Environmental Research and Consultancy Department

A Low Noise Arrival Metric

CAP 2302

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Executive Summary

A major government review of noise from arriving aircraft, published in 1999, identified that the use of Continuous Descent Operations (CDO) was the primary means of reducing noise experienced on the ground beneath arriving aircraft. The report recommended the development of a new code of practice to promote the use of CDOs and to monitor compliance. This was subsequently published in 2002 and a second edition published in 2006.

Since the early 2000s, the designated London airports have regularly reported operational compliance with the CDO definition on a monthly and annual basis. Under the current CDO definition, the designated London airports have reached and maintained high compliance rates.

In 2017, preliminary research performed by CAA’s Environmental Research and Consultancy Department (ERCD) identified that the existing CDO definition was not sufficiently sensitive to provide an effective noise measure. The current CDO definition focuses on the avoidance of prolonged level flight. This presents the following issues:

- Permittance of shallow angle approaches which are classified as CDO, and which could be noisier at certain points on the approach compared to a traditional non-CDO approach.
- On newer aerodynamically efficient low drag aircraft (e.g. A350 and B787-8) it may not be possible to deliver optimal low noise arrivals within the existing operational constraints and the current CDO definition. These aircraft types may require shallower descent segments or level flight during the initial approach (at higher altitude) in order to reduce speed on approach and remain in a Low Power/Low Drag (LP/LD) configuration whilst complying with CDO requirements.

The study analysed approach performance for four aircraft:

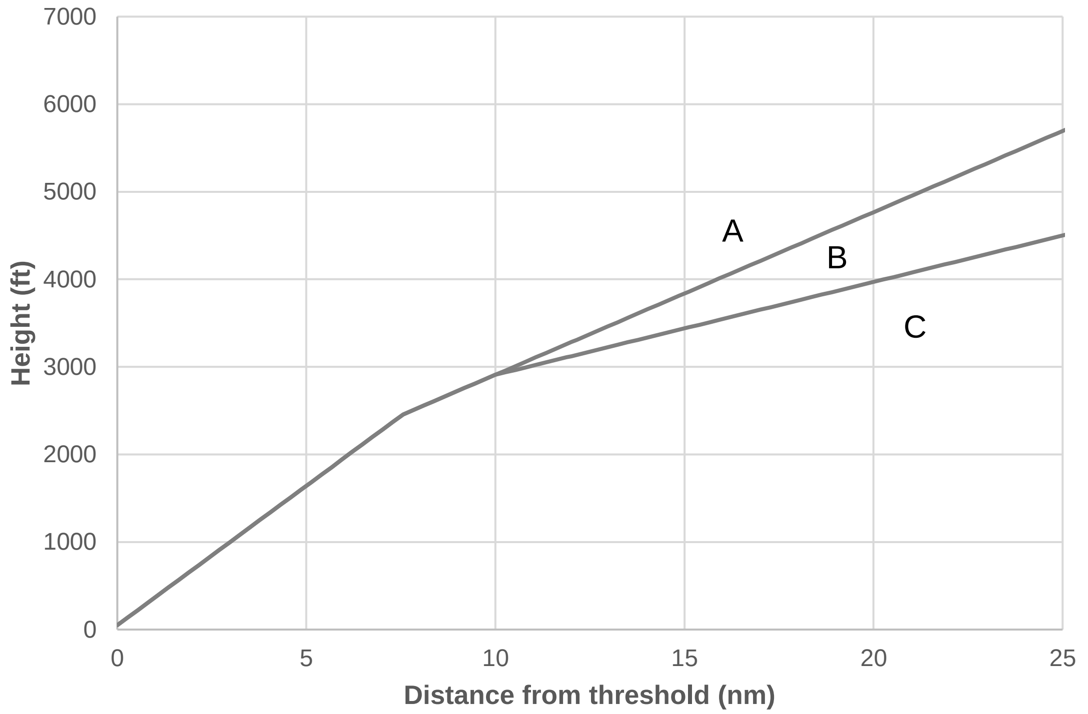
- Airbus A320
- Airbus A380
- Boeing 787-8
- Bombardier Dash 8

Of the aircraft studied, it was found that the Boeing 787-8 is the most difficult aircraft to slow down whilst descending because it has the lowest drag. As a result, further analysis was only undertaken for the Boeing 787-8 and is presented in the report. The analysis found that:

- For modern aircraft types and current operational speed constraints, optimum noise is achieved for intermediate approach angles around 2.5 degrees

- To achieve a 3 degree intermediate angle requires additional drag, which generates additional airframe noise and additional thrust when flying at constant speed, increasing noise when compared with intermediate approach angles of around 2.5 degrees
- Shallow angle CDO profiles significantly increase noise compared with the optimum intermediate approach profile
- Short level segments at heights of around 6,000 ft, when used to decelerate an aircraft at idle power, result in little noise increase relative to the optimum profile, whereas level segments flown at constant speed close to the Instrument Landing System (ILS) intercept increase noise for the entire intermediate approach phase (10-20 NM from touchdown)
- Shallow angle CDO profiles are noisier than non-CDO approaches with steeper intermediate approach angles

These insights led to the development of height-based criteria for a low noise arrival metric that would incentivise increased initial/intermediate descent angles, but not to the extent that would necessitate any changes in speed control or aircraft configuration. To better incentivise low noise arrival performance, two height boundary conditions are proposed as illustrated below, creating three height zones or low noise categories.



Quantitatively, the upper and lower boundaries are defined as:

Upper boundary:

- A line starting at 50 ft height above the landing runway threshold, extending out to 7.5 nm at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5 NM and 10 NM

- A line at an angle of 1.75 degrees between 10 NM and 6,000 ft altitude above mean sea level (AMSL)

Lower boundary:

- A line starting at 50 ft height above the landing runway threshold, extending out to 7.5 nm at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5 NM and 10 NM
- A line at an angle of 1.0 degrees between 10 NM and 6,000 ft above mean seal level (AMSL)

Testing indicates that the criteria would rate 45-50% of arrivals in the optimum category, with around 15-20% of arrivals in the second category and 35-40% in the lowest category.

The following recommendations are made:

- Monitoring systems should be developed to implement the proposed low noise arrival metric definitions, and be appropriately validated.
- Concurrent monitoring of CDO and low noise metric performance should be undertaken. The identification of proportions of flights classified as both CDO and non-CDO, within the three low noise arrival categories should be assessed and reviewed with a view as to whether the existing CDO criteria should be incorporated into the proposed low noise arrival metric definitions or remain separate.
- Recognising the current inability to monitor LP/LD performance, encourage development of automated systems to monitor landing gear deployment.

Contents

Chapter 1

Introduction

From as early as 1978, CAA studies[1] have identified best practice measures to reduce arrival noise in the form of Continuous Descent Operations (CDO), which aim to keep aircraft higher for longer during their approach, and Low Power/Low Drag (LP/LD) procedures, which maintain a more aerodynamic aircraft configuration for longer. A CDO is commonly referred to as a Continuous Descent Approach (CDA) in the UK, which is typically measured from an altitude of 6,000 ft. However, the term CDO is used throughout this report in keeping with international usage.

A major government review of noise from arriving aircraft, published in 1999[2], identified that the use of CDO was the primary means of reducing noise experienced on the ground beneath arriving aircraft. The report recommended the development of a new code of practice to promote the use of CDOs and to monitor compliance. This was subsequently published in 2002[3] and a second edition published in 2006[4].

Since the early 2000s, the designated London airports have regularly reported operational compliance with the CDO definition on a monthly and annual basis. Under the current CDO definition, the designated London airports have reached and maintained high compliance rates. However, in 2017, preliminary research performed by the CAA's Environmental Research and Consultancy Department (ERCD) identified that the existing CDO definition was not sufficiently sensitive to provide an effective noise measure.

The current CDO definition focuses on the avoidance of prolonged level flight. This presents the following issues:

- Permittance of shallow angle approaches which are classified as CDO and which could be noisier at certain points of the approach compared to a traditional non-CDO approach.

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[1] CAA Paper 78002, A Technical Evaluation of Initial Trials of Quieter Approach Procedures at London (Heathrow) Airport Summary Report, Civil Aviation Authority, February 1978.

[2] Noise from Arriving Aircraft: Final Report of the ANMAC technical working group, Department of the Environment, Transport and the Regions (DETR), December 1999.

[3] Noise from Arriving Aircraft: An Industry Code of Practice, Department for Transport, Local Government and the Regions (DTLR), et al., February 2002.

