Environmental Research and Consultancy Department

Civil Aviation Authority

ERCD REPORT 0206

A Practical Method for Estimating Operational Lateral Noise Levels

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Summary

This report presents a study that was undertaken at Gatwick airport to establish an alternative method for estimating operational aircraft noise levels at the lateral (sideline) certification measurement location. In operational circumstances, the lateral noise level is very difficult to measure on the standard 450 m sideline because the maximum level must be captured. An alternative method is described that relies on measuring take-off power noise beneath the aircraft rather than to the side. These estimates, which are referred to as *pseudo-lateral* noise levels, are not *true* lateral levels, but they are highly correlated with them.

April 2003

Prepared on behalf of the Department for Transport by the Civil Aviation Authority

On behalf of ERCD, his co-author would like to acknowledge the substantial contribution made to this study by their friend and colleague Mike Smith who sadly passed away on 17 June 2000.

ISBN 0 86039 920 6

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The latest version of this document is available in electronic format at www.caa.co.uk, where you may also register for e-mail notification of amendments.

Published by TSO (The Stationery Office) on behalf of the UK Civil Aviation Authority.

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Glossary of Terms

A-weighted	A weighting that is applied to the electrical signal within a noise-measuring instrument as a way of simulating the way the human ear responds to a range of acoustic frequencies.
aal	Aircraft height above the aerodrome level.
ANMAC	Aircraft Noise Monitoring Advisory Committee. The committee is chaired by the Department for Transport and comprises representatives of the airlines, Heathrow, Gatwick and Stansted airports and airport consultative committees.
dBA	Decibel units of sound pressure level measured on the A-weighted scale.
EPNdB	The measurement unit for EPNL.
EPNL	Effective Perceived Noise Level. Its measurement involves analyses of the frequency spectra of noise events as well as the duration of the sound.
ERCD	Environmental Research and Consultancy Department of the Civil Aviation Authority.
ICAO	International Civil Aviation Organisation
kts	Knots (nautical miles per hour)
NTK	Noise and Track Keeping monitoring system. The NTK system associates radar data from air traffic control radar with related data from both fixed (permanent) and mobile noise monitors at prescribed positions on the ground.
SEL	The Sound Exposure Level generated by a single aircraft at the measurement point. This accounts for the duration of the sound as well as its intensity.
SOR	Start-of-roll: The position on a runway where aircraft commence their take-off runs.

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1 Introduction

1.1 The scheme of night restrictions which came into operation at Heathrow, Gatwick and Stansted airports in 1993 contained a 'quota count' (QC) system based on each aircraft's certificated noise data. Aircraft movements (arrivals or departures) at each airport count against the noise quota according to their QC classifications. The Aircraft Noise Monitoring Advisory Committee (ANMAC) was tasked with overseeing the monitoring of noise performance of aircraft covered by their QC classification. The intention was to discover if any aircraft was performing significantly above and/or below its QC classification and, if necessary, to review its classification. The QC monitoring work (Ref 1) was undertaken on behalf of ANMAC by the Environmental Research and Consultancy Department (ERCD) of the Civil Aviation Authority.

1.2 To assess the working of the QC classification system it was considered that the most suitable approach would be to determine noise levels under 'operational' conditions (using data from the London airports' NTK system) at the three certification measurement points specified in Chapter 3 of ICAO Annex 16, Volume 1 (Ref 2): *approach*, under a 3 degree descent path 2000 m from runway threshold; *lateral* (or sideline), 450 m to the side of the initial climb after lift-off (or 650 m for Chapter 2 aircraft[1]); and *flyover*, under the departure climb path, 6500 m from start-of-roll (SOR).

1.3 However, it is generally recognised that lateral noise levels are much more difficult to determine accurately than flyover and approach levels, since the longitudinal position of the lateral reference point is not fixed. The requirements state that it must be the point on the 450 m sideline where the measured noise level is greatest. To measure the operational lateral level directly would require a row of monitors along the sidelines (both left and right) of each flight track, typically between about 3 and 6 km from SOR; as actual tracks at the three London airports are widely dispersed about the noise preferential route centrelines at those distances, this would be practically impossible. An alternative, simpler procedure to that laid down in ICAO Annex 16 was needed for use in the process of QC monitoring.

1.4 This report presents a study that was undertaken in the 'rural' areas to the west of Gatwick airport to establish an alternative methodology for the 'in-service' estimation of lateral noise levels. The proposed alternative was to measure full power take-off noise directly under the fight path.

2 Background

2.1 The noise certification standards in Chapter 3 of ICAO Annex 16 require that an array of microphones be used to determine the highest level of lateral noise, wherever it occurs, on a line 450 m to the side of the take-off flight path. This is because, unlike the other certification conditions where measurement is directly beneath the aircraft flight path and there is little to impede the propagation of sound from the aircraft to the microphone, several natural forces affect its progress sideways to the lateral point.

2.2 Disregarding the asymmetry effects unique to propeller noise, in the simpler case of jets, the lateral effects are still numerous. They include shielding of engine noise

[1] Since 1 April 2002, Chapter 2 aircraft above 34,000 kg (MTOW) have not been permitted to operate at UK airports, other than in most exceptional circumstances.

sources by the fuselage and other adjacent structure, including other engines; the disruption of sound propagation by the aerodynamic flowfields around the engine nacelles, the wings and fuselage; and also, at very low angles of sound incidence, the naturally-high absorptive qualities of the ground ('overground attenuation') as well as refraction caused by wind and air temperature gradients.

2.3 All these factors are usually embraced by the general term 'lateral attenuation' and are frequency-dependent, varying with engine type as well as the installation geometry of the particular aircraft (the number of engines and their disposition with respect to the wings and fuselage). They influence the noise received at any one point on the ground to a varying degree as the aircraft climbs and the propagation geometry varies. As a result, the time-integrated lateral EPNL determined in certification is often subject to greater variability than underflight measurements. Hence the requirement for an array of microphones along either the port or starboard 450 m displacement line and confirmatory measurements on the opposite side; a process which is clearly impracticable around major airports. Even in the certification context, it is a tedious and costly process and the subject of 'equivalent procedures'.

2.4 For example, in the 1980s the certificating authorities worldwide accepted some simplification by recognising that, on average, the peak lateral noise from jet-powered aircraft occurs when the aircraft is at a height of around 1000 ft and therefore that two single microphones, one each side of the flight path, could be used adjacent to the 1000 ft point, instead of a full array. In fact, in its domestic noise regulation FAR-36 (Ref 3), the US FAA actually went so far as to endorse this procedure by requiring the 'sideline' noise peak to be determined when the aircraft was at 1000 ft, whilst other nations accepted this method as a cheaper alternative to the more rigorous process of Annex 16.

2.5 Now, at 1000 ft (300 m) height, the angle of elevation of the aircraft relative to the 450 m lateral measuring point is around 35 degrees; an angle that is high enough for sound propagation to be only minimally affected by most 'lateral attenuation' effects. In fact, because any lateral attenuation is limited to the low-angle early part of the noise-time history, a lateral measurement at 450 m is very close to that measured directly beneath the aircraft when its slant distance (closest distance) is the same as the slant distance of the lateral point, providing the power setting and speed are the same (see **Figure 1**).

2.6 When the aircraft passes through 300 m, the slant distance from the aircraft to the 450 m lateral offset point is around 550 m, and the 'equivalent' underflight distance at which the same noise level occurs might be expected to be about the same. However, it was reasoned that this needed checking to ensure that in practice any slight asymmetry of the sound source between the lateral elevation angles of 35 degrees and the 90 degree 'overhead' position did not produce a different value. Hence, the main objective of the experiment now described was to determine the real 'equivalent' distance and establish the methodology for measuring 'pseudo-lateral' noise under everyday operational conditions.

3 Gatwick Test Programme

3.1 Noise monitor array

3.1.1 Gatwick airport was selected as the site for a proving exercise because of its single runway operational mode and the comparatively open surrounding countryside with the greater potential for the placement of noise monitors at the necessary locations. It was anticipated that data would be collected more rapidly at Gatwick than at Stansted (which also has a single runway) due to the greater number of aircraft movements there. Furthermore, the majority of aircraft departing from Gatwick along the noise preferential routes do not begin turning until beyond 6 km from SOR.

3.1.2 To this end, three rows of NTK microphones were deployed over the last four months of 1996 - one row in line with the extended runway centreline, the other two as close to 450 m either side as was logistically possible (**Figure 2**). Except for Site 1, which is a fixed noise monitor, all of the noise monitors were mobile units. Although not critical for the study, it had been intended to have at least three microphones in all the rows, but practicalities of land ownership, housing disposition and equipment security prevented this. The centreline array was used to determine the noise level beneath the take-off flight path as a function of the minimum slant distance, whilst the lateral arrays were used to determine lateral noise as a function of elevation angle, from which the peak level could be obtained.

3.1.3 The two lateral arrays were thought necessary to allow for any slight deviations from the straight-out take-off track and also any gross propagation imbalance brought about by crosswind, topographical or other local effects. The positioning of the microphones was such that the 300 m height condition for peak lateral noise, which varies markedly in terms of distance from SOR for two, three and four engine aircraft and take-off weight, was embraced in the overall range of aircraft heights as they passed the microphones (**Figure 3**).

3.1.4 At the London airports, the radar data in the NTK system are filtered outside a given rectangular area surrounding the airfield to eliminate known areas where radar reflections are a problem. Furthermore, the NTK system requires four consecutive radar returns (i.e. four radar revolutions) in order to identify an aircraft movement as an arrival or departure (as opposed to spurious data such as an aircraft over-flight). A consequence of these two factors is that radar data for aircraft departing from Gatwick are usually not visible in the NTK system before 2.5 km from SOR or below 500 ft aal. Therefore, to ensure good data acquisition at take-off power for both slower and faster climbing aircraft, noise monitors were required at more than one location directly under the flight-path. For this study, two mobile monitors were positioned on the extended runway centreline: at 3.5 km from SOR, as close as was practically possible to the end of the runway; and at 4.6 km from SOR (i.e. approximately halfway between the 3.5 km monitor and Site 1).

3.1.5 Although certificated aircraft noise levels are measured in EPNL, the only integrated noise metric available at the time in the London airports' NTK system was A-weighted SEL - development of the system's EPNL facility had been substantially delayed and did not become fully operational until June 1998. To avoid further delay, the test programme was carried out using SEL. (In 1998 a check study was undertaken to verify the equivalence of the methodology for both units - see paragraph 3.3.1.)

