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Estimation of lateral attenuation of air-to-ground jet or turbofan aircraft noise in one-third octave bands

Associated software: ESDUpac A8227



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THE PREPARATION OF THIS DATA ITEM

This Data Item has been compiled by ESDU under a contract with the Ministry of Defence (Procurement Executive) funded by the Department of Industry. The work on aircraft noise lateral attenuation was carried out in cooperation with the Aircraft Noise (A21) Committee of the Society of Automotive Engineers as part of that organisation's detailed investigation of factors that influence lateral noise attenuation. Through this cooperative venture many data that otherwise would not have been available, have been provided for inclusion in the ESDU analysis used to construct this Data Item.

The work on this particular Item was monitored and guided by the following Working Party:

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(Continued on back cover)

ESTIMATION OF LATERAL ATTENUATION OF AIR-TO-GROUND JET OR TURBOFAN AIRCRAFT NOISE IN ONE-THIRD OCTAVE BANDS

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ESTIMATION OF LATERAL ATTENUATION OF AIR-TO-GROUND JET OR TURBOFAN AIRCRAFT NOISE IN ONE-THIRD OCTAVE BANDS

1. NOTATION

		<i>SI Units</i>
A_L	one-third octave band lateral attenuation	dB
D	distance along flight track between aircraft and observer (see A.1)	m
H	height (see Sketch A.1)	m
G	ground-reflection correction	dB
L	far-field sound pressure level	dB*
P	attenuation of sound pressure level due to spherical wave spreading and molecular absorption	dB
R	propagation distance between centroid of engine exhausts and observer (see Sketch A.1)	m
S	sideline distance (see Sketch A.1)	m
x, y, z	Cartesian coordinates (see Sketch A.1)	
β	angle in vertical plane, between line joining observer and centroid of engine exhausts and the ground plane (see Sketch A.1b)	deg
θ	angle of radiation relative to aircraft/engine axis (see Sketches A.1 and Section A.2)	deg
<i>Subscripts</i>		
a	aircraft	
f	free-field	
m	measured	
o	observer	
r	reference	
s	sideline	
u	under-the-flight-path	

* The reference pressure for all decibels is 20 μ Pa.

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2. NOTES

This Item provides a means of estimating the one-third octave band far-field lateral attenuation of noise from jet or turbofan powered aircraft propagating in the vicinity of the ground plane. In the literature lateral attenuation is defined in a number of different ways and as yet there is no universally accepted definition.

In this Item, lateral attenuation, A_L , is defined as the difference between the one-third octave band under-the-flight-path and sideline “free-field” sound pressure levels where the propagation distance, R , and source radiation angle*, θ , associated with the two far-field sound pressure levels are the same. It is assumed that there is clear line of sight between the aircraft and the observer.

The effect of any reflection of an acoustic wave by the ground surface on the measured spectrum is dependent upon the geometric relationship between the aircraft and observer, the acoustic properties of the ground surface, and the sound frequency. Unless special steps are taken with microphone mountings (*i.e.* flush mountings or high mountings) there may be considerable differences, in both magnitude and frequency distribution, in the effect of the reflected wave on the measured noise spectrum. It is therefore necessary to remove the effects of the reflected wave before subtracting to evaluate lateral attenuation.

The term “free-field” is used to describe measured noise levels which have been corrected for the effects of the reflected wave from the ground surface using the method given in ESDU 94035. The theory used in ESDU 94035 considered the reflection of a spherically-diverging wave, propagating through a still, uniform atmosphere at the boundary between two semi-infinite flat media. Therefore lateral attenuation is the sum of all the effects due to non-ideal conditions, the absorption of sound as it propagates over a porous surface, and any source installation effects.

One-third octave band values of lateral attenuation are presented as a function of propagation distance, R , and elevation angle, β , and frequency. Data are provided as a series of carpets, but it must be realised that each line is the best smoothed line drawn through the data. The data scatter about the smooth line is discussed in Section A.3.

A computer program to predict lateral attenuation, known as ESDUpac A8227, is described in Appendix B.

In developing the prediction procedure presented in this Item no data on propeller-driven aircraft or helicopters were used. As the characteristics of propeller and rotor noise sources are very different from those of jet engines, the use of this Item for propeller-driven aircraft and helicopters is not recommended.

Lateral attenuation is often required in subjective units (*e.g.* for noise contours), and values in these units may easily be calculated from the data given in this Item for any particular spectrum. However, before converting the values of one-third octave band lateral attenuation which are contained in this Item to subjective units, the effect of ground reflections on the under-the-flight-path and sideline spectra must be included as necessary. The Addendum to this Item outlines the procedure which should be used when calculating noise exposure, at sideline positions, in time-integrated units such as EPNL.

2.1 Sideline Noise Estimation

The noise level on the ground, L_{om} , when there are no barriers between the aircraft and observer is estimated from the free-field aircraft level, L_a , as follows

$$L_{om} = L_a + G - P - A_L, \quad (2.1)$$

* Within the scatter of the data there was no obvious correlation of lateral attenuation with radiation angle. Further information is given in Section A.3.

where G is the ground-reflection correction, P is the attenuation due to spherical spreading (inverse square law) and atmospheric absorption, and A_L is the lateral attenuation. The “free-field” source level, L_a , may either be calculated from theoretical or empirical relationships, or deduced from noise measurements. ESDU 80038 gives a means of removing the effects of the reflected wave from the measured signals, and should be used in the estimation of the free-field source levels.

The effect of a barrier on the observed noise level can be calculated using the procedure given in ESDU 79011. The loss due to shielding by a barrier will give a further reduction in the value of L_{om} .

