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Aircraft Noise Modelling and Trajectory Optimisation for Reduced Environmental Impacts at Major Australian Airports

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Abstract
The requirements set by the most important Air Traffic Management (ATM) research initiatives (SESAR and NextGen) and environmentally sustainable aviation research initiatives (Clean Sky, and Environmentally Responsible Aviation), aim at lowering operating costs and improving the environmental sustainability of aviation. In line with these requirements, the methodology of using noise modelling and simulation techniques in conjunction with Demographic Distribution Database (D³) and Digital Terrain Elevation Database (DTED), allows the development of novel approaches and algorithms for aircraft trajectory optimisation in the present and likely future airspace scenarios and, in particular, in proximity of airports and densely populated areas. Aircraft noise modelling in major Australian airports is essential in order to understand the noise impacts associated with air traffic, determining the Australian Noise Exposure Forecasts (ANEFs) and to assist in effective airport planning strategies. Based on the statutory requirements prescribed, the aircraft trajectories are optimised to minimize the effects of noise around the airports considering both population and digital terrain data. The key mathematical models for noise and trajectory optimisation are presented. The objective of the noise modelling process is to describe the noise parameters currently adopted for airport design and operations, and to predict values for all relevant future scenarios. Noise analysis and impact mitigation measures are discussed. Quantification of noise at the major Australian airports, including Sydney and Melbourne airports is presented.

Keywords
Aircraft Noise Model, Environmentally Sustainable Aviation, 4D Trajectory, Trajectory Based Operations, Aircraft Noise Management.

1. Introduction
The global air transport industry is foreseen to grow at a rate of 4.7 per cent annually in the near future taking into account factors including population growth, urbanization, emerging markets, technological advancements and environmental impacts (Airbus, 2013). In the recent times, airports have started to cater to both well-established major airlines and Low-Cost Carriers (LCCs) and have become a provider of key infrastructure and services facilitating air travel (Ashford et al., 2013). The key improvement areas identified by the Global and regional aviation organisations for the Australian and global aviation sector are increased safety, capacity, efficiency, cost-effectiveness and environmental sustainability. In order to achieve the set goals, airline manufacturers and airport operators are collaborating to implement sustainable and environmentally-friendly solutions to lower the carbon footprint of the aviation sector. A number of global and regional research initiatives are addressing the Air Traffic Management (ATM) modernisation challenges both in terms of operations and environmental sustainability. The Single European Sky Air Traffic Management Research (SESAR) and the Clean Sky Joint Technological Initiative (JTI) for Aeronautics and Air Transport are the major programmes developing and implementing innovative concepts for the future air transportation in Europe (EU, 2014, JU, 2011). In parallel with the air transport modernisation efforts in Europe driven by SESAR/Clean Sky, the Next Generation Air Traffic System (NextGen) programme and the Environmentally Responsible Aviation (ERA) project by the National Aeronautics and Space Administration (NASA) are driving the modernisation process in the United States (FAA, 2013, Nickol, 2011). To alleviate the environmental impacts caused by the aviation sector and at the same time not compromising on growth of the industry, several targets are defined by the aviation programmes. The Advisory Council for Aeronautics Research and Innovation in Europe (ACARE) for aircraft has identified ambitious goals including reduction of Carbon Dioxide (CO₂) emissions (fuel consumption) by 75% per passenger Kilometre, reduction of Nitrogen Oxides (NOₓ) emission by 90% and reduction of perceived external noise by 65% (ACARE, 2008, ACARE, 2012). Synergies between the SESAR and NextGen concepts of operations are

