Measurement of acoustic source data of taxiing aircraft for noise modelling

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ABSTRACT

Noise from airport ground activities can be a significant contribution to the ambient sound climate in communities close to airports. The shortfall in robust acoustic source data for aircraft ground activities, including taxiing and engine ground running, is a limitation to the accuracy of noise modelling supporting impact assessments associated with changes in airport operations. The aim of this study was to develop a robust survey methodology for the purpose of obtaining acoustic source data of aircraft ground activities. The study addressed two major challenges: the theoretical principle and experimental design for characterizing complex moving sources (i.e. the sound power, spectra and directivity); and the practical problems involved in on-site measurement. The theoretical principle is to consider an aircraft, moving in-line past a microphone, as reciprocally equivalent to a stationary aircraft alongside a line-array of microphones. Increasing the number of microphones in the array is equivalent to increasing the number of angles in the polar distribution plots. Measurements of the noise emissions from a selected aircraft gave a repeatability within 7.0 dB, and reproducibility within 15.7 dB.

1. INTRODUCTION

1.1. Background

In 2020, the authors were asked to report on the noise aspects associated with development proposals for a new airport terminal building, modifications to both landside and airside infrastructure and changes to the duration of daytime flying hours at Leeds-Bradford Airport (LBA), United Kingdom.

The development proposals are the first of its type to be brought forward under the EIA Regulations[1], with noise identified as a principal concern by the local community.

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2. CONTEXT AND LITERATURE REVIEW

2.1. Study overview

Modern airports are complex transportation hubs directing the movement of hundreds of thousands of passengers and freight and can generate significant levels of noise in surrounding areas and communities. For the purpose of regulation and development, it is essential that established and verified noise modelling methods exist for the prediction of emissions as a result of any proposed airport developments or operational changes.

In examining the emissions from aircraft activities, it is necessary for a noise assessment model to include the ground noise activities (aircraft on the ground before and after the take-off and landing cycle, including taxiing and engine ground run), which can be significant where long aircraft taxiways are proposed.

Whilst noise modelling packages such as the Federal Aviation Administrations (FAA) Integrated Noise Model Version 7.0 (INM)[2] and its replacement the Aviation Environmental Design Tool (AEDT)[3] are well established with respect to air noise modelling, they are comparatively limited for the modelling of noise emissions from aircraft ground activities. For aircraft ground noise, INM does not explicitly support taxiing noise and AEDT utilizes standard thrust settings, and aircraft sound power, spectral and directivity indices data set.

The AEDT data does not cover all aircraft, and generally the applied directivity patterns are a composite based upon empirical data. Studies have demonstrated that the use of a composite directivity pattern [4] limits the accuracy of the predicted levels due to variances across the aircraft fleet mix, and therefore an important consideration in instances where airport ground activities are likely to result in significant noise at nearby residences

To address the associated shortfall in data, previous studies have been undertaken, to develop a methodology for the estimation of aircraft sound power, spectra, and directivity indices during taxiing by direct measurement. These were at Madrid-Barajas Airport (Spain) [5][6][7], and at Dulles International Airport (USA), Reagan Washing National Airport (USA), and T. F. Green Airport (USA)[8]. Due to the limited amount of aircraft taxiing noise data available, airport noise models have used the data collected at these airports.

However, the data highlighted above applied to the specific airports being surveyed and the applicability of this data for the prediction of aircraft taxiing noise emissions at other airports has not been considered. Differences in airport layout, metrological conditions, and airport specific aircraft operations, such as thrust settings and operation of the Auxiliary Power Unit (APU), will influence the aircraft's sound power level, spectra and directivity, and should be considered in the associated noise modelling package.

The aim of this study was to design a monitoring methodology to optimise the quantity and quality of aircraft ground noise data. The repeatability of the monitoring methodology was assessed using data collected at several measurement locations at an airport. The data collected was used to inform the development of a three-dimensional sound propagation model considering aircraft taxiing noise and engine ground running activities.

