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AN ANALYSIS OF AIRCRAFT FLYOVER NOISE

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FOR THE COMMANDER

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A detailed analysis of a set of Boeing 727 aircraft flyover noise measurements is presented. The flyover data were acquired over a wide range of sideline distances and angles of aircraft elevation with respect to the measurement position. Relationships are derived for excess attenuation due to ground effect and reflection interference as a function of both frequency and angle of aircraft elevation. Angle of elevation is found to be the →

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SUMMARY

A detailed analysis of a set of Boeing 727 aircraft flyover noise measurements is presented. The flyover data were acquired over a wide range of sideline distances and angles of aircraft elevation with respect to the measurement position. Relationships are derived for excess attenuation due to ground effect and reflection interference as a function of both frequency and angle of aircraft elevation. Angle of elevation is found to be the principal normalizing factor for excess attenuation in the frequency range 50 - 1600 Hz over measurement distances of 800 - 9000 feet. Ground effect, separable from ground reflection interference phenomena in this analysis, was found to be a maximum in the frequency range 125 - 400 Hz and as high as 17 dB at an aircraft elevation angle of 4°. No significant ground effect was identified at elevation angles greater than 50°. Spectral distortion due to reflection interference is found to be important at high angles of elevation but diminishes rapidly at aircraft elevation angles of less than 20°. Engine or fuselage shielding effects were not obvious in the data and could not be quantified from the analysis. Recommendations are presented on the use of the results of this analysis to guide the development of improved flyover noise prediction techniques.

PREFACE

This research was performed for the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio under Project/Task 723104, Measurement and Prediction of Noise Environments of Air Force Operations. Technical monitor for this effort was Mr. Jerry D. Speakman of the Biodynamic Environment Branch, Biodynamics and Bioengineering Division.

The author would like to acknowledge, with thanks, the efforts of the Boeing Company to make available the data upon which this study was based.

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INTRODUCTION

In a recent review of aircraft sideline noise[1], trends in exce ,s attenuation (attenuation not clearly attributed to distance spreading or atmospheric absorption factors) were found to be a strong function of the angle of elevation of the aircraft with respect to the observer. This characteristic has been reported previously and is interesting since many excess attenuation prediction models include distance as well as angle of elevation as a principal variable upon which attenuation magnitudes are based.

The prior review examined several aircraft flyover data sets and excess attenuations were generally limited to evaluation in Effective Perceived Noise Levels (EPNL). This measure is a complex calculation involving frequency weighting, tone corrections, and time integration. Results of this type do not usually support the development of any more than a gross empirical relationship for excess attenuation. A more detailed analysis was included in the previous report for samples of Boeing 727 aircraft flyover data where one-third octave band time history information was available. Excess attenuations of 15 to 20 dB were clearly evident in these data. These results, moreover, were found to be consistent with 727 data reported in the review from other sources.

This preliminary detailed analysis of the 727 data, although limited in scope, proved to be interesting, and a more complete analysis of the data from this same test program has now been completed to include a more diverse range of aircraft altitudes (400, 850, 1400 feet) and sideline distances (overhead to 9000 feet). Angles of elevation of the aircraft with respect to the observer range from 2.5° to 90°. This report presents the results of these further analyses and offers recommendations for use of the results in the continuing development of improved methods for flyover noise prediction.

DISCUSSION

Even today, there still exists a basic inability to physically relate aircraft flyover noise measurements taken at positions where the angles of elevation of the aircraft with respect to the observer are substantially different. The presence of the ground surface, together with a possible partial shielding of the noise source on multi-engine aircraft are both effects which at first sight are sensitive to elevation angles.

For example, measurements under the flight path, using a microphone height of say 4 feet, are severely distorted by sound wave reinforcement and cancellation at the microphone due to the presence of the reflected wave from the ground. This interference effect is frequency dependent and thus will impact flyover measurements differently for aircraft having disimilar noise signatures. On the other hand, when angles of elevation become smaller, a progressively increasing attenuation, with a broad maximum in the range of 125-500 Hz is often reported. The latter is popularly referred to as ground effect and is considered to result from sound propagating at near grazing incidence over a finite impedance ground surface. As with classical interference, this phenomenon is also frequency dependent and potentially impacts aircraft noise to a varying degree depending upon the spectrum of the aircraft noise signature.

Although considerable research has been undertaken on sound propagation over ground and sophisticated mathematical models proposed and supported through sometimes limited experimental evidence, a satisfactory and useable model for an aircraft-independent prediction scheme for flyover noise has not resulted. In fact, a continuing technical controversy exists on how to effectively handle the problem. This situation is encouraged, no doubt, by the need to seek a meaningful solution in a state of relative scientific bewilderment.

The problem is not trivial. Poorly based noise prediction methods can result in inadequate noise exposure estimates or the need for substantial adjustment to estimates through extensive and sometimes expensive noise monitoring programs.

One of the major problems in the development of an excess attenuation model has been a lack of substantial data. Many empirical prediction schemes have been proposed based on studies of extensive flyover data in subjective noise measures such as EPNL. While such an approach may be partly successful, unless they are developed specifically for each generic aircraft type, they do not represent a generalized method for noise prediction. On the other hand, frequency dependent attenuation factors have been developed although their application may not be totally appropriate for a broad variety of flyover noise measurement situations since the data base for these analyses has not been from actual flyovers. In parallel is a further deterrent to the development of a good data base - the detailed analysis of flyover data is a time consuming and somewhat tedious procedure. Computer applications can obviously minimize the effort required, although considerable foresight is necessary to prepare for such analyses. Postmortem analysis, undertaken after all the conventional data processing is complete, is a far from optimum approach.

The study reported here does not aim to provide a general solution to the excess attenuation problem. It does aim, however, to demonstrate that a relatively simple but thorough analysis of flyover data sets can uncover significant data trends relating to the character of excess attenuation. While it is difficult to say whether the trends reported would be the same for all aircraft, the study may serve to encourage derivative studies of a similar type for other aircraft. A combination of findings from several independent studies together with suitable interpretations could lead to substantial improvements in flyover noise prediction.

FLYOVER DATA DESCRIPTION

The Boeing Company, as part of a retrofit feasibility program, undertook extensive flyover noise measurements on the 727 aircraft[2]. Data were acquired simultaneously on either side of the flight track to sideline distances of 6000 feet and on one side of the flight track to a distance of 9000 feet. Aircraft altitudes ranged from 400 to 9000 feet. All data analyzed in this study are from microphones located 4 feet above ground level. The ground surface was sandy soil with a light scattered sagebrush cover.

The overall test program included a large matrix of engine power settings and aircraft flyover altitudes. The analyses reported herein represent an abbreviation of the total data and are limited to the highest engine thrust condition and to the nominal flyover altitudes and sideline measurement distances given in the table below.

	Sideline Distance, Ft.					
	0	+750	±1500	±3000	±6000	+9000
Altitude Feet	Angle of Elevation, degrees					
400	-	28	15	7.6	3.8	2.5
850	90	49	29	16	8.1	5.4
1400	90	62	43	25	13	8.8

For each flyover, measurements were tak... at all sideline positions simultaneously. Unfortunately, data from the microphone located on the flight track is not available for the 400 foot altitude flyover. Also, although the microphone array was generally symmetrical about the flight track, there was no microphone located at the -750 foot nor the -9000 foot sideline positions.

The data used for analysis in the study was basic, and comprised:

- one-third octave band spectrum and A-level time histories using one-half or one second integration times
- aircraft position relative to the nominal altitude and flight track
- aircraft speed and thrust setting
- local ground station observations of the ambient temperature and relative humidity.

DATA ANALYSIS

The following paragraphs outline the calculations that were undertaken on the flyover data. A tabular summary of all of the derived values used in the analyses may be found in the Appendix to this report.

Composite Flyover Spectrum

The composite spectrum comprises the maximum one-third octave band levels recorded during the flyover event even though these maxima may not have occurred at the same instant in time. This spectrum may be A-weighted to give a composite A-level which will generally be between zero and 2 dBA above the maximum A-level actually recorded during the flyover event.

Integrated Flyover Spectrum

The integrated spectrum comprises the time integral of each one-third octave band during the flyover event normalized to a reference duration of one second. Integration limits for each band were, at a minimum, the 10 dB downpoint during the event. Thus:

$$IL(i) = 10 \log \int_{-\infty}^{+\infty} 10^{\frac{L(i)}{10}} dt$$

where IL(i) = integrated level of ith frequency band

L(i) = level of ith frequency band at time t

or, when computed from flyover signals sampled at discrete intervals

$$IL(i) = 10 \log \sum_{K=0}^{K=\frac{d}{\Delta t}} 10^{\frac{L(i)K}{10}} + 10 \log \Delta t$$

where d is the time interval during which L(i) is within 10 dB of the maximum value of L(i), and Δt is the time interval between noise level samples.

The integrated spectrum may also be A-weighted to give a form of the sound exposure level (SEL). Although strictly speaking SEL is a time integral of the A-level time history, in practice the results indicated essentially no numerical difference between the two methods of calculations. Of course, this fact may *not* hold true for aircraft with spectral characteristics differing from those of the 727.

Normalized Flyover Spectra

Both composite and time-integrated flyover spectra were normalized to a distance of 1000 feet using traditional distance ($\frac{1}{r^2}$) and atmospheric absorption values (per ARP 866)[3]. For application of absorption factors, a directivity angle of 115° was assumed for all frequencies. While this assumption could give rise to errors when normalizing data from large sideline distances or at higher frequencies, it provides a reasonably close estimate for absorption losses by using a realistic directivity angle.

For the composite spectra, normalization is straightforward. Corrections were added to each one-third octave band as follows:

$$\text{dB correction} = 20\text{Log}\frac{d}{1000} + \frac{(d-1000)}{\text{Sin }115^\circ}\ \frac{\alpha}{1000}$$

where d = closest distance of approach (CPA) of aircraft to measurement position

α = absorption in dB/1000 ft per ARP 866 for the frequency band.

For the integrated spectrum, distance and absorption adjustments must also be made. In addition, the normalization process must consider the changing duration characteristics of the flyover event with distance. This is usually accomplished with an adjustment factor which effectively increases the duration of the event by a factor of two (or 3 dB) for each doubling of distance from the source (10 dB per decade of distance increase). This duration effect is reflected in an increase in the numerical difference between the integrated level and the maximum level as the distance between the source and receiver increases.

When compared with measured data, 10 dB per decade distance adjustments tend to overestimate the duration effect. Several available data sets[4] indicate a duration adjustment with distance closer to 5 to 7 dB per decade. To minimize errors in normalization, the best straight line relationships between the integrated level minus maximum level and log distance (CPA) were determined for each one-third octave band. The slope of this best fit line was used to normalize the duration effect of the data with the following equation:

$$\text{dB correction} = (20-b)\text{Log}\frac{d}{1000} + \frac{(d-1000)}{\text{Sin }115^\circ}\ \frac{\alpha}{1000}$$

where d and α are the CPA distance and absorption factor respectively and b is the slope of the "duration effect" line in dB/decade.

The normalized spectra provide the basis for determining excess attenuation (which can be either positive or negative) between the various measurement positions. The general concept of this approach is important since it obviates the need for selecting any one particular measurement location (for example, overhead) as a reference point when there is no a priori knowledge of any ground effects that are present in that spectrum.

In normalization, it is also important to take into account variations in aircraft thrust setting and speed between each flyover event. In the data set studied, aircraft thrust setting was essentially constant for all test conditions and no corrections were required. Flyovers were normalized to a speed of 300 feet per second - only the 400-foot flyover required a small (-0.5 dB) adjustment in the integrated band values.

RESULTS

A summary of flyover information pertaining to each of the data sets used in the study is presented as Table 1. For each nominal altitude and sideline distance, the following information is given:

CPA - closest point of approach of aircraft to microphone during flyover

δ - angle of elevation of aircraft with respect to the microphone at the aircraft CPA

SEL - sound exposure level from integration of A-level time history

AL - the maximum A-level recorded during the flyover event.

The ground station temperature and relative humidity for each flyover is also given. A-level time histories were not available for the 850 foot altitude flyover at the overhead and 6000 foot sideline measurement positions.

TABLE 1 - SUMMARY OF AIRCRAFT FLYOVER INFORMATION

	Nominal Sideline Measurement Distance, Ft.								
	0	+750	+1520	-1520	+3000	-3000	+6000	-6000	+9000
	Aircraft Altitude 400 Ft (T=69°F, RH=33%)								
CPA, ft.	-	776	1506	1612	2978	3065	5986	6033	9003
δ °	-	26.3	13.2	12.4	6.6	6.5	3.3	3.2	2.5
SEL	-	105.8	97.6	96.1	91.2	90.8	74.1	77.2	70.1
AL	-	100.3	89.1	87.2	83.1	81.3	66.7	65.1	56.2
	Aircraft Altitude 850 Ft (T=62°F, RH=40%)								
CPA, ft.	813	1045	1642	1809	3029	3190	5990	6113	8992
δ °	83.3	51.1	29.7	26.7	15.5	14.7	7.6	7.3	4.9
SEL	108.2*	107.3	98.7	97.7	92.2	92.6	81.1*	84.9*	76.8
AL	-	101.7	91.9	89.8	81.1	85.1	-	-	63.7
	Aircraft Altitude 1400 Ft (T=62°F, RH=38%)								
CPA, ft.	1382	1521	1975	2131	3219	3390	6089	6228	9058
δ °	84.7	64.9	44.2	40.3	25.4	24.1	13.2	12.9	9.0
SEL	106.2	106.1	101.6	98.7	93.7	93.0	86.9	85.9	80.7
AL	97.8	98.8	94.9	92.9	84.7	83.3	76.3	75.2	69.5

* Values calculated from integrated noise spectra rather than from A-level time histories.

