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Measurement and Analysis of Aircraft Noise and Radar Data

CAP 3150

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Chapter 1

Introduction

The role of ERCD

1.1 The Environmental Research and Consultancy Department (ERCD) of the Civil Aviation Authority (CAA) provides a range of research and advisory services in the field of aviation and the environment. This includes the production of annual noise exposure contours for Heathrow, Gatwick and Stansted, as well as for other UK airports and local authorities in the UK. ERCD also offers technical advice to government to support the development of policy on aviation noise.

1.2 Heathrow, Gatwick and Stansted are designated aerodromes for the purposes of Section 78 of the Civil Aviation Act 1982, allowing the government to set certain noise controls at these airports. To carry out its work on behalf of government, ERCD makes extensive use of aircraft noise and radar data extracted from the London airports' Noise and Track Keeping (NTK) systems.

1.3 Most major airports have NTK systems, which take data from air traffic control (ATC) radars and combine them with noise measurements and flight information such as call sign, aircraft registration, aircraft type and destination.

1.4 ERCD obtains this data from the three London airports via links with each airport's remote NTK server. It is this information that keeps the ANCON aircraft noise model database up to date. ERCD also uses its own noise monitoring equipment to measure aircraft noise levels for other specialist projects.

The purpose of this report

1.5 This report describes the procedures used by ERCD for measuring and analysing noise and radar data from aircraft operations.[1] Good practice measurement guidance is also provided to airports and other stakeholders on issues to consider when conducting their own aircraft noise studies.

1.6 The relevant international standard for a continuous airport noise monitoring system is ISO 20906, which describes the requirements for unattended monitoring of aircraft operations in the vicinity of airports.[2] Where appropriate, this report makes reference to applicable parts of the ISO standard. Readers

[1] This report replaces ERCD Report 0406, *Techniques used by ERCD for the Measurement and Analysis of Aircraft Noise and Radar Data*, CAA, 2005, which has been withdrawn.

[2] ISO 20906:2009/Amd.1.2013(E), *Acoustics - Unattended monitoring of aircraft sound in the vicinity of airports*, International Organization for Standardization (ISO)

may also refer to SAE ARP4721, which also provides guidance on monitoring aircraft noise and operations in the vicinity of airports and is broadly aligned with the ISO standard.[3]

1.7 There is no national or international requirement for airport NTK systems in the UK to meet the requirements of ISO 20906 or SAE ARP4721. The CAA also acknowledges that for technical and/or practical reasons it may not be possible for airport operators to fully conform to the ISO or SAE standards. However the CAA strongly recommends that airport NTK systems are installed and operated in accordance with international standards as far as possible and that their overall performance is periodically verified.

1.8 This report does not provide a technical description of the UK civil aircraft noise contour model ANCON. The methods by which noise exposure contours are calculated using ANCON are described in the latest European guidance on noise modelling, ECAC.CEAC Doc 29.[4]

The structure of this report

1.9 The report is structured as follows:

- Chapter 2 provides a description of the noise measurement equipment used by ERCD and guidance on calibration procedures.
- Chapter 3 describes typical aircraft noise measurement procedures and guidance on the selection and installation of sites for unattended noise monitoring.
- Chapter 4 describes how noise and radar data are normally analysed by ERCD when conducting noise studies.
- Chapter 5 presents the conclusions of the report.
- Appendix A provides a list of terms and abbreviations.
- Appendix B provides an overview of the London airports' NTK systems.
- Appendix C provides a summary of the good practice guidance for airports.

[3] SAE ARP4721/1, *Monitoring Aircraft Noise and Operations in the Vicinity of Airports: System Description, Acquisition, and Operation,* SAE International

[4] European Civil Aviation Conference, *Report on Standard Method of Computing Noise Contours around Civil Airports*, ECAC.CEAC Doc 29, Fourth edition, December 2016.

Chapter 2

Noise measurement equipment

Airport noise monitoring terminals

2.1 ERCD obtains the majority of its noise data for research purposes via the London airports' NTK systems. The systems currently comprise 12 fixed (permanent) noise monitoring terminals (NMTs) at Heathrow, five at Gatwick and eight at Stansted.

2.2 The fixed noise monitors are positioned at approximately 6.5 km from the start of roll (SOR) positions and are operated by each airport to monitor aircraft that exceed the departure noise limits.[5] In addition to the fixed monitors the airports also utilise mobile (temporary) noise monitors, which can be deployed anywhere inside the NTK radar coverage areas at each airport (see Appendix B for further details). The locations of the current noise monitoring sites installed around each London airport can be seen on their respective flight tracking websites.[6]

2.3 ISO 20906 states that airport noise monitors shall conform to the performance specifications of IEC 61672-1 for a Class 1 sound level meter.[7] The noise monitors installed at the London airports are all Class 1 precision instruments which meet IEC 61672-1 performance requirements.

2.4 The NTK noise monitors differ from conventional handheld Class 1 sound level meters only in so far as they have to be weatherproof and vandal-resistant, so they can be left unattended over long periods of time; the applicable electroacoustic performance specifications are the same.

2.5 The microphones of the fixed NTK monitors are positioned on masts typically about 6 m above ground level. For practical reasons the mobile microphones are positioned on shorter tripods, usually 3 to 4 m above ground level. In all cases the microphones are mounted vertically (pointing straight up) and fitted with windshields. Figures 1 and 2 show examples of typical fixed and mobile monitor installations.

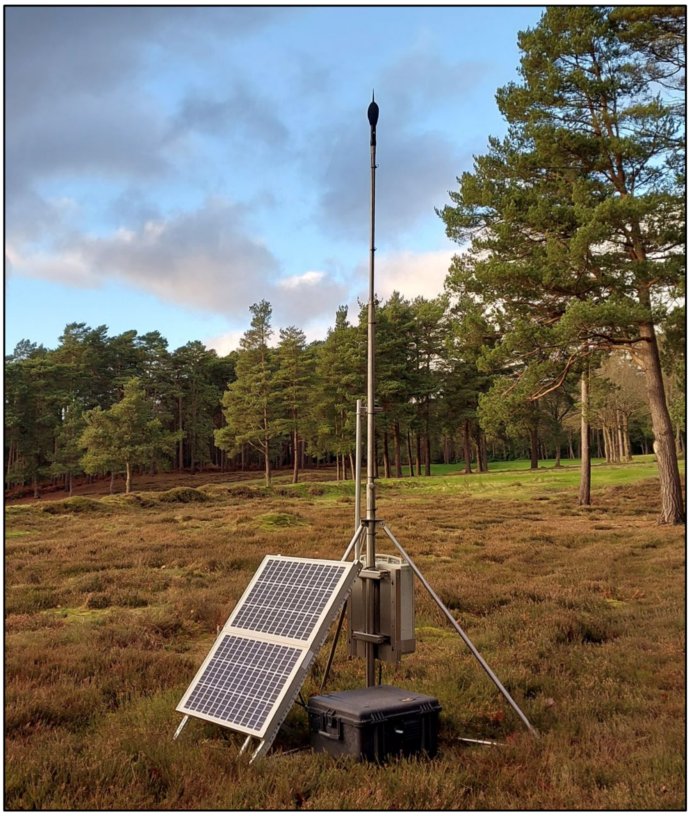
[5] Noise limits for departing aircraft have applied at Heathrow since 1959, at Gatwick since 1968 and at Stansted since 1993. The fixed noise monitors were installed specifically for enforcing these limits.

[6] See https://eu.webtrak.aero/lhr4 for Heathrow, https://eu.webtrak.aero/lgw2 for Gatwick and https://eu.webtrak.aero/stn3 for Stansted.

[7] IEC 61672-1, *Electroacoustics - Sound level meters - Part 1: Specifications*

Figure 1 NTK fixed noise monitor

Figure 2 NTK mobile noise monitor



2.6 The airport noise monitors are normally connected to the NTK systems by means of mobile data connections (to download the stored data) and can be powered by a combination of solar panels and batteries at sites where mains power is unavailable. Methanol fuel cells are also used across a number of airport sites to provide extra charge when solar panels are unable to fully recharge the batteries.

Acoustical calibration and testing

2.7 ISO 20906 states that acoustical sensitivity checks of each airport noise monitor should be performed at least once per year using a sound calibrator, although more frequent checks (for example quarterly) are recommended. The sound calibrator used for this purpose should conform to the Class 1 requirements of IEC 60942 and have been calibrated by a nationally recognised calibration laboratory within the previous 12 months.[8]

2.8 In order to perform these checks, the signal from the sound calibrator is manually applied to the microphone to check the acoustical sensitivity of the measurement system. The signal used is normally a sinusoidal tone at a relatively high sound pressure level (typically in the range 94 to 124 dB).

2.9 On-site calibration checks using a sound calibrator are currently performed every three months on each NTK noise monitor at Heathrow, Gatwick and Stansted. Whilst the risk of any change in sensitivity may be considered low, regular on-site acoustical checks using a sound calibrator provides additional assurance that the sensitivity of each monitor is unchanged since the previous calibration check.

2.10 ISO 20906 also states that if an acoustical sensitivity check indicates a change in sensitivity greater than 0.5 dB since the previous check, the noise monitor should be considered defective. In such cases the instrumentation should be removed from service and recalibrated (see paragraph 2.13). All data measured by the noise monitor since its last acoustical sensitivity check should also be treated with caution and discarded if necessary.

2.11 Carrying out regular on-site acoustical calibration checks can also allow more frequent inspections of the noise monitor to be undertaken to assess, for example, the general condition of the microphone assembly/windshield, or to help identify possible changes to the local environment such as new building works/construction noise nearby or overgrown vegetation and trees.

[8] IEC 60942, *Electroacoustics - Sound calibrators*

2.12 At the London airports, daily internal system calibration checks are carried out automatically to confirm the day-to-day performance of the NTK monitors.[9] Daily reports are generated by each system giving information such as counts of noise events, calibration check results, battery levels and clock drift.

