Auralisation for Airport Noise Impact Assessments: Measurements and Applications

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ABSTRACT

Recent projects at local and overseas airports have highlighted some of the benefits and challenges in the use of auralisation as a tool for communicating the expected noise impacts from new airport or airport expansion projects. Opportunities for future development are also presented, including the use of signal processing to simulate changes to flight paths, changed meteorological conditions, or the changed noise emission characteristics of potential future aircraft. These projects also provide a useful body of data to investigate the application of the predicted noise levels from AS2021 in practice. The measurements suggest that AS2021 is broadly accurate in predicting noise levels from operation of Australian airports under typical flight conditions, but also highlight operational practices which may significantly increase the actual noise levels compared to the predicted noise levels that are based on idealised flight profiles.

1. INTRODUCTION

Noise from aircraft can have a significant impact on people that live near airports and is a major community concern when considering changed or additional flight operations. Proposed increases in capacity (often due to increases in peak, rather than overall demand) and expansion of runway facilities in major cities in Australia and overseas is likely to exacerbate the issue. Proposed new airports (e.g. a second airport for Sydney) and additional parallel runways will result in new populations being exposed to significant levels of aircraft noise. During the planning and development phases of an airport expansion project, community response to aircraft noise impacts is significant political and commercial risk (Fidell, 2015) that requires careful consideration.

The Commonwealth Department of Infrastructure and Regional Development's (DIRD) *Guidance Material for Selecting and Providing Aircraft Noise Information* (DIRD n.d.) provides principles to be followed in communicating aircraft noise impacts to potentially-affected communities. The *Guidance Material* establishes the principle of a "right to know" for communities to have access to details regarding the flight patterns of an airport and how these may affect the received noise levels. Under this principle of "right to know", "transparent information" must be communicated to allow potentially-affected communities to make their own judgments regarding the degree of impact – in essence, providing "fact" without "interpretation". This recognises that there can be considerable difference between an individual's response to noise and the averaged community reaction to noise. The *Guidance Material* states that:

> *It is vital that when using an aircraft noise descriptor it is selected so that it matches the needs of the issue being examined. In the past this match has not been achieved effectively and this has contributed significantly to the expert and non-expert failing to reach a common understanding about aircraft noise exposure patterns around airports.*

The traditional approach to describing aircraft noise in Australia and internationally is using aircraft noise exposure contours (e.g. Australian Noise Exposure Forecast, ANEF). However, it is accepted that the ANEF and other equal-energy noise contours (such as DNL, used in the US, or L_{night}, adopted by the European Union) do not, by themselves, provide a complete picture of aircraft noise level impacts (Plotkin et al, 2011, Southgate, 2011).

The use of ANEF contours for reporting of noise impacts to non-noise experts and in community consultation has come under scrutiny since the opening of the third runway expansion at Sydney Airport in the 1990s led to significant public complaints regarding noise impacts from the airport. A 1995 Senate Enquiry (*Falling on Deaf Ears;* Department of the Senate *1995*) into the third runway expansion identified 'major deficiencies' in the assessment of aircraft noise for that project.

The Senate Enquiry prompted the development of a discussion paper *Expanding Ways to Describe and Assess Aircraft Noise* (DOTARS, 2000) published by the Department of Transportation and Regional Services (DOTARS). *Expanding Ways* acknowledged that the majority of complaints regarding aircraft noise from Sydney Airport actually came from *outside* the 20 ANEF contour.

In response, *Expanding Ways* introduced the "number above" indices N60 and N70, and the use of the Transparent Noise Information Package (TNIP) software (DOTARS, 2000) as alternate approaches for describing aircraft noise impacts. In order to provide a better understanding of the potential for aircraft noise impacts and to assist in describing aircraft noise to non-experts, the discussion paper recommended the use of flight-path maps, showing the number of movements and type of aircraft flying on particular flight paths, and several additional aircraft noise metrics. In particular the use of the N70 metric was proposed as a way of reporting noise impacts in a way that corresponded most closely to the community's understanding of aircraft noise – by the number of aircraft noise events (DIRD n.d.). The N70 is a measure of the number of events which are equal to, or exceed, a maximum aircraft noise level ($L_{Amax,slow}$) of 70 dB(A) at a given location. N values can be determined for any noise level, for example, an N60 or N80 could also be calculated.

