Guidance on comparing calculated aircraft noise levels with measurements

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1. Introduction

Aircraft noise exposure contours are being increasingly used to set noise limits at airports and combined with a growing interest in noise contours from a broader range of stakeholders, there is much greater scrutiny of airport noise contours and how they are calculated.

Airport contour contours are very sensitive to input parameters such as aircraft mass, input flight procedures and the engine source emission characteristics. Some of this information may be compared and validated against observations, for example, the flight trajectory calculated from input flight procedures, may be compared with observed radar flight trajectories, but this does not fully validate take-off mass assumptions and engine power settings. Because airlines routinely adapt engine power settings based on take-off mass, similar flight trajectories can be observed for a relatively wide range of take-off masses, where instead, engine power setting varies rather than aircraft height.

For landing operations, the noise calculation is much less sensitive to aircraft mass, but is sensitive to aircraft configuration and speed and how this relates to the source noise characteristics in the ICAO Aircraft Noise and Performance (ANP) database Noise Power Distance (NPD) data.

These different uncertainties in input parameters can be addressed by comparing calculated noise exposure levels to measured noise exposure levels. This provides an end to end check as to how successive inputs and the ICAO ANP database result in a calculated noise exposure and how that compared with measured levels. Whilst comparing calculations with measurements is sometimes thought of in terms of the overall calculation, i.e. L_{den} and L_{night} this can disguise differences on per aircraft basis. As the fleet naturally evolves over time, it is important that individual aircraft noise exposure levels, particularly for those contributing most to overall noise exposure, are well represented in terms of calculated and measured levels for both landing and take-off.

This note provides guidance on the collection and processing of measured aircraft noise levels so that they may be suitable for comparison with calculated noise levels. The note then provides practical advice on the potential causes of differences and how to adjust either input data or the ANP database NPD data in order to reduce the differences.

1.1. L_{Aeq}, SEL and L_{Amax}

Although the key output for policy is L_{den}, it is of limited value for comparison purposes. A calculated L_{den} value could match a measured L_{den} value, but this could be due to the overprediction of one aircraft type and the underprediction of another type, the two errors cancelling out to give a fortuitous match of calculated and measured L_{den}. A true comparison of calculated and measured noise levels must be done systematically on an aircraft by aircraft basis to ensure that calculations accord with measurements for all relevant aircraft types[1]. If necessary, calculated and measured SEL values can be integrated with appropriate time of day

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[1] The noise level and number of operations of each type will determine that type's overall contribution to the L_{den} level. The combination of noise level and number of operations can be expressed as the 'noise energy' contribution for that type = $N \times 10^{(SEL/10)}$ where SEL is the sound exposure level at a given location. Experience shows that the top 10 'noise energy' contributors will contribute >80% of the total noise energy at a given location.

weightings to give calculated and measured L_{den} values.

2. Collection and processing of noise measurement data

It easy to obtain poor quality noise measurement data. In many other fields poor quality data collection often leads to an underestimation, however, in the field of noise measurement, poor quality noise measurement can easily lead to an overestimation of measured noise levels. The subject has been extensively studied over the years and various international guidance documents has been published to assist, such as ISO 3891 first published in 1978[2] and now superseded by ISO 20906[3].

Chapter 2 describes the requirements and processes to be followed to ensure collection of appropriately high quality noise measurement data, how data is corrected to give under track noise levels and how meteorological conditions are managed.

2.1. Measurement locations

Noise monitor locations should be sited directly under flight paths wherever possible and if not possible, at locations where the elevation angle between the noise monitor and aircraft overhead is at least 60°, to avoid the added complexity and uncertainty associated with lateral attenuation.

The features of noise monitor locations should, wherever possible, be consistent with the requirements set out in section 4.2 of ISO 20906[3], which aim to ensure that the site is obstacle free within a field of view of ±10dB of the L_{Amax}, equivalent to an elevation angle of 20° from the ground up to the aircraft as it approaches and as it departs. ISO 20906 also recommends that there are no reflecting surfaces within 10m of the microphone and that it is at least 6m above ground to minimise ground reflections. The requirements of ISO 20906 are quire stringent and it may not always be possible to meet all the requirements and identify a secure site in the desired area.