In calculating the one-third octave frequency band observed noise level on the ground, L_{om} , account should also be taken of the background noise level. For practical purposes, if the predicted level is within 10 dB of the background level then the observed level will be a combination of the noise due to the aircraft and the ambient noise level. ESDU 66017 gives a means of separating the total sound pressure level into its individual components assuming that the sound pressure levels of all but one of its components are known. If the predicted observed level, L_{om} , is more than 10 dB below the background level then the noise due to the aircraft is not significant and thus can be ignored.

2.1.1 Ground-reflection correction, G

The ground-reflection correction is estimated using the method given in ESDU 80038 in which the acoustic impedance of the ground plane is characterised by its specific flow resistance per unit thickness. The ground-reflection correction is relatively insensitive to variations in the specific flow resistance and it is recommended that, for most cases, a value of 200 kN s/m^4 be used for this parameter. However, when the area surrounding the observer position is acoustically hard (e.g. concrete), a different value of specific flow resistance should be used. Guidance on values of specific flow resistance for various surfaces is also given in ESDU 94035.

2.1.2 Attenuation due to spherical spreading and molecular absorption, P

In practice the reduction in the sound pressure level due to the propagation through the atmosphere is calculated assuming rectilinear propagation. This reduction is estimated using the inverse square law to account for spherical spreading and the method of ESDU 78003 may be used to obtain atmospheric attenuation.

2.2 Lateral Attenuation, A_L

The magnitude of lateral attenuation increases with distance and, at low elevation angles, increases with decreasing elevation angle. At larger distances, the values of lateral attenuation tend asymptotically to a value which depends on frequency and elevation angle.

Owing to the refraction effects from wind shear and temperature gradients, and also atmospheric turbulence near the ground, the lowest elevation angle of data applicability is five degrees. Also, at low elevation angles, when the propagation path of the direct ray is near to the ground, it is possible that undulations of the ground surface may significantly affect the measured noise level by the formation of shadow areas.

For propagation distances greater than 1200 m, it is recommended that the value of lateral attenuation for a distance of 1200 m is used.

3. DATA PRESENTATION

Two sets of lateral attenuation data are provided, one for each of two common configurations of subsonic

jet-powered civil aircraft. The two configurations are:

- (a) aircraft with engines mounted below the wing,
and
- (b) aircraft with engines mounted on the rear fuselage.

Ideally, the noise level on the ground is given by the sum of the individual contributions for each engine. These individual contributions are calculated using lateral attenuation data appropriate to the specific engine location. However, when calculating the observed noise level using a single source to represent the total aircraft noise, the one-third octave band lateral attenuation should be calculated using the data for the engine location applicable to the most significant source of noise.

The values of lateral attenuation, A_L , are found for the given combination of propagation distance and elevation angle by reading the value of A_L from the appropriate graph. However, when repetitive calculations of lateral attenuation are being made, it is recommended that the computer program which is presented in Appendix B should be used. The computer program uses the basic data used to plot Figures 1–48 and employs a second-order interpolation procedure, in both propagation distance and elevation angle, to obtain values of lateral attenuation at intermediate values of elevation angle and propagation distance.

For the two aircraft configurations considered, the following table identifies the Figure number giving A_L in each of the one-third octave bands over the frequency range considered.

One-third octave band centre frequency Hz	Figure number	
	<i>Aircraft with engines mounted below the wing</i>	<i>Aircraft with rear-mounted engines</i>
50	1	25
63	2	26
80	3	27
100	4	28
125	5	29
160	6	30
200	7	31
250	8	32
315	9	33
400	10	34
500	11	35
630	12	36
800	13	37
1000	14	38
1250	15	39
1600	16	40
2000	17	41
2500	18	42
3150	19	43
4000	20	44
5000	21	45
6300	22	46
8000	23	47
10000	24	48

4. EXAMPLE

Determine the free-field values of the one-third octave band lateral attenuation for an aircraft with engines installed below the wing, for bands with centre frequencies from 50 Hz to 10 kHz. The geometric relationships between the aircraft and observer, see Sketch A.1 are as follows:

$$\begin{aligned} D &= 100 \text{ m,} \\ S &= 800 \text{ m,} \\ H_a &= 100 \text{ m,} \\ H_o &= 1.2 \text{ m,} \end{aligned}$$

First calculate the propagation distance using Equation (A.1)

$$\begin{aligned} R &= [(H_a - H_o)^2 + D^2 + S^2]^{1/2}, \\ &= [(100 - 1.2)^2 + 100^2 + 800^2]^{1/2}, \\ &= 812.3 \text{ m.} \end{aligned}$$

Calculate the elevation angle using Equation (A.2)

$$\begin{aligned} \beta &= \sin^{-1}[(H_a - H_o)/R], \\ &= \sin^{-1}[(100 - 1.2)/812.3], \\ \beta &= 7.0^\circ. \end{aligned}$$

The values of one-third octave band lateral attenuation are found by reading from Figures 1–24 for values of $\beta = 7^\circ$ and $R = 812 \text{ m}$, and are tabulated below.

Value of one-third octave band lateral attenuation

<i>One-third octave band centre frequency</i>	A_L	<i>One-third octave band centre frequency</i>	A_L
Hz	dB	Hz	dB
50	2.9	800	4.0
63	3.1	1000	4.0
80	4.3	1250	4.2
100	4.6	1600	4.6
125	5.0	2000	4.7
160	5.3	2500	3.9
200	5.5	3150	3.5
250	5.2	4000	3.2
315	5.0	5000	3.1
400	4.3	6300	1.8
500	4.2	8000	1.1
630	4.1	10 000	1.0

5. DERIVATION AND REFERENCE

5.1 Derivation

The derivation lists sources of data which have assisted in the preparation of this Item.

