

Low Noise Level Modelling Assurance

CAP 3197

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Contents

Contents	3
Executive summary	4
Chapter 1	6
Introduction	6
Uncertainty	6
Lower noise exposure	7
Chapter 2	10
Confidence in low noise exposure level estimates	10
Chapter 3	12
Factors contributing to increased uncertainty at lower levels	12
Generation of aircraft tracks and vertical profiles	13
Validation using noise measurements	14
Chapter 4	17
Possible changes enabling estimates to lower noise exposure levels	17
Chapter 5	18
Conclusions	18
ANNEX A: CAP 2091 noise modelling categories for UK airports	21
ANNEX B: Summary of validation confidence at low noise exposure levels	22

Executive summary

This paper sets out the confidence that the Civil Aviation Authority's (CAA) Environmental Research and Consultancy Department (ERCD) has in estimating aircraft noise exposure at the lower levels that are increasingly used in research and policy analysis. It replaces *ERCD Report 1006 – Measurement and Modelling of Aircraft Noise at Low Levels*, as ERCD's current statement of position on this issue.

Modelling capability and confidence

Applying the minimum standards in *CAP 2091 – CAA Policy on Minimum Standards for Noise Modelling*, which defines the CAA's current, proportionate framework for aircraft noise modelling across UK airports, ERCD is confident that the ANCON noise model can provide sufficiently reliable estimates of aircraft noise exposure down to around 40-45 dB $L_{Aeq,16h}$ and 35-40 dB $L_{Aeq,8h}$ for historic reporting, noise management and policy development, and recognising that uncertainty continues to increase gradually below these ranges.

Where uncertainty increases

Uncertainty increases at lower exposure levels because of the practical limits on validating modelled noise using measurements. As individual aircraft noise events become quieter with distance from the airport, they approach background noise levels and are increasingly affected by non-aircraft noise and meteorological variability. At most UK airports, low-level contours remain within ranges where validation is feasible or where outputs can be proportionately extrapolated beyond the validated range using established acoustic propagation principles. Heathrow is, however, the most constrained case: its traffic volume and contour extent mean that at levels approaching 45 dB $L_{Aeq,16h}$ and below, individual aircraft events are often no longer separable from background noise, placing a practical limit on direct measurement-based validation. Importantly, this constraint relates to the feasibility of validating calculated noise exposure levels using measurements, not to a failure of the underlying noise modelling physics.

A second consideration is that it is not practical to calculate noise from every individual flight operation. Instead operations are grouped together where their characteristics in terms of aircraft type, runway and importantly their flight track and vertical profile are similar. However, at low noise exposure, far from an airport, operations become widely dispersed in terms of both their lateral tracks and their vertical flight profiles. Relying on operations represented as discrete groups becomes progressively less precise and increases calculation uncertainty. Again, this effect is most pronounced at Heathrow, where high traffic volumes and the influence of arrival holding stacks lead to greater dispersion and variation in flight tracks and vertical profiles at large distances from the airport. At other UK airports, because traffic volumes are lower, noise exposure at the

same levels occurs closer to the airport (than at Heathrow) and consequently dispersion effects are generally less complex and can be adequately addressed within the standard modelling framework set out in CAP 2091.

Steps taken to improve validity

For most UK airports, modelling that is compliant with CAP 2091 provides sufficient robustness at low exposure levels without additional measures. For Heathrow, ERCDC has improved validity by developing methods to represent arrival tracks and vertical profiles out to the holding stacks through use of greater numbers of unique tracks and profiles, capturing the greater lateral spread. In addition, the method accounts for level flight as aircraft pass through the holds and noise contributions from level-flight. These measures make model inputs more representative of real operations. Whilst this approach works well in the backwards looking context, i.e. calculating a prior year's noise exposure, it creates other challenges when trying to predict future noise, where future flight tracks and profiles are not known, other than the statistical representations taken from historic data.

Future prospects

Advances in airport noise monitoring systems have improved the quality of noise data within the measurable range. However, they do not overcome the underlying physical limitation that aircraft noise becomes indistinguishable from background noise at low exposure levels in urban environments. Routine validation of 40-45 dB $L_{Aeq,16h}$ levels at Heathrow using unattended automated monitoring is therefore unlikely in the short to medium term.

