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ARRIVALS NOISE AT HEATHROW AIRPORT

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1. Background

Both departures and arrivals noise have the potential to create significant noise problems for residents at either end of a busy airport main runway. Departing aircraft are obliged to use high thrust settings to climb to the desired cruising altitude and accelerate the aircraft to the optimum cruising speed. As a result, they can generate significant noise at source. However, modern aircraft types (particularly those with only two engines) are usually capable of climbing quite quickly. A high rate of climb limits the area exposed to the highest noise levels on the ground. In addition, most departures will generally disperse in different directions, depending on route, once they have attained sufficient height. Flight track dispersion helps to limit the aggregate noise exposure at any one place on the ground.

Arrivals will generally use much lower thrust settings than departures, thus generating much lower noise levels at source. However, all arrivals are required to maintain a relatively shallow glide slope down to the runway threshold for some considerable distance. This means that the height above the ground is usually much lower than for typical departures at similar distances from the airport. In addition, there are no opportunities for flight track dispersion as would normally occur with departures. Because of the differences in engine thrust settings and because there can be a significant contribution from aerodynamic sources when the various slow speed lift devices, landing gear etc are deployed, the character of typical arrivals noise can be quite different from that of typical departures noise. Mainly because of the differences in flight profiles, arrivals noise can be as significant as departures noise for some people residing immediately underneath the approach glide slopes, depending on the distance from the runway.

Both departures and arrivals noise are limited at source by internationally agreed noise certification procedures, with compulsory retirement of older noisier aircraft types. There are also departure noise limits measured at noise monitoring stations deployed underneath the main departure routes. There is a general perception that all these factors have had a greater effect on departures noise levels than on arrivals noise levels. BAA Heathrow therefore decided to carry out a series of studies of arrivals noise at Heathrow in order to understand more about arrivals noise. It should be noted that all measurements were carried out using A-weighted overall sound levels and that only arrivals established on the approach glide slope were included in any of the studies. Noise levels prior to joining the 3 degree glide slope or any possible differences in sound quality were outside the scope.

2. Phase 1 study

BAA Heathrow commissioned Ian H Flindell & Associates to carry out the initial phase 1 study of arrivals noise levels at Heathrow in September and October 1994, using data from a temporary deployment of five of Heathrow Airport's Noise and Track Keeping (NTK) system semi-portable noise monitors under the approach path to runway 27L at Heathrow (Flindell & McKenzie, 1995). Previous studies had found different average noise levels for different aircraft types, as expected, but there also appeared to be significant unexplained variability in the data. The overall aim for the phase 1 study was to investigate this variability and if possible, to determine the main causes. The variables considered were as follows;

- aircraft type
- flight configuration (for a limited sample)
- instantaneous engine thrust setting (for a limited sample)
- height above ground over the noise monitor
- meteorological and situational factors as available for analysis

The five noise monitors were deployed over a one month period and recorded a combined total of 2955 arrivals events over six separate good weather days where a number of observers were stationed at different monitoring positions to observe aircraft landing configurations and record heights photographically. Of this total, 2292 cases were fully validated against radar height and track records. Some data was lost due to equipment malfunctions and some arrivals events were masked by other noise sources occurring at the same time.

The British Airways B757 aircraft was selected for more detailed investigation using aircraft Flight Data Recorder (FDR) print-outs of all relevant flight parameters for the final ten minutes before landing. The British Airways B757 fleet at Heathrow is composed of mostly identical aircraft which are all fitted with the same type of engines and other equipment which might affect noise levels on the ground. This does not apply to many other aircraft types at Heathrow which can have a number of variants in terms of engine fit, etc. Observers selected the 6 noisiest and 6 quietest B757 arrivals for each of five test days for subsequent FDR analysis. Complete FDR records were obtained for 57 B757 arrivals in total.

The problem of obtaining precise time synchronisation between FDR records and noise monitor data was identified as a key issue in an earlier pilot exercise. For this study, an observer was stationed on the public viewing area at Terminal 2 at Heathrow and noted the precise time (to the nearest second) at which the wheels of each landing aircraft touched down. The FDR records could then be precisely time aligned against the noise monitor and radar height and track data using the data record for the landing gear squat switch. The observer also recorded aircraft types and registration numbers for later confirmation against the NTK system database.