3.1.6 Radar data were used to position the aircraft with respect to all the monitors. Measured noise data at the lateral microphones were corrected for distance variations (away from 450 m) according to the industry supplied Noise-Power-

Distance (NPD) relationships for each aircraft type (or appropriate aircraft substitution), which are based on data acquired during the certification process (Ref 4). To limit the effects of extreme weather variations as much as possible, noise measurements recorded under extreme conditions (wind speeds greater than 10 kts at 10 m above ground, temperature outside the range 2 to 30°C and relative humidity outside the range 30 to 90%) were excluded from the analysis.

3.2 Results

3.2.1 **Figures 4 to 8** present the westerly take-off SEL data recorded in 1996 for a sample of the jet-powered aircraft operating regularly at Gatwick. These embrace five types; ranging from the largest to the smallest commercial jets with two, three and four engines of low and high bypass ratio (Chapter 2 and 3 types) - the B747-200, L1011, B737-200 and B737-400 and the BAe-146.

3.2.2 In each figure, the upper half (a) gives the results from the lateral monitors expressed in terms of angle of elevation subtended as the aircraft passed each monitor, with a suggested mean line (polynomial best fit) that indicates the peak lateral level (normalised to 0 dBA). In the lower half of each figure (b), the SEL values from the centreline monitors have been normalised with respect to the peak lateral level in (a) and are presented as a function of slant distance above the monitor. On these, two high-thrust curves from **Reference 4** have been superimposed for comparison with the rate of decay of noise with distance of the in-service results.

3.2.3 It immediately becomes apparent from all the upper plots (a) that the variation of lateral noise level with angle of elevation is somewhat 'flat' and deviates little more than 1 dBA within 10 degrees either side of the peak. This is precisely why it was possible to select a single 'equivalent' height of 1000 ft for noise certification purposes without incurring any significant errors. However, firstly the centreline (underflight) data need interpreting.

3.2.4 Interpretation is necessary because pilots will reduce (or 'cut back') engine power after take-off to conserve engine life. Before 1 November 2001[2], the minimum height aal at which cutback was permitted in the UK was 1000 ft. This meant that take-off power (whether maximum or 'de-rated') was only guaranteed whilst the aircraft was below 1000 ft (300 m). Consequently, the peak lateral noise at 300 m may have been a composite of take-off and reduced power noise whilst underflight noise above 300 m might largely have been from the reduced power sector of the flight profile.

3.2.5 Taking the case of the B747-200 in **Figure 4(b)**, the measured data points are seen to parallel the two high-thrust NPD curves until they start to fall away more rapidly beyond some 350 m. This indicates that pilots of this older type of B747 were probably initiating power reduction very soon after achieving the minimum 300 m height. In the case of the L1011 in **Figure 5(b)**, the situation appears somewhat similar. However, with the faster-climbing B737 types in **Figures 6(b) and 7(b)**, the power reduction seems to be delayed to beyond 400 m although, in terms of time from brake-release, the situation may be similar to the B747 and L1011. For the BAe-146 in **Figure 8(b)**, the evidence of power reduction is not clear and the rate of decay of noise is perhaps less than indicated by the NPD curves.

[2] After this date, the minimum permitted height was reduced to 800 ft aal.

3.2.6 However, in general terms, the fact that power reduction takes place above a height of 300 m, the slant distance at which the largely take-off power-controlled peak lateral level is reproduced beneath the flight path cannot be judged without disregarding the measured data where reduced power dominates. Instead, to determine the 'equivalent' distance at which the lateral level would occur, it is necessary to extrapolate the observed take-off power noise levels below 300 m to determine the distance at which the 'true' peak lateral level is reproduced; the obvious extrapolation methodology being to rely on the appropriate NPD relationships.

3.2.7 That is why, in each lower figure (b), this procedure has been followed to deduce the average equivalent slant distance at which the peak lateral level is reproduced under the flight path, as indicated by the intercept of the mean (bold) decay curve and the horizontal axis. In all cases, this is seen to be slightly greater than the nominal 550 m closest-distance of the lateral point. This difference is explicable by the impact of a small amount of lateral attenuation which gives a slightly lower noise level at the lower angle of elevation to the side of the flight path.

3.2.8 Repeating the extrapolation process described above for the most common aircraft types at Gatwick during the 1996 test programme gives the summary results presented in **Table 1**. Across all aircraft types, the average slant distance at which the peak lateral level is reproduced is shown to be 590 m.

3.2.9 Whilst it is clear that there is no unique distance at which a measurement beneath the flight path will reproduce precisely the operational peak lateral noise level for all aircraft types, a nominal (and slightly cautious) slant distance of 600 m would produce small errors. Individual errors would range from minus 0.6 to plus 0.5 dBA; possibly no worse than the errors which would arise in the measurement of the 'true' lateral level with all its variability due to directivity and propagation effects.

3.3 Validation of methodology using EPNL

3.3.1 Because the 1996 tests were carried out in SEL, a check study was undertaken in 1998 to verify the equivalence of the methodology in EPNL (the aircraft certification noise unit). Comprising a series of simultaneous SEL and EPNL measurements at underflight and lateral locations, the study revealed consistent differences between relative levels of SEL and EPNL beneath and to the side of the flight path for a variety of aircraft types. On the basis of those results, the use of the pseudo-lateral measurement technique for QC monitoring in EPNL was endorsed by ANMAC.

3.3.2 In addition, NTK monitors were deployed during the summer months of 2001 for a separate monitoring study at two of the original 1996 test sites. Although the work was unplanned, ERCD took the opportunity to analyse EPNL data from the monitors to substantiate the equivalence of the methodology in EPNL. The 2001 tests also provided data for a wider variety of modern aircraft types. However, because only two microphone locations were available for the tests (Sites 7 and 8 in **Figure 2**), limited data above 300 m were recorded for some slower climbing aircraft types.

3.3.3 **Figures 9 to 13** present the EPNL data for five common aircraft types that operated during the summer months of 2001 – the A300-605R, A321-211, B757-200, B777-200 and MD82/83. Although the data are somewhat limited beyond 300-400 m, evidence of power reduction after take-off for some aircraft is again indicated by the measured data points, which start to fall away more rapidly beyond some 350 m (compared with the two high-thrust NPD curves).

3.3.4 Repeating the extrapolation process described in paragraph 3.2.6 for the most common aircraft types at Gatwick during the 2001 tests gives the summary results presented in **Table 2**. Across all aircraft types, the average slant distance at which the peak lateral level is reproduced is shown to be 573 m and as before, a slant distance of 600 m would produce relatively small errors in all cases (individual errors would range from minus 1.0 to plus 0.4 EPNdB).

3.4 Certification procedure for propeller-driven heavy aircraft

3.4.1 The merits of the pseudo-lateral methodology were effectively endorsed by a recommendation that a Working Group of the Committee on Aviation Environmental Protection (CAEP) had given to ICAO in 1995 (Ref 5): that the use of lateral measurements for the certification of propeller-driven heavy aircraft should be discontinued - because that practice had raised severe practical difficulties. The proposed alternative was to measure full power take-off noise directly under the flight path. Subsequently, in November 1997, the CAEP proposal was added to Annex 16 as an alternative to the traditional 450 m lateral procedure (after 18 March 2002 it became the *only* full power certification procedure for propeller-driven heavy aircraft). Although propeller aircraft were not studied in the Gatwick tests, the full power certification procedure states that measurements should be made 650 m under the flight path. The marginally smaller slant distance indicated by the Gatwick results for jets may be attributable to the very different spectral and directivity characteristics of jet and propeller aircraft.

4 Conclusions

4.1 Using a sample of the most common types of aircraft operating at Gatwick, this study has shown that the noise level in SEL/EPNL beneath jet-powered aircraft at a nominal slant distance of 600 m (2000 ft), with the engines at take-off power, is approximately equal (on average within 1 dBA/EPNdB for the aircraft studied) to the noise level at the ICAO Annex 16 450 m lateral point.

4.2 It was clear that the results of this proving exercise opened up the practical possibility of measuring the noise beneath the aircraft at take-off power to estimate the average in-service lateral level, rather than the near-impossible task of measuring the true lateral level at major airports by using a vast matrix of monitors. Thus, the 'principle of equivalence' was proposed to ANMAC, whereby the noise measured under the flight path, between the end of the runway and the fixed monitor locations, could be extrapolated to 600 m using standard decay curves; and the resultant level could be assumed to represent the lateral level for the purpose of calculating an aircraft's operational departure QC[3].

4.3 In practice, where measurements are made around an operational airport, data should be acquired under the flight path when aircraft are below the height at which there is any reduction from take-off power and the results extrapolated to 600 m to determine the pseudo-lateral noise level. Therefore, a noise monitor would need to be located as close as possible to the runway end, typically about 3.5 km from SOR, to capture data for fast climbing aircraft. Depending on the radar coverage at a

[3] To allow for the difference in lateral certification position between Chapter 2 and Chapter 3, an adjustment of +1.75 EPNdB is applied to the average departure levels of Chapter 2 aircraft to calculate their QC classifications. However, in the process of QC monitoring it is not necessary to adjust the measured pseudo-lateral levels of Chapter 2 aircraft in the same way, since the measurements already relate to the 450 m lateral position.

particular airport, an additional centreline noise monitor may also be required at a more distant location, say between about 4.5 and 5 km from SOR, to capture data for slower climbing aircraft. The monitoring technique described above therefore requires that radar (or other) data are available to determine, with sufficient accuracy, the position of the aircraft below the minimum height at which cutback can occur.

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2 International Standards and Recommended Practices, Environmental Protection, Annex 16, Amendment 7, Volume I, Aircraft Noise: International Civil Aviation Organisation (ICAO), Montreal, 1993.

3 Federal Aviation Regulation (FAR) Part 36 - Noise Standards: Aircraft Type and Airworthiness Certification: U.S. Department of Transportation, Federal Aviation Administration (FAA), Washington D.C., 1992.

4 Integrated Noise Model (Version 6.0c): U.S. Department of Transportation, Federal Aviation Administration (FAA), Washington D.C., September 2001.

5 Report of the Third Meeting: Committee on Aviation Environmental Protection (Doc 9675, CAEP/3): International Civil Aviation Organisation (ICAO), Montreal, December 1995, pp 1-7 – 1-8.