Overall conclusion

Overall, CAP 2091-compliant modelling provides a robust and proportionate basis for estimating low-level aircraft noise exposure at most UK airports. Heathrow remains the most constrained case for direct measurement-based validation at the lowest levels, and importantly, these limitations reflect physical constraints rather than deficiencies in the modelling framework. Modelled noise exposures remain reliable for policy and appraisal because they are grounded in validation at higher levels, internationally recognised propagation methods, refined track/profile modelling and a wider global evidence base that supports the use of modelled noise exposure in environmental noise policy.

Chapter 1

Introduction

- 1.1 Research studies into the impacts of aircraft noise around airports are requiring the calculation of civil aviation noise to levels lower than previously calculated at various UK airports. In light of this, the Environmental Research and Consultancy Department (ERCD) of the Civil Aviation Authority (CAA) has been commissioned by the Department for Transport (DfT) to set out the relative levels of confidence we have in the results of the calculations at these lower levels. This publication replaces [ERCD Report 1006 – Measurement and Modelling of Aircraft Noise at Low Levels](#), and reflects subsequent analysis, experience, and the formalisation of modelling standards.
- 1.2 This note responds to the following questions posed by DfT:
- i. The lowest noise exposure levels we are confident in estimating down to using ANCON¹, and how these may vary across airports.
 - ii. The factors which contribute to increased uncertainty when modelling at levels below those given under i above.
 - iii. Whether we foresee any changes, e.g. in technology, that would enable us to reliably estimate noise at lower exposure levels.

Uncertainty

- 1.3 Aviation noise models calculate noise exposure in the vicinity of airports, and are necessary because it is not feasible nor practical to measure noise in every location around an airport. Absolute noise exposure levels estimated by models are only accurate within a margin of error, however. There are uncertainties in both modelling noise and measuring noise.
- 1.4 Noise exposure modelling uncertainty leads to uncertainty in calculating the population exposed to a given level of noise. For a given noise exposure, an area with a higher population density will lead to a higher uncertainty in the estimated population exposure and, for a given exposure-response function, a higher uncertainty in total population impacted (the number of people estimated to be highly annoyed or sleep-disturbed).
- 1.5 Consequently, the publication of [CAP 2091 – CAA Policy on Minimum Standards for Noise Modelling](#) refined and formalised the historic approach taken by the CAA which has been to manage uncertainty based on population noise exposure

¹ ANCON is the UK Civil Aircraft Noise contouring model.

uncertainty rather than noise exposure uncertainty, which results in airports with smaller populations being permitted to use lower fidelity modelling. This might result in a smaller airport having a higher decibel uncertainty in modelled noise exposure, which is effectively compensated for through lower population density, such that the population uncertainty remains lower at airports with lower population noise exposure.

- 1.6 The reason for taking this tiered approach is that the CAP 2091 policy was designed to be proportionate, in recognition of the significant costs involved in airport noise monitoring and modelling. The CAA expects the noise analysis to be sufficient for it to carry out its duties but also proportionate to the size and likely noise effects of the airport or the proposal under consideration.

Lower noise exposure

- 1.7 *ERCD Report 1006 – Measurement and Modelling of Aircraft Noise at Low Levels* concluded that the lowest average summer day noise exposure that could be modelled was 51 dB $L_{Aeq,16h}$.
- 1.8 Some noise attitude surveys have shown annoyance effects at noise exposure levels in the range 40–45 dB $L_{Aeq,16h}$. Consequently, the Aircraft Noise Attitude Survey (ANAS)² was designed to survey populations down to 45 dB $L_{Aeq,16h}$. As with any such survey, there is uncertainty when estimating noise exposure in advance to define the sample. When taking an intentionally inclusive approach to mitigate the risk of under representing people experiencing the lowest levels, some respondents will naturally fall below the nominal lower bound once actual noise exposures are calculated. The ANAS dataset therefore includes individuals exposed to levels down to around 40 dB $L_{Aeq,16h}$.
- 1.9 An L_{Aeq} is the equivalent continuous noise level that contains the same total noise energy of the individual noise events over a given time period. In the UK we use an average summer day of 16 hours from 07:00 to 23:00, and an average summer night period from 23:00 to 07:00. An $L_{Aeq,16h}$ noise level is a combination of the average noise level of each flight and the number of flights, and therefore the same

² The Department for Transport's Aviation Noise Attitudes Survey (ANAS) is a large-scale UK social research study examining how long-term exposure to aircraft noise relates to public annoyance, building on the earlier Survey of Noise Attitudes (SoNA) 2014. It aims to provide updated evidence and exposure–response relationships to inform government aviation noise policy. Additionally, the Aviation Night Noise Effects (ANNE) study is commissioned research examining how night-time aircraft noise affects sleep disturbance and annoyance, with particular focus on how these effects vary at different times of night. It provides evidence to support future night-noise policy, complementing the findings of ANAS, and being undertaken in parallel.