FDR data analysis

This analysis looked at the relationships between instantaneous height, thrust setting, other relevant aircraft flight parameters and instantaneous noise level on the ground for the 57 B757 arrivals with comprehensive FDR and noise data. It was hypothesised that small changes in instantaneous thrust setting (and other flight parameters) necessary to maintain the required speed and flight configuration during the descent could contribute to variability in noise levels recorded on the ground. For the analysis of the data, the main problem which had to be overcome was the constantly changing slant distance from source to receiver throughout the flyover. This not only causes constantly changing attenuation due to distance from source to receiver throughout the flyover at constantly changing angles to the source, but also causes a constantly changing propagation delay which can be quite significant as compared to the overall duration of the flyover event. The changing propagation delay was separately calculated for each second during each flyover, taking into account the steadily decreasing height and ground speed as each arrival approached closer to the runway. This was necessary in order to determine which part of the FDR records corresponded to the instantaneous noise level on the ground.

There were three sets of height data available. The NTK system uses air traffic control radar data which in turn interrogates the aircraft barometric altimeter converted to read in feet above the airfield runway datum and adjusted for local atmospheric pressure at sea level. This system necessarily has limited resolution for this type of study. The FDR records radio altimeter data which has much finer resolution than the barometric altimeter close to the ground. However, the radio altimeter measures height above the nearest surfaces to the aircraft which includes buildings, etc. and not the height above the microphone close to the ground. The observer on site took photographs of each B757 arrival when vertically overhead. This provides an accurate instantaneous height reading but there is only one observation for each flyover at each attended monitoring position. For the FDR data analysis it was decided to use the radio altimeter data with linear regression through successive data points to average out for the uneven ground surface and with small adjustments where necessary for calibration against the photographic height records.

A theoretical model was developed assuming constant sound power at source (determined by extrapolation back from sound levels on the ground) with an allowance for attenuation due to the constantly changing distance (spherical spreading plus a component for excess attenuation) and an empirically derived directivity correction. The model also took into account changing propagation delays during the flyover which cause a steeper rise and extended decay than would otherwise be expected. The instantaneous differences between the predicted flyover event time histories (calculated using the theoretical model) were then compared against actual event time histories to investigate the extent to which residual variability could be explained by instantaneous changes in thrust setting.

Some small time synchronised variations in actual instantaneous sound levels appeared to be correlated with some observed changes in thrust setting but there was no consistency. Other changes in thrust setting were observed which had no effect or even an apparently opposite effect. No other FDR parameters such as flap settings etc. were found to have any consistent effects either for this sample. It should be noted that the differences in operating parameters between the different B757 aircraft investigated in this analysis were generally very small. It is possible that larger differences in operating parameters could have had more consistent effects on noise levels, such that might occur, for example, under more extreme meteorological conditions. However, under normal conditions it seems that small changes in instantaneous thrust setting do not have any consistent effect on instantaneous sound levels on the ground.

Extended data set analysis

For the extended data set applicable to other aircraft types, there was no FDR data and therefore little point in looking at separate event profiles. Comparison of $L_{Amax(1\ sec)}$ data for each arrival against a theoretical model accounting for differences in assumed sound power for each aircraft type and for height over the noise monitor (using NTK height data) gave the highest correlation coefficient (r = 0.925) for a simple A-weighted distance attenuation model using 20 dB per decade of distance for geometric divergence and 0.02 dB per m for linear excess attenuation attributable to atmospheric absorption and any other causes. The correlation coefficient was not very sensitive to differences in the assumed linear attenuation coefficient over a range from 0.01 dB per m up to 0.03 dB per m. Around 60% of observations were between plus and minus 1.75 dB of the best fit model and around 90% were between plus and minus 3.5 dB (when differences in generic aircraft type and measured height over the monitor had been taken into account).

Outlier analysis showed that some low noise levels may have been caused by joining the glide slope late, which would not appear to be a problem from the noise point of view. Overall, the main determinants of arrivals noise levels on the ground appeared to be height over the noise monitor and the equivalent average sound power assumed for each generic aircraft type, with significant residual variability due to unexplained causes.

