Options for Aircraft Noise Reduction on Arrival and Landing

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Abstract

This paper demonstrates the noise reduction potential from modified final approach and landing procedures of commercial aircraft. A conventional trajectory is compared with a steep approach with a 4.5-degree glide slope (first option), and with a displaced landing, wherein an aircraft approaching with a 3-degree slope is allowed to land with a second threshold (second option). The reference airplane is the Airbus A320-211. Examples of noise footprints are shown for generic cases of constant ground impedance. It is shown that a noise reduction of −1 EPNL reduction is possible with a 450 m landing displacement or with a 3.5 degree glide slope. Noise reduction occurs below the flight track and moderate lateral distances. It is also shown that at larger lateral distances, 200 m or above, the noise level increases compared to the reference case. The ground model has been extended to include variable impedance and actual airfields. Finally, it is shown that an Embraer E195 model landing on a steep trajectory has a reduced noise almost everywhere in a selected region around the airfield.

1 Introduction

There is increased interest in the operational changes of commercial aircraft to reduce noise and to improve airport capacity. The rationale is that operational changes can be implemented in a shorter time frame than the development and entry into service of a new generation of commercial airplanes, at a relatively lower cost.

Arrival and departure are different phases that require different considerations. In this paper we shall be concerned with arrival and landing trajectories only. This area of research focuses on three different concepts: 1.) steep approach, with glide angles above the conventional 3 degrees; 2.) displaced landing; 3.) continuous descent approach. In principle, we could include a slower air speed, but this is related to aircraft stall and to the ability to produce lift, which is a combination of high-lift system design and operation. Delayed deceleration is one option that has been assessed recently. A fair comparison between trajectories can only be made when flight times and fuel consumption are taken into account, because an increase in any of these quantities might not be an acceptable solution to airline operators.

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Whilst the problems involved require complete understanding of flight safety, air traffic management, trajectory management and pilots workload, a key issue is whether any operational changes have real benefits.

Some industry briefs emphasise the need to restrict noise as much as possible within the airport area. In fact, aircraft noise remains a pressing issue because of the expansion of air traffic to early- and late-hours of the day, and the fact that many airfields are now encroached by residential areas. London City airport (IATA: LCY) already requires steep final approaches at $\gamma = 5.5$ degrees glide slopes, something which is only feasible with smaller airplanes. The standard approach is done on a 3-degree glide slope, unless there are special requirements for obstacle avoidance (tall buildings and mountains). There is evidence that a 3.2 degree final approach yields modest benefits.\(^2\)

A displaced landing is done at the conventional glide slope, but touch-down is downstream the runway threshold, as illustrated in Figure 1. For a displaced landing, there must be sufficient field length to bring the aircraft to a halt. For example, Frankfurt airport (IATA: FRA) has three 4,000 m long runways, and is already capable of operating dual thresholds to increase capacity under a scheme called High Approach Landing System/Dual Threshold Operation\(^3\). A similar situation exists at Tokyo Narita, where a displacement of 750 m is allowed on runway 34L. Earlier studies by Verbeek\(^4\) focussed on the increase of landing capacity of a runway with dual-threshold, in particular on issues of wake dynamics and aircraft separation, with the view of improving noise impact around the airfield.

An analysis shown by Hileman et al.\(^5\) for a conceptual wing-body aircraft demonstrated the noise reduction possibilities by a combined steep-descent (3.9 degrees) and a displaced threshold (1,200 m). The authors contend that their conceptual aircraft design would only be heard within the confines of the airport, which would extend 1,000 m beyond a 3,000 m runway. Critically, in that study the ground reflection was empirically corrected to a constant +3 dB. The ground has an important effect and cannot by dealt with with a simple algebraic correction. Steep descents were also considered by Antoine & Kroo\(^6\) for a conventional aircraft configuration optimised for minimum environmental impact.