$L_{Aeq,16h}$ noise level can be obtained for different combinations of average noise level and numbers of operations, as shown in Table 1.

Table 1: Relationship between $L_{Aeq,16h}$ and Sound Exposure Level (SEL) and number of noise events over a 16-hour day

SEL (dB)	10 events	25 events	50 events	100 events	200 events
80	42.4	46.4	49.4	52.4	55.4
75	37.4	41.4	44.4	47.4	50.4
70	32.4	36.4	39.4	42.4	45.4
65	27.4	31.4	34.4	37.4	40.4

- 1.10 As can be seen, 40 dB $L_{Aeq,16h}$ corresponds to an average Sound Exposure Level as low as 65 dB SEL for 200 events over a 16-hour period. That average level means a minimum level of 60 dB SEL when accounting for the inherent spread (distribution) of measured noise levels. A rough rule of thumb is that the SEL is around 10 dB higher than the associated maximum noise level, L_{ASmax} , however these lower noise levels will be associated with higher altitude, longer duration events and the SEL to L_{ASmax} difference will be higher, typically 12-14 dB. This implies an L_{ASmax} in the range 46-48 dB L_{ASmax} .
- 1.11 ISO 20906: *Acoustics – Unattended monitoring of aircraft sound in the vicinity of airports* requires that the background noise level is 15 dB below the L_{ASmax} in order to measure SEL without contamination from background noise. This implies that the background level must be 15 dB below the range 46-48 dB, i.e. in the range 31-33 dB L_{Aeq} . In practice, flights disperse far from an airport such that the number of events will not be as high as 200 events, but in the range 50-100 events. This

increases noise levels by 3-6 dB, and so leads to a requirement for background levels in the 34-36 or 37-39 dB L_{Aeq} .

- 1.12 At night time, the levels of interest are lower, around 40 dB $L_{Aeq,8h}$ and potentially lower. The numbers of movements are naturally lower at night, such that the relevant SEL, L_{ASmax} and background levels are correspondingly higher, around an average of 70-75 dB SEL, which leads to a requirement for a background level in the range 41-43 dB L_{Aeq} .

Chapter 2

Confidence in low noise exposure level estimates

- 2.1 Minimum standards for noise modelling practice are set out in [CAP 2091](#). Any noise modelling required by the CAA for a regulatory decision is required to meet these standards, regardless of the party undertaking the work or the model used. ERCD applies the CAP 2091 standards by default in its aircraft noise modelling work, whether it is for a regulatory decision or otherwise. In the latter case, rare exceptions are only made if deemed necessary, acceptable and agreed with the commissioner of the work. In any case, our reporting of our noise modelling work will make clear what standard of modelling has been met.
- 2.2 The minimum standards are set for five categories of airport, A to E, principally according to the magnitude of their population noise exposure at Lowest Observed Adverse Effect Levels (LOAELs) defined by Government as 51 dB $L_{Aeq,16h}$ daytime and 45 dB $L_{Aeq,8h}$ night-time. The higher the population exposure, the higher the population uncertainty for a given noise exposure uncertainty, and therefore the greater the level of sophistication needed in the modelling to achieve sufficiently reliable noise exposure estimates (as explained in the following section). In other words, CAP 2091 does not maintain constant noise exposure uncertainty across the five A to E categories, we purposely accept greater noise exposure uncertainty when the overall population exposure is lower. See ANNEX A for examples of UK airports and their respective categories.
- 2.3 The highest standards are set for Category A airports, i.e. the UK airports designated for noise management by DfT (Gatwick, Heathrow and Stansted), owing primarily to their strategic importance, and in the case of Heathrow, to its population noise exposure.
- 2.4 Progressively lower noise modelling sophistication is required for Category B to E airports, owing to the decreasing population noise exposure which permits increased modelling uncertainty on a proportionate basis. As shown by the examples in ANNEX A, the other major UK airports fall within these Categories.
- 2.5 Heathrow has the highest noise exposure of all UK airports, and within Chapter 3 we set out why it is necessary to take specific additional measures to manage the increased uncertainty when modelling noise at Heathrow down to lower levels. This is because both the contour size and the population density mean that population exposure is greater for a given decibel uncertainty at Heathrow than at any other UK airport.
- 2.6 After Heathrow, Manchester has the next highest population noise exposure of the major UK airports. For context, considering noise exposure in terms of contour area,

