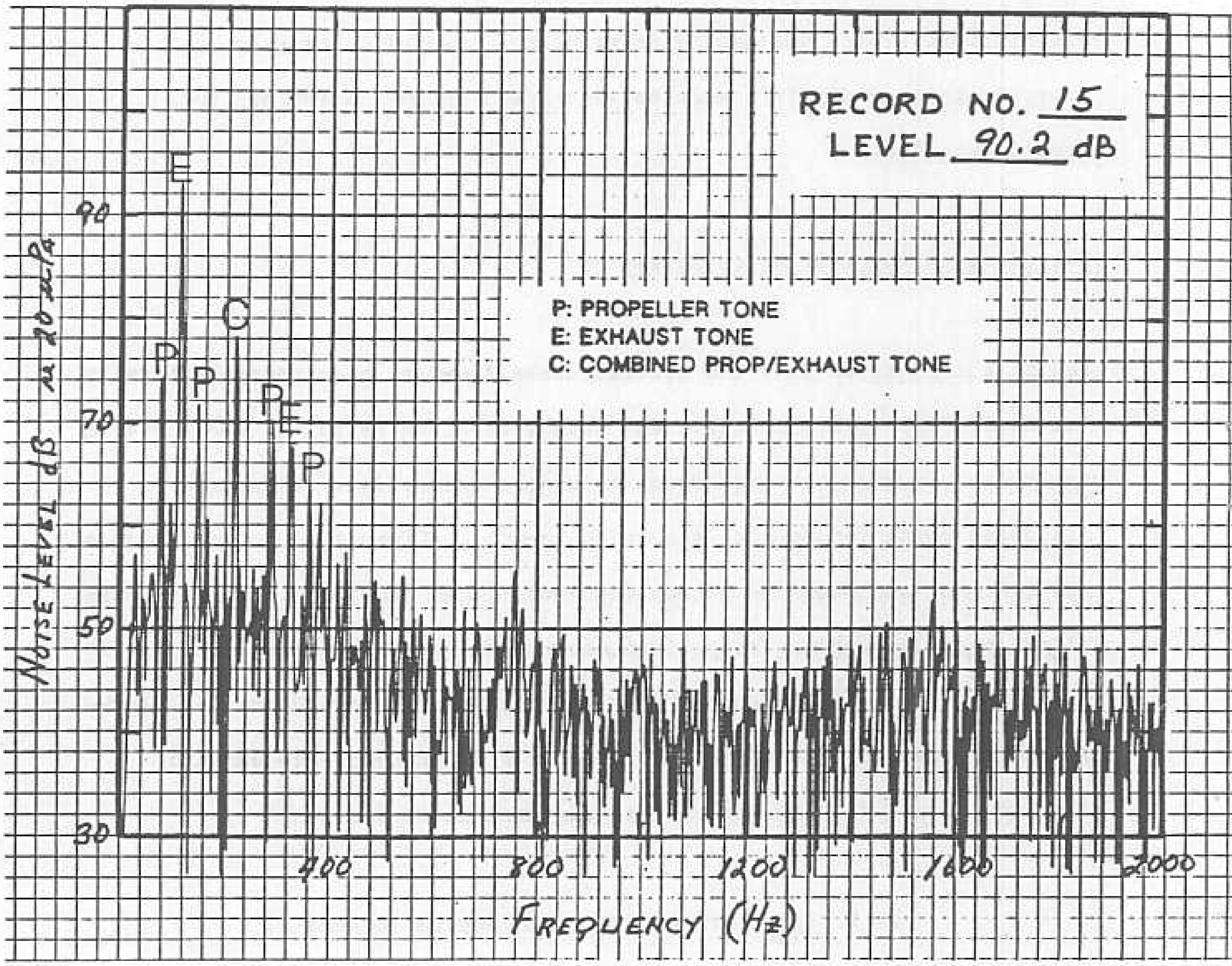


FIGURE C.1.1G.A3 CESSNA C182 2—BLADE
EVENT A3 7 mm GROUND MICROPHONE 11-22-86
0.5 SECOND AVERAGE

FIGURE 5a COMPOSITE NARROWBAND SPECTRA
C182 (2-BLADE)
'A' SERIES: 16'' MP & 1900 RPM

(FLAT WEIGHTED)

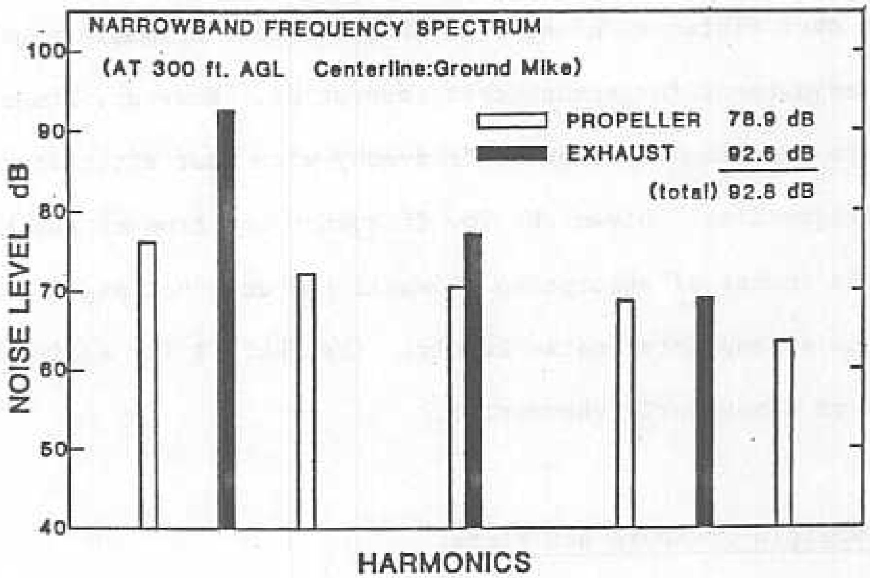
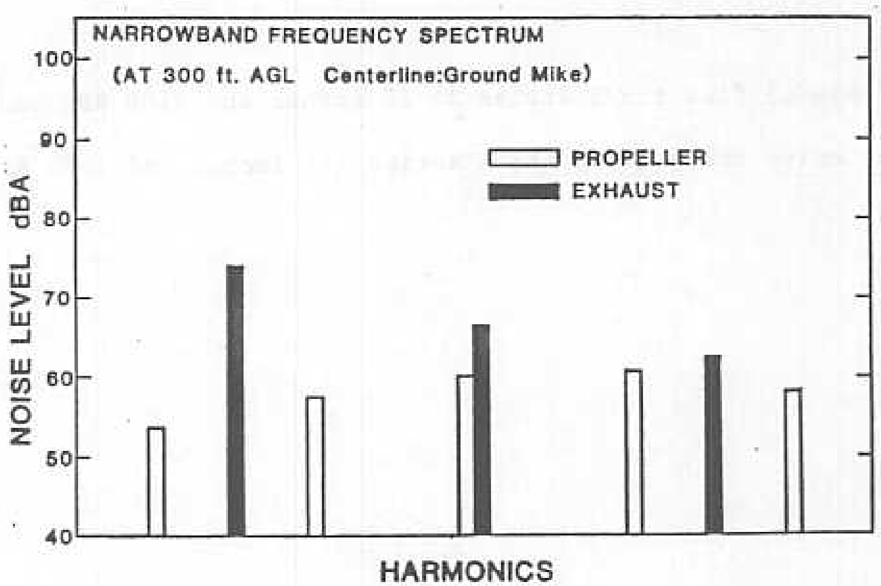


FIGURE 5b ABOVE SPECTRUM w/A-WEIGHTING



Thus at a desired distance of 1,000 feet, the noise level at 424 feet must be adjusted by algebraically adding the quantity 20 x $\log_{10}$ (424/1000) or -7.5 dB.

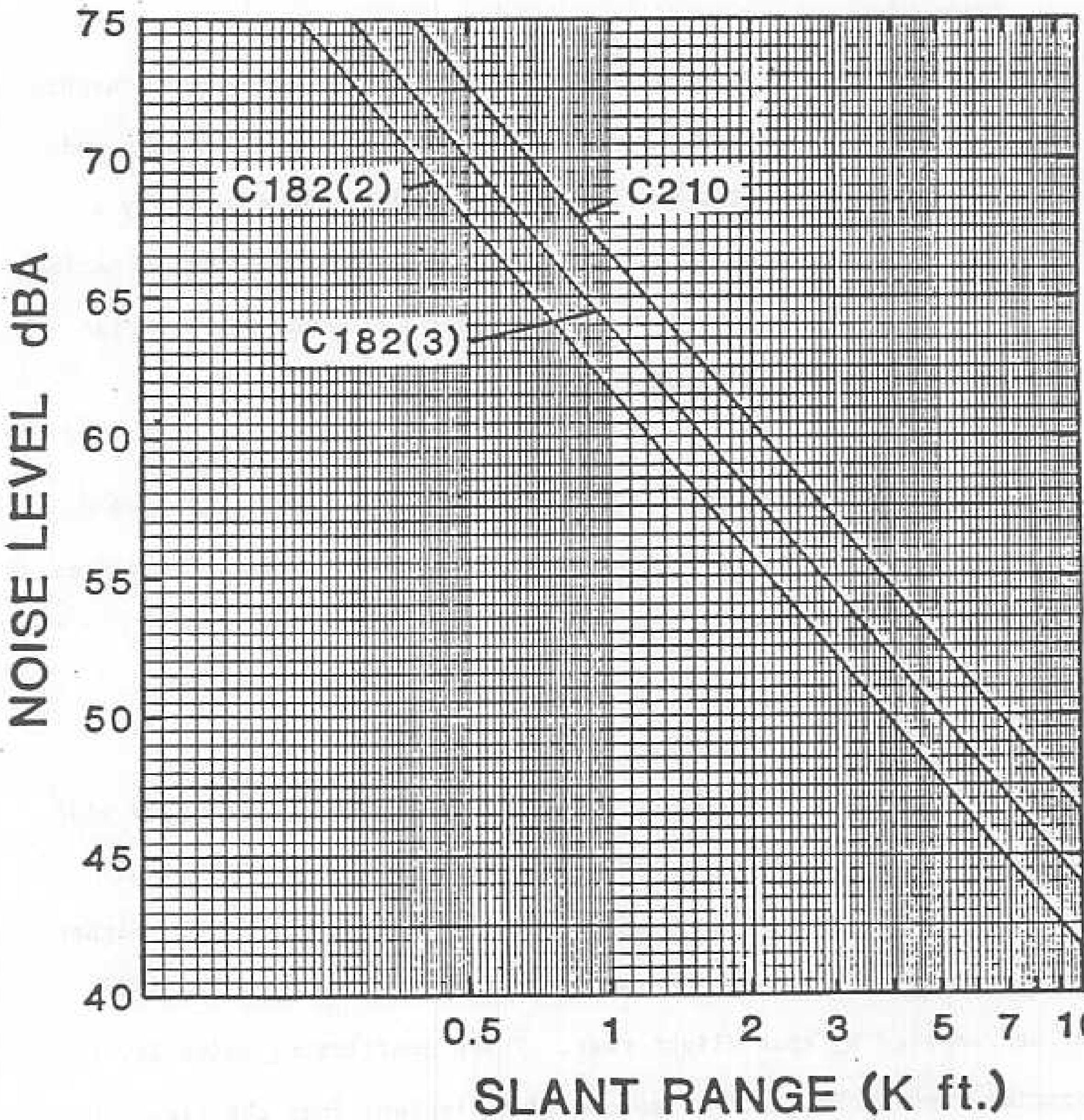
Averaged sideline values from the A series for each of the three fixed-wing aircraft are plotted and extrapolated to 10,000 feet in Figure 6. Propagation over distances of several thousand feet normally requires an additional adjustment for atmospheric absorption. However, atmospheric absorption is a strong function of frequency with most attention occurring at higher frequencies. Given the low frequency spectrum of the test aircraft, the amount of absorption is small and does not significantly influence the extrapolated noise levels. (See Ref. 1 for additional information on atmospheric absorption.)

Increased Manifold Pressure and Flaps:

Test series B and C examined the influence of increased manifold pressure (plus 2 inches scheduled) and additional flaps (10 degrees to 20 degrees) on noise levels from the fixed-wing aircraft. A-weighted noise levels for B and C series are included in Table 2.

The C182 (2-blade) flew the B series at 18 inches and 2100 RPM adding 4 to 5 dBA to the noise produced by the A series (16 inches and 1900 RPM).

FIGURE 6 dBA versus SLANT RANGE



C210(2) 69.2 dBA @ 424 ft. SL 16"/1900 RPM

C182(3) 71.4 dBA @ 424 ft. SL 17"/2000 RPM

C210(3) 74.0 dBA @ 424 ft. SL 16"/2100 RPM

Most of this increase can be attributed to increased propeller noise. For the increased-flaps C series conducted at approximately the same manifold pressure and RPM as the A series, the noise levels were the same as the A series levels.

The C182 (3-blade) flew the A series at 16 to 17 inches manifold pressure and 1900 to 2100 RPM. Series B was consistently flown at 18 inches and 2100 RPM. As a result of the smaller change in RPM, there was only a 2 dBA difference between the A and B series. The increased-flaps C series was conducted at B series manifold pressure and RPM resulting in noise levels comparable to the B series.

The C210 was consistently flown at 2100 RPM throughout the A, B, and C series resulting in little difference in noise levels between the series.

Directivity:

Sideline microphones were deployed in an effort to determine if one side of the aircraft was louder as a result of the exhaust pipe location. However, the south sideline microphone noise levels were slightly higher for both eastbound and westbound runs. Thus, the issue of directivity cannot be resolved by this flight test. These conflicting noise levels can possibly result from slight southward deviations from the flight track caused by the north-south crosswind component.

Bell 206:

Bell 206 noise levels during the 50 knot, 300 ft. AGL level flyover test were equivalent to the levels produced by the reference series flown by the C210. Thus, the dBA versus slant range relationship for the C210 in Figure 6 can be used for extrapolating Bell 206 noise levels to larger distances. From previous testing, noise levels are known to increase with higher airspeeds during level flight. However, level flyover noise is not necessarily representative of noise levels produced during ascents, descents, and turns.

The Bell 206 acoustic signal can also be analyzed by narrowband frequency spectroscopy. Figure 7 illustrates an unweighted spectrum obtained at the maximum noise from Event B7 from the 50 knot level flyover series. In the spectrum, main rotor harmonics occur at integer multiples of 13 hertz. Tail rotor harmonics occur at integer multiples of 85 hertz. The spectrum also reveals that, with A-weighting applied, the tail rotor is the dominant source of discrete noise during a 50 knot level flyover. In addition to the readily identifiable main and tail rotor harmonics, the other numerous spectual lines represent "broadband" or random noise generated by the rotors and turbine exhaust.

