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VARIABILITY OF FLYOVER NOISE MEASURES FOR REPEATED FLIGHTS OF TURBOJET AND PISTON ENGINE TRANSPORT AIRCRAFT

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16. Abstract

Various flyover noise measures are reported for noise data recorded at five ground positions located underneath and to the side of the flight path during 20 controlled level flight flyovers of two aircraft, (a four-engine piston airplane and a four-engine turbojet airplane) during one day of flight tests. Noise measures are compared to show the degree of variability among flyover measurements during repeat runs or among measurements made at different positions during the same flyover and to show the degree of correlation between different flyover noise measures. The reported flyover measures range from those derived from simple frequency weighting networks, such as the A- or N-weighted sound levels, to those computed from one-third octave band spectra such as the preceived noise level.

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VARIABILITY OF FLYOVER NOISE MEASURES FOR REPEATED FLIGHTS OF TURBOJET AND PISTON ENGINE TRANSPORT AIRCRAFT

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SUMMARY

Various flyover noise measures are reported for noise data recorded at five ground positions located underneath and to the side of the flight path during 20 controlled level flight flyovers of two aircraft, (a four-engine piston airplane and a four-engine turbojet airplane) during one day of flight tests. Noise measures are compared to show the degree of variability among flyover measurements during repeat runs or among measurements made at different positions during the same flyover and to show the degree of correlation between different flyover noise measures. The reported flyover measures range from those derived from simple frequency weighting networks, such as the A- or N-weighted sound levels, to those computed from one-third octave band spectra such as the perceived noise level.

The scatter in data about regression lines fitted to plots of the various flyover noise measures as a function of slant distance did not show significant differences among the noise measures. The standard deviations for measurements directly under the flight path during the seven flyovers of a turbojet aircraft at 2000 ft altitude ranged from 0.3 to 0.6 dB, reflecting rather small variability in measurements. For a measurement position 2000 ft to the side of the flight path, standard deviations increased to 0.7 to 1.1 dB, indicating an increase in variability with slant distance. These standard deviations are approximately one-half to one-third the size of standard deviations for individual one-third octave band noise level measurements.

Differences between various noise measures were computed and generally showed good agreement with differences reported previously. The standard deviations for the differences are typically quite small, ranging from 0.2 dB to a maximum of 0.8 dB indicating that the simpler measures, such as the A- or N-weighted noise levels, can provide quite accurate estimates of more complex calculated measures.

SYMBOLS

AL — the A-weighted sound level, expressed in dB

AL (int) — the time-integrated A-level, in which A-levels are integrated over the flyover signal duration*

d — the signal duration, in seconds, is the time in which the flyover signal is within 10 dB of its maximum value

D — the integrated duration correction for the EPNL is defined by

$$D = 10 \log \sum_{k=0}^{k=2d} \text{antilog} \left[\frac{PNLT\ (k)}{10}\right] - PNLTM - 13$$

EPNL — the effective perceived noise level expressed in EPNdB, and defined as EPNL = PNLTM + D, in accord with Ref. 1

k — the number of half-second time increments elapsed from the time at which the signal was first within 10 dB of its maximum value

_L (k) — the __ level calculated at the k^{th} time increment

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* for the data reported herein, the integrated measures were approximated by the following summation process from noise levels measured at half-second intervals

$$\_L\ (int) \approx 10 \log \sum_{k=0}^{k=2d} \text{antilog} \left[\frac{\_L\ (k)}{10}\right] - 3$$

NL	the N-weighted sound level as defined in Ref. 2, expressed in dB. It is related to the D-weighted sound level, DL, by NL = DL + 7
NL (int)	the time-integrated N-level, in which N-levels are integrated over the flyover signal duration*
PNL	the perceived noise level at any instant of time, expressed in PNdB, and calculated in accordance with Ref. 3.
PNLC	the composite perceived noise level, calculated from the maximum one-third octave frequency band sound pressure levels occurring during a flyover, irrespective of the time at which the maximum band levels occur
PNLM	the maximum value of the perceived noise level (PNL) that occurs during a flyover
PNLT	the perceived noise level value adjusted for the presence of discrete frequencies, in accordance with Ref. 1
PNLTM	the maximum value of the perceived noise level adjusted for discrete frequencies (PNLT) that occurs during a flyover

* ibid page 3

INTRODUCTION

In this study, comparisons of the noise levels measured on the ground during a number of aircraft flyovers made by two aircraft during one day of testing provide information concerning two aspects of flyover noise measurement and interpretation. The comparisons show the degree of variability in aircraft flyover noise measurements during repeat runs or among measurements made at different ground positions during the same aircraft flyover. The variability which may be expected during repeat flyovers is a problem of specific concern in FAA noise standards for aircraft certification (Ref 4). For example, the certification requirements require 90% confidence limits to be placed on the average noise level as determined from repeat measurements. Variability is also of concern in aircraft noise monitoring systems. Such variability is affected not only by such obvious factors as variability in aircraft performance and measurement errors but also by the fluctuations and variability in received ground signals due to the sound propagation characteristics of the atmosphere.

Comparisons of the variability of differences between several flyover noise measurements are also presented. In recent years a relatively large number of measures have been advocated for describing aircraft flyover noise. These measures range from relatively simple frequency-weighted measures of the maximum noise levels such as the A-level and N-level to measures which are calculated from detailed spectrum analysis of the flyover signal throughout the noise signal time history, as required in the computation of the EPNL. For many engineering purposes (which may include the design of noise monitoring systems and methods for describing the noise around operating airfields) there is a need to know how well one may estimate measures involving relatively complex data analysis or computation from more simply-measured quantities.

The measurements discussed in this study were all made during a single day during which meteorological conditions, if summarized only in terms of ground measurements of temperature, humidity and wind, did not change significantly throughout the tests. Thus the degree of variability observed will be less than one would expect from repeat measurements made under a wider range of meteorological conditions or over a longer time span involving seasonal changes in weather conditions.

DESCRIPTION OF FIELD MEASUREMENTS

The field tests were conducted at NASA Wallops Island Station, Virginia on 29 April 1969. The tests consisted of a morning set of seven flyovers by a four-engine turbojet transport aircraft (Convair 880) and an afternoon set of seven flyovers by the same aircraft. In the afternoon there were also six flyovers by a four-engine piston-powered transport aircraft (Lockheed 1049G). Flights of the turbojet transport aircraft were made at altitudes of 1500 ft and 2000 ft; piston transport aircraft flyovers were at altitudes of 700 and 1500 ft. The flight paths of the level flight flyovers were tracked along a major portion of the flight track using a ground-based Bell Aerosystem GSN-5 localizer and positioning unit. The pilots were instructed to accept some speed variation if necessary in order to hold engine power and altitude constant along the straight line portion of the flight track. Table I lists the individual flights and basic aircraft operating parameters as reported by flight crew observations.

Noise was recorded at five measurement positions as shown in Fig. 1. One position was measured directly under the flight path and other positions were located at various distances from the flight track.

Noise recording instrumentation is indicated in block form in Fig. 2. Noise signals from each microphone were recorded on two channels of an FM tape recorder, one channel having conventional flat frequency response and the other channel containing a low frequency de-emphasis circuit The data reported herein is based upon analysis of tape channels recorded with the flat frequency response channel.

Meteorological measurements were made on site at two surface positions. In addition radiosonde measurements of temperature and humidity were made at intervals before and following the flight to obtain measures of temperature, humidity, and winds aloft. Surface temperature, humidity and winds are summarized in Table II. Further descriptions of the meteorological conditions are provided in Ref. 5.

Except for the high humidity the reported surface condition generally met the meteorological requirements for aircraft noise certification tests. Generally, conditions aloft also fell within the certification requirement with the exception of the relative humidities in excess of 90% observed at the approximate altitude of 1200 ft during the afternoon flights. Also noted was a morning temperature inversion which disappeared before the afternoon measurements.

DATA ANALYSIS

One-third octave band sound pressure levels were determined at 1/2 second intervals during the useful portions of the flyover noise signal. Figure 3 indicates the data reduction instrumentation in block form. Noise signals recorded on FM channels with conventional flat frequency response were played back into a Hewlett-Packard Real Time Audio Spectrum Analyzer. Under control of a Digital Equipment PDP-8 computer, the noise signals were analyzed by the Spectrum Analyzer at half-second intervals in one-third octave frequency bands extending from 50 Hz to 10,000 Hz center frequencies. Acoustic calibration signals recorded on the tape at the time of the field experiment were utilized as a calibration standard for the noise signal. In addition, frequency response corrections for the record and playback systems were introduced into the computer.

The output of the PDP-8 computer was a paper tape in which noise spectra at half-second intervals were recorded in binary form. Later, the paper tape was read into the PDP-8 computer at which time various flyover noise measures were calculated from the third octave band spectra. A number of the calculated flyover noise measures are presented in Table III for each flyover and measurement position for which valid data was obtained.* The minimum slant distance (obtained from radar tracking data) is also listed in the table, as are several measures of the duration of the signal within 10 dB of the maximum flyover signal level.