With regards to continuous descent, there has been more research. For example, Clarke et al.\(^7\) contend that such a procedure can decrease the peak noise level by as much as 7 dBA. This procedure is no different from the ones considered in this paper at altitudes below 1,500 feet.

The accurate determination of these operational changes requires a large number of microphones
on the ground, to make sure that the benefits are uniform across the airfield. Only sparse noise measurements exist on pre-defined areas. One exception is the work of Ishii et al.\textsuperscript{8}, in which it is shown that measurements were taken over a 4.4 km\textsuperscript{2} grid with a microphone resolution of 400 m. Therefore, direct comparisons of noise footprint predictions with measurements are currently not possible. However, notional noise footprints are routinely produced by aircraft manufacturers and airports to assess the long-term noise impact, using best-practice computer codes such as INM\textsuperscript{9}.

The approach used in this study is based on a scientific method for aircraft noise prediction, as discussed in the next section. Practical methods such as INM are fast enough to produce long-term averages around an airfield. By contrast, the present approach provides comprehensive data for a single flight trajectory, including noise breakdown from the different noise sources, useful for detailed engineering analysis.

The analysis that follows discusses the noise emission and propagation at typical commercial airfields. Other aspects such as airport capacity, safety of the operational procedures, and instrument landing must be subject of a separate study and are not addressed in this contribution.

2 Aircraft Noise Simulation

The aircraft noise simulation presented here is based on a simplification at the basic level of noise source generation, as discussed in earlier papers. This simplification produces rapid solutions to otherwise complex physical problems in stochastic external environments. The development of the computer model is described in previous papers\textsuperscript{10;11;12}. Ref.\textsuperscript{10} provides a review of the state-of-the-art of aircraft noise prediction and Refs.\textsuperscript{13;14;15} serve as a validation with fly-over data for several airplanes.
An earlier paper addressed the viability of steep descents from the aerodynamic point of view, and demonstrated that there are limits to the glide slope: \( \gamma = 4.5 \) degrees is a realistic value for an Airbus A320-class of aircraft. A typical trajectory on landing is shown in Figure 2, where the simulated values of net thrust (FN), engine rpm (N1\%) and true air speed (KTAS) are plotted against flight time. Some key events are also shown, such as landing gear and flap deployments (these events are instantaneous, rather than continuous).

![Figure 2: Typical events in a landing trajectory, including instantaneous changes in configuration.](image)

Briefly, the simulation method is a combination of semi-empirical and physics-based models built around models for the airplane and the aero-thermodynamics of the power-plant (gas turbine engines and propellers). The noise models are coupled with the flight mechanics, so that the correct parameters are exchanged between the various sub-models. In particular, the exchange of parameters include the engine state (over 20 parameters across the engine), the airplane speed, position and configuration, and the external atmospheric conditions. The accuracy of the final noise estimation is due to a combination of factors, which may include — critically — inaccuracy of any of the underlying models, from the geometry to the aero-thermodynamics to position or configuration errors. The noise prediction itself is split between noise sources and acoustic wave propagation. Since the propagation of acoustic signals takes places over long distances with possibly variable external conditions (atmosphere, winds, ground properties) long-range noise prediction must be viewed with caution. The approach described sacrifices several details, from the configuration.
to the physics, in return for providing general trends that are sufficiently accurate for engineering purposes, for numerical optimisation, for decision making and more. The overall accuracy is limited by the weakest link in the computational chain, which may or may not be the noise prediction itself, as previously demonstrated\textsuperscript{14}.

Noise simulation methods currently in use include the Integrated Noise Model\textsuperscript{9} and derivatives thereof. These methods are fully empirical and rely on databases to predict aircraft noise. For example, in INM extrapolation of noise at lateral microphone positions is done with an ANSI standard\textsuperscript{17} — a method that is not comparable with the numerical solution of the wave equation used by our model.

3 Results and Discussion

The airplane model used for the noise prediction is an Airbus A320-211 powered by CFM56-5C4 turbofan engines, with manufacturer’s weight variant V16 (MTOW = 73,500 kg).

