Environmental Research and Consultancy Department

ERCD REPORT 1007

Noise Measurements of Reverse Thrust at Heathrow and Stansted Airports

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Summary

This report describes a noise measurement study undertaken by ERCD to support the development of improved reverse thrust modelling assumptions to be included in ANCON, the UK aircraft computer noise model. A summary of the measured noise levels is also provided.

December 2010

The authors of this report are employed by the Civil Aviation Authority. The work reported herein was carried out under a Letter of Agreement placed on 9 September 2010 by the Department for Transport. Any views expressed are not necessarily those of the Secretary of State for Transport.

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Glossary of Terms

ADS-B	Automatic Dependent Surveillance-Broadcast. Aircraft equipped with ADS-B continuously broadcast precise position and velocity information derived from the aircraft's onboard navigation system.
dBA	Decibel units of sound level on the A-weighted scale, which incorporates a frequency weighting approximating the characteristics of human hearing.
GPS	Global Positioning System
L_{eq}	Equivalent sound level of aircraft noise in dBA, often called 'equivalent continuous sound level'. For conventional historical contours this is based on the daily average movements that take place within the 16-hour period (0700-2300 local time) over the 92-day summer period from 16 June to 15 September inclusive.
L_{max}	The maximum sound level (in dBA) measured during an aircraft fly-by.
Mode S	Mode Select (Mode S) is an improvement on classical Secondary Surveillance Radar and provides enhanced surveillance capability and a capacity to handle increased levels of air traffic.
NTK	Noise and Track Keeping monitoring system. The NTK system associates air traffic control radar data 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, measured in dBA. This accounts for the duration of the sound as well as its intensity.

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1 Introduction

1.1 The amount of aircraft noise experienced by people living around Heathrow, Gatwick and Stansted Airports during the summer of each year is estimated by the Environmental Research and Consultancy Department (ERCD) of the Civil Aviation Authority on behalf of the Department for Transport (DfT). The noise exposure contours are generated by the UK civil aircraft noise contour model (ANCON), which calculates the emissions and propagation of noise from arriving and departing air traffic (Ref 1).

1.2 Noise from each departure is modelled from the start of take-off roll along the runway. For arrivals, the noise emission up until the end of the landing roll, including reverse thrust, is considered in the model. Although the resulting additional noise energy generated by aircraft on the runway is relatively small in comparison to other phases of flight, both take-off roll and reverse thrust noise can be noticeable features of the noise environment at points close to the runway. It is therefore important that they are modelled with sufficient accuracy.

1.3 The output from ANCON is validated by comparing noise calculations at grid points with noise measurements made at equivalent distances from the airport. Measurements of start of take-off roll noise have been undertaken relatively recently by the international modelling community in order to obtain an updated directivity pattern for air noise modelling purposes[1]. However, there have been no similar studies conducted in recent years to monitor and quantify levels of reverse thrust noise to the side of a runway.

1.4 Accordingly, ERCD undertook a limited set of noise measurements at Stansted and Heathrow Airports, in July 2008 and September 2009 respectively, to support the development of improved reverse thrust modelling assumptions to be included in ANCON. This report describes those studies and provides a summary of the measured noise levels; any subsequent changes to the modelling assumptions incorporated into ANCON will be reported separately. It is recommended that this report be read in conjunction with ERCD Report 0406 (Ref 2), which describes the best practice monitoring techniques used by ERCD when carrying out aircraft noise studies.

2 Test Programme

2.1 Background

2.1.1 Ideally, to collect suitable reverse thrust noise data for noise modelling purposes an array of several noise monitors would be required, located in open terrain close to one or both sides of the runway, in the region where noise from reverse thrust is expected to occur for the aircraft types under consideration. From previous monitoring experience this region occurs between the touchdown point up to a point approximately 1,000 m further down the runway.

2.1.2 If costs were not a concern, deploying such an array of monitors at an airport might be feasible if there were no restrictions on access to the monitoring locations. However, the requirement to monitor airside and relatively close to the runway severely limits the availability of suitable sites due to safety and security issues. An initial review of the layout at the three London airports highlighted an order of

[1] A joint NASA/US DoT study was conducted at Washington Dulles Airport in October 2004. Results are expected to be published in the near future.

preference of Stansted, Heathrow and Gatwick for reverse thrust monitoring. The desire was to undertake some attended monitoring, but with the bulk of the monitoring obtained unattended. Risk of contamination from other airside noise sources and local roads was therefore a significant factor. Stansted offered by far the best opportunity for minimising intrusion from other noise sources. Perimeter roads were initially a concern at Heathrow and the proximity of the South Terminal at Gatwick made it the least preferable site. The following sections describe in more detail aspects of the monitoring locations at Stansted and Heathrow. Despite the logistical complexity of such a study, BAA staff at the Stansted and Heathrow Flight Evaluation Units had indicated a readiness to assist ERCD by providing the necessary airside access and security clearance.

2.1.3 Although the fleet mix of aircraft types operating at Stansted was quite limited, the inclusion of Heathrow considerably broadened the mix of aircraft types and was thus considered varied enough to eliminate any immediate need to collect measurements at Gatwick. For example, one of the most frequently operated aircraft types at Gatwick is the CFM-powered Airbus A319, which is also operated by the same airline at Stansted. Thus it should be appropriate to assume broadly similar levels of reverse thrust at both airports for this particular aircraft type. However, such an assumption may not be valid for other aircraft types, since the use of different operating procedures by different airlines and differences in taxiway exit layouts at each airport may cause differences in reverse thrust noise. To overcome such difficulties, additional measurements would need to be obtained at Gatwick at some future stage.

2.2 Stansted monitoring sites

2.2.1 Stansted Airport was selected as the site for an initial study because potential monitoring locations north of the runway were quite favourable, being some distance from the aprons. Additionally, the northern perimeter road is used relatively infrequently, and there were suitable locations for landside observations. The downside against monitoring at Stansted was the limited variation in fleet mix, though it was considered this would at least provide large data samples for a few important aircraft types.