SEL and A-level Relationships with Distance

Figures 1 and 2 show the relationship between SEL* and AL respectively as a function of CPA distance. Included on each of these figures for relative comparison are curves from Ref. 5 for SEL and AL based upon extrapolation using standard distance and absorption values (air-to-ground propagation). Although the absolute y-axis location of the reference curves is arbitrary, they have been located so as to pass through the group of data points at a CPA distance of approximately 3000 feet. This point was chosen because, from a preliminary view of the data, the slope of the reference curves seem to fit the data points well where elevation angles were between 10° and 30°. These points include CPA distances ranging from 1500 to 9000 feet. At higher angles of elevation, greater than about 30°, data points appear relatively high compared to the reference curve and at low angles of elevation, less than 10°, a generally progressive increase in attenuation with decreasing angle is noticeable. These trends are considered significant and will be discussed later.

Duration Effects

For time-integrated noise measures such as SEL, the principal reason that levels reduce with increasing distance between source and receiver is the attenuation of sound due to distance spreading and atmospheric absorption. However, in an integrated measure, these losses are somewhat offset by the fact that at greater distances, the integral value is increased relatively speaking due to a longer time history characteristic. It is generally assumed that this duration effect results in a 3 dB increase for each doubling of distance - or 10 dB/decade. The actual relationship may be characterized by examining the difference between the integrated and maximum values (A-level or 1/3 octave band) during the flyover event and the CPA distance between source and receiver.

Since the actual duration effect must be determined before normalization of SEL or integrated band levels to a given distance can be reasonably accomplished, relationships between the time-integrated and maximum values for both A-level and each one-third octave band were established.

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* Except for the three instances noted in Table 1, SEL values represent integration of measured A-levels with time.

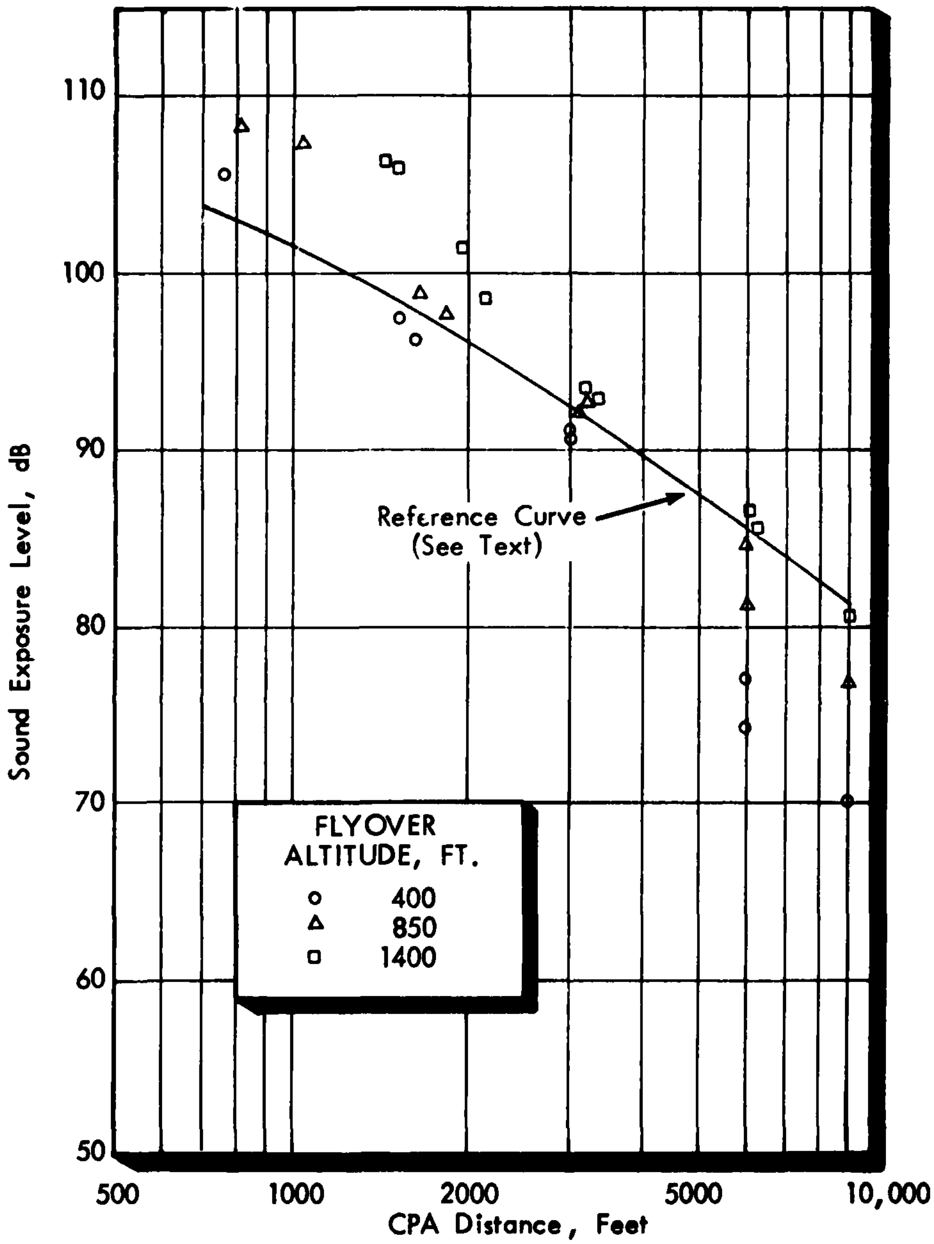


FIGURE 1. SOUND EXPOSURE LEVEL AS A FUNCTION OF AIRCRAFT CPA DISTANCE

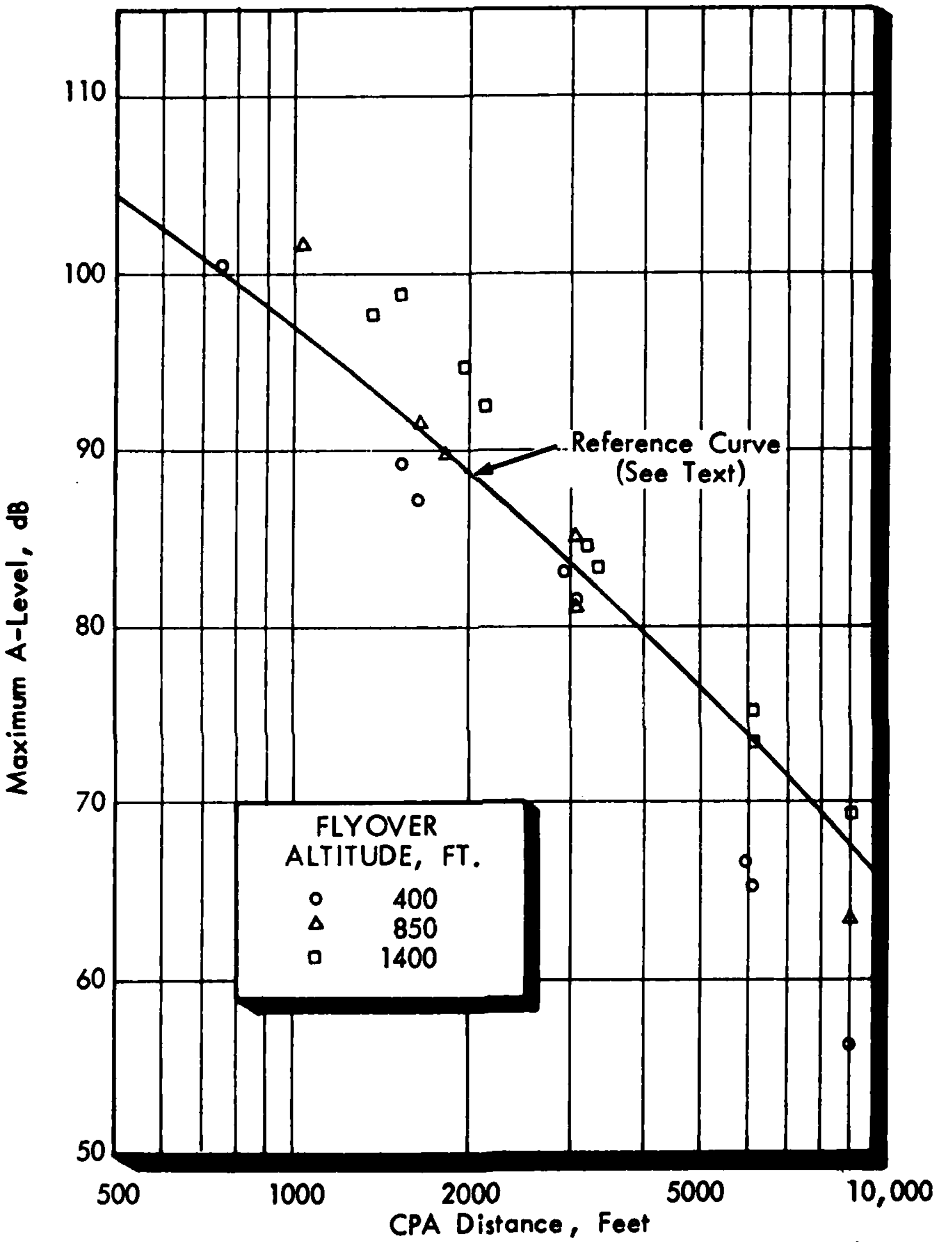


FIGURE 2. MAXIMUM A-LEVEL AS A FUNCTION OF AIRCRAFT CPA DISTANCE

Linear regression lines were determined assuming that the following relationship was realistic:

(Time-Integrated)-(maximum level) = a + bLogx

where x is the CPA distance.

In this assumed relationship, b is the line slope and is equal to the duration effect in dB/decade. The value b for each frequency band can then be used to normalize integrated data from the measured distance to the reference distance using the equation outlined in the data analysis section.

Figure 3 presents data, with the regression lines shown, for both A-level and two representative one-third octave frequency bands. A summary of the values of b for each frequency band are shown graphically on Figure 4 together with the correlation coefficient determined for each line. A tabular summary of the information given on Figure 4 is provided in the Appendix.

Figure 4 shows that the duration effect is relatively frequency independent and while slight variations do exist between bands, these variations do not appear to be significant. A duration effect of 6 to 6.5 dB/decade is indicated. This is in good agreement with the average change of 5.7 dB/decade reported in Ref. 4 for analysis of both approach and takeoff noise signals produced by several types of jet aircraft[6].

Excess Attenuation from Normalized Spectra

When distance and absorption factors have been corrected for, any differences that remain between the data sets may be assigned to the category of excess attenuation. If effects due to engine or fuselage shielding are present in the data, then these would necessarily be included in such a gross approach. This fact must be remembered, particularly if relationships between excess attenuation and aircraft elevation angle are considered at high elevation angles - for example, at angles greater than 30°. However, all excess attenuations, whether resulting from ground effects or shielding, will be considered together in this study.