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explored and one such programme is the Atlantic Interoperability Initiative to Reduce Emissions (AIRE), which aims at the enhancement of energy efficiency, and reduction of aircraft engine emissions and noise by gathering and analysing data from the research carried out in the modernisation programmes (Hotham, 2011, Nieuwenhuisen and de Gelder, 2012, Reynolds et al., 2010). Australian initiatives for sustainability are aligned with those of the Asia-Pacific region with Australia’s involvement in the Asia and South Pacific Initiative to Reduce Emissions (ASPIRE) programme (Hayman, 2009, Shresta et al., 2009). In addition to aircraft emissions, noise exposure around airports is a predominant environmental issue. In an initial investigation, the relationship between noise exposure and fuel efficiency was found to generally involve a trade-off and based on this relation, the Aircraft Noise Design Effects Study (ANDES) concluded that a general rule of thumb is that a 3 dB noise reduction at flyover points (where the noise rewards are greatest) would, on average, increase fuel burn and hence emissions by 5% (ICCAIA, 1994, Penner et al., 1999). This relationship is extendable to other noise measuring points including approach and sideline. However, the trade-off can be balanced to obtain substantial reductions in aircraft emissions and noise by adopting priority based performance criteria. Research results have shown that improvements in the Flight Management System and ATM can directly contribute to noise abatement and help in bringing down aircraft engine emissions (ICAO, 2010, Oxford, 2010). It is also envisaged that optimisation of horizontal and vertical path of the aircraft can lead to 50 million tonnes CO₂ decrease (ICAO, 2010). A number of airports worldwide are currently implementing novel solutions and technologies for improving sustainability including:

- Reduction of gaseous emissions and energy consumption by:
  - Improved use of ground equipment including Ground Power Units (GPU) and Auxiliary Power Units (APU).
  - Decreased surface transport traffic congestions in and around the airport locations.
- Sustainable runway development and aircraft de-icing.
- Landside development and redevelopement by:
  - Increased use of renewable energy, greener vehicular ground transportation systems, improved airport ground access system and transformation of major airports into multimodal transport nodes.
- Airside development and redevelopement by:
  - Increased coordination between Airline Operations Centres (AOC), Air Navigation Service Providers (ANSP) and Air Traffic Management (ATM) systems, implementation of integrated Departure and Arrival Management (DMAN/AMAN), and introduction of pre-departure sequencing and clearance.
- Noise impact reduction by introduction of Continuous Climb and Descent Operations (CCO/CDO).
- Operational improvements including efficient management of congestion and queues, implementation of Airport Collaborative Decision Making (A-CDM), Re-categorisation (RECAT) of wake turbulence and traffic demand peak prediction and analysis methods.

Table 1 summarises the data pertaining to the major Australian airports (Productivity Commission, 2011).

<table>
<thead>
<tr>
<th>Airport</th>
<th>Passengers (millions)</th>
<th>Aircraft Movements (thousands)</th>
<th>Revenue ($ m)</th>
<th>Investment ($ m)</th>
<th>Noise and Flight Path Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>34.5</td>
<td>275</td>
<td>901</td>
<td>227</td>
<td>Yes</td>
</tr>
<tr>
<td>Melbourne</td>
<td>26.0</td>
<td>188</td>
<td>518</td>
<td>137</td>
<td>Yes</td>
</tr>
<tr>
<td>Brisbane</td>
<td>18.9</td>
<td>154</td>
<td>424</td>
<td>151</td>
<td>Yes</td>
</tr>
<tr>
<td>Perth</td>
<td>10.0</td>
<td>81</td>
<td>248</td>
<td>66</td>
<td>Yes</td>
</tr>
<tr>
<td>Adelaide</td>
<td>7.0</td>
<td>72</td>
<td>149</td>
<td>4</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2. Aircraft Noise

The noise produced by aircraft around airports represents an ecological, economic, operational and social problem and affects specifically the communities in the proximity of airports and densely populated areas (Upham, 2003, Whitelegg, 2000). In the context of airport design and redesign, assessment and prediction of aircraft noise plays an important role. Aircraft are, in general, complex noise sources. The number of noise sources of an aircraft differs with respect to its type and the
propulsion system. The noise level perceived as a result of aircraft operations in and around an airport depends upon a number of factors including:

- Types of aircraft using the airport.
- Total number of take-offs and landings on a daily basis.
- Time of day that the aircraft operations occur (day and night).
- Runways that are used (in case of multiple runways).
- Meteorological conditions.
- Airport-specific flight procedures.
- Restrictions on timing of aircraft operations.