Table 1 Gatwick Results (1996 SEL Data)

AIRCRAFT TYPE	NUMBER OF AIRCRAFT MONITORED	AVERAGE UNDERFLIGHT SLANT DISTANCE AT WHICH PEAK LATERAL LEVEL OCCURS (m)
A320/CFM56-5A1,-5A3	74	580
B737-200/JT8D-15A	523	640
B737-400/CFM56-3C1	653	560
B747-200/RB211-524D4	119	590
B757-200/RB211-535E4	405	550
B767-200/CF6-80A2	72	590
BAe-146/ALF502R-5	287	570
DC10-30/CF6-50C2	150	620
F100/Tay 620-15	82	640
L-1011/RB211-22B	96	560
AVERAGE		590
STD DEV		33

Table 2 Gatwick Results (2001 EPNL Data)

AIRCRAFT TYPE	NUMBER OF AIRCRAFT MONITORED	AVERAGE UNDERFLIGHT SLANT DISTANCE AT WHICH PEAK LATERAL LEVEL OCCURS (m)
A300-605R/CF6-80C2A5	343	590
A320/CFM56-5B4	473	580
A320/V2500-A1	727	640
A321/CFM56-5B3	341	560
A321/V2533-A5	125	540
A330/TRENT 772B	213	550
AVRO RJ100/LF507-1F	2577	560
B737-200/JT8D-15(HK)	226	550
B737-300/CFM56-3C1	1119	550
B737-400/CFM56-3C1	3291	570
B737-700/CFM56-7B24	55	540
B747-200/PW JT9D-7J	79	580
B747-200/RB211-524D4	129	560
B747-400/CF6-80C2B1F	207	620
B757-200/RB211-535E4	837	580
B757-300/RB211-535E4-B	123	540
B767-300/CF6-80C2B7F	139	520
B767-300/RB211-524H	347	560
B767-400/CF6-80C2B7F	43	630
B777-200/GE90-85B,-90B	345	580
B777-200/TRENT 892-17	129	590
B777-200/TRENT 895	189	600
CANADAIR REGIONAL JET	260	570
DC10-30/CF6-50C2	148	600
MD-82,-83/JT8D-217,-219	336	570
AVERAGE		573
STD DEV		29