2. CONVEYING AIRCRAFT NOISE INFORMATION TRANSPARENLY

Aircraft operations, particularly jet aircraft, produce high levels of noise. While the noise impacts are generally greatest nearer to the take-off and landing flight paths, the impacts of aircraft noise can extend a long way from the airport, and cover large sections of the community. Furthermore, since aircraft noise impacts may be widespread, and are not clearly restricted to pre-existing and defined locations (such as adjacent to freeways or railway corridors), new aircraft noise impacts can 'surprise' unsuspecting communities that were previously unaffected or only marginally-affected. Noise from aircraft operations is therefore a very emotive issue, and can generate high levels of public reaction.

Aircraft noise assessments are, by their nature, very complicated, since they must account for a large number of variables (e.g. proposed flight tracks, aircraft types, weather conditions etc.) and many options. The noise assessment must also combine technical accuracy with ways of fairly-describing expected impacts to a lay audience in a succinct and representative manner. Indeed, the high-profile 'failure' of the aircraft noise assessment for the 3rd Runway at Sydney's Kingsford Smith airport attracted substantial media and public criticism, and cemented the community's distrust in the assessment process. This has brought subsequent assessments for projects such as the 2nd Sydney Airport at Badgery's Creek under increased public scrutiny, and resulted in new and better ways of describing aircraft noise to the general public (e.g. TNIP, N70).

Furthermore, there is increasing concern about using single number technical descriptors such as ANEF or DNL (or even N70) for aircraft noise (Fidell, 2015), since the subjective quality of aircraft noise is changing– noise from aircraft has evolved and changed so much in the intervening period, predominantly due to a change from older and noisier pure jet engines on 'Chapter 2' aircraft to more efficient high-bypass turbofan engines on modern 'Chapter 3' and 'Chapter 4' compliant aircraft. The subjective difference in characteristic between jet aircraft and piston aircraft is what sparked the development of parameters such as (A)NEF in the 1950s (Beranek, 2008); in this light, the ongoing evolution in the subjective characteristics of aircraft noise emission should be accompanied by a concurrent evolution in the methods used to describe and communicate aircraft noise to the community.

Finally, with increasing number of aircraft movements occurring, but with aircraft (in general) becoming quieter, the pattern of aircraft noise exposure from future airports is likely to be different to existing scenarios, typically with a higher number of "quieter" events.

These factors all pose challenges to future methods for communicating aircraft noise information, whether as part of a formal Environmental Impact Statement (EIS) process, or as part of a wider community engagement process. In short, the aircraft noise assessment must be:

- scientifically based
- technically rigorous, with a comprehensive and robust methodology
- transparent, open to review, and with no hint of anything being 'hidden'
- fairly representative of the expected impacts
- presented in a clear manner, which effectively communicates the extent of the impacts.

Given the existing levels of community mistrust and concern regarding aircraft noise, a failure to adequately and comprehensively address aircraft noise issues during the EIS stage of a new airport or runway development is likely to be unacceptable to both the approval agencies and the general public, and could also result in lengthy and costly delays to the project, which in the worst case could jeopardise the viability of the project as a whole.

For some infrastructure projects (most notably wind farms), developers have sometimes taken potentially affected residents at newly-planned sites on tours of existing developments in order for them to experience the particular sound (i.e. wind farms) for themselves. However such study tours are necessarily limited in the number of people who can attend and, more importantly, are subject to the particular weather and operational conditions that exist at the time of the tour.

Auralisations have the benefit that they:

- can be shown to a wide range of the potentially affected community,
- allow a wide range of 'virtual flight operations' to be experienced, and
- allow direct 'back-to-back comparison between various operational scenarios, so that subtle aural characteristics can be more easily compared (Arntzen, 2015, Sahai, 2016).

Auralisation offers the potential to significantly improve this process of communication by accurately conveying the frequency characteristics of aircraft noise events in a more-sophisticated way than any single-number technical index can. Arup is a pioneer in the field of auralisation, having established over ten SoundLab auralisation facilities around the world, and recently using mobile versions of the SoundLab as community consultation tools on major new infrastructure projects such as the High Speed 2 rail line in the UK. The Arup SoundLabs have facilitated greater stakeholder input into acoustic design and have had significant impact on the design of numerous architectural, environmental and transportation projects.

The SoundLab provides an intuitive understanding of specific acoustic parameters, allowing them to be heard during the acoustic design and planning phase. It allows for difficult acoustic terminology to be demonstrated, listened to and easily understood for various aircraft and flight paths at various locations, under a range of environmental and receiver conditions including inside buildings.