2.13 In addition to the acoustical sensitivity checks and automatic system checks described above, ISO 20906 states that the electroacoustic performance of each noise monitor shall be periodically tested by a nationally recognised calibration laboratory in accordance with the procedures described in IEC 61672-3.[10] The recommended time interval for testing is once a year and the maximum allowable interval is two years. A periodic calibration ensures that the instrumentation continues to provide accurate measurements. At Heathrow and Gatwick, all noise measuring equipment is removed from service and calibrated by a UKAS accredited calibration laboratory once a year.[11]

2.14 When submitting an airport noise monitor for periodic laboratory calibration, the sound level meter and its associated microphone should be treated as a matched pair, since the serial number(s) displayed on a calibration certificate cover the particular instrumentation submitted for calibration at that time. If, for example, following a laboratory calibration, the microphone was replaced with a different microphone, then the noise monitor's current calibration would no longer be valid.

ERCD sound level meters

2.15 It may be necessary for some specialist noise studies for ERCD to carry out attended noise measurements. For this purpose, ERCD has access to handheld Class 1 sound level meters, which can be used with different microphone setups if required (see Chapter 3).

2.16 Before and after each series of attended measurements, on-site acoustical sensitivity checks are carried out using a sound calibrator to verify the accuracy of the sound level meter. Each sound level meter and sound calibrator currently in use is also sent to a nationally recognised calibration laboratory on an annual basis to be calibrated.

[9] While not technically a calibration method, the instrumentation currently installed at the London airports uses a Charge Injection Calibration (CIC) technique to monitor the stability of each noise monitoring terminal.

[10] IEC 61672-3, *Electroacoustics - Sound level meters - Part 3: Periodic tests*

[11] In the UK, laboratory calibrations that are accredited by the United Kingdom Accreditation Service (UKAS) can provide a higher level of confidence in the results than a standard traceable calibration.

Summary guidance for airports: noise measurement equipment

- Airport noise monitors should conform to the performance specifications of IEC 61672-1 for a Class 1 sound level meter.
- On-site acoustical sensitivity checks of each noise monitor should be performed at least once per year using a sound calibrator, although more frequent checks (for example quarterly) are recommended.
- Sound calibrators that are used for acoustical sensitivity checks should conform to the Class 1 requirements of IEC 60942 and should be calibrated by a nationally recognised calibration laboratory at least once per year.
- If an acoustical sensitivity check indicates a change in sensitivity greater than 0.5 dB since the previous sensitivity check, the noise monitor should be considered defective. The instrumentation should be removed from service and recalibrated. All data measured by the noise monitor since its last acoustical sensitivity check should be treated with caution and discarded if necessary.
- The electroacoustic performance of each noise monitor should be periodically tested by a nationally recognised calibration laboratory in accordance with the procedures described in IEC 61672-3. The recommended time interval for testing is once a year and the maximum allowable interval is two years.
- Further guidance on noise measurement equipment and calibration procedures is provided in ISO 20906.

Chapter 3

Noise measurement procedures

Attended and unattended monitoring

3.1 Noise measurements can either be attended or unattended. With attended measurements, an observer is needed on site at the noise monitor to note down information relating to each noise event. This method is particularly useful where identification of the noise source is difficult, but it is labour intensive and uneconomical especially when large numbers of readings are required. For this reason, unattended measurements from the NTK noise monitors are normally used, since the equipment is weatherproof and can be left alone for long periods after set-up to record aircraft noise events.

3.2 For relatively short-term unattended noise studies it may be impractical to install airport NTK noise monitors. In such cases weatherproof environmental kits can be used to convert handheld sound level meters into all-weather noise monitoring systems that can be operated for several days at a time without interruption (Figure 3).

Figure 3 ERCD all-weather noise monitoring system

3.3 Initially it may be appropriate to conduct some attended measurements to determine whether a site is suitable for longer term unattended monitoring. It might also be considered useful to perform attended measurements after a long period of unattended monitoring as a check.

Considerations for noise monitoring sites

Site selection

3.4 Normally the choice of measurement site is determined by it being at a certain distance along a flight path, in a particular area or at a specific address.

3.5 Ideally the ground immediately surrounding the noise monitor should be flat with relatively soft or grassy ground cover (see also paragraphs 3.10 to 3.16). Additional requirements are that the measurement site should be free of nearby obstructions such as buildings and large trees, and free of large nearby reflective surfaces (other than the ground) that could significantly interfere with the measurement of sound from aircraft.[12] To prevent excessive ground effects, ISO 20906 also recommends that sites where the angle of elevation to aircraft is less than 30° should be avoided for monitoring operations on a specific flight path.[13]

3.6 An important factor that can influence the accuracy of any noise measurement is the level of background noise, which is the residual noise level in the absence of any specific aircraft noise. A commonly used indicator of the background noise level is L_{A90}, which is the A-weighted noise level exceeded for 90% of the measurement time. While noise monitors are equipped with windshields, it is important to note that the noise generated by nearby trees and long grass during windy conditions can also affect measured noise levels.

3.7 ISO 20906 provides guidance on determining acoustically suitable sound-monitoring sites to help minimise the possibility of the background noise contaminating measurements or interfering with the measurement of aircraft noise. The guidance states that noise monitors should only be installed at sites where the maximum sound pressure levels (L_{ASmax}) of aircraft events of interest are at least 15 dB greater than the average background noise level. This requirement additionally limits the range of monitoring sites that may be used,

[12] ISO 20906 states that the line-of-sight from the flight path to the noise monitor should be free of obstructions for the most important segment of the flight path. For a straight flight path, this region is estimated to correspond to a line-of-sight angle of about 70° either side of the minimum slant distance. The ISO standard notes, however, that monitoring sites are often pre-determined and sometimes may not conform fully to all requirements, in which case the user should accept a greater measurement uncertainty at the site.

[13] Ground effects is the term used to describe frequency-dependent interactions of the direct sound wave and the sound wave reflected from the ground.

particularly in urban areas, near roads or railways, and at greater distances from the airports (where aircraft are higher and therefore quieter).[14]

3.8 Other important considerations for any new fixed or mobile monitor sites are:

- Accessibility for installation and for routine servicing. For most fixed sites, building works are also required to lay a concrete base and to install the mast and equipment.
- Security and likelihood of vandalism (monitors and their associated equipment have been stolen, damaged or destroyed).
- Land ownership (permissions, restrictions, inconvenience to owner/occupier).
- Possibility for installation of mains power. Reduced sunlight during winter months means that solar panels may not always keep batteries fully charged. Also, the presence of adjacent trees can significantly reduce the performance of solar panels, and the panels can be an attractive target for vandals/thieves.

3.9 It is recognised in practice, however, that the site selection process can often be a compromise between competing requirements.

Effect of microphone height on measured noise levels

3.10 Measured aircraft noise levels can depend on the height of the microphone above the ground surface. This is because sound waves arrive at the microphone directly from the source and also as reflected waves from any nearby surfaces, including the ground itself.

3.11 A microphone positioned a few feet or more above ground level will normally measure a slightly higher A-weighted noise level than a microphone in ‘free-field’ conditions due to the overall augmentation of the direct and reflected sound waves.[15]

3.12 To minimise measurement uncertainty, ISO 20906 recommends that microphones should be positioned on masts at least 6 m above ground level, with no other large reflecting surfaces nearby. However, no distinction is made between the microphone heights of permanent and temporary (mobile) monitor installations. By comparison, SAE ARP4721 states that temporary noise

[14] ISO 20906 notes that additional measurement uncertainty is introduced for data collected at sites that do not meet this requirement.

[15] Free-field is used to describe an ideal sound measurement environment where there are no reflections from nearby surfaces.

monitors may use microphone heights ranging from 1.2 to 6 m, provided there are no other large solid objects nearby.[16]

3.13 As noted in Chapter 2, the microphones of the fixed NTK monitors at the London airports are positioned on masts typically about 6 m above ground level, whereas mobile microphones are positioned on shorter tripods, usually 3 to 4 m above ground level. In addition, a microphone height of 1.2 m is normally used for attended noise measurements (see paragraph 3.17).

3.14 It is considered unlikely that the differences between these microphone heights would cause a significant mismatch between measured aircraft noise levels, provided that monitors are sited in non-obstructed areas with relatively soft or grassy ground cover. This is because, unless the ground surface is highly reflective, large differences would only arise at low angles of elevation (for example, below about 30 degrees) or for aircraft with dominant low frequency components, such as propeller-driven aircraft.[17] As data for elevation angles less than 60 degrees are usually excluded for ERCD measurement studies (see paragraph 4.9), any differences would be minimal.

3.15 This has been checked previously by ERCD by comparing aircraft noise levels measured simultaneously over soft ground at different microphone heights, ranging between 1.2 m and 6 m.[18] These checks revealed no significant or consistent differences between measurements. Thus, aircraft noise measurements are recorded at the different microphone heights without the need for adjustments.

3.16 For some specialist noise studies, however, it can be preferable to install microphones at ground level in order to eliminate ground effects almost entirely. One such application is for the measurement of noise from Unmanned Aircraft Systems (UAS or 'drones'), which can exhibit a higher tonal content in their sound signatures compared to conventional aircraft, making them more susceptible to ground reflection interference effects. Specific guidance on the measurement of noise from UAS aircraft has been published separately by EASA and ISO.[19,20]

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[16] For permanent monitors, the SAE guidance recommends a microphone height of at least 6 m above ground level (or at least 3 m above neighbouring rooftops, whichever is higher).

[17] Bütikofer, R. & Thomann, G. (2005). *Aircraft Sound Measurements: The Influence of Microphone Height*, Acta Acustica united with Acustica. 91. 907-914.

[18] ERCD Report 0205, *Quota Count Validation Study: Noise Measurements and Analysis*, CAA, 2003.

[19] *Guidelines on Noise Measurement of Unmanned Aircraft Systems Lighter than 600 kg Operating in the Specific Category (Low and Medium Risk)*, EASA, 12 June 2023.

[20] BS ISO 5305:2024 *Noise measurements for UAS (unmanned aircraft systems)*

Typical measurement practices

Attended noise monitoring

3.17 For most attended ERCD monitoring studies, the sound level meter is set up on a standard tripod with the microphone positioned at a height of 1.2 m above ground, which is also the microphone height specified in the ICAO requirements for aircraft noise certification.[21]

3.18 Before measurements are conducted, the sound level meter is calibrated with a sound calibrator and the calibration data recorded. A windshield is then fitted to the microphone and a reading of the general background noise level is taken. In addition, a note is made of the prevailing atmospheric conditions such as wind strength and direction. A map may also be sketched showing the monitoring location and the position of any neighbouring objects. The measurement position is also surveyed using GPS equipment to determine a precise location.