The robustness of the measured aircraft ground noise data was assessed by preliminary estimates of the reproducibility for the same aircraft type at other airports.

The study also considered whether the measurement method specified could be adapted so that the number of sensors used, and associated data could be reduced, while maintaining acceptable accuracy and repeatability.

2.1. Source measurement methods

For the estimation of the sound power from a large moving source, such as a moving aircraft, which cannot be undertaken within a strict test environment, there are engineering grade (BS EN ISO 3744:2010)[9], survey grade (BS EN ISO 3746:2010)[10] and precision methods available, which can be undertaken within an industrial building or outdoors. They determine the sound power and the sound energy level in frequency bands emitted by a sound source traversing a defined route at a steady speed and operation. Given the required aircraft hangar dimensions to undertake such measurements, the most appropriate test environment would be a flat outdoor area, with low background noise. Both the required number of microphones and their positions depend on the dimensions of the measurement surfaces, which make up the 'reference box'.

The underlying principles of previous methods for the estimation of aircraft taxiing sound power and directivity indices by direct measurement [5][6][7][8] can be described as follows:

i. an array of measurements around a stationary source can be considered equivalent to a single measurement location next to a moving source
ii. measured sound pressures in the line array can be de-propagated to obtain the polar distribution of the sound power if the angle and distance between the microphones and the stationary source at a known time is determined
iii. in principle, it should also be possible to measure a polar plot of a moving source using one microphone, and only if, the angle and distance between the microphone and source is known precisely at each moment of measurement
iv. Additional microphones, forming the line-array, provide measurements of repeatability and of supplementary source-receiver vectors.

The measurements method requires an assumption that the speed of the moving source is constant whilst passing through the measurement array, and that the source emissions are symmetrical

3. MEASUREMENT METHODOLOGY

3.1. Methodology

The airport of the present study was Leeds-Bradford Airport (LBA) in West Yorkshire, UK. The aircraft taxiing routes are dependent upon whether there are easterly or westerly operations at the airport, and whether the aircraft are arrivals or departures. The procedure was a development of a previous survey of another airport (unnamed because of confidentiality requirements). The measurement arrays were of time synchronized microphones for continuously logging spectra and equivalent noise level in 100 milli-second intervals ($L_{Aeq,\,100s}$). To reduce human error when identifying the time at which the aircraft passes a microphone, the equipment had triggers, which would be set against the corresponding measured sound pressure and used to simplify post processing. The use of automatic digital triggers using infra-red beams was investigated but deemed not practical for safety reasons associated with beams and the pilots of the passing aircraft.

The monitoring equipment consisted of three Rion NL-52 sound level meters (SLMs) deployed 40m from the aircraft taxiway centreline. The SLMs were positioned at a total array length of 80m with the SLM spaced 40m apart. The survey method was a development of that used in previous surveys [5][6][7][8] and Airport A, which had a total array length of 100m, and SLM 50m apart and 50m from the aircraft taxiway centreline.

A measurement array with SLM microphones at varying heights was not possible due to safety restrictions given the proximity of larger aircraft, and therefore microphones at heights of 1.5 m from ground level were used. A photograph of an aircraft in the measurement array is shown in **Figure 1**.

Figure 1: Photograph: LBA - taxiing aircraft in noise measurement array

The LBA measurement survey took place over the period 05:00 – 16:30hrs, in 2019 during the greatest concentration of aircraft movements in the morning (06:00 – 08:30hrs) and the afternoon (14:00 – 16:00hrs). Meteorological conditions were calm, and there had been light overnight rainfall. Surveyors recorded aircraft number and type, and noted the general noise environment. The SLM microphones, cables and windshields meet the requirements of Class 1 (61672-1:2013)[11], and the filters meet the requirements of (61260-1:2014)[12], as specified in (BS EN ISO 3744:2010)[9].

4. Measurement results

The aircraft movements were identified using the digital triggers and exported for analysis. The data analysis focused on obtaining data on the: sound power level; sound spectra; and directivity indices.