FIGURE 7 EXAMPLE BELL 206
NARROWBAND SPECTRUM

(50 KIAS, 200 ft. AGL, LEVEL FLYOVER)

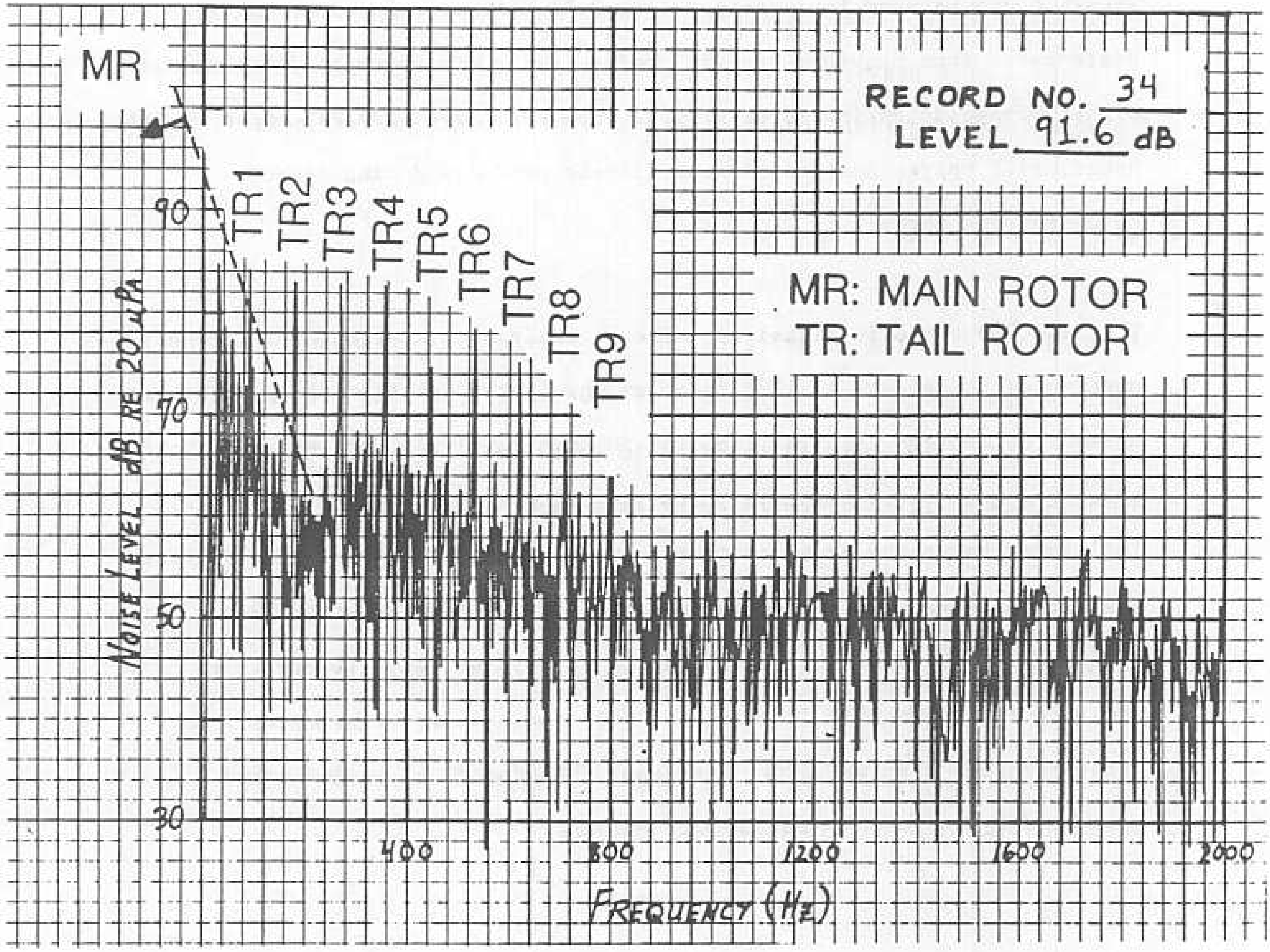
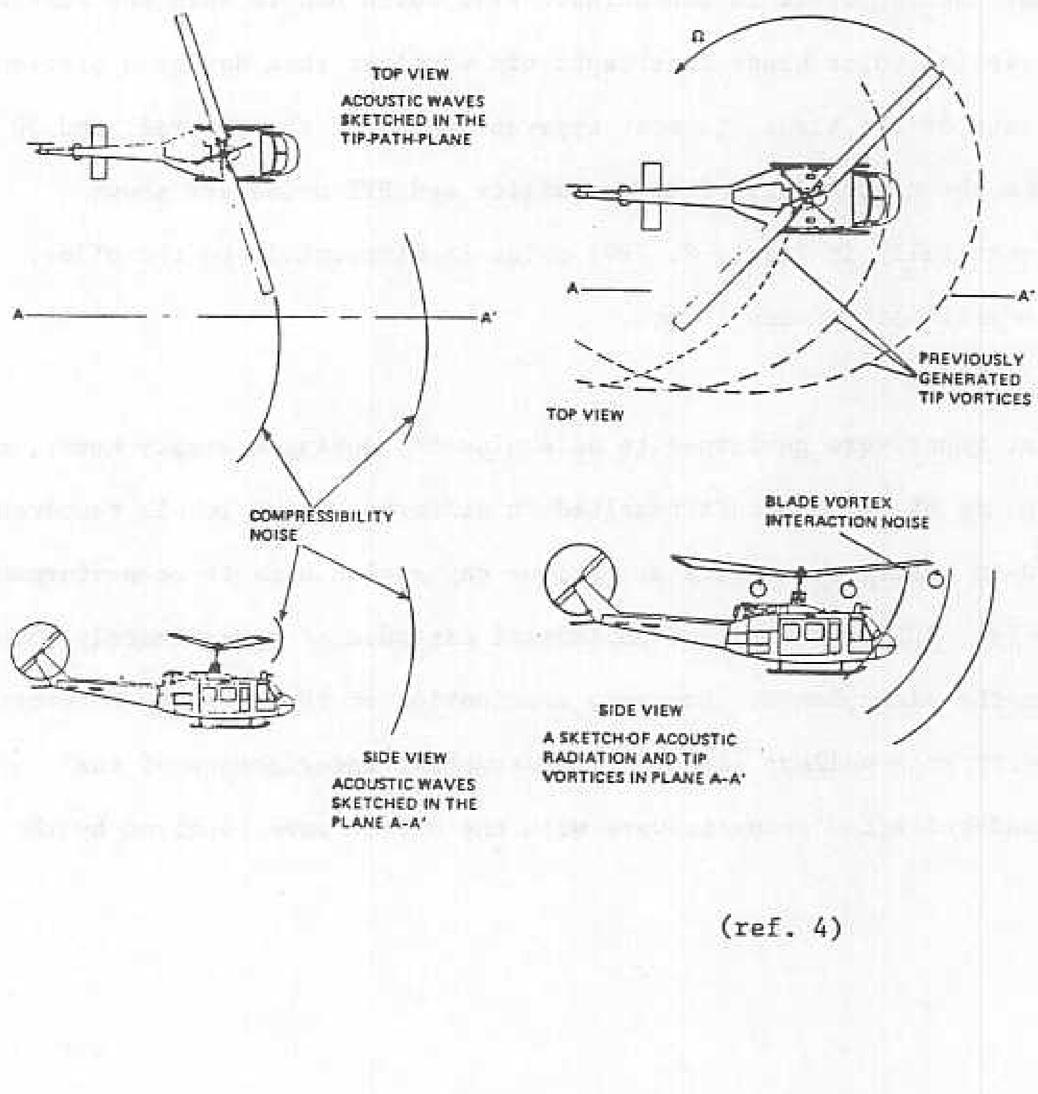


FIGURE C.4.1G.B7 BELL 206 HELICOPTER 11-22-86
EVENT B7 7 mm GROUND MICROPHONE
SITE 1G: CENTERLINE-CENTER
0.5 SECOND AVERAGE

Other flight regimes are conducive to the formation of highly distinctive rotor impulsive noise--especially from a 2-blade single rotor helicopter. High speed forward flight can cause "compressibility" noise. This results from the high speed of the advancing rotor tip approaching sonic velocity and the consequent compression of the air moving over the blade surface to form a wave of acoustic energy. Compressibility noise directivity is at maximum forward of the aircraft and in the plane of the rotor disc. A second source of strong impulsive noise, blade-vortex interaction (BVI), occurs during descents and turns. BVI, which occurs when the advancing or retreating rotor blade intercepts tip vortices shed during a previous passage of the blade, is most apparent ahead of the aircraft and 30^{o} below the rotor disc. Compressibility and BVI noise are shown schematically in Figure 8. BVI noise is discernible to the pilot; compressibility noise is not.

Hover tests were performed to determine if, during a steady hover, a side exposure of the aircraft resulted in different noise levels compared to a head-on position. Hovers at various yaw angles were to be performed at 500 feet AGL at a constant horizontal distance of approximately 1300 feet from the microphones. However, examination of the narrowband spectra interference valleys (caused by destructive interference of the ground-reflected acoustic wave with the direct wave received by the

FIGURE 8 COMPRESSIBILITY AND BLADE-VORTEX INTERACTION NOISE



(ref. 4)

elevated microphone) shown in Figure 9 reveals that the helicopter had an excessive drift toward the microphone location. Since altitude drift may have also contributed to the observed shift of the interference valleys toward lower frequencies, it is not possible to reliably correct the noise data to account for the resulting changes in slant distance. However, it appears that yaw angles of 45° and 90° will increase noise levels by at least 2 dBA and 5 dBA respectively.

FIGURE 9 NARROWBAND SPECTRA FROM HOVER TEST

FIGURE 9a
HEAD-ON EXPOSURE
0 DEGREES

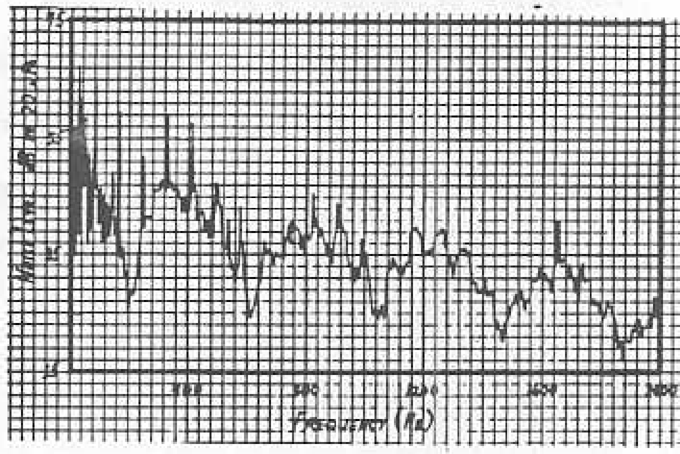


FIGURE E.4.1.D10 EVENT D10 — BELL 206 HELICOPTER — 11-22-86
1.2 m MICROPHONE — 6.4 SECOND AVERAGE
SITE 1: CENTERLINE—CENTER

FIGURE 9b
45 DEGREES LEFT YAW

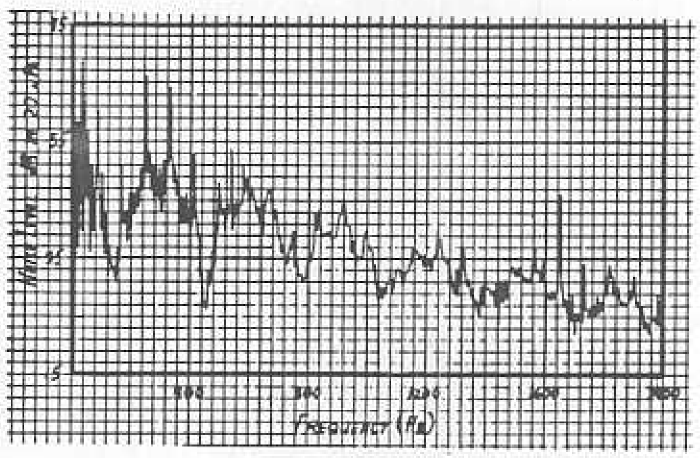


FIGURE E.4.1.D11 EVENT D11 — BELL 206 HELICOPTER — 11-22-86
1.2 m MICROPHONE — 6.4 SECOND AVERAGE
SITE 1: CENTERLINE—CENTER

FIGURE 9c
90 DEGREES LEFT YAW

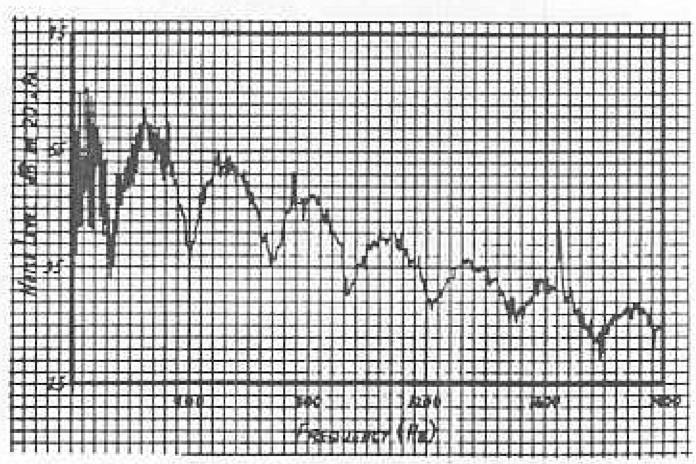


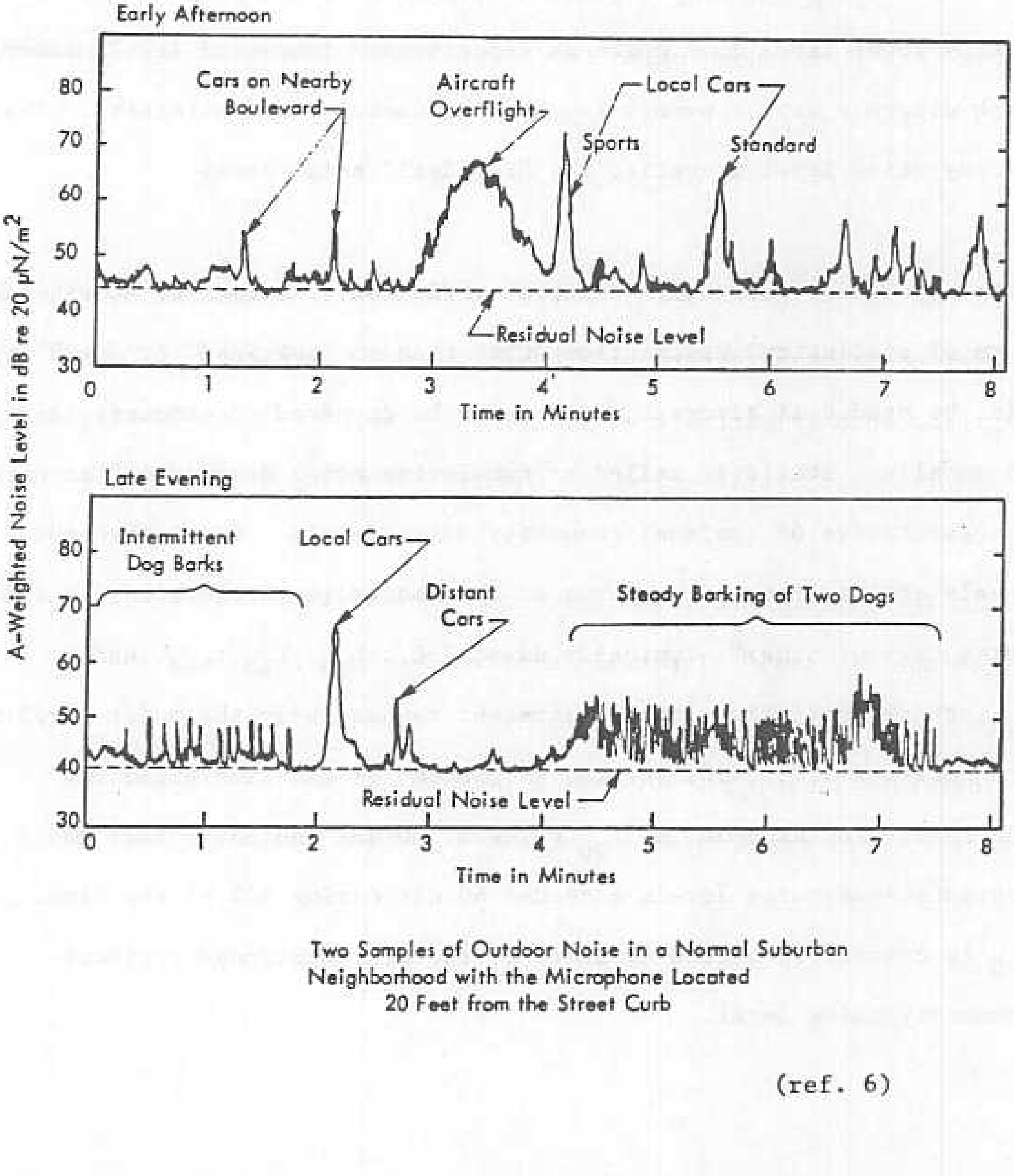
FIGURE E.4.1.D12 EVENT D12 — BELL 206 HELICOPTER — 11-22-86
1.2 m MICROPHONE — 6.4 SECOND AVERAGE
SITE 1: CENTERLINE—CENTER

Community Noise Levels:

Community noise levels vary substantially as a function of location, time, and time of day. Examples of short-term temporal variation for a suburban location are shown in Figure 10. Noteworthy features of the noise level versus time plots are (1) the noise level (dBA) varies over a range of 33 dB for the eight minute sample, and (2) noise can be characterized as a steady lower level upon which is superimposed increased levels associated with discrete single events (such as automobiles and aircraft). The steady noise level is called the "residual" noise level.

Given the large short-term temporal variation in community noise, some form of statistical description other than an "averaged" or "peak" value will be needed if aircraft noise is to be compared to community levels. An excellent statistic called a "cumulative noise descriptor" is more representative of residual community noise levels. Cumulative noise levels are represented in terms of the "noise level exceeded for a stated percentage of time." Typically denoted L_1, L_{10}, L_{50}, L_{90}, and L_{99}, these cumulative levels represent respectively the noise level that are exceeded 1, 10, 50, 90, and 99 percent of the time period of interest. For example, an L_{90} value of 60 dBA indicates that the instantaneous noise levels exceeded 60 dBA during 90% of the time. L_{90} is considered a good estimate of the aforementioned residual community noise level.