The three main sources of aircraft noise are aerodynamic, propulsive and noise from other mechanical, thermochemical and fluid dynamic processes. Aerodynamic noise is produced due to the airflow around the wings including high-lift systems, fuselage, airframe and control surfaces of an aircraft. Propulsive noise is due to the fan, the jet and the core, which includes all the remaining subsystems including compressor stages, combustor and turbine stages (Filippone, 2014). The jet noise is linked to the intense exhaustion of the burnt gases at very high temperature. Landing gear noise is attributed to the vortex-force generated by the quasi-periodic unsteady flow separation behind the different structural components (Casalino et al., 2008). The noise produced by the fan is a result of the superimposition of a wide-band noise and noise with harmonics. In case of compressor noise, which is similar to fan noise, but the harmonics are less emergent due to interaction phenomena. The aircraft noise sources are illustrated in Figure 1. Secondary noise is generated from the primary sound waves as a result of reflections from the aircraft structure and when the receiver is at a sufficient distance, the contributions are merged into a single point source (Zaporozhets et al., 2011). Generally, the atmosphere acts as a low pass filter for the noise propagation spectrum, due to thermo-fluid-dynamics and molecular processes. The noise effect caused by aircraft operations depends on a number of factors including individual listener’s cultural and socio-economic background as well as their psychological and physical situation. The effects of aircraft noise vary from no effect, to minor annoyance, to even potential health hazards (Franssen et al., 2004). Generally noise from departing aircraft is greater than from that of an arriving aircraft since the minimum aircraft and receiver distance is approximately 120 m with a conventional trajectory with a glide slope of 3° (Filippone, 2014). On a departure, the noise level experienced on the ground from a particular aircraft is influenced by the aircraft type and size, Standard Instrument Departure (SID) used, aircraft settings, climb rate and the meteorological conditions.

![Figure 1: Aircraft noise sources.](image)

### 3. Measurement of aircraft noise

The relationship between the acoustic characteristics of the primary and secondary aircraft noise sources and the flight mode parameters must be established for evaluating the noise levels. Planning, developing and evaluation (design and redesign) of airports are dependent on the noise contours obtained around the airport. The varied aircraft types, flight procedures, propulsive systems contribute to the intricacy of the aircraft noise contour assessment process. A huge dataset is generally used for evaluation purposes and as a result, the complexity of the noise model to be adopted also increases.
The measurement of aircraft noise at airports may involve several metrics including (Müller and Mösér, 2013):

- **Assessment of the performance of individual aircraft:**
  - Single event metrics:
    - A-Weighted Sound Exposure Level (SEL / LAE).
    - A-Weighted Maximum Sound Level (LAmx / LASmax).
    - Time Above A-weighted noise level (tLA).
  - Aircraft certification metrics:
    - Effective Perceived Noise Level (EPNL / LEPN).
    - Tone-Corrected Maximum Perceived Noise Level (PNLTM / LPNTmax).
- **Cumulative noise metrics:**
  - Day-Evening-Night Average Level (LDEN).
  - Night Average Level (Lnight).

The aircraft noise metrics defined is obtained on the basis of a number of assessment criteria including:

- **Generic criteria:**
  - Contour area.
- **Site-specific criteria:**
  - Number of people encircled in a certain contour.
  - Number of houses/households encircled in a certain contour.
  - Noise levels in user-defined enforcement points.
- **Dose-response relationships:**
  - Number of expected awakenings due to a single night-time flyover (SEL).
  - Number of expected sleep disturbances, European standard (Lnight).
  - Number of expected sleep disturbances, Dutch standard (Lnight).
  - Number of people being highly annoyed, European standard (LDEN).
  - Number of people being highly annoyed, Dutch standard (LDEN).