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* Several sets of measurements were excluded from the table because of faulty recordings or a fault in the data analysis.

The flyover noise level measures tabulated in Table III can be grouped into two general classes:

(a) Measures dependent upon the frequency spectrum shape and maximum signal ampitude. This would include measures derived from a simple frequency network such as the A- or N-level and those computed from third-octave band spectra, such as the PNL.

(b) Measures dependent upon the time history of the flyover noise signals as well as the spectrum shape and signal ampitude. This would include the time-integrated A- and N-levels and the effective perceived noise level (EPNL) which, alone of all the integrated measures listed in Table III, includes an adjustment for the presence of discrete frequencies. (However, for the aircraft and power settings used during the flyovers, discrete components were not very significant,hence the EPNL values do not reflect any large corrections for the presence of discrete frequencies.)

The various time-integrated noise levels are generally defined as:

$$\_L\ (\text{int}) = 10 \log \left[\frac{1}{T} \int_{t\,(1)}^{t\,(2)} \text{antilog}\ \frac{L}{10}\, dt\right] \qquad \text{Eq. (1)}$$

where T is an arbitrary normalizing time constant, and where t (1) and t (2) are the limits of the time duration d during which the _L is within a specified value of the maximum _L.

For the data reported in Table III, the integration of Eq. (1) was replaced by a summation of noise levels determined at half-second intervals over the flyover periods in which the noise level was within 10 dB of the maximum level. Thus, in the data analysis, Eq. (1) was replaced by:

$$L\ (int) = 10 \log \left[\frac{1}{T} \sum_{k=0}^{k=2d} \text{antilog} \frac{L\ (k)}{10}\right] - 3 \qquad \text{Eq. (2)}$$

where k is the number of half-second time increments elapsed from the time at which the signal was first within 10 dB of its maximum value. For the EPNL, T was taken as 10 seconds; for the integrated A- and N-levels, T was set at one second.

Integrated measures were also computed in accord with Eq. (2), except with the summation extending over the top 20 dB of the signal envelope. In agreement with previous analysis of flyover measures (Ref. 6), such measures, not reported, typically show small increases over values for 10 dB summation, with the increases typically ranging from 0 to 0.5 dB.

FLYOVER MEASURE COMPARISONS

Figures 4 through 10 show selected portions of the flyover noise data tabulated in Table III plotted as a function of minimum slant distance. Shown are data for the EPNL - PNLC, PNLM, AL, NL, and the quantity EPNL -PNLC. Also shown in Fig. 10 is the signal duration interpreted as the time within 10 dB of the maximum tone-corrected perceived noise level.

Shown in the figures are linear regression lines (noise levels vs. log (slant distance)) fitted by the method of least squares. Since one expects a linear as well as a logarithmic term in the curves relating noise levels with slant distance a more complex curve instead of a linear regression line might have been warranted had the data been obtained over a larger range of slant distances. However, for these flyovers the range in slant distances was 2 to 1 for the turbojet aircraft and slightly over 3 to 1 for the piston aircraft. Particularly for the turbojet aircraft data, this ratio of slant distances is not sufficient to accurately determine changes in noise levels as a function of slant distance.

For the regression lines shown in Figs. 4 through 9,Table IV lists the intercept at 1000 ft slant distance and the slope indicated in dB per doubling of distance. The table also lists the statistic $S_{y/x}$ which provides an indication of the degree of variability not accounted by the regression line fit to the data. (Ref. 7).*

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* For a large sample and assuming normal distribution of levels about the true regression line, one would expect that 68% of the measured levels should lie within $\pm S_{y/x}$ of the regression line, or 95% should lie within $\pm 2 S_{y/x}$.

One will note that, except for the A-levels for the turbojet flyovers, the curves for measures which do not reflect signal duration all have slopes within a narrow range between 6.8 to 7.3 dB per doubling of distance. However, the A-level measurement for the turbojet transport aircraft shows a lesser slope.

One would expect the curves for measures reflecting signal duration to show smaller slopes with distance than measures not reflecting signal duration because of the increase in signal duration with slant distance as indicated in Fig. 10. This expection is confirmed by the slope of the regression line fitted to the EPNL data for the piston aircraft, but does not hold for the EPNL data for the turbojet aircraft. In this case, the EPNL vs PNLC data show an almost flat trend with distance. It is expected that this trend for the EPNL data (or the maximum A-level measurements discussed above) would not be observed for flyover measurements taken over a greater range of slant distances.

The values for the statistic $S_{y/x}$ of the flyover measure given in Table IV are generally comparable values running from 0.8 to 1.4 dB. Thus the scatter in data about the fitted regression line did not appear to be drastically different for any of the measures listed in Table IV.

Another measure of variability in flyover measures can be obtained by examining the differences in flyover noise levels observed at the same measurement position during repeat runs of the aircraft at the same nominal altitude and flight conditions. Table V lists the mean values and standard deviations for seven flyover measurements at Position 2 (under the aircraft)and at Position 5, furthest from the aircraft flight path. Data are reported for the seven flyovers of the four-engine turbojet aircraft at a nominal altitude of 2000 ft. In computing the values reported in Table V the measured noise levels reported in Table III have been adjusted for minor differences in slant distances during different flyovers using the slope values given in Table IV.

The standard deviations reported for the various measures at Position 2 range from 0.3 to 0.6 dB reflecting rather small variability in repeat flyovers. The standard deviations calculated for Position 5 measurements are somewhat larger, ranging from 0.7 to 1.1 dB, reflecting an increase in variability as minimum slant distance is increased.

The standard deviations given in Table V may be compared with those of Table V of Ref. 5 which are reported for sound levels measured in one-third octave frequency bands during portions of the same flyover signals. Such a comparison indicates that the variability for the flyover measures of Table V are approximately one-half to one-third the size of the standard deviations for the one-third octave band measurements.

The standard deviations for the first four measures given in Table V do not indicate large differences in variability among measures reflecting signal integration or duration considerations. For the last four values listed in Table V, reflecting measurements not including duration considerations, the composite perceived noise level indicates somewhat lower variability than the other measures.

Table VI lists the results of comparisons among several of the flyover noise measures. Listed in Table VI are the mean difference between various noise level measures and the standard deviations for the differences. Three measures are compared with the effective perceived noise level and two measures are compared with the maximum perceived noise level.

In addition, two measures, the N-weighted and A-weighted noise levels, are compared with the composite perceived noise level, a very common measure of aircraft noise levels in the last few years. The average differences between the composite perceived noise level and A- or N-weighted levels are in good agreement with the differences reported earlier (Ref. 8).

It is interesting to note that the differences between the effective perceived noise level and the integrated A-levels or integrated N-levels are approximately the same as the differences between the composite perceived noise level and the maximum A- or N-levels.

The standard deviations listed in Table VI for the differences range from 0.2 dB to a maximum of 0.8 dB. The differences between the various simpler measures and the EPNL show standard deviations ranging from 0.3 to 0.6 PNdB, an acceptably moderate degree of variability for many field measurement purposes where high accuracy is not required in estimating the effective perceived noise level. Comparisons of A-level or N-weighted levels with the calculated perceived noise levels (PNLC or PNLM) show standard deviations ranging from 0.2 to 0.8 dB again indicating that the simplier measures often provide very good estimations of the more complex calculated measures.

Of course, for measurements extended to a wider variety of aircraft, aircraft operating conditions, or atmospheric conditions, greater variability among measures may be expected. For example, typical values reported previously for a relatively wide range of jet transport aircraft show standard deviations of the order of 1.0 to 2.0 dB for differences between PNLC and A- or N-weighted measures.

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TABLE I

LOG OF AIRCRAFT TEST FLIGHTS - 29 APRIL 1969, NASA, WALLOPS STATION, VIRGINIA

A/C	Flight No.	Time EDST	Alt, ft	IAS, Kn	A/C gross Wt, 1000 lbs	Engine Settings
880	111	0630	1500	208	143.1	EPR 2.2
	112	0639	1520	205	140.3	2.2
	113	0645	1530	205	138.5	2.2
	114	0652	1975	204	136.4	2.2
	115	0659	2050	202	133.7	2.2
	116	0707	2100	205	131.5	2.2
	117	0714	1500	203	129.6	2.2
880	211	1641	1500	210	150.5	EPR 2.2
	212	1648	1550	198	148.3	2.2
	213	1655	1500	208	146.2	2.2
	214	1703	2200	208	142.9	2.2
	215	1710	2100	204	141.2	2.2
	216	1718	2050	205	139.7	2.2
	217	1728	2000	208	133.5	2.2
1049G	221	1517	700	220	101.6	BMEP 234,2600 RPM
	222	1524	700	220	100.8	234,2600
	223	1531	700	220	100.0	234,2600
	224	1538	1500	220	99.2	234,2600
	225	1546	1500	220	98.4	234,2600
	226	1553	1500	220	97.6	234,2600