Normalized time-integrated and maximum sound pressure levels are presented as a function of aircraft angle of elevation on Figure 5 for each one-third octave frequency band up to a center frequency of 1600 Hz. The 1600 Hz band was the highest frequency

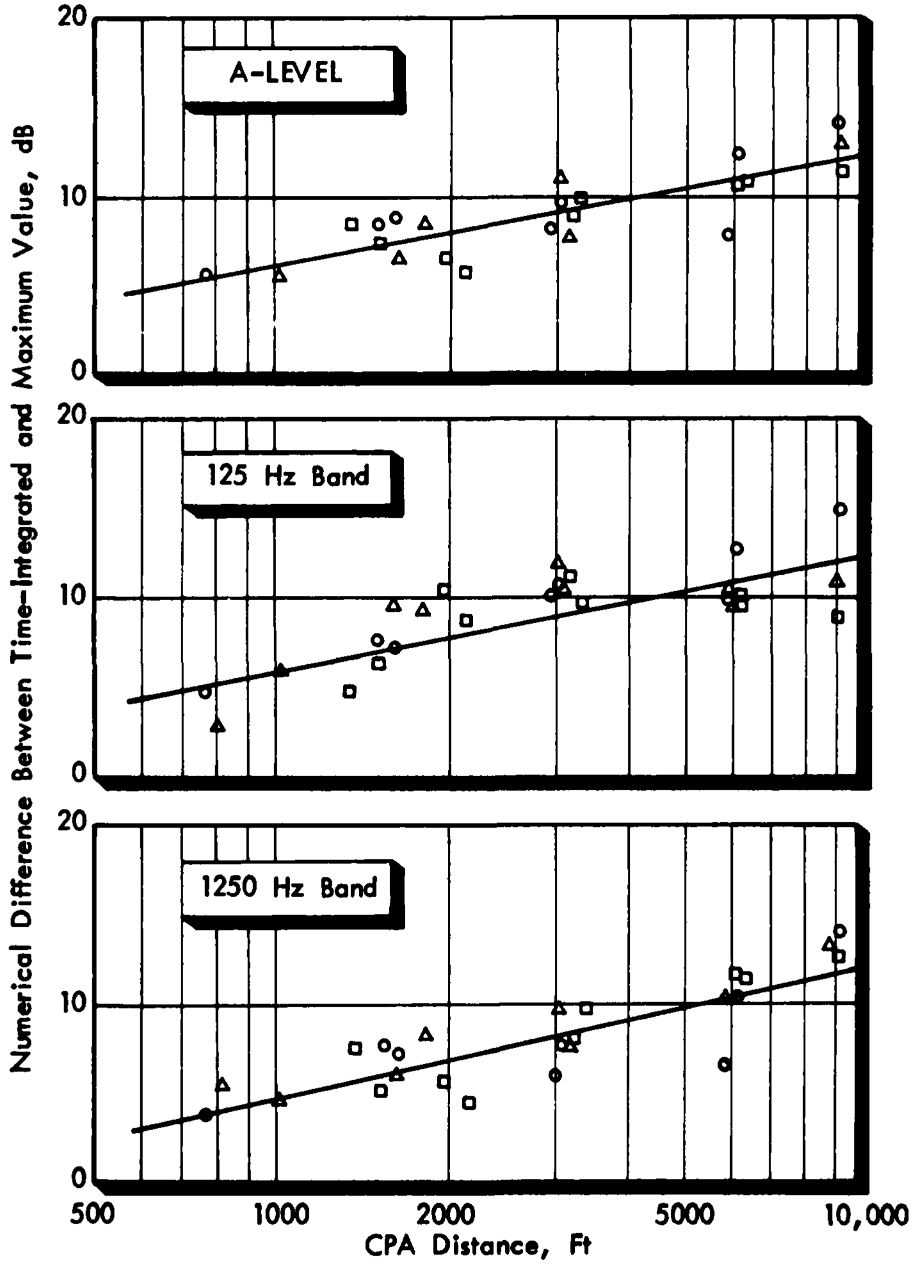


FIGURE 3. RELATIONSHIP BETWEEN TIME-INTEGRATED AND MAXIMUM LEVELS DURING FLYOVER AS A FUNCTION OF AIRCRAFT CPA DISTANCE

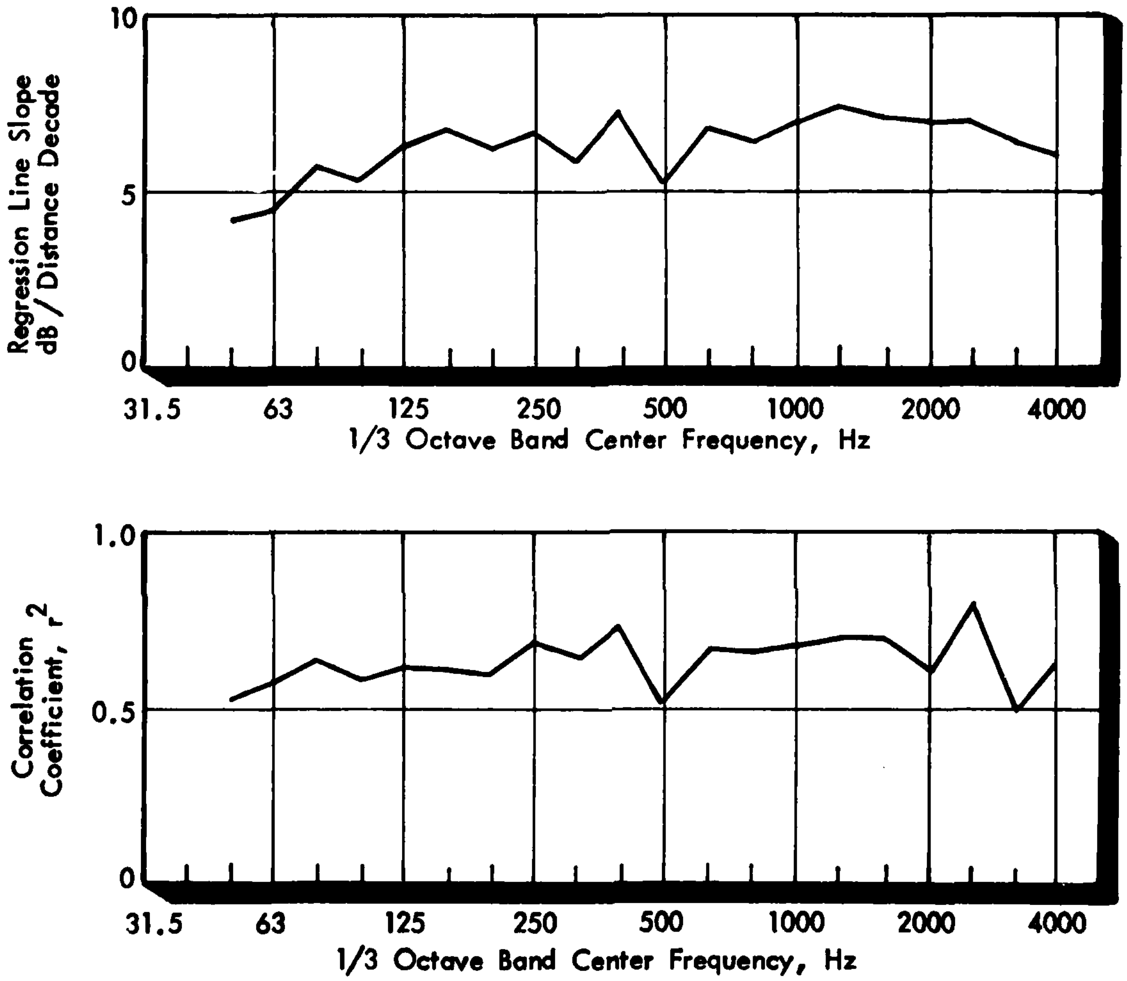


FIGURE 4. SUMMARY OF REGRESSION ANALYSIS TO DETERMINE DURATION EFFECT AS A FUNCTION OF FREQUENCY

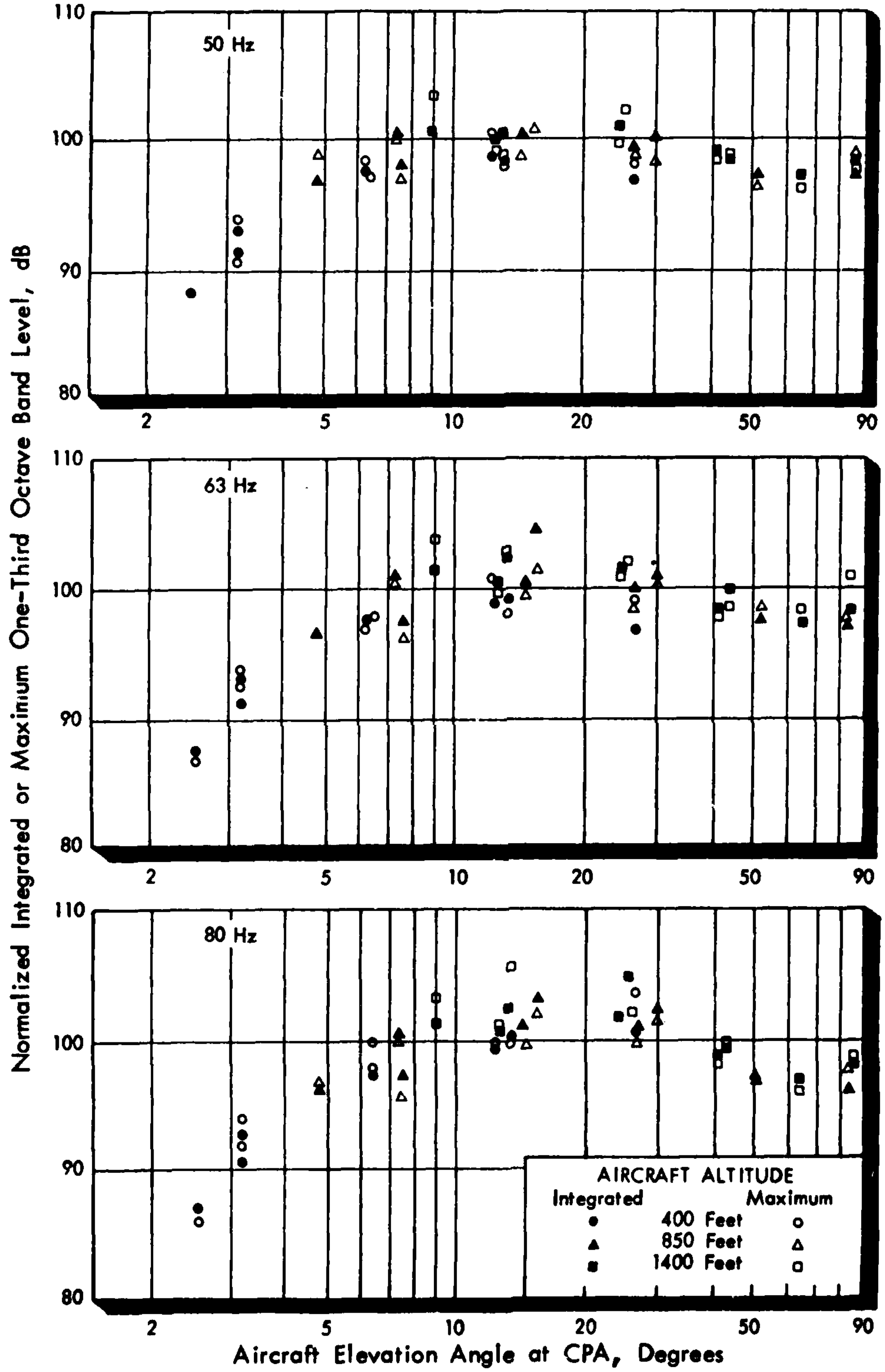


FIGURE 5. INTEGRATED AND MAXIMUM ONE-THIRD OCTAVE BAND LEVELS NORMALIZED TO A DISTANCE OF 1000 FEET AS A FUNCTION OF AIRCRAFT ELEVATION ANGLE