Australian Noise Exposure Forecast (ANEF) is the Australian standard for employed for forecasting aircraft noise and it provides a forecast of the cumulative noise effect annually (Burton, 2004). The ANEF also including changes in the weather patterns and airline schedules. The resultant ANEF is a measure of the total noise exposure over a 12-month period averaged on a yearly basis to represent an average annual day aircraft noise exposure level. ANEF contours are given values of 20, 25, 30, 35 and 40 and as the contour value increases, the noise level also increases. According to the Airports Act, the ANEF contour 30 is a significant noise level (BACPL, 2012). N contours supplement the ANEF standard and they better describe the aircraft noise levels. The N contours measure the number of aircraft noise events per day – exceeding 70, 65 or 60 decibels described by: N60 as 100 or more events exceeding 60 decibels per day, N65 as 50 or more events exceeding 65 decibels per day, N70 as 20 or more events exceeding 70 decibels per day and night contours as 6 or more events exceeding 60 decibels per day. In addition to ANEF and N contours, operational noise levels including Australian Noise Exposure Index (ANEI), which is based on historical data and Australian Noise Exposure Concept (ANEC), which is based on forecast data are employed. Figure 2 shows an example of the Noise Monitoring Terminals (NMT) in red circles and runways in and around Sydney airport (Airservices, 2008).

![Figure 2: Noise measurement points in Sydney.](image)
4. Trajectory Optimisation for Noise Mitigation

Aircraft noise guidelines have been developed by national or international aviation organisations including the ICAO guidance in its Circular 205, the Society of Automotive Engineers (SAE) Committee A-21 and the European Union recommended use of the European Civil Aviation Conference - Conférence Européenne de l’Aviation Civile (ECAC-CEAC) Doc. 29 (ECAC, CEAC, 1997, ICAO, 1988, Quindry, 1976). The generation and propagation of aircract noise through the atmosphere is paramount for trajectory optimisation. The optimiser needs to include a mathematical model of aircraft noise to allow the minimisation of perceived noise on the ground. Due to the inherent complexity of frame and aircraft engines, multiple acoustic sources from various locations are generally superimposed together to form an accumulative source of noise. In order to generate an optimal trajectory, the Integrated Noise Model (INM) from the Federal Aviation Administration (FAA) is generally used as a reference model with respect to noise abatement aspects. Noise is calculated based on interpolation of data specified in the Noise-Power-Distance (NPD) table containing empirical measurements for each aircraft type under reference conditions. The INM model uses a grid-based approach and a number of metrics including exposure-based, maximum noise level and time-based are adopted (Boeker et al., 2008). In order to critically evaluate the noise levels, the Aviation Environmental Design Tool (AEDT) developed by the FAA, serves as a multi-purpose framework integrating the INM and the Model for Assessing Global Exposure to the Noise of Transport Aircraft (MAGENTA), a global noise model (Noel et al., 2009). The overall sound level \( L \) is given by:

\[
L = 10 \log_{10} \left( \sum_{i=1}^{n} 10^{L_i} \right)
\]

(1)

where \( L \) is the sum of \( n \) noise levels \( L_i \) all at the same frequency. The sensitivity due to perturbation on the sound level \( dL_i \) on the sound levels \( L_i \) of \( n \) contributes is given by (Filippone, 2014):

\[
L + dL = 10 \log_{10} \left( \sum_{i=1}^{n} 10^{(L_i+dL)} / 10 \right)
\]

(2)