The first step is a verification that the noise predictions are reasonably accurate. For this purpose, we use flyover noise data described in Ref.\textsuperscript{15}. Figure 3 shows a comparison between measured data and predicted noise level for the reference aircraft on a straight landing trajectory with $\gamma = 3$ degrees. The microphone is approximately below the flight path, at a distance estimated as 1,700 m from touch-down. LAS denotes the A-weighted noise level recorded in slow mode by a noise meter. The predicted noise peak is slightly below the experimental value, but the overall trend of the noise level is acceptable in consideration that the measurements were taken in an open field.
Figure 3: Comparison between noise predictions and flyover measurements for an Airbus A320-211 on a landing trajectory, fully described in Ref. 15.

3.1 Steep-Descent and Displaced Landing

The flight conditions at the start of the final approach are as follows: mass \( m = 58,820 \) kg, altitude of 1,500 feet above the airfield; airfield altitude \( z = 70 \) m (240 feet); wind speed at the airfield \( V_w = 3.9 \) kt (headwind, included in the noise propagation); constant relative humidity = 70%, standard day. No background noise is included, and no wing-fuselage noise scattering has been accounted for. Furthermore, the fan liner boundary layer is switched to true, with the APU noise model operating. The ground was assumed to be flat and covered in grass (flow resistivity \( \sigma_e = 0.4 \cdot 10^5 \) N s/m\(^4\)); the noise propagation model was that of Rasmussen/Almgren, modified and extended as described in previous work.

The results are shown in Figure 4a and Figure 4b, for the effective perceived noise level (EPNL) and the A-weighted maximum sound pressure level (LAm\(^\text{ax}\)), respectively. The black dot denotes the reference point, which refers to the conventional landing trajectory and touch-down point at the runway threshold. On the horizontal axis there is the touch-down displacement.

Table 1 shows a summary of key test cases. Note that the flight trajectories of Case 1 and Case 3 are distinguished not only from the glide slope, but also on the true air speed, descent rate, configuration and flight time. All the trajectories considered start from 1,500 above ground level. The terminal point is always on the ground, with the airplane having slowed down to a ground speed < 25 m/s. The flight time of the steep descent is shorter because all the trajectories start at the same altitude. For Case 1 and Case 2 the only difference is the touch-down point. Note
that the simulated flight time is included in the table. A steep trajectory starting from the same altitude as a conventional trajectory is executed in a shorter time. This may have consequences on the total noise exposure and engine exhaust emissions (this a separate problem which could be included in a multi-disciplinary analysis).

Table 1: Summary of reference test cases; see also Figure 1.

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\gamma = 3$ degrees</td>
<td>130.0</td>
</tr>
<tr>
<td>2</td>
<td>$\gamma = 3$ degrees, displaced 1,500 feet</td>
<td>130.0</td>
</tr>
<tr>
<td>3</td>
<td>$\gamma = 4.5$ degree</td>
<td>96.2</td>
</tr>
</tbody>
</table>

Noise differences from this case have been plotted. Figure 7a shows the difference

$$\Delta \text{EPNL} = \text{EPNL}_1 - \text{EPNL}_2$$  \hspace{1cm} (1)

Figure 7b shows the difference

$$\Delta \text{EPNL} = \text{EPNL}_1 - \text{EPNL}_3$$  \hspace{1cm} (2)

The white areas denote positive changes in noise metric, i.e. the noise predicted in this areas increases over the reference Case 1, as discussed below. The EPNL increase is estimated to as much as 3 dB EPNL about 1,000 m away from the flight track. The first thing to note is that the
gains are mostly below the flight path, and laterally for up to 200 m. At distances $|y| > 0$ the gains are reversed, as a small increase in noise level is predicted. This is a propagation and scattering effect, which is rather sensitive to the numerical method used for the prediction of long-range propagation. In the case shown in Figure 8, there is a positive difference $\sim 1$ EPNL.