1. RICKLEY, E.J. Meteorological effects noise tests. Letter Report DST 331-FA853-78-1 U.S. Department of Transportation, Transportation Sytem Centre, Kendall Square, Cambridge, MA 02142, January 1978.
2. – Unpublished information for the BAe 1-11. British Aerospace PLC, Aircraft Group, Weybridge-Bristol Division.
3. – Unpublished information for the Boeing 727. Boeing Aircraft Company.
4. – Unpublished information for the IAI 1124, Israeli Aircraft Industries.
5. – Unpublished information for the C141, Airforce Aerospace Medical Research Laboratory, Biodynamics and Bioengineering Division, Wright Patterson Air Force Base, May 1978.
6. – Unpublished information for the E3A. Air Force Aerospace Medical Research Laboratory, Biodynamics and Bioengineering Division, Wright-Patterson Air Force Base, June 1978.
7. – Unpublished information for the L1011. Royal Aircraft Establishment, Farnborough, September 1979.
8. – Unpublished information for the KC135A. Air Force Aerospace Medical Research Laboratory, Biodynamics and Bioengineering Division, Wright-Patterson Air Force Base, January 1980.
9. SAE Prediction method for lateral attenuation of airplane noise during takeoff and landing AIR 1751, Society of Automotive Engineers, March 1981.
10. – Unpublished information for the Boeing 747. NASA Langley Research Centre, Hampton, Virginia, November 1980.

5.2 Reference

The reference given is a recommended source of information supplementary to that in this Item. In this particular case, partial reference to Derivation [10](#) will be found in the following reference.

11. WILLSHIRE, W.L, Jr Lateral attenuation of high-by-pass ratio engined aircraft noise. NASA Technical Memorandum 81968, April 1981.

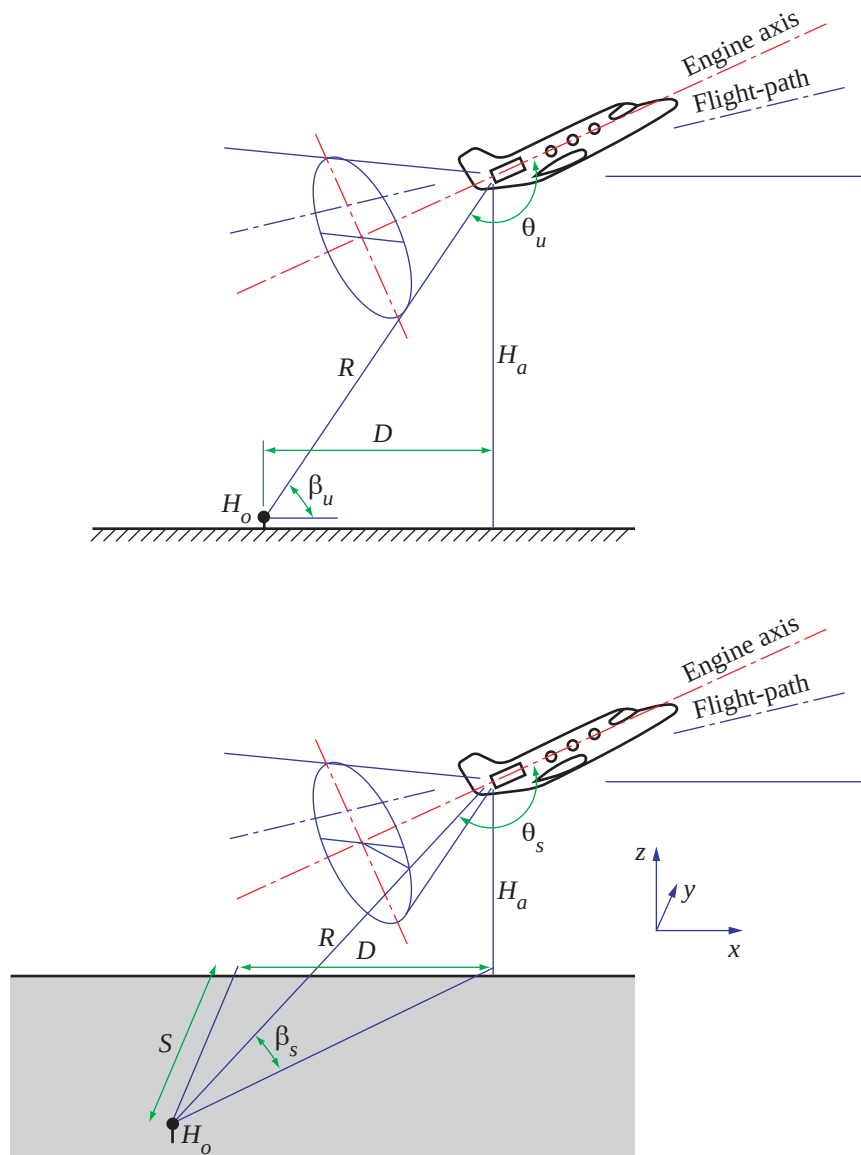
APPENDIX A – ANALYSIS FOR ONE-THIRD OCTAVE BAND LATERAL ATTENUATION

A.1 NOTES

In this Appendix further information is given on the definitions of terms and the analysis procedure used in the derivation of the data presented in this Item.

A.2 DEFINITION OF TERMS

In any one-third octave band, lateral attenuation has been found to be dependent on the propagation distance, R , and the elevation angle, β . The geometric relationship between the source and the observer is shown in Sketch A.1.



Sketch A.1 Geometric relationship between source and observer

The propagation distance, R , is given by

$$R = [(H_a - H_o)^2 + D^2 + S^2]^{1/2}, \quad (\text{A.1})$$

where D is the separation between the aircraft's position and observer's position projected onto the flight-track, and S is the sideline distance.

The angle of elevation, β , is given by

$$\beta = \sin^{-1}[(H_a - H_o)/R]. \quad (\text{A.2})$$

The angle of radiation, θ , is defined as the angle between the longitudinal axis through the engine, projected onto the plane of symmetry of the aircraft, and the line between the centroid of the engine exhaust nozzles and the observer.