2.2.2 Arrangements were made to deploy three noise monitors to obtain measurements of aircraft landing on runway 22. The noise monitors were installed airside on 14 July 2008 and removed four days later. Equipment at each site consisted of a sound level meter installed in a weatherproof case and connected to an outdoor microphone kit. The monitors were spaced at 150 m intervals along the northern side of the runway, approximately 200 m from the runway centreline – see **Figures 1 and 2**. The longitudinal locations of the outermost sites (Sites 1 and 3 in **Figure 1**) were constrained by safety requirements to avoid navigational equipment, airport taxiways, and other safety zones.

2.2.3 The equipment was set up to record one-second dBA values of L_{eq} and L_{max}, in addition to the SEL for each event. To supplement data recorded at the three airside sites, ERCD also carried out attended measurements and observations at a fourth landside location adjacent to the airport boundary – see Site 4 in **Figure 1**. The rationale for carrying out on-site observations, typically between 1700 and 0100 hours on each of the four study days[2], was as follows:

[2] This time period was selected because arrivals were expected to be the dominant type of operation during those hours, thus maximising sample sizes and limiting potential noise contamination from departure operations.

(i) The amount of reverse thrust used for each arrival could be judged subjectively and then correlated to the measured data.

(ii) Attendance on site would provide additional confidence in the data with regard to aircraft and event identification.

2.2.4 In general, whenever reverse thrust is available on an aircraft, a minimum or 'idle' level of reverse thrust will be selected on touchdown, directing airflow forward but without increasing the engine power above idle. However, depending on an aircraft's landing weight, the runway length and state, local weather conditions, and also airline operating procedure, additional reverse thrust may be used[3]. Thus the noise level from a particular aircraft type/operator can vary considerably from flight to flight depending on the amount of reverse thrust used.

2.2.5 However, when modelling landing noise in ANCON only one representative reverse thrust level is currently used for each aircraft type (in accordance with international noise modelling guidance). To try and account for the actual variation of reverse thrust in this study, each arrival was categorised as using either 'idle/no reverse' or 'above idle reverse' based subjectively on the reverse thrust noise heard by ERCD staff at the observation position; aircraft were judged to have used above idle reverse where there was a clearly noticeable change in the level and/or tonal content of the noise event. It should be emphasised however that the primary aim of the study was not to determine reverse thrust utilisation rates, but simply to measure the average noise levels to the side of the runway of landing aircraft.

2.2.6 Whilst on site, aircraft movements on and around the airfield were monitored by ERCD using a Mode-S/ADS-B receiver connected to a laptop for data logging – see **Figure 3**. Aircraft equipped with Mode-S/ADS-B transponders can transmit parameters such as GPS position, speed, heading, altitude and flight number to suitable receivers. Use of the Mode-S receiver allowed ERCD to identify aircraft in real-time, which was necessary during the latter part of the monitoring period each evening once daylight had faded. NTK records were used on return to the office to identify those aircraft that were not Mode-S equipped (and also to identify aircraft that operated during the unattended measurement periods). In the longer term, it is planned to use the Mode-S speed data to determine whether there is any correlation of reverse thrust noise level with final approach speed for particular types of aircraft, to better understand factors that might affect reverse thrust and potentially to provide enhanced modelling of reverse thrust.

2.3 Heathrow monitoring sites

2.3.1 At Heathrow, monitoring in the vicinity of the southern runway was effectively ruled out due to potential noise contamination from Terminal 4 and the Cargo Centre. However, the northern runway at Heathrow has been used for similar studies in the distant past and seemed the more appropriate runway to monitor alongside.

2.3.2 Although the close proximity of the perimeter roads north of the airfield provide sources of potential noise contamination, it was anticipated that the relatively short distance between the runway and the noise monitors would minimise the likelihood of event contamination, i.e. any reverse thrust noise measured at those locations would likely be significantly higher in level compared to other sources, particularly for many of the larger aircraft types of interest that operate at Heathrow. However, due to the

[3] Reverse thrust is normally used in combination with other deceleration devices, such as wheel braking and spoilers, in order to achieve a desired rate of deceleration. Increasing the level of reverse thrust will therefore not significantly affect the landing distance, but will reduce brake wear.

lack of suitable landside observation points in the vicinity of the northern runway, it was accepted that all measurements would have to be unattended. It was therefore not possible to categorise the landing events at Heathrow according to the level of the reverse thrust noise heard.

2.3.3 On that basis, three noise monitors were installed airside on 14 September 2009 and removed four days later. The monitors were spaced at 200 m intervals along the northern side of the runway, approximately 130 m from the runway centreline, to obtain measurements of aircraft landing on runway 09L – see **Figure 4**. Aircraft movements on and around the airfield were monitored by ERCD over the study period using a Mode-S/ADS-B receiver that was temporarily installed in BAA's offices on the perimeter road.

2.4 Longitudinal monitor positions

2.4.1 The table below summarises the longitudinal distance of each monitoring site relative to the nominal touchdown point at Stansted and Heathrow respectively.

Site	Stansted (m)	Heathrow (m)
Site 1	450	600
Site 2	600	800
Site 3	750	1,000

2.4.2 Monitoring at Heathrow intentionally covered a longer distance, due to the layout of the rapid exit taxiways on runway 09L and also because of the greater proportion of large, long-haul aircraft operating. Originally it was intended to include a fourth site closer to touchdown, but this proved too difficult to incorporate from a logistics perspective.

3 Results

3.1 Stansted measurements

3.1.1 The intention was to record a valid noise event at each airside monitor for every arrival, which would be supplemented with data from the landside noise monitor where possible. In total, 581 westerly arrivals were logged by ERCD during the four-day period of attended measurements, giving a total of 1,743 airside measurements. This was supplemented by 399 landside measurements. However, routine practical difficulties associated with the measurement of noise for some of the landing events (e.g. contamination from other noise sources such as taxiing aircraft and local helicopter operations) meant that approximately 20 percent of all arrivals failed to register valid noise readings.