An analysis of the flight trajectories indicates that the steep approach takes place with a higher speed. When the airplane passes $x = -2,500$ m on a 4.5-degree slope, it has a higher speed (+7 kt) and a higher flap setting (FLAP3 instead of FLAP2). This configuration leads to higher noise level at low- to mid frequencies, which tend to propagate further. The increase in the source-receiver distance is not by itself sufficient to guarantee a decreased noise level. However, the event described
Figure 6: EPNL predictions along the flight track, $y = 0$.

Figure 7: Changes in predicted EPNL with a combination of steep glide (4.5 degrees) and landing displacement (1,500 feet/450 m). White areas represent an increase in noise level.

is known to occur at take-off/departure$^2$, when different noise abatement procedures may lead to local increase or decrease in noise level.
A previous investigation has indicated that the differences in results achieved by using two different noise propagation models (the present one and a linear ray tracing), are of the order of $\sim 0.2$ EPNL in most cases, with discrepancies increasing when the aircraft is close to the ground, or when $y/z$ is very small (grazing angles) or when the propagation distances are large, $>1$ km.

This statement is further demonstrated by the results shown in Figure 9. This figure displays the predicted noise metrics at a position $x = -2,500$ m (with microphones moving sideways) up to a distance $y \simeq 1$ n-mile. Two different noise propagation models have been implemented in the computer program: a wave equation model, from Rasmussen$^{18}$ and Almgren$^{19}$ and a linear ray tracing method$^{20}$. In particular, Figure 9, referring to the A-weighted maximum sound pressure, indicates that over a distance greater than 500 m laterally, there is no difference between the two methods, and oscillations in the SPL could be due to numerical issues.

Direct comparisons with the ANSI-SAE$^{17}$ standard attenuation model cannot be done, because this standard only returns an attenuation value independent of the frequency, and regardless of the ground properties. In any case, the EPNL calculated with this standard appears to taper off at large lateral distances.

Back to the analysis of the noise footprint, a difference of over $-6$dB is found in the comparison between the standard trajectory and the steep trajectory, but only in small areas below the flight track, as shown in Figure 10. This finding is similar to the results of Clarke et al.$^7$, who considered a continuous descent approach.
Figure 9: EPNL and LAmax predictions across the flight track, $x = -2,500$ m; the vertical dashed line at $x = 450$ m is the Federal Aviation Regulation (FAR) distance for sideline noise certification.

3.2 Noise Mapping at Airfields

The previous analysis showed typical isolines on a flat grid characterised by fixed-impedance ground. The next step in the model is to use variable-impedance ground properties, along with elevation data to construct a detailed approximation of the airfield and its surrounding area. Once this is done, the noise propagation model is modified to calculate the position of the bounce points of the acoustic waves. At these points we associate the correct ground characteristics, and known values of the impedance and other properties.

To begin with, an airfield model is generated with a computer program that uses geographical information from Omniscale*. The result is a Cartesian grid, with minimum resolution of $\sim 30 \times 30$.

Each grid cell is associated to an RGB-value (Red-Green-Blue), which is then parsed into a set of ground properties: wetted/area & body of water, grass, forest, brown fields, built-up area, tarmac & asphalt, railway, etc. More specifically, we derive a database, valid for all cases, that appears as:

- white roads and taxi strip 0
- red motorways 1
- blue rivers/lakes 2
- green fields 3
- green woods 4
- brownish fields 5

Each integer attribute is then associated to a value of the ground impedance. Finally, the geographical map is transformed into an impedance map, an example of which is shown in Figure 11 for London City airport and its surrounding region.

In principle, aircraft noise could be computed at each point of this map. However, this is extremely time consuming (it takes 20-30 seconds on a desk-top computer to calculate the noise at each grid point, in absence of wind; presence of wind shear can increase computing times by a factor 10 or more). Instead, it is possible to select sub-zones of interest to investigate the effects of community noise, such as the rectangular zone indicated in Figure 11. The zone straddles the river and is 3-km long to the East of the runway, under the arrival flight path. A sub-zone to the East of the airfield is noted by a rectangular box, along with the flight track.