3. Phase 2 study

The main purpose of the phase 2 study was to investigate a much larger sample of arrivals noise events by using one year's worth of data collected between April 1995 and March 1996 at the fixed departure noise monitor located in Horton which is just off to the south of the 09L arrivals approach track. A larger sample size was needed because the phase 1 study sample size was too small to allow the effects of different engine fits within generic aircraft types to be investigated. The phase 2 study found similar levels of variability to the phase 1 study, but it was concluded that the effect of small variations in aircraft track could have had a disproportionate effect on noise levels because the fixed noise monitor position was not directly underneath the glide slope centre line. This possibility could not be further investigated without proceeding to a further Phase 3 study with properly aligned noise monitors.

4. Phase 3 study

The Phase 3 study was carried out over a 4 month period between November 1996 to March 1997 using three semi-portable noise monitors distributed under the 27L approach path to obtain more definitive data about the various sources of variability (Flindell & McKenzie, 1999a). The main objective was to investigate the precise causes of observed residual variability in arrivals noise levels over a large enough sample size to give statistical validity. The noise monitors were positioned at 2670 m, 6960 m and 8890 m from the runway threshold. The nearest noise monitor was positioned at the closest point at which NTK system height data could be obtained. The furthest noise monitor was positioned at a distance at which the majority of arrivals noise events would still be distinguished from other background noise sources, although this also depends on the relative proximity to other background noise sources. Corresponding meteorological data was obtained from the Met. Office so that effects of hourly wind, temperature and other variables could be investigated.

The total database comprised records for 45,918 aircraft events over the 4 month period. The main determinants of noise levels continued to be the aircraft type/engine fit category and the height over the noise monitor. Typical standard deviations at each noise monitor within each separate aircraft type/engine fit category were of the order of 1 to 2dB. This degree of variability is again similar to that observed in the phase 1 study. It means that most arrivals within a single aircraft type/engine fit category will be within plus or minus 2 to 4 dB above and below the mean for that aircraft type/engine fit category at that noise monitor position. In the phase 3 study, it was not possible to investigate possible variation in noise at source as a contributor to this range but there was no evidence from the results of the phase 1 study that this was a significant factor. In addition, there was no evidence of any significant deviations from the required height and track that would be expected to have any large effect on arrivals noise levels on the ground.

For sub-samples of B737-400/CFM56-3C1, B757/RB211-535C, and 747-400/RB211-524H2 aircraft type/engine fit categories (selected for further analysis because of their prominence in the overall data set) both actual height over the noise monitors and the corresponding meteorological conditions were found to have small effects as follows; Overall, average noise levels increased as each aircraft descended the glide slope, but considering the data at each noise monitor separately, there was in each case a small negative effect of height on noise levels on the ground, i.e. noise level increased slightly with increased height. This counter-intuitive finding may in part have been due to the effect of some other intervening or confounding variable. For example, this result could have been explained if aircraft flying slightly higher were also found to be using slightly higher thrust. There is no data available against which to test such hypotheses. In addition only those combinations of meteorological and operating conditions that occur in practice can be investigated in any study of this type. This imposes strict limitations on the type of comparisons which can be made. The only way to overcome this problem would be to adopt fully orthogonal experimental designs where the meteorological and operating conditions of interest are separately controlled over the complete range of variation desired. This type of experiment is not feasible at an operating airport.

The higher vector head winds were found to be associated with higher sound levels by from 0.03 to 0.15 dB/knot. This means that a strong head wind of 25 knots could increase noise levels by up to 3.75 dB for some aircraft type/engine fit categories. Possible explanations are, first, that headwinds could require increased thrust to maintain required ground speed, and second (less likely) headwinds could affect the propagation of sound from aircraft to the ground in some way, Vector cross winds were found to be associated with higher sound levels in a similar way, and the most likely explanations would seem to be the same. Increased surface temperatures were also found to be associated with higher sound levels with an effect ranging from 0.1 dB/degree centigrade to 0.2 dB/degree centigrade. Variation in surface temperature over a 10 degree centigrade range could account for increased noise levels of up to 2 dBA higher. Differences in relative humidity were not found to have any effect, yet increases in air pressure were found to be associated with increased noise levels by from 0.12 dB/kPa. to 0.54 dB/kPa. One problem is that different meteorological conditions as measured at nearby sites do not arise independently and without independent parametric control of all key variables it is impossible to disassociate interactions from direct effects. This means that it should not be assumed that these separate effects found were necessarily additive or cumulative.