after Heathrow, Gatwick has the next highest noise exposure by area, followed by Stansted and then Manchester. Manchester has a relatively high population noise exposure due to the combination of both its noise exposure and its location near to densely populated areas of Manchester.

- 2.7 London City, Birmingham, Glasgow and the other major airports which have population noise exposures that are lower still, do not present the same challenges than those at Heathrow and by meeting the standards set out in CAP 2091, they can be modelled adequately to the low noise levels mentioned in paragraph 1.8, and potentially below, without taking additional measures. Further context is given to this in Chapter 3.

Chapter 3

Factors contributing to increased uncertainty at lower levels

- 3.1 It is important to distinguish between the capability of a noise model to calculate aircraft noise exposure and the ability to validate those calculations using noise measurements. Noise modelling is based on established acoustic propagation physics and operational data and can be applied at exposure levels lower than those at which aircraft noise can be reliably measured in the field. Validation using measurements provides confidence in model performance, but practical limits on measurement do not imply that modelling below those limits is not valid; rather, they indicate that confidence must increasingly rely on the model's physical basis, calibration at higher levels, and consistency of application.
- 3.2 Generally, the busier an airport is, the further out that noise measurements would need to be collected to validate model outputs down to a given noise exposure level. This is because, for a fixed single-event noise level, higher traffic volumes produce larger cumulative noise contours (see Table 1), meaning that to validate the lowest contour level, monitors must be located at greater distances from an airport where aircraft are higher and thus quieter, and where ambient conditions that affect noise propagation through the air are more variable. Consequently, while validation at low exposure levels is most challenging at Heathrow, less busy airports with smaller contours can usually obtain suitable measurement data more readily because the aircraft are relatively lower in height at the locations of the lower noise level contours, and therefore closer to the ground and noisier at those monitor locations.
- 3.3 The two main factors which contribute to noise modelling uncertainty are as follows, and will be explored in detail in this section:
- i. how the tracks and vertical profiles flown by real aircraft are represented by the inputs (flight tracks and profiles) used by the noise model.
 - ii. the ability to validate calculated noise levels against noise levels measured of real aircraft flyovers (noise events); and
- 3.4 We can improve on point i by putting more resources into specifying the inputs. Further from the airport, flight operations become more dispersed, and it becomes less robust to aggregate operations into groups represented by fewer tracks and/or profiles.
- 3.5 There are, however, practical limits to the extent that we can address point ii and validate calculations using measurements because the noise levels of individual

aircraft flyovers reduce with increasing distance from the airport, and get closer to the noise levels of other noise sources.

3.6 Both of these points are explored further in the following sections.

Generation of aircraft tracks and vertical profiles

- 3.7 Modelling noise exposure at most UK airports down to 40-45 dB $L_{Aeq,16h}$ can be done to meet CAP 2091 standards without taking additional measures to reflect arrival and departure tracks.
- 3.8 For Heathrow, modelling noise exposure down to 51 dB $L_{Aeq,16h}$ does not require detailed modelling of the arrival holding stacks at Heathrow, and therefore on a proportionate basis, arrival flight paths are extrapolated out to the approximate location of the holding stack beacon.
- 3.9 Recent analysis has shown that due to the much higher traffic volumes at Heathrow than at other UK airports, modelling down to 40-45 dB $L_{Aeq,16h}$ requires a better representation of the arrival tracks in the vicinity of Heathrow's four holding stacks. This is not solely a flight track issue, but a combined flight track and vertical profile issue, since aircraft typically operate in level flight in the holding stacks, leading to higher engine thrust and higher noise emission.
- 3.10 For this reason, ERCD has developed bespoke methods to generate representative arrival tracks and vertical profiles extending to the holding stacks and beyond.
- 3.11 For departures, the current modelling approach, using mean tracks with laterally dispersed sub-tracks and type-specific vertical profiles, follows international best practice³ and is already considered adequate down to 40-45 dB $L_{Aeq,16h}$. Departure operations generate higher source noise levels than arrivals, though they climb more steeply than arriving aircraft descend, so they spend more time at greater heights above the ground which increases the propagation distance, partially offsetting the effect of the higher source noise levels by the time the noise reaches observers on the ground. Some departures do level off as their route takes them underneath a holding stack. This level-off reduces source noise emission, but increases the time the aircraft spends at lower altitudes, however, these two factors tend to cancel out, unlike arriving aircraft in holds, where there is a net increase in noise.
- 3.12 The dispersion of departure tracks increases more rapidly with distance from the runway than for arrivals due to the practice to vector aircraft off the Standard Instrument Departure routes (SIDs) above 4,000 feet, though it tends to follow a