TABLE II

TYPICAL SURFACE WEATHER PARAMETERS DURING FLIGHTS

Time EDST	A/C	Flt No.	Temp °F	R.Hum. %	Wind Speed, Kn	Bar. Press Press in Hg.
0630 0720	880	111- 117	58 58.5	100 100		
1515 1600	1049G	221- 226	61 59.5	85 88		
1640 1730	880	211- 217	59.5 59.5	88 80		
0630 to 1730		Max Min	70 57	100 67	9.5 0	29.89 29.85

TABLE III

SUMMARY OF MEASURED FLYOVER NOISE MEASURES

Aircraft	Flight No.[1]	Meas Pos[2]	Slant Dist Ft.	EPNL EPNdB	PNLTM PNdB	PNLM PNdB	PNLC PNdB	N-Level dBN	A-Level dBA	Integr. N-Level dBN	Integr. A-Level dBA	dur[3] (PNLT) sec	dur[3] (N-Level) sec	dur[3] (A-Level) sec
880	111	2	1520	109.6	110.7	109.3	110.8	110.6	97.0	119.3	106.2	14.0	14.0	15.0
		3	1900	108.4	108.9	107.7	108.6	108.5	96.1	118.0	105.1	16.0	16.5	16.0
		4	2136	106.4	106.8	106.1	106.9	106.9	94.6	116.5	103.9	18.0	18.0	18.5
		5	2454	105.4	105.2	104.0	105.1	105.1	93.2	115.3	102.9	19.0	19.0	19.5
880	112	2	1481	109.8	110.9	109.6	110.7	111.0	97.4	119.4	106.4	15.0	14.0	15.5
		3	1873	108.3	108.8	107.4	108.6	108.3	95.9	117.9	105.0	16.0	17.0	16.5
		4	2114	106.4	107.2	106.0	106.8	106.9	94.4	116.4	103.7	16.5	16.5	17.0
		5	2466	104.8	104.4	103.2	104.4	104.2	92.3	114.7	102.4	20.0	20.5	20.0
880	113	1	1838	112.6	114.3	112.6	113.2	113.2	100.6	121.6	108.7	16.0	15.5	15.0
		2	1504	109.7	110.8	109.6	110.7	110.9	97.2	119.5	106.4	14.0	14.5	15.5
		3	1852	108.5	109.2	107.9	108.8	108.8	96.6	118.1	105.3	15.5	15.5	15.5
		4	2085	107.1	108.0	106.5	107.7	107.5	95.0	116.8	104.3	16.0	16.5	18.0
		5	2413	105.5	106.2	104.9	105.8	106.1	93.5	115.5	103.1	19.0	19.5	19.5
880	114	1	2169	110.8	111.4	109.6	110.2	110.4	98.6	119.3	106.9	18.5	17.5	17.0
		2	1878	107.2	108.3	106.8	107.8	108.1	94.7	116.9	104.2	15.0	15.5	17.5
		3	2151	106.7	106.7	105.4	106.6	106.1	93.9	116.2	103.6	18.5	19.0	18.5
		4	2351	105.4	106.2	105.0	105.8	105.8	93.8	115.2	102.7	18.0	18.0	17.5
		5	2651	103.6	103.9	102.6	104.7	103.6	91.2	113.5	101.4	19.5	20.5	21.0
880	115	1	2206	105.6	106.4	105.9	106.8	107.0	95.4	116.0	103.7	16.5	16.5	15.5
		2	1937	106.9	107.3	105.9	107.0	106.9	94.3	116.6	103.8	17.5	18.0	17.5
		3	2228	106.1	106.4	104.9	106.3	105.8	93.5	115.7	103.2	17.0	17.5	18.0
		5	2721	103.5	103.4	102.4	103.3	103.3	91.0	113.7	101.5	24.0	24.0	22.5
880	116	1	2302	106.0	106.8	105.7	106.6	106.6	95.3	115.8	103.6	18.0	17.5	17.0
		2	2055	106.3	106.7	105.4	106.4	106.6	93.6	116.1	103.6	18.0	17.5	19.5
		3	2327	105.7	105.8	104.6	105.4	105.4	93.2	115.3	102.8	19.5	19.0	19.0
		5	2842	103.2	102.4	101.7	102.6	102.6	90.5	113.2	101.2	26.5	22.0	25.0
880	117	1	1812	109.1	111.2	109.2	109.8	110.3	97.4	118.5	105.6	14.0	14.0	14.0
		2	1466	109.7	111.0	109.9	110.8	111.3	97.7	119.5	106.4	14.0	14.0	14.0
		3	1828	109.1	110.5	108.2	109.7	109.3	96.3	118.6	105.7	14.5	15.5	16.5
		4	2065	107.4	108.6	107.2	107.8	108.0	95.6	117.0	104.4	16.0	16.0	17.0
		5	2393	105.2	106.6	104.6	105.4	105.8	93.2	114.9	102.6	18.5	18.5	19.5
880	211	1	1791	107.8	109.6	108.2	108.8	109.2	96.8	117.5	104.6	14.5	15.0	13.5
		2	1408	110.9	111.3	110.3	111.4	111.5	98.1	120.6	107.5	16.0	16.0	16.0
		3	1770	109.8	111.0	109.7	110.4	110.8	97.5	119.4	106.6	15.0	15.5	15.5
		4	2012	108.7	109.9	108.2	108.7	109.2	96.8	118.2	105.7	16.5	17.5	18.5
		5	2373	106.9	107.1	105.9	106.8	107.2	94.9	116.9	104.5	21.5	22.0	21.0
880	212	1	1866	107.7	108.3	107.1	108.0	108.1	95.8	117.5	105.1	18.0	18.0	18.0
		2	1502	110.5	111.0	109.6	110.6	110.7	97.9	120.1	107.3	15.0	16.5	17.5
		3	1812	110.3	111.7	109.9	110.6	110.5	98.4	119.8	107.0	16.5	17.0	17.0
		4	2039	110.2	111.6	110.0	110.6	111.1	98.8	119.7	107.0	16.0	16.5	15.5
		5	2364	107.2	108.6	107.5	107.8	108.7	96.5	117.0	104.6	18.5	17.0	16.5
880	213	1	1803	108.4	110.0	108.7	109.3	109.4	97.0	118.2	105.5	16.0	16.0	16.5
		2	1419	110.7	111.4	110.1	111.0	111.3	98.2	120.4	107.4	16.0	15.5	16.0
		3	1761	110.2	111.1	109.7	110.4	110.6	98.3	119.8	107.0	17.0	18.5	17.5
		4	1998	108.9	109.8	108.2	109.1	109.3	96.6	118.4	105.6	15.5	16.5	15.5
		5	2344	106.7	107.6	106.3	107.0	107.6	94.8	116.7	104.2	22.0	21.5	22.0
880	214	1	2274	106.5	107.0	106.5	107.1	107.2	95.5	116.4	104.4	20.5	18.0	19.5
		2	1947	107.6	107.9	106.7	107.3	107.4	95.3	117.4	104.8	19.0	19.0	18.5
		3	2134	107.3	108.6	107.0	107.5	107.9	95.5	116.7	104.2	16.5	17.0	17.5
		4	2310	107.5	107.8	106.6	107.4	107.5	96.0	117.2	104.8	18.5	18.5	18.5
		5	2569	105.2	105.4	104.3	105.8	105.5	93.1	115.2	102.7	22.0	22.0	21.5

TABLE III (Con't)