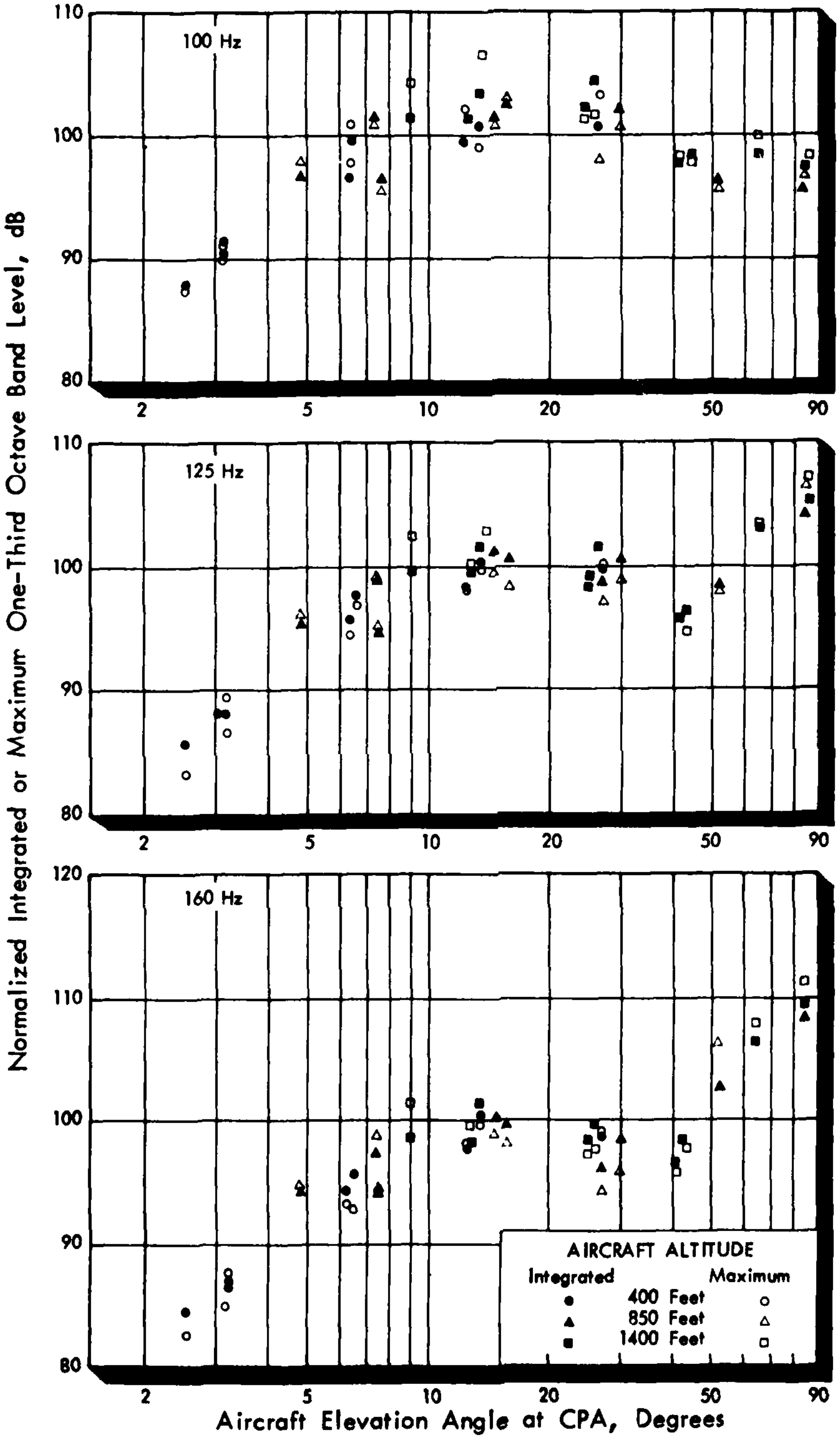
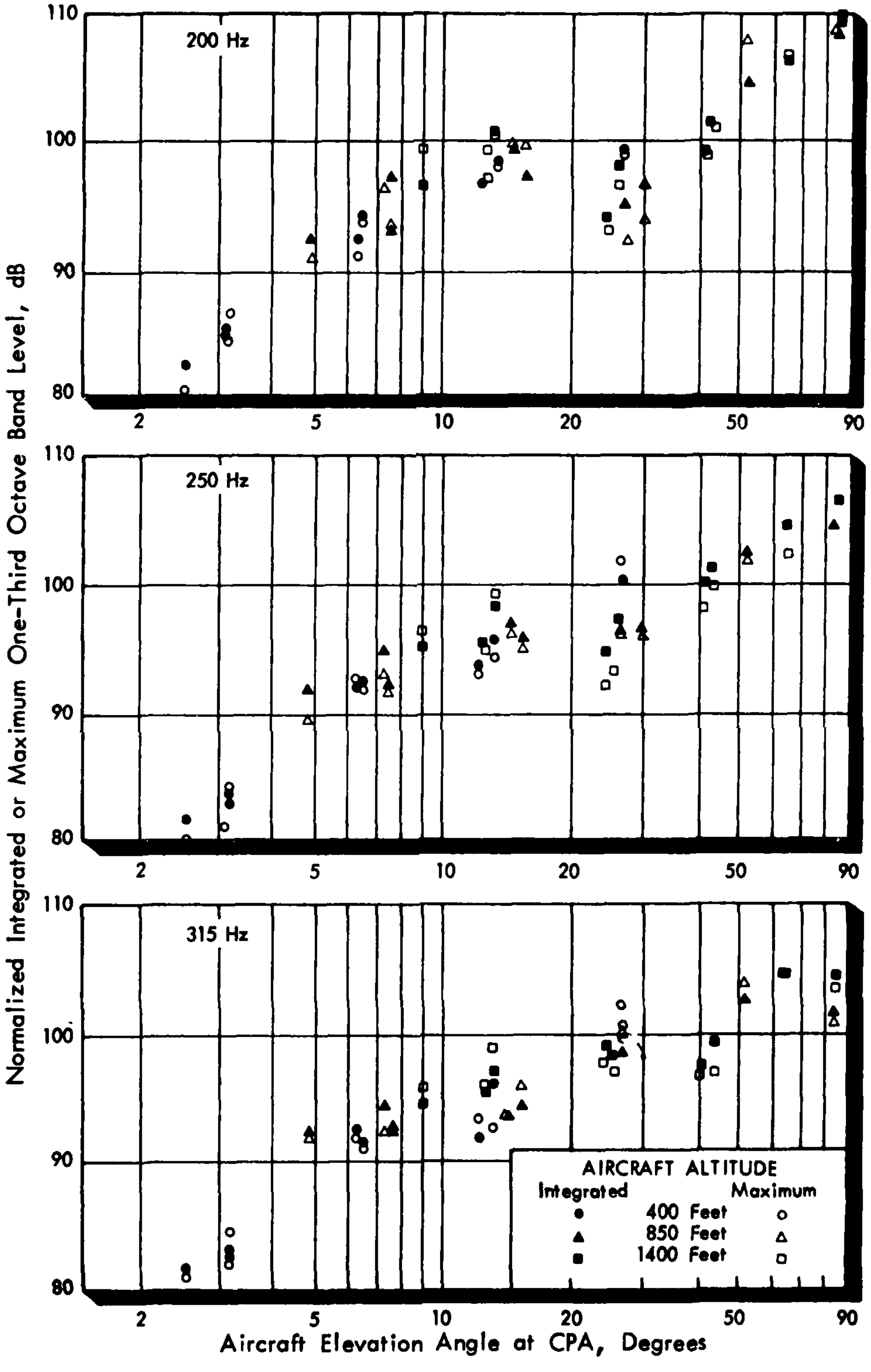


FIGURE 5. (CONTINUED)



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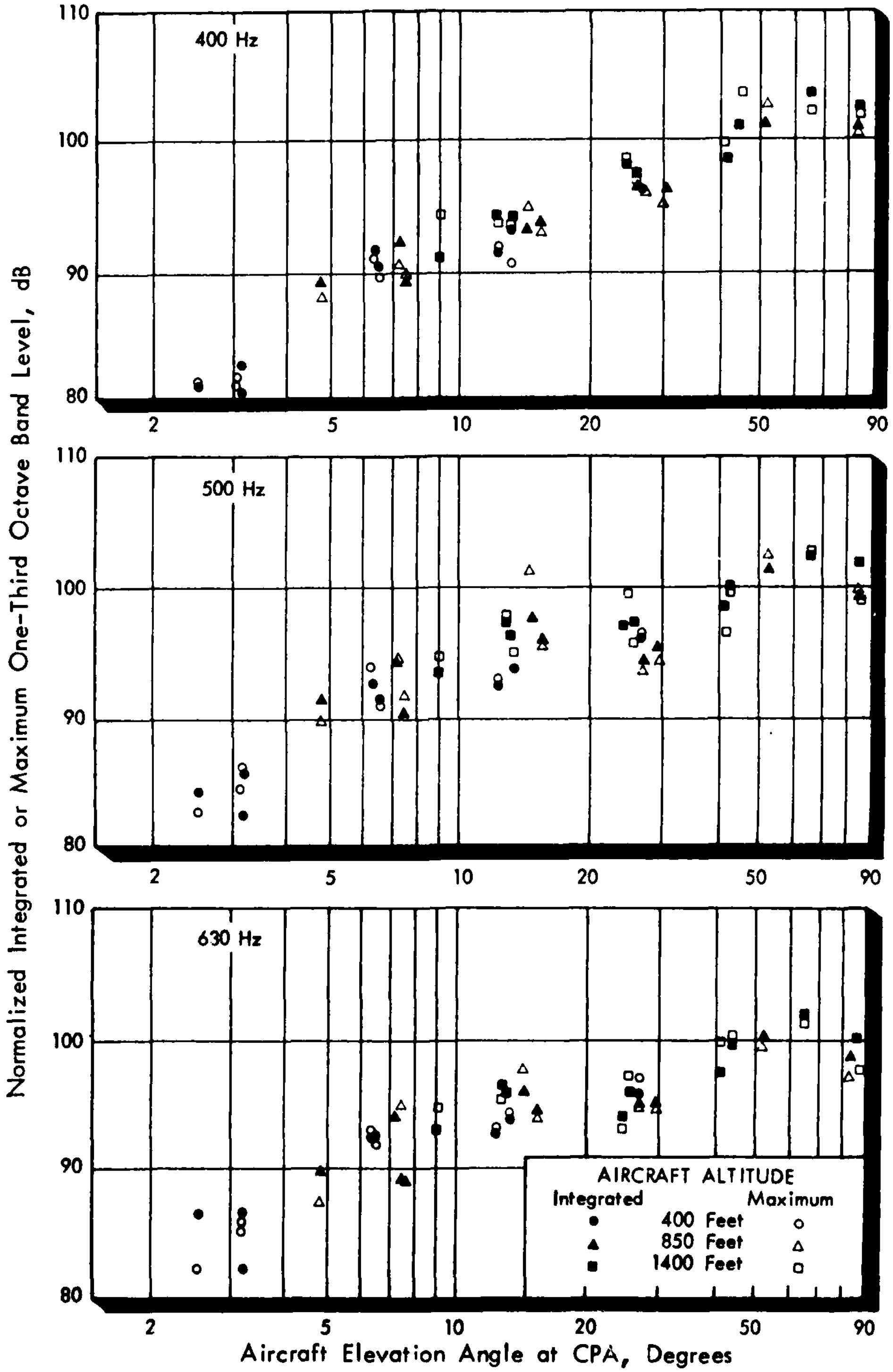

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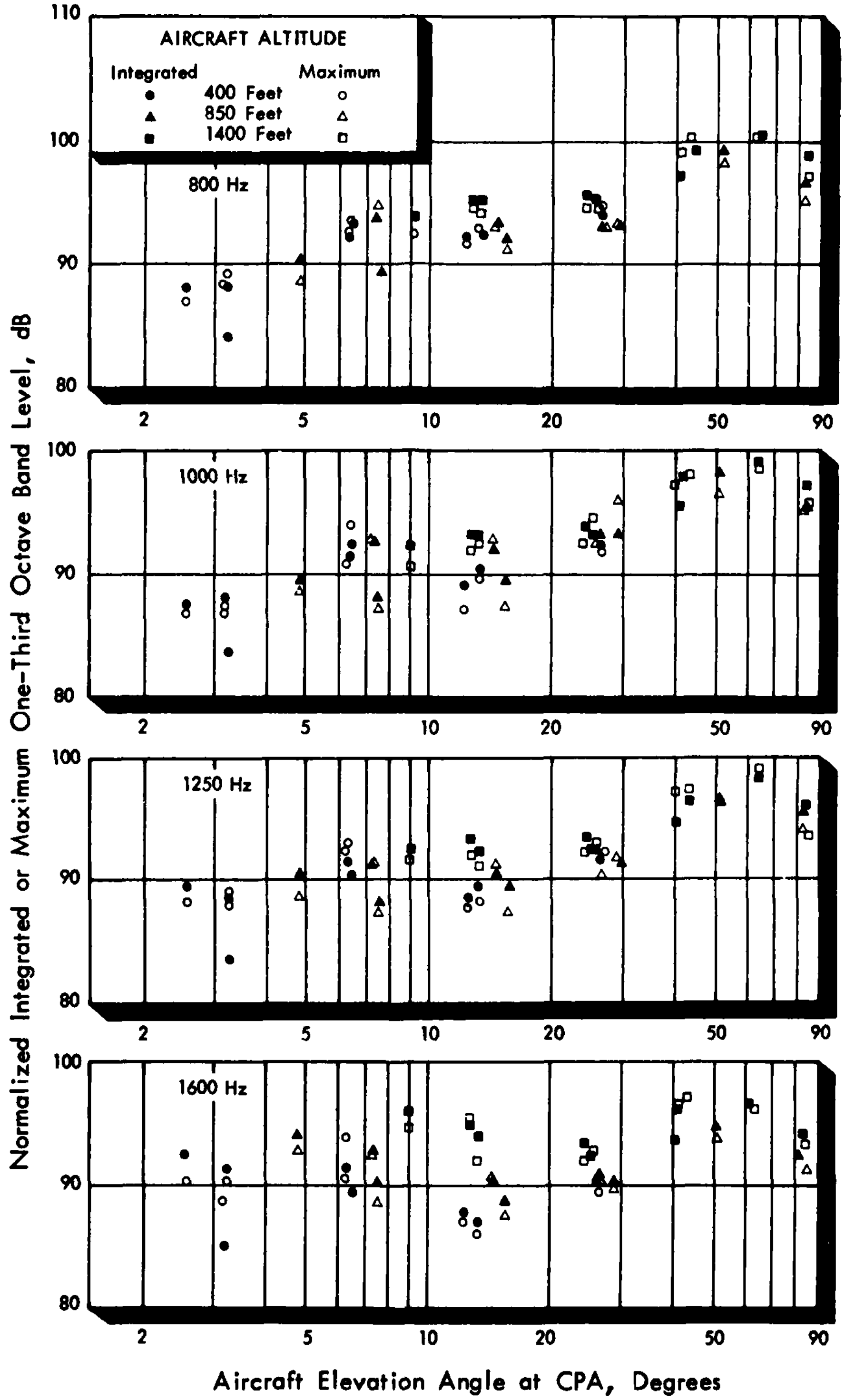


FIGURE 5. (CONCLUDED)

band for which reliable data could be established at all measurement positions. Fortunately, 50 Hz to 1600 Hz is generally considered to cover the range of interest for excess attenuation and this was supported by the fact that at 1600 Hz, only relatively minor trends in data as a function of elevation angle were evident.

Normalized data trends were similar for both integrated and maximum band levels, although the integrated data tended to have slightly less scatter as a function of elevation angle. To enable both integrated and maximum level data to be plotted together on the same axes, the duration effect determined at the normalization distance of 1000 feet has been added to the maximum values. Normalized spectra, both composite and integrated, are tabulated in the Appendix, as are the 1000 ft duration corrections for each frequency band.