4.1. Sound power levels

As with the authors' previous measurement surveys at Airport A and that of others at Madrid-Barajas, source levels were calculated as sound power levels. For each aircraft pass-by, there were three digitally triggered time-histories. The data for each measurement position was time synchronized with the data collected at the other SLMs. It was therefore possible to accurately determine the position of the aircraft (i.e. the source-receiver vector) at three times i.e. when the aircraft noise passed each SLM.

The taxiing speed of the aircraft within the measurement array was determined by the distance and time between SLM 1 and 3. The calculated aircraft taxiing speeds at LBA were in the range 5.5 – 11.8 ms^{-1} and were used to determine the location of each aircraft 25 seconds before the nose of the aircraft passed SLM 1, and 25 seconds after the tail of the aircraft passed SLM 3.

The measured octave band levels between 63-8000 Hz, L_P ($L_{eq,\ 100ms}$) were de-propagated to the source position (aircraft centre) according to the standard (ISO 9613-2:1996)[13], as in Equation (1), to derive an associated sound power level, L_w:

$$L_w = L_p + A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc} \tag{1}$$

A_{div} is the attenuation due to geometric divergence and based upon the calculated source to individual microphone slant distance (m), A_{atm} is the attenuation due to atmospheric absorption and was based upon an average temperature (18 C) and relatively humidity (74 %) recorded during the measurement survey, A_{gr} is the attenuation due to ground effects and assumed suitable corrections for the intervening ground not being fully reflective with respect to all microphone positions and all aircraft positions. A maximum proportion of porous ground between source-microphone positions as noted to be 0.25 (source, receiver and middle region), A_{bar} and A_{misc} is the attenuation due to barriers and other site specific factors, such as dense foliage, respectively. No corrections in either respect were considered.

For each octave band level in the range 63 – 8000 Hz, the source sound power level is an energetic average of the de-propagated values.

4.2. Sound spectra

The ISO 9613-2 methodology, and the corrections therein, are related to octave band centre frequencies between 63 – 8000 Hz. The linear source levels were determined for octaves in this range, and A-weighting corrections applied to the energetic average. Statistical analysis of the measurement spectra from each of the three time-histories was undertaken to remove measurements with large deviations from the mean.

4.3. Directivity indices

The directivity indices can be dimensionless, a decibel correction to a stated nominal value, or related to the derived source level. The last method was adopted based upon the magnitude of the de-propagated measured level and presented as a polar plot. The size of the measurement array limited the de-propagated levels to an angular range of 140 degrees (i.e., 110 to 250 degrees, with the aircraft nose at 90 degrees). It has been assumed that the aircraft emissions are the same on either side of the aircraft, and the 40-degree range of angles at the nose and tail of the aircraft, where measurements could not be undertaken, are represented by a straight line.

The directivity of the emissions from the aircraft during taxiing was determined for each of the three time-histories separately. Where the same angle and source-microphone distance is presented, the respective value is an energetic average of the corresponding de-propagated values. Statistical analysis of the aircraft directivities for each of the three-time histories associated with a single pass-by was undertaken to remove measurements with large deviations from the mean, as used to inform the measurement repeatability.

5. MEASUREMENT REPEATABILITY

The uncertainty associated with a measurement can be represented by its repeatability. This is related to the differences in results when undertaking measurements of the same source at the same measurement locations. The repeatability analysis has considered the sound power level and directivity differences of the measurements undertaken at Airport A, for ten aircraft of the same type (Airbus A319).

5.1. Sound power level repeatability

International Standards (BS EN ISO 3746:2010)[9] recommend that a measurements repeatability is determined from at least six successive measurements at a single microphone position, with a target value of less than 1.5 dB. This approach however relies upon strict test environment controls, including a known source location and constant levels of background noise.