[4] Noise from Arriving Aircraft: An Industry Code of Practice, 2nd Edition, Department for Transport (DfT) et al., November 2006.

- On newer aerodynamically efficient low drag aircraft (i.e. A350 and B787-8) it may not be possible to deliver optimal low noise arrivals within the existing operational constraints and the current CDO definition. These aircraft types may require shallower descent segments or level flight during the initial approach (at higher altitude) in order to reduce speed on approach and remain in a LP/LD configuration whilst complying with CDO requirements.

The high compliance percentage associated with the current CDO definition means that there is no further incentive or reward to further reduce noise from arriving aircraft. An alternative, low noise arrival definition would incentivise additional reductions in approach noise and support the development of more advanced navigation arrival procedures, whilst also adapting to allow for the optimum low noise arrivals on new aircraft types. An alternative solution would potentially deliver further improvements in noise reduction, enable environmental benefits and help aviation to grow sustainably.

In 2017, a national cross-industry project was established to develop a new low noise arrival metric which would supplement the current CDO definition and provide a new target to reduce arrival noise in the near term on both the current in-service fleet and new aircraft types. A new low noise arrival metric would take into account the latest understanding on aircraft noise modelling, reflecting the increasing importance of airframe noise as jet noise is reduced, accommodate LP/LD operations, and focus on optimising approaches within the main area of concern for approach noise; between 7,000 ft and 1,800 ft above aerodrome level.

In the long-term, the outcomes of this study will inform the design of future Performance Based Navigation (PBN) arrival procedures to minimise noise impacts.

This study was sponsored by the Future Airspace Strategy (FAS) and overseen by Sustainable Aviation (SA). CAA ERCD were approached to undertake the technical aspects of the study, whilst NATS tested the criteria using historic radar data.

The report is structured as follows:

- Chapter 2 presents the background to the study
- Chapter 3 presents the study methodology
- Chapter 4 presents the results of the arrival performance and noise analysis
- Chapter 5 presents the proposed low noise arrival metric
- Chapter 6 presents the conclusions and recommendations

Chapter 2
Background

Continuous Descent Operation

The arrivals code of practice measures an arrival as a CDO if it contains, below an altitude of 6,000 ft:

- no level flight; or
- one phase of level flight not longer than 2.5 nautical miles (NM)

In order to set aircraft up for approach to landing, Air Traffic Control (ATC) descend aircraft and reduce their speed. During busy periods, arriving aircraft can be directed by ATC to holding stacks.

For a typical non-CDO approach, an aircraft would be given clearance by ATC from the bottom level of the holding stack (normally a Flight Level equivalent to 7,000 ft) to descend to an altitude of typically 3,000 ft and decelerate from the holding speed of 220 kt down to 180 kt. The aircraft would then be required to fly level for several miles before intersecting the 3 degree glide path to the runway. During this period of level flight, additional engine power would be required to maintain level flight at a constant speed, and the aircraft noise source would be closer to the ground than would have been the case for a CDO approach.