3.19 It is normal practice for aircraft noise measurements to be made using the A-weighting filter and S (slow) meter response settings (see Appendix A for an explanation of these terms). As a minimum, the following parameters are usually recorded:

- L_{ASmax} (maximum A-weighted sound pressure level)
- SEL (Sound Exposure Level)
- Event start time
- Event duration
- Time of L_{ASmax}

3.20 Depending on the monitor location, noise events may be picked up from other sources such as nearby road traffic or non-local aircraft flyovers. To ensure that extraneous noise events are not recorded during attended monitoring, the meter can be set up to record individual aircraft noise events by manually pressing the 'start' and 'stop' instrument keys. If interference from another noise source is heard during the event, the contaminated event can be immediately discarded (or marked for later attention).

3.21 Alternatively, most Class 1 sound levels meters are capable of continuously logging a range of noise parameters at intervals of one second or less, allowing the total noise climate to be captured for analysis at a later time. To inform any subsequent analysis, such an approach would normally require sufficiently detailed written notes to log the times when specific noise events were heard.

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[21] Annex 16 – Environmental Protection, Volume I – Aircraft Noise, ICAO, Eighth Edition, July 2017

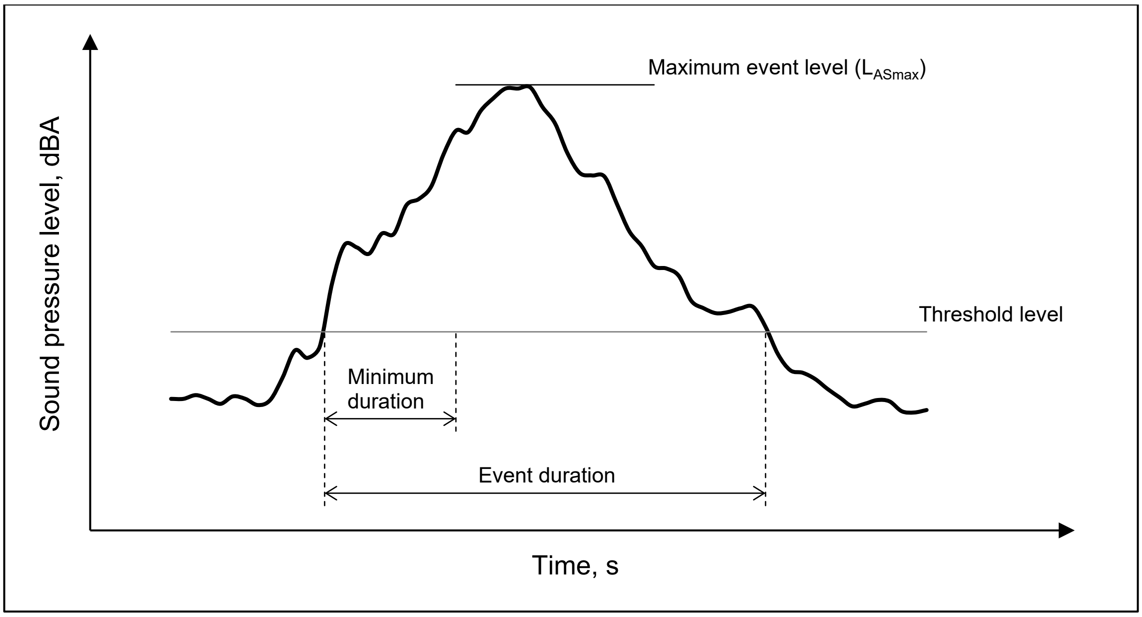
3.22 For each event recorded during attended monitoring, the measurement times are noted and the sound source under investigation is described. Any unrelated noise events of significance during the measurement period are also noted. Following completion of the measurements, another check is performed using a sound calibrator to check for any calibration drift. If a drift greater than 0.5 dB is recorded, it is possible that the equipment could have developed a fault. In such cases, the noise measurements would be discarded and the equipment returned to the manufacturer for servicing and calibration.

Unattended NTK noise monitoring

3.23 A critical requirement of airport NTK monitoring systems is the ability to link aircraft operations to noise events while minimising the risk of capturing non-aircraft noise events and without eliminating quieter aircraft noise events, the omission of which would skew upwards calculated average noise event levels.

3.24 NTK systems typically use a threshold-based system of noise event detection (Figure 4). To qualify as a noise event, the continuous time-varying A-weighted sound level measured by a noise monitor must exceed a threshold sound level for a minimum duration. By using a minimum event duration, monitors can exclude loud but very short events that could not be caused by aircraft. Event detection parameters are defined by the system user and can vary from monitor to monitor.

Figure 4 Threshold-based noise event detection



3.25 For each measured noise event, radar data or other flight path information is then utilised by the system software to determine whether an aircraft passed within a defined zone around the noise monitor close to the time of L_{ASmax}. If an aircraft is identified the software correlates the noise event with that particular flight, otherwise the event is classified as non-aircraft noise.

3.26 If the threshold level is set too low, the system can become overwhelmed with non-aircraft noise events which could make the identification of genuine aircraft noise events more difficult and increase the overall uncertainty of average measured aircraft noise levels. If the threshold is set too high, genuine quieter aircraft noise events can be missed, which would cause any calculated average noise levels to be biased slightly upwards.

3.27 At locations where the background noise level is frequently varying, it can be difficult selecting an appropriate threshold level that is low enough to capture quieter aircraft noise events but high enough to ensure that extraneous (non-aircraft) noise events are not routinely recorded.

3.28 It is important to note that the selection of the threshold level may also affect the measurement of Sound Exposure Level (SEL). To obtain an accurate SEL it is necessary to measure the aircraft noise level while it is within at least 10 dB of the L_{ASmax}. SEL values will be underestimated for noise events where the associated L_{ASmax} is less than 10 dB above the monitor threshold level.[22] This requirement can further restrict the choice of suitable sites for studies involving an assessment of aircraft SELs.

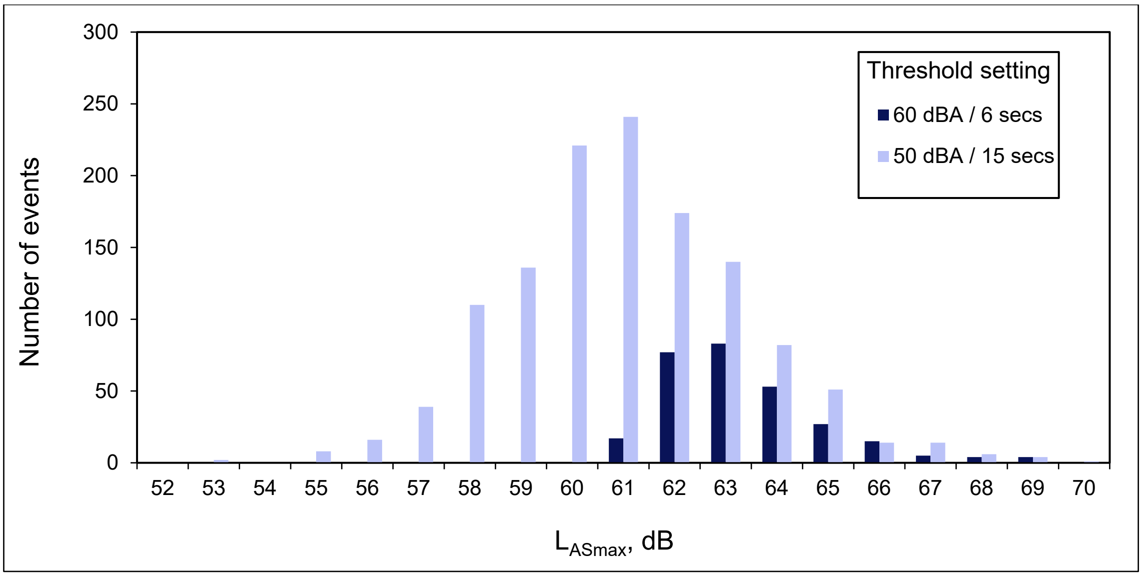
3.29 Depending on the general level of background noise, threshold levels between 50 dBA and 65 dBA are typically used at monitoring sites around the London airports, with a minimum event duration of at least 6 seconds. When a new noise monitor is set up, appropriate values for the threshold level and minimum duration would normally be selected based on ambient conditions at the time of installation. Following an initial period of monitoring these parameters can then be reviewed if necessary to optimise the collection of noise event data.[23]

[22] Any part of the noise event that is below the threshold level does not contribute to the SEL.

[23] The latest generation of NTK systems also provide the capability to change the event detection parameters after measurements have been recorded to try and improve the detection rates of aircraft noise events (allowing historic data to be reprocessed using the updated parameters).

3.30 By way of example, Figure 5 shows the frequency distribution of L_{ASmax} noise levels measured at one monitoring site over two separate periods, with L_{ASmax} levels grouped in 1 dB intervals. The total number of aircraft overflights during both periods was approximately the same.

Figure 5 Distribution of measured aircraft L_{ASmax} levels using different threshold settings



3.31 Initially the monitor was deployed with a threshold level of 60 dBA and a minimum event duration of 6 seconds. The threshold level was subsequently lowered to 50 dBA (enabled by consistently low background levels at that location), while also increasing the minimum duration to 15 seconds to mitigate any risk of capturing shorter non-aircraft events.[24] Figure 5 illustrates quite clearly the potential for improving the acquisition of aircraft noise events by optimising an NMT's event detection parameters, although this may not always be feasible at some sites.

3.32 Periodic checks on the percentage of flight tracks passing by each noise monitor that have no associated noise event can also help to identify scope for improvements to NTK system performance. However, there may always be some aircraft types that are too quiet to be measured reliably because of the background noise level.

[24] With the threshold level set at 50 dBA, the average duration of aircraft noise events at this particular site was about 35 seconds.

3.33 In addition to conventional fixed thresholds, NTK technology also exists to detect when an aircraft may be causing noise to increase at a monitor location. Since August 2022, the majority of Heathrow's mobile noise monitors have been set up with the Aircraft Noise Event Extraction Methodology (ANEEM), a system developed by Heathrow's Noise and Track Keeping system supplier.[25] The ANEEM system is intended to eliminate the need to manually set a threshold level in response to the varying background noise. ANEEM looks to see whether the measured noise levels are plausible for the particular aircraft type. No event is generated unless the system has found a plausible aircraft event.