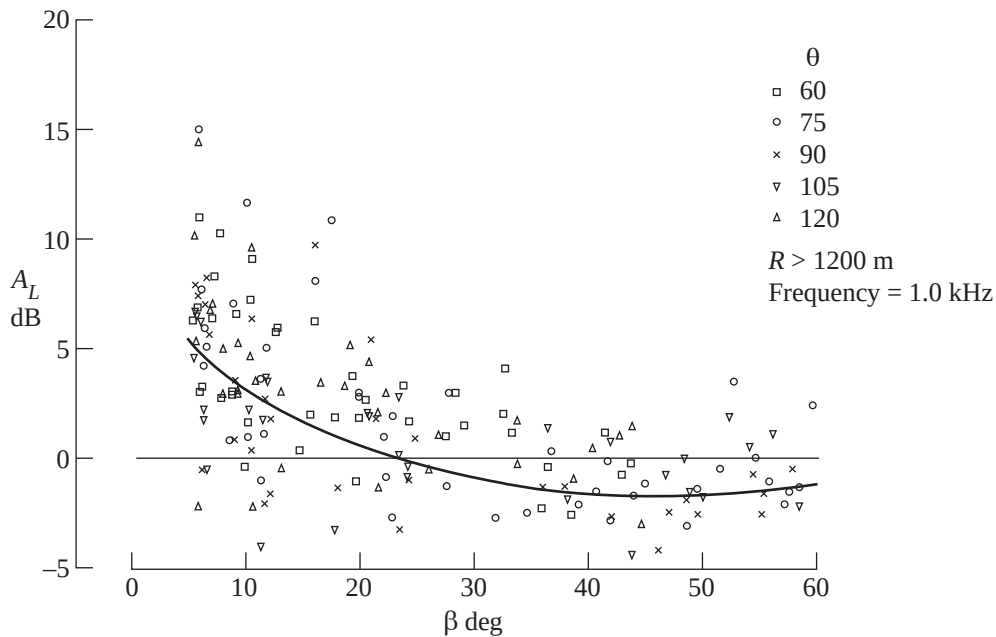
A.3 ANALYSIS FOR LATERAL ATTENUATION

The data presented in this Item have been derived from empirical correlations of the values of lateral attenuation estimated from flight noise measurements on a number of aircraft types. The sources of data are listed in Section 5.

The analysis for lateral attenuation was made using spectra with radiation angles, θ , between 60° and 120° to the engine axis. Data for each radiation angle were considered separately and analysed using the procedure presented in ESDU 81035.

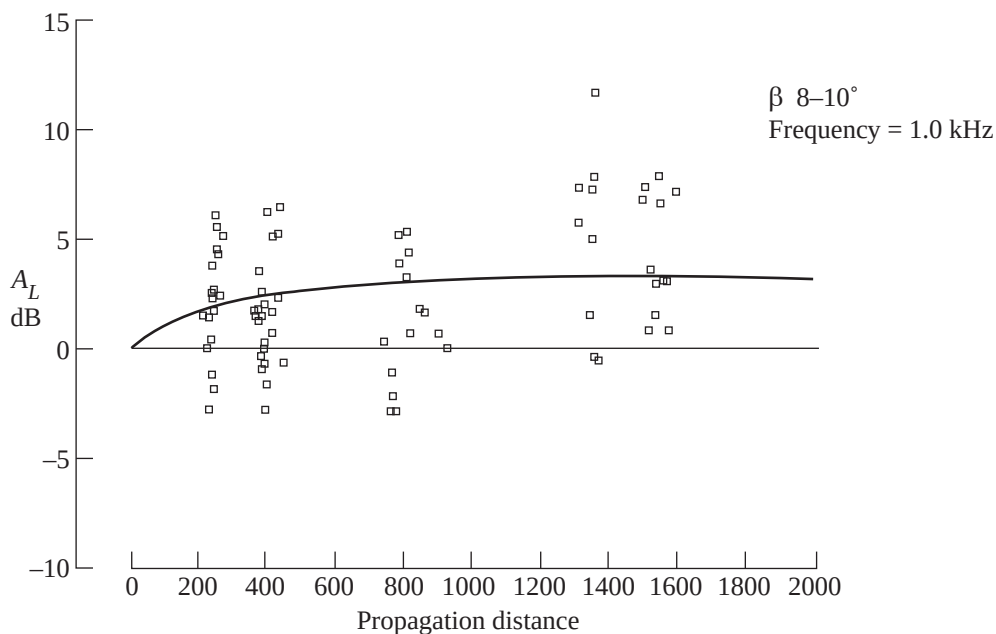
For each one-third octave band, the variation of lateral attenuation with elevation angle was investigated for bands of propagation distance. The bandwidth of these bands varied with propagation distance. At small distances (< 300 m) the bandwidth was one-half the maximum value of propagation distance, and at large distances (> 1000 m) the ratio of bandwidth to the maximum propagation distance in that band was approximately one-fifth.

A typical example of the variation of one-third octave band lateral attenuation with elevation angle, using data from one of the larger data sets, is presented in Sketch A.2. The different symbols present values of lateral attenuation for different radiation angles. The line shown in this sketch is the final correlation line, taken from Figure 14, for a propagation distance of 1200 m.