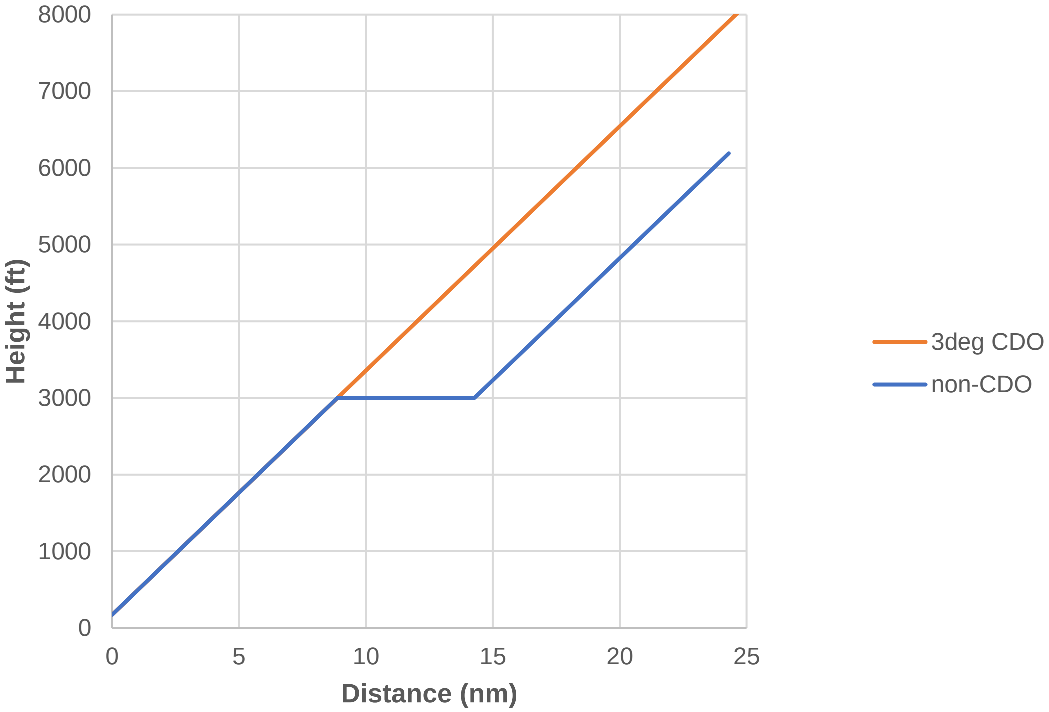
In contrast to a non-CDO approach, a CDO approach is flown when the aircraft stays higher for longer, descending continuously from the level of the bottom of the stack (or higher if possible) and avoiding any extended level segments of flight prior to intercepting the 3 degree glide path. A continuous descent requires significantly less engine thrust than required for level flight and increases the distance between the aircraft and the ground, allowing the emitted noise to attenuate further before reaching ground level. CDO descent rates vary, such that an optimal CDO would require low or idle engine thrust, whereas the existing CDO definition allows aircraft to achieve a CDO by applying a reduced rate of descent, requiring higher thrust and with the aircraft noise source closer to the ground.

The noise benefit of a CDO will vary depending on the altitude and length of level flight associated with a non-CDO, as well as the descent rate and associated thrust settings of the CDO flight. Previous analysis has shown that a typical non-CDO has approximately 5 NM of level flight at altitudes between 3,000 and 6,000 ft. Compared to an optimal CDO, this results in noise increases of up to 2.5 to 5 dB, varying over distances of 10 to 20 NM from touchdown. Further detail can be found in CAA CAP 1554[5].

[5] CAA CAP 1554 Review of Arrival Noise Controls, Civil Aviation Authority, July 2017.

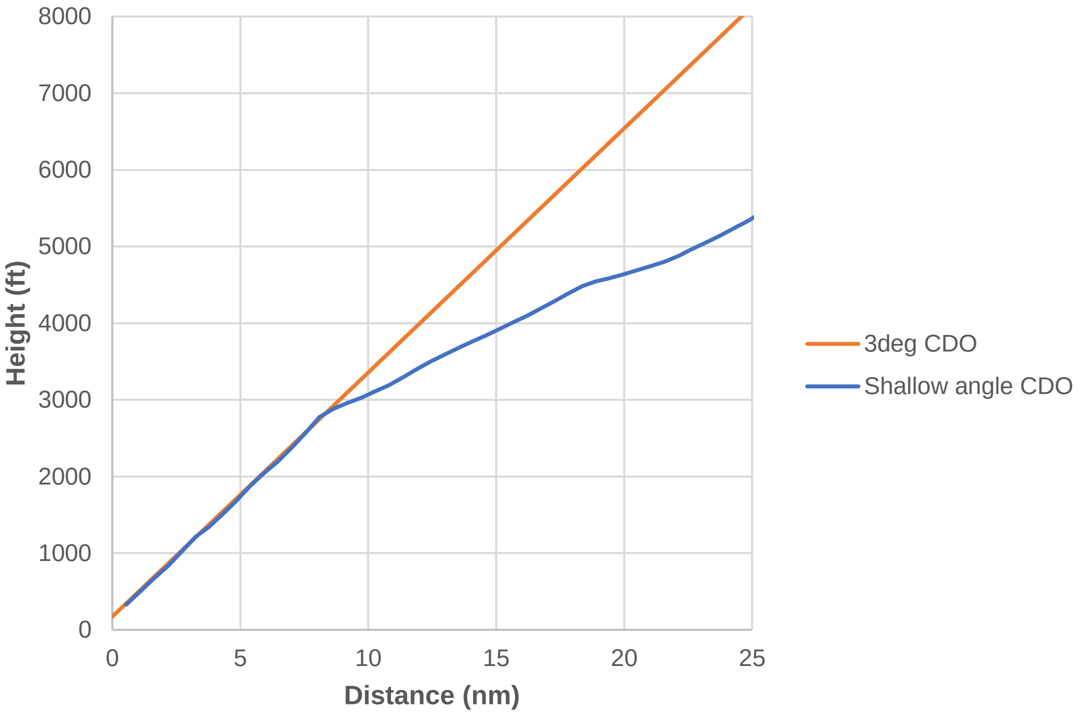
A CDO approach is flown when an aircraft stays higher for longer, descending continuously, and avoiding any extended level segments of flight prior to intercepting the 3 degree glide path. The angle of descent affects noise on the ground. **Figure 1** illustrates target CDO and typical non-CDO arrivals respectively.