[25] https://envirosuite.com/platforms/aviation/aneem

Summary guidance for airports: site selection and installation

- Ideally the ground immediately surrounding the noise monitor should be flat with relatively soft or grassy ground cover. Additional requirements are that the measurement site should be free of nearby obstructions such as buildings and large trees, and free of large nearby reflective surfaces (other than the ground).
- To prevent excessive ground effects, ISO 20906 recommends that sites where the angle of elevation to aircraft is less than 30° should be avoided for monitoring operations on a specific flight path.
- To minimise measurement uncertainty, ISO 20906 recommends that microphones should be positioned on masts at least 6 m above ground level. SAE ARP4721 states that temporary noise monitors may use microphone heights ranging from 1.2 to 6 m, provided there are no other large solid objects nearby. In practice, any differences between microphone heights can usually be ignored, provided that monitors are sited in non-obstructed areas with relatively soft or grassy ground cover.
- To minimise the possibility of the background noise contaminating measurements or interfering with the measurement of aircraft noise, ISO 20906 states that noise monitors should only be installed at sites where the maximum sound pressure levels (L_{ASmax}) of aircraft events of interest are at least 15 dB greater than the average background noise level. Additional measurement uncertainty is introduced for data collected at sites that do not meet this requirement.
- To obtain an accurate SEL it is necessary to measure the aircraft noise level while it is within at least 10 dB of the L_{ASmax}. SEL values will be underestimated for noise events where the L_{ASmax} is less than 10 dB above the monitor threshold level.
- When a new noise monitor is set up, appropriate values for the threshold level and minimum duration parameters can be selected based on ambient conditions at the time of installation. Following an initial period of monitoring these parameters can then be reviewed if necessary to optimise the collection of noise event data.
- Further guidance on the selection and installation of sites for unattended noise monitoring is provided in ISO 20906.

Chapter 4
Data analysis

NTK flight track data

4.1 The source of aircraft positional data collected by and held in the London airports' NTK systems is NATS Secondary Surveillance Radar (SSR). Radar 'returns' for aircraft are given for each revolution of the main radar head at each airport, typically about once every four seconds. Appendix B provides further details.

4.2 Regular checks on the validity and completeness of the NTK flight databases are carried out independently of the system provider by ERCD (and by the airports) to ensure the accuracy of each system's records. These checks include:

- Comparisons of daily numbers of NTK movements with Air Traffic Control (ATC) runway logs.
- Confirmation of the correct runway and route assignment (e.g. via a visual inspection of flight tracks).
- Confirmation of the correct aircraft type and registration assignment (e.g. by comparing NTK records with ATC runway logs).

4.3 Independent checks are also carried out periodically to assess the accuracy of the radar data in the NTK systems to verify that there are no significant errors or bias in the aircraft position data.[26] Straightforward comparisons of aircraft ground tracks against known geographical features (such as runway centrelines) also provides assurance that radar tracks in the NTK systems are being displayed correctly on a day-to-day basis.

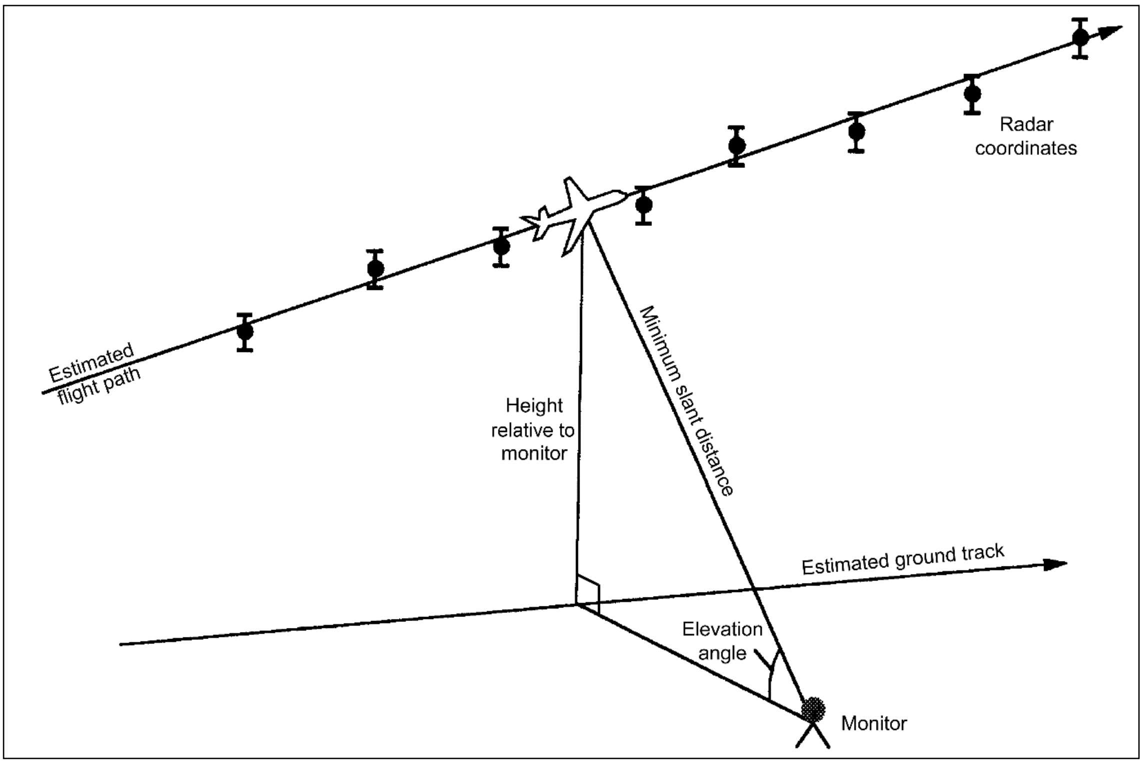
Calculation of minimum slant distance and angle of elevation

4.4 For most ERCD studies, NTK radar data are required to position arriving and departing aircraft with respect to the noise monitors on the ground. Once the geometry of the aircraft noise source with respect to the monitor is known, it is then possible to quantify the measured aircraft noise levels as a function of the

[26] See for example NLR-CR-2016-089 *Verification of Heathrow Noise and Track Keeping Systems* (NLR, 2016) and CAP 1878 *Flight path accuracy of the Gatwick Noise and Track Keeping System* (CAA, 2020).

minimum slant distance, which is the closest distance of the monitor from the aircraft flight path, see Figure 6.[27]

Figure 6 Calculation of source-to-receiver geometry



4.5 Most NTK systems will automatically calculate the minimum slant distance and the associated angle of elevation to each noise monitor. However, ERCD normally extract the radar points from the NTK systems and analyse the data using specially developed ERCD software, which also calculates additional parameters for each flight such as the track distance flown (to relevant monitors) and aircraft bank angle.

4.6 For some specialist studies it is useful to have an indication of aircraft bank angle since it can have a significant effect on noise levels on the ground (due to lateral directivity of the aircraft noise sources). Because bank angle can be inferred from aircraft speed and turn radius, it too can be readily estimated from an analysis of radar data.[28]

4.7 In ERCD's radar analysis software, locations between individual radar points are estimated using a localised polynomial fit of each of x, y and z (height) value, independently of time. Minimum slant distances to noise monitors are then

[27] The position of the aircraft at the point that the minimum slant distance occurs is often referred to as the Point of Closest Approach (PCA).

[28] In the presence of a wind, an aircraft’s motion relative to the ground, and therefore its radar track, is not truly representative of its flight configuration. However, for most purposes it can be assumed that the effect of wind on aircraft bank angle is relatively insignificant.

calculated, taking into account any differences in ground elevation between the heights of the monitors and the runway. ERCD's radar analysis software also calculates the aircraft height and angle of elevation for each aircraft/monitor combination at the aircraft's closest point.

4.8 Once processed, the flight path information can be imported into a relational database application and combined with noise event data and other information such as weather data (see paragraph 4.20).

4.9 For noise model validation purposes the data are screened to minimise the effects of lateral attenuation by excluding data for aircraft with angles of elevation less than 60 degrees at the point of closest approach. Lateral attenuation is the excess sound attenuation caused by the ground surface, which can be significant at lower angles of elevation.

4.10 Naturally, for certain noise studies, data may be required at elevation angles less than 60 degrees, but normal ERCD practice is to exclude such events. The remaining noise measurements are then adjusted to what would have been measured had the aircraft flown directly over the noise monitor (at 90 degrees).

4.11 Noise adjustments for this purpose are usually made on the assumption that the noise level falls by 8 dB per doubling of distance (dd). Since 'spherical spreading' accounts for 6 dB/dd, this rule attributes 2 dB/dd to atmospheric absorption. While this is an approximation of what is in reality a highly complex process, its application in this context is considered appropriate.[29]

4.12 However, for routine airport noise monitoring the objective is normally to quantify the 'as-measured' noise levels at a particular location, irrespective of where aircraft may be flying in relation to the monitor. In such cases, adjustments to the measured noise levels to account for any lateral variation of flight tracks would not be necessary.