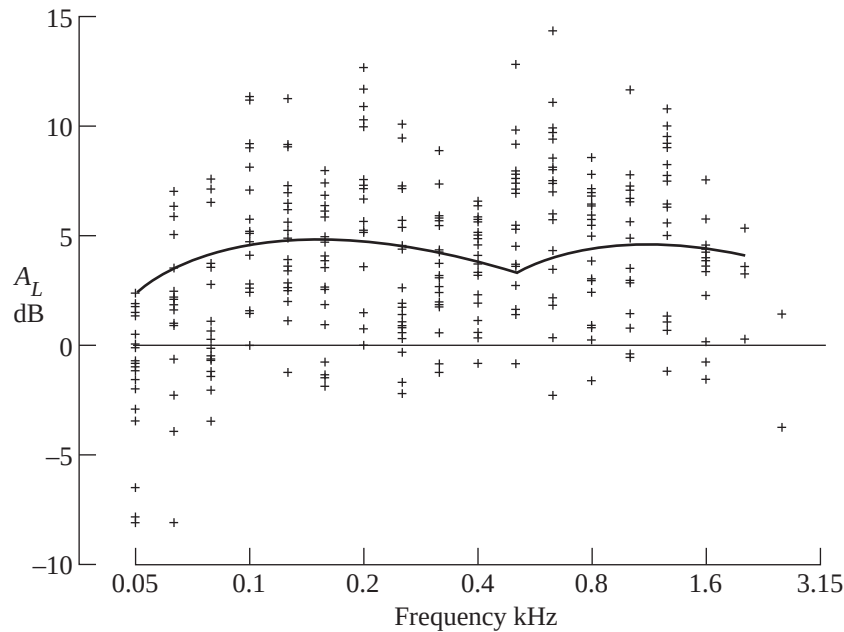


Sketch A.2 Variation of lateral attenuation with elevation angle

In the analysis of the one-third octave band lateral attenuation data, it was found that within the scatter of the data, the variation of lateral attenuation with propagation distance tended to an asymptotic value for distances greater than 1200 m. Similar scatter of data as that shown in Sketch A.2 is seen when one-third octave band lateral attenuation is correlated against propagation distance and frequency. Typical examples of these correlations for an aircraft with engines below the wing are presented in Sketches A.3 and A.4. The correlation lines shown in these Sketches have been taken from the data presented in Figures 1–24.



Sketch A.3 Variation of lateral attenuation with propagation distance

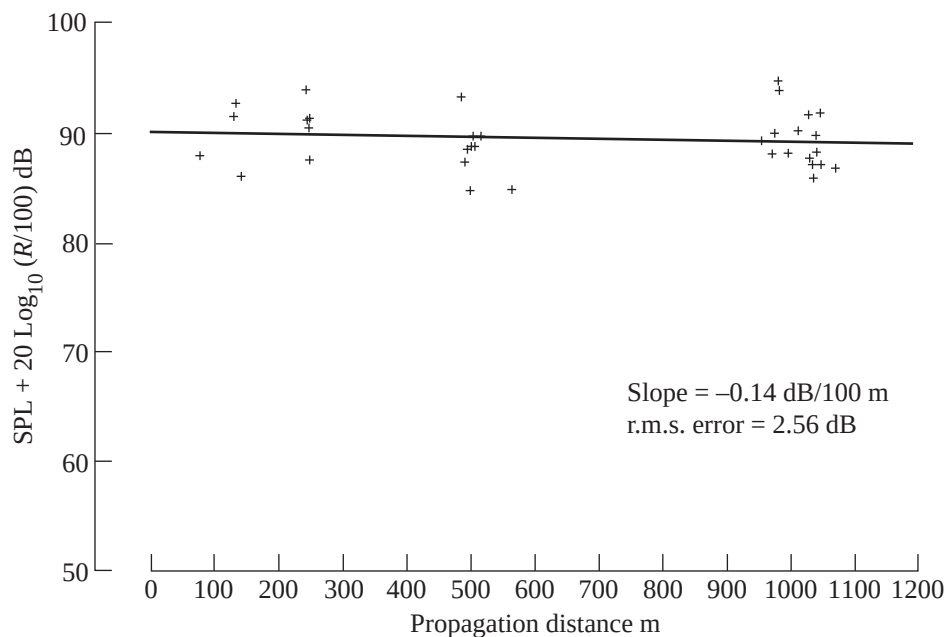


Sketch A.4 Variation of lateral attenuation with frequency

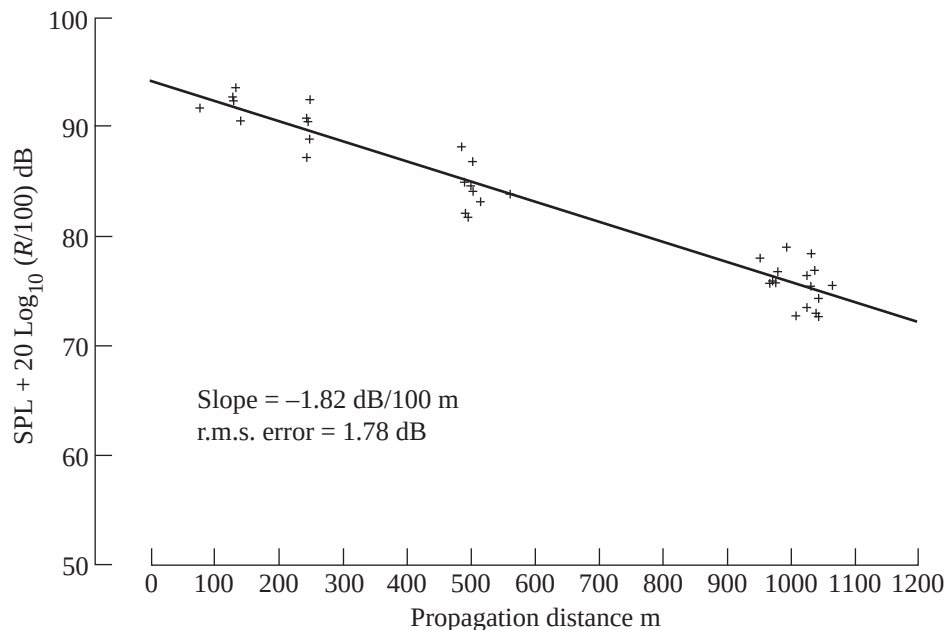
A.3.1 Precision of Data

The values of the one-third octave band lateral attenuation given in this Item have been derived from noise measurements using the method of analysis given in ESDU 81035. An integral part of the procedure is the regression analysis of the under-the-flight-path noise data. From this regression analysis, the under-the-flight-path reference spectrum was obtained (see ESDU 81035, Section 4.2). This reference spectrum was extrapolated to the propagation distance of the sideline location considered using the atmospheric attenuation rate given by the modulus of the slope of the regression line.