FIGURE 10 EXAMPLE SHORT-TERM TEMPORAL VARIATION of COMMUNITY NOISE LEVELS

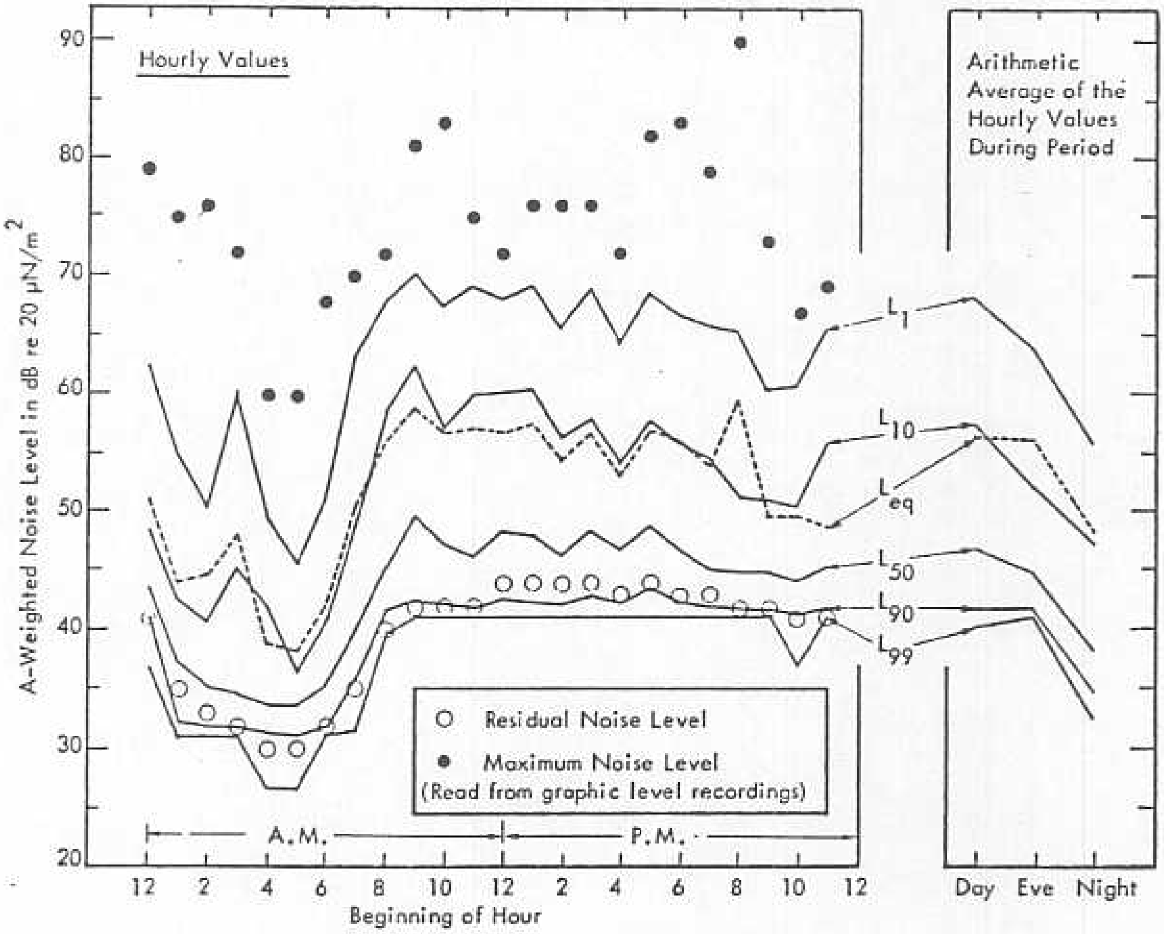


Two Samples of Outdoor Noise in a Normal Suburban Neighborhood with the Microphone Located 20 Feet from the Street Curb

(ref. 6)

Figure 11 shows how cumulative hourly noise levels typically vary over a 24-hour period at a suburban monitoring location. In the particular example cited in Figure 11 (location "M" in suceeding figures), the highest hourly daytime residual noise level is approximately 12 dBA louder than the quietest hourly night-time residual noise level.

FIGURE 11 EXAMPLE HOURLY COMMUNITY NOISE LEVELS (dBA)



Statistical Portrayal of Community Noise Throughout 24 Hours at a Residence in a Normal Suburban Neighborhood. Data Include the Maximum & Residual Noise Levels Read from a Graphic Level Recorder, Together with the Hourly & Period Values of the Levels Which are Exceeded 99, 90, 50, 10 and 1 Percent of the Time, and the Energy Mean Equivalent Level (L_{eq})

(ref. 6)

Figures 12, 13, and 14 illustrate typical community noise levels at various locations for daytime, evening, and nighttime respectively. A complete description of each monitoring site and hourly noise levels for the locations referenced in Figures 12, 13, and 14 are presented in Appendix E.

Figure 15 isolates and presents the L_{90} residual noise levels from the previous figures as a function of location and day/evening/nighttime intervals. Figure 15 indicates the following trends:

(1) There is a 7 to 10 dBA difference between average daytime and average nighttime residual noise levels.

(2) Evening residual noise levels are essentially the same as daytime levels.

(3) Residual noise levels differ up to 40 dBA between inner city (near freeway) and rural farm locations.

(4) Typical daytime residual L_{90} values are as follows:

(a) inner city 70 dBA

(b) urban residential 50 dBA

(c) suburban residential 45 dBA

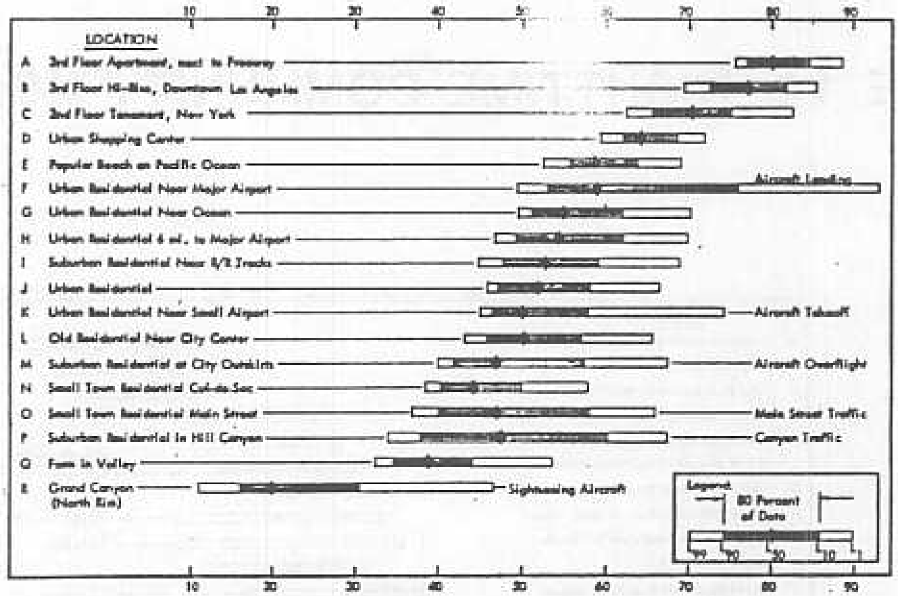
(d) small town residential 40 dBA

(e) rural farm 35 dBA

(f) boondocks 20 dBA

The primary value of the preceeding discussion and the material in Appendix E is to illustrate via a variety of noise descriptors the considerable temporal and spatial variation of community noise. However, using such aggregate or overall noise descriptors such as dBA does not readily permit a direct comparison between aircraft and community noise on an aircraft detectability basis. A direct comparison using aggregate values would be possible only if the spectral signature (noise level as a function of frequency) of the aircraft and community were very similar in shape. The issue of detectability is addressed in the following section.

FIGURE 12 DAYTIME COMMUNITY NOISE LEVELS

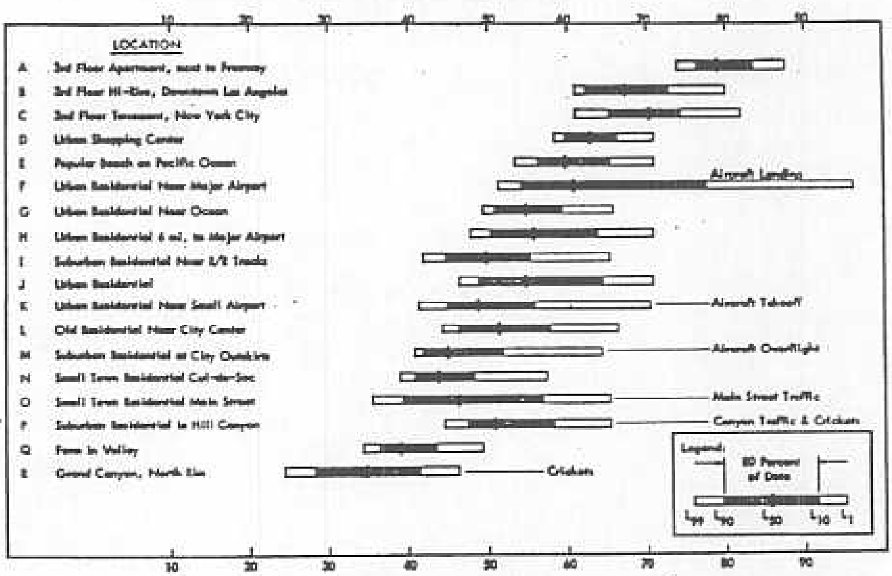


A-Weighted Outdoor Noise Level in dB re 20 μN/m²

Daytime Outdoor Noise Levels Found in 18 Locations Ranging Between the Wilderness and the Downtown City, with Significant Intruding Sources Noted. Data are Arithmetic Averages of the 12 Hourly Values in the Daytime Period (7:00 a.m. - 7:00 p.m.) of the Levels Which are Exceeded 99, 90, 50, 10 and 1 Percent of the Time

(ref. 6)

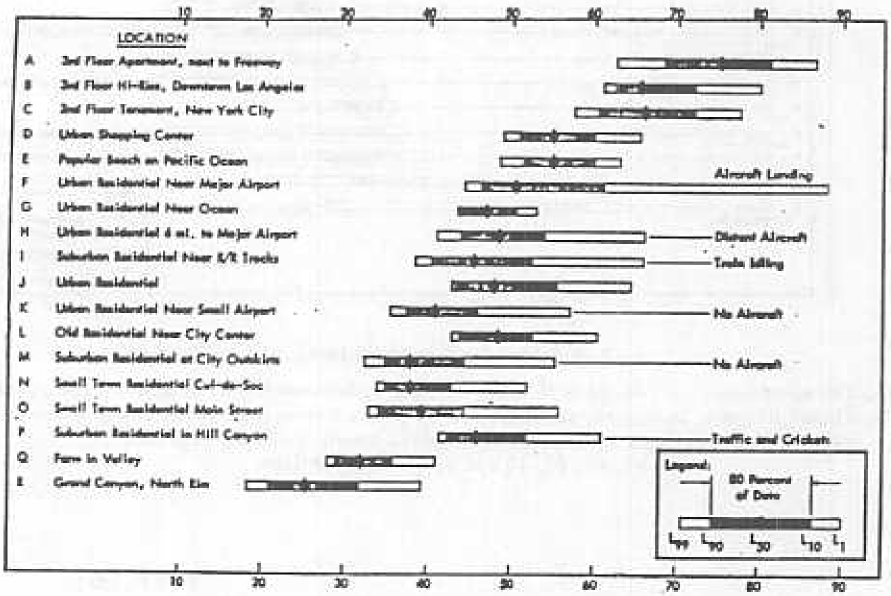
FIGURE 13 EVENING COMMUNITY NOISE LEVELS



A-Weighted Outdoor Noise Level in dB re 20 μN/m²

Evening Outdoor Noise Levels Found in 18 Locations Ranging Between the Wilderness and the Downtown City, with Significant Intruding Sources Noted. Data are Arithmetic Averages of the 3 Hourly Values in the Evening Period (7:00 p.m. - 10:00 p.m.) of the Levels Which are Exceeded 99, 90, 50, 10 and 1 Percent of the Time

FIGURE 14 NIGHTTIME COMMUNITY NOISE LEVELS

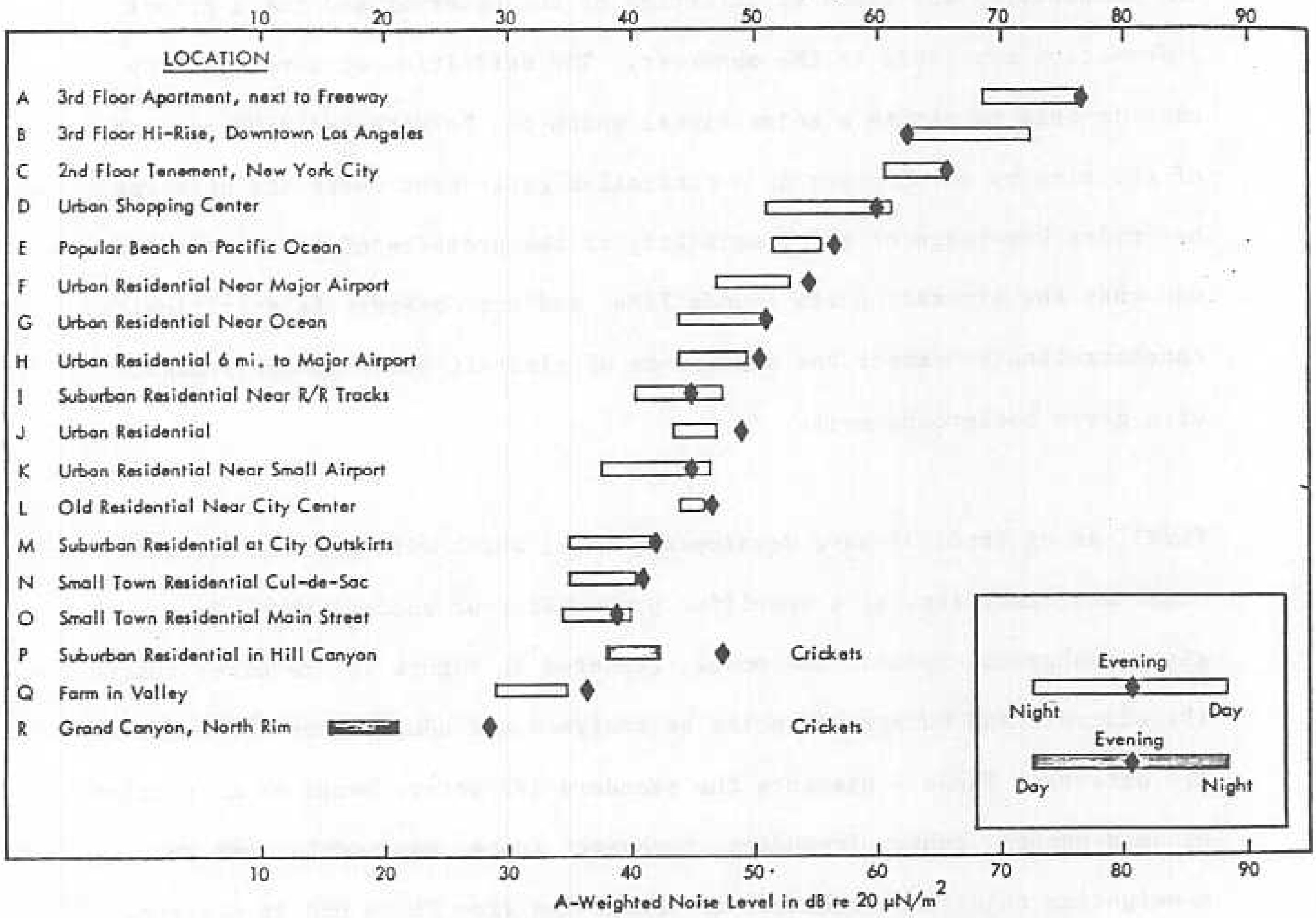


A-Weighted Outdoor Noise Level in dB re 20 μN/m^2

Nighttime Outdoor Noise Levels Found in 18 Locations Ranging Between the Wilderness and the Downtown City, with Significant Intruding Sources Noted. Data are Arithmetic Averages of the 9 Hourly Values in the Nighttime Period (10:00 p.m. - 7:00 a.m.) of the Levels Which are Exceeded 99, 90, 50, 10 and 1 Percent of the Time

(ref. 6)

FIGURE 15 DAYTIME, EVENING, and NIGHTTIME RESIDUAL NOISE LEVELS



Residual Outdoor Noise Level (L_{90}) for Day, Evening and Nighttime for 18 Locations Ranging Between the Wilderness and the Downtown City