Flight profiles and mean tracks

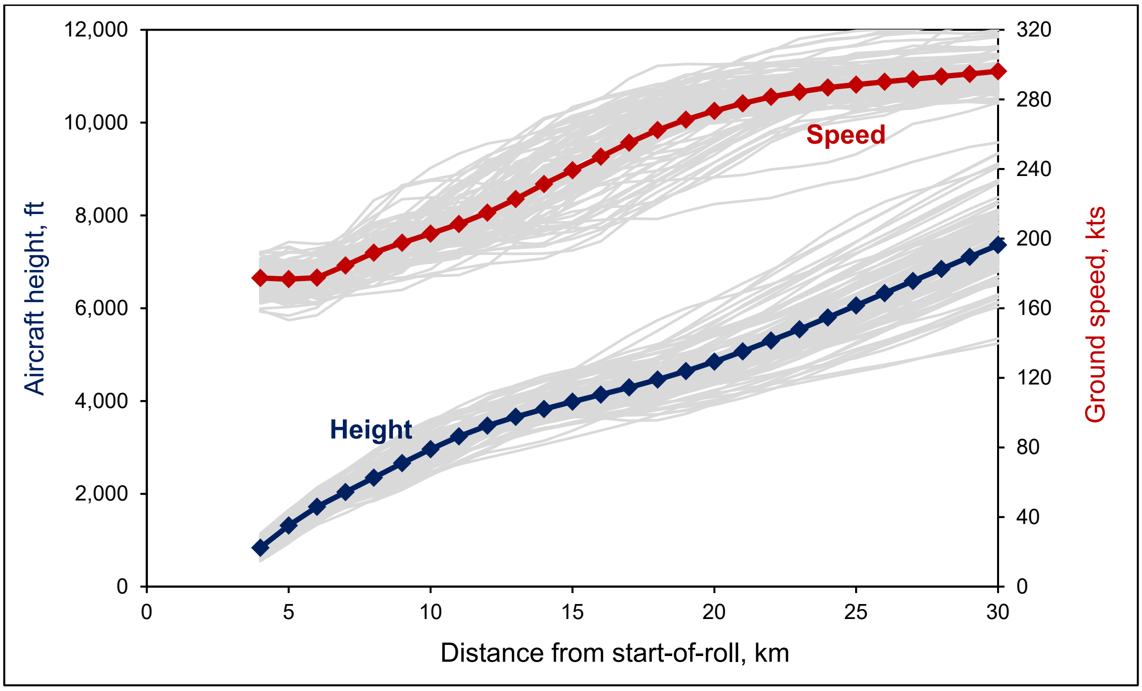
4.13 Ideally, all individual radar tracks would be used to model long-term aircraft noise exposure in the vicinity of an airport. However, limitations on computer processing speed generally make it impractical to consider each aircraft movement separately. Instead, the actual distribution of flight tracks (vertically and laterally) is simplified for modelling purposes in ANCON by averaging flight profiles and tracks, in accordance with international best practice guidance.[4]

[29] While an 8 dB/dd relationship is used to adjust measured L_{ASMax} noise levels to an 'overhead' reading, the corresponding relationship used for adjusting SELs is 5 dB/dd.

4.14 Mean profiles of height and ground speed against track distance are calculated separately for each aircraft type at each airport (for arrivals and departures) from an analysis of radar data using ERCD's specialised radar analysis software.

4.15 The calculated flight profiles are then subdivided into appropriate linear segments for modelling purposes. Figure 7 shows an example of the calculated mean height and speed profiles for a sample of B777-300ER departures. For each set of mean profiles, the engine power settings are then estimated using the equations of motion of the aircraft.

Figure 7 Example of mean departure height and speed profiles (B777-300ER)

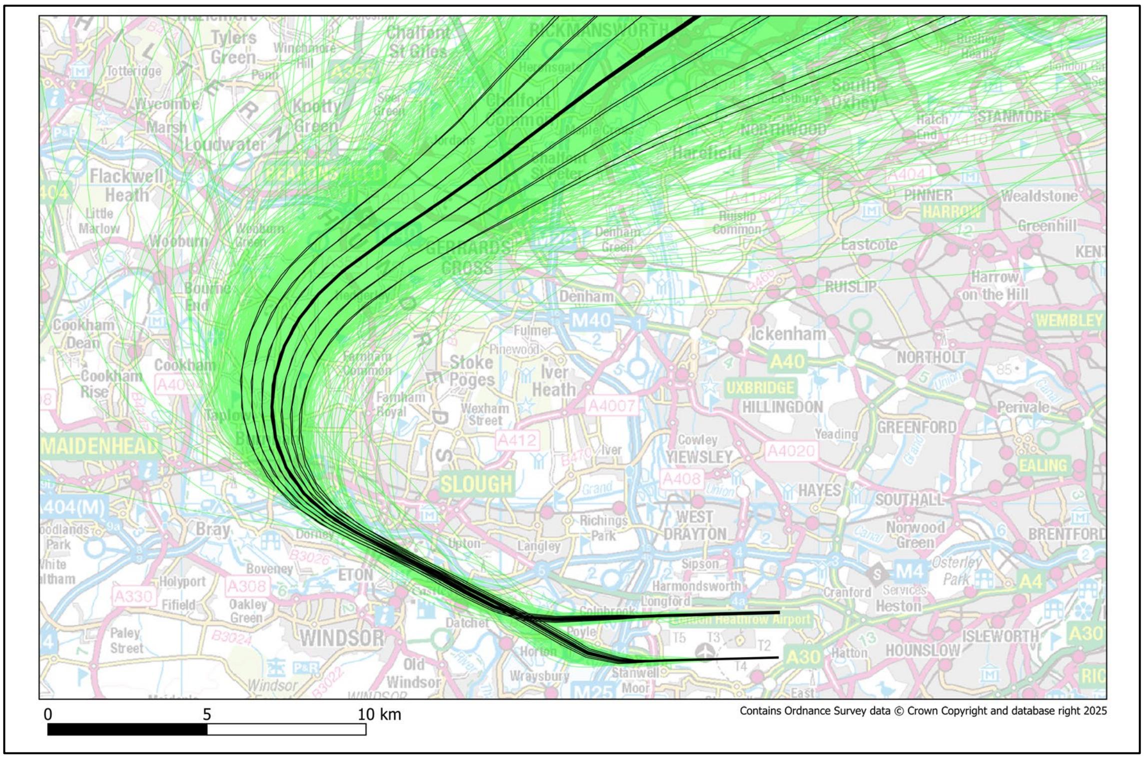


4.16 Because ANCON uses input data based on actual flight profiles, the estimated power settings (and noise emission) reflect typical airport operation. In contrast, some noise models make generic assumptions regarding power settings and aircraft performance that may not reflect typical operations at the relevant airports.

4.17 Accurate noise exposure estimation also requires a realistic simulation of the lateral scatter of flight tracks actually observed in practice. ANCON uses mean ground tracks for each departure route, which are calculated from an analysis of NTK radar data using ERCD's radar analysis software. Also calculated are the proportions of traffic allocated to each route.

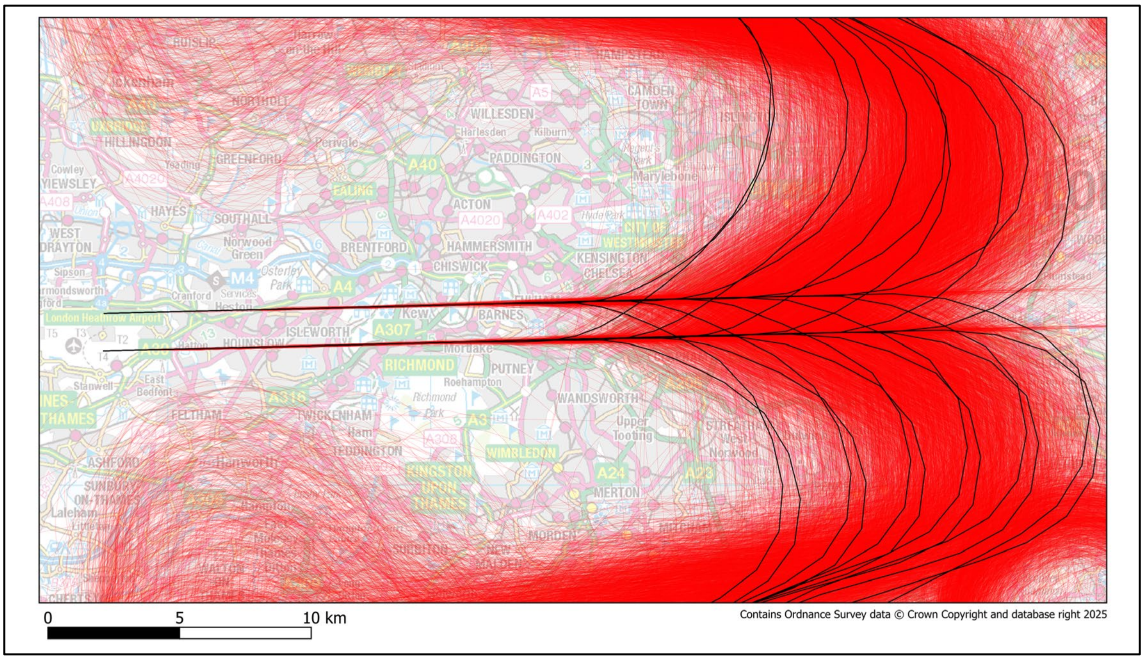
4.18 In order to reflect the track dispersion along each departure route, a number of symmetrically spaced dispersed tracks are established. The dispersed departure tracks are based on the statistical variations (standard deviations) of individual flight paths about each mean track. Figure 8 shows an example of the mean and dispersed tracks calculated for departures along the westerly Brookmans Park (BPK) SID at Heathrow, with underlying radar data also shown.

Figure 8 Example of Heathrow westerly BPK departure mean and dispersed tracks



4.19 Prior to joining the Instrument Landing System (ILS) for final approach, the dispersion of arriving aircraft is modelled by clustering the individual radar tracks onto mean arrival ‘spurs’. Figure 9 shows an example of modelled approach spurs for westerly arrivals at Heathrow, with underlying radar data also shown. (Approach tracks are also typically represented by symmetrically spaced subtracks around each main spur, although these have not been shown in Figure 9 for presentational reasons.)

Figure 9 Example of Heathrow westerly arrival ‘spur’ tracks



Analysis of noise event data

Filtering for bad weather conditions

4.20 To ensure that noise measurements collected for ERCD studies are as reliable as possible, aircraft noise levels recorded under extreme meteorological conditions are usually excluded from analysis to limit the effects of weather variations as much as possible. Mean half-hourly weather readings are obtained from METAR weather stations at each airport and combined with the NTK noise data.[30] Measurements are then rejected if they do not meet the following weather criteria recommended in ISO 20906:

- no precipitation
- wind speed no greater than 10 m/s

[30] A number of NTK monitor sites at Gatwick and Stansted are fitted with separate weather stations that also feed meteorological data into each NTK system. However, for practical reasons ERCD relies on the official METAR stations at all three London airports for its weather readings.