From the data points of Figure 5, which show decreasing noise levels with decreasing angles of elevation, it is evident that excess attenuation is principally a function of angle of elevation over the frequency range of 50 to 1600 Hz. Admittedly for angles of elevation less than 5° all distances are greater than 6000 feet, but in the elevation angle range of 5 to 90°, there appears to be no great dependence upon distance even though the propagation distances involved range from 800 to 9000 feet.

A clearer method of presenting the data of Figure 5 is in terms of a series of curves based on the points of Figure 5, representing attenuation values relative to the SPL (integrated or maximum) at the overhead measurement position. This has been done in Figure 6 where attenuation curves are presented for each frequency band. Figure 6 does not promote an overhead measurement as a favored reference value but merely enables the excess attenuation trends as a function of frequency and elevation angle to be conveniently displayed. Excess attenuations, which may be positive or negative relative to the overhead reference position, can be determined from these curves between any two measurement positions with differing angles of elevation. In conjunction with conventional distance and atmospheric absorption corrections any of the points in Figure 1, for example, could be predicted from any one of the other points. This is a significant statement in terms of aircraft flyover noise normalization.

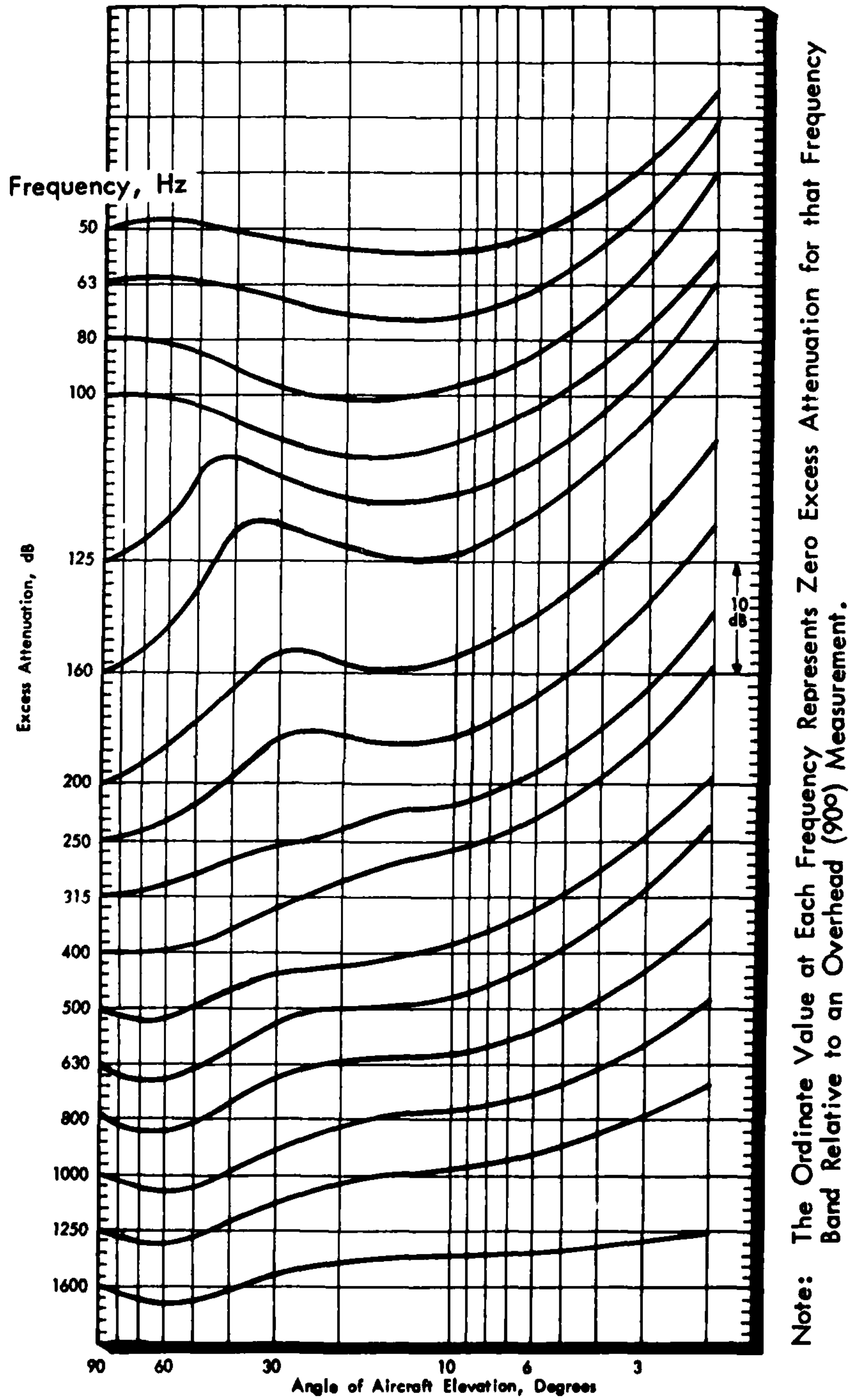


FIGURE 6. EXCESS ATTENUATION RELATIVE TO OVERHEAD MEASUREMENT POSITION AS A FUNCTION OF FREQUENCY AND ANGLE OF AIRCRAFT ELEVATION

The curves of Figure 6 indicate clearly the maxima and minima in measured data due to the interference of direct and reflected sound waves. Simple theory[7] would depict the frequency of the maxima and minima to increase with decreasing elevation angle and this is consistent with the curves of Figure 6. Further, the curves indicate that the magnitude of the spectral distortions becomes less significant as the elevation angle decreases. Theoretically, for a simple stationary source, this should not occur although a possible explanation for this trend is outlined in the following paragraph.

For the initial cancellation point - when the time delay between direct and reflected sound waves is equal to a one-half period - a maximum cancellation effect can be achieved only when complete correlation exists between direct and reflected waves. In practice, long sound propagation distances through a non-uniform atmosphere, a moving noise source, together with the effective time-averaging of flyover data, cause these discrete sound wave relationships to no longer exist at the microphone. As a result, the somewhat dramatic spectral effects of wave cancellation are minimized, if not eliminated. However in both overhead and low elevation angle situations, measurements are made above a reflecting surface. Theoretically then, if the direct and reflected waves are equal in magnitude, broadband, and random in phase at the microphone, the measured level would be 3 dB above the level of the direct wave only - that is the level measured in the absence of any reflections.

The curves of Figure 6 may be smoothed to eliminate the discrete element of reflective interference. Assuming that any measurement of an overhead flyover made above a reflecting plane will nominally be + 3 dB relative to free-field, the measured spectrum may be adjusted to eliminate discrete interference effects as shown in Figure 7. The adjustments derived may then be applied to the curves of Figure 6 at the 90° angle of elevation and a smooth curve drawn to intercept the excess attenuation curves at angles between 10-15°. The resulting series of curves, Figure 8, are considered to represent the best estimate of the ground effect contribution to excess attenuation. Figure 6, of course, includes both interference and ground effect factors.

Using the curves of Figure 8, the attenuation may be developed for a discrete series of angles of elevation. These attenuation "spectra" are presented in Figure 9 for a range of elevation angles from 2° to 32°.