3.1.2 After additional filtering for noise events recorded in high wind speeds[4], approximately two-thirds of the logged arrivals were found to have clean noise events, resulting in a total of 1,296 noise measurements across the four monitoring locations. **Table 1** gives the average SEL values obtained for each aircraft/engine variant[5] during the

[4] Although the noise propagation paths from the aircraft to the noise monitors were relatively short and therefore unlikely to have been significantly influenced by meteorological factors, noise measurements acquired in wind speeds greater than 10 knots (measured on the airfield) were excluded to minimise any uncertainty. In addition, there was no precipitation during the periods of attended measurement, which might have affected landing distances and therefore the level of reverse thrust used, due to the wet runway surface.

[5] As defined for noise modelling purposes.

periods of attended measurement. Only those types for which there was an overall sample of at least six measurements at any one monitor have been included. Results are shown separately for arrivals that were judged to have used either idle/no reverse or above idle reverse.

3.1.3 For conventional statistical analysis it is usually appropriate to calculate the arithmetic average (or mean). Since the decibel scale is not linearly related to noise energy an alternative average is used when constructing measures of total noise exposure, e.g. L_{eq} contours. This is the decibel value of the average sound energy, which is referred to in this report as the logarithmic average (or 'log average') and is always higher than the arithmetic average. For completeness both types of average values are provided in this report, in addition to other summary statistics.

3.1.4 As shown in **Table 1**, a large proportion of the monitored arrivals were comprised of just two types of aircraft: the Boeing 737-800 and a variant of the Airbus A319 powered by CFM engines. Aircraft movements from these types currently account for more than 70 percent of movements at Stansted. As expected, attended measurements for other types of aircraft are limited and in the majority of cases the sample sizes are small.

3.1.5 A clear difference between the log average noise levels for the two categories of reverse thrust is evident for both the 737-800 and the A319/CFM in **Table 1**. As noted earlier, in accordance with international noise modelling guidance only one representative reverse thrust level is currently used for each aircraft type in the ANCON model. Although there are currently no plans to enhance this aspect of the model, the data collected provides a useful starting point from which to examine this issue.

3.1.6 **Table 1** also shows that in many cases the measured levels have relatively high standard deviations, indicating a great deal of variability in reverse thrust noise, even after categorisation into the two types of reverse thrust noise heard. This variability is illustrated for example in **Figure 5**, which presents the measured distributions of SEL for 737-800 arrivals that were judged to have used either idle/no reverse or above idle reverse. The results for some of the quieter above idle events (i.e. those that fall toward the left hand side of the upper plot) also suggest that it may have been difficult to judge subjectively whether some of the quieter landings had actually used any additional reverse thrust or not.

3.1.7 Since the airside noise monitors were operating continuously throughout the study period, an analysis of the pooled (attended and unattended) dataset is also provided in **Table 2**. In many cases, the 95 percent confidence intervals[6] of the average SELs are no greater than 3 dBA (and for the two most frequently operated types the confidence intervals are less than 1 dBA). Thus, while the unattended measurements cannot be categorised into the same reverse thrust type categories as the attended measurements, the pooled dataset provides useful information on the overall average reverse thrust noise levels for some of the other, less frequently operated, aircraft types at Stansted. However, it should be noted that the unattended dataset may be subject to some additional uncertainty with regard to aircraft and event identification.

3.1.8 The use of above idle reverse thrust at night (after 2330 hours) was noted by ERCD staff on several occasions whilst on-site at Stansted. The UK Aeronautical Information Publication[7] provides the following guidance to airlines at Heathrow, Gatwick and Stansted Airports on the use of reverse thrust at night:

> *To minimise disturbance in areas adjacent to the aerodrome, commanders of aircraft are requested to avoid the use of reverse thrust after landing, consistent with the safe operation of the aircraft, between 2330 hours to 0600 hours (local time)*

3.1.9 **Table 3** presents the average (pooled) measured noise levels during the periods 0600-2330 hours and 2330-0600 hours for those aircraft types where sufficient data were available for a meaningful comparison. The results for the 737-3/4/500 and 737-800 show a marked reduction in the average noise level at each site between 2330 and 0600 hours. Results for the A319/CFM however show the opposite trend (i.e. a slight increase in the average measured noise level between 2330 and 0600 hours), although the differences are not statistically significant[8].

3.2 Heathrow measurements

3.2.1 Unrelated equipment failure at two of the Heathrow sites[9] (Sites 2 and 3 in **Figure 4**) meant unfortunately that the Heathrow dataset is limited to noise measurements from Site 1 only. Nonetheless, the relatively high traffic levels resulted in 2,632 noise events being recorded and this, together with the wide variation in fleet mix at Heathrow, meant that 1,507 clean noise events were still acquired for a large number of different aircraft types. **Table 4** gives the log average SEL values and other summary statistics recorded at Site 1 for each aircraft type at Heathrow. As with the Stansted data, measurements acquired in high wind speeds have been excluded, and only those types for which there was an overall sample of at least six measurements are shown.

3.2.2 It can be seen from **Table 4** that in many cases the measured levels have relatively high standard deviations which, like the Stansted results, indicate a great deal of variability in reverse thrust noise. However due to the relatively large sample sizes obtained, the 95 percent confidence intervals of the average SELs for the majority of aircraft types are no greater than 3 dBA (with some less than 1 dBA).

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[6] The 95% confidence interval is the interval around the sample mean within which it is reasonable to assume the true value of the mean lies.

[7] See AD 2-EGLL-1 for Heathrow, AD 2-EGKK-1 for Gatwick and AD 2-EGSS-1 for Stansted.

[8] i.e. no greater than would be expected as a chance result.

[9] One monitor was found to be significantly out of calibration at the end of the measurement period, and therefore its data could not be relied upon.