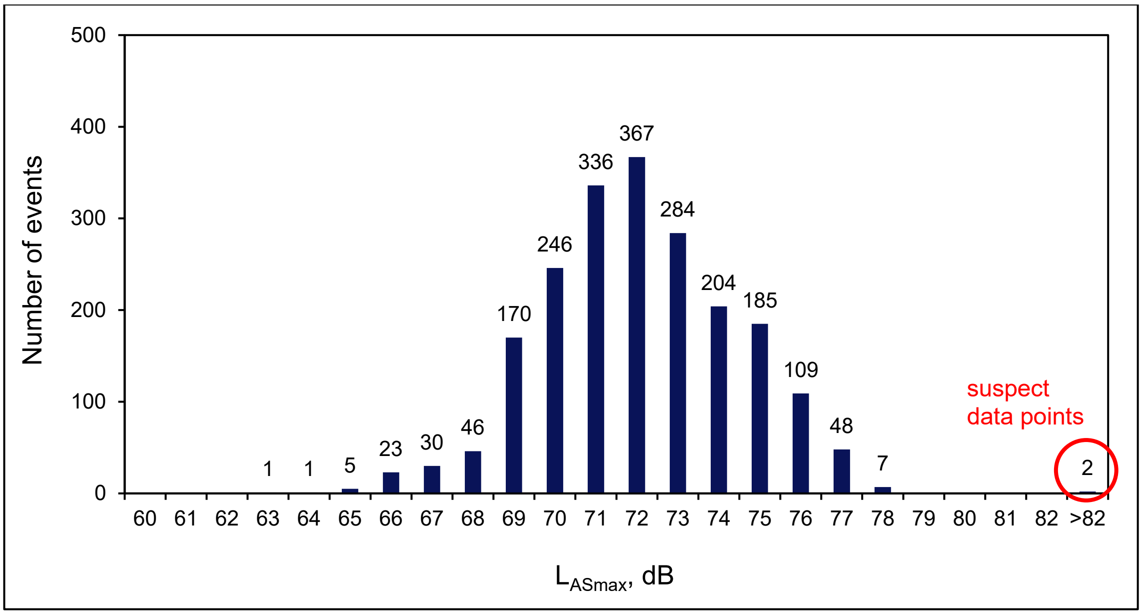
Checking noise events for extreme outliers

4.21 The distributions of aircraft noise levels, like those of many physical variables, are usually found to be normally distributed. This is the familiar 'bell-shaped' curve, the shape of which can be defined in terms of its mean (arithmetic average) and standard deviation.[31] Unless there is clear evidence to suggest otherwise, normality is often assumed.

4.22 Additional checks are undertaken by ERCD to ensure, as far as reasonably possible, that the final noise datasets contain valid measurements by looking for evidence of extreme outliers (which can affect calculated mean values). While different statistical tests can be employed for this task, one straightforward method is to plot the measured noise levels and make a judgment based on a visual inspection of the results.

4.23 For example, Figure 10 shows the frequency distribution of L_{ASmax} noise levels measured for a sample of A320neo departures at one monitoring site. While the overall shape of the distribution appears reasonable, the results show that there were two unusually noisy departures (both above 82 dB in this case, which was several decibels higher than the next noisiest events).

Figure 10 Distribution of measured A320neo departure L_{ASmax} levels



4.24 Alternatively, the same measured noise levels can be plotted against their corresponding minimum slant distances, see Figure 11. When plotted in this way, the measured noise levels should generally follow a downward sloping line, with noise level decreasing with increasing slant distance. Again, the results clearly show that there were two unusually noisy departures.

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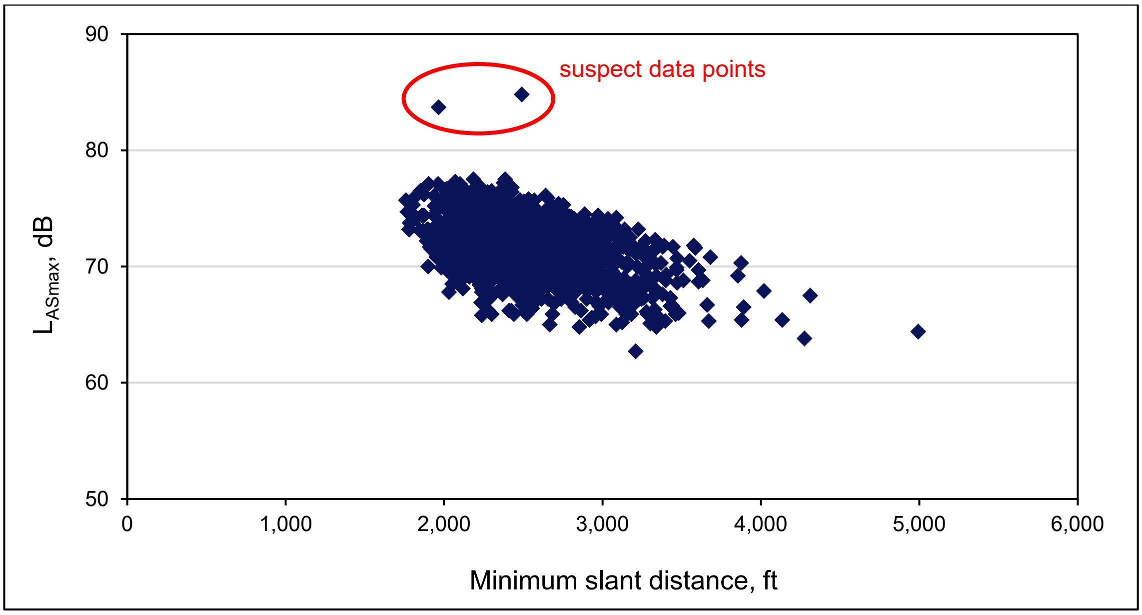
[31] A perfectly normal distribution is unusual in practice, although most distributions approximate to this shape.

Figure 11 Measured A320neo departure L_{ASmax} levels versus minimum slant distance



4.25 Using either type of graphical presentation, any significantly outlying data points can be easily identified for further investigation. By listening to the audio recordings captured for the two highlighted noise events it was subsequently confirmed that both events were contaminated by non-aircraft noise. In cases such as these, the noise events would be discarded prior to any final analysis.[32]

4.26 However, when screening data in this way it should be noted that some outlying data points may be entirely valid measurements for unusually noisy (or quiet) aircraft operations. In general, outlying data points should be retained unless there is clear evidence that they represent erroneous measurements.

Sample size considerations

4.27 The goal of most aircraft noise measurement studies is to generalise the results from a sample of data to the wider population. A general rule in statistics is that a sample size of at least 30 measurements ($n \geq 30$) is required to ensure the sample is representative and reliable. While this requirement is often easily achieved at busier airports for the most common aircraft types (especially when monitoring over a prolonged period of several months), a paucity of flights for some types of operation may make this more difficult to achieve.

4.28 Although larger sample sizes generally give more reliable results, there may be cases where it is helpful nonetheless to report results for sample sizes less than 30. However, caution may be needed when interpreting results as the samples may not necessarily be representative of the wider population. Similar

[32] If audio recordings were unavailable, the shapes of the noise level time history profiles could be inspected to look for obvious signs of event contamination.

caution should also be applied for noise studies only lasting a few days or weeks (even with relatively large sample sizes), since data collected over longer periods or at different times of the year may produce significantly different results.

Presentation of results

4.29 After screening for unfavourable meteorological conditions and any erroneous measurements, the noise data can then be grouped into appropriate aircraft type categories for final analysis. For noise model validation purposes the groupings are typically based on specific airframe and engine combinations. For some studies it may be necessary to subdivide even further, for example, by airline operator or distance flown.[33]

4.30 For conventional statistical analysis it is usually appropriate to calculate the arithmetic average (mean) value for a particular dataset. However, since the decibel scale is not linearly related to noise energy, an alternative average is normally used when constructing measures related to the computation of cumulative sound exposure. This is the decibel value of the average sound energy, which is often referred to as the logarithmic average, or 'log average'. For noise model validation purposes, log average SELs (rather than arithmetic average SELs) are calculated when comparing measurements with noise model outputs.[34]

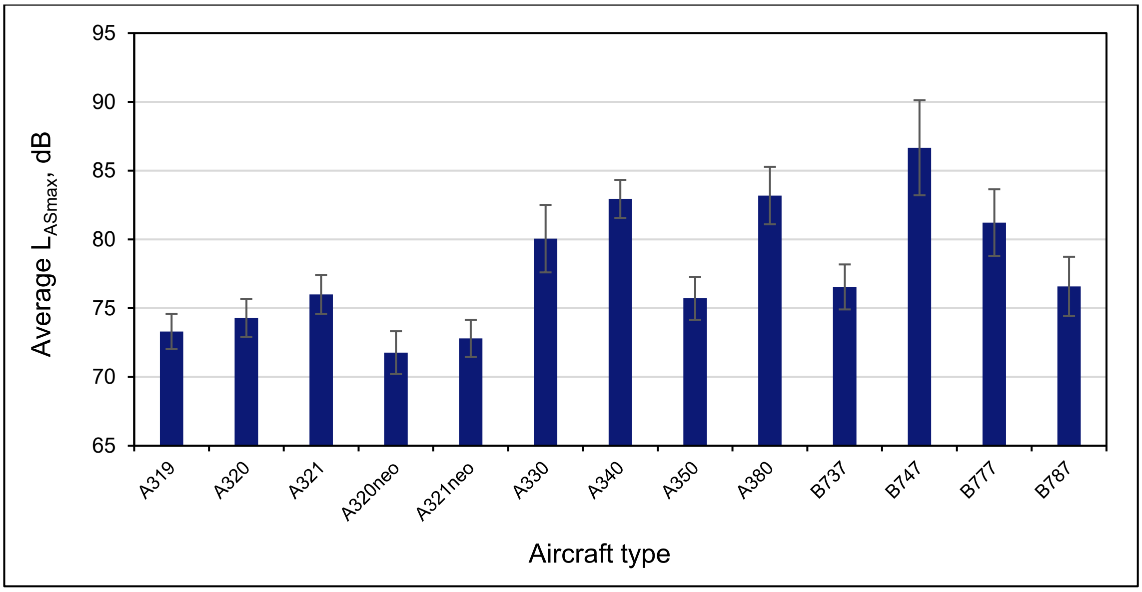
4.31 However, for routine airport noise monitoring the arithmetic average can be used to analyse measured L_{ASmax} or SEL event data, with summary statistics presented in tabular and/or graphical form.