3. FACTORS AFFECTING AIRCRAFT NOISE IN THE COMMUNITY

The aviation industry is currently in a state of change, with significant changes to aircraft fleets as older aircraft models (e.g. Boeing 747-400) are phased out and new aircraft models are introduced. This is part of a larger programme of industry upgrades which are expected to reduce fuel consumption, and allow for capacity increases (or at least maintenance of existing capacity) within existing noise exposure footprints. Future tools for communicating aircraft noise impacts should be able to demonstrate the results of these potential future changes to aircraft noise levels.

With regard to the acoustic characteristics of aircraft, the key improvement is likely to be the more widespread introduction of lighter aircraft manufactured largely out of composite materials (eg. the Boeing 787 'Dreamliner' or Airbus A350), plus higher capacity aircraft such as the Airbus A380. These are expected to have 20% greater fuel efficiency, per passenger, than previous generation aircraft, and result in fewer flight movements for the same level of capacity.

In addition, new engine options ('neo') for existing aircraft models (e.g. Airbus A320 and A330), including the use of geared turbofan (GTF) engines and 'next generation' models (e.g. the Boeing 737 MAX, 747-8 and the 777-8/9) will result in changes in the noise emission characteristics of even these older aircraft designs.

Overall, these changes could result in either a reduction in aviation movements or a much lower level of growth in the next 30 years, resulting in reduced noise levels around airports. The aircraft industry has also made significant reductions in aircraft noise emission since the 1960's particularly through the introduction of high-bypass turbofan engines. Achieving significant further noise reductions is likely to be considerably more difficult. A wide range of noise reduction techniques are noted in the literature (Casalinoa et al., 2008).

Noise from aircraft was first regulated by the introduction of the US Federal Aviation Authority's (FAA) aviation regulations FAR Part 36 and ICAO Annex 16 Chapter 2 in 1971. More stringent noise requirements came into force under 'Chapter 3' restrictions in 1981, and 'Chapter 4' restrictions in 2006.

Apart from further incremental reductions to engine and airframe noise, additional noise reductions are most likely to come from the adoption of 'low noise' flight operations. Already many airports require the use of 'noise abatement' flight procedures, such as PANS-OPS NADP (Noise Abatement Departure Procedure), although the requirement to operate safely usually over-rides any requirement to adopt low-noise operating modes.

There are also several new 'on-board' technologies available to airlines, such as Required Navigational Performance (RNP) and Continuous Descent Approach (CDA) flight management systems which use advanced GPS systems to allow more accurate aircraft positioning and higher approach flight paths which result in fewer 'noisy' manoeuvring movements.

4. MEASUREMENT AND RECORDING OF AIRCRAFT NOISE

Arup has recently conducted projects at two Australian and one UK airport consisting of extensive measurement and high-quality spatial recording of aircraft operations in order to produce auralisations of existing and future aircraft operations for use as a community consultation tool. (For client confidentiality reasons the airports cannot be directly named.)

For each aircraft, measurements were conducted of existing airport operations at locations underneath the flight path. Four measurement locations were used: “on-axis” locations at (nominally) 5 km and 10 km from the runway threshold, as well as corresponding “lateral” locations offset 2 km to the side of the flightpath, as shown in Figure 1. The actual distances were adjusted based on the receiver locations specific to the airport.

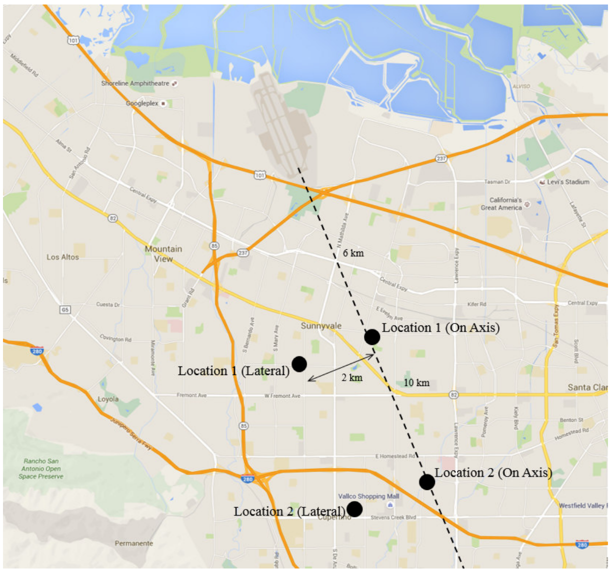

Figure 1: Indicative arrangement showing locations of measurement locations relative to an airport

Locations with low ambient noise levels were selected to minimise the effect of extraneous noise on the measurements or recordings. This led to some challenges in site selection (e.g. construction works starting up at a proposed location between the planning stage and the measurement dates required selection of an alternate location) as well as some challenges during measurement (e.g. garbage collection truck pass-bys coinciding with key aircraft flyovers). In addition, representative ambient noise levels at locations under future planned flight paths were measured (and calibrated recordings taken) to provide context for demonstrations of future flight path impacts.