³ ECAC/CEAC Doc. 29 Fourth Edition, 2016. <https://www.ecac-ceac.org/documents/ecac-documents-and-international-agreements>

more predictable pattern of increasing spread either side of a SID. Modelling uncertainty therefore remains lower than that for arrivals at locations where noise levels are at 40-45 dB $L_{Aeq,16h}$.

- 3.13 At night, when traffic volumes and stack-holding activity are lower, contours are correspondingly smaller, even at the lower noise levels of 35-40 dB $L_{Aeq,8h}$, and the noise model's performance can be validated with greater confidence. Sufficient radar and track data exist to support modelling out to these distances, ensuring consistency between historical and future assessments.

Validation using noise measurements

- 3.14 As already discussed in Chapter 1, aircraft noise is assessed in isolation, so clean separation from other sound sources is fundamental to reliable validation. ISO 20906: *Acoustics – Unattended monitoring of aircraft sound in the vicinity of airports* requires that individual aircraft events be measurable to at least 10 dB below their maximum level (L_{ASmax}) to avoid underestimating Sound Exposure Level (SEL), and that noise monitor event-detection thresholds be set at least 5 dB above background noise levels to prevent contamination (i.e. non-aircraft sounds interfering with events). Where this separation cannot be maintained, background noise may contaminate measurements and reduce their reliability. This limitation creates a practical boundary beyond which unattended noise monitoring cannot provide robust validation data.
- 3.15 With the exception of Heathrow airport whose noise is dominated by larger wide-bodied aircraft, at almost all other UK airports the dominant aircraft are the Airbus A320 or Boeing 737 aircraft. Although these are quieter than many wide-body types, their high number of operations result in them being the dominant aircraft in terms of overall noise exposure. Far from the airport, where noise levels are in the range 40-45 dB $L_{Aeq,16h}$, noise events have been observed to be less than 5 dB above background noise levels and therefore measurements could not be used for noise validation purposes.
- 3.16 At Heathrow, the extent of the long-term average noise contours at levels of 40-45 dB $L_{Aeq,16h}$ also fall outside the practical validation boundary. Site surveys undertaken by ERCD around Heathrow and reported in *ERCD Report 1006 – Measurement and Modelling of Aircraft Noise at Low Levels*, indicate how difficult it is to find locations with sufficiently low background noise levels for reliable low-level aircraft noise monitoring. Daytime background noise levels at measurement sites typically lay between 40 and 50 dB, depending on location and meteorological conditions. In calm, still air, the quietest sites recorded levels in the low- to mid-30s dB, but light winds commonly increased these by up to 10 dB, and exposure to distant road traffic often raised them further into the 45-50 dB range. Over the same period, aircraft noise events produced L_{ASmax} values generally between 45 and 60 dB, with most in the 50-55 dB range. Thus, even under favourable conditions,

aircraft peaks were typically 5-15 dB above background, and with light to moderate wind the differences were smaller still. ERCD concluded that, except during brief periods of calm when background levels fell below 40 dB, such environments provide insufficient separation between aircraft noise events and background noise for unattended monitoring of aircraft noise at or below 45 dB $L_{Aeq,16h}$ exposure levels.