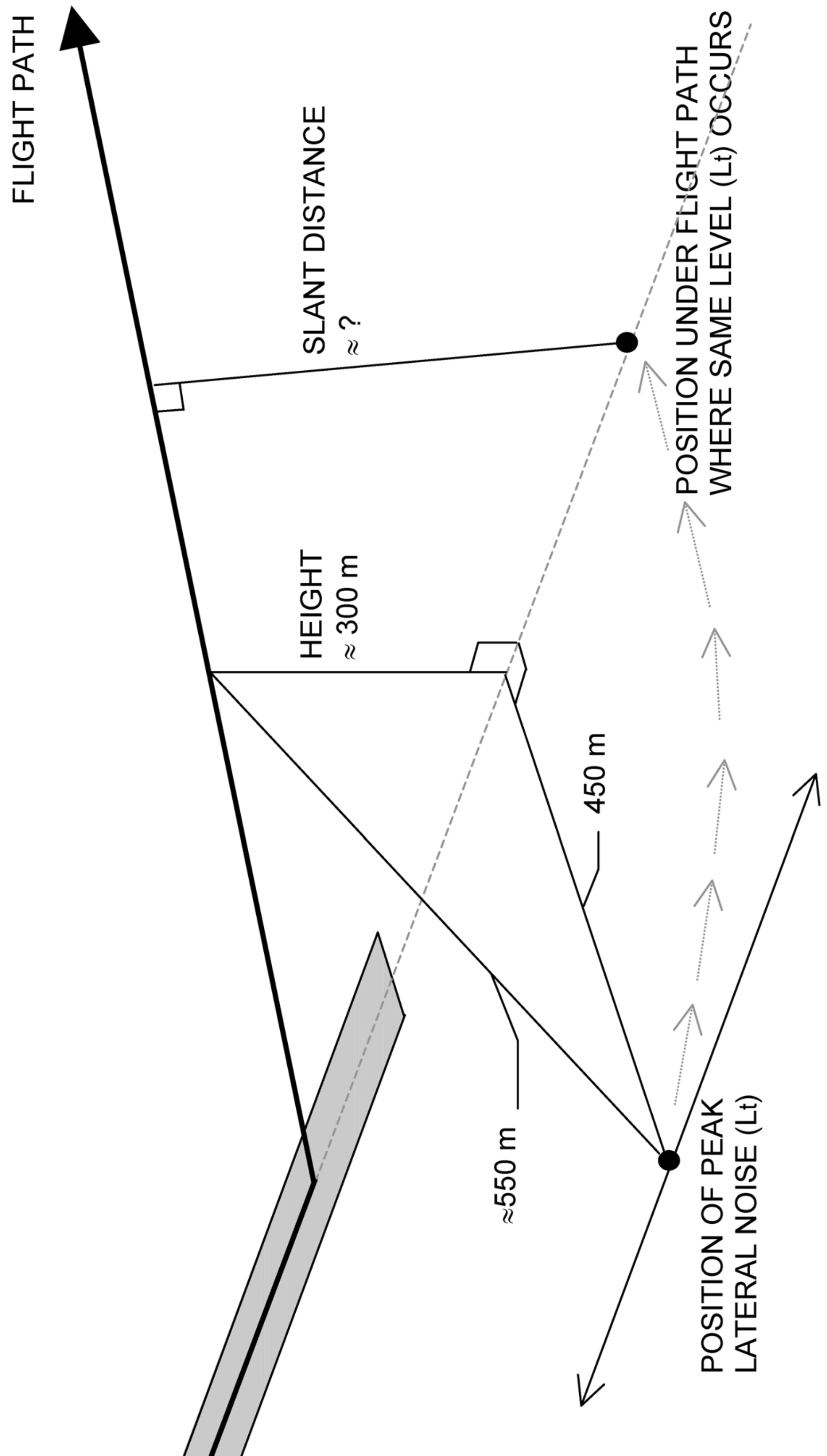


Figure 1 Pseudo-Lateral Noise Measurement

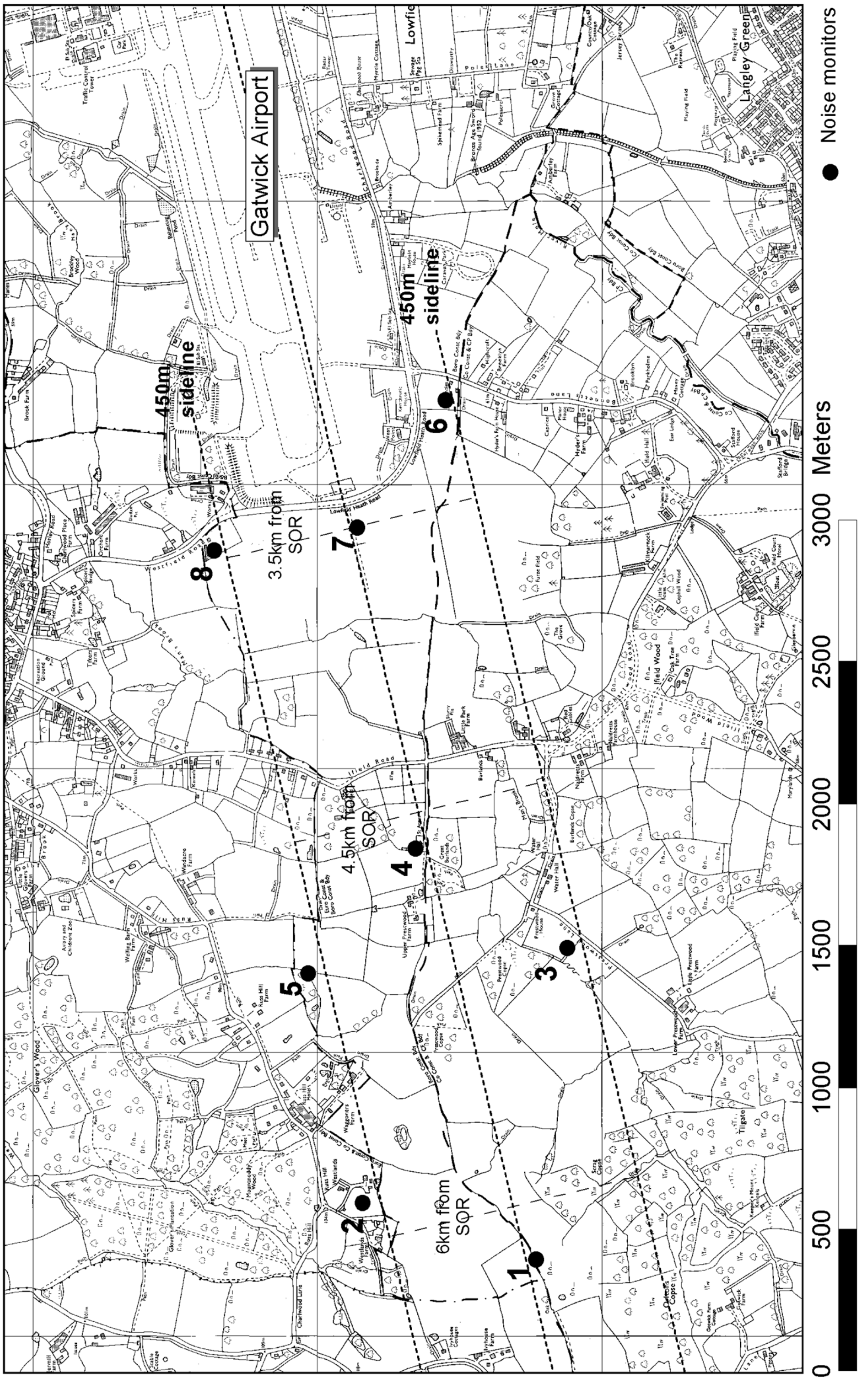


Figure 2 Noise Measurement Locations

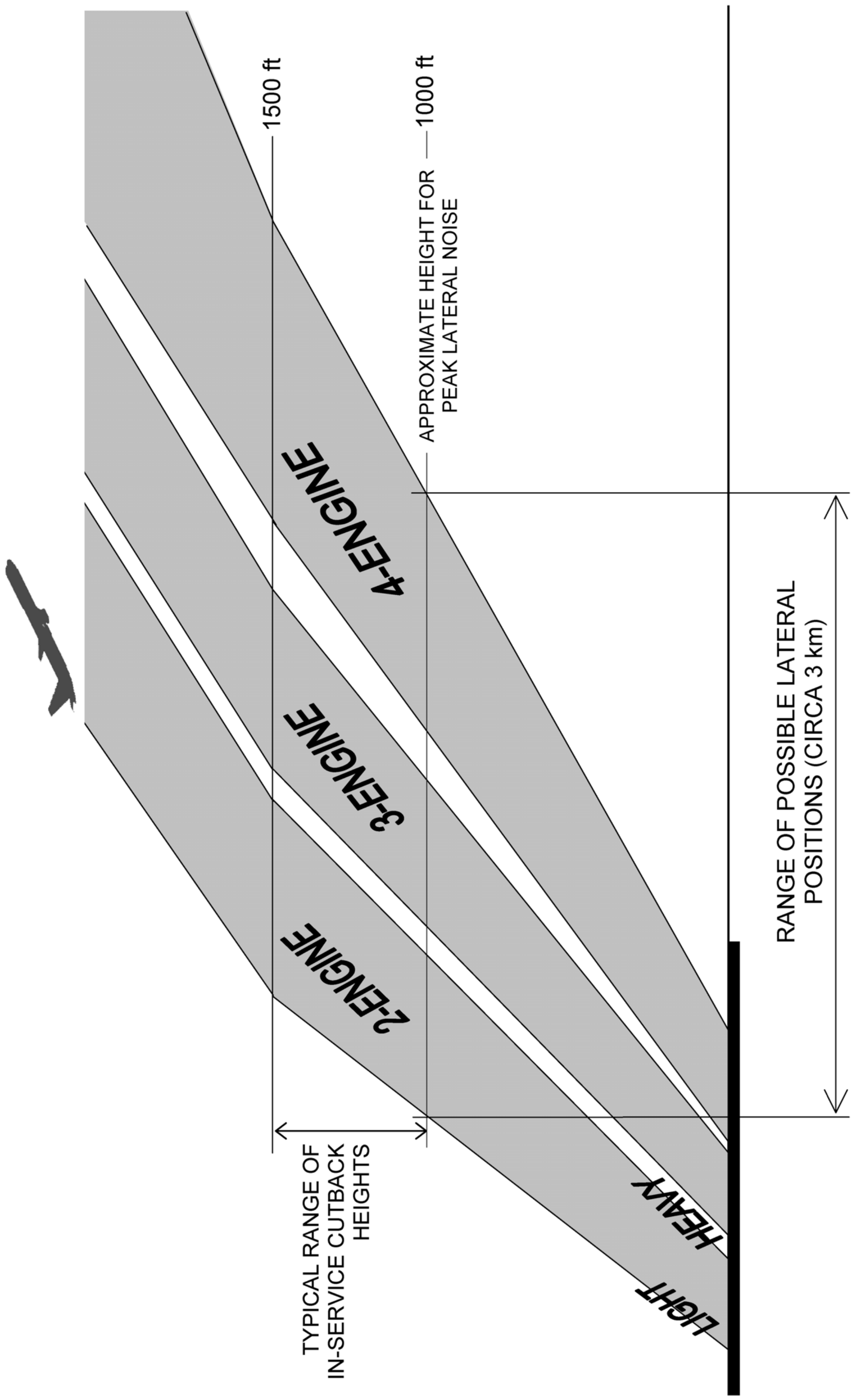
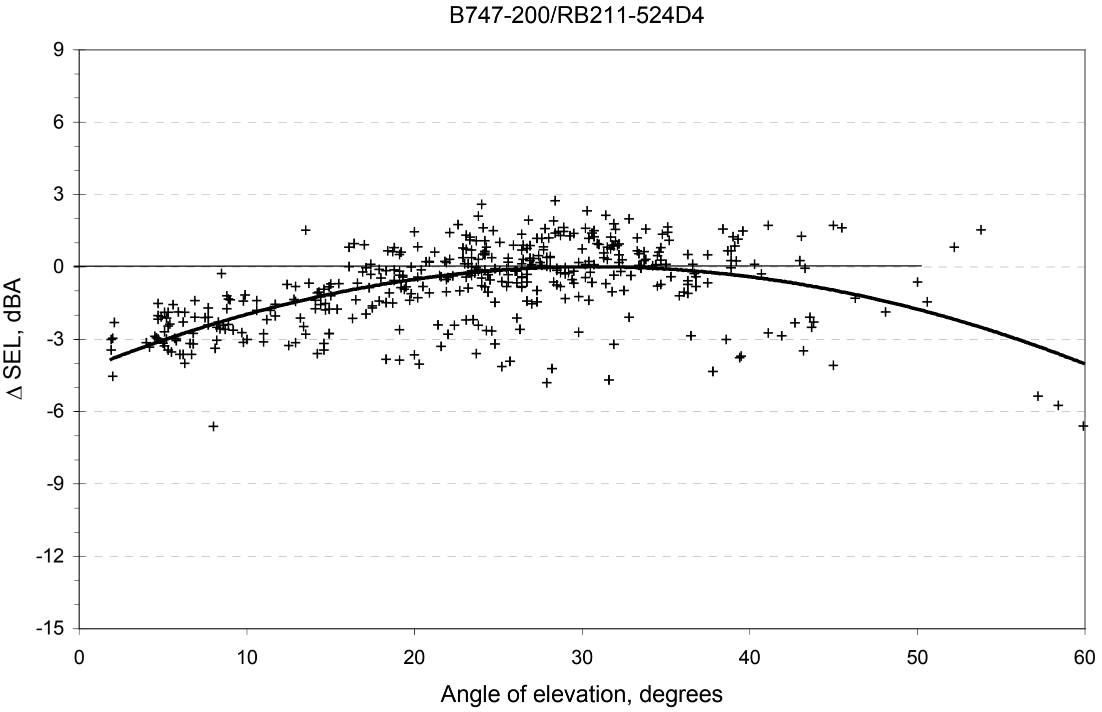
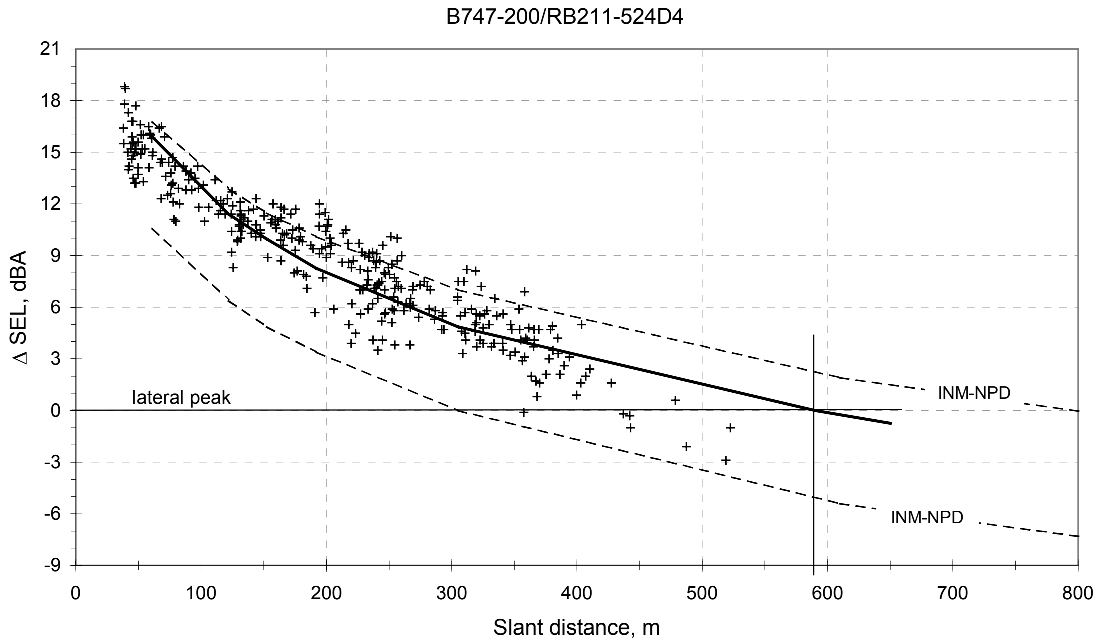