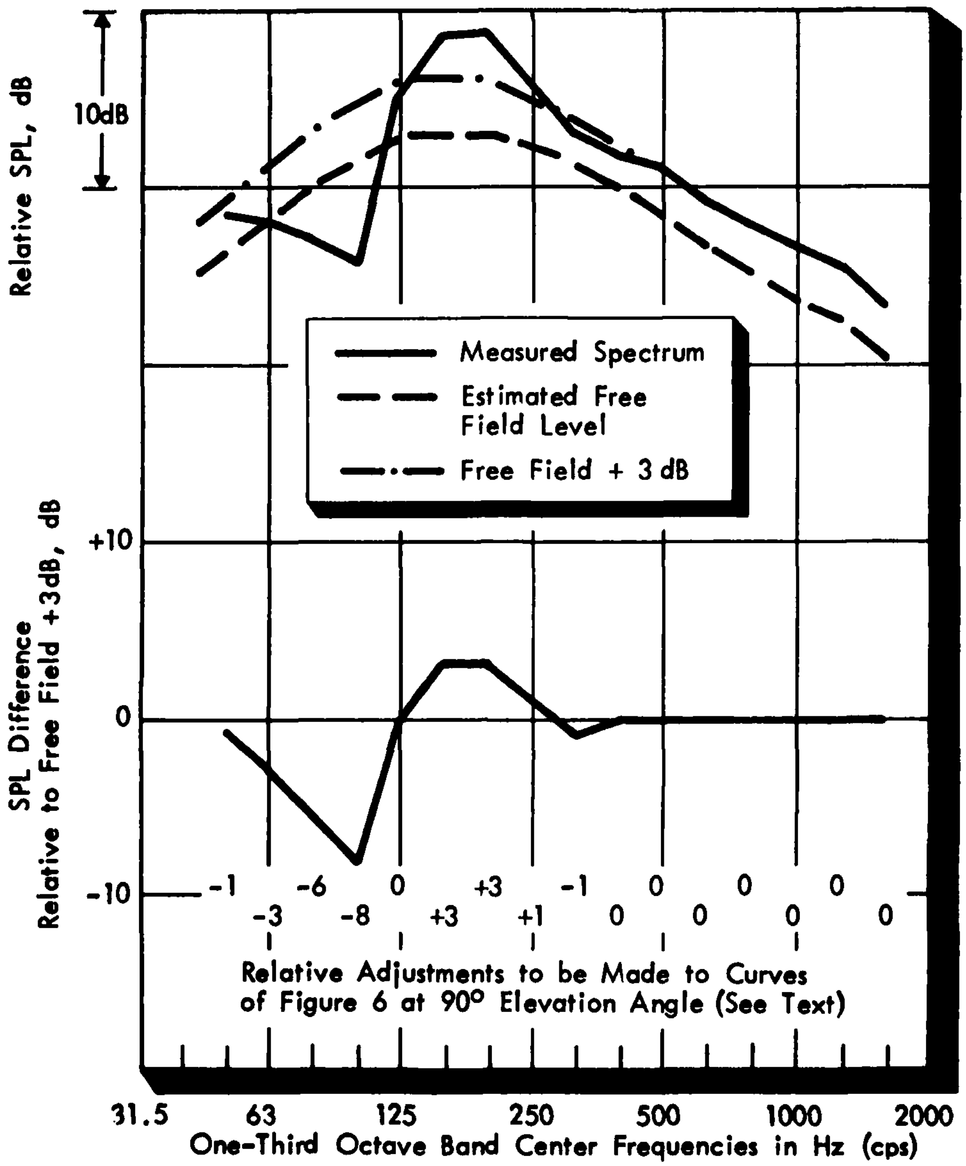


FIGURE 7. NORMALIZATION OF OVERHEAD SPECTRUM TO A UNIFORM +3dB RELATIVE TO FREE FIELD LEVEL

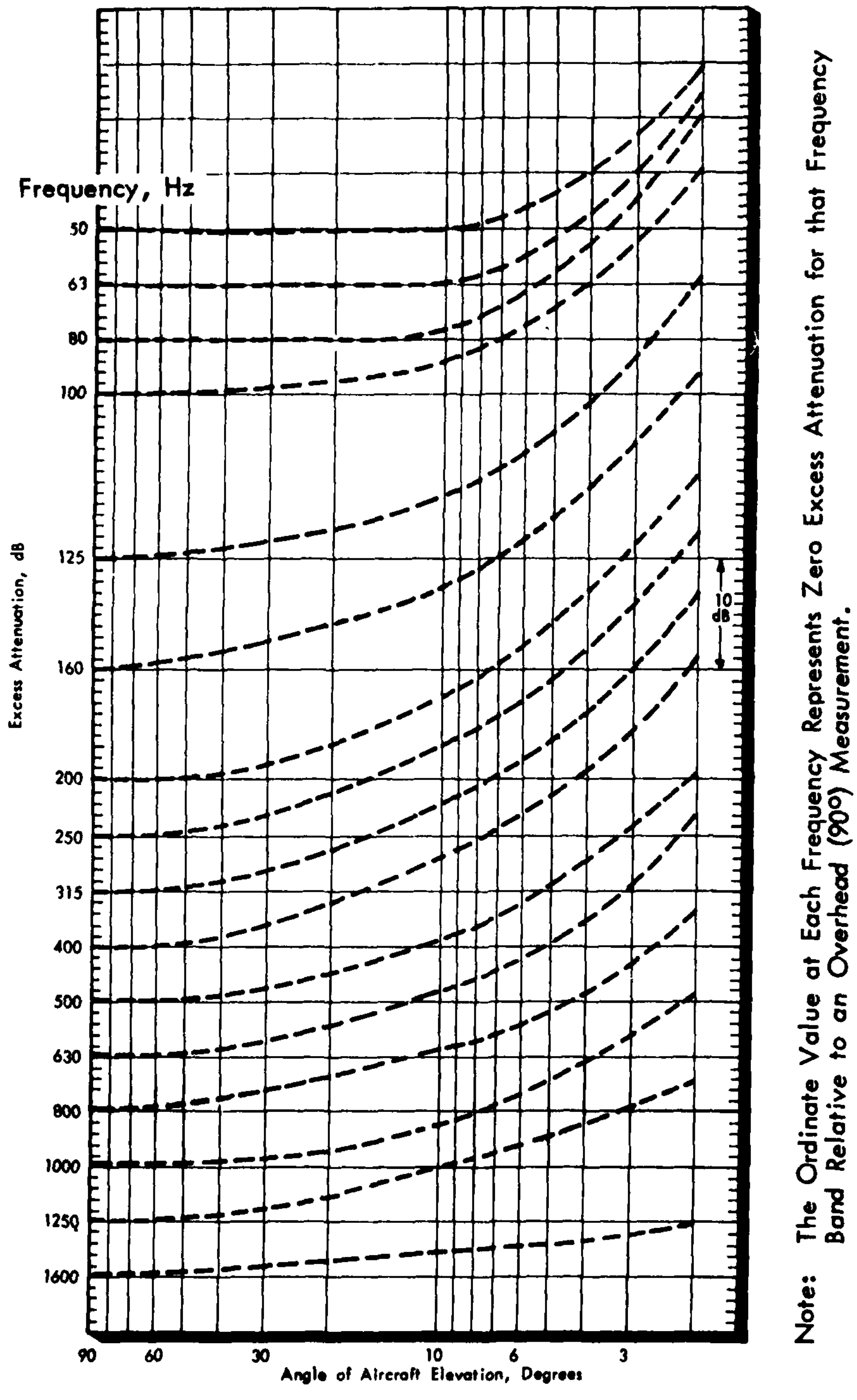
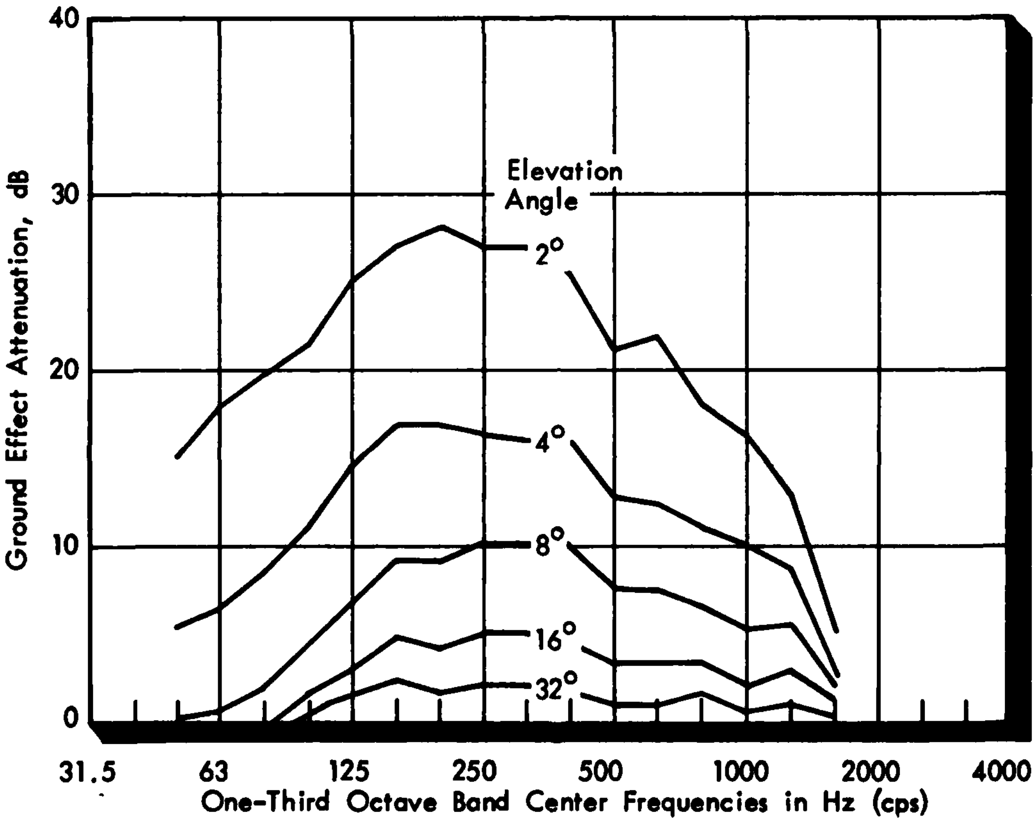


FIGURE 8. ESTIMATED GROUND EFFECT ATTENUATION RELATIVE TO OVERHEAD MEASUREMENT POSITION AS A FUNCTION OF ANGLE OF AIRCRAFT ELEVATION AND FREQUENCY



THESE CURVES DO NOT INCLUDE DISCRETE SPECTRAL DISTORTION DUE TO INTERFERENCE EFFECTS BETWEEN DIRECT AND GROUND REFLECTED SOUND WAVES

FIGURE 9. GROUND EFFECT AS A FUNCTION OF FREQUENCY FOR A RANGE OF AIRCRAFT ELEVATION ANGLES

For the 727 3-engine configuration, it seems unlikely that there would be no engine or fuselage shielding effects in measured data. However, from the data herein if shielding effects are present, they would appear to be subtle and certainly not quantifiable without comparison to similar data sets from other aircraft configurations or from data acquired independently to assess the magnitude of the shielding effect for the unique configuration of the 727 aircraft.

The ground effect attenuation spectrum for a 2° elevation angle (from Figure 9) is compared in Figure 10 with the excess ground attenuation predicted by over-ground propagation algorithms currently incorporated in NOISEMAP[8]. In Figure 10, NOISEMAP predictions of excess ground attenuation for distances of 4000 and 6000 feet* are shown. The 2° elevation angle spectrum shows greater attenuation at frequencies between 125 and 1600 Hz. Both the 2° elevation angle and NOISEMAP excess ground attenuation spectra show maximum attenuation in the same general frequency range (approximately 125 Hz to 400 Hz) although the 2° spectrum shows considerably greater attenuation at higher frequencies in the range from 400 Hz to 1250 Hz.

Of course, the excess ground algorithms currently incorporated in NOISEMAP were derived from a much different kind of field measurement than those utilized in this study. Thus, fairly sizeable differences are not unexpected. Further, the current study examines data for one aircraft for one set of weather and surface conditions.

CONCLUSIONS

The conclusions to be drawn from this flyover noise analysis study are relatively straightforward. Although data from only three flights were analyzed, the sets of data represent a portion of an overall series of noise tests which generally exhibited classical examples of so-called excess attenuation. There is no reason to believe that other data from this test series would not follow the trends indicated by the samples analyzed in this study.

In the absence of any knowledge on work presently being undertaken by others, the results derived from this study

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* With the NOISEMAP algorithms, maximum excess ground attenuation values are attained at a distance of 6000 ft. The algorithms include a 5 dB "shielding" attenuation that is independent of frequency and distance.

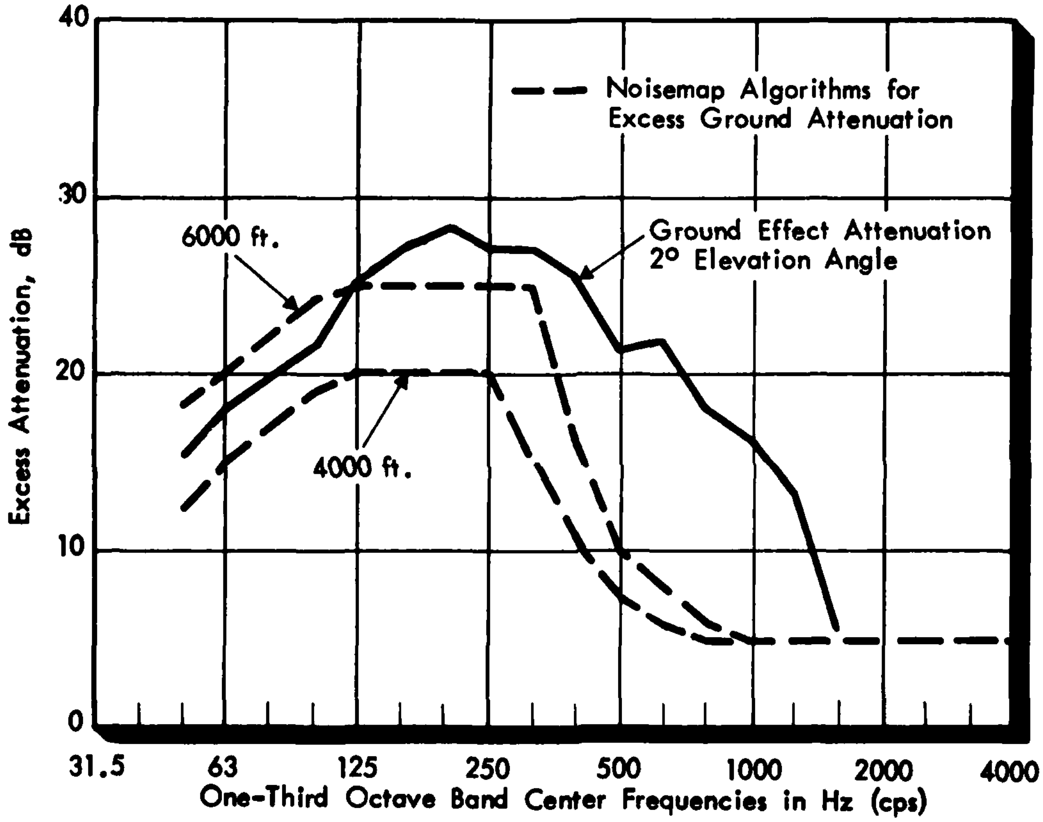

FIGURE 10. COMPARISON OF MEASURED GROUND EFFECT FOR 2° ELEVATION ANGLE WITH CURRENT NOISEMAP EXCESS GROUND ATTENUATION

represent the first time that excess attenuation characteristics have been developed as a function of frequency from actual aircraft flyover measurements.

The flyover data indicated that, when corrections for distance and atmospheric absorption have been applied, excess attenuations - whether positive or negative - are a function of the angle of elevation of the aircraft only. This was true for one-third octave bands ranging from 50 to 1600 Hz and for measurement distances of 800 feet to 9000 feet.

At frequencies above 1600 Hz, measured data and atmospheric absorption corrections become less confident at large measurement distances. However, trends in the data indicate that excess attenuation also becomes minimal at frequencies above 1600 Hz. This finding is generally consistent with other reports on excess attenuation effects.

Attenuation not accounted for by distance and absorption corrections could be separated into two distinct regions. Interference effects, caused by the interaction of direct and ground reflected sound waves at the microphone, were principally observed at angles of elevation greater than 20°, and ground effect which appears to be a progressive increase in attenuation as the angle of elevation of the aircraft decreases. The character of this ground effect was similar to that reported in other studies of sound propagation over ground with a maximum attenuation occurring between 125 and 400 Hz. At angles of elevation of 4°, for example, ground effect attenuation was approximately 17 dB at 200 Hz. Ground effect was essentially zero at elevation angles greater than 50°.

Interference effects were predominant in measurements made at high angles of elevation with overhead measurements exhibiting the most distinct spectral trends. As would be expected from simple theory, the frequency range 50 Hz - 500 Hz was most susceptible to interference effects. At elevation angles below 20°, interference became minimal due to the fact, it is hypothesized, that the precise correlation of direct and reflected waves that is required to cause interference cannot be maintained over large propagation distances from a moving noise source. Analysis techniques also serve to dilute the severity of spectral distortion due to interference.

The combination of ground and interference effects cause the flyover noise levels, in terms of sound exposure level, to range approximately ± 7.5 dB compared to the slope of the SEL versus distance curve that would be predicted using normal air-to-ground propagation prediction methods over the measurement distances of this study.

Due to the somewhat cancelling nature of interference and ground effects in the elevation angle range of 10° to 30°, current NOISEMAP air-to-ground prediction methods usually normalize data satisfactorily over a wide range of measurement distances. However, it was clearly apparent that to satisfactorily normalize data over the entire test data range, excess attenuations (positive or negative) must be applied at all angles up to 90°.

While it is fairly certain that some form of shielding effects must exist in multi-engine aircraft configurations, if present in these data, the effects were subtle. No quantitative variations or obvious data trends could be assigned to shielding specifically. Comparison of these data with similar data from other aircraft configurations, however, may isolate data trend differences that could be assigned specifically to configuration shielding effects.

The combination of interference and ground effects has a significant impact on the measured noise level (A-level or SEL) from the 727 aircraft at angles of elevation between 30 and 90° (overhead). Shielding effects, probably present but not quantified in this study, may also contribute to unexpected data trends in this angle of elevation regime. At high engine thrust settings, the 727 acoustic signature is jet noise dominated and low frequency noise (less than 500 Hz) contributes significantly to A-weighted noise levels. For aircraft with higher frequency noise characteristics controlling the A-weighted level, the excess attenuation impact would be substantially less at high angles of elevation, even though similar spectral influences from excess attenuation may be present in low frequency range.

A general and significant conclusion of this study is that available aircraft flyover data are readily amenable to re-analysis. It has been demonstrated that with the expenditure of a relatively modest amount of time, together with the use of simplistic analysis techniques, valuable information pertaining to the nature of aircraft flyover noise can be generated. With due consideration to the high cost of providing new flyover data, re-analysis of existing measurements represents a potentially attractive alternative for providing an expanded data base for the development of improved noise prediction techniques.