Given variances in the aircraft engine thrusts associated with the A319 during taxiing (speeds in the range 5.6 – 16.7 ms^{-1} were recorded at Airport A) and the limited number of manned microphones during each pass-by, it was not possible to obtain six measurements of the same source. However, the statistical range of the derived sound power levels for each of the three time-histories has been calculated, **Table 1**. The average difference is generally lower at higher frequencies when levels are less likely to be influenced by extraneous noise sources. This is likely to be a contributing factor to the 10 dB average differences at 250 Hz for aircraft pass-bys movement number 3 and 4.

An additional factor is the aircrafts use of the Auxiliary Power Unit (APU), used for cabin air and electric power. During some aircraft taxiing events the APU was audible, and therefore a likely contribution to the derived sound power level, sound spectra, and source directivity.

Due to the changes in operational conditions, the averages (**Table 1**, **Figure 2**) could not be obtained according to the standard repeatability requirements. The present results are of the order 4.9 - 7.0 dB, and exceed the target level of 1.5 dB. It is expected that a more controlled test environment and less variation in aircraft operational conditions would give a better agreement with the target repeatability of 1.5dB.

Table 1: Airport A A319 - Sound power level, L_w (average level differences, dB)

	Octave Band Centre Frequency (Hz)				
Movement Number	**250**	**500**	**1000**	**2000**	**4000**
Average	6.7	7.0	4.9	5.3	5.3

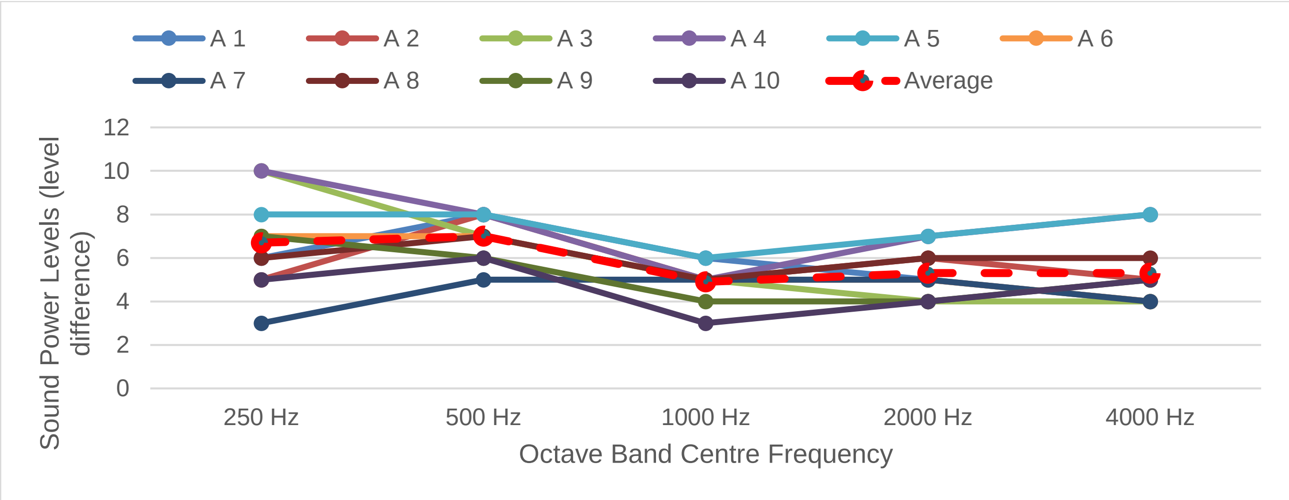

Figure 2: Airport A A319 - Sound power level, L_w (level differences, dB)

5.2. Directivity and spectra

The repeatability of the A319 measurement at LBA in terms of the spectra derived from the three SLM is in **Table 2**. The range in octave band centre frequency values is between 0.8 – 9.1 dB, with the smallest range at mid-frequencies. The polar plot of the directivity is shown in **Figure 3**.