Figure 3 Finding the Lateral Peak – Reasons for the 3 km Array

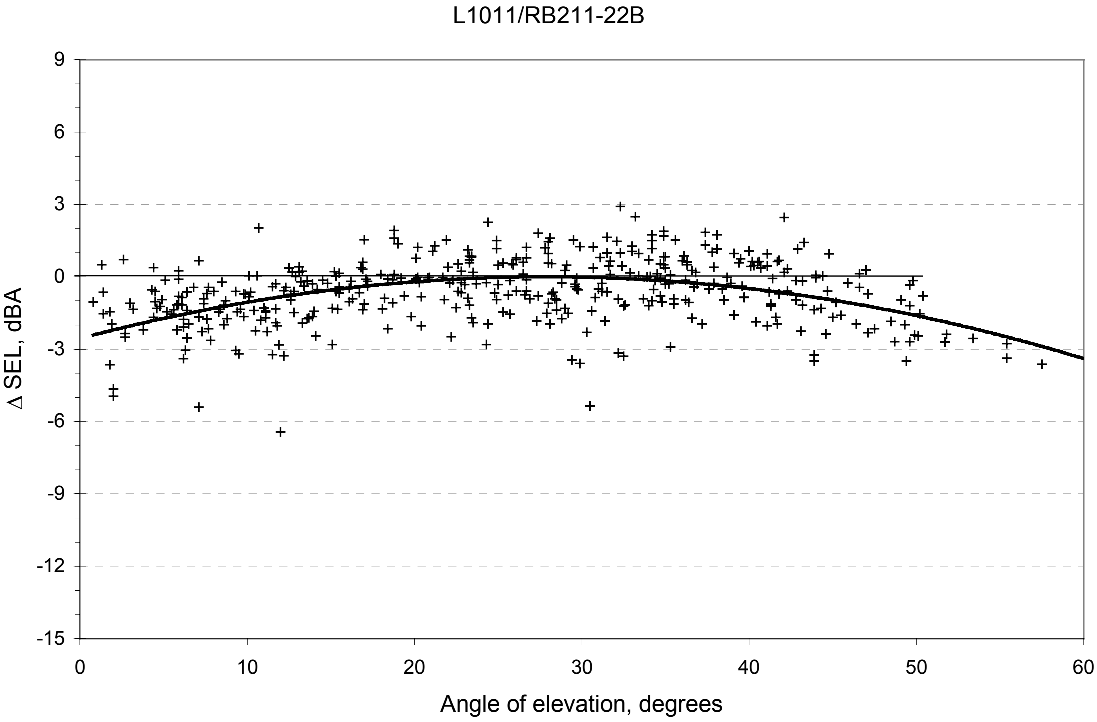


(a) Peak lateral level

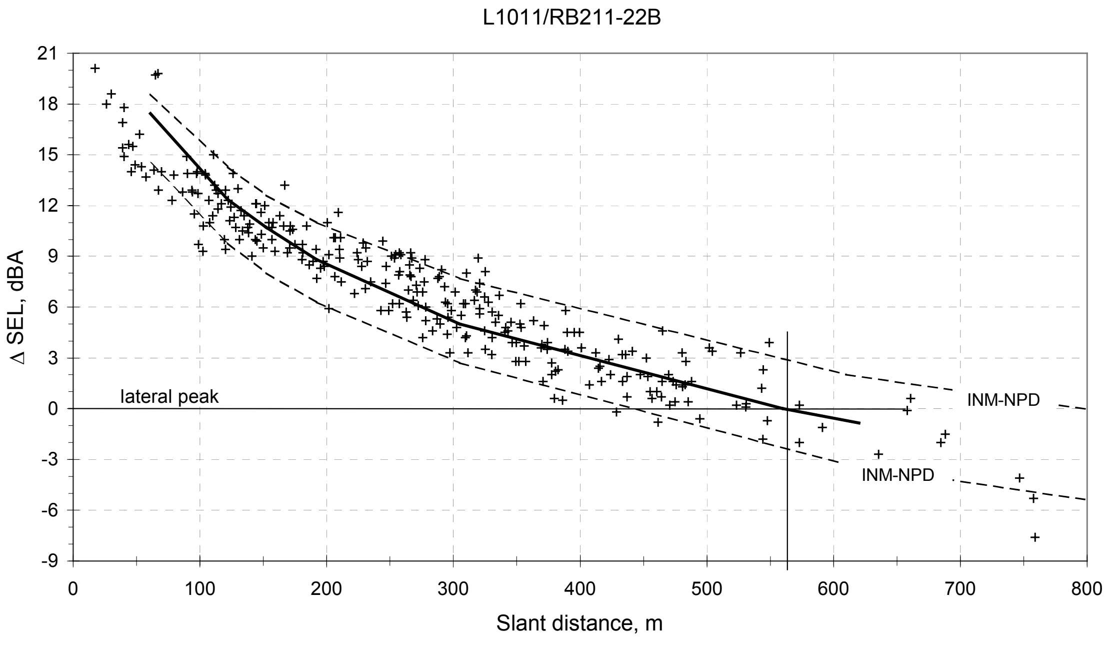


(b) Slant distance at which lateral level is replicated

Figure 4 B747-200/RB211-524D4 Noise Levels

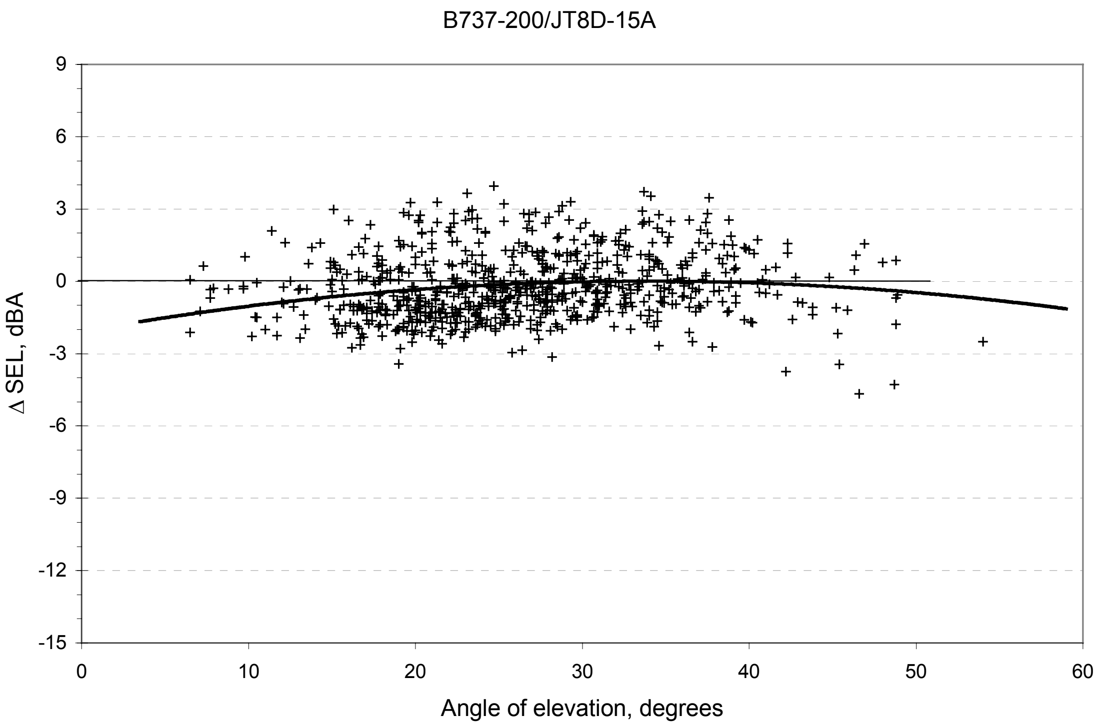


(a) Peak lateral level

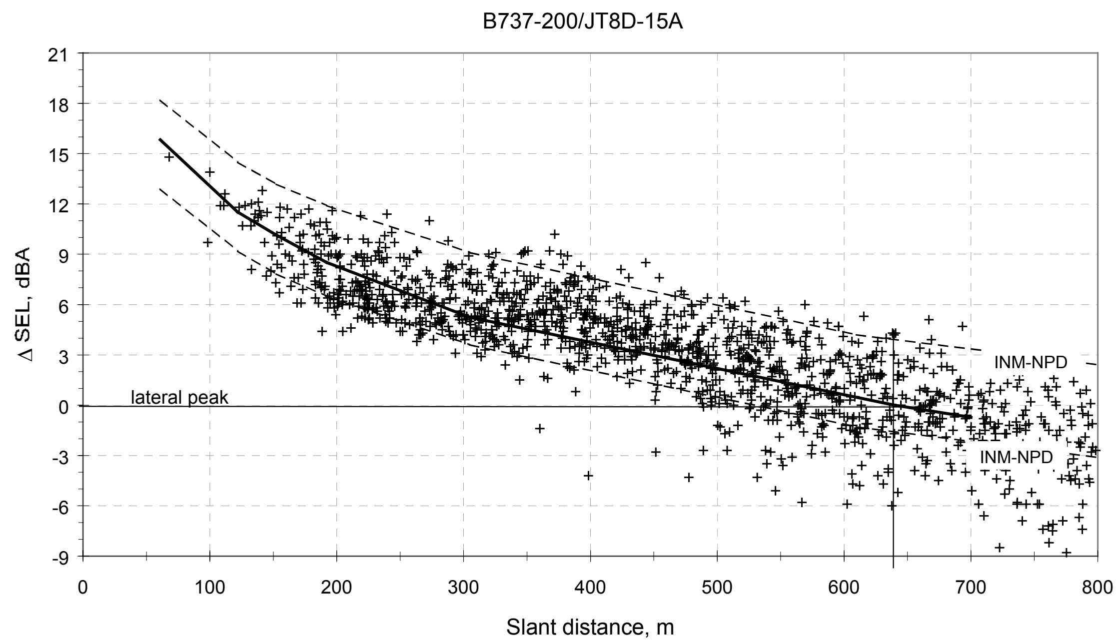


(b) Slant distance at which lateral level is replicated

Figure 5 L1011/RB211-22B Noise Levels

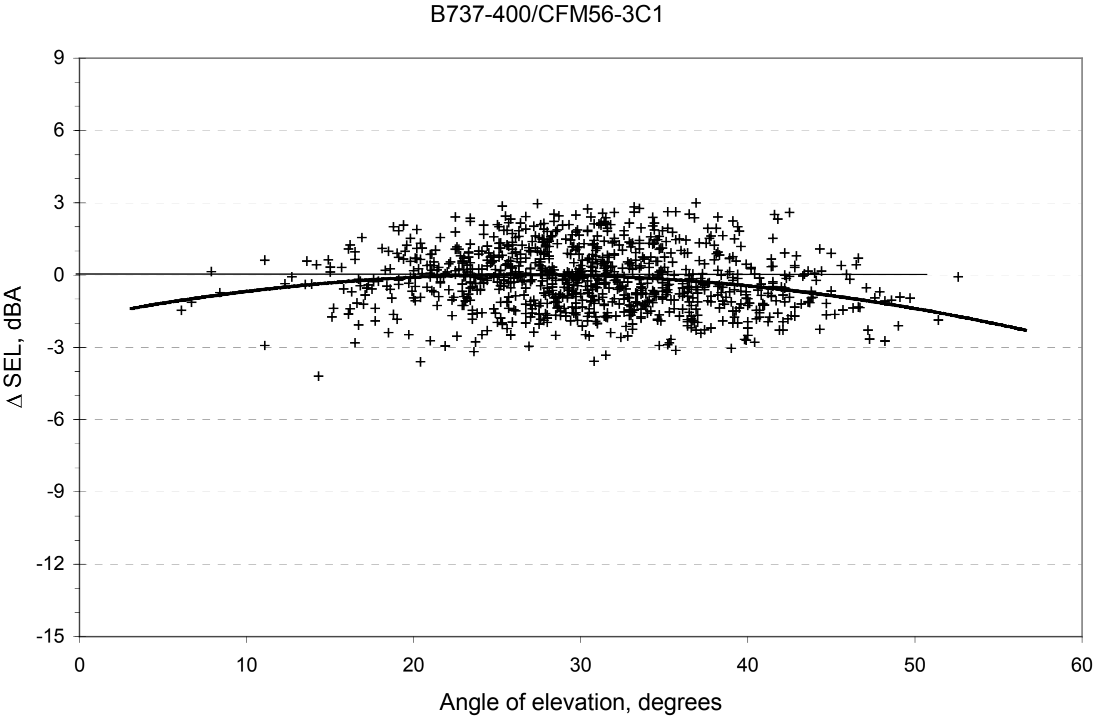