It was found from numerical tests that in the absence of complex topographical details, this
level of resolution is not needed; grid cells of 50 × 50 m are sufficient, and good results can be obtained with grid resolutions of 60 to 70 m.

There is the possibility of adding some basic acoustic barrier effects, if any such barrier is known to exist between the reflection of the acoustic wave and the noise receiver. Within each grid cell, it is not possible to discern differences in elevation or topographical details. Therefore, each grid cell is associated to a fixed ground impedance. Some topographical corrections to noise propagation are possible in a few instances, for example shielding offered by trees, forested areas, dense foliage, tall grass and virtually infinite barriers. These corrections have not been considered in the results shown below.

This airfield in Figure 11 is too short (1,500 m) to consider displaced landings. Thus, we consider the comparison between standard and steep trajectories, with \( \gamma = 4.5 \) degrees, as in the previous example. The flight trajectories have been stopped as the aircraft touches down on the runway. The ground run has not been included in the simulation to avoid unresolved numerical difficulties arising from noise propagation close to the ground. As in the previous case, we calculate the noise difference between the two trajectories. In this instance we have a variable-impedance ground, and minor obstacles considered (trees and small buildings up to a height of 4 m).

The sub-zone to the East of the airfield straddles through the river Thames. To speed-up the computations, ground impedance values corresponding to bodies of water are deselected, and all noise metrics are set to zero at those grid points. In this instance, about 23% of computing time is saved. The built-up area is estimated at just below 20%. This zone has been modelled with cell sizes 49.5 × 79.8 m. In this instance the airplane model is the Embraer E195 with CF34 turbofan engines.

The noise level difference between the conventional and the steep approach for this zone is shown in Figure 12, where the runway is to the West across the river. For completeness, we show a map of the ground impedance (Figure 12a), and the noise map for the conventional approach at 3 degrees (Figure 12b). The blanked areas refer to grid points identified as “water” (the river and other unnamed bodies of water). Differences of over \(-6\) EPNL have been predicted below the flight track and for lateral distances up to 200 m. However, the pattern is rather complex and not all areas show equivalent reductions in noise exposure. At lateral distances beyond the ones shown, there are local increases in noise exposure, as indicated in the generic case shown in Figure 8.

The effect of ground impedance alone is estimated as \(\pm 0.1\) dB on the A-weighted maximum
Figure 12: Simulated noise level on a selected area East of London City airport between a conventional and a steep approach. The arrow denotes the flight track. White areas are field points discarded from computation.
4 Conclusions

Noise reduction is achieved in small incremental steps, and landing trajectory optimisation is one of those strategies that could be beneficial to the overall environmental impact. The analysis shown in this contribution indicates that there is scope for noise reduction on arrival with at least 1 EPNL gain by changes in operational practices, which would have to be tested, implemented and fully assessed from the point of view of flight safety. A landing displacement of 1,500 feet (≈450 m) would lead to a noise reduction of −1 EPNL at the conventional glide slope. Alternatively, to achieve the same noise reduction the glide slope would have to increase to almost 3.5 degrees. A 1,500 feet (450 m) extension of the runway to accommodate larger aircraft would be required.

The noise reduction is not uniform across the ground, and due to the peculiarities in noise radiation, propagation, scattering and ground effects, there can be local increases in noise level, as demonstrated by using two independent noise propagation models. There is a need for accurate measurements and predictions of lateral noise propagation over long distances. This is required to dispel any doubt arising from the reversed gains at community locations.

A numerical method for a realistic airfield has been developed as part of the analysis proposed. Although further developments are possible, the method can produce detailed noise exposure maps around realistic airfields, and allows parametric analysis of different approach trajectories.

Acknowledgments

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