Aircraft	Flight No[1]	Meas Pos[2]	Slant Dist Ft.	EPNL EPNdB	PNLTM PNdB	PNLM PNdB	PNLC PNdB	N-Level dBN	A-Level dBA	Integr. N-Level dBN	Integr. A-Level dBA	dur[3] (PNTL) sec	dur[3] (N-Level) sec	dur[3] (A-Level) sec
880	215	1	2216	106.3	106.4	105.6	106.4	106.5	95.1	116.1	104.0	21.0	17.5	16.5
		2	1941	107.5	107.7	106.1	107.3	107.2	95.0	117.2	105.1	20.0	20.5	22.0
		3	2213	106.8	107.4	105.8	106.5	106.7	94.1	116.4	104.3	19.5	20.0	22.5
		4	2406	106.4	108.5	107.2	107.5	108.1	96.2	116.4	104.0	16.5	17.0	16.5
		5	2687	104.7	104.9	103.9	104.5	104.9	93.0	114.7	102.5	25.5	23.5	23.0
880	216	1	2233	105.8	106.4	105.6	106.3	106.4	94.6	115.8	103.7	19.5	19.5	21.0
		2	1936	107.4	108.6	107.2	107.5	108.1	95.5	117.1	104.7	17.0	17.5	17.0
		3	2191	107.3	108.8	107.3	107.7	108.0	95.8	117.0	104.7	16.5	18.0	19.0
		4	2385	107.5	110.5	109.1	109.4	110.2	98.2	117.4	105.2	16.0	16.5	15.5
		5	2676	104.9	105.5	104.5	105.2	105.8	93.3	115.1	103.0	21.5	20.5	21.5
880	217	1	2124	106.4	107.0	106.1	106.7	107.1	95.6	116.3	104.4	18.5	18.0	17.0
		2	1879	107.9	107.5	106.3	107.3	107.2	94.8	117.6	105.2	19.5	20.0	20.0
		3	2229	106.9	107.2	106.1	106.8	106.7	94.7	116.6	104.3	19.5	20.0	20.5
		4	2440	106.4	106.8	105.7	106.2	106.7	95.0	116.3	104.3	21.0	20.5	20.5
		5	2749	104.7	104.1	104.1	104.5	105.1	93.1	115.0	103.0	24.5	24.5	24.0
1049G	221	1	1281	104.0	107.3	105.5	106.8	104.8	91.5	111.7	98.9	11.0	11.0	13.0
		2	711	106.4	111.5	110.1	113.4	109.8	96.6	111.1	101.9	7.0	2.5	7.0
		3	1314	102.6	104.8	103.1	104.3	102.4	89.5	110.4	97.4	15.5	15.5	13.5
		4	1627	100.4	101.6	101.0	102.1	100.0	87.7	108.4	95.8	18.0	16.5	16.0
		5	2048	98.0	98.1	96.9	98.6	96.1	84.0	105.8	93.0	23.0	23.5	21.0
1049G	222	1	1254	101.9	105.2	104.0	105.0	103.0	90.9	110.4	98.1	11.0	11.0	10.5
		2	706	106.3	110.9	109.6	110.2	108.8	96.2	114.4	102.1	8.0	8.0	8.0
		3	1334	102.5	105.4	103.4	105.1	102.3	89.2	110.2	97.1	11.5	13.5	14.0
		4	1651	100.3	101.1	99.4	101.3	98.5	86.3	108.0	95.3	17.0	18.0	17.5
1049G	223	2	721	106.5	112.2	110.4	110.8	109.4	95.9	114.4	101.5	7.0	7.5	8.0
		3	1364	101.2	104.0	102.2	103.2	101.4	88.3	108.9	96.1	13.5	13.5	13.5
		4	1681	99.8	101.0	100.1	103.3	99.3	87.1	107.9	95.4	20.0	19.5	19.0
		5	2113	98.2	98.3	97.1	99.3	96.2	83.7	106.1	93.4	21.0	21.0	20.5
1049G	224	1	1819	101.6	103.1	102.0	103.4	101.2	87.9	110.3	97.4	15.0	16.5	17.0
		2	1504	102.3	105.7	103.8	104.9	102.9	90.0	110.4	97.9	12.0	13.0	13.5
		3	1895	100.7	101.7	99.9	102.6	100.3	86.8	109.1	96.0	15.5	16.5	17.0
		4	2135	100.0	100.5	99.2	101.1	98.3	85.2	108.1	95.1	20.0	20.5	20.5
		5	2480	99.0	97.8	96.8	99.5	96.0	83.2	107.0	93.8	26.5	26.5	26.0
1049G	225	1	1929	100.1	101.4	99.4	100.9	99.4	86.8	108.6	95.7	18.0	18.5	17.0
		2	1612	101.5	104.6	103.4	104.5	102.5	89.1	110.0	97.2	12.0	13.0	13.0
		3	1959	100.7	102.3	100.3	101.5	99.9	87.0	108.7	95.7	16.0	18.0	18.0
		4	2182	99.4	101.2	100.0	100.7	99.8	86.8	107.8	94.7	19.0	19.0	17.0
		5	2511	97.3	97.8	96.5	98.7	95.7	82.8	106.2	93.1	22.5	28.0	26.5
1049G	226	1	1837	100.2	101.8	100.8	101.9	100.6	87.4	109.2	96.2	16.0	16.5	16.5
		2	1463	102.0	105.2	103.3	104.5	102.4	90.1	110.1	97.7	12.0	13.0	12.5
		3	1807	101.8	106.0	103.1	104.5	102.7	88.3	109.9	96.6	10.5	14.0	15.5
		4	2040	100.1	100.5	99.9	101.2	99.5	86.5	108.8	95.7	19.0	18.0	18.5
		5	2390	98.9	99.3	97.9	99.7	97.4	84.3	107.1	94.0	20.5	20.5	20.5

Note 1 - See Table I

2 - See Fig. 1

3 - Measured at 10 dB down from maximum values

TABLE IV

SUMMARY OF REGRESSION LINE ANALYSIS OF VARIOUS MEASURES OF FLYOVER NOISE LEVELS

Regression Line Parameter	EPNL, EPNdB	PNLM, PNdB	PNLC, PNdB	N-Level dBN	A-Level dBA	EPNL -PNLC
	A. Four Engine Turbojet Aircraft					
Slope (dB per doubling of distance	-6.7	-7.1	-7.3	-7.3	-5.8	0.6
Level in dB at 1000 ft slant distance	114.4	114.3	115.3	115.5	101.6	-1.0
$S_{y/x}$ in dB	1.1	1.3	1.2	1.3	1.4	0.5
	B. Four Engine Piston Aircraft					
Slope (dB per doubling of distance	-4.5	-7.2	-6.8	-7.0	-7.0	2.4
Level in dB at 1000 ft slant distance	104.2	106.6	107.9	105.8	92.9	-3.7
$S_{y/x}$ in dB	0.8	1.2	1.2	1.3	1.0	0.8

TABLE V

COMPARISON OF VARIABILITY IN FLYOVER NOISE MEASURES FOR REPEAT FLYOVERS OF A FOUR-ENGINE TURBOJET TRANSPORT AIRCRAFT

Flyover Noise Measure	Position 2 (Note 1)		Position 5 (Note 2)	
	Mean, dB	Std. dev., dB	Mean, dB	Std. dev., dB
EPNL	107.6	0.4	104.7	0.7
NL (int)	117.3	0.4	114.8	0.7
NL + $10 \log[-\frac{d_{NL}}{15}]$	108.5	0.5	106.6	1.1
AL (int)	104.8	0.5	102.6	0.8
PNLC	107.6	0.3	104.9	0.8
PNLM	106.6	0.6	103.9	1.0
NL	107.7	0.5	104.9	1.1
AL	95.0	0.6	92.5	1.1

Note 1 - Mean levels for seven flyovers reported for adjusted minimum slant distance of 1880 feet.

2 - Mean levels for seven flyovers reported for adjusted minimum slant distance of 2570 feet.

TABLE V.I

COMPARISON OF MEAN DIFFERENCES BETWEEN
VARIOUS FLYOVER NOISE MEASURES

Noise Measure Comparisons	Four-engine piston aircraft (Note 1)		Four-engine turbojet aircraft (Note 2)	
	Mean Difference, dB	Std. Dev. of Differences, dB	Mean Difference, dB	Std. Dev. of Differences, dB
EPNL - AL (int)	4.7	0.4	2.8	0.5
EPNL - NL (int)	1.8	0.5	0.3	0.3
EPNL - $[NL + 10 \log \frac{d_{NL}}{15}]$	0.0	0.6	-1.0	0.6
PNLM - NL	0.7	0.4	-1.0	0.2
PNLM - AL	13.6	0.5	11.4	0.5
PNLC - NL	2.2	0.7	-0.2	0.3
PNLC - AL	15.1	0.8	12.2	0.6

Note 1 - Based on 28 flyover measurements.

2 - Based on 66 flyover measurements.