(a) Peak lateral level

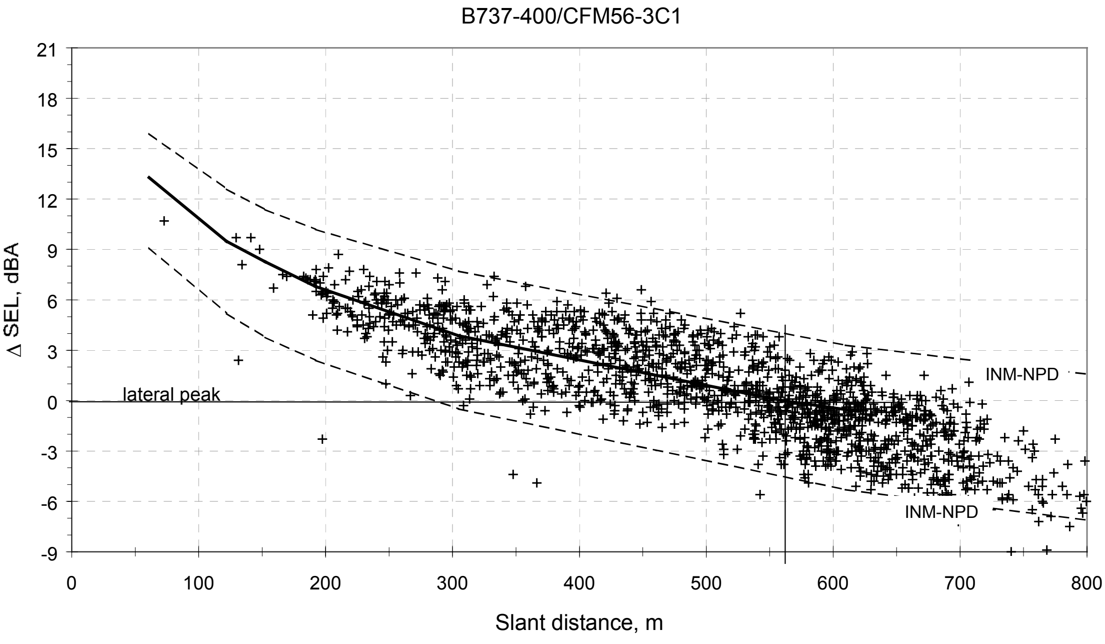


(b) Slant distance at which lateral level is replicated

Figure 6 B737-200/JT8D-15A Noise Levels

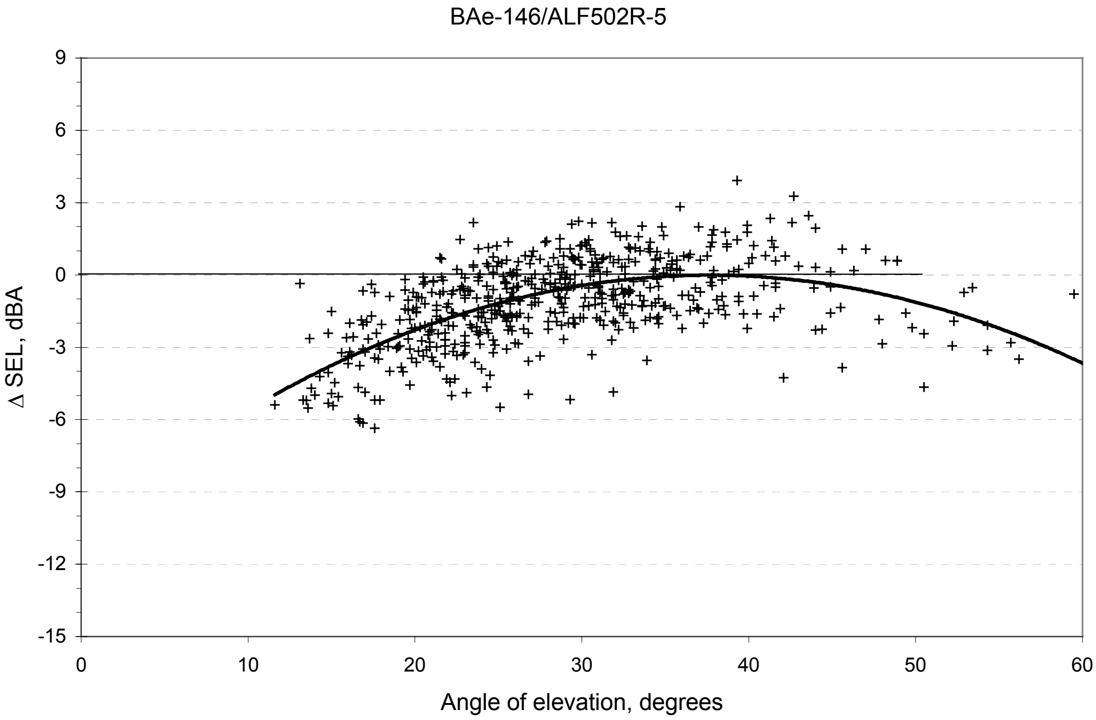


(a) Peak lateral level

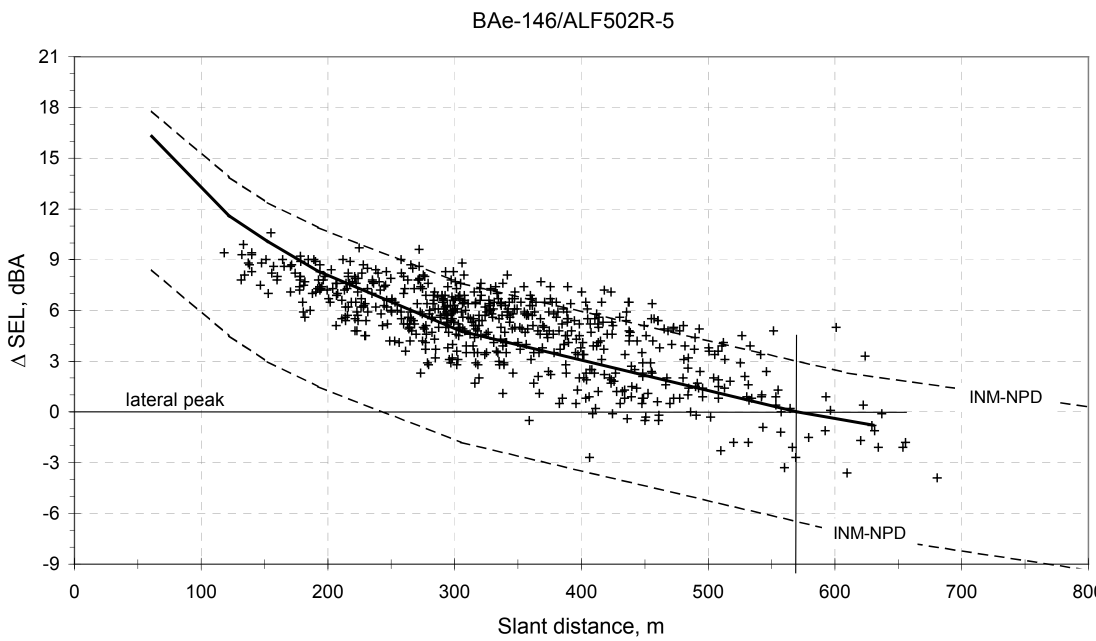


(b) Slant distance at which lateral level is replicated

Figure 7 B737-400/CFM56-3C1 Noise Levels

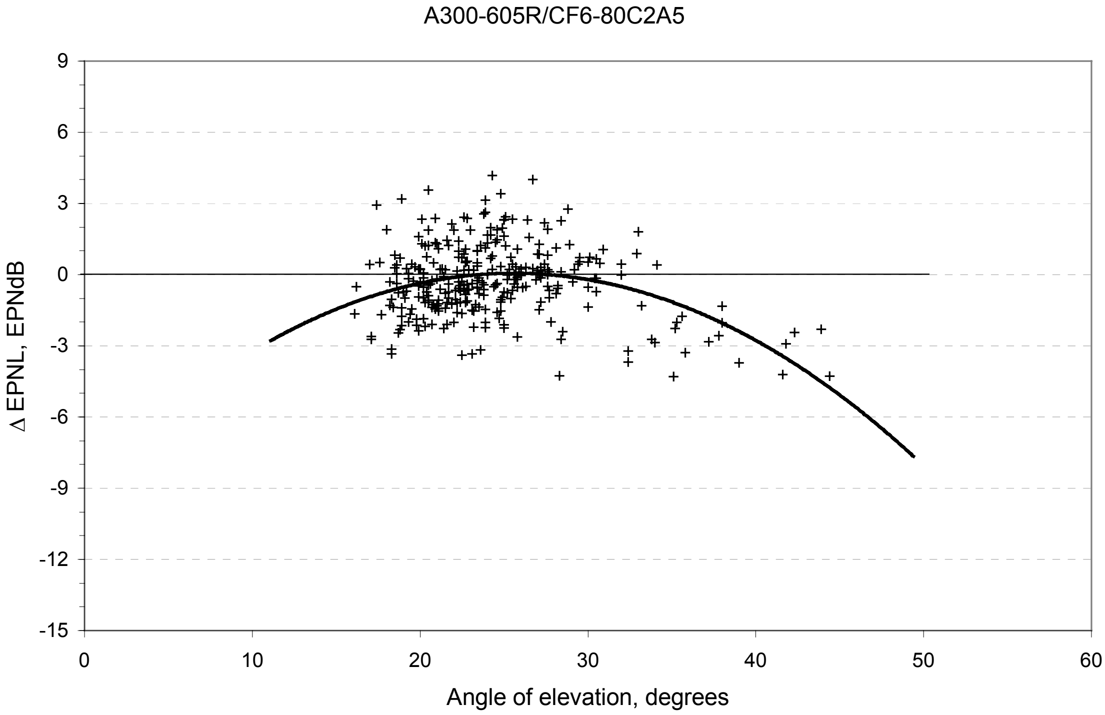


(a) Peak lateral level

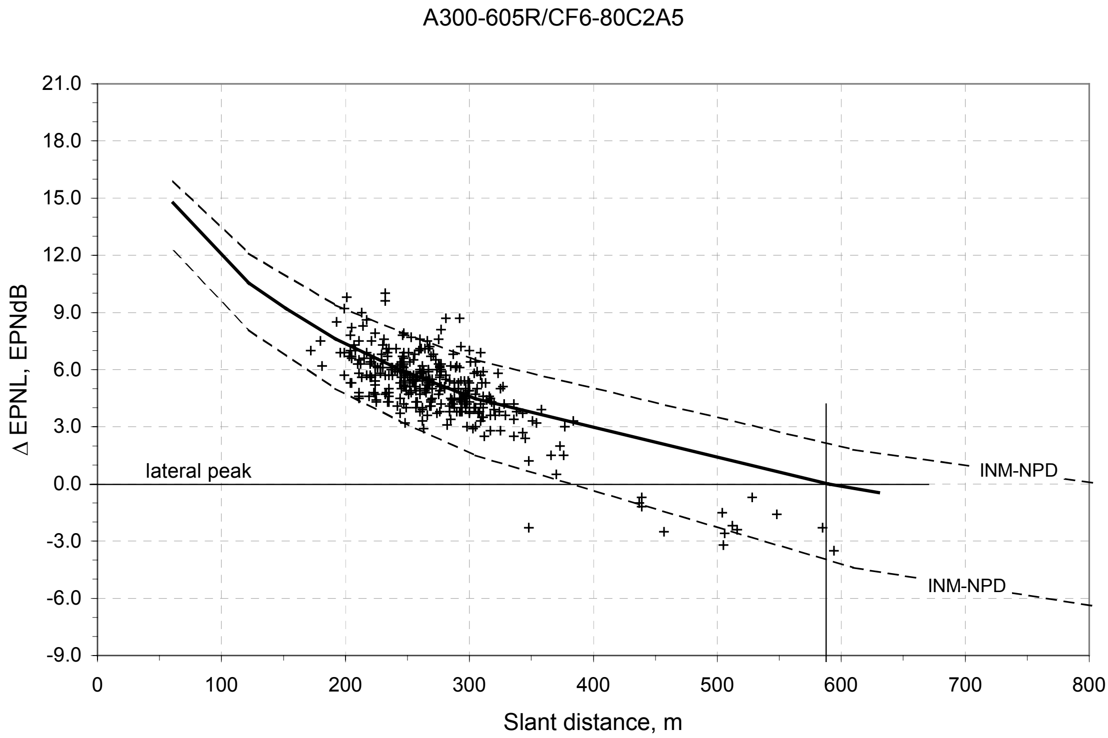


(b) Slant distance at which lateral level is replicated