Measurement locations naturally need to cover the area of interest, e.g. the extent of the 48dB L_{den} noise contour. Noise measurement equipment is expensive, as are the resources required to identify suitable measurement locations, deploy and maintain noise monitors, and collect process measurement data. It will not always be possible to obtain measurements in all desired locations in a single calendar year and thus a pragmatic approach will need to be adopted. As explained in section 2.5, there are benefits to obtain measurements in multiple locations along flight paths, rather than focussing solely in one area of interest, e.g. around level of 48dB L_{den}. In the UK, it has been found that for a given airline/aircraft type and operating procedure, mean measured SELs do not vary by more than 1dB from one year to the next – where they do is indicate of a change of operating procedure or a change in take-off mass, e.g. due to a change in market(s) served (change in distance flown). Using a careful approach, it is possible to obtain measurements at a given number of locations over 2-3 years, rather than in single year, using either half or a third of the number of noise monitors. It is recommended that at least two years of noise measurements are obtained for some measurement locations, so the average measured SELs may be compared for each year in order to demonstrate that the measured levels appear consistent and robust.

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[2] ISO, ‘Procedures for describing noise heard on the ground, ISO 3891, 1978, withdrawn.

[3] ISO, ‘Unattended monitoring of aircraft sound in the vicinity of airports’, ISO 20906, 2009.

2.2. Measurement ambient conditions

Unlike for noise certification, where measurements are corrected to a reference standard, there is a requirement to preserve the prevailing ambient as far as possible. Including every noise measurement, regardless of ambient conditions tends to increase measurement variation without significantly altering the mean measured value. Previously, the UK CAA followed the guidance in ISO 3891, which typically excluded 30-40% of noise measurements, where:

- any occurrence of precipitation,
- wind speed above 5 m/s (10 kt), and
- relative humidity and temperature such that the sound attenuation in the one- third octave band centred on 8 kHz is more than 10 dB/100 m.

However, with ISO 20906 replacing ISO 3891, the UK CAA has since adopted the more relaxed conditions in ISO 20906:

- any occurrence of precipitation, and
- wind speed above 10 m/s (20 kt).

The conditions can still result in 20-30% of measurement being rejected, however, the rejection serves to reduce measurement variation, and thereby reducing measurement uncertainty by reducing the measured standard deviation.

2.3. Measured SEL values and monitor threshold

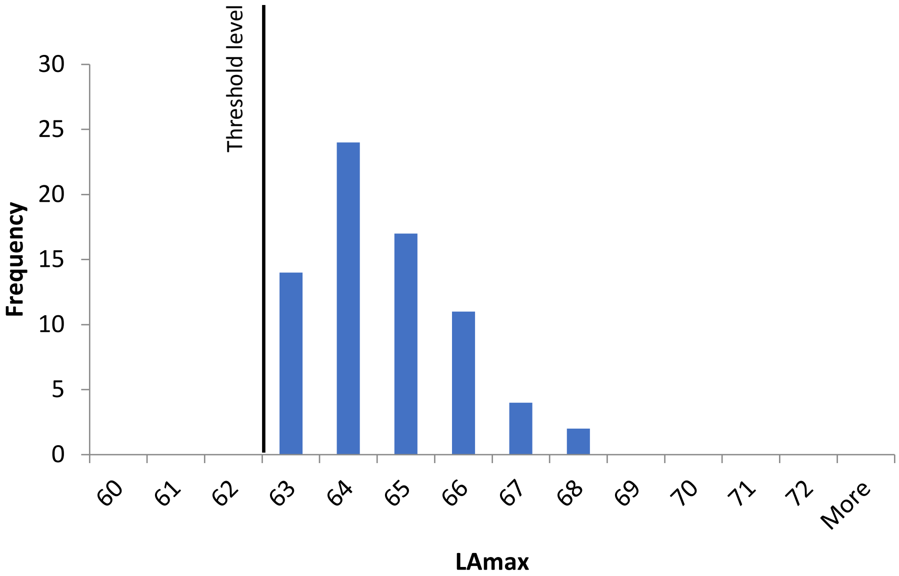
It is important that the measured levels are obtained from locations relevant to the calculated noise contours and in particular where noise levels are relevant for policy and noise management. L_{den} levels are dependent on the time of day weightings, the SEL and the number of operations. The greater the number of operations, the lower the SEL required for a given L_{Aeq} or L_{den} level as shown in Table 1.