The noise-radius concept is used considering the complexity of aircraft noise modelling based on the aircraft engine type, thrust setting and atmospheric conditions, which have significant impact on the noise magnitude (Zaporozhets et al., 2011). The optimisation of aircraft vertical trajectory with minimum noise impact using analytical jet noise model has been studied (Khardi and Abdallah, 2012). Generally, the INM is a standard approach recognised globally and it is often used as a reference model used in several research studies for noise reduction in addition to avoidance of noise-sensitive area using fly zones. Observer locations (e.g. NMT) in a Three Dimensional (3D) space are used for measuring noise and the noise models employed offer the possibility to refine the noise calculation based on the locations identified strategically. The methodology adopted requires the descriptive data at each observer location and hence a Demographic Distribution Database (D\(^3\)) is used in conjunction with the noise model. The \( D^3 \) model aids in estimating the population in a user defined grid in a global or local scale. Additionally, the Digital Terrain Elevation Database (DTED) is used for taking into account the geographic details. The availability of \( D^3 \) and DTED are specifically important for assessing environmental impact of aircraft noise in the Terminal Manoeuvring Area (TMA). Trajectory optimisation is generally performed to avoid the densely populated areas in and around the airports taking into account the topographical conditions, metrological data and trajectory constraints. The constraints on the trajectory can be ATM operational, airspace, airline, flight parameters and/or aircraft dynamics based constraints. Several studies have been carried out for optimising the aircraft trajectory based on a number of cost functions such as number of sleep disturbances resulting in reduction of noise annoyance on specific regions around an airport (Camilleri et al., 2012, Chircop et al., 2012, Cooper et al., 2012, Gauci et al., 2012, Gu et al., 2012, Navaratne et al., 2012, Pisani et al., 2013, Sammut et al., 2012). Reduced noise procedures implemented are Noise Abatement Departure Procedures (NADP) including NADP1, NADP2, its associated variations, ICAO-A procedure (Filippone, 2014). Steep trajectory approach, spiral trajectories and touch-down displacement principles have been proposed and trialed to reduced noise while landing. Generally, the optimisation or reduced noise is not harmonious with the cost function for minimising other environmental emissions. Reduction in noise by increasing time results in higher fuel consumption and as a consequence, higher emissions (Prats et al., 2011, Torres et al., 2011). Hence a multi-disciplinary, multi-objective and multi-model approach is adopted for optimising the trajectories under conflicting cost functions (Gardi et al., 2014, Gardi et al., 2013, Ramasamy et al., 2013, Ramasamy et al., 2014). Figure 3 illustrates the trajectory optimisation process specific to noise reductions. The cost \( J \) for noise can be expressed in relation to the state vector, \( X(t) \) and control vector, \( V(t) \) as:

\[
J[t,X(t),V(t)] = 10 \log_{10} \left( \sum_{i=1}^{n} 10^{\max_{i}/10} \right)
\]

(3)
Furthermore, advances in navigational technology allow to further mitigate the effects of aircraft noise by using the capability of Global Navigation Satellite System (GNSS) and Flight Management System (FMS) to meet the Required Navigation Performance (RNP) levels and to design more flexible procedures, including curved flight paths (Sabatini et al., 2013a, Sabatini et al., 2013b). Fuel consumption optimisation is achieved by minimising the difference between the aircraft initial and final mass, which is included as the $i^{th}$ Differential Algebraic Equation (DAE) in the three Degree of Freedom 3-DOF aircraft dynamics model. The cost function, $J$ is given by:

$$J_{\text{fuel}} = \int_{t_0}^{t_f} x(t) \cdot x(t_f) \, dt = x(t_f) - x(t_0)$$

$$J_{\text{fuel}} = -\int_{t_0}^{t_f} dm = m(t_f) - m(t_0)$$

where $t_0$ and $t_f$ are the initial and final times, $m$ is the mass of the aircraft, $x$ is the state vector. Considering aircraft emissions, although engine design and relevant factors play a key role in mitigating the total amount of emissions released, emissions from aircraft engines are generally considered as a function of fuel burn, multiplied by a direct emission factor, $\varphi$. Hence, the emission rate defined with respect to emissions, $e$ and time, $t$ is given:

$$J_{\text{emission}} = \int_{t_0}^{t_f} \varphi \cdot e(t) \, dt = (m(t_f) - m(t_0)) \cdot \varphi$$

Based on the cost functions, the total number of trajectories computed is dictated by the total number of priority levels pre-stored in the FMS given by a performance weighting layout. An example of this layout is shown in Table 2. The performance weightings ($K$) are a-priori articulation of preferences agreed by the CDM participants.
Table 2: Performance weighting layout.