Figure 8 BAe-146/ALF502R-5 Noise Levels

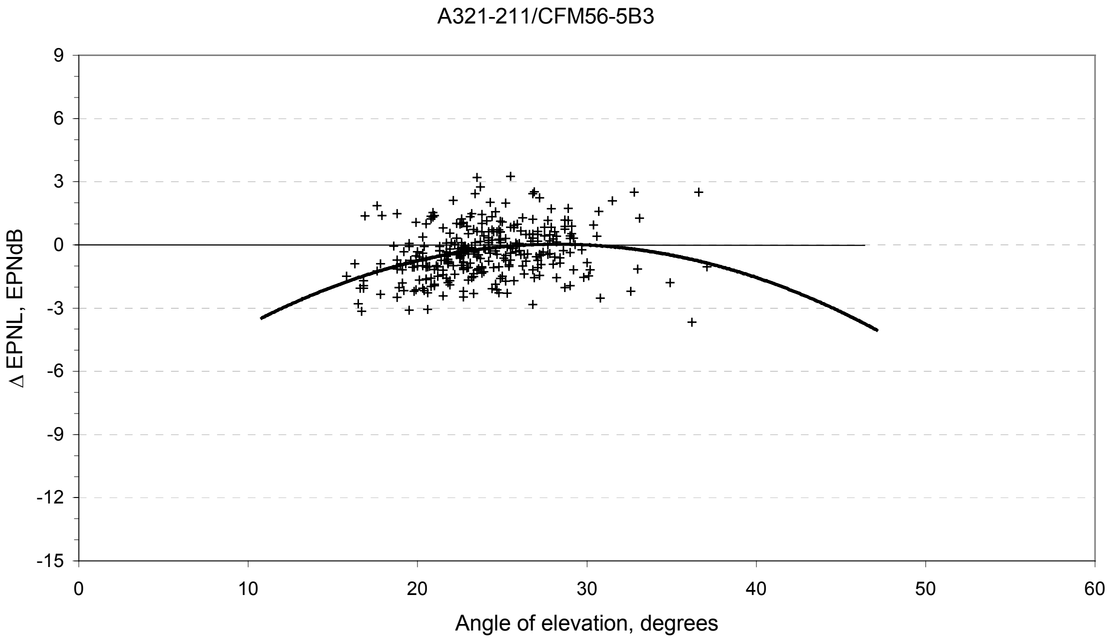


(a) Peak lateral level

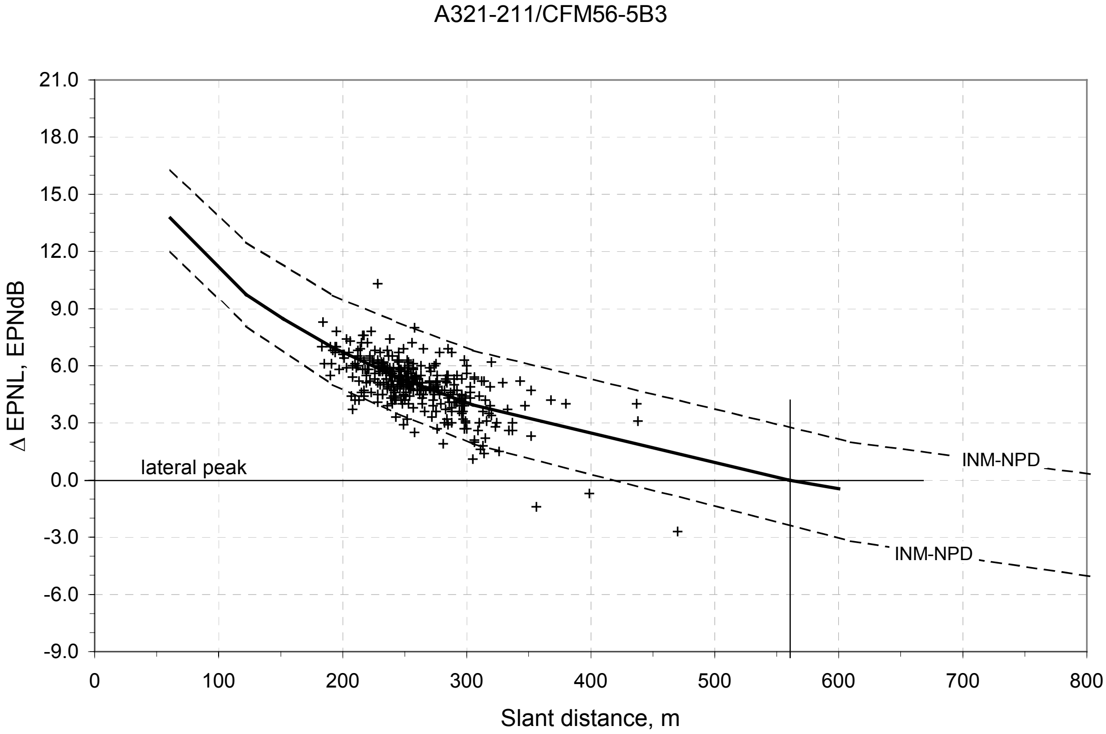


(b) Slant distance at which lateral level is replicated

Figure 9 A300-605R/CF6-80C2A5 Noise Levels

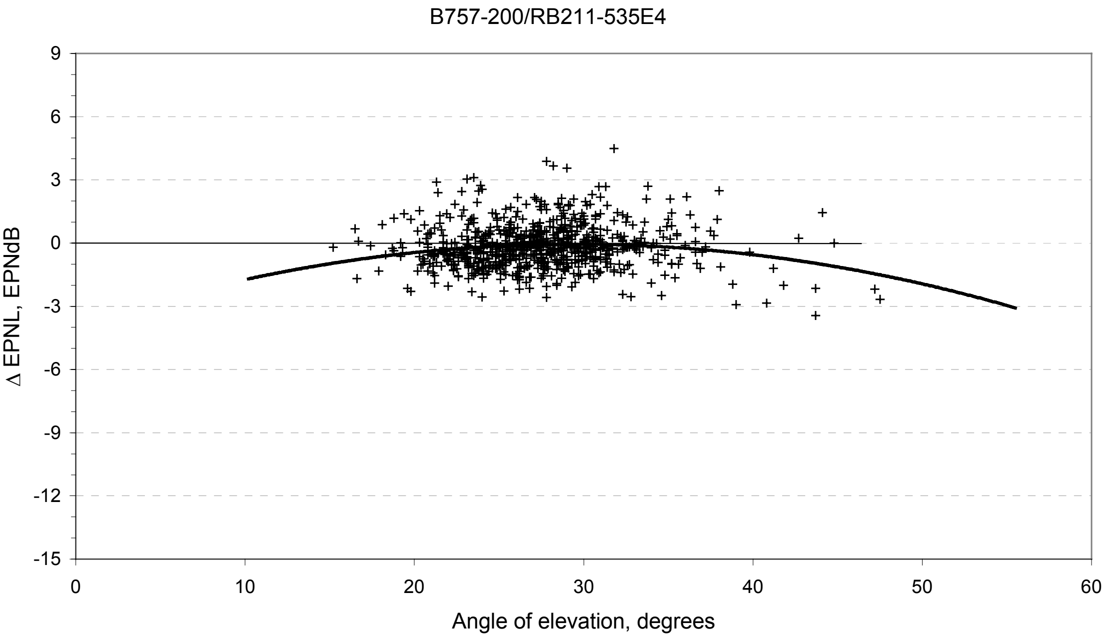


(a) Peak lateral level

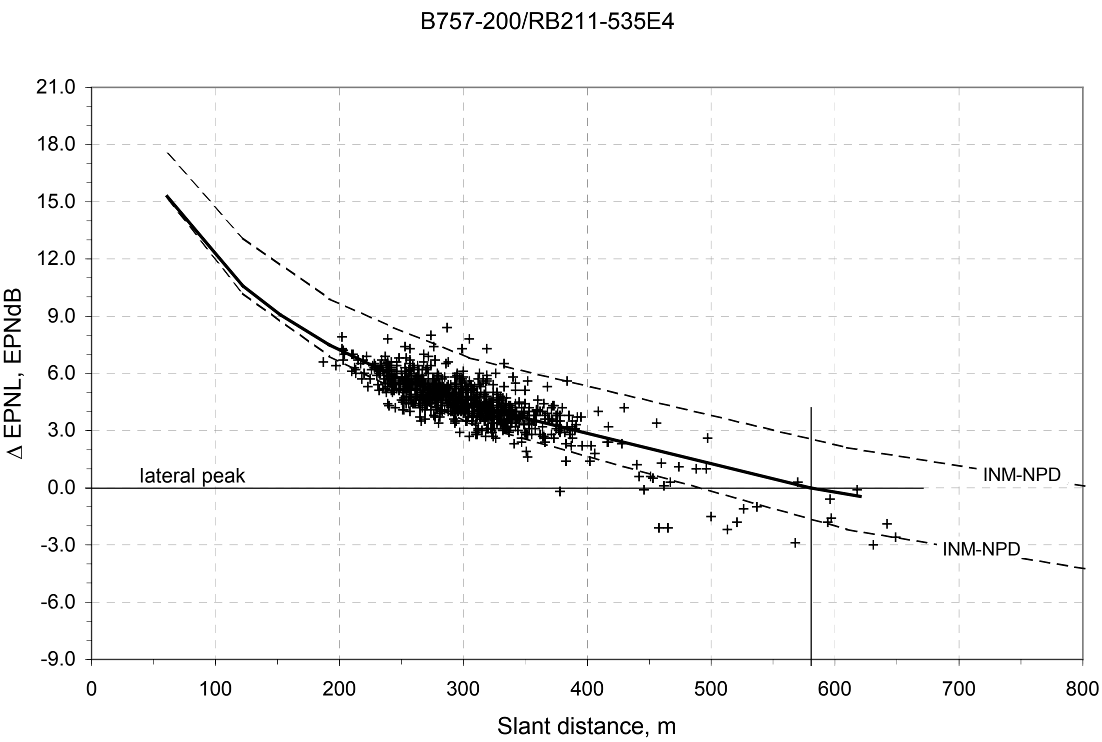


(b) Slant distance at which lateral level is replicated

Figure 10 A321-211/CFM56-5B3 Noise Levels

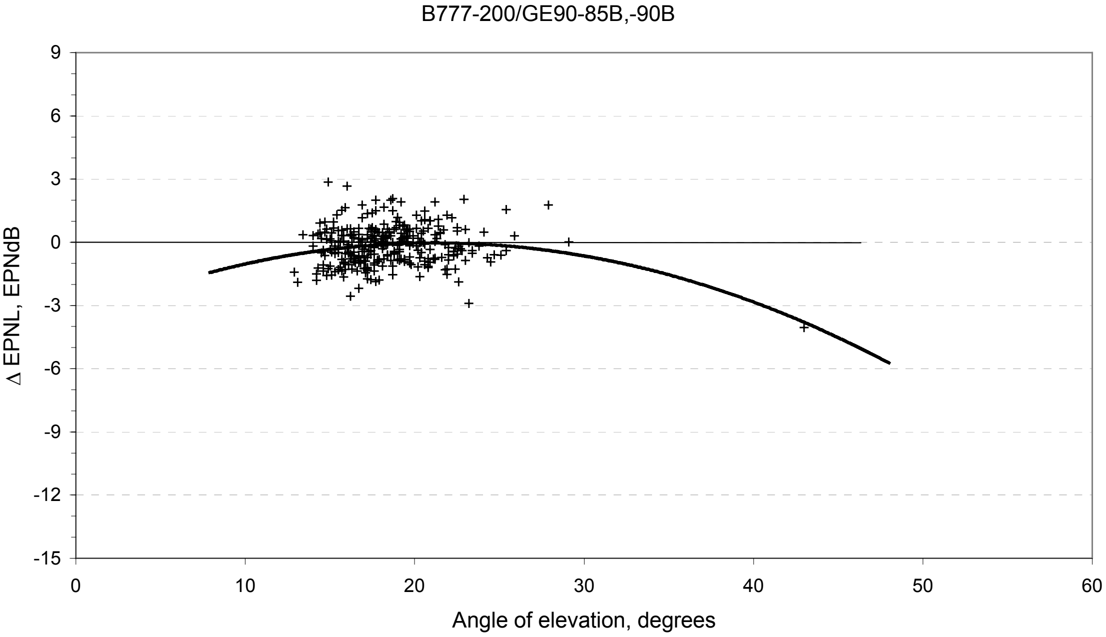