Table 1: Relationship between 24h L_{Aeq}, SEL and number of events

		Number of events				
		25	50	100	200	400
SEL	60	24.6	27.6	30.6	33.6	36.7
	70	34.6	37.6	40.6	43.6	46.7
	80	44.6	47.6	50.6	53.6	56.7
	90	54.6	57.6	60.6	63.6	66.7

Although L_{Amax} plays no role in the calculation of L_{Aeq} or L_{den}, the L_{Amax} of a measured noise event must be sufficiently above the monitor threshold, or trigger level, such that the measured SEL is valid. Ideally the measured L_{Amax} needs to be at least 10dB above the monitor trigger level for a valid SEL. Depending on the numbers of noise events, levels of 48 dB L_{den} could be associated with SEL levels as low as 70dB. An SEL of 70dB implies an L_{Amax} of 58-60dB and hence a monitor threshold of 48-50dB L_{Amax}. The first effect of the L_{Amax} threshold being too high causes an underestimation of the SEL. Eventually, the monitor will not record quieter events (Figure 1) causing an overestimation of L_{Amax} and SEL.

Figure 1: Example of a distorted measurement distribution caused by the measurement threshold being too high



2.4. Sample size

Small measurement samples increase the risk of measurement bias as they may not be representative of typical operations and typical ambient conditions. Secondly, small samples increase the uncertainty around the mean measured level. Whilst the standard deviation of the measurements gives an indication of the overall variance, a better indicator of the uncertainty of the mean is given by the 95% Confidence Interval, which is calculated using

$$95\%\ CI = \frac{2 \times SD}{\sqrt{N}}$$

Where:

SD – measurement standard deviation
N – number of measurements

For outdoor aircraft noise measurements typical standard deviations range from 1.5 to 2.5dB. For sample of 50 measurements the resulting uncertainty about the mean value ranges from ±0.4 to ±0.7dB. This level of sampling uncertainty implies a preference for measurement samples of at least 50 measurements. For the most common aircraft types operating this is readily achievable, but for less common aircraft types this can sometimes be hard to achieve in all measurement locations.

2.5. Monitor arrays

Close attention to the siting of noise monitors will reduce the risk of measurements being affected by reflections or shielding from ground surfaces or adjacent structures. In the case of unattended noise monitors, careful site selection away from other noise sources will reduce the risk of contamination.

However, there remains a risk that a site’s characteristics or circumstances may change after a monitor has been deployed. In such situations, where these are identified it may be necessary to exclude such measurement data from comparisons. In other situations, the characteristics may change either without one’s knowledge. One way of mitigating this risk is to deploy multiple noise monitors along a single arrival or departure flight, where they form a measurement array, in that one can compare measurements between noise monitors, along the flight path. In a well-functioning measurement system, a similar number of measurements should be recorded at each monitoring site. Variations in the number of measurements across the sites could indicate issues with the matching of noise events to operations, contamination from non-aircraft noise events, too high a monitor threshold or too a background level.