3.2.3 As noted above, the UK Aeronautical Information Publication provides guidance to airlines on the use of reverse thrust at night during the period 2330-0600 hours. However, the limited number of night-time arrivals that landed on runway 09L over the study period meant that it was not possible to carry out a meaningful comparison of the average reverse thrust noise levels between the periods 2330-0600 hours and 0600-2330 hours.

3.2.4 Despite concerns about possible contamination of the landing events by other sources of noise (e.g. from the nearby perimeter roads or terminal areas), the typical level of reverse thrust noise was found to be significantly higher than the general background level at Site 1. For example, **Figure 6** shows the noise level time history for a fifteen-minute period of monitoring on one particular morning. **Figure 7** shows similar data during the afternoon on another day. The time history traces show the various aircraft that landed at Heathrow during those periods (including several from the Airbus A320 family) were all easily measurable above the general background level at the time.

3.3 Comparisons between Stansted and Heathrow

3.3.1 Site 2 at Stansted and Site 1 at Heathrow were at the same longitudinal distance from the nominal touchdown point. However, Site 1 at Heathrow was 70 m closer to the runway centreline. The Heathrow data can be normalised to the Stansted data by applying standard overground attenuation (Ref 1), which in this case equates to a reduction of 2.3 dB for aircraft with wing-mounted engines, and a reduction of 2.6 dB for aircraft with fuselage-mounted engines.

3.3.2 After normalising, comparisons between the airports show that in some cases measurements were consistent, e.g. 0.1 dB difference between Boeing 737-800s at Stansted and Heathrow. In contrast A319/320/321 aircraft with IAE V2500 engines were, on average, between 6 to 9 dB quieter at Heathrow than Stansted. Data samples at Stansted for this case are very small. Results for the A319/CFM however, which is the most common Airbus type at Stansted, show the opposite trend; the CFM-powered variant was approximately 6 dB quieter at Stansted than Heathrow. These results suggest that further monitoring, possibly at Gatwick would be needed to better understand airport and/or airline factors affecting reverse thrust, especially where the same airline operates at two different airports.

4 Conclusions

4.1 Monitoring of reverse thrust noise at Stansted and Heathrow Airports was undertaken by ERCD to support the development of improved reverse thrust modelling assumptions in the ANCON noise model. In the short term, it is anticipated that some of the data can be applied to the modelling of reverse thrust noise at Gatwick, although additional measurements may be necessary at some future stage. The results of any further studies will be reported in due course.

4.2 For the two most frequently operated types at Stansted, the study revealed clear differences between the log average noise levels of arrivals that were judged to have used either idle/no reverse or above idle reverse. Useful data have also been collected for several other, less frequently operated, aircraft types at Stansted.

4.3 Despite equipment failure at two of the Heathrow monitoring sites, the relatively high traffic levels and wide variation in fleet mix meant that useful data were still acquired at the remaining Heathrow site for a large number of different aircraft types.

Acknowledgements

The study could not have been undertaken without the help of staff at the Stansted and Heathrow Flight Evaluation Units. ERCD would like to thank all those involved, including Airside Operations staff, for their assistance and cooperation.

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1 Rhodes D P, *The UK Civil Aircraft Noise Contour Model: ANCON version 2.3*, ERCD Report 0606, Civil Aviation Authority, To be published

2 White S, *Techniques used by ERCD for the Measurement and Analysis of Aircraft Noise and Radar Data*, ERCD Report 0406, Civil Aviation Authority, January 2005

Table 1 Attended noise measurements of reverse thrust at Stansted

Aircraft Type		SEL, dBA (Attended)											
		Above Idle Reverse				Idle/No Reverse				Total			
		Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4
Airbus A319/CFM	Log Avg	86.3	84.9	83.3	82.1	79.2	76.9	76.6	74.9	83.5	82.0	80.8	79.7
	Mean	82.0	80.4	79.2	77.6	78.8	76.5	76.5	74.7	80.1	78.1	77.7	76.1
	Std Dev	5.6	5.5	5.4	5.4	2.0	1.8	1.1	1.5	4.1	4.2	3.9	4.1
	Count	19	19	12	16	28	27	15	18	47	46	27	34
	95% CI	2.7	2.6	3.4	2.9	0.8	0.7	0.6	0.7	1.2	1.2	1.5	1.4
Airbus A320/CFM	Log Avg	90.8	89.9	87.3	85.7	78.2	76.7	75.1	74.4	89.6	88.7	86.7	84.6
	Mean	89.1	87.0	84.9	83.4	78.2	76.6	75.1	74.1	86.4	84.4	83.5	81.0
	Std Dev	4.3	5.6	5.2	5.1	0.1	1.1	-	2.5	6.2	6.8	6.0	6.2
	Count	6	6	6	6	2	2	1	2	8	8	7	8
	95% CI	4.5	5.9	5.4	5.4	0.8	10.2	-	22.2	5.2	5.7	5.6	5.2
Airbus A321/CFM	Log Avg	93.0	91.6	90.3	88.0	86.1	87.0	89.5	85.1	91.1	90.1	90.1	87.0
	Mean	91.9	91.1	89.1	87.1	83.6	82.8	87.7	80.4	88.2	87.4	88.7	84.1
	Std Dev	3.8	2.5	3.6	3.0	5.3	7.6	5.9	7.9	6.1	6.6	3.8	6.4
	Count	5	5	5	5	4	4	2	4	9	9	7	9
	95% CI	4.7	3.1	4.4	3.7	8.4	12.1	53.0	12.5	4.7	5.1	3.6	4.9
Boeing 737-3/4/500	Log Avg	90.1	90.6	86.7	87.0	79.7	79.7	79.7	78.1	89.0	89.7	85.9	86.3
	Mean	88.2	88.0	84.5	84.4	79.4	79.4	78.8	77.7	86.1	86.2	83.3	83.2
	Std Dev	4.4	5.1	4.4	4.8	1.8	1.7	3.1	2.1	5.5	5.8	4.7	5.1
	Count	19	19	19	19	6	5	5	4	25	24	24	23
	95% CI	2.1	2.4	2.1	2.3	1.9	2.1	3.8	3.3	2.3	2.4	2.0	2.2
Boeing 737-700	Log Avg	90.4	90.5	85.9	85.3	83.6	77.4	78.9	76.7	88.9	88.9	84.9	84.5
	Mean	88.0	87.7	84.7	82.2	80.2	76.9	78.9	76.4	85.0	84.1	83.2	81.1
	Std Dev	5.7	6.4	3.5	6.3	5.6	2.5	0.2	2.4	6.7	7.5	4.0	6.1
	Count	8	8	6	8	5	4	2	2	13	12	8	10
	95% CI	4.8	5.3	3.7	5.3	6.9	3.9	1.9	21.6	4.1	4.7	3.3	4.4
Boeing 737-800	Log Avg	91.9	92.2	90.3	89.0	82.6	81.2	80.3	77.9	90.5	90.8	89.5	87.8
	Mean	89.6	89.6	87.7	86.2	80.7	78.8	77.6	76.0	86.8	86.4	85.6	83.6
	Std Dev	5.0	5.5	5.7	5.7	3.3	3.4	3.2	3.1	6.1	7.0	6.6	6.8
	Count	169	169	164	161	77	72	42	56	246	241	206	217
	95% CI	0.8	0.8	0.9	0.9	0.8	0.8	1.0	0.8	0.8	0.9	0.9	0.9
Large Twin Turboprop	Log Avg	88.4	89.0	87.5	86.5	87.4	87.2	87.5	83.7	88.0	88.3	87.5	85.5
	Mean	88.1	88.4	86.4	84.9	86.7	86.6	85.3	82.5	87.5	87.6	85.9	83.9
	Std Dev	1.8	2.5	3.8	4.3	3.2	3.3	5.5	4.5	2.3	2.8	4.2	4.2
	Count	4	4	4	4	3	3	3	3	7	7	7	7
	95% CI	2.8	4.0	6.0	6.8	8.0	8.1	13.8	11.1	2.2	2.6	3.9	3.9