RECOMMENDATIONS

The following recommendations are made based upon the findings of this study:

Attenuation factors developed from these 727 flyover analyses should be applied to the noise characteristics of other aircraft and revised noise level versus distance curves calculated. Comparison of these revised curves with available measured data and with levels predicted using the current NOISEMAP procedures should be made. The possible impact of a revision to the present prediction procedures, both in terms of single event levels and contour areas, should be assessed.

An effort should be made to seek other available flyover measurements that may be suitable for the application of anlayses similar to those in this study. Analysis of data from different aircraft configurations in particular would enhance the data base for developing improved prediction techniques.

Consideration should be given to the use of at least one sideline microphone during the aquisition of flyover noise measurements for use in the standard data file. This sideline microphone should give an aircraft angle of elevation between 10° - 20° at the aircraft closest point of approach position.

The experimental trends described in this report should be compared with the results that would be predicted by available mathematical models for sound propagation over a ground surface.

Although an indirect product of this study, it is recommended that revisions be considered for the relationship currently used in the NOISEMAP procedure to relate A-level and SEL as a function of distance from the aircraft source. It appears that from this study and from other data, a duration effect of 5 to 7 dB/decade of distance increase would be more appropriate than the presently used 10 dB/decade.

APPENDIX

TABULATIONS OF MEASURED AND DERIVED NOISE MEASURES

This appendix presents tabulations of measured and derived noise measures used in this study.

The aircraft flyover altitudes and sideline measurement distances identified on Tables 2 through 5 are the nominal values only. Closest point of approach (CPA) distances are actual values, however, and reflect minor deviations in flyover altitudes and aircraft offsets from the flight track. For this reason, angles of elevation should be taken from Table 1 in the main text, and should not be calculated from the altitudes given on these Appendix tables.

TABLE 2 - COMPOSITE FLYOVER SPECTRA

FLYOVER ALTITUDE 400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9003	5986	2978	1506	776	-	1612	3065	6033
Frequency, Hz				SPL, dB					
50	61.0	67.5	81.2	87.4	93.3	-	88.9	81.0	70.7
63	59.1	69.1	81.6	86.9	93.5	-	89.0	79.3	70.0
80	59.7	69.5	83.6	90.1	99.3	-	89.2	81.4	71.3
100	60.4	67.0	84.5	88.9	98.9	-	91.5	80.9	67.5
125	56.7	67.3	81.4	90.7	97.2	-	88.4	78.6	64.0
160	55.5	65.0	77.2	90.3	95.4	-	88.3	77.1	62.3
200	53.0	63.6	78.2	88.8	96.0	-	87.4	75.5	60.8
250	52.6	61.8	77.6	86.0	99.7	-	83.9	76.9	58.3
315	51.9	60.8	75.1	83.2	99.0	-	83.4	75.3	58.2
400	50.8	56.6	74.2	82.2	95.4	-	82.8	75.9	56.8
500	50.4	59.3	73.8	83.3	92.5	-	82.2	76.3	58.1
630	49.5	60.0	75.5	85.3	94.7	-	83.0	75.9	59.4
800	50.6	60.7	75.5	83.0	91.7	-	81.5	74.2	60.0
1000	49.1	58.9	76.7	80.8	89.7	-	77.4	73.0	58.0
1250	44.9	55.5	74.0	78.6	90.3	-	77.5	73.2	56.6
1600	38.6	50.9	72.6	76.3	87.8	-	76.5	69.1	52.4
2000	-	44.3	67.1	73.2	86.6	-	71.2	65.0	45.4
2500	-	-	60.2	71.2	84.4	-	69.4	59.8	-
3150	-	-	52.9	68.5	82.5	-	66.9	53.4	-
4000	-	-	41.8	63.8	79.5	-	62.4	42.9	-
A-Weighting	57.0	66.7	83.2	90.5	101.2	-	89.0	82.1	66.0

TABLE 2 - COMPOSITE FLYOVER SPECTRA (CON'T)

FLYOVER ALTITUDE 850 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	8992	5986	3029	1642	1045	813	1809	3190	6033
Frequency, Hz				SPL, dB					
50	71.7	73.7	83.6	86.7	89.3	93.9	86.1	81.0	76.6
63	69.5	72.8	84.4	88.9	90.8	92.5	86.0	81.7	76.9
80	70.5	73.2	86.0	90.8	90.3	93.4	88.2	82.8	77.7
100	71.0	72.5	86.3	89.6	88.9	92.4	86.2	83.6	78.1
125	70.1	73.4	82.3	88.7	92.2	102.9	86.1	83.5	77.0
160	68.8	72.8	82.8	85.8	100.4	106.1	83.3	82.7	77.1
200	64.3	71.3	84.1	84.1	102.5	105.7	81.4	83.8	73.8
250	62.7	69.9	81.4	86.7	97.2	100.7	86.7	80.5	70.8
315	63.3	69.2	80.1	88.5	98.0	97.2	89.2	76.8	68.7
400	60.0	67.0	77.9	86.2	97.9	98.2	86.3	79.4	67.2
500	58.2	65.8	78.2	83.3	96.5	95.6	81.7	83.4	68.7
630	55.2	63.3	77.5	85.8	94.4	94.7	84.7	80.8	67.4
800	53.3	61.3	73.2	82.5	92.4	91.7	81.5	74.9	67.3
1000	51.9	59.1	70.1	86.5	91.7	92.8	81.5	75.2	64.4
1250	47.4	56.3	69.2	81.6	91.4	91.6	79.0	72.2	60.3
1600	42.9	52.0	67.2	79.0	88.7	89.1	77.7	69.4	56.1
2000	-	46.8	63.4	76.9	86.6	88.0	77.2	66.4	49.3
2500	-	38.1	59.5	74.7	85.4	86.9	73.9	61.3	41.9
3150	-	-	56.0	71.5	82.0	84.8	70.8	55.4	-
4000	-	-	45.1	67.0	80.3	83.5	66.7	43.8	-
A-Weighting	64.9	71.3	83.4	92.5	102.3	103.4	90.9	85.7	74.8

TABLE 2 - COMPOSITE FLYOVER SPECTRA (CONT'D)

FLYOVER ALTITUDE 1400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9058	6089	3219	1975	1521	1382	2131	3390	6228
Frequency, Hz				SPL, dB					
50	76.2	74.8	84.7	85.9	85.5	87.9	84.6	81.6	75.3
63	76.7	79.4	84.5	85.1	87.3	91.0	83.7	83.0	76.2
80	77.1	83.2	85.4	87.5	86.1	89.9	85.2	84.6	78.3
100	77.2	83.3	84.6	85.4	89.9	89.1	84.7	84.1	77.8
125	76.1	80.7	83.3	84.7	94.2	98.9	82.4	81.8	77.8
160	75.2	79.7	81.6	86.3	97.4	102.9	83.3	80.5	77.0
200	72.6	78.5	80.2	89.8	97.5	101.9	86.7	76.3	76.4
250	69.5	77.1	77.7	89.0	93.7	98.2	86.7	76.0	72.4
315	67.1	75.0	80.4	85.5	95.5	95.2	84.4	80.5	71.8
400	65.5	69.8	81.1	92.5	93.9	94.9	88.1	81.8	70.3
500	62.2	68.7	77.4	86.8	92.8	90.1	85.0	81.0	71.1
630	62.0	67.8	80.1	88.8	92.2	89.7	87.2	75.0	69.1
800	57.3	66.4	75.9	87.8	90.9	88.4	85.5	75.3	66.8
1000	53.9	64.1	76.3	86.3	90.2	87.6	84.5	73.4	63.0
1250	49.3	59.0	73.1	84.8	89.7	85.4	83.3	71.3	59.5
1600	43.9	54.5	70.4	83.5	86.2	84.6	81.2	68.6	56.7
2000	-	49.4	66.5	81.7	82.9	81.9	77.9	64.6	49.9
2500	-	39.8	60.7	77.3	82.4	78.9	74.6	59.7	42.7
3150	-	-	55.4	72.4	79.7	75.8	70.2	54.4	-
4000	-	-	43.8	65.5	75.0	72.7	64.4	42.2	-
A-Weighting	70.5	76.9	85.0	95.4	99.5	99.2	93.0	84.1	75.7

TABLE 3 - TIME-INTEGRATED FLYOVER SPECTRA

FLYOVER ALTITUDE 400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9003	5986	2978	1506	776	-	1612	3065	6033
Frequency, Hz.				SPL, dB					
50	72.9	79.2	-	95.8	99.2	-	96.1	90.0	80.8
63	72.1	79.1	-	96.8	100.5	-	96.1	90.0	80.6
80	73.0	79.3	-	98.3	103.5	-	97.1	90.7	81.0
100	72.7	78.4	92.9	98.4	102.8	-	96.7	89.7	79.1
125	71.4	76.8	91.4	98.2	102.0	-	95.6	89.1	76.7
160	69.8	75.2	89.3	98.5	100.8	-	95.2	87.7	75.3
200	66.7	72.6	87.7	96.7	101.6	-	94.2	85.5	72.8
250	65.3	70.5	85.8	93.6	102.4	-	91.2	85.1	70.8
315	63.8	68.7	83.8	90.7	101.9	-	89.0	84.6	69.1
400	62.9	66.7	83.5	90.9	98.7	-	88.8	84.6	68.9
500	63.3	66.7	83.2	91.3	98.5	-	89.1	84.3	69.8
630	63.5	66.7	84.8	91.4	98.2	-	89.8	84.6	70.7
800	63.8	66.6	84.6	89.7	96.4	-	88.9	82.9	70.7
1000	61.8	65.0	83.3	87.8	94.9	-	85.8	82.2	69.5
1250	57.9	61.9	79.9	86.3	94.1	-	84.7	80.7	67.0
1600	52.3	57.7	76.9	83.4	92.8	-	83.2	77.8	63.3
2000	-	51.5	72.5	81.5	90.8	-	79.8	73.9	56.7
2500	-	-	67.9	78.1	88.7	-	76.9	68.3	-
3150	-	-	62.2	74.7	86.0	-	73.5	62.4	-
4000	-	-	51.2	69.9	83.1	-	67.9	51.3	-
A-Weighting	70.0	74.1	91.1	97.8	105.3	-	96.0	90.8	77.2

TABLE 3 - TIME-INTEGRATED FLYOVER SPECTRA (CONT'D)

FLYOVER ALTITUDE 850 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	8992	5986	3029	1642	1045	813	1809	3190	6033
Frequency, Hz				SPL, dB					
50	80.8	85.2	-	96.6	97.0	99.3	95.4	92.2	88.0
63	81.1	84.8	97.2	97.7	97.4	98.8	96.0	92.6	88.4
80	81.9	85.6	96.1	99.3	96.7	97.8	97.1	93.8	88.9
100	81.1	84.0	95.2	98.8	95.9	97.2	96.2	93.5	88.8
125	80.8	82.8	93.7	97.8	98.2	105.5	95.2	93.8	87.3
160	80.0	82.6	93.0	95.6	102.6	109.4	92.4	93.2	86.4
200	77.0	80.7	89.9	93.5	104.6	109.2	91.2	92.1	84.8
250	75.4	79.4	88.3	93.2	102.1	105.8	92.8	89.1	82.1
315	74.2	78.1	86.0	94.8	102.4	103.1	94.3	85.2	80.5
400	72.2	76.4	86.4	93.3	101.2	103.0	92.7	85.8	79.2
500	70.2	74.7	87.1	91.5	101.5	101.1	89.8	88.5	78.5
630	68.5	73.4	86.1	91.7	100.0	100.3	91.5	87.0	78.3
800	66.7	72.1	82.8	90.1	98.8	98.5	88.6	83.5	76.6
1000	64.2	69.7	79.9	89.5	98.0	97.3	88.5	82.2	74.4
1250	60.7	67.2	78.8	87.6	96.2	97.0	87.2	79.6	70.5
1600	55.2	63.3	75.8	85.4	94.5	94.3	85.0	76.5	66.1
2000	-	57.7	72.8	82.7	92.4	93.0	82.8	72.8	60.0
2500	-	47.6	68.1	79.6	90.3	90.5	79.3	68.5	51.5
3150	-	-	63.3	76.3	87.8	-	76.4	62.8	-
4000	-	-	51.7	71.5	84.3	-	71.2	50.6	-
A-Weighting	76.8	81.1	91.9	98.6	107.2	108.2	97.7	92.7	84.9

TABLE 3 - TIME-INTEGRATED FLYOVER SPECTRA (CONT'D)