<table>
<thead>
<tr>
<th>Priority</th>
<th>Weightings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_{\text{fuel}}$</td>
</tr>
<tr>
<td>Priority 1</td>
<td>$K_{\text{fuel}1}$</td>
</tr>
<tr>
<td>Priority 2</td>
<td>$K_{\text{fuel}2}$</td>
</tr>
<tr>
<td>Priority 3</td>
<td>$K_{\text{fuel}3}$</td>
</tr>
</tbody>
</table>

5. Noise Management

Based on the European Directive 2002/30/EC, the concept of noise management is viewed as a balanced approach wherein international aviation organisations, Governments, aircraft manufacturers, airliner and airport operators focus on the following key areas (EU, 2002, Licitra et al., 2014, Stevens et al., 2010):

- Reduction of noise at the source through aircraft technology improvements.
- Compatible land-use planning by moving incompatible land users (hospitals and schools) away from the airport environment and flight paths, and to encourage compatible land users (industry) to locate around the airport facilities.
- Increased adoption of noise abatement procedures. The size and shape of the noise contours around an airport are influenced by both airborne and ground-based operational procedures. In Australia, the major airports work together with Airservices Australia and airline operators to implement these procedures and thus minimising the number of people affected by aircraft noise. An example is directing aircraft to utilise flight paths that pass over rural or semi-rural areas during peak hours, or spreading the use of all available flight paths (departure and arrival) to lessen the intensity of aircraft noise levels. In this case, from the ATM technology point of view, optimisation of the aircraft engine setting and trajectory definition to avoid the noise-sensitive area can significantly contribute to the execution of noise abatement procedures and restrictions. Specific NADP have been implemented for both noise-sensitive and noise-insensitive areas.
- Introduction of operating restrictions such as reduced access or prohibition of noisy aircraft and introduction of night time flight restrictions (Morrell and Lu, 2000).

Airservices Australia has set up permanent noise monitoring equipment in a number of suburbs around major airports and the online tool WebTrak can be used to get data on aircraft noise levels (Airservices, 2012). Additionally, the noise abatement committee, community aviation consultation group and aircraft noise ombudsman are involved in the noise management process.

Figure 4: Aircraft noise management measures. (FAA, 2010)
Other noise management strategies are sound insulation programs implemented in schools and institutions, installation of noise barriers to shield noise-sensitive land uses from aircraft including installation of ground engine run up enclosures (GREs), preferential runway use designs to direct aircraft operations on particular runways so that the noise levels can be minimised, cockpit procedures designs to reduce the noise levels experienced on the ground, flight track geometry changes and airport layout improvements for taxi, ground, departure and arrival operations (Miller et al., 2008). Figure 5 illustrates the jet aircraft trajectory plots for arrivals and departures in Sydney, Melbourne, Brisbane, Perth and Adelaide airports (Airservices, 2014c, Airservices, 2014e, Airservices, 2014b, Airservices, 2014d, Airservices, 2014a).

Figure 5: Jet aircraft trajectory plots for Sydney, Melbourne, Brisbane, Perth and Adelaide airports.
The N70, N80 and N90 values are obtained for each NMT in all the quarters of 2013. N70 is calculated by dividing the total number of Correlated Noise Events (CNE), equal to or greater than 70 dBA detected during the quarter by the number of days in the quarter that the NMT is in operation. In a similar manner, N80 and N90 are the CNE based noise thresholds and correspond to 80 dBA and 90 dBA respectively. The noise levels measured at each NMT location in and around major Australian airports including Sydney, Melbourne, Brisbane, Perth and Adelaide is shown in Table 3 respectively (Airservices, 2014i, Airservices, 2014g, Airservices, 2014h, Airservices, 2014j, Airservices, 2014f). Optimising the aircraft trajectory (flying away from the residential houses) has resulted in halving the noise by 10 dBA in Canberra airport.