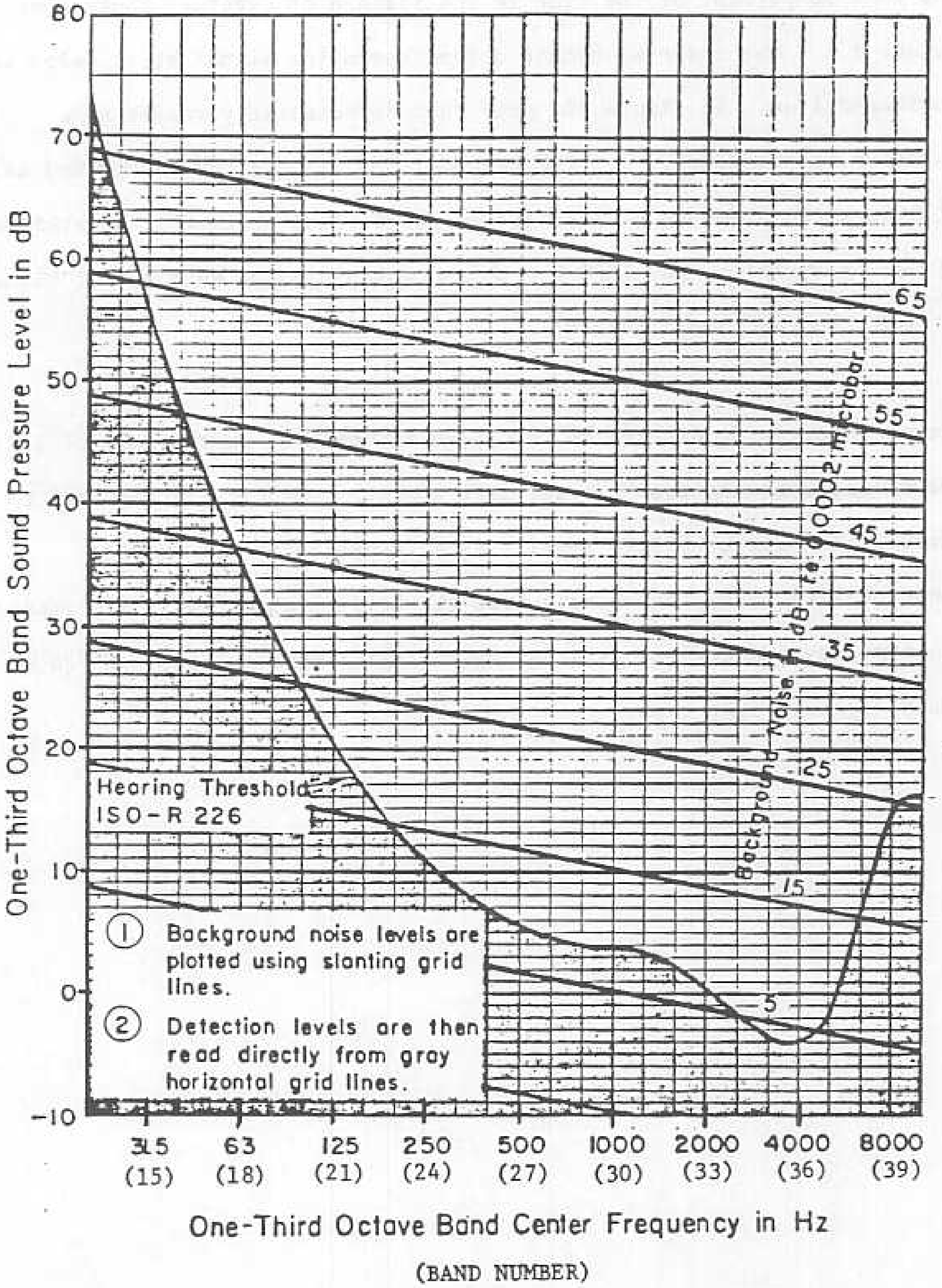
(ref. 6)

Detectability:

The ability to detect an overhead aircraft will depend on the strength and spectral characteristics of both the aircraft noise and the background community noise at the location of the observer. Other factors include the sensitivity and state of attention of the observer and the a priori information available to the observer. The definition of detectability used in this report is a noise signal which can be detected "50" percent of the time by an observer in a controlled experiment where the observer has prior knowledge of the possibility of the presence of aircraft noise and what the aircraft noise sounds like, and the observer is specifically concentrating to detect the occurrence of aircraft noise in the presence of a given background noise.

Fidell et al (ref. 3) have developed a model which will predict aircraft noise detectability, at a specified probability of success rate, in a given background noise. The model, depicted in Figure 16, requires that the aircraft and background noise be analysed and compared on the basis of 1/3 octaves. Table 4 presents the standard 1/3 octave bands as a function of band number, center frequency, frequency range (bandwidth), and the A-weighting adjustment required if conversion from dB to dBA is desired. Table 4 shows that 1/3 octaves are adjacent slices of the frequency

FIGURE 16 DETECTABILITY MODEL (FIDELL et al) (ref. 3)



spectrum with bandwidth (the width of the slice) increasing with higher frequencies. The line marked Hearing Threshold in Figure 16 indicates the level of a pure tone at which the average human observer reports detecting the tone 50 percent of the time in the absence of external background noise; i.e., the observer cannot detect any noise signal at or below the indicated line. In Figure 16, note that detectability varies as a function of frequency. At, for example, 125 Hz, a given background noise will mask the presence of aircraft noise of equal strength. However, at higher frequencies, say 1000 Hz, the background noise must be 5dB higher in order to mask the aircraft.

From the foregoing discussion, detailed information in the form of 1/3 octave sound levels from the aircraft and the community is required to exercise the detectability model. As an exercise in use of the detectability model, noise data from the C182 (2-blade) will be compared to community noise data collected by the TSC acoustics crew subsequent to the Dahlgren flight test.

Table 4 Standard 1/3 Octave Frequency Bands

BAND NO.	CENTER FREQUENCY	FREQUENCY RANGE	A-WEIGHTING ADJUSTMENT
12	16	14.1-17.8	-56.7
13	20	17.8-22.4	-50.5
14	25	22.4-28.2	-44.7
15	31.5	28.2-35.5	-39.4
16	40	35.5-44.7	-34.6
17	50	44.7-56.2	-30.2
18	63	56.2-70.8	-26.2
19	80	70.8-89.1	-22.5
20	100	89.1-112	-19.1
21	125	112-141	-16.1
22	160	141-178	-13.4
23	200	178-224	-10.9
24	250	224-282	-8.6
25	315	282-355	-6.6
26	400	355-447	-4.8
27	500	447-562	-3.2
28	630	562-708	-1.9
29	800	708-891	-0.8
30	1000	891-1122	0
31	1250	1122-1413	+0.6
32	1600	1413-1778	+1.0
33	2000	1778-2239	+1.2
34	2500	2239-2818	+1.3
35	3150	2818-3548	+1.2
36	4000	3548-4467	+1.0
37	5000	4467-5623	+0.5
38	6300	5623-7079	-0.1
39	8000	7079-8913	-1.1
40	10000	8913-11220	-2.5
41	12500	11220-14130	-4.3
42	16000	14130-17780	-6.6
43	20000	17780-22390	-9.3

C182 (2-blade) 1/3 Octave Noise Levels:

One-third octave noise levels averaged over the individual events of the C182 (2-blade) A series (1900 RPM; 16" MP; 300 ft. AGL; centerline ground microphone) are presented in column 2 of Table 5. The major contributing exhaust and propeller tones are shown in Table 5 as a function of 1/3 octave band number. For this exercise, the aircraft is assumed to be circling a target at a slant range of 5280 feet. The extrapolated 1/3 octave noise levels expected at the target are shown in column 6 of Table 5. The extrapolated values in column 6 were derived from column 2 by first accounting for spherical spreading via the previously discussed formula (eq. 1), 20 log (300/5280) = -25 dB. The column 2 values are then adjusted for atmospheric absorption by the absorption values shown in column 5 (which were derived from the absorption rates shown in column 4). Finally, the column 2 values were adjusted to remove the influence of the ground mounted microphone by subtracting 6 dB. The lookdown angle from the aircraft (Figure 20) is assumed to be a value between 45° and 60° such that the dominant exhaust tone is unaffected by the presence of the reflecting ground surface. (NOTE: The lookdown angle can substantially affect the actual sound level received at the target's ear level. This is discussed later in the section "Optimized Observation Lookdown Angle.") The 1/3 octave noise levels in column 6 of Table 5 are ready for comparison to background community noise levels.

Table 5 C182 (2-blade) 1/3 Octave Levels
"A" Series Average Ground Microphone

(Col. 1) Band No./ Center Freq	(Col. 2) Noise Level (@) 300ft(dB)	(Col. 3) Components (tone no.)	(Col 4.) Atmos. Abs. Rate(dB/1000ft)	(Col 5.) Atmos Abs. over 500ft	(Col. 6) Noise Level (@) 1 mile
18/63	73.6	P(1)	0.1	0.5	42
19/80	70.5	-	0.1	0.5	39
20/100	89.6	E(1)	0.2	1.0	58
21/125	77.1	P(2)	0.2	1.0	45
22/160	69.7	-	0.3	1.5	37
23/200	75.5	E(2)+P(3)	0.3	1.8	43
24/250	68.6	P(4)	0.4	2.0	36
25/315	71.6	E(3)+P(5)	0.6	3.0	37
26/400	68.6		0.7	3.5	34
27/500	65.7		0.9	4.5	30
28/630	64.2		1.1	5.5	28
29/800	63.0		1.4	7.0	26
30/1000	60.0		1.8	9.0	20
31/1250	61.8		2.2	11.0	20
32/1600	65.4		2.9	14.5	20
33/2000	62.8		3.6	18.0	14
34/2500	60.5		4.6	23.0	6
35/3150	60.1		5.9	29.5	0

P = Propeller
E = Exhaust
Atmos. Absorption at 77°F and 70% RH (Ref. 1)
(see Appendix A for 1/3 octave data for each

ground plane mic

~ 4-5 dB higher than
4-ft height mic

does not show pseudotones
like a 4-ft mic would

Background Community 1/3 Octave Noise Levels:

During March 1987, the TSC acoustics laboratory made measurements of community noise at a variety of sites in and near Boston, Massachusetts. The report from that effort is reproduced in Figure 17. Noise data from the seven monitoring sites (A1-A7) are presented in 1/3 octave levels as well as averaged overall unweighted sound pressure level (OASPL) and averaged overall A-weighted sound level (AL). The sites range in noise levels from quiet surburban (46 dBA) to near freeway (80 dBA). The 1/3 octave levels shown in Figure 17 represent the arithmetic mean of 50 consecutive 2-second samples. Assuming a normal distribution, an estimate of the residual or L_{90} values of the 1/3 octave data can be calculated from the standard deviations (listed in Figure 17) by subtracting the quantity (1.65 times standard deviation) from the arithmetic mean. The resulting residual community levels, listed in Table 6, are now available for comparison to the C182 (2-blade) 1/3 octave spectra via the detectability model.

U.S. Department of Transportation
Research and Special Programs Administration

Memorandum

Date: April 21, 1987

Reply to Attn of: DTS-48

Subject: INFORMATION: FBI Small Aircraft Noise Measurement Program
Letter Report DTS-48-FA-753-LR-14

From: E.J. Rickley *E.J. Rickley*

To: K. Jones, FAA/AEE-120

Thru: A.E. Barrington, Chief *A.E. Barrington*
Safety & Environmental Technology Division

FIGURE 17
COMMUNITY NOISE LEVELS IN BOSTON

This report contains Tabulations of 1/3 Octave Noise Data for seven typical urban locations (Sites A1-A7) measured in the Greater Boston area on March 18, 1987 at a four-foot microphone (Table No. E.1). The spectral data presented were obtained by averaging the sound pressure level in each 1/3 octave band over a 100 second period. Included in the table is the standard deviation around the arithmetic average of 50 consecutive 2-second data samples in each frequency band, which provides an indication of the temporal nature of the noise measured at each site.

A separate table (Table No. E.2) describes the measurement locations, and outlines the events which occurred during each measurement period.

This report concludes the processing of data in support of the FAA Small Aircraft Noise Measurement program for the FBI Aviation and Special Operations Unit, Washington, D.C.

TABLE NO. F.1

COMMUNITY NOISE -- GREATER BOSTON AREA

1/3 OCTAVE NOISE DATA

AS MEASURED MAR. 18,1987

DOT/TSC 4/ 8/87

SOUND PRESSURE LEVEL dB re 20 microPascal

BAND NO. / SITE:	A1	A2	A3	A4	A5	A6	A7
14	63.2	64.9	66.7	51.8	62.9	53.1	66.5
15	62.5	66.5	68.0	54.1	66.8	54.6	66.2
16	61.4	67.9	72.2	56.0	67.8	52.4	67.7
17	61.2	74.8	73.5	61.3	69.1	52.9	70.7
18	61.1	72.1	73.9	58.0	71.0	58.1	70.1
19	60.9	68.0	80.9	54.6	69.2	54.9	71.7
20	59.4	66.3	73.1	51.9	64.9	54.7	72.5
21	55.4	65.2	70.7	49.9	64.0	50.2	70.1
22	53.0	63.7	69.4	48.8	61.4	48.5	68.9
23	48.4	61.9	66.7	44.7	57.4	46.5	68.3
24	47.3	60.6	66.3	41.1	55.2	45.7	67.0
25	46.8	59.9	65.9	38.8	53.7	43.8	66.2
26	47.1	59.7	64.9	37.2	53.5	42.9	68.0
27	47.1	60.1	64.9	36.7	52.5	43.2	69.8
28	47.1	59.7	65.6	36.9	52.6	43.4	69.1
29	46.6	58.5	65.2	36.7	47.5	42.9	70.2
30	46.3	57.7	65.9	35.5	47.6	42.4	72.3
31	44.6	56.4	64.9	33.9	46.3	40.3	72.1
32	41.3	53.9	64.0	30.9	44.8	37.4	71.5
33	39.8	51.4	63.0	26.2	42.3	34.6	69.1
34	37.2	49.5	60.4	23.2	39.7	32.1	66.6
35	-	48.5	58.2	21.9	37.0	29.3	64.3
36	-	45.0	59.9	21.3	34.7	26.5	61.5
37	-	42.9	57.7	20.7	-	24.4	58.6
38	-	41.5	52.9	21.0	-	23.3	56.0
39	-	-	-	20.9	-	21.7	52.9
40	-	-	-	21.5	-	20.9	-
AL	54.7	66.7	74.6	45.9	59.6	50.7	80.0
DASPL	70.4	79.3	84.5	65.4	77.1	64.0	83.1
PNL	66.2	78.9	88.1	57.5	72.8	61.6	91.9
PNLT	67.7	79.2	88.5	57.7	73.7	61.8	92.2

STANDARD DEVIATION(dB) OF 50-2 SECOND SAMPLES OF DATA

BAND NO.	A1	A2	A3	A4	A5	A6	A7
14	3.7	2.0	3.9	1.3	2.5	1.2	4.1
15	2.7	1.4	4.0	1.3	3.6	1.1	3.6
16	2.5	2.1	5.2	1.8	3.4	1.2	3.7
17	2.5	6.2	4.6	2.1	2.7	1.1	4.1
18	2.3	4.2	4.9	3.2	3.1	4.1	4.0
19	3.1	3.3	7.0	2.4	2.6	2.8	3.3
20	3.6	3.0	5.8	1.6	2.4	3.4	3.9
21	2.2	3.4	5.3	1.1	2.8	2.1	3.2
22	1.6	3.2	5.4	1.7	3.0	2.0	3.3
23	1.2	2.5	5.6	1.0	2.3	2.4	3.8
24	1.2	2.7	6.3	0.7	1.6	3.3	3.5
25	1.1	3.1	5.9	0.9	1.4	3.4	3.5
26	1.0	3.0	6.0	1.2	1.3	3.9	4.3
27	1.4	3.6	6.7	1.2	1.2	3.8	5.1
28	2.1	3.7	6.8	1.3	1.3	3.7	4.3
29	2.5	3.8	6.9	1.3	1.5	3.5	3.5
30	2.8	3.8	7.2	1.1	1.5	3.9	3.3
31	3.0	4.1	7.2	1.4	1.5	4.3	3.1
32	2.6	4.0	7.8	2.0	1.7	4.7	3.0
33	3.8	4.0	7.9	1.5	1.9	5.4	3.2
34	4.1	4.2	8.1	1.4	2.1	6.0	3.6
35	-	4.5	8.0	1.3	2.2	5.7	3.9
36	-	4.1	8.6	1.4	2.6	4.9	4.5
37	-	4.4	8.7	1.4	-	4.2	4.7
38	-	4.8	8.0	1.6	-	3.7	4.8
39	-	-	-	1.3	-	2.8	4.8
40	-	-	-	0.8	-	1.7	-
AL	2.1	3.4	6.8	0.8	1.3	3.6	3.2
DASPL	2.3	3.1	5.4	1.6	1.4	2.3	3.0
PNL	2.7	3.3	7.0	1.3	1.8	4.1	3.2
PNLT	3.2	3.5	4.9	1.5	1.9	4.2	3.3

BANDS 14 TO 40 - STANDARD 1/3 OCTAVE BANDS 25 TO 10KHz
100 SECOND AVERAGING TIME

TABLE NO. F.2

3/30/87
DOT/TSC

COMMUNITY NOISE MEASUREMENT LOCATIONS 3/18/87

SITE A1 TIME: 9:36
EMPLOYEE PARKING LOT IN CITY.
NEAREST BUILDING: 180'. ROAD NEAR LOT: 600'.
6 VEHICLES PER MINUTE. 70% CARS & LIGHT TRUCKS. 30% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
CARS IN LOT; SPEED: 5-20 MPH. CARS AND TRUCKS ON ADJACENT ROAD; SPEED:30-40 MPH. PEDESTRIANS IN LOT. DOORS SLAMMING.
OTHER NOISE SOURCES:
WORKMEN TAPPING ON GLASS: 350'. HIGH-FLYING PLANES.
HEAVY CONSTRUCTION MOTOR, SIREN AND BRAKE SQUEAL IN DISTANCE.