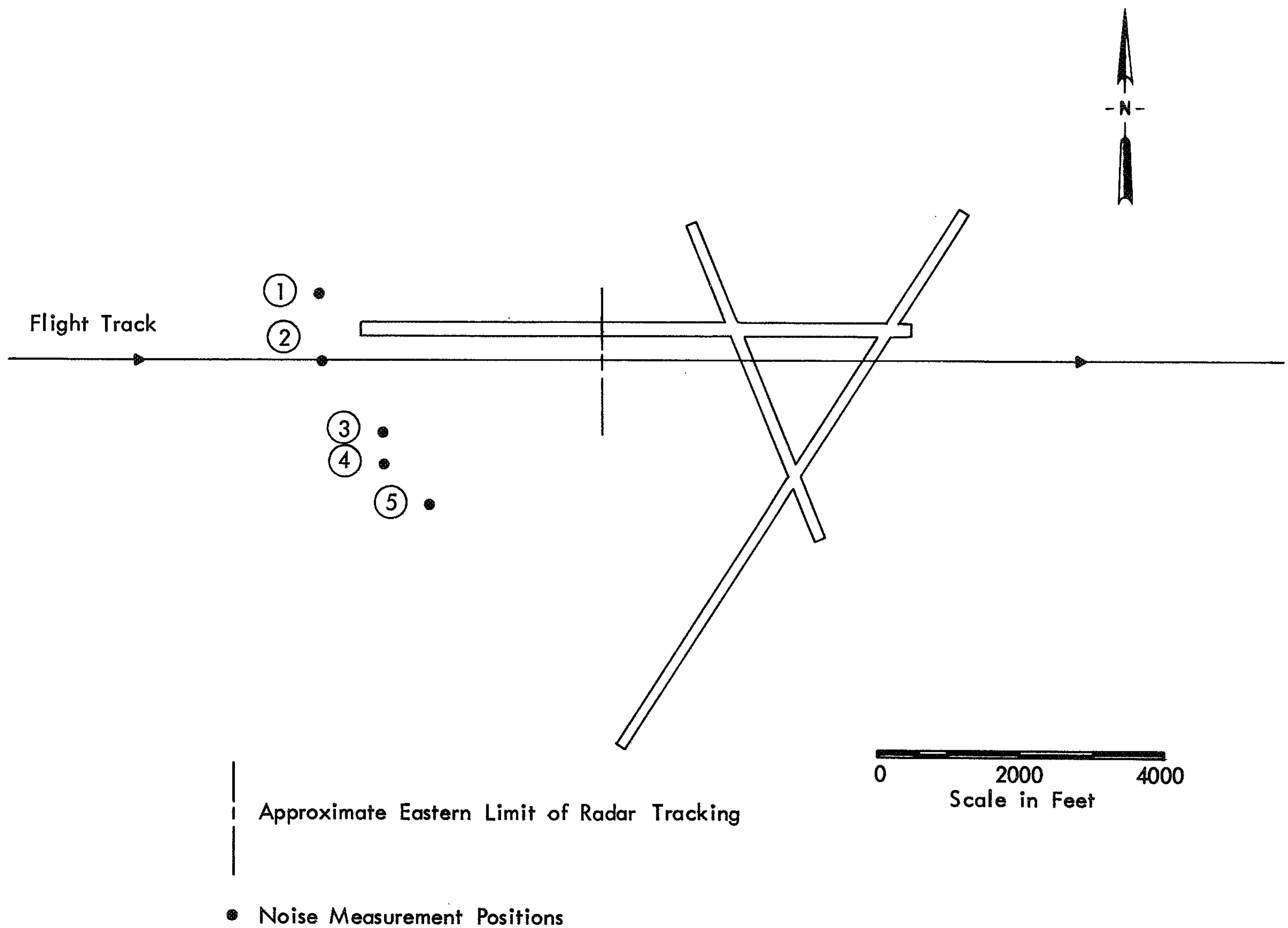
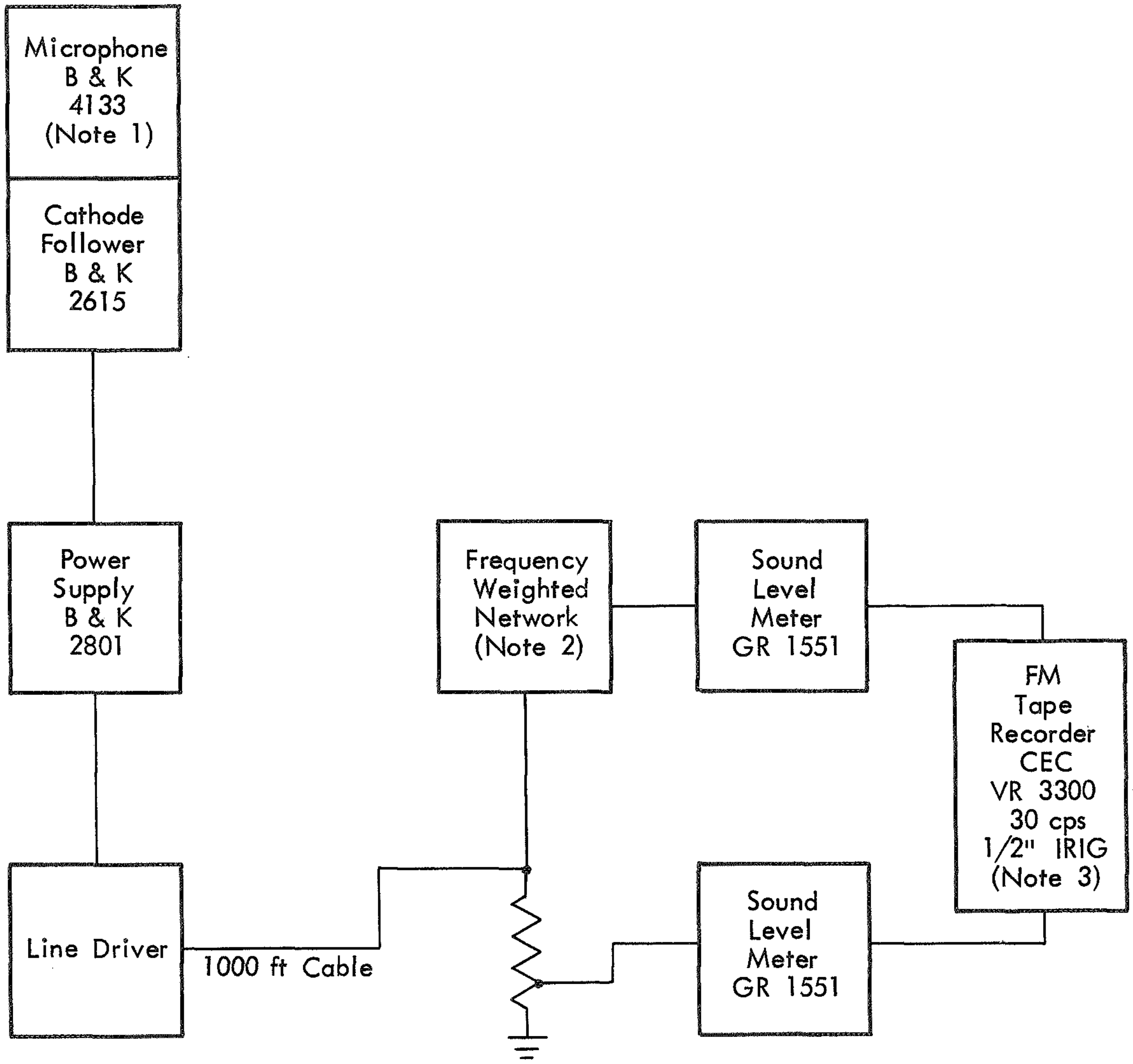


FIGURE 1. LOCATIONS OF NOISE MEASUREMENT POSITIONS WITH RESPECT TO AIRCRAFT PATH



NOTES:

1. Microphone placed 1.2 m (5 ft) above ground with diaphragm perpendicular to flight path.
2. High-pass filter, -36 dB atten at 100 Hz, -6 dB atten at 20 kHz.
3. Voice time synchronization signal (from central station) recorded on separate channel