At each location, the published flight schedules and websites such as FlightAware were used to plan the measurement sessions, aiming to measure and capture recordings of each major aircraft type regularly using the airport. Online tools (e.g. FlightRadar 24) were used to identify and track aircraft on approach/departure; these tools usually provided sufficient warning of an approaching aircraft to allow measurements to be planned to capture the flyover. Two locations were monitored simultaneously for each day of the measurement programme; this meant that measurements at the 5 km and 10 km distances were conducted on separate days.

One challenge in obtaining full datasets was the measurements were subject to the wind conditions that occurred on the days of measurement, which meant that not all flight paths were in use during the measurement sessions. This meant that on four out of the five measurement days at one airport, the flight paths were such that only arrivals were measured; aircraft on departure were only measured on one day when wind conditions differed.

Because aircraft on departure tend to adopt diverging tracks once more than ~5 km from the runway threshold, for departures the only measurements that were conducted were on-axis measurements at 5 km. At other locations, departing aircraft would not regularly overfly the location. For arrivals, the flight tracks are more-consistent with most aircraft directly overflying the 10 km on-axis locations and virtually all aircraft directly overflying the 5 km location.

The studies conducted were preliminary studies based on the available measurement time; however for a full study this would potentially mean extensive (and unpredictable) site time in order to capture sufficient data under all possible operational conditions.

4.1 Equipment

For the two Australian projects, aircraft noise levels were measured simultaneously at each location using a Brüel and Kjær Type 2250 or Type 2270 Precision Sound Level Meter, measuring the $L_{Amax,slow}$ noise level from the aircraft fly-over as well as taking a calibrated audio recording. A Soundfield© ST350 Ambisonic microphone was located adjacent to the sound level meter (sufficiently far away to avoid affecting the measurement but close enough so that the sound field was essentially identical at both the microphone and the meter). An image of the site set-up is shown in Figure 2.

The SoundField© microphone has four separate capsules arranged in a tetrahedron, which allows the three-dimensional 'spatial' character of the sound to be captured. The sound is recorded in a four-channel ambisonic format called 'B-Format' which separates the sound into distinct orthogonal X, Y, Z channels and an omni-directional (W) channel. This B-Format recording is then played back in the Arup SoundLab via a spatialisation engine (the *Spat* Ambisonic Decoder) to accurately recreate the recordings through the specially arranged ambisonic loudspeaker array. The way this is recreated is determined through the use of spherical harmonic mathematics and the sound through each loudspeaker is determined based specifically on its orientation and physical location relative to the listener to recreate the original recording accurately in a very immersive and highly realistic listening experience.

Figure 2: Typical measurement setup

5. ANALYSIS

An overview of the measured aircraft types from an Australian airport is given in Table 1 below. In total 346 aircraft events were measured over four consecutive days of operation of the airport. The airport was operating with arrivals above the measurement locations for three days of operation, with the aircraft operating with departures above the measurement location for the fourth day. Note at this airport the closest measurement location was at 6 km from the runway threshold, which corresponded to the closest noise-sensitive receivers.

Table 1: Summary of Measured Aircraft Types and Average Flyover Noise Level, $L_{Amax,S}$ dB(A) re 20 µPa

$L_{Amax,slow}$	6 km On-Axis Arrival	6 km Lateral Arrival	10 km On Axis Arrival	10 km Lateral Arrival	6 km On-Axis Departure
Airbus A320	74	52	69	61	
Airbus A330	77	54	71	60	79
Airbus A380	76	57	72	59	
Boeing 717	72	49	68	57	
Boeing 737	75	55	70	60	76
Boeing 747	82	57	74	61	84
Boeing 767	78	54	71	59	
Boeing 777	78	55	72	62	79
Boeing 787	75	52	69	60	
Bombardier DHC8	71	50	67	56	60
Embraer 190	71	52	68	57	74
Total Number of Aircraft Measured	**37**	**86**	**113**	**90**	**20**

These average noise levels were compared with the published data from AS2021 (Standards Australia, 2015), which are based on predicted noise levels from the Integrated Noise Model (INM) software package. For lateral locations, AS2021 only provides data out to 1,400 m lateral to the centreline for arrivals; data for the 2 km lateral measurement locations was calculated based on the 1,400 m data accounting for the additional geometric spreading loss from 1,400 m to 2,000 m (i.e. neglecting any additional atmospheric absorption and assuming that aircraft directivity is approximately constant once distance becomes sufficiently large and change in inclination angle is small).