Figure 1. Optimum CDO arrival profile vs a non-CDO profile



In today's operation, a CDO angle of descent can vary and as such, arrivals are categorised as CDO compliant but may not necessarily be low noise arrivals. **Figure 2** below illustrates a CDO compliant aircraft with a shallow angle of descent. The aircraft in this example would have a larger noise impact on the ground compared to the target CDO.

Figure 2. Example of a shallow angle CDO approach



Low Power/Low Drag (LP/LD)

For most arriving aircraft, pilots are instructed by ATC to fly at set speeds. This is necessary in order to achieve a uniform flow of arriving aircraft and maintain a high landing rate. As an aircraft reduces speed during the initial and intermediate approach phases to comply with ATC instructions, flaps are deployed to allow the aircraft to fly slower and prepare for landing. For a given aircraft type and mass, each flap setting has a minimum safe flight speed. Landing gear is typically deployed in the final approach phase in accordance with safety criteria, and for some aircraft its deployment can also be linked to a flap setting.

LP/LD is the collective term used to describe the aircraft configuration that creates the lowest noise for a given speed and/or altitude during an approach. Selecting more flap than is required for a given speed will typically lead to more airframe noise, higher engine power needed to balance the greater drag, and thus increased noise. The 1999 ANMAC review[6] considered only flap angle during the final approach phase and concluded that LP/LD offered no more than 1 dB noise reduction.

[6] Noise from Arriving Aircraft: Final Report of the ANMAC technical working group, Department of the Environment, Transport and the Regions (DETR), December 1999.

In contrast, deployment of the landing gear significantly increases airframe noise and aircraft drag, and to maintain the flight path requires increases in engine thrust. The combined effect may be as much as 5 dB. Further detail can be found in CAA CAP 1554[7].

Although aircraft flying a CDO will typically be operating in a LP/LD configuration, there is no formal definition of LP/LD. At present, monitoring of all aspects of LP/LD is only possible through access to Flight Data Recorder (FDR) information. However, the largest component, landing gear, can be identified visually albeit using resource intensive visual methods.