SITE A2 TIME:10:03
4 LANE STREET IN CITY NEAR OFFICE BUILDINGS. CONSTRUCTION ON UPPER FLOORS OF HIGH-RISE BUILDING 115' AWAY. CONSTANT TRAFFIC.
STOPLIGHT 220' AWAY.
16 VEHICLES PER MINUTE. 90% CARS & LIGHT TRUCKS. 10% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
TRAFFIC PASSING, STOPPING AND STARTING; SPEED:0-35 MPH. PEDESTRIANS PASSING WITHIN 10'. CONSTRUCTION NOISE.
OTHER NOISE SOURCES:
CROSSWALK BELL. HORNS IN DISTANCE. HELICOPTERS.

SITE A3 TIME:10:17
THREE-WAY INTERSECTION IN CITY. COMMERCIAL ZONE: SHOPS, RESTAURANTS, BUS STOPS, ETC. NEAREST BUILDING: 15'. BUILDINGS ACROSS STREET:100'.
25 VEHICLES PER MINUTE. 80% CARS & LIGHT TRUCKS. 20% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
4 LANES OF HEAVY TRAFFIC INTERSECTED BY 2 LANES OF MODERATE TRAFFIC.
SPEED: 0-35 MPH. PEDESTRIANS WITHIN 10'. CAR STARTING WITHIN 15'.
OTHER NOISE SOURCES:
SUBWAY RUMBLE UNDER SIDEWALK. MAN SHOVELING SAND AND TRASH WITHIN 15'. SPEECH. BRAKE SQUEALS.

SITE A4 TIME:10:50
LARGE, WOODED CEMETARY AT EDGE OF CITY. WOODS > 1000' IN ALL DIRECTIONS. MANY BIRDS. SUBDUED ROAR OF CITY NOISE IN BACKGROUND.
PRIMARY NOISE SOURCES:
BIRDS CALLING.
OTHER NOISE SOURCES:
DISTANT PLANES. DISTANT HORNS. LAWN TRACTOR AND SEVERAL CARS ON CEMETARY PATH 400' AWAY.

SITE A5 TIME:11:51
PARKING LOT IN SUBURBAN SHOPPING AREA. NEAREST BUILDING:100'.
4 LANE ROAD:150'. CONSTANT TRAFFIC ON ROAD.
3 VEHICLES PER MINUTE IN LOT.
PRIMARY NOISE SOURCES:
CARS IN LOT; SPEED:0-20 MPH. DOORS SLAMMING. MOTOR STARTUPS.
PEDESTRIANS IN LOT.
OTHER NOISE SOURCES:
TRAFFIC ON ROAD; SPEED:30-45 MPH. BIRDS CALLING.

SITE A6 TIME:12:42
OPEN, GRASSY AREA BORDERED BY WOODS. 2 LANE ROAD 80' AWAY.
3 VEHICLES PER MINUTE.
ANOTHER 2 LANE ROAD 1000' AWAY.
4 VEHICLES PER MINUTE.
PRIMARY NOISE SOURCES:
CARS ON NEAR ROAD; SPEED:30-45 MPH. BIRDS CALLING.
OTHER NOISE SOURCES:
CARS ON FAR ROAD; SPEED:30-45 MPH. DISTANT PLANES. HELICOPTER.

SITE A7 TIME:13:22
6 LANE DIVIDED INTERSTATE HIGHWAY REST AREA. CENTER OF NEAREST TRAVEL LANE:20'. CENTER OF FARTHEST TRAVEL LANE: 220'.
125' ACROSS PAVED REST AREA TO A WOODED SLOPE.
100 VEHICLES PER MINUTE. 90% CARS & LIGHT TRUCKS. 10% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
6 LANES OF TRAFFIC; SPEED:45-65 MPH.
OTHER NOISE SOURCES:
PLANE FLYOVER. CARS PULLING IN TO REST AREA.

WEATHER: PARTLY CLOUDY; GUSTING WINDS: 0-15 MPH, N-NE.
TEMPERATURE : 40-53ºF RELATIVE HUMIDITY: 45%
BAROMETRIC PRESSURE: 1016 MILLIBARS.

(NOTE: VALUES ARE APPROXIMATE)

Table 6 Estimated 1/3 Octave (L_{90}) Levels at Seven Boston Area Monitoring Sites (dB)

SITES (A1-A7)

Band No.	A1	A2	A3	A4	A5	A6	A7
18	57	65	66	53	66	51	64
19	56	63	69	51	65	50	66
20	54	61	64	49	61	49	66
21	52	60	62	48	59	47	65
22	49	58	60	46	56	45	64
23	47	58	58	43	54	42	62
24	45	56	56	40	53	40	61
25	45	55	56	37	51	38	60
26	45	55	55	35	51	36	61
27	45	54	54	35	50	37	61
28	44	54	54	35	50	37	62
29	42	52	54	35	45	37	64
30	42	51	54	34	45	36	67
31	40	50	53	32	44	33	67
32	37	47	51	28	42	30	67
33	34	45	50	24	39	26	64
34	30	43	47	21	36	22	61
35	–	41	45	20	33	20	58

(see Figure 17 for original data and site description)

Example Detectability Analysis:

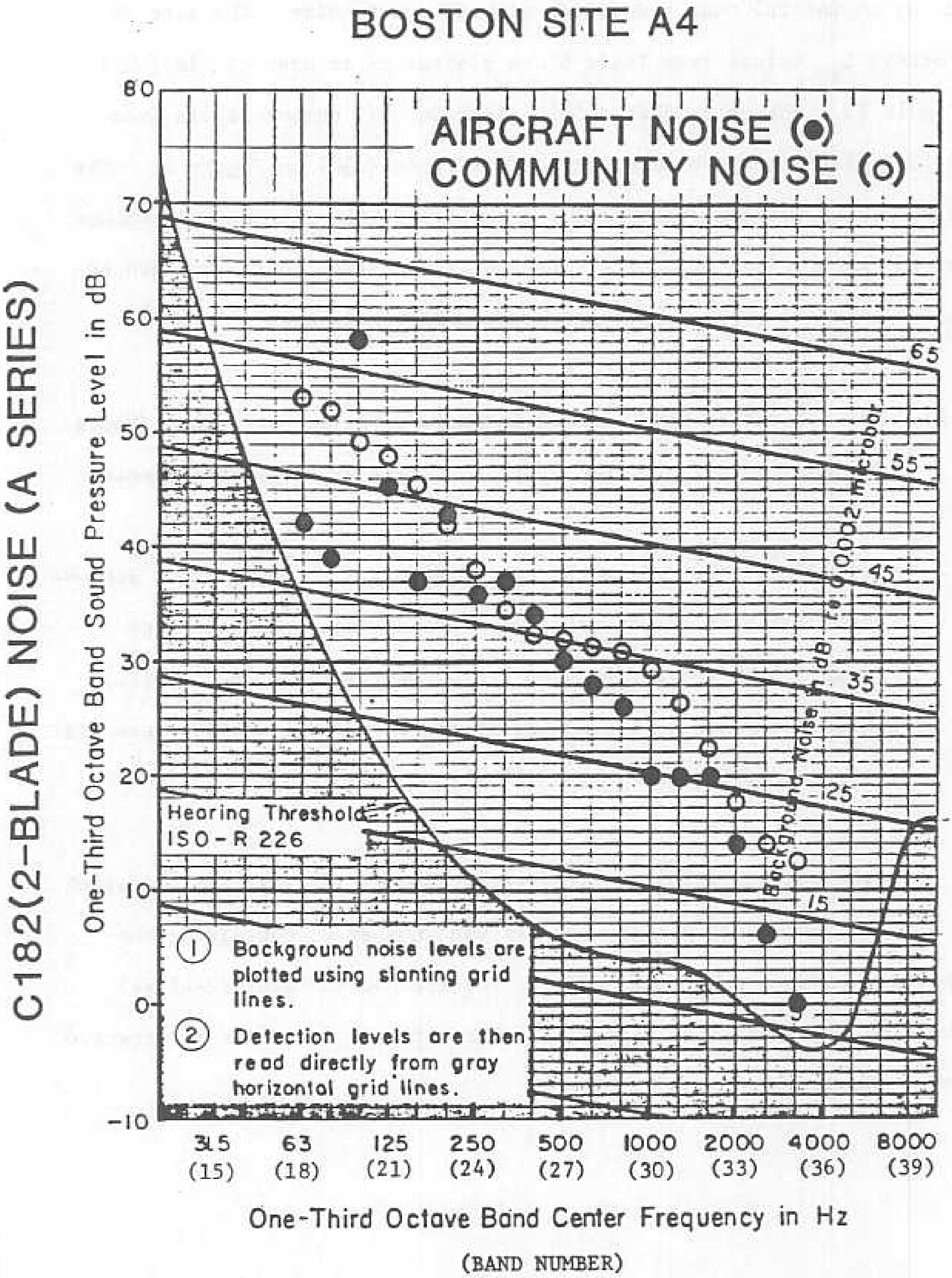
Site A4, the quietest of the Boston area monitoring locations, will be used for an initial test comparison with aircraft noise. The site A4 1/3 octave L_{90} values from Table 6 are plotted as an open circle (○) on Figure 18. The extrapolated C182 (2-blade) 1/3 octave levels from Table 5 (column 6) are plotted as solid circles (●) on Figure 18. The resulting plot confirms that band 20, containing the fundamental exhaust tone, is the critical band of aircraft noise relative to the background noise at site A4. Other observations from Figure 18 are:

1. The 1/3 octave bands containing only propeller harmonics (bands 19 and 22) indicate that propeller noise would not be detected.

2. Band 20 must be reduced by approximately 9 dB in order to achieve the 50% detectability criteria. Attempting to achieve 9 dB reduction by increasing slant range (SL) via (20 log 5280/SL) quickly reveals that a new slant range of nearly 15,000 feet will be required.

Data from the other six Boston sites are presented in Figure 19. In each case the critical detectability band is band number 20 containing the fundamental exhaust tone. In addition to site A4, the C182 (2-blade) would be detected at sites A1 and A6. The aircraft would not be detected at sites A2, A3, A5, and A7.

FIGURE 18 DETECTABILITY CHART

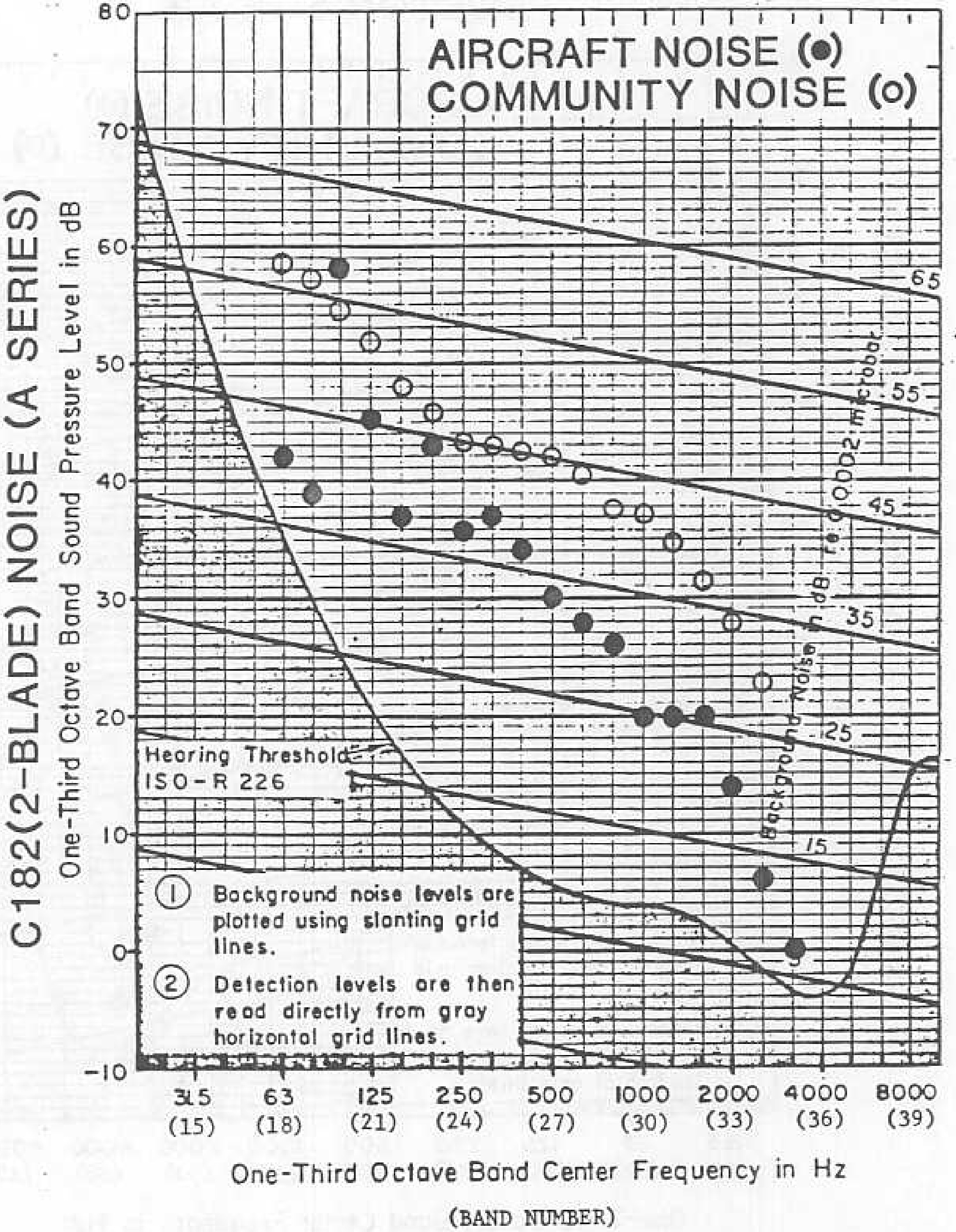



```
SITE A4 TIME:10:50
        LARGE, WOODED CEMETARY AT EDGE OF CITY. WOODS ) 1000' IN ALL
        DIRECTIONS. MANY BIRDS. SUBDUED ROAR OF CITY NOISE IN BACKGROUND.
    PRIMARY NOISE SOURCES:
        BIRDS CALLING.
    OTHER NOISE SOURCES:
        DISTANT PLANES. DISTANT HORNS. LAWN TRACTOR AND SEVERAL CARS ON
        CEMETARY PATH 400' AWAY.
```

(ref. 3)