The following figures present the measured noise levels for each aircraft type at each measurement location, with the 'average measured aircraft' (the arithmetic average of all measurements, which was the level presented in the SoundLab auralisation), and the predicted AS2021 level also included for reference.

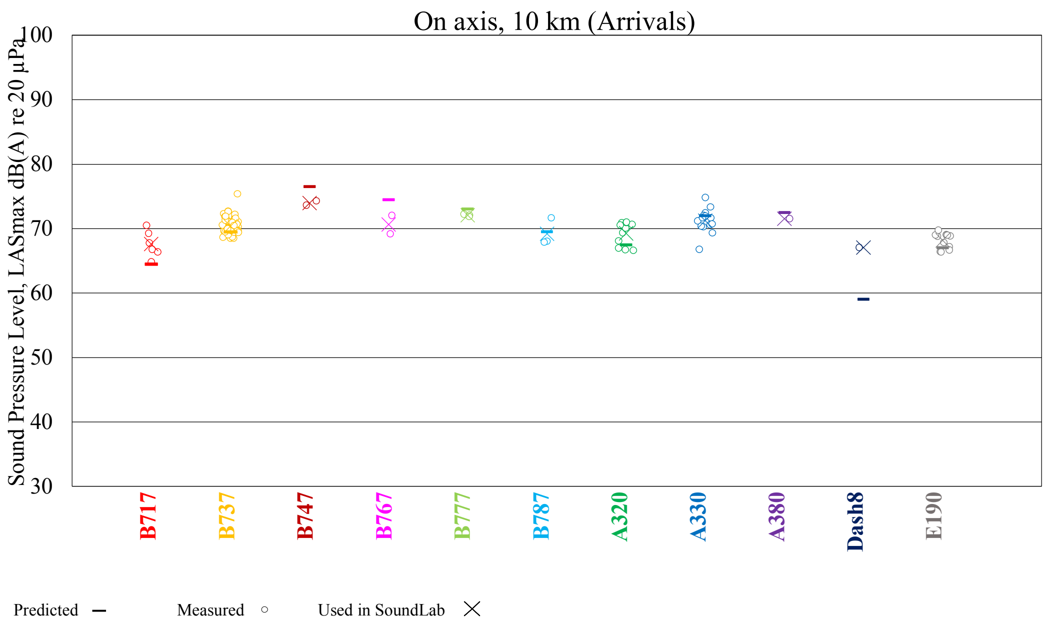

Figure 3 Summary of On-Axis Arrival Noise Levels, 10 km

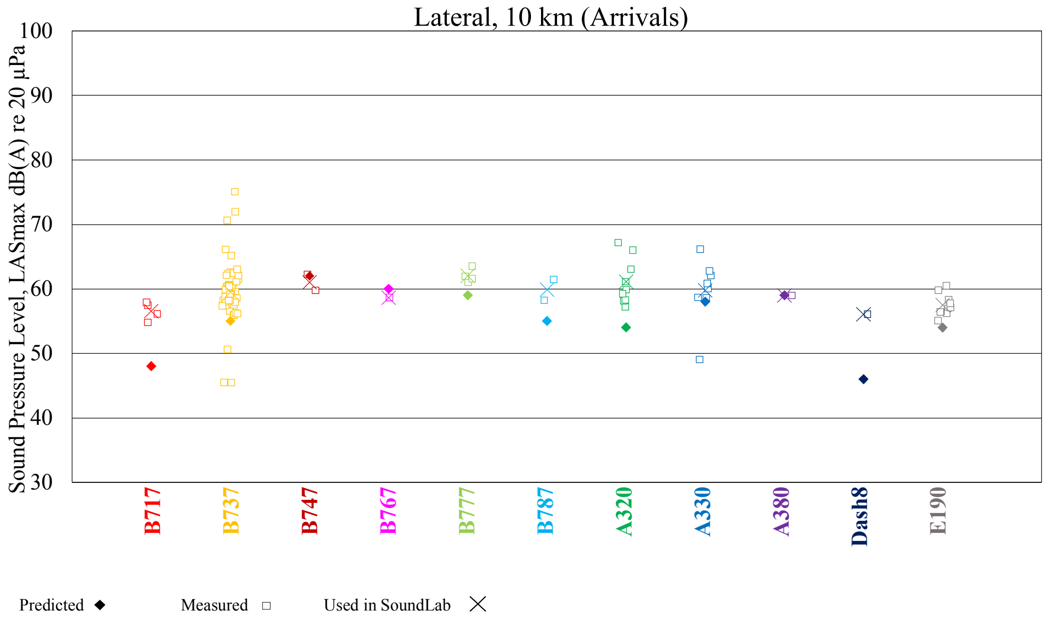

Figure 4 Summary of Lateral Arrival Noise Levels, 10 km

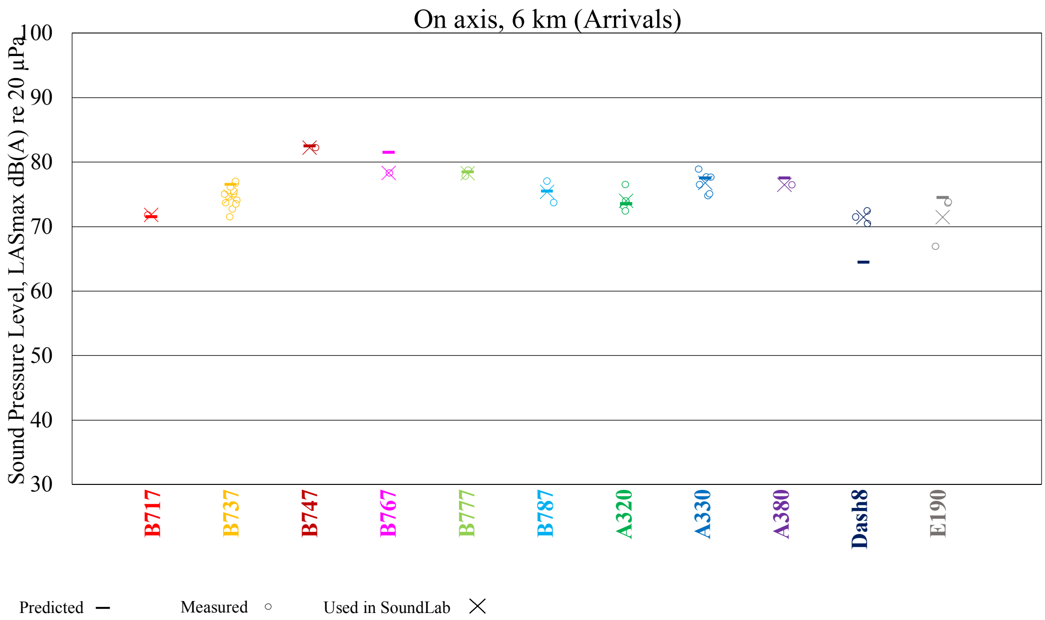

Figure 5 Summary of On-Axis Arrival Noise Levels, 6 km

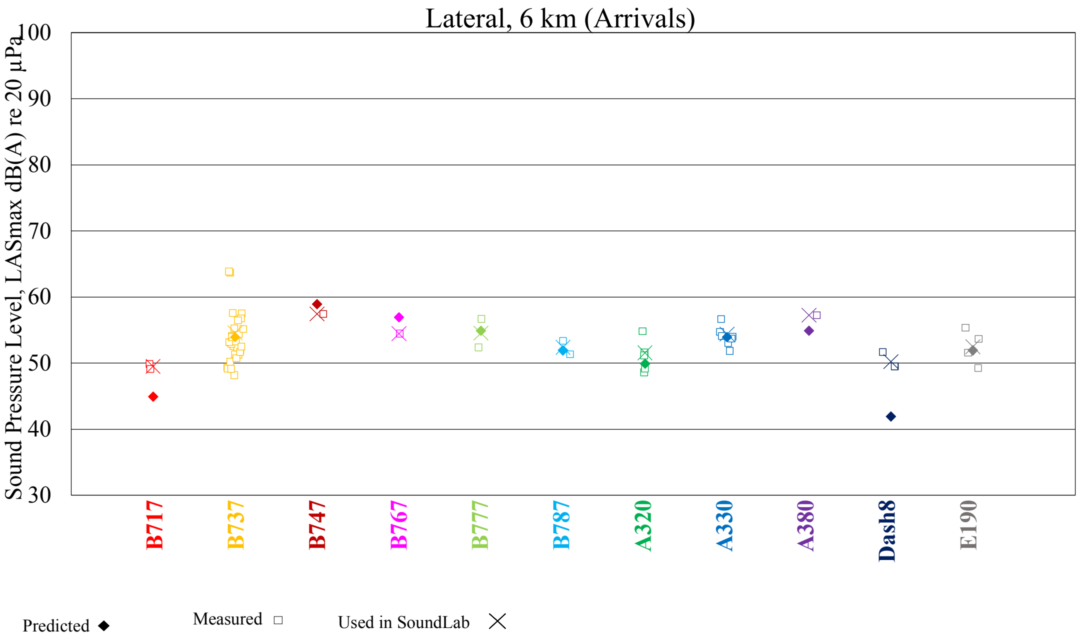

Figure 6 Summary of Lateral Arrival Noise Levels, 6 km

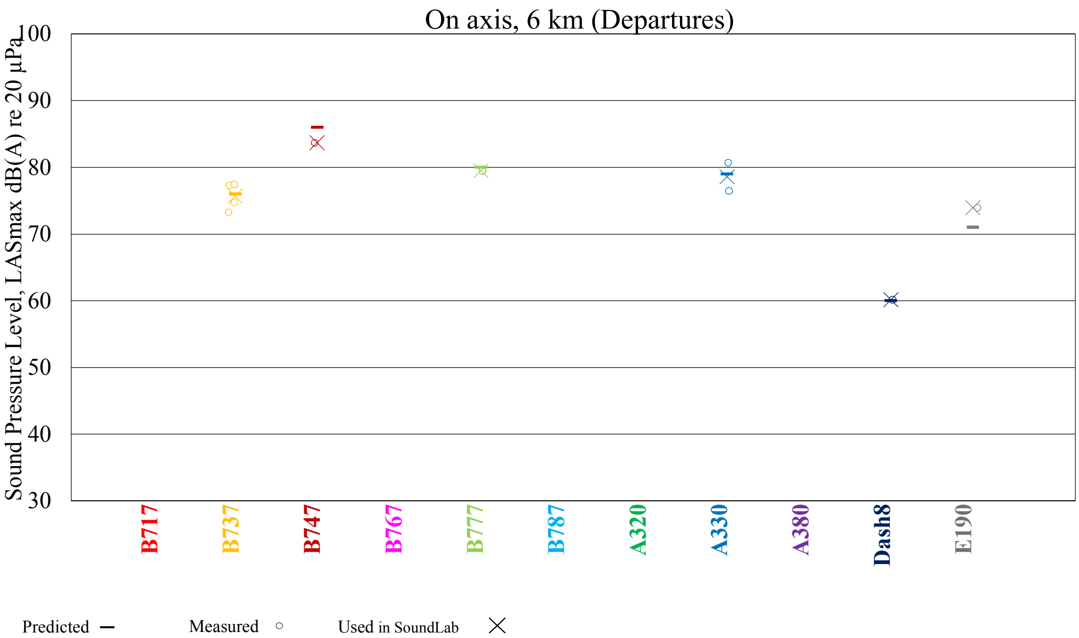

Figure 7 Summary of On-Axis Departure Noise Levels, 6 km

In general, there is good agreement between the INM-predicted level for each type and the average measured noise level, however there can be considerable spread in the data. In particular, there is less-good agreement for lateral locations. This may reflect uncertainty