Problem Statement

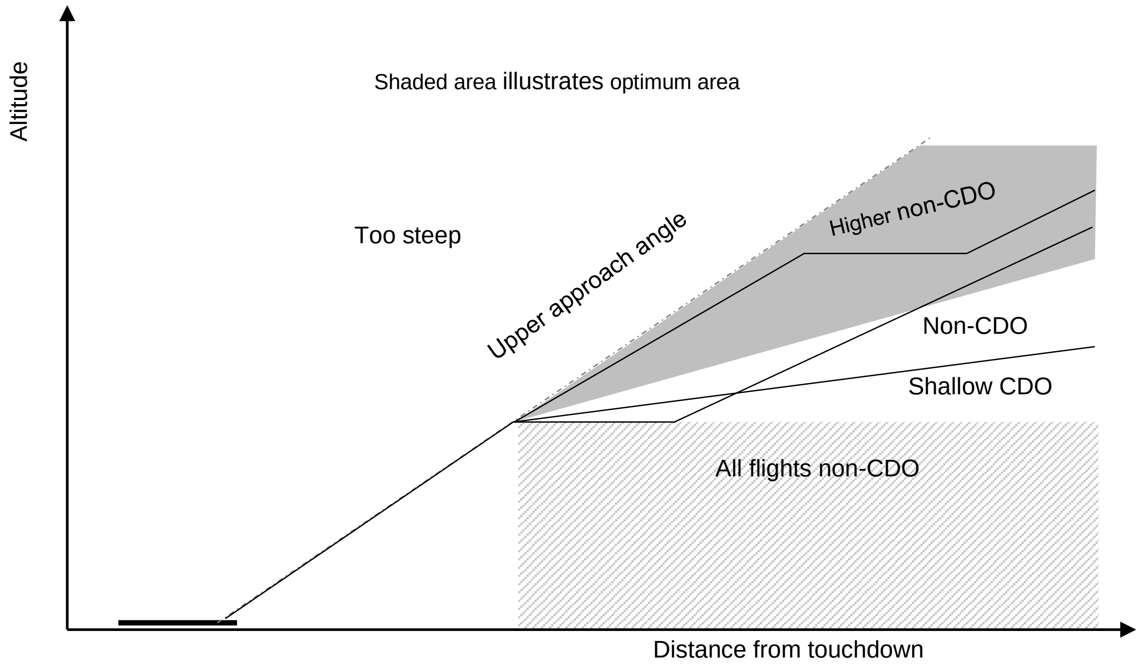
In 2017, preliminary research performed by CAA ERCD identified that the existing CDO definition was not sufficiently sensitive to provide an effective noise measure. The current CDO definition focuses on the avoidance of prolonged level flight. This presents the following issues:

- Permittance of shallow angle approaches which are classified as CDO, and which could be noisier at certain points on the approach compared to a traditional non-CDO approach.
- On newer more aerodynamically efficient low drag aircraft (i.e. A350 and B787-8) it may not be possible to deliver optimal low noise arrivals within the existing operational constraints and the current CDO definition. These aircraft types may require shallower descent segments or level flight during the initial approach (at higher altitude) in order to reduce speed on approach and remain in a LP/LD configuration whilst complying with CDO requirements.

[7] CAP 1554 Review of Arrival Noise Controls, Civil Aviation Authority, July 2017.

Figure 3 shows variation in CDO and non-CDO approach profiles. As long as no level segment longer than 2.5 NM is performed in the hatched area, any path will be compliant with the UK CDO definition. However, an approach profile with a level segment just exceeding 2.5 NM in length, and therefore not CDO-compliant but occurring at higher altitude than a shallow angle CDO, is likely to be quieter overall.

Figure 3. CDO and non-CDO approach paths



The first objective of the study was to assess the noise exposure of a range CDO and non-CDO approach profiles and confirm that higher descent approach profiles in the grey shaded area in Figure 3 produce the lowest noise outcome. The assessment would take into account the latest understanding on aircraft noise modelling, reflecting the increasing importance of airframe noise as jet noise is reduced, accommodate LP/LD operations, and focus on optimising approaches within the main areas of concern for approach noise; between 7,000 ft and 1,800 ft above aerodrome level.

Having confirmed this, the second objective was to develop a low noise arrival metric that encourages approaches in the grey shaded region in Figure 3. The new metric will complement the current CDO definition and provide a new target to reduce arrival noise in the near term on both the current in-service fleet and new aircraft types.

Chapter 3

Study Methodology

Introduction

Development of a low noise arrival metric requires that the parameters that contribute towards a low noise arrival be identified and optimised, whilst complying with operational and safety requirements.

The following process was undertaken in the development of the low noise arrivals metric:

1. Refinement of CAA ERCD’s noise model to disaggregate current noise sources into component elements (i.e. noise generated by engine, airframe and undercarriage). Further detail on the development of separate jet and airframe noise models is presented in Appendix B.

2. Estimation of noise exposure for a range of approach trajectories

   Development of a range of approach flight trajectories (speed, height, engine thrust and configuration as a function of distance from landing) and estimation of their associated noise exposure to assess how varying aspects of the trajectory affect subsequent aspects of the trajectory in performance terms and noise exposure at different locations on the ground.

3. Development of low noise metric criteria

   Development of criteria to define one or more low noise arrival criteria based on the outputs from task 2.

4. Testing of the proposed low noise metric criteria

   Testing of the criteria using historic radar data for a number of UK airports, and subsequent refinement of the low noise approach metric definition.