FIGURE 19a DETECTABILITY CHART

BOSTON SITE A1

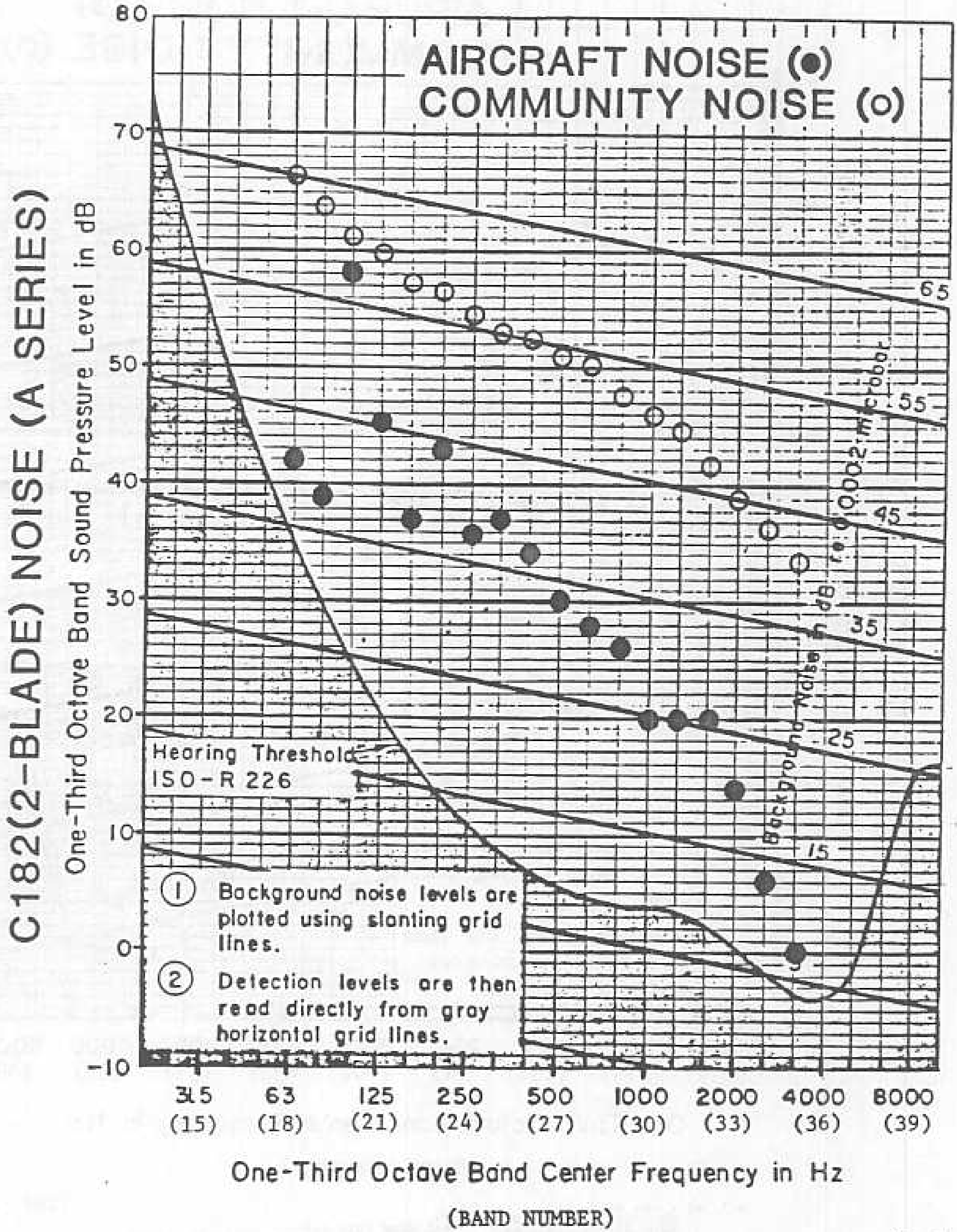


(ref. 3)

SITE A1 TIME: 9:36
EMPLOYEE PARKING LOT IN CITY.
NEAREST BUILDING: 180'. ROAD NEAR LOT: 600'.
6 VEHICLES PER MINUTE. 70% CARS & LIGHT TRUCKS. 30% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
CARS IN LOT; SPEED: 5-20 MPH. CARS AND TRUCKS ON ADJACENT ROAD;
SPEED:30-40 MPH. PEDESTRIANS IN LOT. DOORS SLAMMING.
OTHER NOISE SOURCES:
WORKMEN TAPPING ON GLASS: 350'. HIGH-FLYING PLANES.
HEAVY CONSTRUCTION MOTOR, SIREN AND BRAKE SQUEAL IN DISTANCE.

FIGURE 19b DETECTABILITY CHART

BOSTON SITE A2

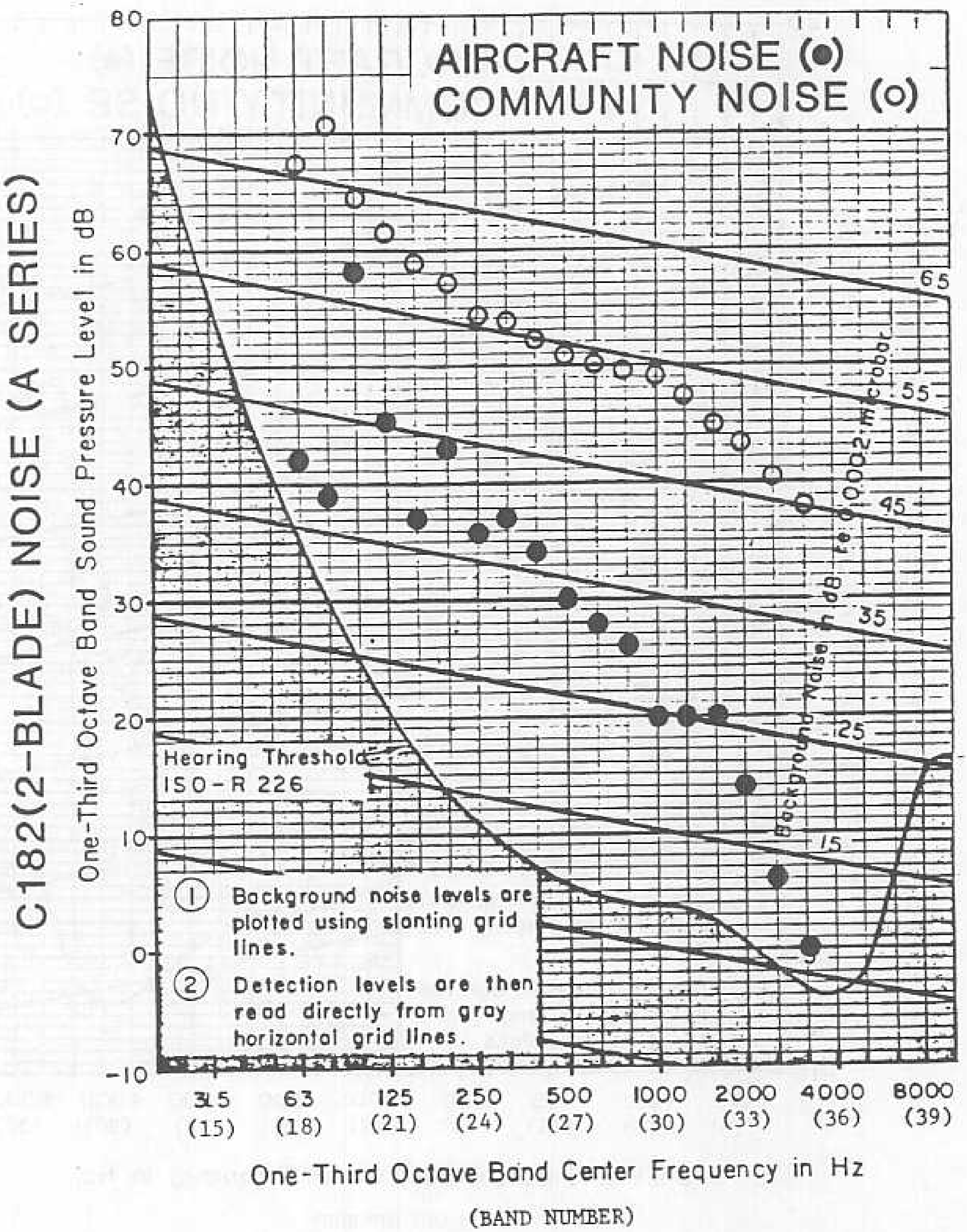


(ref. 3)

```
SITE A2 TIME:10:03
        4 LANE STREET IN CITY NEAR OFFICE BUILDINGS. CONSTRUCTION ON
        UPPER FLOORS OF HIGH-RISE BUILDING 115' AWAY. CONSTANT TRAFFIC.
        STOPLIGHT 220' AWAY.
        16 VEHICLES PER MINUTE. 90% CARS & LIGHT TRUCKS. 10% HEAVY TRUCKS.
   PRIMARY NOISE SOURCES:
        TRAFFIC PASSING, STOPPING AND STARTING; SPEED:0-35 MPH. PEDESTRIANS
        PASSING WITHIN 10'. CONSTRUCTION NOISE.
   OTHER NOISE SOURCES:
        CROSSWALK BELL. HORNS IN DISTANCE. HELICOPTERS.
```

FIGURE 19c DETECTABILITY CHART

BOSTON SITE A3

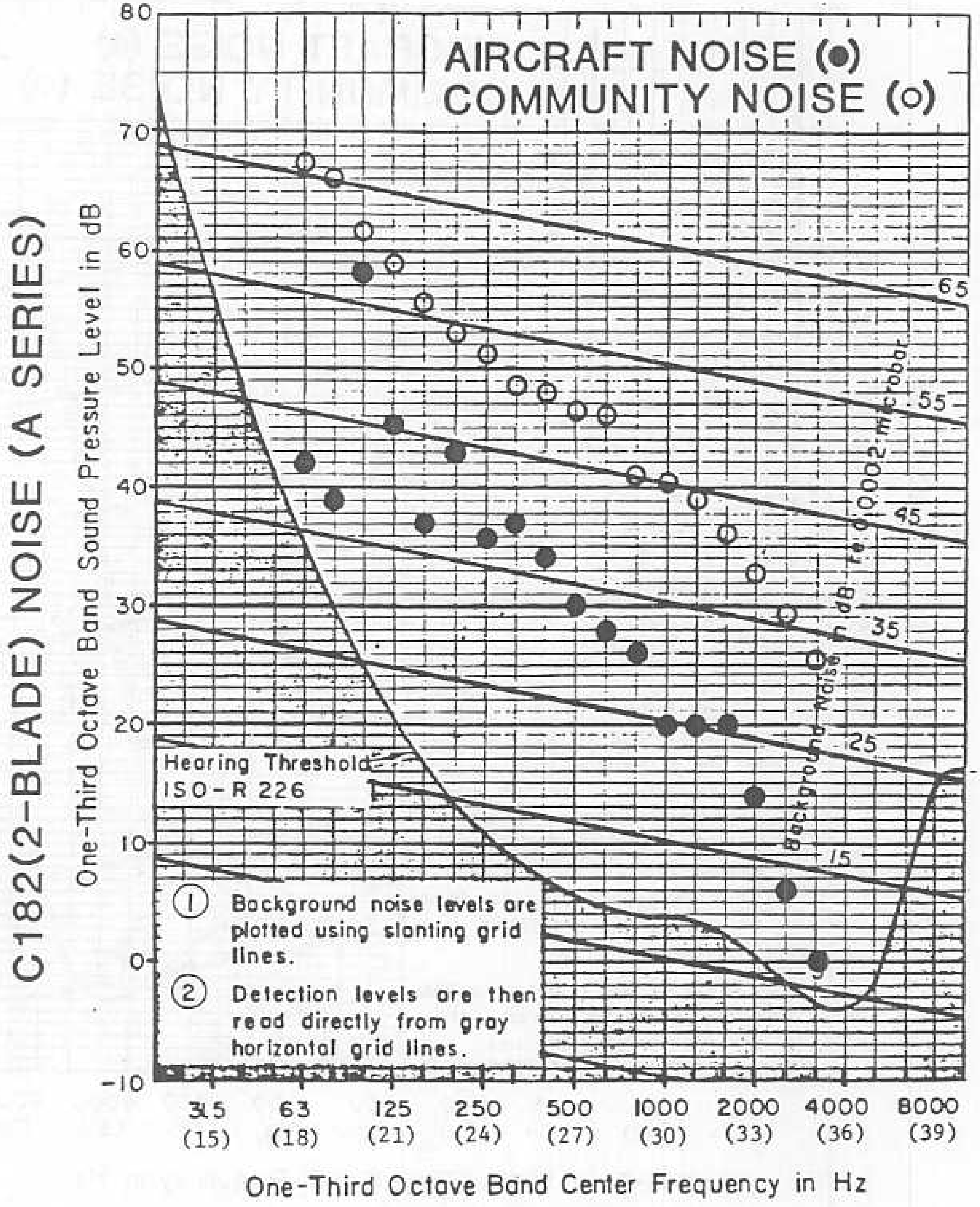


(ref. 3)

```
SITE A3 TIME:10:17
        THREE-WAY INTERSECTION IN CITY. COMMERCIAL ZONE: SHOPS, RESTAURANTS,
        BUS STOPS, ETC. NEAREST BUILDING: 15'. BUILDINGS ACROSS STREET:100'.
        25 VEHICLES PER MINUTE. 80% CARS & LIGHT TRUCKS. 20% HEAVY TRUCKS.
    PRIMARY NOISE SOURCES:
        4 LANES OF HEAVY TRAFFIC INTERSECTED BY 2 LANES OF MODERATE TRAFFIC.
        SPEED: 0-35 MPH. PEDESTRIANS WITHIN 10'. CAR STARTING WITHIN 15'.
    OTHER NOISE SOURCES:
        SUBWAY RUMBLE UNDER SIDEWALK. MAN SHOVELING SAND AND TRASH WITHIN
        15'. SPEECH. BRAKE SQUEALS.
```

FIGURE 19d DETECTABILITY CHART

BOSTON SITE A5



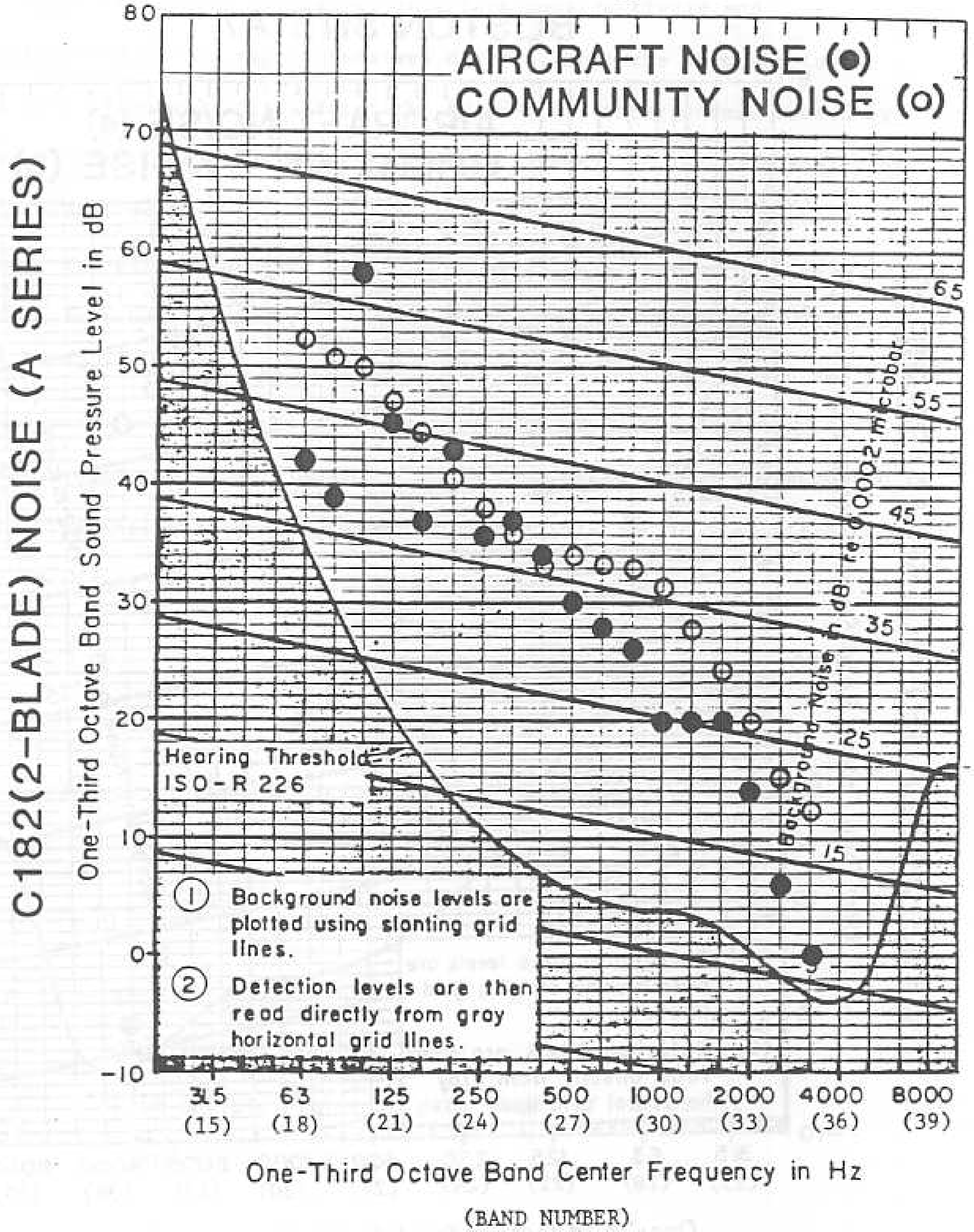
(BAND NUMBER)

(ref. 3)

```
SITE A5 TIME:11:51
        PARKING LOT IN SUBURBAN SHOPPING AREA. NEAREST BUILDING:100'.
        4 LANE ROAD:150'. CONSTANT TRAFFIC ON ROAD.
        3 VEHICLES PER MINUTE IN LOT.
    PRIMARY NOISE SOURCES:
        CARS IN LOT; SPEED:0-20 MPH. DOORS SLAMMING. MOTOR STARTUPS.
        PEDESTRIANS IN LOT.
    OTHER NOISE SOURCES:
        TRAFFIC ON ROAD; SPEED:30-45 MPH. BIRDS CALLING.
```