Overall statistical analysis using multiple regression found that the effect of height was significant at the nearest two but not at the most remote noise monitor. The effects of vector head wind, vector cross wind, visibility and in this case, relative humidity, were all significant whereas the effects of surface temperature, pressure and cloud cover were not. Rainfall and atmospheric stability (an indicator for temperature lapse rate with height) were significant at the nearest noise monitor only. In the statistical analysis, when the effects of all significant variables were allowed for in a multiple regression equation there was a small reduction in the overall standard deviation, but there was still significant residual variability which could not be explained by any variables investigated in this study.

Different operators often fly aircraft with nominally different engine fits within the same generic aircraft type category. Where differences in average noise levels between different operators of the same generic aircraft type category are observed, it is not clear to what extent these differences might be attributed to the different engine fits or to differences in operating procedures (if any). To increase the number of comparisons which could be made, aircraft types with nominally different engine fits but with the same certificated approach EPNdB noise levels were then grouped together. In some cases, aircraft types with nominally different engine fits have the same certificated approach EPNdB noise levels, suggesting that such differences in nominal engine fit are not significant for approach noise. The certificated approach EPNdB noise levels were obtained from the US Federal Aviation Administration (FAA) database which covers most but not all aircraft type/engine fit categories operating in the UK. Noise levels expressed in EPNdB are often assumed to be around 13 dB higher than L_{Amax} noise levels for the same event at the same place although the difference varies depending on the frequency spectrum and other factors. Certificated approach noise levels are also measured closer to the runway threshold (2000 m) than any the measurements in these studies.

The comparison between certificated approach EPNdB noise levels (where available) and actual measured LAmax noise levels showed that the certificated approach EPNdB noise levels provided a reasonable but not a perfect guide to the relative rank ordering of actual arrivals noise levels measured in L_{Amax}. In the phase 3 study, the correlation was within around 5 dB above and below the mean.

When individual operators flying aircraft type/engine fit categories with nominally similar certificated approach EPNdB noise levels were compared, for some aircraft type/engine fit categories there was no significant variation in average noise levels but for others there was some variation in average noise levels of up to around 3 dB which could not otherwise be explained. It was therefore decided that a further phase 4 study would be useful to investigate the contribution that possible differences in standard operating procedures might make towards explaining these differences.

5. Phase 4 study

The first part of the phase 4 study (Flindell & McKenzie, 1999b) was an arrivals noise seminar hosted by BAA Heathrow which was well attended by aircraft operators. The seminar was held to present the results of previous studies to operators and to discuss the possibility that differences in standard operating procedures might explain some of the residual variability. Seven operators agreed to provide information on the altitudes, distances from the runway threshold and speeds at which different flap settings were selected and at which the landing gear was deployed, together with landing weight and other relevant data for a restricted set of aircraft types. This data was then compared against arrivals noise levels data collected by deploying three semi-portable noise monitors under the 27L approach track at Heathrow in the same way as had been done for the previous studies.

The phase 4 study was carried out over a 3 month period from July to September 1998 using 3 semi-portable noise monitors under the 27L approach track as for previous studies. The same 2670 m and 6960 m distance noise monitor positions were used as in the phase 3 study but the furthest noise monitor was moved out to a new site at 12600 m from the 27L arrivals runway threshold. Over 20,000 validated arrivals noise events were recorded at one or more of the noise monitors (usually at all three), and of the 932 operational data records supplied (for all arrivals runways), around 500 operational data records with corresponding noise data were available for more detailed analysis. There was no indication that operators supplying operational data were any more or less noisy than average.

The Safety Regulation Group of the Civil Aviation Authority provided access to the UK noise certification database which provides a better match for aircraft types operating in the UK than the FAA database which was used for the phase 3 study. Chart 1 shows the relationships between mean measured noise level (L_{Amax}) at the three monitoring positions compared against the certificated approach noise level (EPNdB) as provided by the CAA for each class of aircraft type/engine fit category with a common certificated approach noise level.