Table 2 Pooled noise measurements of reverse thrust at Stansted

Aircraft Type		SEL, dBA (Attended + Unattended) Site 1	Site 2	Site 3
Airbus A300	Log Avg	88.7	91.2	90.9
	Mean	85.4	85.3	84.4
	Std Dev	4.8	6.8	6.5
	Count	12	12	11
	95% CI	3.0	4.3	4.4
Airbus A319/CFM	Log Avg	81.9	80.3	79.5
	Mean	79.4	77.5	77.5
	Std Dev	3.4	3.4	3.0
	Count	92	88	59
	95% CI	0.7	0.7	0.8
Airbus A319/IAE	Log Avg	88.2	89.4	84.9
	Mean	82.5	83.4	80.4
	Std Dev	7.4	8.9	7.5
	Count	7	5	5
	95% CI	6.8	11.0	9.3
Airbus A320/CFM	Log Avg	90.3	88.7	86.2
	Mean	85.9	84.2	82.5
	Std Dev	6.8	6.6	6.0
	Count	14	14	13
	95% CI	3.9	3.8	3.6
Airbus A320/IAE	Log Avg	89.5	89.7	89.0
	Mean	87.0	86.2	87.1
	Std Dev	5.6	7.1	4.8
	Count	11	12	9
	95% CI	3.7	4.5	3.7
Airbus A321/CFM	Log Avg	91.2	90.2	89.8
	Mean	86.8	85.8	85.8
	Std Dev	6.9	7.3	6.7
	Count	14	14	12
	95% CI	4.0	4.2	4.2
Airbus A321/IAE	Log Avg	91.2	93.4	91.3
	Mean	89.8	91.5	89.2
	Std Dev	4.1	5.0	5.4
	Count	9	9	9
	95% CI	3.1	3.9	4.1
Boeing 737-3/4/500	Log Avg	89.1	89.5	86.2
	Mean	85.5	85.3	83.1
	Std Dev	6.0	6.5	5.1
	Count	43	43	41
	95% CI	1.9	2.0	1.6
Boeing 737-700	Log Avg	90.2	90.3	88.2
	Mean	85.5	84.0	83.9
	Std Dev	7.1	8.2	6.4
	Count	34	33	22
	95% CI	2.5	2.9	2.8
Boeing 737-800	Log Avg	91.7	92.1	91.2
	Mean	88.7	88.5	87.9
	Std Dev	6.0	6.9	6.5
	Count	472	467	417
	95% CI	0.5	0.6	0.6
Boeing 767-300/GE	Log Avg	94.8	95.5	94.4
	Mean	90.3	90.4	89.1
	Std Dev	7.7	8.5	8.5
	Count	7	7	7
	95% CI	7.1	7.8	7.9
Executive Jet	Log Avg	87.3	85.1	84.3
	Mean	83.9	83.0	81.7
	Std Dev	5.2	4.7	5.2
	Count	10	10	10
	95% CI	3.7	3.4	3.7
Large Twin Turboprop	Log Avg	87.5	87.7	86.4
	Mean	86.3	86.2	84.3
	Std Dev	3.6	4.1	4.8
	Count	12	12	12
	95% CI	2.3	2.6	3.0
MD-11	Log Avg	91.9	93.6	95.3
	Mean	88.6	89.3	91.2
	Std Dev	5.2	6.4	6.1
	Count	9	9	9
	95% CI	4.0	4.9	4.7

Table 3 Comparison of measured noise levels during the periods 0600-2330 hours and 2330-0600 hours at Stansted