Examples of the regression analysis for the one-third octave bands centred at 250 Hz and 2 kHz are presented in Sketches A.5 and A.6 respectively.

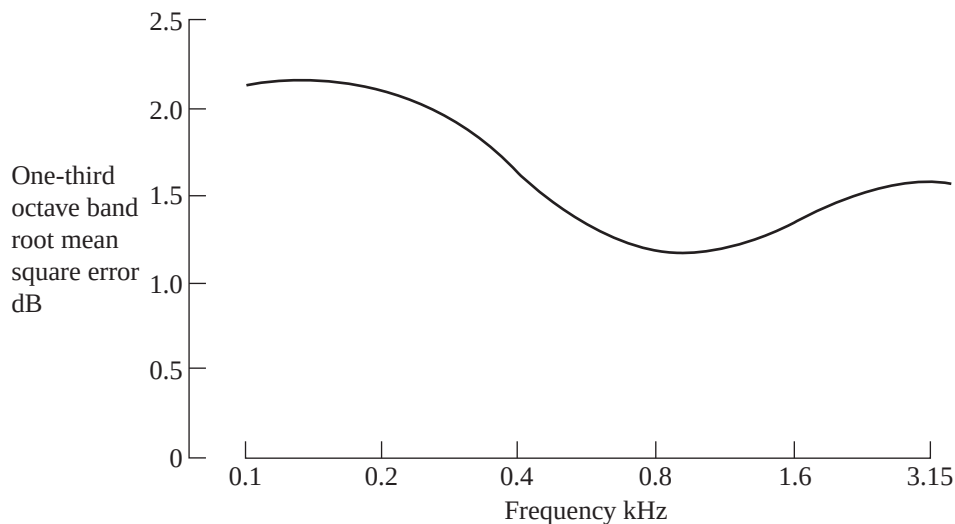


Sketch A.5 Regression analysis for the one-third octave band centred at 0.25 kHz



Sketch A.6 Regression analysis for the one-third octave band centred at 2.0 kHz

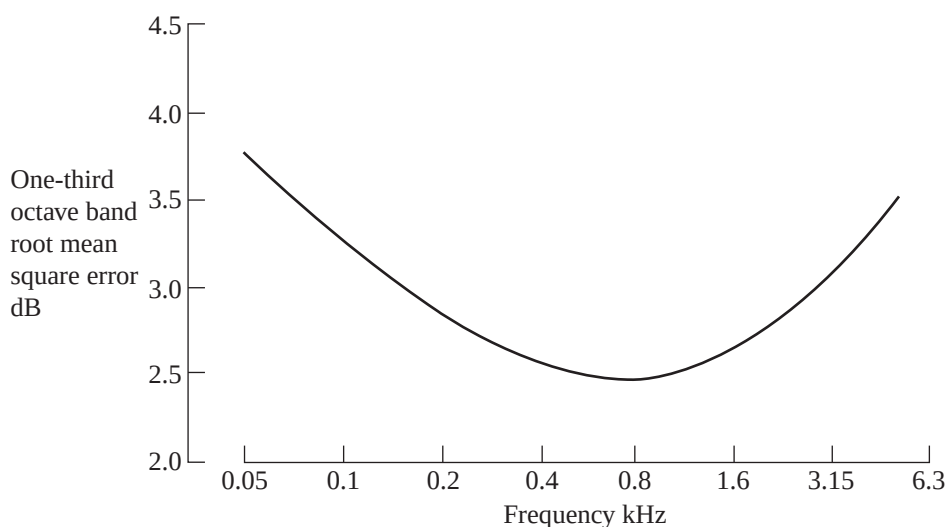
The root mean square error of the regression analysis was found to be frequency dependent and had a value of between 1.0 and 2.5 dB. An example of the variation of the one-third octave band root mean square error with frequency is presented in Sketch A.7.



Sketch A.7 Variation of the rms error of the regression analysis with frequency

As a further check, the values of the slope of the regression line were compared with the values of atmospheric attenuation coefficient calculated using ESDU 78002 and ESDU 78003. In general there was good agreement between the two values of atmospheric attenuation.

As lateral attenuation is calculated from the difference between the extrapolated “free-field” under-the-flight-path spectrum and the “free-field” sideline data, the error in the values of lateral attenuation will not be less than that in the under-the-flight-path data. The variation of the root mean square error with frequency, derived from comparing the prediction procedure with the measured data, for one of the larger data sets is shown in Sketch A.8.



Sketch A.8 Variation of the rms error of lateral attenuation with frequency

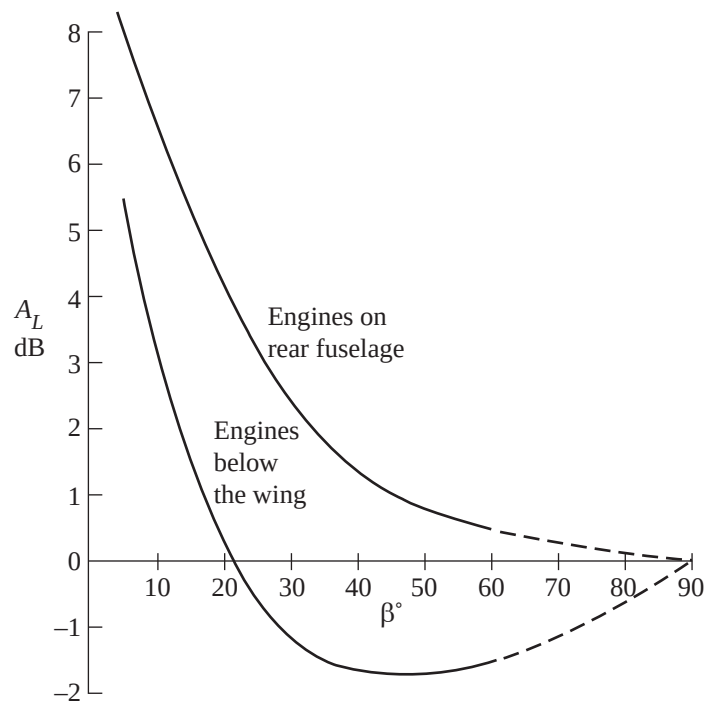
It is well known that the statistical error of the standard one-third octave band analysis procedure increases at both high and low frequencies. However, at the typical sideline distances over which this Data Item is likely to be used, the sound pressure levels of the mid-frequency band (0.5–2 kHz) normally determines the level in frequency integrated units such as dBA and perceived noise level.