FIGURE 2. TYPICAL FLYOVER NOISE MEASUREMENT INSTRUMENTATION

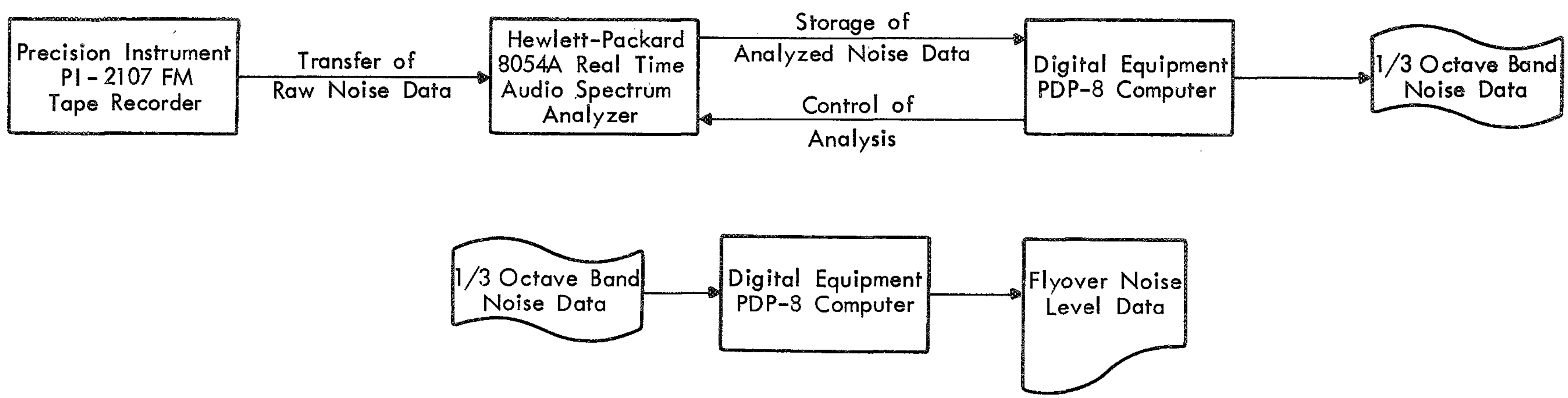
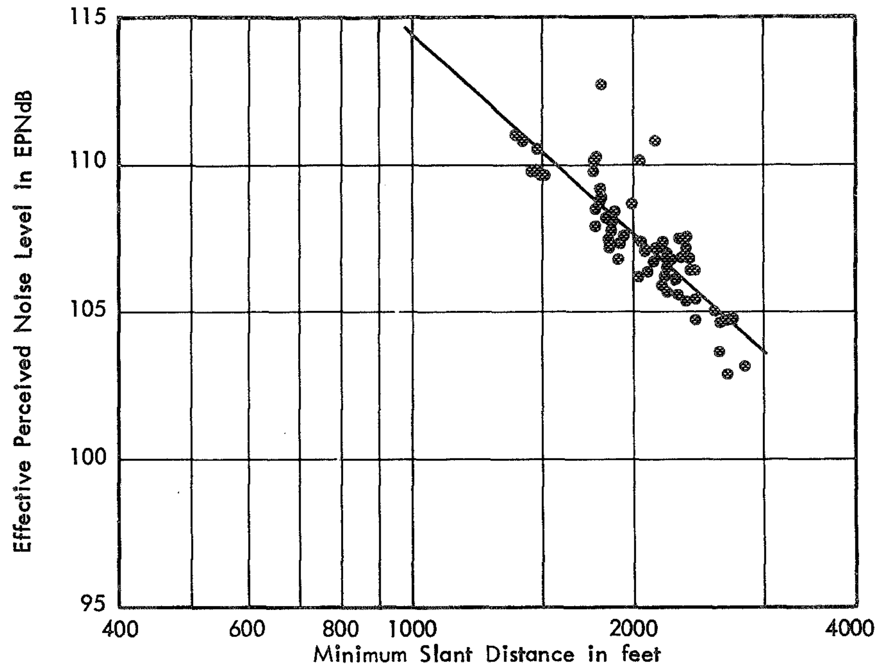
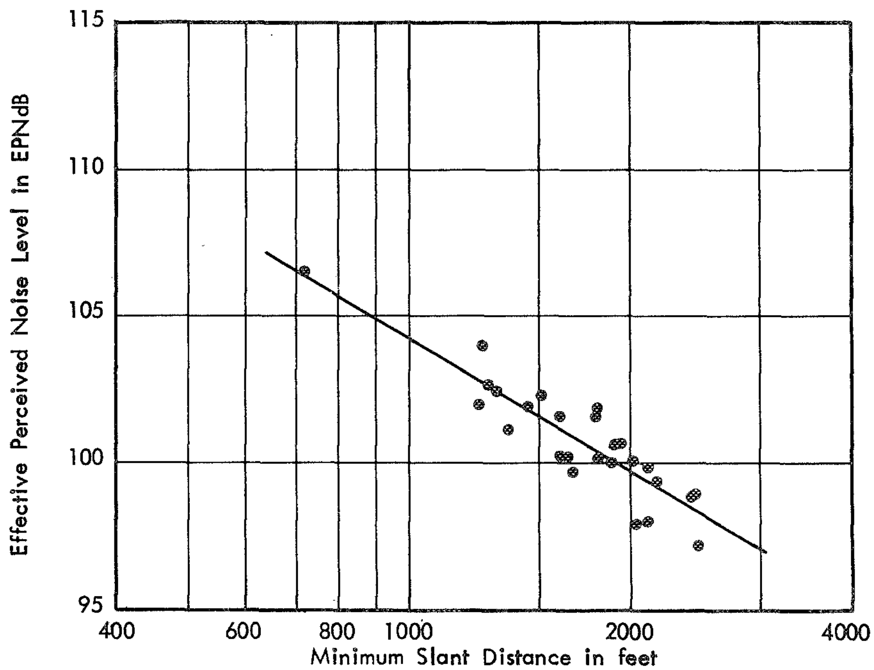


FIGURE 3. SCHEMATIC OF DATA ANALYSIS

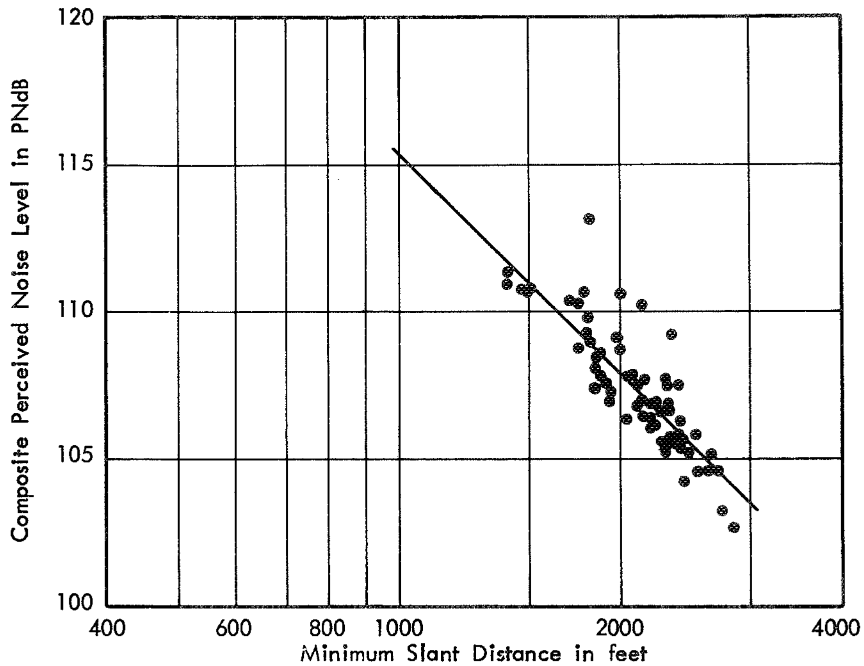


A. FOUR-ENGINE TURBOJET AIRCRAFT

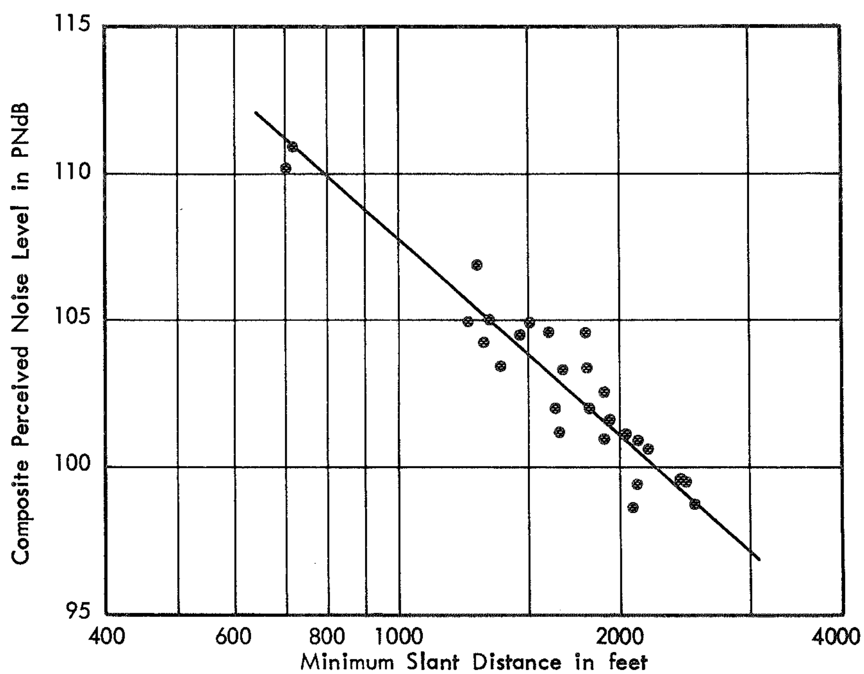


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 4. VARIATION IN EFFECTIVE PERCEIVED NOISE LEVELS (EPNL) AS A FUNCTION OF MINIMUM SLANT DISTANCE