Table 3: Noise levels measured at NMT locations in 2013.

<table>
<thead>
<tr>
<th>NMT Location</th>
<th>Noise Parameters</th>
<th>2013 Q4</th>
<th>2013 Q3</th>
<th>2013 Q2</th>
<th>2013 Q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runway 34L Threshold Sydney Airport</td>
<td>N70</td>
<td>338.5</td>
<td>373.0</td>
<td>342.9</td>
<td>336.4</td>
</tr>
<tr>
<td></td>
<td>N80</td>
<td>233.1</td>
<td>247.9</td>
<td>239.3</td>
<td>234.7</td>
</tr>
<tr>
<td></td>
<td>N90</td>
<td>37.0</td>
<td>27.1</td>
<td>42.4</td>
<td>39.5</td>
</tr>
<tr>
<td>Bulla (Near Melbourne Airport)</td>
<td>N70</td>
<td>243.8</td>
<td>182.2</td>
<td>203.4</td>
<td>240.4</td>
</tr>
<tr>
<td></td>
<td>N80</td>
<td>30.9</td>
<td>23.4</td>
<td>48.5</td>
<td>46.4</td>
</tr>
<tr>
<td></td>
<td>N90</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Cannon Hill (Near Brisbane Airport)</td>
<td>N70</td>
<td>128.3</td>
<td>117.9</td>
<td>78.6</td>
<td>107.0</td>
</tr>
<tr>
<td></td>
<td>N80</td>
<td>1.4</td>
<td>1.2</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>N90</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Brooklyn Park (Near Adelaide Airport)</td>
<td>N70</td>
<td>129.6</td>
<td>138.8</td>
<td>126.5</td>
<td>123.0</td>
</tr>
<tr>
<td></td>
<td>N80</td>
<td>111.9</td>
<td>110.0</td>
<td>100.8</td>
<td>107.5</td>
</tr>
<tr>
<td></td>
<td>N90</td>
<td>55.6</td>
<td>47.2</td>
<td>43.1</td>
<td>53.8</td>
</tr>
<tr>
<td>Queens Park (Near Perth Airport)</td>
<td>N70</td>
<td>160.8</td>
<td>167.3</td>
<td>160.1</td>
<td>149.5</td>
</tr>
<tr>
<td></td>
<td>N80</td>
<td>16.5</td>
<td>13.5</td>
<td>12.5</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>N90</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The noise levels obtained are used for airport planning and redesigning strategies such as the addition of the third runway in Melbourne airport. The proposed third runway redefines the manner in which noise will be perceived around the airport. Figure 6 illustrates the noise forecast for the proposed third runway (current noise level in orange and expected in blue) (Melbourne Airport).

Figure 6: Aircraft noise forecast including third runway for Melbourne airport.

6. Conclusion

A number of efforts are currently undertaken by international aviation organisation, airlines, airports, aircraft manufacturers and Governments to address the environmental effects caused by aviation. In line with the requirements defined by the policy makers and sustainability programmes, the reduction of environmental impacts including aircraft noise in and around airports is considered as one of the key elements in mitigating the detrimental effects. The primary and secondary sources of aircraft noise and the various measurement metrics used for quantification purposes were discussed. The noise modelling approaches and algorithms for aircraft trajectory optimisation adopted to reduce noise at the vicinity of
thee airports were presented. Noise monitoring and management measures were discussed outlining the noise levels of the major Australian airports. In the future studies, efforts are required to further develop noise mitigation strategies to better protect the communities around airports, implement legalisation measures and to introduce improved noise abatement procedures.

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