(a) Peak lateral level

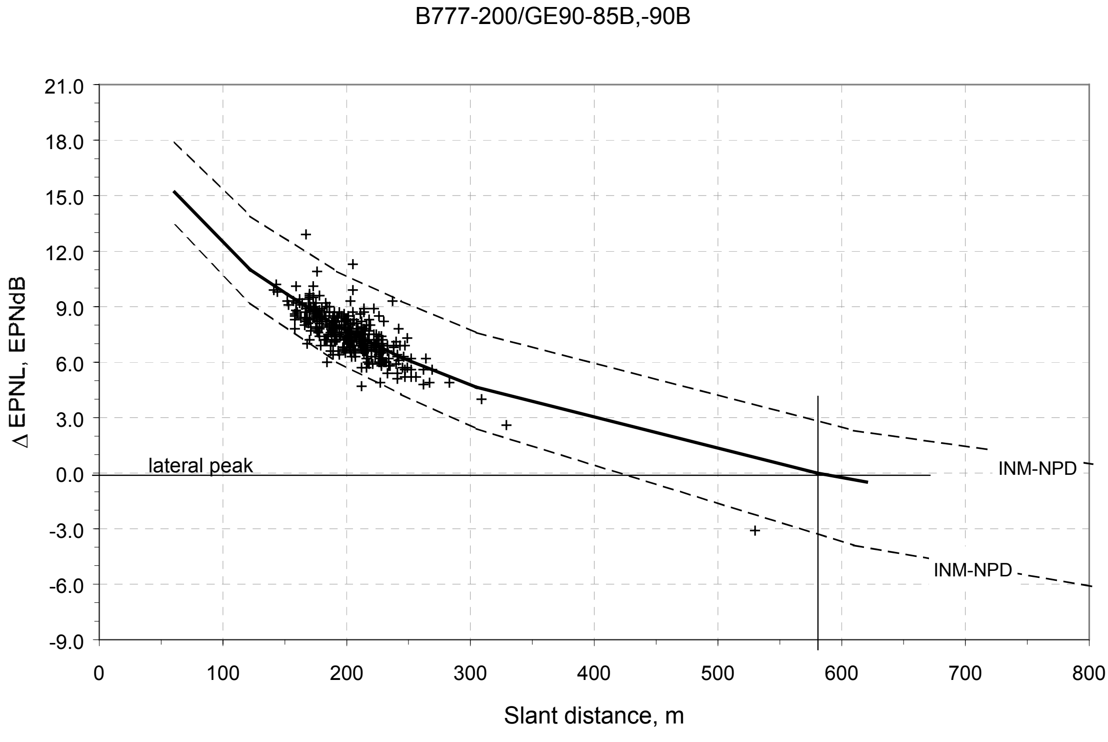


(b) Slant distance at which lateral level is replicated

Figure 11 B757-200/RB211-535E4 Noise Levels

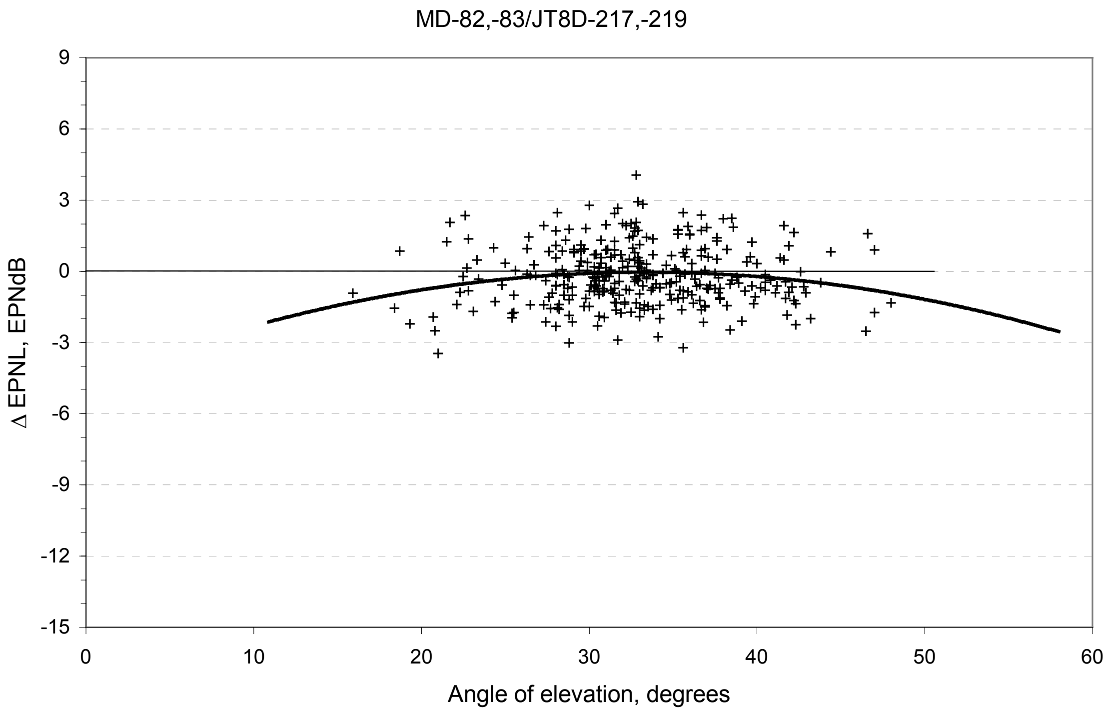


(a) Peak lateral level

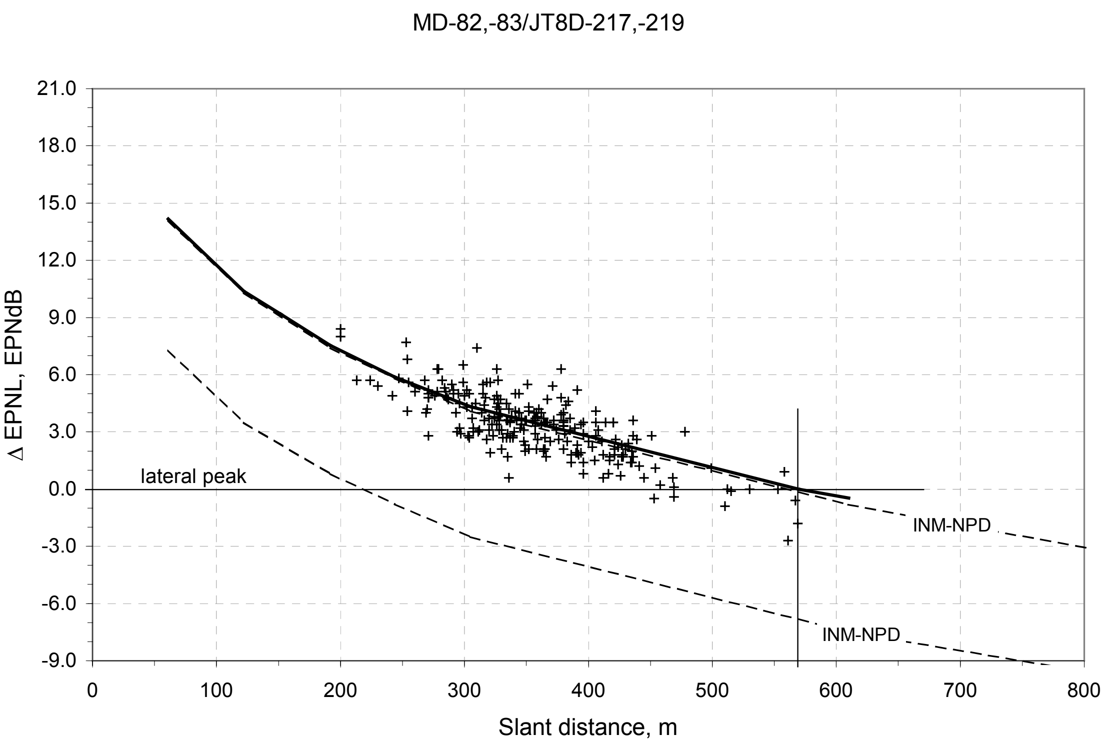


(b) Slant distance at which lateral level is replicated

Figure 12 B777-200/GE90-85B,-90B Noise Levels



(a) Peak lateral level



(b) Slant distance at which lateral level is replicated

Figure 13 MD-82,-83/JT8D-217,-219 Noise Levels