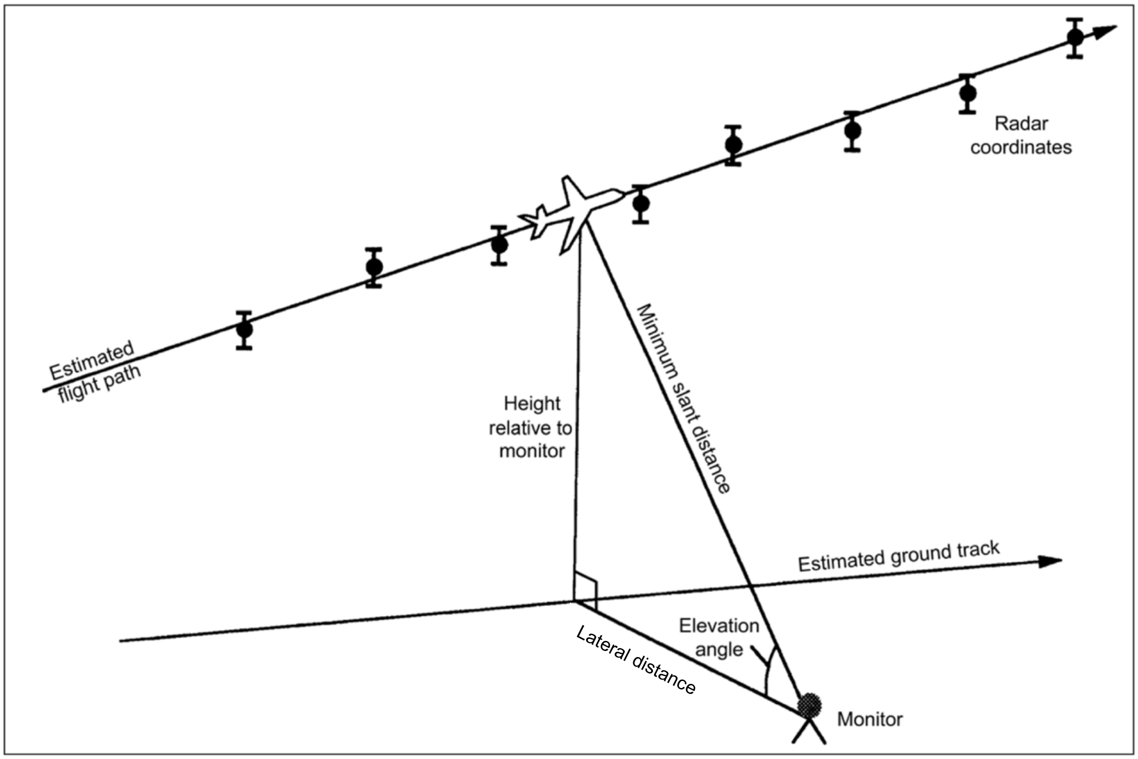
2.6. Time synchronisation

Noise measurements are normally linked to aircraft operational data based on measurement time and information on the location of aircraft at the same time. Time synchronisation of noise monitors and aircraft position information are crucial to the correct and accurate matching of measurements to aircraft operations. A number of techniques can be used to assure that noise monitor events are being accurately matched to aircraft operations. In a well functioning system it should be possible to obtain valid noise measurements for at least 90% of operations of a given aircraft type and flight path. Proportions below 90% indicate a significant proportion of measurements are not being matched to operations increasing risk of measurement bias. A second technique is for measurements correlated with operations, to review the slant distance of each operation at the time of the measurement against the measure noise level. Slant distance is the closest distance between an operation and the noise monitor and there should be a clear correlation of decreasing noise levels with increasing slant distance.

3. Calculated vs measured levels

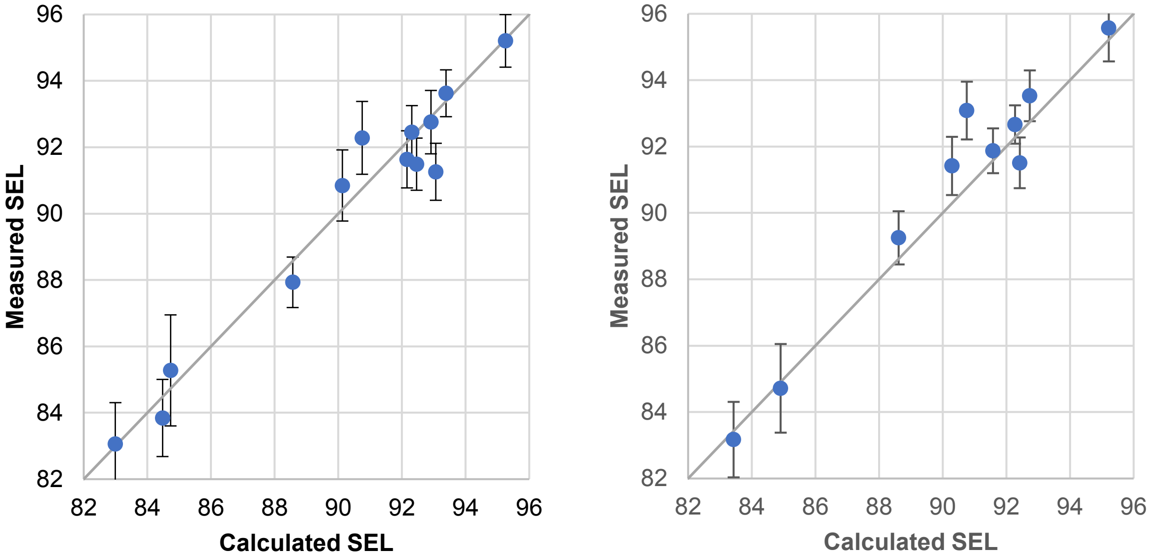
There are at least two distinct ways in which calculated levels may be compared against measured levels, each with their own pros and cons. In the first way, calculated levels can be estimated for each measurement location, using the input flight paths and profiles to define the relative location of the flight trajectories in relation to the noise monitor, i.e. the lateral distance, slant distance and elevation angle (Figure 2).