Aircraft Type		SEL, dBA (Attended + Unattended)					
		0600-2330 hours			2330-0600 hours		
		Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Airbus A319/CFM	Log Avg	81.7	79.8	78.2	82.8	82.0	82.7
	Mean	79.2	77.2	77.2	80.7	78.6	79.0
	Std Dev	3.2	3.1	2.5	3.6	4.3	4.3
	Count	76	72	48	16	16	11
	95% CI	0.7	0.7	0.7	1.9	2.3	2.9
Boeing 737-3/4/500	Log Avg	89.9	90.1	87.2	85.9	87.2	82.2
	Mean	86.5	86.2	84.4	82.9	83.0	80.2
	Std Dev	6.1	6.7	5.0	5.1	5.5	4.1
	Count	31	31	28	12	12	13
	95% CI	2.3	2.5	2.0	3.2	3.5	2.5
Boeing 737-800	Log Avg	91.9	92.3	91.5	89.5	89.4	87.6
	Mean	89.1	89.0	88.4	84.4	83.4	82.2
	Std Dev	5.8	6.7	6.2	6.3	6.9	6.9
	Count	428	423	382	44	44	35
	95% CI	0.6	0.6	0.6	1.9	2.1	2.4

Table 4 Unattended noise measurements of reverse thrust at Heathrow

Aircraft Type	SEL, dBA (Site 1)				
	Log Avg	Mean	Std Dev	Count	95% CI
Airbus A319/CFM	88.9	84.9	5.5	28	2.1
Airbus A319/IAE	82.7	82.0	2.3	204	0.3
Airbus A320/CFM	91.6	86.3	6.5	146	1.1
Airbus A320/IAE	84.9	83.0	3.4	236	0.4
Airbus A321/CFM	93.8	88.4	7.0	69	1.7
Airbus A321/IAE	89.4	84.4	5.1	105	1.0
Airbus A330	96.3	90.7	6.6	41	2.1
Airbus A340-2/300	97.2	94.1	6.2	26	2.5
Airbus A340-5/600	95.4	92.7	4.2	40	1.3
Boeing 737-3/4/500	90.2	86.3	5.5	61	1.4
Boeing 737-6/700	84.1	83.4	2.6	10	1.9
Boeing 737-8/900	94.3	88.3	7.5	23	3.2
Boeing 747-400/GE	89.1	88.7	1.8	14	1.0
Boeing 747-400/PW	95.6	89.7	6.3	9	4.9
Boeing 747-400/RR	90.2	89.2	2.7	87	0.6
Boeing 757-200/RR	89.1	85.0	4.6	54	1.3
Boeing 767-300/GE	97.4	91.8	6.9	23	3.0
Boeing 767-300/PW	91.8	88.6	5.8	21	2.6
Boeing 767-300/RR	85.6	84.9	2.6	53	0.7
Boeing 767-400	94.0	88.8	7.0	9	5.4
Boeing 777-200/GE	86.5	85.2	2.8	62	0.7
Boeing 777-200/PW	93.3	88.4	5.7	22	2.5
Boeing 777-200/RR	95.2	90.3	6.3	50	1.8
Boeing 777-300/GE	95.5	92.0	5.5	52	1.5
CRJ-700	91.4	88.1	6.4	6	6.7
ERJ-135/145	79.6	79.5	1.0	6	1.1
Executive Jet	94.5	89.6	7.8	9	6.0
MD-80	94.0	88.2	6.5	41	2.0