The overall phase 4 database was used to produce a table of the relative noise rankings of different operators of aircraft type/engine fit categories with similar noise capabilities as indicated by the CAA certificated approach noise database. The noise level data collected at the 2670 m and 6960 m monitoring positions for each operator of each different aircraft type/engine fit category was very similar between the phase 3 and 4 studies for all categories where a direct comparison could be made, with the majority of differences being less than 1 dB. In both studies, the ranges of mean noise levels between different operators of comparable aircraft type/engine fit categories classified using the CAA certificated approach noise database were small.

For the limited sample with operational data records, operating procedures for most arrivals were found to be generally similar. However, there were some differences in terms of the precise heights at which the landing gear was lowered and at which the various landing flap settings were selected. For those cases where the effect of the landing gear up or down could be compared, noise levels on the ground were found to be around 1-2 dB higher with the landing gear down, depending on aircraft type. For those cases where the effect of different flap settings could be compared, noise levels could be either higher or lower with increased flap settings, depending on the aircraft type.

More detailed statistical analysis of the limited operations data sample suggested some quite complex interactions between operational parameters, landing weight, and height over each noise monitor, none of which apart from landing weight could be understood as establishing any definite pattern. Because of unavoidable statistical confounding between the different variables examined, it was not possible to reach any more definite conclusions from this analysis.

Turning to the overall data sample, the range of mean arrivals noise levels across different operators of aircraft type/engine fit categories with the same certificated approach EPNdB noise levels were mostly around 1 dB or less, with a maximum range of 3.5 dB at the 6960 m monitoring position for the B737-400/CFM56-3C-1 engine fit category which had 17 different operators in the sample. For most aircraft types the range of mean arrivals noise levels between different operators were too small to suggest that possible differences in standard operating procedures were at all significant, but for the B737-400 and perhaps one or two other aircraft types, the range of mean arrivals noise levels across different operators was large enough to suggest that possible differences in standard operating procedures could have had an effect. However, it should be noted that actual operating procedures on a day-to-day basis are determined by the aircraft type/engine fit category flown, by air traffic control instructions, by the operating conditions at the time, and by standard safety requirements. In addition, this research suggests that the noise capabilities of different engine fits within generic aircraft type designations can explain most if not all of previously observed variability in mean arrivals noise levels (having taken the effect of different average heights over different noise monitor positions into account). Further, it seems likely that if it had been possible to include the effect of different landing weights in the noise classifications, then even more of the residual variability might have been explained.

The results of phase 4 showed that individual arrivals noise levels can be affected by operational variables, meteorological variation and landing weight plus other random factors. However, the major variation in average arrivals noise levels achieved by different operators of the same generic aircraft type can generally be explained by the underlying noise capabilities of the particular engine fit as indicated by the approach certificated noise levels database for that aircraft type/engine fit category. There was no evidence that operators have any flexibility to influence the actual arrivals noise levels registered by individual aircraft within the constraints set by the type of aircraft flown, air traffic control instructions, and basic safety procedures during the final approach.

6. Conclusions

The principal findings of the phase 1 study were that the main determinants of arrivals noise levels on the ground were the different levels of sound power generated at source by different aircraft types and the height over the noise monitors as the aircraft descend the approach glide slope. There was significant residual variability in the data which was not explained by changes in instantaneous thrust settings. The phase 2 study investigated arrivals data collected at an existing departures noise monitor but this was found to be not ideal because the possible effect of small variations in track could not be determined. The principal findings of the phase 3 study which investigated a large sample (45,918) of arrivals events using noise monitors under the approach track were the same as in phase 1. In addition there were a number of meteorological variables which separately had small effects on mean arrivals noise levels. When the effects of all these variables were considered together however, they only had a small effect in reducing the overall residual variability. For many aircraft type/engine fit categories, the differences between individual operators of the same category of aircraft were small, but there were some categories of aircraft where between operator differences could have been due to differences in standard operating procedures. The phase 4 study, mainly carried out to investigate the extent to which possible differences in standard operating procedures might explain some of this residual variability found that in fact there was little evidence that operators actually had any flexibility to influence the actual arrivals noise levels registered by individual aircraft within the constraints set by the type of aircraft flown, air traffic control instructions, and basic safety procedures during the final approach.