Figure 2: Noise event elevation angle (β) between noise monitor and aircraft



The comparison of calculated and measured SEL values can be plotted on a chart of calculated and measured SEL values (Figure 3).

Figure 3: Comparison of calculated and measured SEL values for two different A380 departure procedures



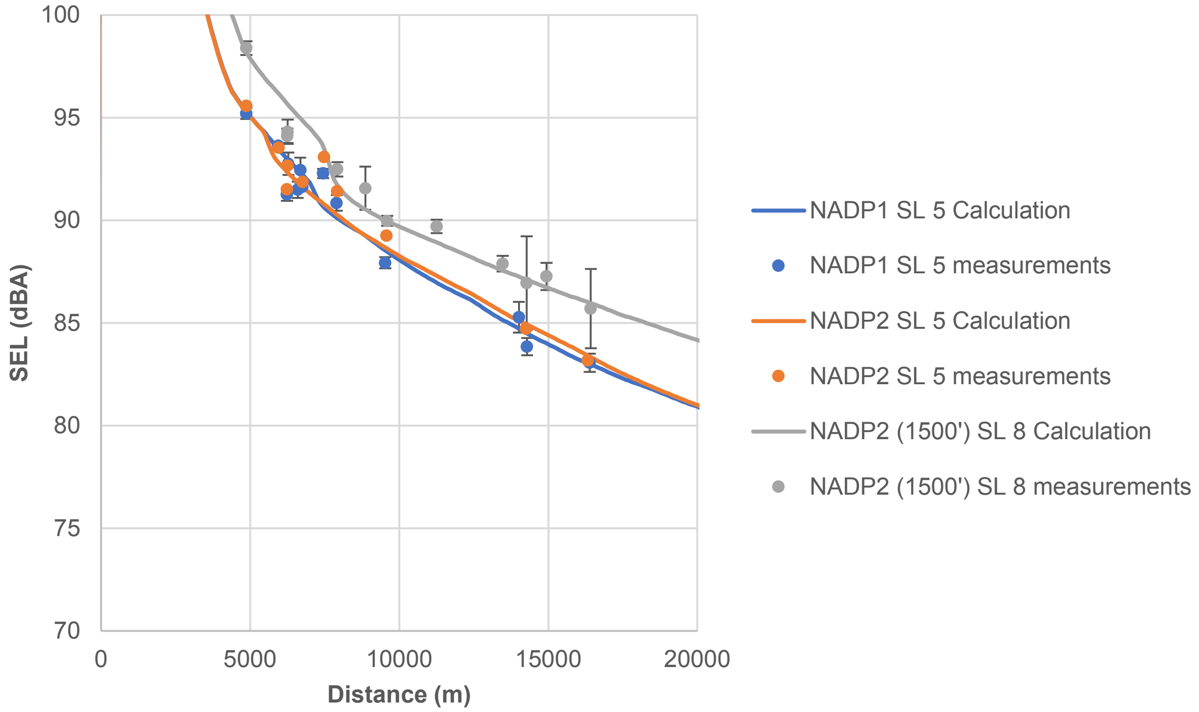
Where discrepancies are identified between calculated and measured levels, the measurement location will need to be identified and associated the operation's characteristics at the closest point of approach, i.e. the aircraft height, lateral distance, slant distance, elevation angle, speed and engine power settings. The guidance in section 4 may then be used to identify the dominant parameters with respect to the calculated level and which might need to be adjusted to provide a better match.