The considerable scatter in the data (see Sketches A.2, A.3 and A.4) could be due to errors in the source location and aircraft tracking, the effect of a non-homogeneous and turbulent atmosphere, which would cause the measured levels to vary with time, and background noise which could be due to either ambient noise or electronic noise in the measuring equipment. For the same airframe/engine configuration, it was not possible to differentiate between results for different radiation angles as the results lay within the data scatter. However, for the two engine/airframe configurations for which data are available, there were significant differences in the values of lateral attenuation, hence data are presented for these two aircraft types.

A.3.2 Analysis Procedure

Values of lateral attenuation were obtained, at fixed noise radiation angles, for each of the one-third octave bands through the frequency range of the measured data. As a general principle, the background noise was removed from the measured signal. However, when the measured sound pressure level in any one-third octave band was within 3 dB of the background noise level no value of lateral attenuation was calculated for that band.

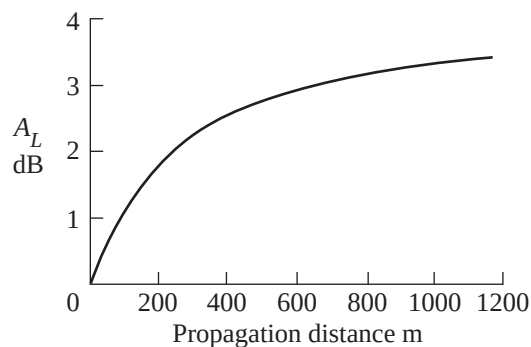
The first step in final data correlation was the investigation, for each aircraft and one-third octave band, of the variation of lateral attenuation with elevation angle for limited bands of range. Comparing the results from different aircraft at this stage of the analysis, it was apparent that the data could be divided into two distinct categories, those with engines mounted on or in the rear fuselage, and those with engines mounted below the wing. Within each aircraft category the data showed consistent trends. For example, data for the aircraft with engines mounted below the wing had negative values of lateral attenuation in all frequency bands at values of elevation angle $> 30^\circ$, whereas the aircraft with rear-mounted engines did not show this trend. Typical variations of lateral attenuation with elevation angle for the two aircraft configurations are presented in Sketch A.9.



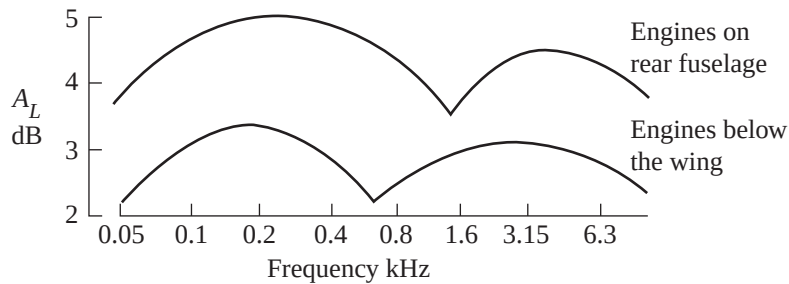
Sketch A.9 Typical variations of lateral attenuation with elevation angle

The lines shown in Sketch A.9 were constrained to be zero for 90° elevation angle. The difference between the two aircraft configurations is probably caused by an installation effect, although at present it cannot be explained.

The subsequent stages in the analysis for lateral attenuation were to cross plot the results against both propagation distance and frequency. Sketches A.10 and A.11 present the typical shapes of the two lines.



Sketch A.10 Typical variation of lateral attenuation with propagation distance



Sketch A.11 Typical variations of lateral attenuation with frequency

In the case of variation of lateral attenuation with propagation distance, the curve was constrained to be zero for a zero propagation distance.

A.3.3 Meteorological Conditions

The meteorological conditions for the tests, where data have been provided, were generally good with no temperature inversions and with low wind speeds at ground level. The good meteorological conditions mean that the effect of refraction, caused by wind and temperature gradients, would be small for the range of elevation angles considered in this Item. However, for elevation angles less than five degrees, these effects could give rise to an increase in the data scatter even in these good meteorological conditions.

APPENDIX B – COMPUTER PROGRAM FOR THE CALCULATION OF AIRCRAFT NOISE FAR-FIELD ONE-THIRD OCTAVE BAND LATERAL ATTENUATION

The computer program, known as ESDUpac A8227 permits the user to predict lateral noise attenuation of air-to-ground jet or turbofan aircraft noise in the far-field in one-third octave bands.

B.1 INPUT DATA

Data may be input to the program either from the keyboard or from a file with directed input. The program can be run by either clicking on the icon associated with the executable version of the program or by typing in the program name, A8227.

Alternatively, the name of the input data file can be specified on the command line using the operating system redirection symbol as in,

A8227 < input filename

In this case visual prompts, which should be ignored, will appear on the terminal screen.

The output is written to a file named by the user as part of the input.

The facility to print out up to three lines of descriptive text which are entered as part of the input is provided.