FLYOVER ALTITUDE 1400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9058	6089	3219	1975	1521	1382	2131	3390	6228
Frequency, Hz				SPL, dB					
50	84.5	87.7	-	94.0	94.6	96.5	94.0	92.5	87.0
63	85.7	89.5	-	95.3	95.5	97.2	93.5	93.4	87.8
80	86.9	91.2	97.5	95.4	94.6	96.3	94.3	94.2	89.0
100	85.8	90.9	96.7	93.9	96.0	95.6	92.8	94.0	88.4
125	84.8	89.9	94.3	92.1	100.4	103.5	91.1	91.5	87.4
160	84.2	90.0	92.7	94.3	103.8	107.6	92.2	90.7	86.5
200	81.0	88.2	90.6	96.9	103.6	107.4	94.4	86.1	84.4
250	78.5	85.4	89.5	96.9	102.1	104.6	95.0	86.6	82.3
315	76.0	82.8	89.8	94.7	102.0	102.5	91.9	90.0	81.0
400	73.5	80.7	89.8	96.6	101.1	100.8	93.5	89.8	80.8
500	72.4	80.2	87.7	94.8	99.5	99.7	92.9	87.4	81.1
630	71.5	79.9	87.0	94.9	99.1	98.1	92.1	84.4	80.2
800	70.1	77.8	85.5	94.3	97.7	96.5	91.0	85.4	77.4
1000	66.9	74.7	83.6	92.6	96.0	94.8	89.7	83.1	74.4
1250	62.1	70.7	81.1	90.6	94.7	93.0	87.7	81.2	70.9
1600	56.0	66.3	78.1	88.9	92.5	91.0	85.5	78.2	66.7
2000	-	60.5	73.8	86.1	89.8	88.9	82.6	73.9	60.3
2500	-	50.4	68.8	82.6	86.8	85.7	78.7	68.8	53.1
3150	-	-	63.1	77.5	82.8	82.3	74.0	62.5	-
4000	-	-	50.6	71.0	78.2	78.1	67.9	49.5	-
A-Weighting	79.9	86.8	93.8	101.5	106.0	106.1	98.7	93.0	85.6

TABLE 4 - COMPOSITE FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET

FLYOVER ALTITUDE 400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9003	5986	2978	1506	776	-	1612	3065	6033
Frequency, Hz				SPL, dB					
50	81.0	83.6	89.9	91.0	91.1	-	93.1	91.0	86.9
63	79.1	85.2	90.3	90.5	91.3	-	93.2	89.3	86.2
80	79.7	85.6	93.3	93.7	97.1	-	93.4	91.4	87.5
100	81.3	83.6	94.4	92.6	96.6	-	95.8	91.1	84.2
125	77.6	83.9	91.3	94.4	94.9	-	92.7	88.8	80.7
160	77.2	82.2	87.3	94.0	93.1	-	92.6	87.5	79.6
200	74.7	80.8	88.3	92.5	93.7	-	91.7	85.9	78.1
250	75.2	79.5	88.0	89.8	97.4	-	88.3	87.5	76.1
315	75.4	79.1	85.7	87.0	96.7	-	87.9	86.2	76.6
400	76.1	76.0	85.2	86.1	93.0	-	87.4	87.2	76.3
500	76.6	79.2	85.0	87.3	90.1	-	86.9	87.9	78.2
630	77.4	81.0	87.2	89.4	92.3	-	87.8	87.9	80.6
800	81.2	83.4	87.8	87.3	89.2	-	86.5	86.9	82.8
1000	82.3	83.2	89.7	85.2	87.1	-	82.6	86.4	82.5
1250	83.4	83.1	88.3	83.4	87.6	-	83.1	87.9	84.4
1600	85.9	84.0	89.1	81.6	84.8	-	82.8	86.1	85.8

TABLE 4 - COMPOSITE FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET (CONT'D)

FLYOVER ALTITUDE 850 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	8992	5986	3029	1642	1045	813	1809	3190	6033
Frequency, Hz				SPL, dB					
50	91.6	89.7	93.4	91.1	89.7	92.1	91.3	91.3	92.8
63	89.4	88.8	94.2	93.0	91.2	90.7	91.2	92.0	93.1
80	90.4	89.2	95.8	95.2	90.7	91.6	93.4	93.1	93.9
100	91.7	89.0	96.3	94.0	89.3	90.6	91.5	94.1	94.8
125	90.8	89.9	92.3	93.1	92.6	101.1	91.4	94.0	93.7
160	89.6	89.3	92.8	90.2	100.8	104.3	88.6	93.2	93.8
200	85.8	88.3	94.3	88.6	102.9	103.8	86.8	94.5	91.1
250	85.0	87.4	91.8	91.3	97.6	98.8	92.2	91.5	88.6
315	86.4	87.2	90.7	93.1	98.4	95.3	94.8	88.0	87.1
400	83.9	85.5	88.7	90.9	98.3	96.3	91.9	90.8	86.1
500	83.7	85.7	89.4	88.1	96.9	93.7	87.5	95.2	88.8
630	82.3	84.3	87.2	90.7	94.8	92.7	90.7	93.1	90.6
800	83.0	83.4	85.3	87.6	92.8	89.7	87.6	87.6	89.6
1000	84.2	82.9	82.8	91.8	92.1	90.7	87.9	88.6	88.3
1250	84.1	82.8	82.9	87.2	91.9	89.4	85.8	86.7	87.0
1600	88.4	84.0	82.9	85.2	89.2	86.7	85.3	86.0	88.4

TABLE 4 - COMPOSITE FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET (CONT'D)

FLYOVER ALTITUDE 1400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9058	6089	3219	1975	1521	1382	2131	3390	6228
Frequency, Hz				SPL, dB					
50	96.2	91.1	95.1	91.9	89.2	90.8	91.3	92.5	91.8
63	96.7	95.7	94.9	91.1	91.0	93.9	90.4	93.9	92.7
80	97.1	99.5	95.8	93.5	89.8	92.8	91.9	95.5	94.8
100	98.1	100.1	95.2	91.5	93.7	92.0	91.5	95.2	94.8
125	97.0	97.5	93.9	90.8	98.0	101.8	89.2	92.9	94.8
160	96.1	96.5	92.2	92.4	101.2	105.8	90.1	91.6	94.0
200	94.4	95.9	91.1	96.0	101.3	104.8	93.6	87.7	94.0
250	92.2	95.0	88.8	95.3	97.6	101.2	93.8	87.7	90.6
315	90.7	93.5	91.8	91.9	99.4	98.2	91.6	92.4	90.6
400	90.0	88.9	92.7	99.1	97.9	98.0	95.4	94.0	89.6
500	88.5	88.8	89.5	93.6	96.9	93.2	92.6	93.7	91.6
630	90.0	89.1	92.7	95.8	96.4	92.9	95.0	88.2	90.8
800	87.1	88.8	89.0	95.0	95.2	91.7	93.6	89.1	89.6
1000	86.4	88.2	90.1	93.8	94.7	91.0	92.9	88.0	87.5
1250	87.1	86.5	88.4	93.0	94.5	89.1	92.5	87.4	87.5
1600	90.6	87.6	88.1	92.7	91.6	88.7	91.6	87.4	90.5

TABLE 5 - TIME-INTEGRATED FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET

FLYOVER ALTITUDE 400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9003	5986	2978	1506	776	-	1612	3065	6033
Frequency, Hz				SPL, dB					
50	88.4	91.5	-	98.2	96.9	-	98.9	97.4	93.2
63	87.3	91.2	-	99.1	98.3	-	98.9	97.3	92.8
80	87.0	90.4	-	100.4	100.4	-	99.6	97.3	92.2
100	88.0	90.4	99.8	100.6	100.6	-	99.4	96.8	91.2
125	85.8	88.1	97.9	100.3	99.9	-	98.1	95.8	88.1
160	84.7	86.7	95.8	100.5	98.8	-	97.7	94.4	86.9
200	82.1	84.5	94.4	98.8	99.5	-	96.8	92.4	84.8
250	81.4	82.8	92.7	95.8	100.3	-	93.8	92.2	83.2
315	81.5	82.2	91.3	96.0	99.7	-	91.8	92.3	82.7
400	80.9	80.1	90.7	93.1	96.6	-	91.5	92.0	82.4
500	84.2	82.3	91.6	93.9	96.1	-	92.3	92.9	85.5
630	84.6	82.1	92.8	93.8	96.0	-	92.7	92.9	86.7
800	88.1	94.1	93.5	92.4	94.0	-	92.2	92.1	88.3
1000	87.9	83.5	92.5	90.5	92.6	-	89.1	91.7	88.1
1250	89.4	83.3	90.2	89.3	91.7	-	88.3	91.4	88.6
1600	92.5	85.0	89.6	87.0	90.1	-	87.6	91.5	91.3

TABLE 5 - TIME-INTEGRATED FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET (CONT'D)

FLYOVER ALTITUDE 850 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	8992	5986	3029	1642	1045	813	1809	3190	6033
Frequency, Hz				SPL, dB					
50	96.8	98.0	-	100.0	97.3	97.9	99.6	100.4	100.9
63	96.8	97.4	104.9	101.1	97.7	97.4	100.1	100.7	101.1
80	96.4	97.2	103.2	102.4	97.0	96.5	100.9	101.2	100.6
100	96.9	96.5	102.7	102.1	96.2	95.8	100.2	101.4	101.4
125	95.7	94.6	100.8	100.9	98.5	104.2	98.9	101.2	99.2
160	94.5	94.1	99.9	98.6	102.9	108.2	96.0	100.4	97.9
200	92.8	93.1	97.2	96.7	104.9	108.3	95.0	99.8	97.3
250	92.0	92.2	95.8	96.4	102.4	104.5	96.7	97.0	95.0
315	92.4	92.1	94.1	98.3	102.7	101.7	98.5	93.7	94.6
400	89.8	89.7	94.0	96.5	101.5	101.7	96.6	93.8	92.6
500	91.6	90.8	96.1	95.3	101.8	99.6	94.4	98.0	94.7
630	90.0	89.3	94.8	95.3	100.3	98.9	95.8	96.1	94.3
800	90.5	89.5	92.2	93.5	99.1	97.0	93.3	93.4	94.1
1000	89.9	88.1	89.6	93.4	98.3	95.8	93.2	92.4	93.0
1250	90.4	88.0	89.4	91.7	96.5	95.4	92.2	90.8	91.5
1600	94.1	90.0	88.8	90.3	94.9	92.5	91.0	90.3	93.0

TABLE 5 - TIME-INTEGRATED FLYOVER SPECTRA NORMALIZED TO A CPA DISTANCE OF 1000 FEET (CONT'D)

FLYOVER ALTITUDE 1400 Ft.

Sideline Distance, Ft.	9000	6000	3000	1520	750	0	-1520	-3000	-6000
CPA Distance, Ft.	9058	6089	3219	1975	1521	1382	2131	3390	6228
Frequency, Hz				SPL, dB					
50	100.5	100.7	-	98.8	97.5	98.8	99.3	101.1	100.1
63	101.5	102.3	-	100.0	97.5	98.7	98.7	101.9	100.7
80	101.4	102.9	105.0	99.7	97.2	98.3	99.1	102.0	100.9
100	101.6	103.6	104.7	98.5	98.8	97.7	97.9	102.3	101.2
125	99.8	101.8	101.8	96.4	103.0	105.5	95.9	99.3	99.5
160	98.8	101.6	100.0	98.5	106.3	109.6	96.8	98.3	98.3
200	96.9	100.7	98.4	101.3	106.3	109.5	99.3	94.2	97.1
250	95.2	98.4	97.4	101.4	104.8	106.7	100.0	94.9	95.5
315	94.3	97.0	98.4	99.5	104.9	104.7	97.3	99.0	95.4
400	91.2	94.2	97.8	101.2	103.9	102.9	98.6	98.2	94.5
500	93.9	96.5	97.3	100.1	102.7	102.2	98.8	97.5	97.7
630	93.2	96.0	96.2	99.9	102.1	100.4	97.7	94.1	96.6
800	94.1	95.5	95.5	99.7	100.9	99.0	97.1	95.9	95.4
1000	92.8	93.4	93.9	98.1	99.2	97.3	95.9	94.0	93.5
1250	92.9	92.4	92.7	96.6	98.2	95.7	94.5	93.4	93.1
1600	96.1	94.0	92.3	96.1	96.7	94.1	93.7	93.3	95.0

TABLE 6

LINEAR REGRESSION CONSTANTS DETERMINED FOR RELATIONSHIP BETWEEN INTEGRATED MINUS MAXIMUM SPL(Δ) AS A FUNCTION OF DISTANCE FROM AIRCRAFT (Δ = a + b LOG DISTANCE)

1/3 Octave Frequency Band Hz	Number of Data Points	a	b (Slope = dB/decade)	r^2 Correlation Coefficient	1000 Foot Intercept
50	23	- 5.15	4.19	0.53	7.4
63	24	- 5.86	4.46	0.57	7.5
80	25	-11.01	5.77	0.64	6.3
100	26	- 9.62	5.30	0.58	6.3
125	26	-12.89	6.23	0.62	5.8
160	26	-14.22	6.65	0.61	5.7
200	26	-13.14	6.16	0.60	5.3
250	26	-13.56	6.31	0.67	5.4
315	26	-11.30	5.52	0.64	5.3
400	26	-16.67	7.08	0.74	4.6
500	26	- 8.82	4.96	0.54	6.1
630	26	-15.09	6.66	0.67	4.9
800	26	-12.52	6.09	0.66	5.8
1000	26	-15.87	6.90	0.67	4.8
1250	26	-17.40	7.35	0.70	4.7
1600	26	-16.05	6.92	0.69	4.7
2000	25	-15.49	6.76	0.62	4.8
2500	23	-15.92	6.78	0.80	4.4
3150	14	-14.00	6.03	0.49	4.1
4000	14	-13.99	5.85	0.64	3.6
A-Level (SEL-ALmax)	23	-12.10	6.07	0.65	6.1
All Bands	486	-13.62	6.32	0.61	5.3
Spectrum Average (Bands averaged for each spectrum)	26	-13.83	6.38	0.89	5.3

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