However, it can be difficult to interpret the location of a noise monitor on such plots and thus the source conditions prevailing – a monitor close-in, but far to the side of the flight path may have lower levels and appear similar to a monitor further away, but directly underneath the flight path.

An alternative method is to standardise (adjust) the measured noise levels to an under-flight measurement and calculate corresponding noise exposure levels for an aircraft directly overhead, effectively setting the lateral distance (Figure 2) to zero. This has the advantage of eliminating the lateral distance and elevation angle as variables in the calculation process and transforms the analysis into two-dimensional one of height and distance, rather than three dimensions. This is reasonable, since in practice the lateral distance is a direct input from radar ground track data and elevation angle is calculated from the aircraft ground track and height. Eliminating elevation angle as a variable is also helpful since it is the primary variable for the calculation of lateral attenuation, which part of the ECAC Doc. 29 4th Edition algorithms and neither an input, nor part of the ANP database. In addition, noise levels at low elevation angles are subject to much greater uncertainty due to local airframe reflections and/or shielding, and atmospheric refraction and scattering of the ray path, which complicate comparisons between calculated and measured values.

Having effectively normalised the data to a point directly underneath the flight path, UK CAA has found it useful to express calculated and measured noise levels as a function of distance from start of take-off roll and from landing threshold, which helps relate noise levels to the aircraft configuration and engine power settings that vary along the flight path. An example comparison of calculated and measured levels for Airbus A380-861 stage length 5 operations with NADP 1 and 2 noise abatement departure procedures is show in Figure 4.

Figure 4: Comparison of calculated and measured noise levels for the Airbus A380-861 with monitor locations referenced to start of take-off roll



In Figure 4, it is much clearer than in Figure 3, that the take-off power reduction and acceleration, that relate the input flight procedure, occur between 5 and 7km from start of take-off roll.

To achieve the match shown in Figures 3 and 4, there was a need to first increase the ANP take-off mass for both stage lengths, in order to match the observed aircraft height profiles and provide a more consistent offset between measured and calculated levels along the flight tracks. An additional correction of +1.5dB to the NPD data was then required to achieve an overall good match with measured noise levels for both stage length 5 and stage length 8 operations.

The technique of relating measured and calculated SELs to distance only remains valid for relatively straight ground tracks. Where the ground tracks experience turns of more than 45 degrees, SELs for locations on the inside of a turn increase relative to the SEL to the side of a straight flight path, due to the longer duration experience by each noise event, whereas SELs for locations on the outside of the flight path decrease due to the shorter duration experienced.

4. Comparison of calculated values and measured values

Differences between calculated and measured noise levels could occur for a number of reasons, the principal ones being:

- Input assumptions that generate the flight profiles
    - Take-off mass
    - Take-off power settings
    - Descent profile and speed
    - Landing flap
    - Landing gear deployment
- Ground tracks
- Meteorological conditions for aircraft performance and noise propagation
- ANP Substitutions
- NPD data

The review of noise model calculations using the Dutch implementation of ECAC.CEAC Doc. 29 4th Edition[4] has shown that the representation of flight profiles and flight tracks is best practice and that the three-dimensional trajectories used for noise calculation are not likely to contribute to differences between calculated and measured noise levels.

For departures, assumptions regarding departure take-off mass that can vary considerably from airline to airline and the ANP NPD data that define source noise levels and their propagation characteristics as the key factors that could result in differences between calculated and measured levels. For arrivals, where mass is not as important as for departure, aircraft configuration (flaps settings and landing gear deployment) and the ANP NPD data are the key factors.