- 3.17 Again, considering Heathrow, modelled average noise event levels at the location of the 45 dB $L_{Aeq,16h}$ noise contour are of the order of 60-65 dB SEL or 50-55 dB L_{ASmax} (see Table 1). To meet the ISO 20906 requirements set out above, locations would need to be found where daytime background noise levels do not regularly exceed 35 dB L_{Aeq} , and preferably lower to capture those events that are quieter than the mean, in order to validate the model at the position of the 40-45 dB $L_{Aeq,16h}$ noise contour. The site survey results indicate that this would be challenging in environments such as those around Heathrow.
- 3.18 Consequently, it is not possible to obtain uncontaminated aircraft noise measurements around Heathrow at exposures at or below 45 dB $L_{Aeq,16h}$. This is primarily an issue at Heathrow, though it does present at other larger airports too. For the majority of the other UK airports, the number of events will be lower and thus the associated SEL and L_{ASmax} levels will be correspondingly higher for relevant $L_{Aeq,16h}$ levels and therefore easier to measure.
- 3.19 At night, the equivalent noise levels of interest are lower, typically around 35-40 dB $L_{Aeq,8h}$, but the number of aircraft movements is also lower. For a given $L_{Aeq,8h}$ level, this means that the contributory single-event levels (SEL and L_{ASmax}) are generally higher than for an equivalent daytime $L_{Aeq,16h}$ level. Background noise levels are also typically lower at night, which further increases the likelihood that aircraft events can be distinguished from ambient sounds. Taken together, these factors mean that measurement-based validation at relevant night-time contour levels is generally more feasible than for the corresponding daytime low-level contours, although the same physical limitations on unattended monitoring still arise as noise exposure levels reduce further.
- 3.20 Under CAP 2091, only four UK airports are required to validate noise modelling using measurements. These are Gatwick, Heathrow, Manchester and Stansted airports. Although the lower noise level contours may fall beyond where noise measurements are routinely obtained, the measurements obtained are extrapolated beyond the model's validated range using well-understood acoustic propagation principles⁴, providing a proportionate level of assurance using the available data.

⁴ By well-understood acoustic propagation principles we mean the standard, internationally accepted methods for calculating how aircraft noise reduces with distance and atmospheric conditions. These include the

- 3.21 Noise modelling is used to inform UK aviation noise policy. The practical implication is that any residual uncertainty at lower exposure levels primarily manifests as a possible offset in the noise exposure element of the exposure–response function that is generated in noise attitude studies. Although it is impossible to quantify such an offset, or even to determine whether one exists, provided that the modelling approach is applied consistently across airports and over time, this offset does not affect the estimation of the proportion of highly annoyed people at each airport. Neither does it affect the comparability of these results with international studies, which typically rely on modelled exposures with less, or even no, validation against noise measurements.
- 3.22 This approach is consistent with those academic studies which have, over the years, built the scientific evidence base on human response to transportation noise. The WHO Systematic Review⁵ underpins current European noise policy and relies primarily on modelled, not measured, noise exposures. It draws on extensive population studies using calculated noise levels, often down to 20-30 dB L_{den}, to derive exposure–response functions for annoyance and health. The pooled data show consistent and statistically significant relationships even at these low levels, indicating that modelled exposures provide a reliable basis for policy and appraisal when supported by established modelling standards and calibration against higher-level measurements.
- 3.23 As noise exposure levels reduce, there is an inherent trade-off between the desire to assess impacts at very low levels and the degree of certainty that can be achieved through direct validation. At higher exposure levels, confidence is supported by both modelling and measurement. At lower exposure levels, particularly around major airports such as Heathrow, confidence increasingly derives from the robustness of the modelling framework, validation at higher levels using direct measurements, and established physical principles, rather than from direct measurement alone.

predictable effects of sound spreading, absorption in the air, reflections from the ground, and the influence of weather. These principles are defined in ECAC Doc. 29 and are built into the ANCON model, and have been validated over many years of use at airports around the world.

⁵ WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance, 2017, International Journal of Environmental Research and Public Health 14:1539. <https://doi.org/10.3390/ijerph14121539>