Figure 1 Noise monitoring locations at Stansted

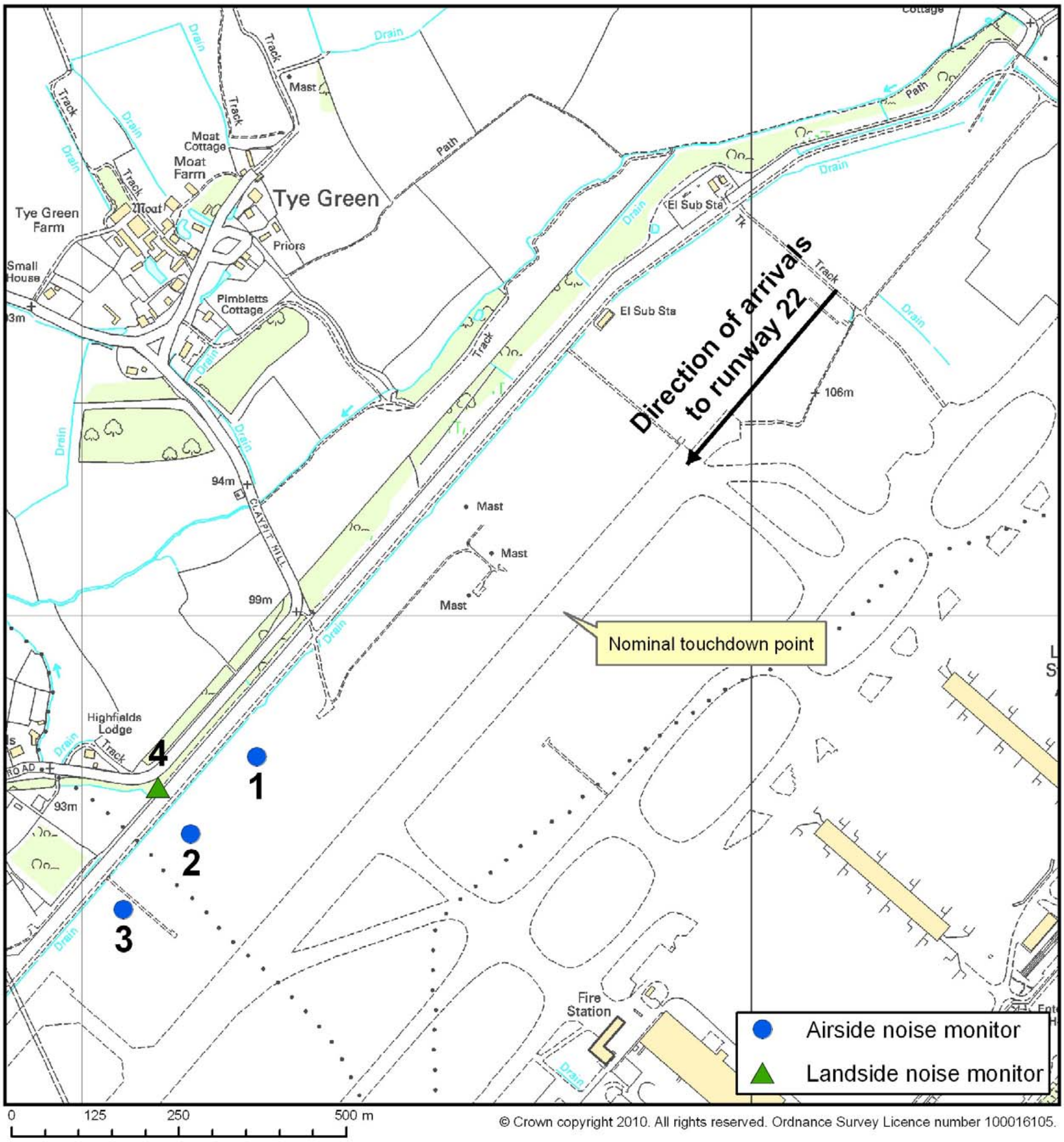

Figure 2 Set up of an airside noise monitor at Stansted

Figure 3 Landside observation site at Stansted

Figure 4 Noise monitoring locations at Heathrow

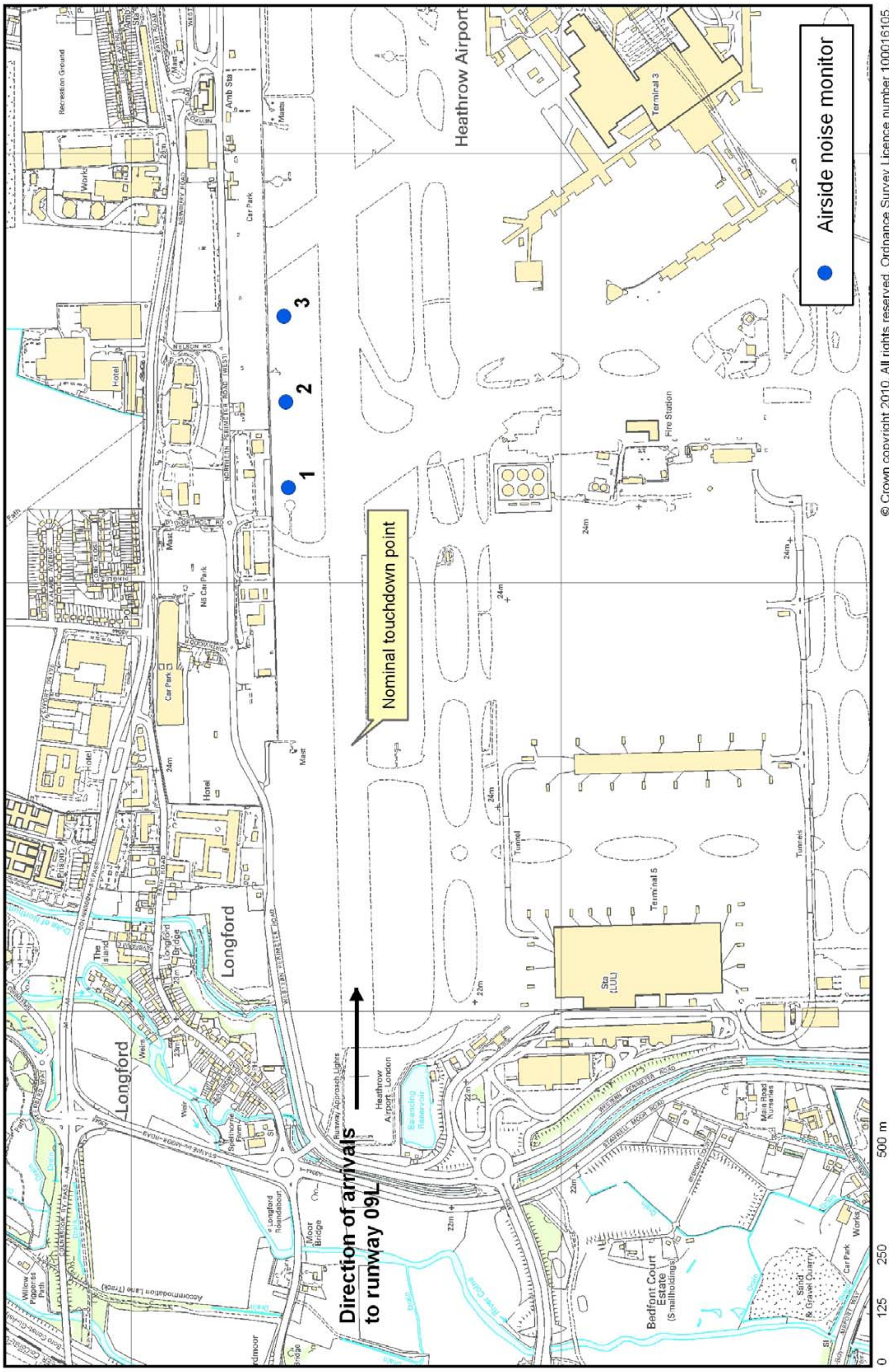