The process of reducing the differences between calculated and measured levels is an iterative process focussing on the key factors. Because of the best practice already applied, this can be narrowed down to the take-off mass and NPD data for departure operations and landing configuration and NPD data for arrival operations. Take-off mass will affect the engine power (thrust) required to fly a given trajectory throughout the departure profile, but have a proportionally greater effect close-in during take-off and initial climb. Where there is a match between calculated and measured SELs in one area, but not in other areas, this may be indicative of inaccurate assumptions regarding the departure flight procedure or the take-off or climb thrust settings. For arrivals, differences between 5-10nm from landing may be indicative or early deployment of landing gear and/or higher landing flap settings. At greater distances, beyond 15nm, where airframe noise dominates, assumptions regarding aircraft speed, flap setting and the NPD data itself will determine the agreement between calculated and measured SELs.

The application of Doc. 29 has resulted in operations being sub-divided into a large number of departure and arrival flight profiles for each aircraft type. Noise measurements will need to be subdivided in a similar manner to the assignment of operations to flight profiles in order that the relevant noise measurements are associated with the most relevant flight profile. This could result in small measurement samples and increase uncertainty of the mean measured SELs.

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[4] Review of Dutch Implementation of ECAC.CEAC Doc. 29 4th Edition. September 2018.

In such circumstances, it may be helpful to consider differences between calculated and measured noise levels across all the sub-divisions together, particularly for departures. For example, large differences for only one departure stage length may be indicative of a take-off mass anomaly, whereas consistent differences across all departure stage lengths for a given aircraft type are more likely to be indicative of a NPD issue. In the example illustrated in Section 3, the take-off mass assumptions were adjusted until a common NPD adjustment was found for both departure stage lengths, that resulted in a good match across all departure procedures and stage lengths. In some cases, it may not be possible to resolve whether the difference lies in a take-off mass assumption or the NPD data. Ultimately this does not matter, so long as an adjustment is made to reduce the difference between calculated and measured noise levels.

The simplest scenario is where there is a systematic decibel difference between calculated and measured noise levels for a given flight profile. As noted above if this occurs for a given type across all stage lengths, then the entire NPD should be adjusted (addition or subtraction of a correction value) so that the calculated values match measurements.

Where calculated values for only one or two stage lengths are found to differ from measured values the differences are more likely due to the take-off mass assumption for those stage lengths.

Where the calculated values match at some distances, e.g. close-in or far from the airport, and the flight profiles are already confirmed as a good match for the profiles associated with the measurements, then more extensive adjustment of flight procedures, engine thrust settings and/or NPD data may be required. Typical adjustments could be to adjust the noise levels in the NPD for only one thrust level (i.e. one curve of the NPD), but taking care not to cross the next thrust line (above or below). If this cannot address the difference (often the case for far-out approach noise) then the shape of the NPD may need to be adjusted by changing the NPD decay rate as a function of distance[5].

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[5] Rhodes, White and Havelock, ‘Validating the CAA Aircraft Noise Model with Noise Measurements’, Noise in London conference, Institute of Acoustics, 23rd May 2001.

5. Conclusions and recommendations

This note provides guidance on the collection and processing of measured aircraft noise levels so that they may be suitable for comparison with calculated noise levels. In particular the note identifies a number of steps to ensure that measured noise levels (SELs) for each aircraft type have been correctly matched to aircraft operations and that at a number of monitoring sites are established along a single arrival and departure flight path, as well as across different flight paths. In addition, it is recommended that at least two years of measurements are obtained and that, whilst some monitors are moved from one location to another year by year to increase the number of sites monitored, that some sites are retained from year to year to further ensure the robustness of the measured levels.