Chapter 4

Possible changes enabling estimates to lower noise exposure levels

- 4.1 It remains the case that validation of aircraft noise contours at lower exposure levels is constrained by measurement practicality. As aircraft noise approaches the level of the background environment, even advanced unattended noise monitoring systems struggle to isolate aircraft sound cleanly from background sources. This imposes a natural lower limit on which noise contour levels can be verified through direct measurement. Although it might be feasible using in-person attended measurements (the practice pre-1990s), the cost would be prohibitive and, even then, measurements would be restricted to quiet locations, raising issues of coverage and equity.
- 4.2 One of the noise and track keeping system suppliers to UK airports has developed the ANEEM (Aircraft Noise Event Extraction Method) system. This enhances accuracy by classifying each detected event according to whether aircraft are the dominant, contributing, or non-dominant source. This allows aircraft events to be detected more reliably under variable background conditions than traditional threshold-based methods, reducing false triggers and improving event attribution.
- 4.3 At Heathrow, which represents the most challenging measurement environment, the extensive Noise and Track Keeping (NTK) network already provides high-quality data to around 51 dB $L_{Aeq,16h}$ and 45 dB $L_{Aeq,8h}$ and in some cases beyond this, but only for noisier types, where we can be assured the noise levels are sufficiently above the background noise levels. The ANEEM system is now deployed across the Heathrow network and has already gathered more robust data samples especially where the measurement environments are most challenging.

Chapter 5

Conclusions

- 5.1 By applying the minimum standards set out in CAP 2091, we are confident that ANCON can provide sufficiently reliable estimates of noise exposure down to around 40-45 dB $L_{Aeq,16h}$ and 35-40 dB $L_{Aeq,8h}$ for the purposes of historic reporting, noise management and to support policy development. The use of a range for each metric rather than a single cut-off reflects the continuous nature of uncertainty in noise modelling and avoids implying a false precision whereby modelling would be considered acceptable at one exact decibel value but not another. It is also important to recognise that uncertainty continues to increase gradually below these ranges.
- 5.2 ANNEX B summarises in tabular form the relationship between modelling capability, measurement feasibility and validation confidence at different exposure ranges. It reinforces a key point of this paper: modelling capability extends below the range in which routine unattended measurement-based validation is feasible, and the level of confidence varies gradually rather than at a single decibel level. In particular, the table distinguishes between the physical validity of the modelling framework and the practical limits of measurement-based validation, the latter of which are most constrained at Heathrow.
- 5.3 Data pooled from noise attitude studies show consistent and statistically significant relationships with noise exposure at these levels, indicating that modelled exposures provide a reliable basis for policy and appraisal when supported by established modelling standards and validation against noise measurements at higher exposure levels.
- 5.4 Across most UK airports, long-term average contours down to around 40-45 dB $L_{Aeq,16h}$ lie within the range where measurement-based validation remains practically achievable or can be proportionately extrapolated using established acoustic propagation principles. This reflects both their smaller noise contour extents and the lower population noise exposure that CAP 2091 explicitly recognises in its tiered modelling requirements.
- 5.5 Heathrow is the exception. Owing to its traffic volume, noise contour size, and population density, Heathrow is the UK airport where low-level noise contours extend furthest from the airport, and where model-measurement validation below 45 dB $L_{Aeq,16h}$ is not feasible. At these distances, individual aircraft noise events become indistinguishable from background noise under typical daytime conditions, placing a practical limit on the lowest exposure levels that can be validated directly.

- 5.6 In all cases, modelling to around 40 dB remains technically valid; the distinction at Heathrow is that confidence below approximately 45 dB $L_{Aeq,16h}$ cannot be reinforced through direct measurement-based validation, rather than that modelling at those levels is unreliable.
- 5.7 Two factors dominate modelling uncertainty at low exposure levels:
- Track and vertical-profile dispersion, which increases with distance from the airport, making it progressively less robust to represent operations using aggregated mean tracks and/or profiles without additional refinement; and
 - Measurement limitations, where background noise masks individual aircraft events and prevents reliable determination of SEL and L_{ASmax} values.
- 5.8 To address the first point, ERCD has improved the validity of Heathrow's low-level modelling by developing bespoke methods to represent arrival tracks and vertical profiles out to the holding stacks, capturing the greater lateral spread and level-flight noise contributions in the holding stacks at long range and at heights above 7,000 feet. For departures, continued use of the Doc. 29-compliant mean-track and dispersed-sub-track approach remains robust, ensuring that the model inputs reflect real operations even where direct measurement is not feasible.
- 5.9 Advances in measurement technology, such as the ANEEM event extraction system in use at Heathrow, have led to incremental improvements within the currently measurable range. However, none remove the underlying physical limitation that aircraft noise becomes indistinguishable from background noise at low exposure levels in urban environments, meaning that routine unattended validation of noise exposure between 40-45 dB $L_{Aeq,16h}$ at Heathrow is unlikely to become feasible in the near term.
- 5.10 In summary, the limits to validation at low exposure levels are physical rather than methodological. For most UK airports, CAP 2091-compliant modelling already provides a robust basis for estimating noise exposure down to around 40-45 dB $L_{Aeq,16h}$. For Heathrow, where measurement at these low levels is not feasible, modelled exposures remain reliable because they are grounded in:
- established, internationally recognised propagation methods;
 - extensive validation at higher levels;
 - enhanced track/profile modelling for long-range arrivals; and
 - a large global evidence base demonstrating that modelled noise is an appropriate foundation for health-based policy analysis at low exposure levels.
- 5.11 Taken together, these factors give assurance that low-level aircraft noise estimates can be used confidently for reporting, appraisal, and policy