Table 2: LBA: A319 - Octave band centre frequency sound power levels, L_w (differences, dB)

SLM Number	Octave Band Centre Frequency (Hz)								Total, dB(A)
	63	125	250	500	1000	2000	4000	8000	
LBA 1	131.5	135.4	129.1	120.7	120.7	126.3	127.6	126.1	133.0
LBA 2	134.5	139.3	131.1	119.0	121.1	125.1	127.0	125.4	132.8
LBA 3	135.9	141.0	133.3	120.9	121.5	125.4	130.0	134.5	136.7
Range	**4.4**	**5.6**	**4.2**	**1.9**	**0.8**	**1.2**	**3.0**	**9.1**	**3.9**

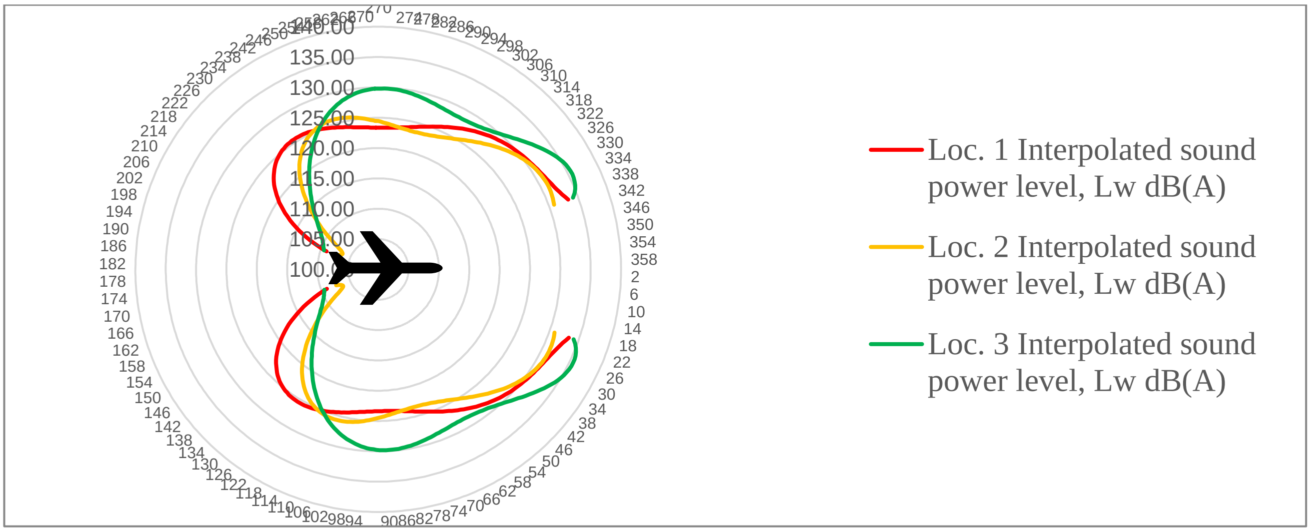

Figure 3: LBA A319 - Sound power level, L_w (directivity differences, dB)

6. MEASUREMENT REPRODUCIBILITY

6.1. Sound power levels reproducibility

The measurement reproducibility was for different aircraft of the same type (A319), and for measurements undertaken at different airports and locations. Therefore, the term ‘reproducibility’ is not strictly appropriate. Differences in engine settings and type, and whether the APU is in operation, are likely to have a large impact upon on this value. Results are given at octave band centre frequencies between 63 – 8k Hz for source level (sound power level) and directivity index.

The linear octave and A-weighted sound power levels for ten A319 aircraft measured at Airport A, the A319 measured at LBA and the A319 sound emission data from Madrid-Barajas, are summarised in **Table 3**, and in **Figure 4**, and show the reproducibility across the three measurements survey is between 4.8 – 15.7 dB.