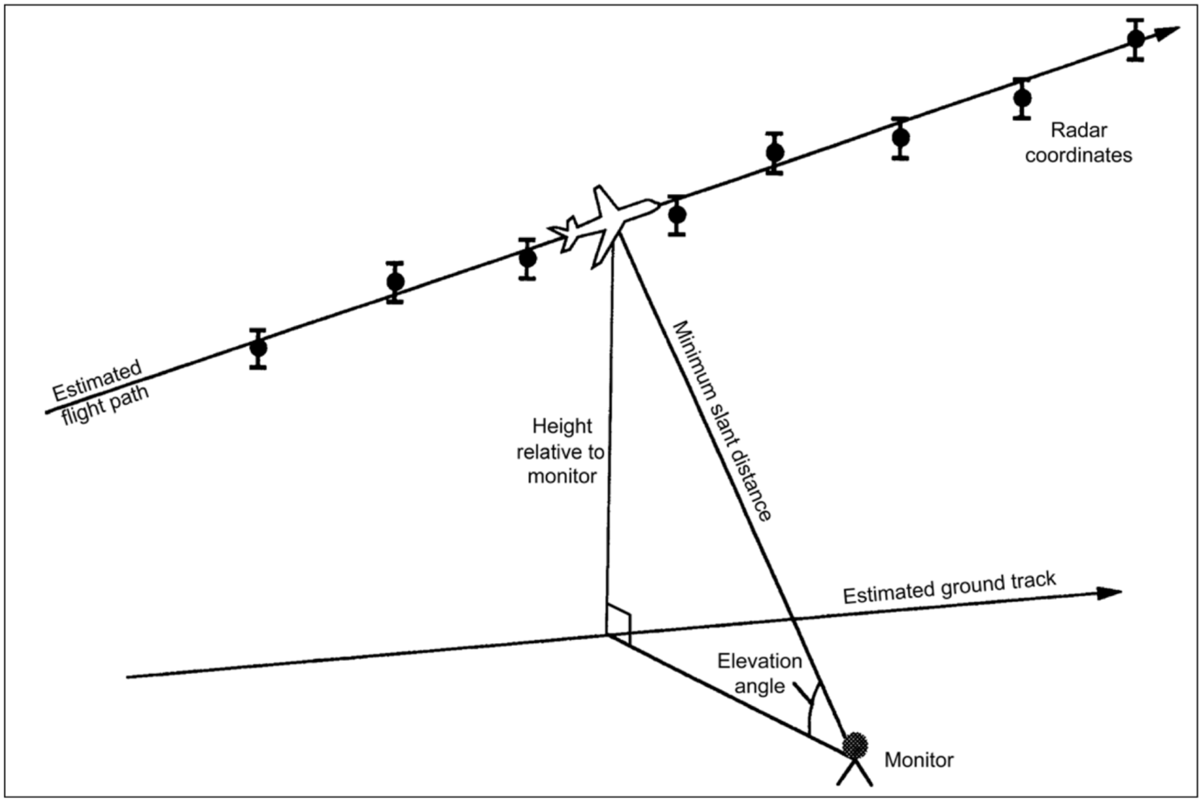
The note provides practical advice on the potential causes of differences and how to adjust either input data or the ANP database NPD data in order to reduce the differences. The process is, by definition, an iterative one, there often being more than one factor that may explain a difference between calculated and measured levels. It should be emphasised that real-world outdoor noise measurements are subject to a number of uncertainties. Noise monitoring equipment can malfunction, data can be contaminated with non-aircraft noise events and the characteristics of monitoring sites, including ambient noise levels and the physical characteristics can change over time. Differences between calculated and measured levels do not automatically mean that the calculated levels are incorrect. It some situations it may be necessary to repeat noise measurements and/or obtain further measurements from other locations to assure that there are genuine differences that requirement adjustment of the calculation inputs and/or ANP database.

Appendix A

Correction of measured noise levels to a location directly overhead a noise monitor

In the UK[6] it is standard practice to reject measurements occurring at an elevation angle (Figure 1) less than 60° and to correct all remaining measurements as though the aircraft was directly overhead a noise monitor. This results in the mean measured value being a mean maximum level and enables monitors along multiple flight paths to be assessed in series, reducing the influence of localised factors that may affect a single noise monitor. The adjustment to overhead conditions for elevation angles greater than 60° can be accomplished on an aircraft by aircraft basis by interpolating along the relevant aircraft NPD curve contained in the ANP database.

Figure 1: Definition of aircraft height, lateral distance, slant distance and elevation angle at the point of closest approach between an aircraft operation and a noise monitor



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[6] White S, 'Techniques used by ERCD for the Measurement and Analysis of Aircraft Noise and Radar Data', ERCD Report 0406, Civil Aviation Authority, January 2005.