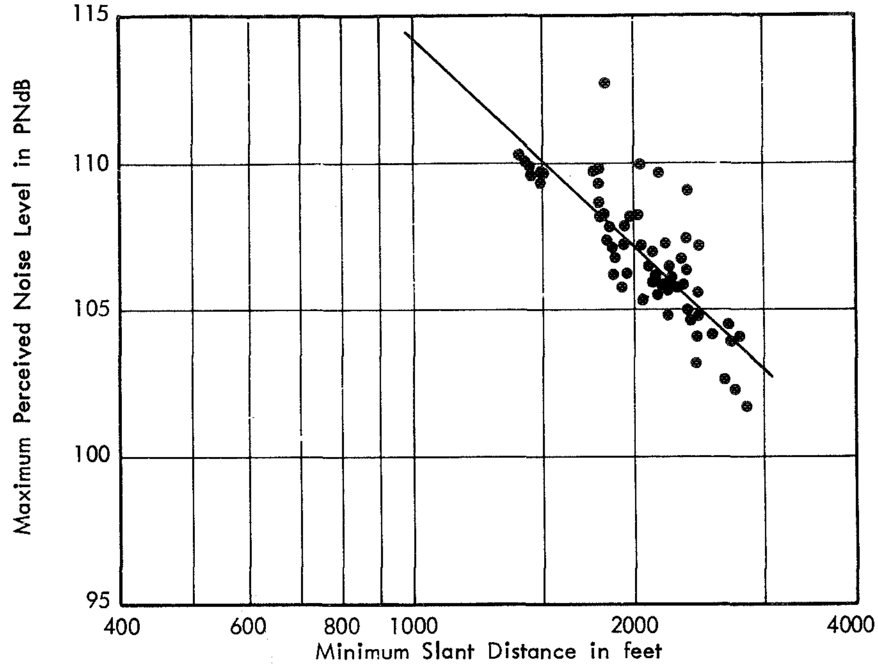


A. FOUR-ENGINE TURBOJET AIRCRAFT

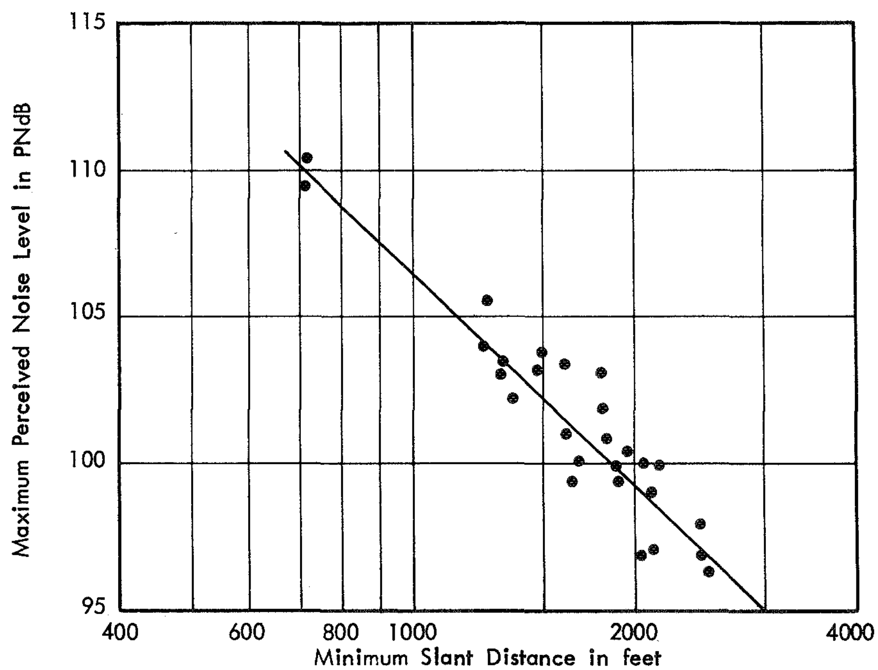


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 5. VARIATION IN COMPOSITE PERCEIVED NOISE LEVELS (PNLC) AS A FUNCTION OF MINIMUM SLANT DISTANCE

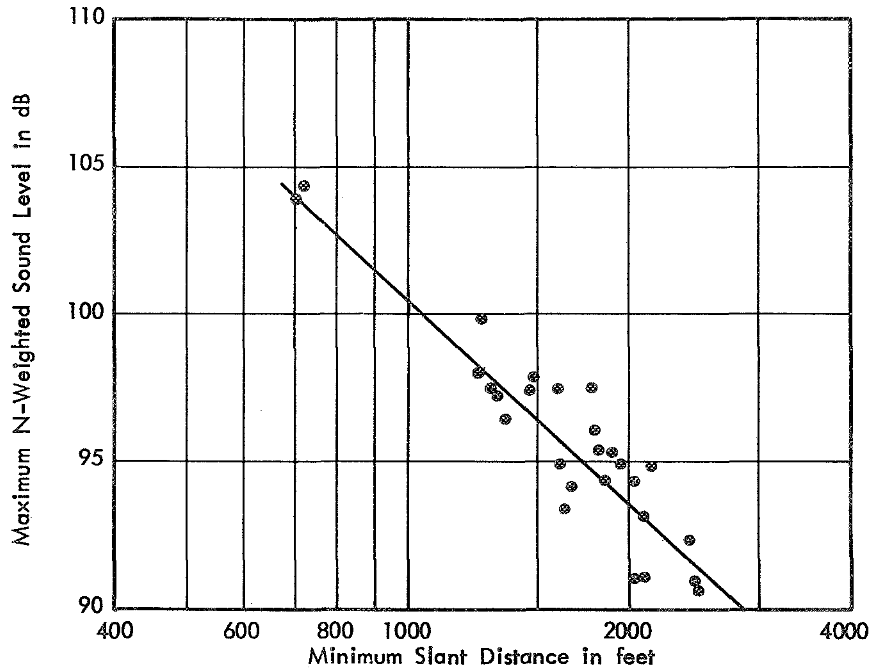


A. FOUR-ENGINE TURBOJET AIRCRAFT

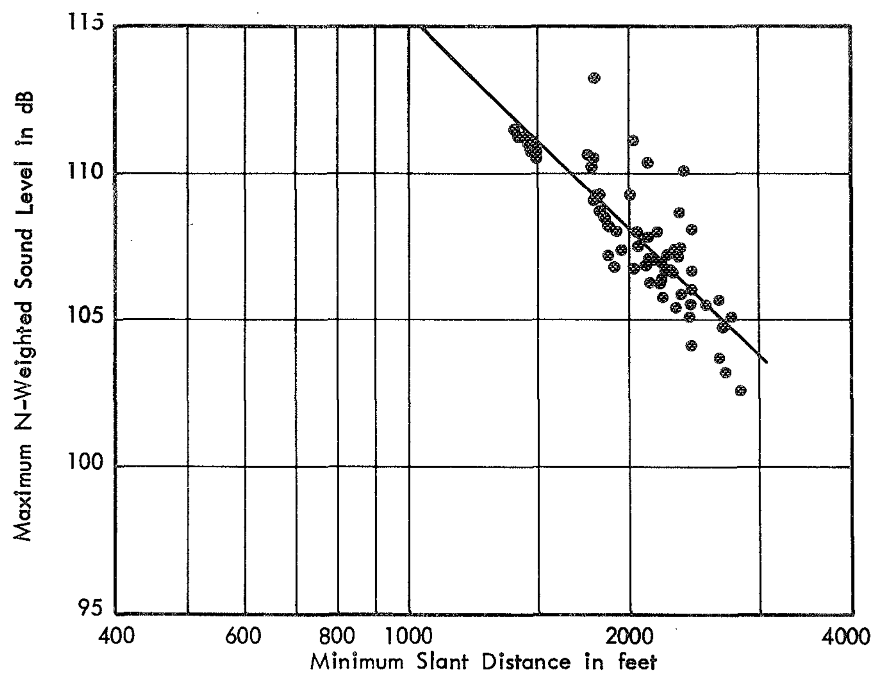


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 6. VARIATION IN MAXIMUM PERCEIVED NOISE LEVELS (PNLM) AS A FUNCTION OF MINIMUM SLANT DISTANCE

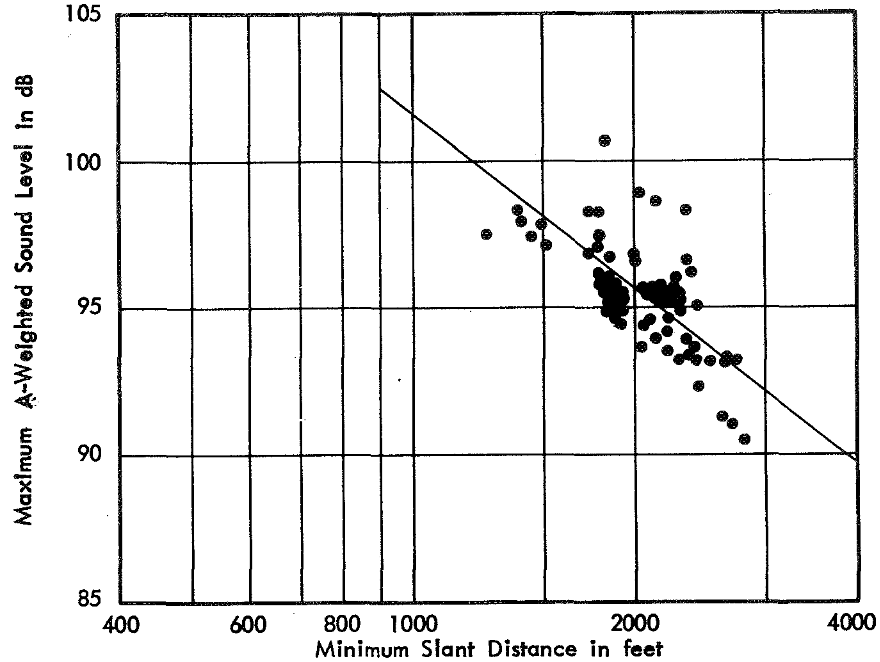


A. FOUR-ENGINE TURBOJET AIRCRAFT

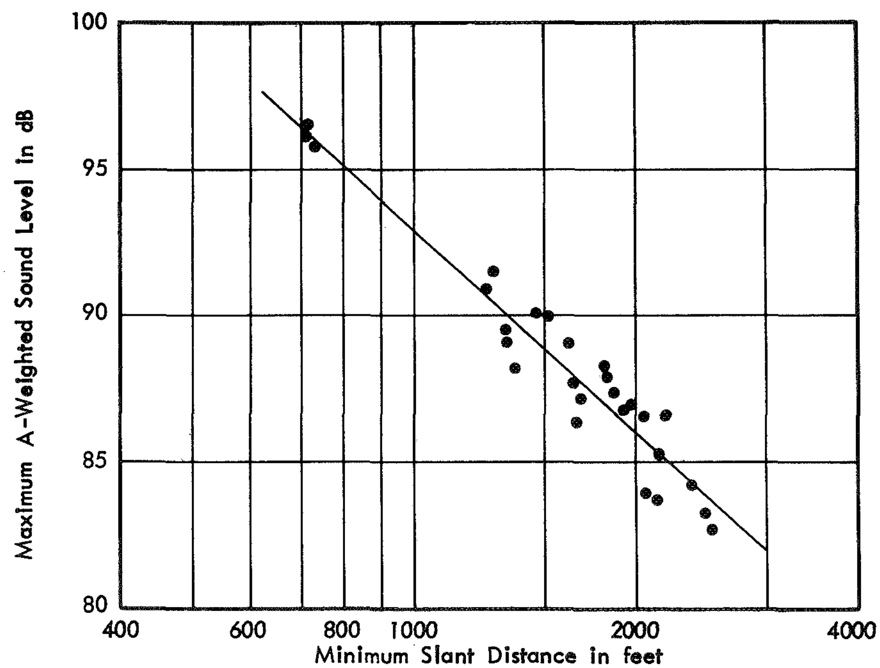


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 7. VARIATION IN MAXIMUM N-WEIGHTED SOUND LEVELS AS A FUNCTION OF MINIMUM SLANT DISTANCE