4.32 Figure 12 provides an example of how noise measurement data from a single monitoring site can be presented graphically in the form of a column chart, in this case showing the average L_{ASmax} noise level by aircraft type. While L_{ASmax} is the simplest measure of an aircraft noise event and is often easier for the public to understand, it takes no account of the event duration. If required, the results could equally be plotted in terms of SEL, which accounts for the duration of an event as well as its intensity.

[33] Aircraft that are flying further are generally heavier because they are carrying more fuel. Since actual take-off weight data are generally unavailable, distance flown (great circle distance) can be used as a proxy for take-off weight.

[34] Arithmetic averaging is used for the validation of L_{ASmax} noise model outputs.

Figure 12 Average measured departure L_{ASmax} levels by aircraft type

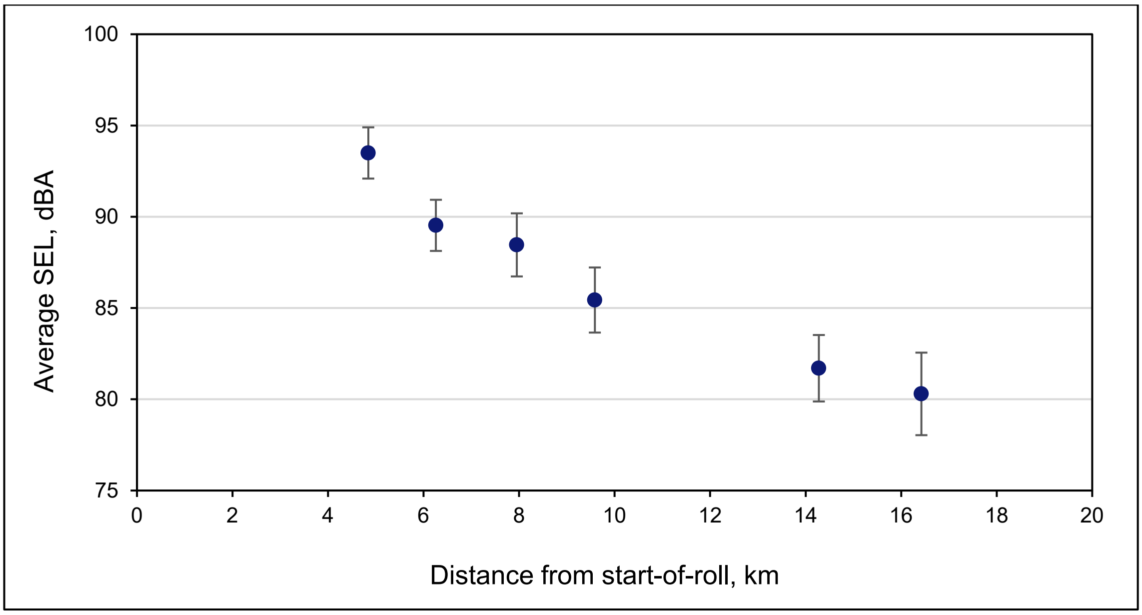


4.33 In Figure 12, departure noise measurements have been arithmetically averaged by generic aircraft type (with no further subdivision). Error bars representing one standard deviation have also been plotted to illustrate the variation of measured levels around each average value. Alternatively, error bars representing the standard error of the mean or the 95% confidence interval for each result could be plotted instead.

4.34 Plotting results in this way can help to highlight the relative noise differences between different sizes and/or different noise generations of aircraft. For departures, comparing the average heights or minimum slant distances between different sets of results may also help to account for any measured differences in noise level (since faster climbing aircraft will be higher above the noise monitor and therefore generally quieter). For arrivals however, most routine airport noise monitoring is typically conducted when aircraft are established on final approach, and so aircraft are more likely to be at the same distance from the noise monitor.

4.35 For studies involving the measurement of noise at more than one location along a flight path, it can be helpful to plot all the results for a single aircraft type on the same chart. Figure 13 provides one such example for a variant of the B777-200 on departure, this time in the form of a scatter chart showing average SELs (although again, results could be plotted in terms of L_{ASmax} if required).

Figure 13 B777-200/GE90 departure SEL noise measurements



4.36 In Figure 13, SEL measurements recorded at six separate locations along the same departure route have been arithmetically averaged and plotted against the average distance flown to each monitor. Error bars representing one standard deviation have also been plotted. Plotting the results from multiple monitors in this way can help to illustrate how average noise levels under the flight path become progressively lower further out from the airport (where aircraft are higher).

4.37 Finally, as mentioned in paragraph 3.19 it is normal practice to measure the maximum sound level of an aircraft event using a sound level meter with frequency weighting A and time weighting S (L_{ASmax}). This definition is consistent with aircraft noise certification standards and international noise modelling methodology. However, ISO 20906 recognises that some NTK systems may define the maximum sound level of an aircraft event in terms of the maximum one second equivalent continuous sound pressure level ($L_{Aeq,1s\ max}$). Although numerically similar, it should be noted that small differences between L_{ASmax} and $L_{Aeq,1s\ max}$ will normally exist for the same noise event.

Summary guidance for airports: data analysis

- Regular checks should be carried out to ensure the accuracy and completeness of NTK flight databases. These checks should include verifying overall NTK movement numbers and the accuracy of aircraft flight details against independent data sources.
- To ensure that measurements collected for specific studies of aircraft noise are as reliable as possible, aircraft noise levels recorded under extreme meteorological conditions should be excluded from analysis. Measurements should be rejected if they do not meet the following weather criteria recommended in ISO 20906:
    - no precipitation
    - wind speed no greater than 10 m/s
- Checks should be undertaken to ensure, as far as reasonably possible, that datasets used for specific studies of aircraft noise contain valid measurements by looking for evidence of extreme outliers (which can affect calculated mean values).
- After screening for unfavourable meteorological conditions and any erroneous measurements, the noise data can then be grouped into appropriate aircraft type categories for final analysis.
- The goal of most aircraft noise measurement studies is to generalise the results from a sample of data to the wider population. Where possible, a sample size of at least 30 measurements ($n \geq 30$) is required to ensure the sample is representative and reliable.
- Although larger sample sizes generally give more reliable results, there may be cases where it is helpful nonetheless to report results for sample sizes less than 30. However, caution may be needed when interpreting results. Similar caution should also be applied for noise studies only lasting a few days or weeks, since data collected over longer periods or at different times of the year may produce significantly different results.
- For routine airport noise monitoring the arithmetic average can be used to analyse measured L_{ASmax} or SEL event data, with summary statistics presented in tabular and/or graphical form. When presenting results graphically, error bars can also be plotted to illustrate the variation of measured levels around each average value. Alternatively, error bars representing the standard error of the mean or the 95% confidence interval for each result can be plotted instead.

Chapter 5
Conclusions

5.1 This report describes the current techniques used by ERCD to measure and analyse aircraft noise and radar data. ERCD is confident, on the basis of the monitoring and calibration methods described above, and from its knowledge of standards and studies elsewhere in the world, that these methods represent robust good practice and deliver data that are more than sufficiently accurate for the types of studies undertaken.

5.2 This report also provides good practice measurement guidance to airports and other stakeholders on issues to consider when conducting their own aircraft noise studies. Chapters 2, 3 and 4 end with a summary of the relevant guidance, which is consolidated in Appendix C for reference.

5.3 The CAA strongly recommends that airport NTK systems are installed and operated in accordance with international standards as far as possible and that their overall performance is periodically verified.

APPENDIX A

Glossary of terms and abbreviations

ANCON	The UK civil aircraft noise contour model, developed and maintained by ERCD. The model calculates the emission and propagation of noise from arriving and departing air traffic and is validated with noise measurements.
A-weighting	A frequency weighting that is applied to the electrical signal within a noise measuring instrument as a way of simulating the way the human ear responds to a range of acoustic frequencies.
dB (or dBA)	Decibel units describing sound level or changes of sound level. It is used in this report to define levels measured on the A-weighted scale, which incorporates a frequency weighting approximating the characteristics of human hearing.
DfT	Department for Transport
L_{A90}	L_{A90} is the A-weighted noise level exceeded for 90% of the measurement time and is commonly used to quantify the level of background noise.
L_{Aeq}	Equivalent continuous sound level. L_{Aeq} is the level of a notional steady sound that over a given period of time would have the same A-weighted sound energy as the fluctuating noise.
L_{ASmax}	The maximum sound level measured during an aircraft event, using frequency weighting A and time weighting S. Often abbreviated to L_{Amax} or L_{max}.
METAR	Meteorological Terminal Aviation Report. A format for reporting weather information from aerodrome meteorological stations. METAR reports are normally updated every 30 minutes.
NATS	Previously known as National Air Traffic Services Ltd. NATS provides air traffic control services at several major UK airports.

NTK	Noise and Track Keeping monitoring system. An NTK system associates air traffic control radar data with related data from 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. The SEL of an aircraft noise event is the sound level, in dBA, of a one second burst of steady noise that contains the same total A-weighted sound energy as the whole event. This accounts for the duration of the sound as well as its intensity.
SOR	Start of roll is where aircraft (using the full runway length) typically begin their take-off run for departure.
Time weighting	Time weighting is used to describe how quickly a sound level meter reacts to changes in sound pressure. There are two commonly used time weightings for environmental noise measurement, fast (F) and slow (S). For aviation noise it is standard practice to use slow weighting.

APPENDIX B

Overview of the London airports' NTK systems

What an NTK system does

B1 A Noise and Track Keeping (NTK) system provides information on:

- Which aircraft are flying in the vicinity of an airport.
- Where they fly to and from.
- Where they are in the air.
- How high and how fast they are.
- Which runways and routes they are using.
- How much noise they make on the ground.
- The corresponding weather conditions.