The structure of the input file is shown in Table [B.1](#).

B.2 EXAMPLE

The input file and the computer program output for the example in Section 4 of the main body of the Item are shown here.

Input file

```
Data Item 82027
Section 4
Example
R01A8227
1
100.0 800.0 100.0
0.0 0.0 1.2
```

Example output

ESDU International plc.

Program A8227

```
ESDUpac Number   :   A8227
ESDUpac Title    :   Estimation of lateral attenuation
Data Item Number :   82027
Data Item Title  :   Estimation of lateral attenuation of
                    air-to-ground jet or turbofan aircraft
                    noise in one-third octave bands
ESDUpac Version  :   2.0 November 1993 Data Item Amendment B
```

See Data Item for full input/output specification and interpretation.

```
Data Item 82027
Section 4
Example
```

Output filename : R01A8227

Input data
=====

```
The engines are mounted below the wing.
x,y,z coordinates of source :   100.00, 800.00, 100.00
x,y,z coordinates of observer :    .00,    .00,   1.20
```

Frequency (Hz)	Lateral Attenuation (dB)
50	3.0
63	3.1
80	4.3
100	4.6
125	5.0
160	5.3
200	5.5
250	5.2
315	5.0
400	4.3
500	4.2
630	4.1
800	4.0
1000	4.0
1250	4.3
1600	4.6
2000	4.7
2500	4.0
3150	3.5
4000	3.2
5000	3.1
6300	1.8
8000	1.1
10000	1.0

B.3 INPUT FILE

TABLE B.1

First line of run title (up to 75 characters)
Second line of run title (up to 75 characters)
Third line of run title (up to 75 characters)
Output filename (up to 12 characters)
If engines are mounted below the wing, enter 1
If engines are mounted on the rear fuselage, enter 2
$x-y-z$ co-ordinates of source*
$x-y-z$ co-ordinates of observer*

* The x , y and z co-ordinates can be separated by commas or spaces or can even be on successive lines.

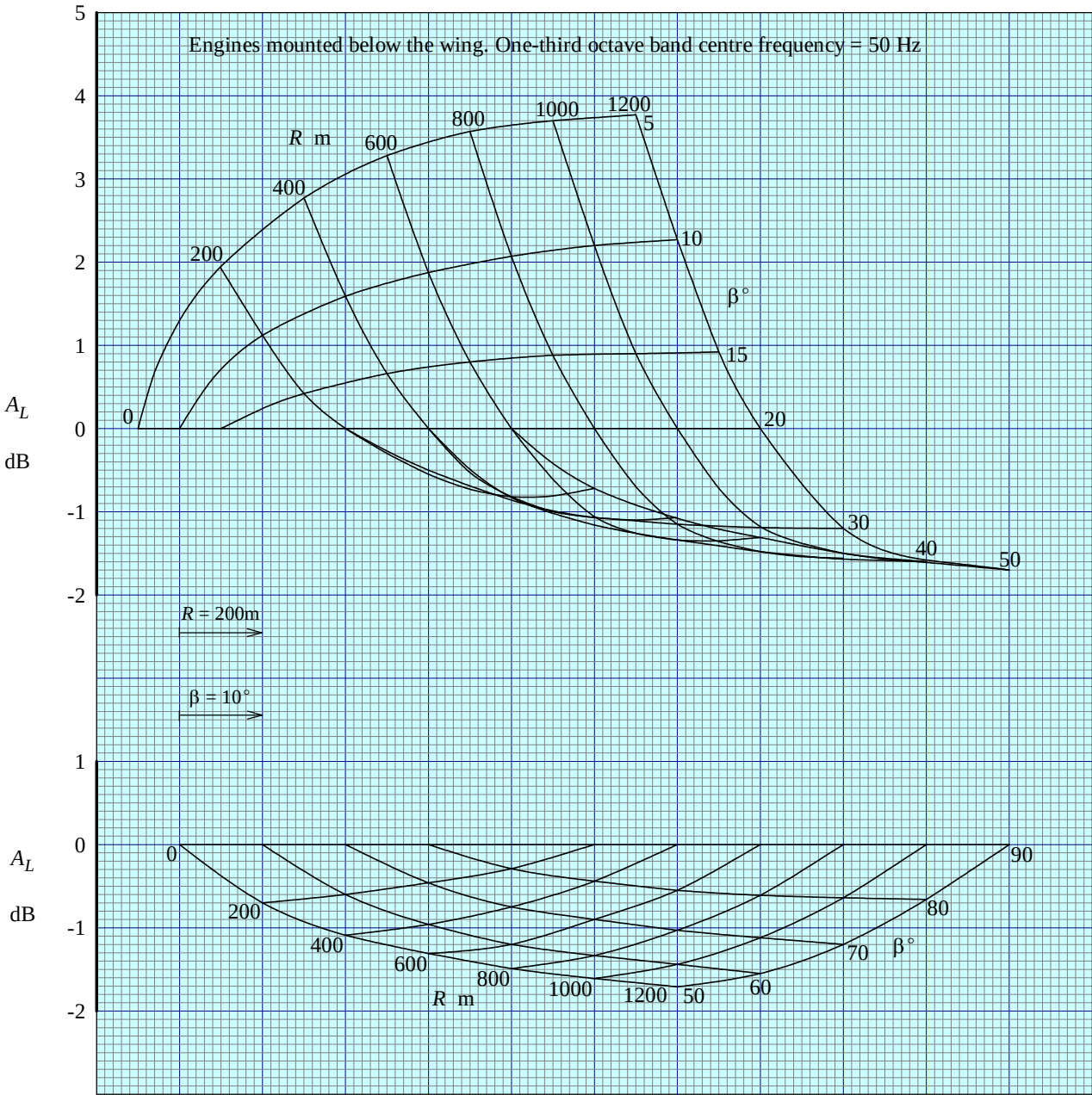


FIGURE 1