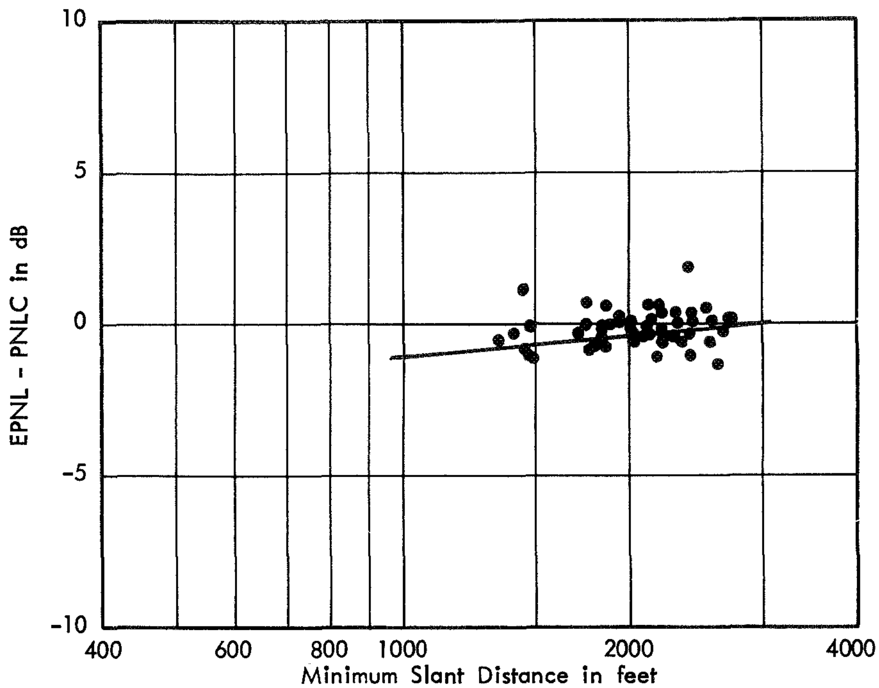


A. FOUR-ENGINE TURBOJET AIRCRAFT

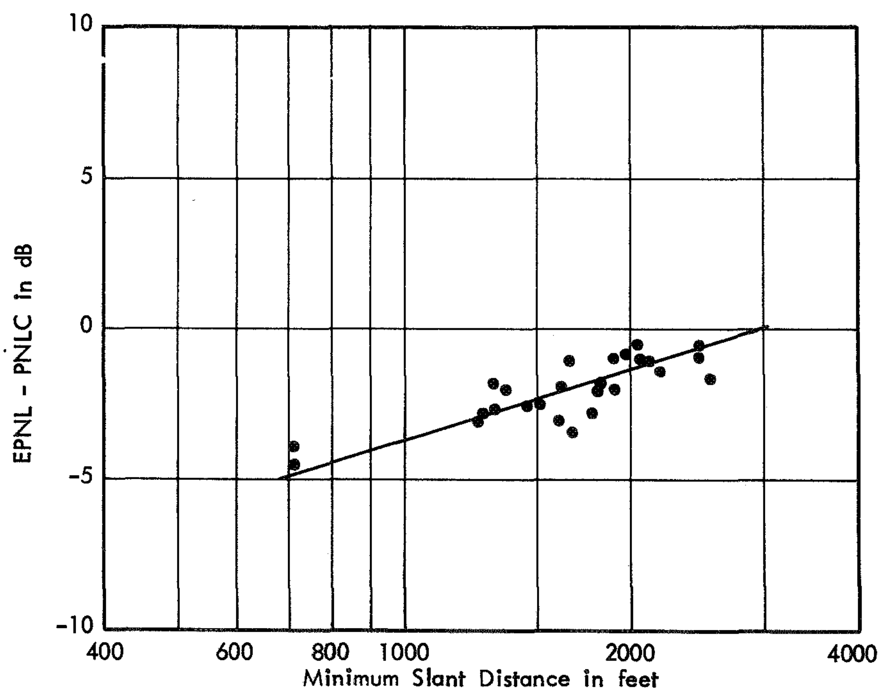


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 8. VARIATION IN MAXIMUM A-WEIGHTED SOUND LEVELS AS A FUNCTION OF MINIMUM SLANT DISTANCE

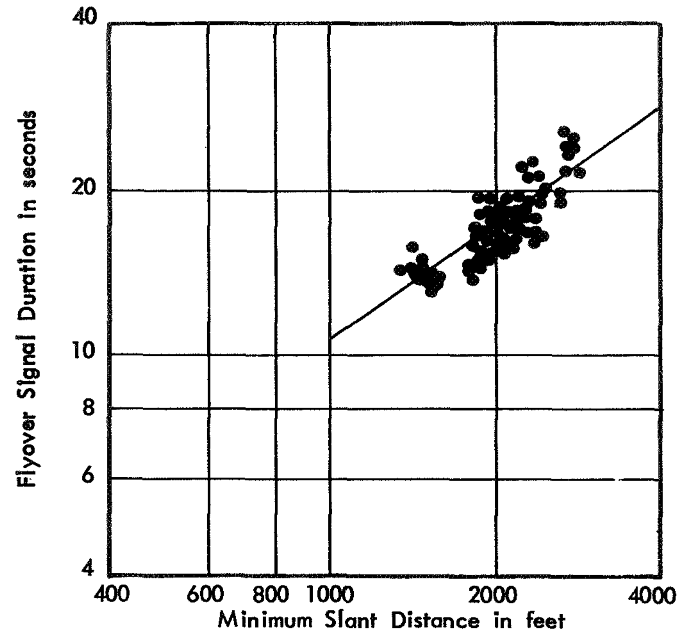


A. FOUR-ENGINE TURBOJET AIRCRAFT

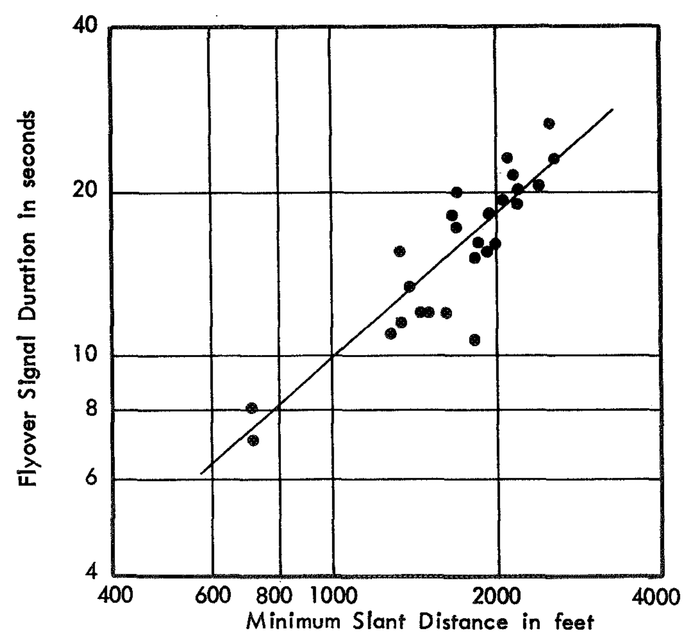


B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 9. DIFFERENCES BETWEEN EFFECTIVE PERCEIVED NOISE LEVELS AND COMPOSITE PERCEIVED NOISE LEVELS AS A FUNCTION OF MINIMUM SLANT DISTANCE



A. FOUR-ENGINE TURBOJET AIRCRAFT



B. FOUR-ENGINE PISTON AIRCRAFT

FIGURE 10. FLYOVER SIGNAL DURATION WITHIN 10 dB OF THE MAXIMUM TONE-CORRECTED PERCEIVED NOISE LEVEL AS A FUNCTION OF MINIMUM SLANT DISTANCE

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