in the actual lateral distance to the aircraft, since the actual track followed may not be directly down the centreline of the nominal flight path. This is particularly apparent for the B737 and A320 aircraft that form the bulk of domestic flights in Australia, which did not necessarily follow a straight track for the last 10 km on arrival, with some aircraft turning onto the track between 6 km and 10 km from the runway, which would affect the true lateral distance to the flight track. Larger aircraft (particularly international arrivals) tended to follow a straight track for the final ~15 km of the approach and this is generally reflected by the tighter clustering of results from larger aircraft types.

The measurements at 10 km demonstrate greater variation than those undertaken closer to the airport. Again, this is likely to reflect uncertainty in the actual track followed; at 10 km there may be considerable lateral variation between the tracks of individual aircraft, while closer to the runway the tracks 'converge' onto the centreline of the runway as aircraft come to the final stages of approach.

There is generally more variation for smaller aircraft types (e.g. Dash-8, E190 and B717) than for larger aircraft. The measured levels for these aircraft are generally higher than predicted, particularly for lateral locations. This may reflect different glidepath angles for these smaller aircraft compared to the assumptions used to produce the INM predicted noise levels; in addition, these aircraft were generally flying short domestic routes (usually outside of the busiest operational hours) and were more likely to be flying on visual flight rules (VFR). The one exception amongst larger aircraft is the Airbus A330; however the dataset includes both domestically- and internationally-configured A330s. Aircraft flown on domestic routes were observed to show more variability in the flight track than international aircraft, which tended to follow the flight path more-closely. This may reflect differences in air-traffic control (VFR vs ILS), differences in the fuel load, pilot familiarity or other, unidentified, factors.