B2 ERCD has access to the NTK systems operated by Heathrow, Gatwick and Stansted airports, with whom ERCD staff work closely. All three London airports currently use a system called ANOMS. The data in each airport's system are replicated to ERCD's systems at the CAA's offices. Data from the airport NTK systems are also fed into online flight tracking tools, allowing local residents and other stakeholders to view aircraft movements and measured noise levels at each airport.[35]

Uses of NTK data

B3 Typical uses of NTK data by ERCD include:

- Routine generation of noise model input data, including average ground tracks, height/ground speed profiles, noise levels and route/traffic analyses.
- Studies on behalf of the Department for Transport (DfT), including:
  - Review of Arrival Noise Controls (CAP 1554)
  - Departure Noise Mitigation (CAP 1691)
  - Quota Count validation study (CAP 1869)
  - Aircraft movements, fleet mix and noise quota usage at Gatwick, Heathrow and Stansted (CAP 3013)

[35] See https://eu.webtrak.aero/lhr4 for Heathrow, https://eu.webtrak.aero/lgw2 for Gatwick and https://eu.webtrak.aero/stn3 for Stansted.

B4 The London airports use their NTK systems mainly to monitor:

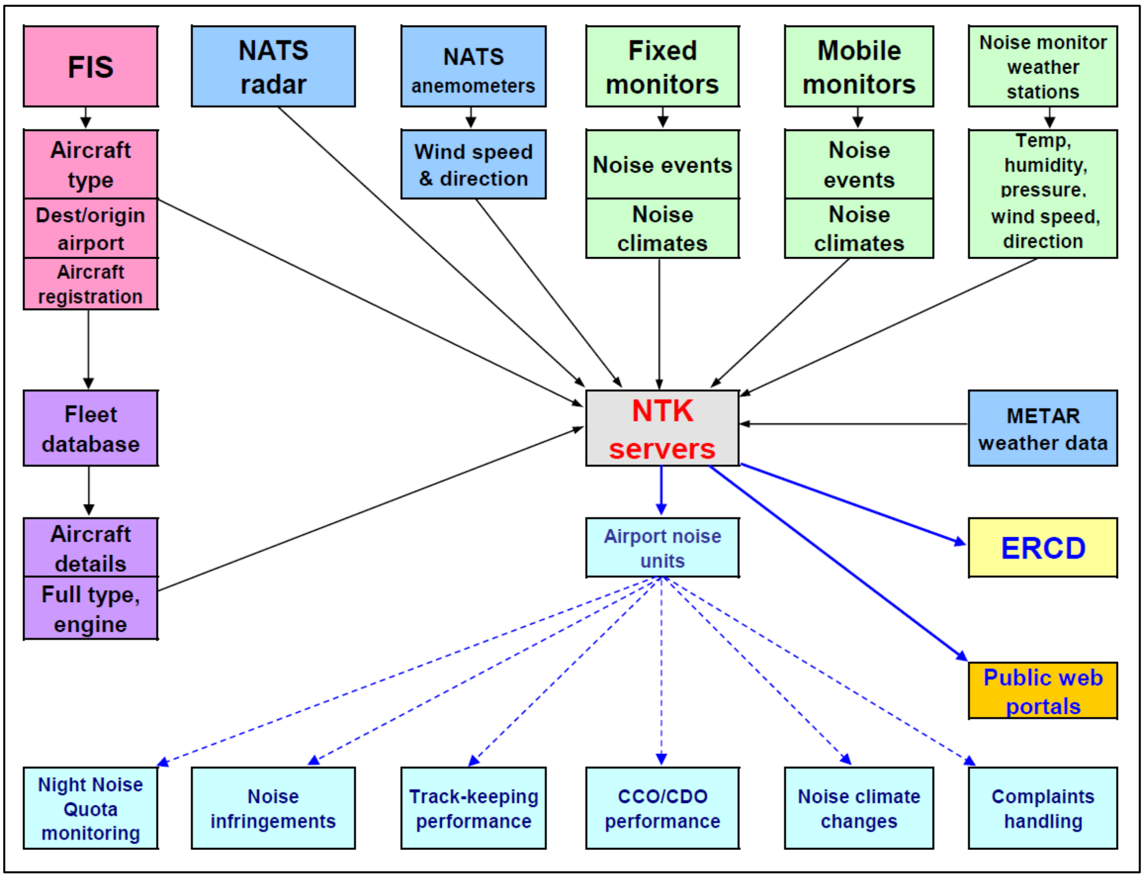
- Aircraft exceeding the departure noise limits.
- Night flight restrictions (Night Noise Quota usage).
- Departure track deviations from the Noise Preferential Routes (NPRs).
- Continuous Climb and Continuous Descent Operations (CCOs and CDOs).

B5 The NTK systems also provide input to each airport's complaint handling team and a variety of local studies of aircraft noise and flight procedures.

Sources of data for the NTK systems

B6 Figure B1 shows the sources of data feeding into the London NTK systems.

Figure B1 Data inputs to and typical outputs from the NTK systems



B7 The source of aircraft positional data collected by and held in the London airports' NTK systems is NATS Secondary Surveillance Radar (SSR). Radar 'returns' for aircraft are given for each revolution of the main radar head at each airport, typically about once every four seconds.

B8 Table B1 lists the current dimensions of the NTK radar coverage area at each airport, which are circular areas centred on each airfield, covering aircraft up to heights of 20,000 ft or more.

Table B1 Radius of NTK radar coverage

Airport	Radius (NM)
Heathrow	35
Gatwick	60
Stansted	40

B9 The aircraft height data in the NTK systems are derived from transmissions of pressure altimeter readings from each aircraft's transponder, which are referenced to a standard atmospheric pressure of 1013.25 hPa. The current radar feeds into each system provide altitude reporting in 25 ft intervals for Mode S equipped aircraft, which covers practically all aircraft in current operation at each airport.[36]

B10 Once the NATS radar data have been transferred to the airports' NTK systems, the reported altitudes are adjusted for QNH (to correct for local atmospheric pressure variations) and airfield elevation, so that the data stored in each system represent aircraft heights above aerodrome level (aal).[37] Flight tracks are then correlated to related noise data from noise monitors on the ground.

B11 For each measured noise event, the system software determines whether an aircraft passed within a defined zone around the noise monitor close to the time of L_{ASmax} (the maximum sound level measured during the event). If an aircraft is identified then the software correlates the noise event with that particular flight, otherwise the event is classified by the system as non-aircraft noise.

B12 In addition to recording discrete noise events, the airport noise monitors continuously monitor the overall noise level to provide hourly reports of noise climate parameters such as $L_{Aeq,1hr}$ and $L_{A90,1hr}$. Audio recordings are also captured by the NTK noise monitors for each measured noise event (aircraft and non-aircraft), allowing the system user to play back and listen to the noise event audio for further analysis.

[36] Mode S is an advanced mode of SSR operation compared to legacy Mode C, offering a better resolution in reported altitude (25 ft versus 100 ft).

[37] QNH is the international code used to represent the atmospheric pressure at mean sea level.

B13 Operational information such as aircraft type, callsign, registration and airport of origin/destination are obtained from a combination of sources within each system, including the NATS radar feed and the airport's Flight Information System. Aircraft registrations can also be cross-referenced with airline fleet databases to obtain more detailed type information for each aircraft (such as engine fit and certificated weight).

APPENDIX C

Good practice noise measurement guidance for airports

Noise measurement equipment

- Airport noise monitors should conform to the performance specifications of IEC 61672-1 for a Class 1 sound level meter.
- On-site acoustical sensitivity checks of each noise monitor should be performed at least once per year using a sound calibrator, although more frequent checks (for example quarterly) are recommended.
- Sound calibrators that are used for acoustical sensitivity checks should conform to the Class 1 requirements of IEC 60942 and should be calibrated by a nationally recognised calibration laboratory at least once per year.
- If an acoustical sensitivity check indicates a change in sensitivity greater than 0.5 dB since the previous sensitivity check, the noise monitor should be considered defective. The instrumentation should be removed from service and recalibrated. All data measured by the noise monitor since its last acoustical sensitivity check should be treated with caution and discarded if necessary.
- The electroacoustic performance of each noise monitor should be periodically tested by a nationally recognised calibration laboratory in accordance with the procedures described in IEC 61672-3. The recommended time interval for testing is once a year and the maximum allowable interval is two years.
- Further guidance on noise measurement equipment and calibration procedures is provided in ISO 20906.

Site selection and installation

- Ideally the ground immediately surrounding the noise monitor should be flat with relatively soft or grassy ground cover. Additional requirements are that the measurement site should be free of nearby obstructions such as buildings and large trees, and free of large nearby reflective surfaces (other than the ground).
- To prevent excessive ground effects, ISO 20906 recommends that sites where the angle of elevation to aircraft is less than 30° should be avoided for monitoring operations on a specific flight path.
- To minimise measurement uncertainty, ISO 20906 recommends that microphones should be positioned on masts at least 6 m above ground level. SAE ARP4721 states that temporary noise monitors may use microphone heights ranging from 1.2 to 6 m, provided there are no other large solid objects nearby. In practice, any

differences between microphone heights can usually be ignored, provided that monitors are sited in non-obstructed areas with relatively soft or grassy ground cover.

- To minimise the possibility of the background noise contaminating measurements or interfering with the measurement of aircraft noise, ISO 20906 states that noise monitors should only be installed at sites where the maximum sound pressure levels (L_{ASmax}) of aircraft events of interest are at least 15 dB greater than the average background noise level. Additional measurement uncertainty is introduced for data collected at sites that do not meet this requirement.
- To obtain an accurate SEL it is necessary to measure the aircraft noise level while it is within at least 10 dB of the L_{ASmax}. SEL values will be underestimated for noise events where the L_{ASmax} is less than 10 dB above the monitor threshold level.
- When a new noise monitor is set up, appropriate values for the threshold level and minimum duration parameters can be selected based on ambient conditions at the time of installation. Following an initial period of monitoring these parameters can then be reviewed if necessary to optimise the collection of noise event data.
- Further guidance on the selection and installation of sites for unattended noise monitoring is provided in ISO 20906.

Data analysis

- Regular checks should be carried out to ensure the accuracy and completeness of NTK flight databases. These checks should include verifying overall NTK movement numbers and the accuracy of aircraft flight details against independent data sources.
- To ensure that measurements collected for specific studies of aircraft noise are as reliable as possible, aircraft noise levels recorded under extreme meteorological conditions should be excluded from analysis. Measurements should be rejected if they do not meet the following weather criteria recommended in ISO 20906:
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