FIGURE 19e DETECTABILITY CHART

BOSTON SITE A6

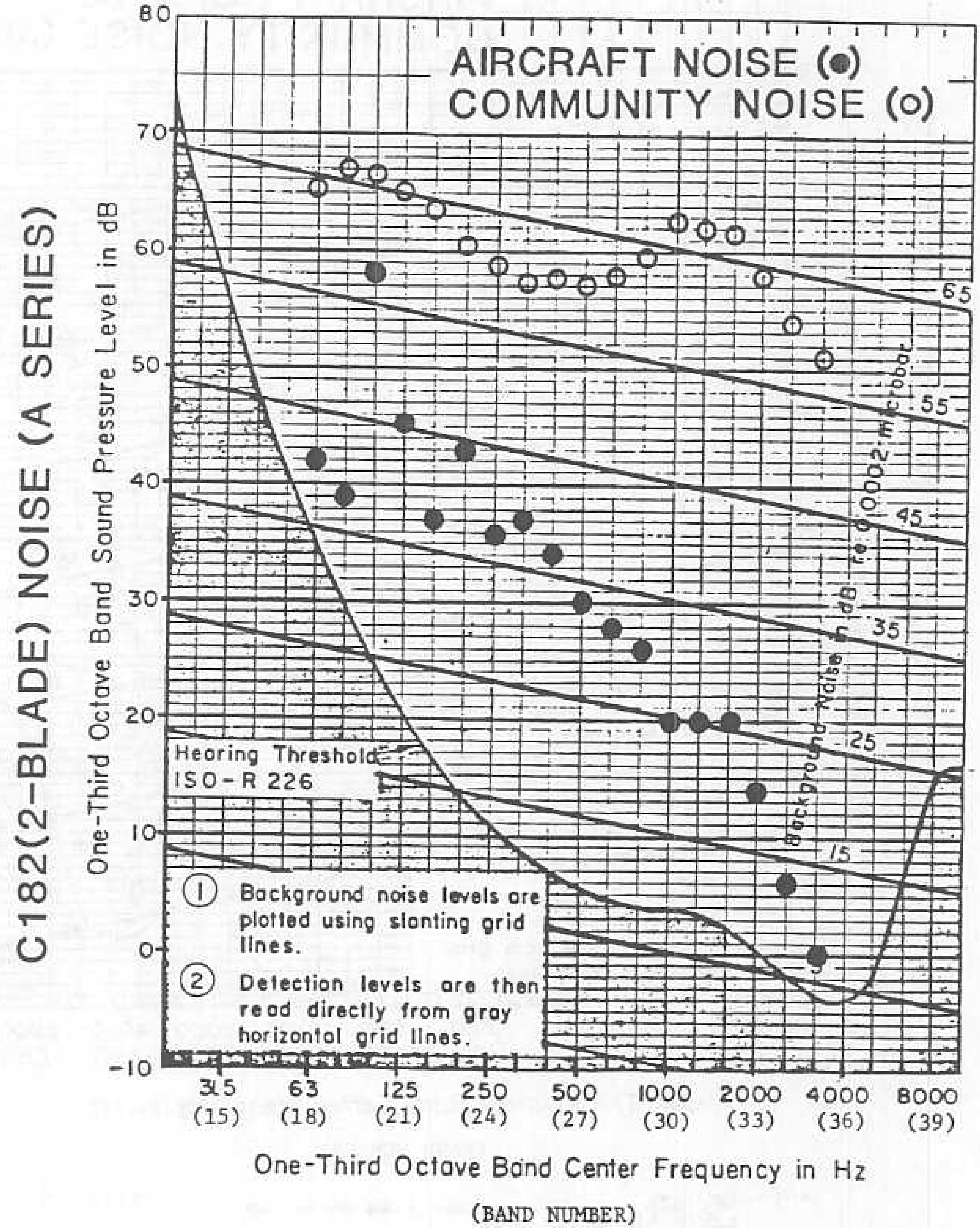



```
SITE A6 TIME:12:42
      OPEN, GRASSY AREA BORDERED BY WOODS. 2 LANE ROAD 80' AWAY.
      3 VEHICLES PER MINUTE.
      ANOTHER 2 LANE ROAD 1000' AWAY.
      4 VEHICLES PER MINUTE.
   PRIMARY NOISE SOURCES:
      CARS ON NEAR ROAD; SPEED:30-45 MPH. BIRDS CALLING.
   OTHER NOISE SOURCES:
      CARS ON FAR ROAD; SPEED:30-45 MPH. DISTANT PLANES. HELICOPTER.
```

(ref. 3)

FIGURE 19f DETECTABILITY CHART

BOSTON SITE A7



SITE A7 TIME:13:22
6 LANE DIVIDED INTERSTATE HIGHWAY REST AREA. CENTER OF NEAREST TRAVEL LANE:20'. CENTER OF FARTHEST TRAVEL LANE: 220'. 125' ACROSS PAVED REST AREA TO A WOODED SLOPE. 100 VEHICLES PER MINUTE. 90% CARS & LIGHT TRUCKS. 10% HEAVY TRUCKS.
PRIMARY NOISE SOURCES:
6 LANES OF TRAFFIC; SPEED:45-65 MPH.
OTHER NOISE SOURCES:
PLANE FLYOVER. CARS PULLING IN TO REST AREA.

(ref. 3)

Optimal Observation Flight Angle

The ground-reflected acoustic signal from an overhead aircraft will, depending on the signal frequency, interfere constructively and destructively with the signal received directly from the aircraft (see Figure 20). Figure 21 illustrates the theoretical interference caused by a tone of given frequency radiating from an aircraft at lookdown angles of 30, 45, and 60 degrees to a four ft. microphone over a hard reflecting surface. The peaks represent reinforcement, up to a maximum of 6 dB, resulting from constructive interference between the direct and reflected signals. The "valleys" result from destructive interference which can reduce a pure tone signal below detection. The important variables are receiver height, emission (lookdown) angle, and frequency of the acoustic signal. The influence of the reflected signal relative to free field can be calculated by the formula

$$dN = 10 \log[2 + 2\cos(2\pi f(dR)/C)] \qquad \text{eq. 2}$$

where: dN is the quantity to be algebraically added to a free field measurement to account for the presence of a reflecting plane.

f is frequency

C is ambient speed of sound

dR is the difference in path length of the direct and reflected wave.

FIGURE 20 LOOKDOWN ANGLE and ACOUSTIC SIGNAL GROUND INTERFERENCE

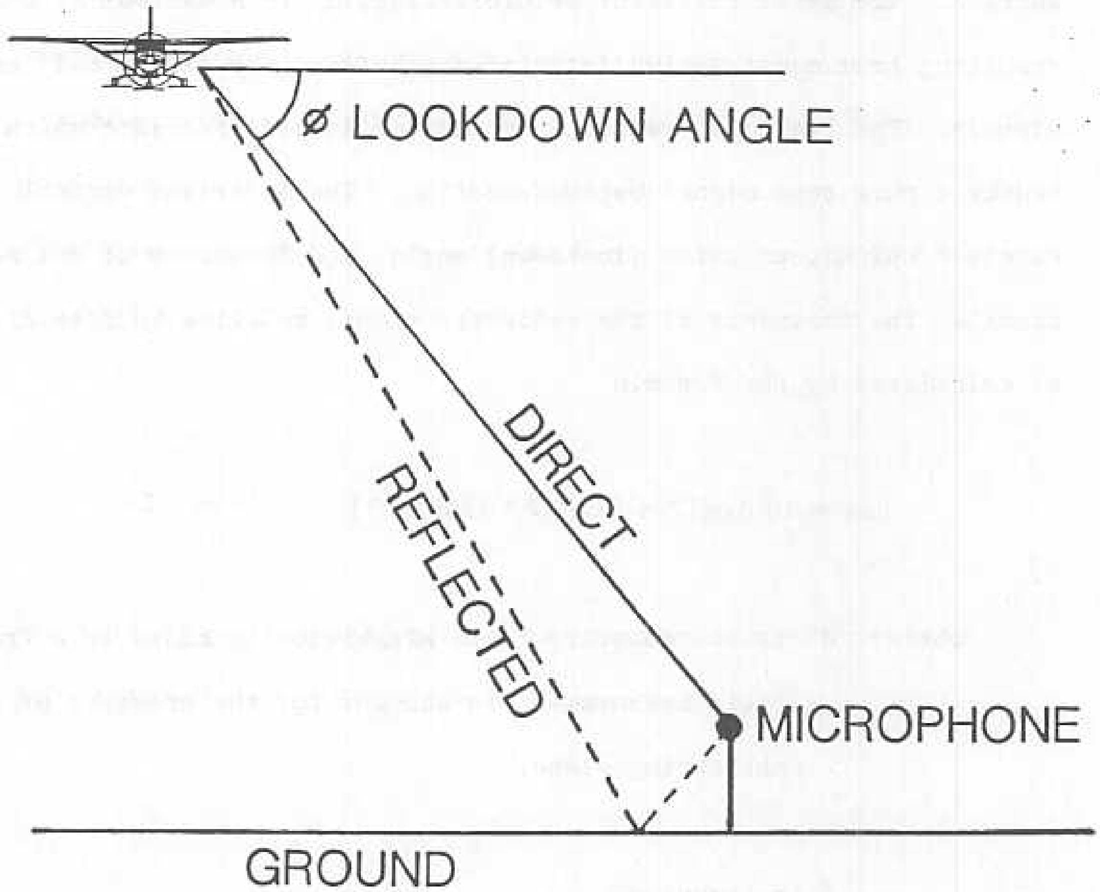


FIGURE 21

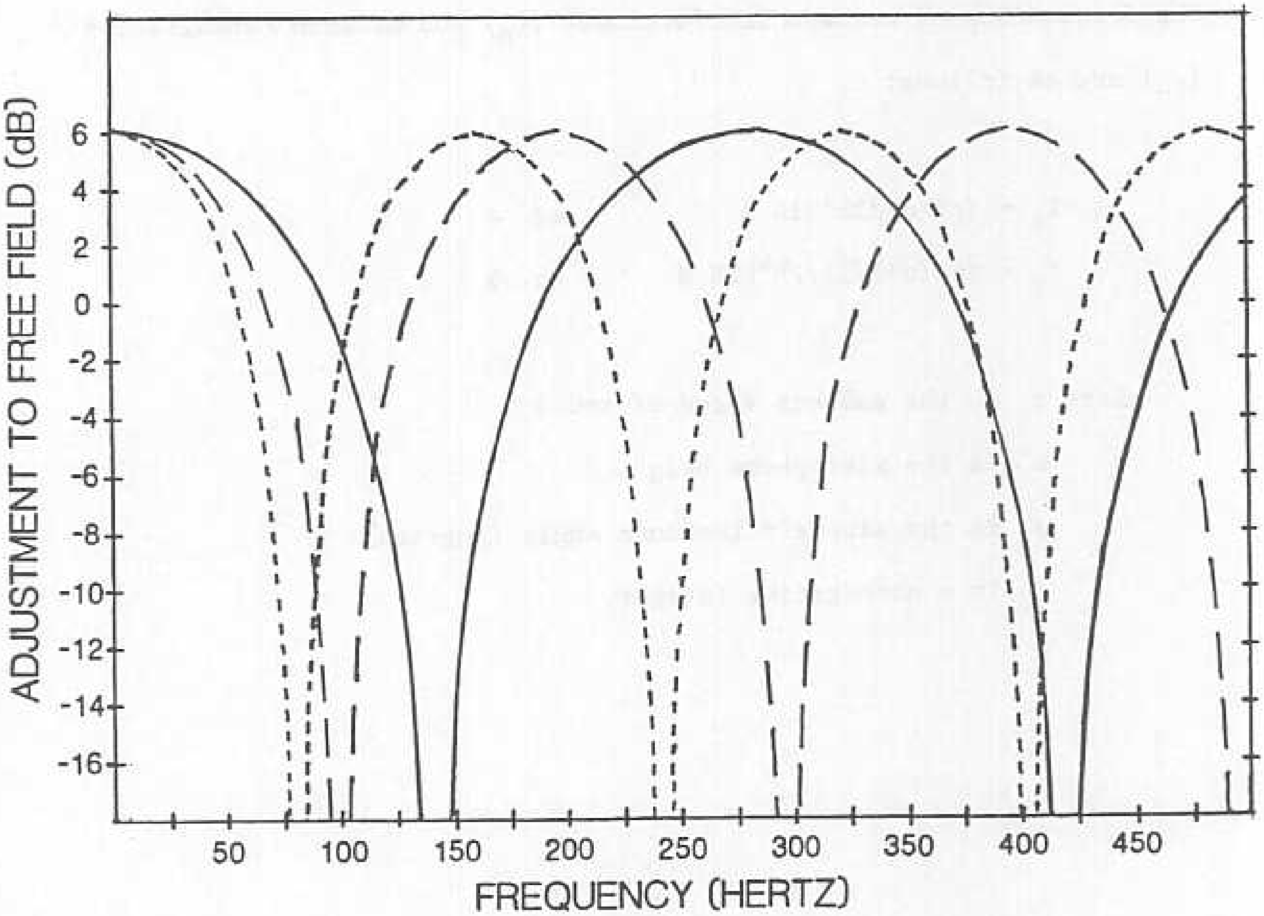
THEORETICAL GROUND INTERFERENCE CURVES

4 ft. RECEIVER ELEVATION

(———————) 30 deg. LOOKDOWN ANGLE

(——— ———) 45 deg. LOOKDOWN ANGLE

(- - - - - - -) 60 deg. LOOKDOWN ANGLE



The quantity dR can be calculated as follows:

$$dR = [r^2 + (h+h')^2]^{1/2} - [r^2 + (h-h')^2]^{1/2} \quad \text{eq. 3}$$

where: r is the horizontal distance between the aircraft and the microphone

h is the aircraft altitude AGL

h' is the microphone elevation AGL

The formula for dN is an approximation applicable only when the source altitude is much greater than the receptor elevation, which is the case for aircraft noise over a near-ground microphone. A complete description of the ground reflection theory is presented in SAE/AIR 1327 (ref. 5). The frequencies of maximum reinforcement (f_R) and maximum cancellation (f_c) are as follows:

$$f_R = (c)(n)/2h'\text{SIN } \phi \quad \text{eq. 4}$$

$$f_c = (c)(n+1/2)/2h'\text{SIN } \phi \quad \text{eq. 5}$$

where c is the ambient speed of sound

h' is the microphone height

ø is the aircraft lookdown angle (degrees)

n is a nonnegative integer

An excellent practical illustration of the ground interference effect is seen in Figure 22 depicting narrowband spectra from the C210 at various microphone locations. The spectra in Figure 22 and the succeeding Figures 23 and 24 were obtained when the aircraft was overhead relative to the centerline microphone location.

Figure 22a is a spectrum from the ground microphone at the centerline microphone location. A ground microphone best represents the true acoustic spectrum emitted by the aircraft with the ground surface influence a constant 6 dB increase across all frequencies.

Figure 22b shows a spectrum from the four ft. elevated microphone at the centerline site. The ground interference (peaks and valleys) is readily apparent in the broadband noise. However, the fundamental combined exhaust and propeller tone is relatively unaffected at the overhead aircraft position (90° lookdown angle).

Figure 22c shows the spectrum from a sideline four ft. microphone site. Given the different geometry resulting in a 45° lookdown angle, the ground interference effect is considerable different from the overhead aircraft case. Here, the dominant fundamental tone falls well within the first interference valley and is consequently dramatically reduced from 93 dB to 67 dB.