6. References

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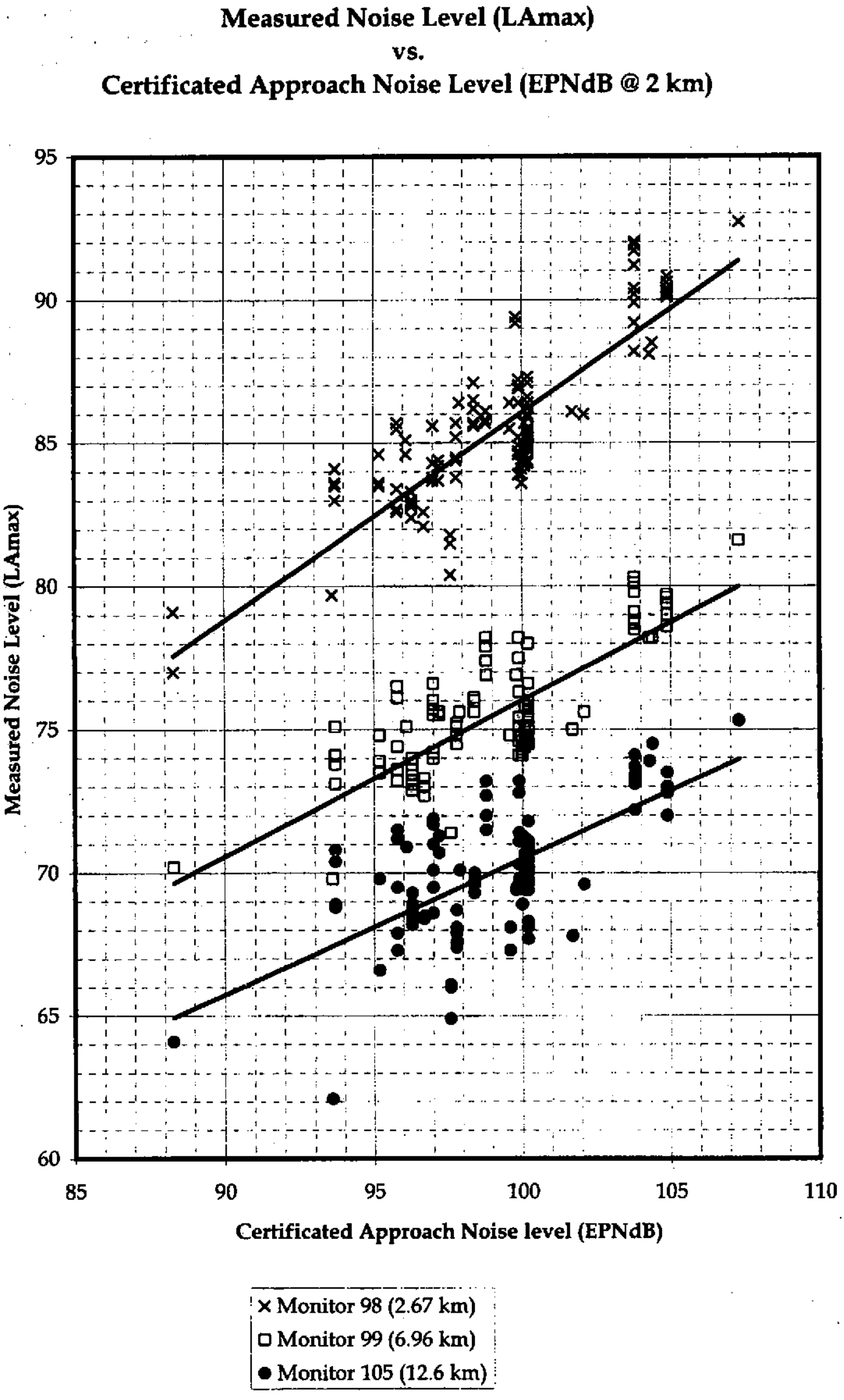
Measured Noise Level (LAmax)
vs.
Certificated Approach Noise Level (EPNdB @ 2 km)
Measured Noise Level (LAmax)
95
90
85
80
75
70
65
60
85
90
95
100
105
110
Certificated Approach Noise level (EPNdB)
× Monitor 98 (2.67 km)
□ Monitor 99 (6.96 km)
● Monitor 105 (12.6 km)