Table 3: A319 - Octave band centre frequency sound power levels, L_w (average differences, dB)

Move-ment Number	Octave Band Centre Frequency (Hz)								Total, dB(A)
	63	125	250	500	1000	2000	4000	8000	
Airport A	123.6	123.9	119.3	115.5	115.1	121.8	121.3	127	129.2
LBA	134.3	139.1	131.5	120.3	121.1	125.6	128.4	130.8	134.6
Madrid	120.1	124.0	118.0	119.7	120.7	118.1	118.3	115.1	125.7
Range	14.2	15.2	13.5	4.8	6.0	7.5	10.1	15.7	8.9

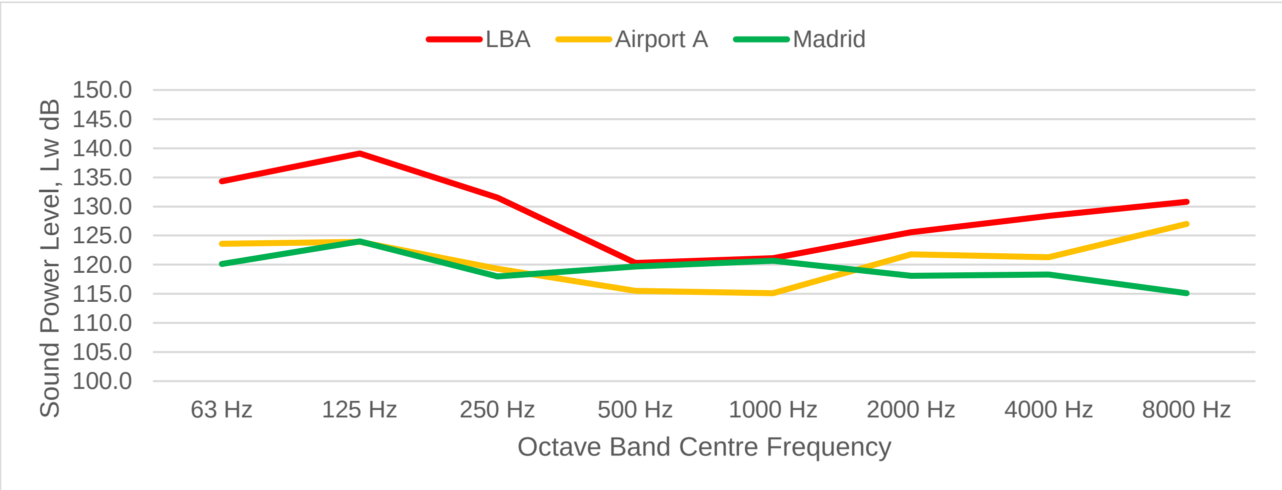

Figure 4: A319 - Octave band centre frequency sound power levels, L_w (average differences, dB)

6. CONCLUSIONS

The repeatability of the measurement method was in the region of 4.9 – 7.0 dB, which is greater than the target level of 1.5 dB.

The reproducibility across the three measurement surveys is between 4.8 – 15.7 dB. These values assumed that the source was the same at the three airports, which is unlikely to be the case. There are changes and variations in source with alterations in the aircraft taxiing speed, engine thrust, meteorological conditions, and airport layout. The methods described are therefore appropriate for site-specific noise surveys.

This study was limited by the relatively few aircraft movements recorded and reproducibility could be improved with a greater sample size, and by greater control of the variation in individual aircraft operations.

An important challenge in the work described was in obtaining an accurate estimate of the source-receiver vector at the time of each short-interval measurement.

In principle, the source directivity, by de-propagating the sound pressure level to give the source sound power level, can be obtained using a single SLM. The use of a line-array of SLMs gives repeated values and an estimate of repeatability.

The operating conditions of taxiing aircraft of a certain type are variable (taxiing speed, use of auxiliary power unit, etc.). It is therefore likely that measurements will continue to be case-specific, applying to a particular airport, in which case, the measurement procedure described is appropriate and relatively straightforward.

In the future, with an increase in similar measurement data for more airports, it may be possible to normalize the source sound powers and directivities to clearly defined operational conditions, such as taxiing speed. Source data produced for a particular aircraft type, at a particular airport could then be transferable in the acoustic modelling of other airport operations.

6. REFERENCES

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