FIGURE 22 GROUND INTERFERENCE EFFECT
C210 EVENT A6

FIGURE 22a
CENTERLINE POSITION
GROUND MICROPHONE

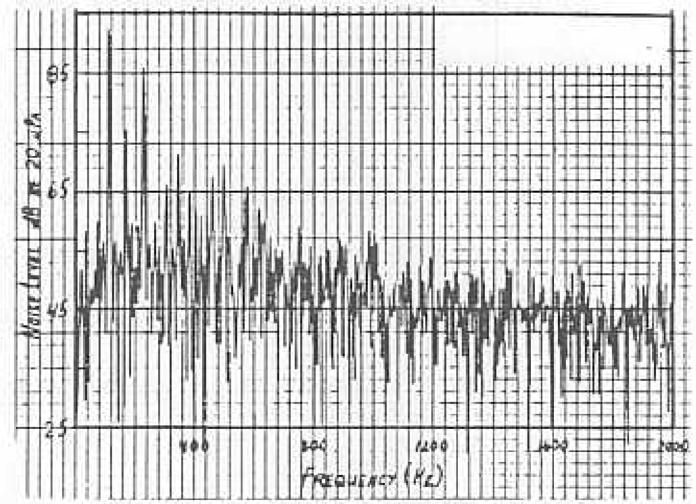


FIGURE 22b
CENTERLINE POSITION
4 ft. MICROPHONE

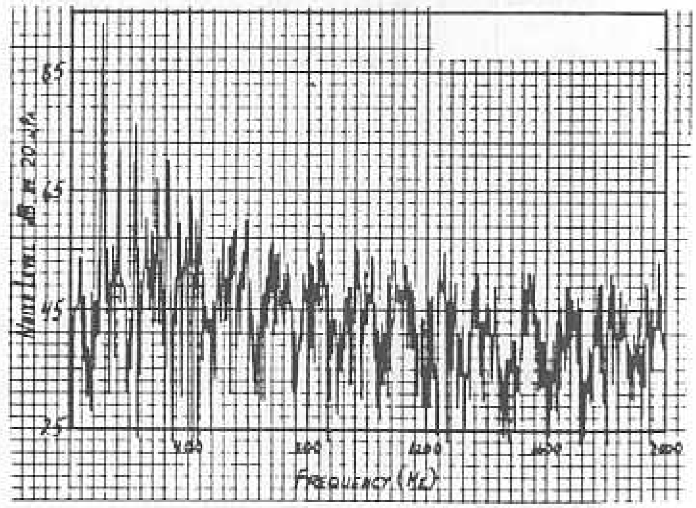
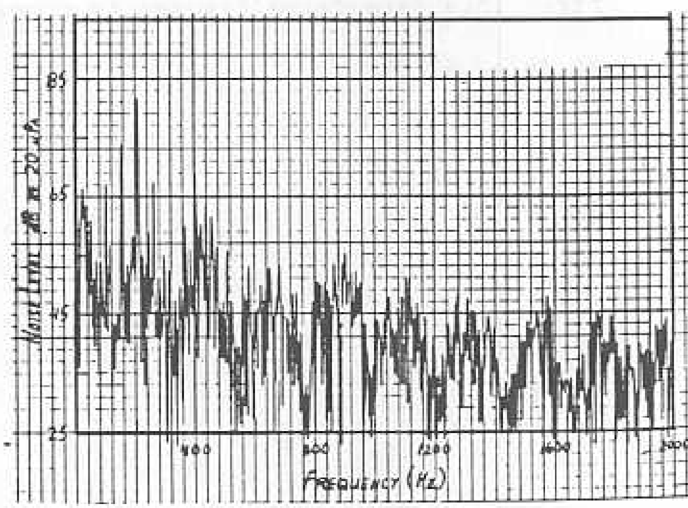


FIGURE 22c
SIDELINE POSITION
4 ft. MICROPHONE



As previously discussed, exhaust and propeller tones occur at evenly spaced intervals--integer multiples of the fundamental or first harmonic tone. The ground interference function shown in Figure 21 also occurs in a pattern of hills and valleys with a constant interval. If the fundamental tone is located in a destructive interference valley, all succeeding odd-numbered harmonics will be similarly affected by destructive interference--all even-numbered harmonics would fall in the constructive or reinforcement areas (potential 6 dB increase) of the ground interference curve.

As illustrated in Figure 23, the same effect is evident in the spectra from the C182 (3-blade). A similar effect is also seen in the C182 (2-blade) as shown in Figure 24. For each of these aircraft, and for the specific conditions of the test (45° lookdown angle and four foot microphone), the dominating fundamental exhaust tone is dramatically suppressed resulting in the second exhaust harmonic becoming the dominant tone.

The previous figures demonstrate the ground interference effect and the applicable theory for predicting the effect. The central question to be addressed is: Can the ground interference effect be used to suppress the dominant exhaust tone and consequently reduce the detectability of the aircraft? The subsequent discussion will answer this question.

FIGURE 23 GROUND INTERFERENCE EFFECT
C182 (3-BLADE) EVENT A5

FIGURE 23a
CENTERLINE POSITION
GROUND MICROPHONE

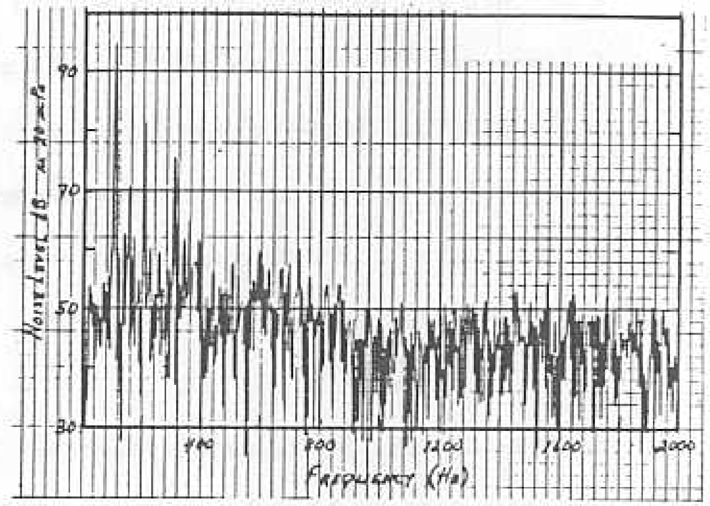


FIGURE 23b
CENTERLINE POSITION
4 ft. MICROPHONE

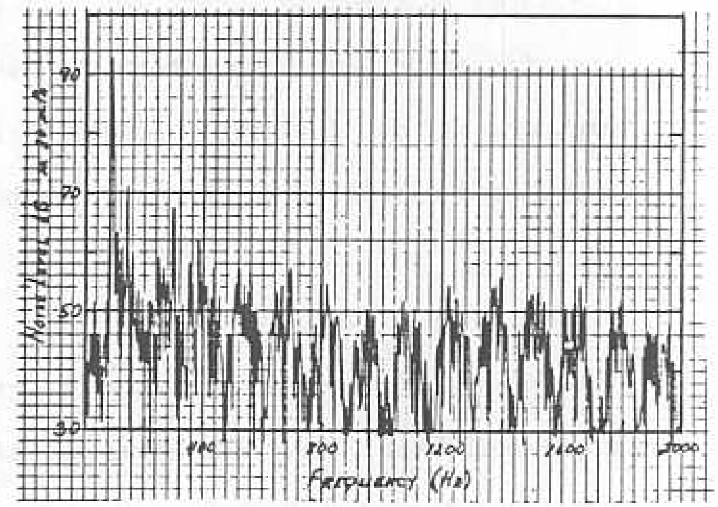


FIGURE 23c
SIDELINE POSITION
4 ft. MICROPHONE

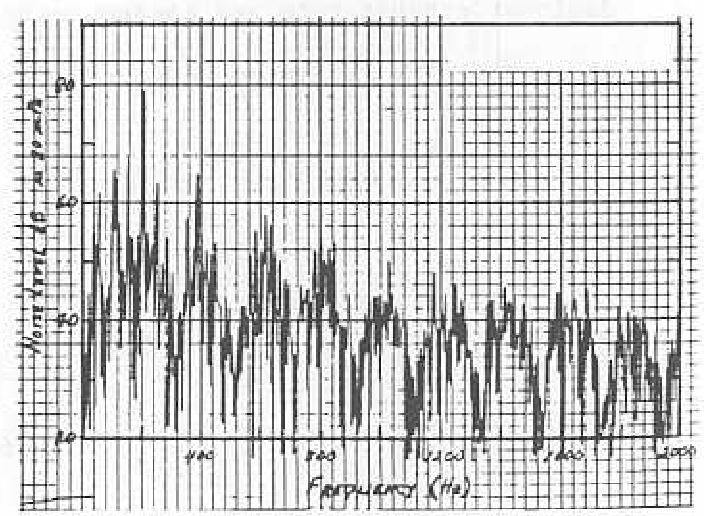


FIGURE 24 GROUND INTERFERENCE EFFECT
C182 (2-BLADE) EVENT A3

FIGURE 24a
CENTERLINE POSITION
GROUND MICROPHONE

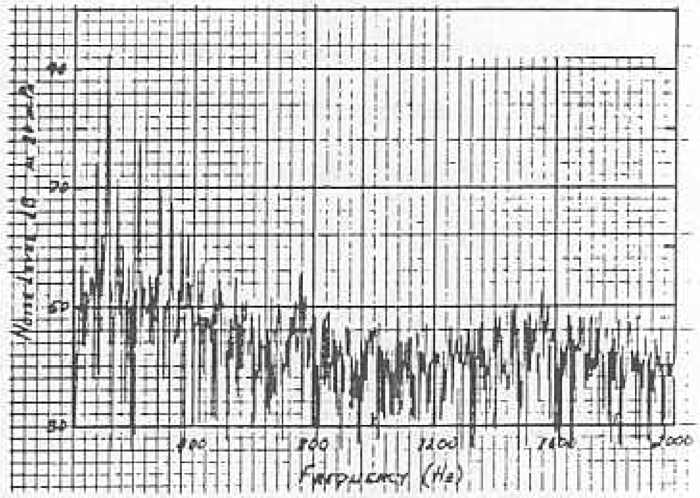


FIGURE 24b
CENTERLINE POSITION
4 ft. MICROPHONE

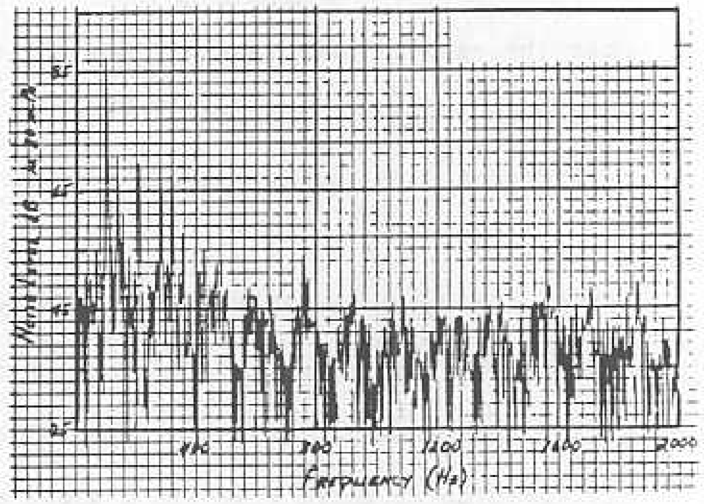
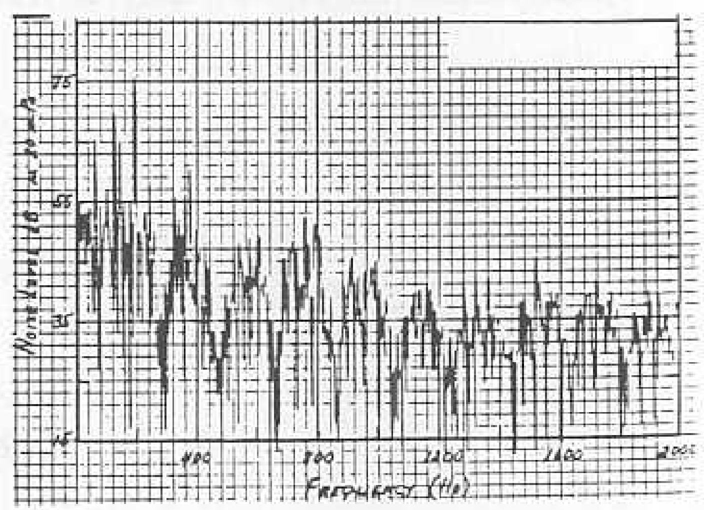


FIGURE 24c
SIDELINE POSITION
4 ft. MICROPHONE



The previous discussion was based on a microphone height of four feet. Receiver height is an important variable in the interference effect and few ground observers, unless seated, will have an ear height of only four feet. Equation 2 was used to recalculate the theoretical interference curves using a receiver height of 5.25 feet, the assumed ear height for a typical standing observer. The recalculated curves, restricted to the primary frequencies of interest, are plotted in Figure 25. The net effect of an increase in receiver height is a shift of the first destructive interference valley toward a lower frequency. The fundamental exhaust tone from a six cylinder engine (RPM/20) is 95 hertz at 1900 RPM. Using a 45° lookdown angle as a reference and at 95 hertz, circling at a 60° lookdown angle would increase the fundamental tone by 6 dB. Circling at a 30° lookdown angle decreases the dominant exhaust tone by 8 dB. Thus, for the example cited and given a constant slant range, circling at a lookdown angle of less than 45° is preferable from a detectability standpoint to a lookdown angle of more than 45°.

Given the range variables, some uncontrolled, the potential advantages offered by the ground interference phenomenon should be used only in a broad and conservative sense. Use of the phenomenon should be restricted to "gaining an extra edge" in a given surveillance situation, and not as a justification for substantially decreasing the slant range.

FIGURE 25

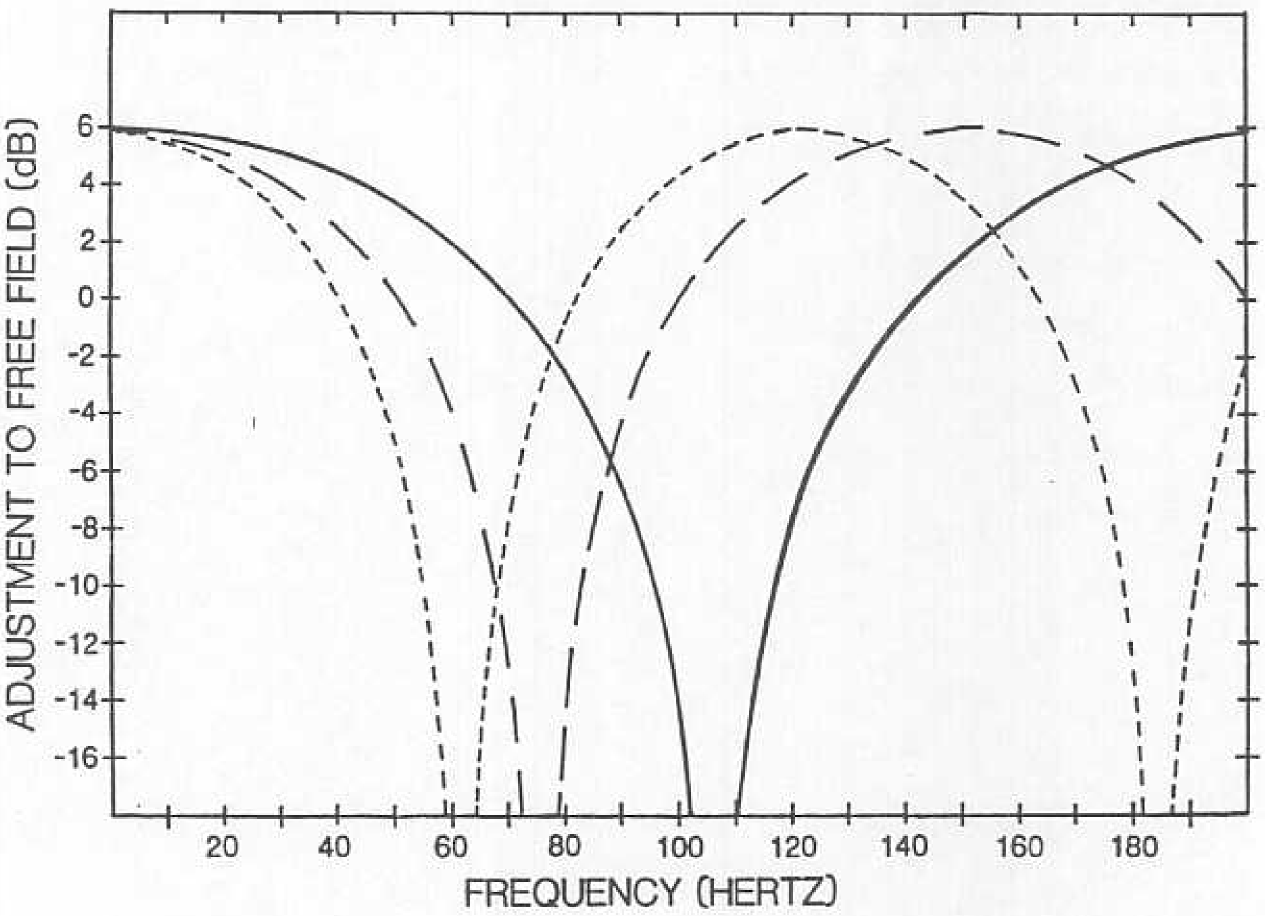
THEORETICAL GROUND INTERFERENCE CURVES

5′ 3″ RECEIVER ELEVATION

(————) 30 deg. LOOKDOWN ANGLE

(—— ——) 45 deg. LOOKDOWN ANGLE

(- - - - - -) 60 deg. LOOKDOWN ANGLE



References

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2. Jones, K.E.; "Acoustic Flight Test of the Piper Lance," DOT/FAA/EE-86/9 Federal Aviation Administration, December 1986.

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4. Boxwell,and Schmitz, F.H.; "Full-Scale Measurements of Blade-Vortex Interaction Noise," Journal of the American Helicopter Society, October 1982, Volume 27-4.

5. "Acoustic Effects Produced by a Reflecting Plane; "AIR 1327, Society of Automotive Engineers.

6. "Community Noise;" NTID300.3, Environmental Protection Agency, December 1971.