Although the dataset for departures is smaller (and only includes aircraft that departed 'straight' from the airport; without turning away from the runway centreline immediately after departure; these aircraft did not directly overfly the measurement location), the predicted levels from AS2021 appear more-accurate for departures than arrivals. This potentially reflects the flight tracks and climb angles for departures being more-consistent, at least in the immediate vicinity of the airport, as all aircraft would be aligned with the runway on departure.

Currently the data is broken down by aircraft type only. It would be of interest to explore additional categorisation of the data within each aircraft type (e.g. domestic/international as a proxy for stage length (which reflects the required fuel load, and therefore take-off weight), by engine type, or even by operator) to investigate whether any additional trends emerge.

6. PLAYBACK

Aircraft noise auralisations were played back using a mobile version of Arup's SoundLab auralisation suite. The mobile version consists of six Genelec 8030A loudspeakers arranged as front, mid and rear pairs with a Genelec 7060B subwoofer (i.e. a 6.1 system), with a Metric Halo 7882 DSP interface and *Spat* ambisonic decoder used to distribute signal to the loudspeakers, as shown in Figure 8. The mobile SoundLab can be adjusted to allow larger listening groups (at the cost of some spatial accuracy) compared to the fixed SoundLabs. The lack of "vertical" speakers in the mobile SoundLab does not significantly affect the subjective impression for general demonstrations.

The mobile SoundLab is calibrated for level using a sound level meter prior to each demonstration. For applications requiring precise control of frequency response, filters can be implemented using the Metric Halo interface, although this is typically not necessary for most demonstrations.

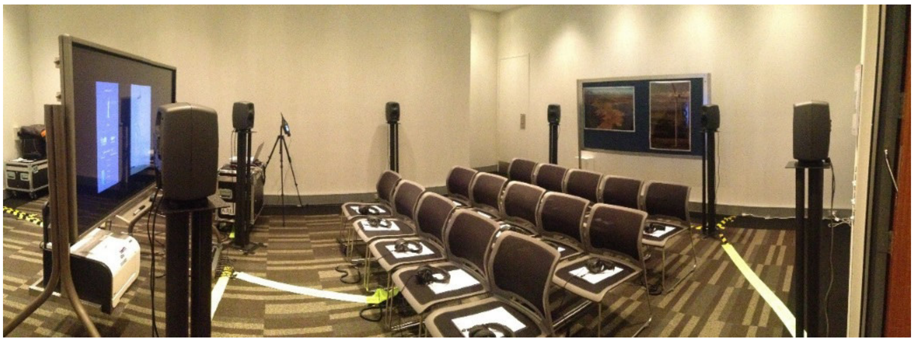

Figure 8 Portable SoundLab set up for group demonstration

The virtual environment of the SoundLab allows for careful comparison between aircraft types (including the ability to switch between aircraft types during a flyover) that is not possible in real life. The effect of noise abatement strategies such as flight path changes can be demonstrated, either by recording real aircraft on different flightpaths, or can be simulated by processing aircraft recordings using a Matlab script to adjust for the changed distance-vs-time (and associated geometric dispersion and atmospheric attenuation) characteristics of the new flight path. This has been used successfully for demonstrations for an airport in the UK, with the entire process of calibration, the playback level and the recordings being peer reviewed by two separate independent consultants.

In particular, the benefit of auralisation is the ability for a listener to consider the subjective response to different aircraft types or flight profiles – especially tonal characteristics such as "whine". This was very apparent in the demonstration when comparing the Boeing 777 and the Airbus A330 which have quite different tonal characteristics (particularly on takeoff/when under power) despite the difference in the average flyover level between these two aircraft types being within 1 dB(A).

7. CONCLUSIONS

Recent experience in the use of auralisation as a transparent approach for demonstrating aircraft noise levels for projects in Australia and the UK has shown the value of auralisation as a consultation tool. By presenting aircraft noise in its simplest form – "how it will sound", without requiring technical acoustic parameters, auralisation offers a tool for informing communities about aircraft noise in an open, technically rigorous manner that satisfies the principles of the *Guidance Material for Selecting and Providing Aircraft Noise Information*. The experience on three airport projects highlights potential opportunities to use auralisation for future research into community perception of aircraft noise.

The measurements for these projects also provide a useful database for comparison with predicted noise levels from the internationally-accepted INM calculation software. Measured aircraft noise at 5 and 10 km from Australian domestic and international airports closely matches the expected noise levels given in AS2021 (and predicted using INM) for most aircraft types.

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