development, while recognising that Heathrow will remain the limiting case for direct measurement and validation.

ANNEX A

CAP 2091 noise modelling categories for UK airports

The following are examples of UK airports with their respective noise modelling categories according to the requirements of CAP 2091 when applicable. Because these categories are set according to the population noise exposure criteria set out in CAP 2091, these categories are based on noise exposure as calculated in 2024.

Category A airports

London Gatwick, London Heathrow and London Stansted Airports are designated for noise management under Section 80 of the Civil Aviation Act 1982. As stated in CAP 2091, the requirements for noise modelling for airports designated for noise purposes are set by the Secretary of State rather than the CAA. Therefore, the CAA recommends that noise at these airports is modelled to Category A standard, but it cannot mandate this. This is the methodology followed by the airports currently designated, and aligns with the 'no decrement' criterion.

Category B airports

Up to and including 2023, noise at Manchester Airport was required to be modelled to Category C standard. However, in 2024, the average night population exposure exceeded 160,000 people, therefore the Category B standard is recommended to apply.

Category C airports

Airports that are required to model noise to Category C standard include: Birmingham, Edinburgh, Glasgow, Leeds Bradford and Luton.

Category D/E airports

The definition of Category D is pending a revision of CAP 2091, so Category D currently shares the Category E definition. Aircraft noise modelling for Newcastle and Southampton Airports is required to meet the Category D/E standard.

ANNEX B**Summary of validation confidence at low noise exposure levels**

Noise exposure range ($L_{Aeq,16h}$)	Modelling capability	Measurement feasibility (unattended noise monitoring)	Validation confidence and basis of assurance
>45 dB $L_{Aeq,16h}$	Noise exposure can be calculated using established aircraft performance data, internationally recognised acoustic propagation methods, and CAP 2091-compliant track and profile inputs.	Individual aircraft events are generally sufficiently above background noise to permit reliable determination of SEL and L_{ASmax} .	Direct measurement-based validation is feasible. Confidence is supported by both modelling physics and routine comparison with measurements.
45–40 dB $L_{Aeq,16h}$	Noise exposure can be calculated using the same established physical principles and modelling framework.	At most UK airports, measurement-based validation may still be feasible in suitable locations or can be proportionately extrapolated beyond the validated range.	Modelling remains technically valid. At most airports, confidence is supported by measurement and/or proportionate extrapolation.
	At Heathrow, enhanced representation of arrival tracks and vertical profiles is required to maintain robustness at long range.	At Heathrow, routine unattended measurement-based validation is not feasible because individual aircraft events are often not sufficiently separable from background noise.	At Heathrow, confidence increasingly relies on the physical basis of the model, validation at higher exposure levels, and refined track/profile representation rather than direct measurement at these levels.

Noise exposure range ($L_{Aeq,16h}$)	Modelling capability	Measurement feasibility (unattended noise monitoring)	Validation confidence and basis of assurance
<40 dB $L_{Aeq,16h}$	Noise exposure can still be calculated using established acoustic propagation principles and aircraft performance data. However, uncertainty continues to increase gradually as distance from the airport and operational dispersion increase.	Routine unattended measurement-based validation is not feasible at major airports, including Heathrow, because aircraft events are typically indistinguishable from background noise under normal conditions.	Confidence derives primarily from the robustness of the modelling framework, validation at higher exposure levels, consistency of application, and the wider international evidence base supporting the use of modelled exposure in policy and appraisal. Direct measurement-based reinforcement at these levels is not achievable in practice.