Figure 5 Distribution of Boeing 737-800 noise levels at Stansted Site 2

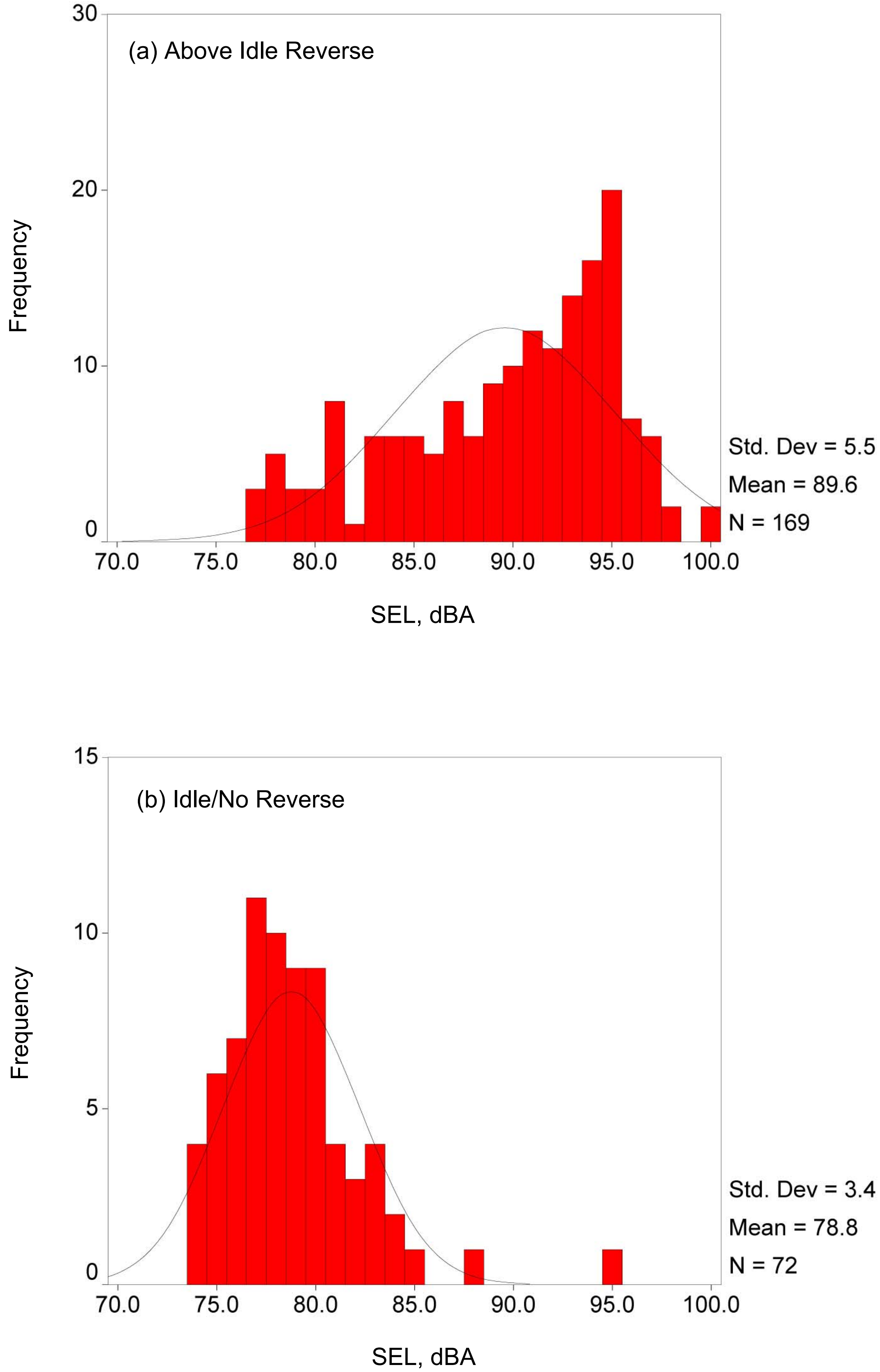

Figure 6 Noise level time history at Heathrow, 14 September 2009

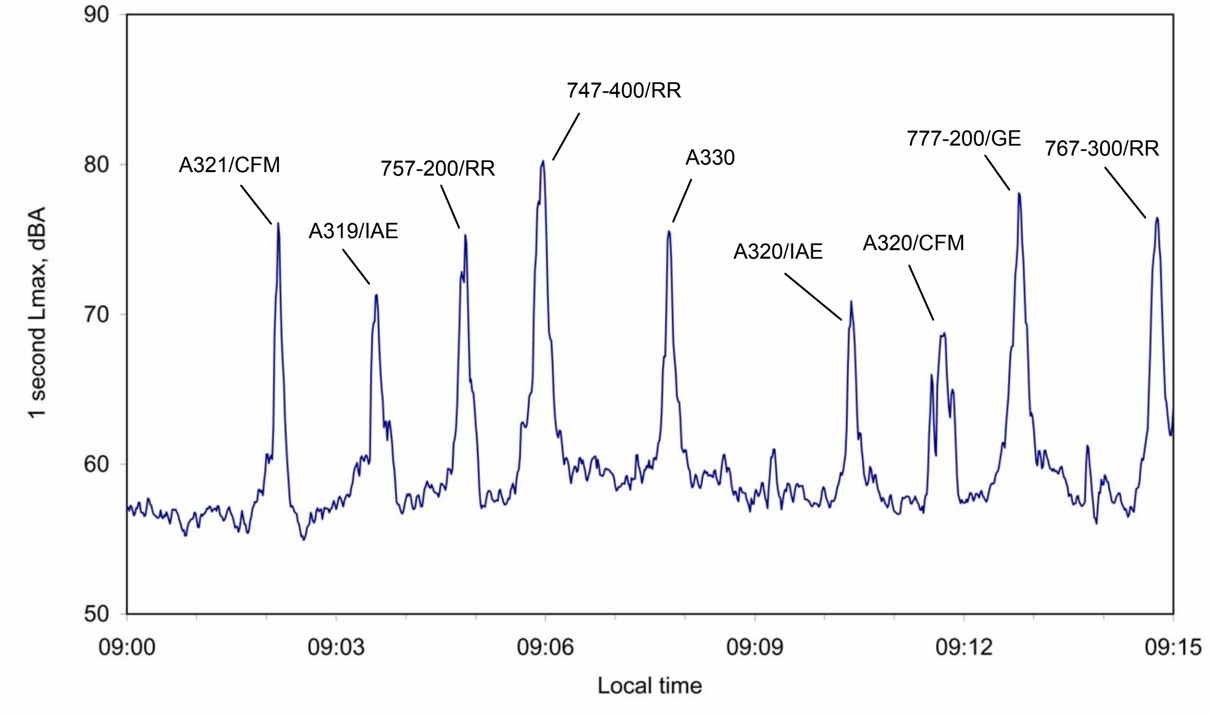

Figure 7 Noise level time history at Heathrow, 17 September 2009