Aircraft selection

Enhancement of the noise model is a time-consuming and iterative task, and as such, it was agreed that the methodology be restricted to four aircraft types. These were chosen on the basis that they were, for the purposes of this study, representative of all aircraft types. This meant that the newly defined categories of approach, based on height and descent angle, could most likely be achieved by all aircraft. The following aircraft were analysed as part of this study:

- Airbus A320 (narrow-body twin)
- Boeing 787-8 (wide-body twin)
- Airbus A380 (wide-body quad)
- Bombardier Dash 8 Q400 (twin propeller)

It was quickly identified that information for the Q400 was not available to the same level of detail as for the other three aircraft and it was therefore not possible to calculate arrival trajectories with sufficient assurance, in particular for the deceleration segments. However, it was the assessment of the Q400's descent performance which identified that its descent capability (i.e. idle descent angle and decelerating descent capability) would not be a limiting factor for this aircraft type compared with the other aircraft, and thus the Q400 would not contribute to the overall definition of a low noise arrival metric. Therefore, further analysis with the Q400 was not undertaken.

Conversely the Boeing 787-8 was identified to be a critical aircraft with regards aerodynamic and deceleration performance and thus additional analysis was undertaken for the Boeing 787-8 only, and in the interests of brevity only analysis results for the Boeing 787-8 are presented in Chapters 4 and 5.

Chapter 4

Identification of a low noise arrival

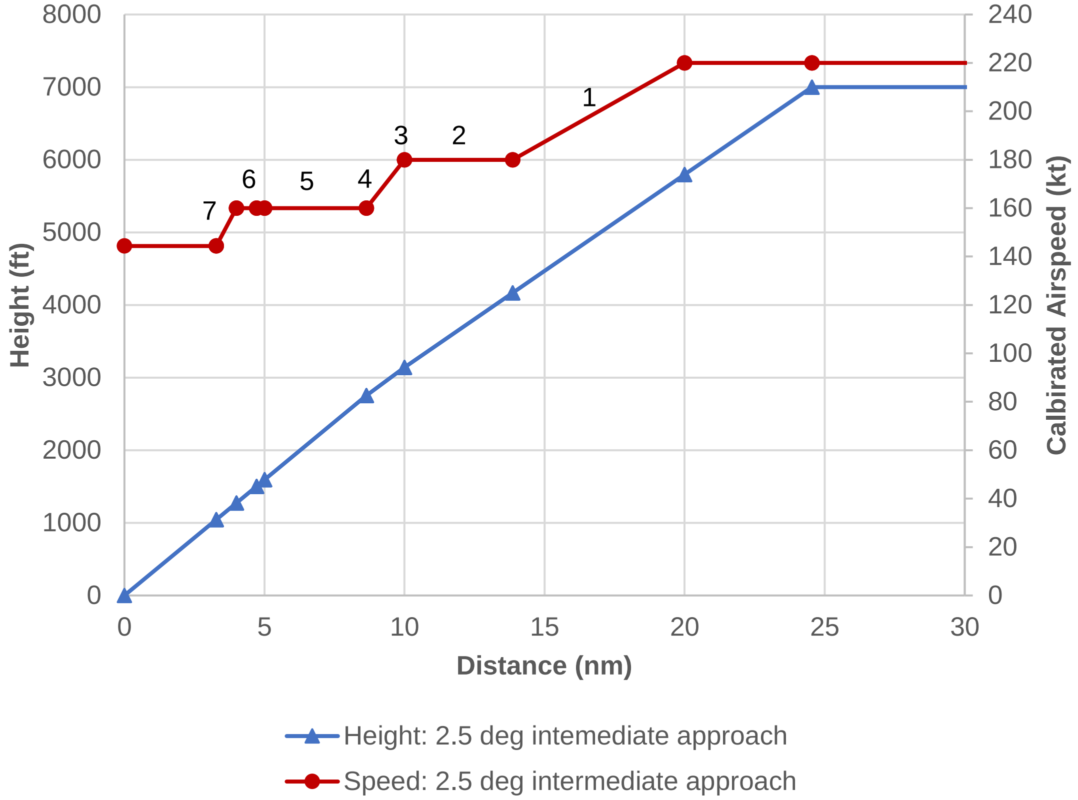
Factors affecting arrivals noise

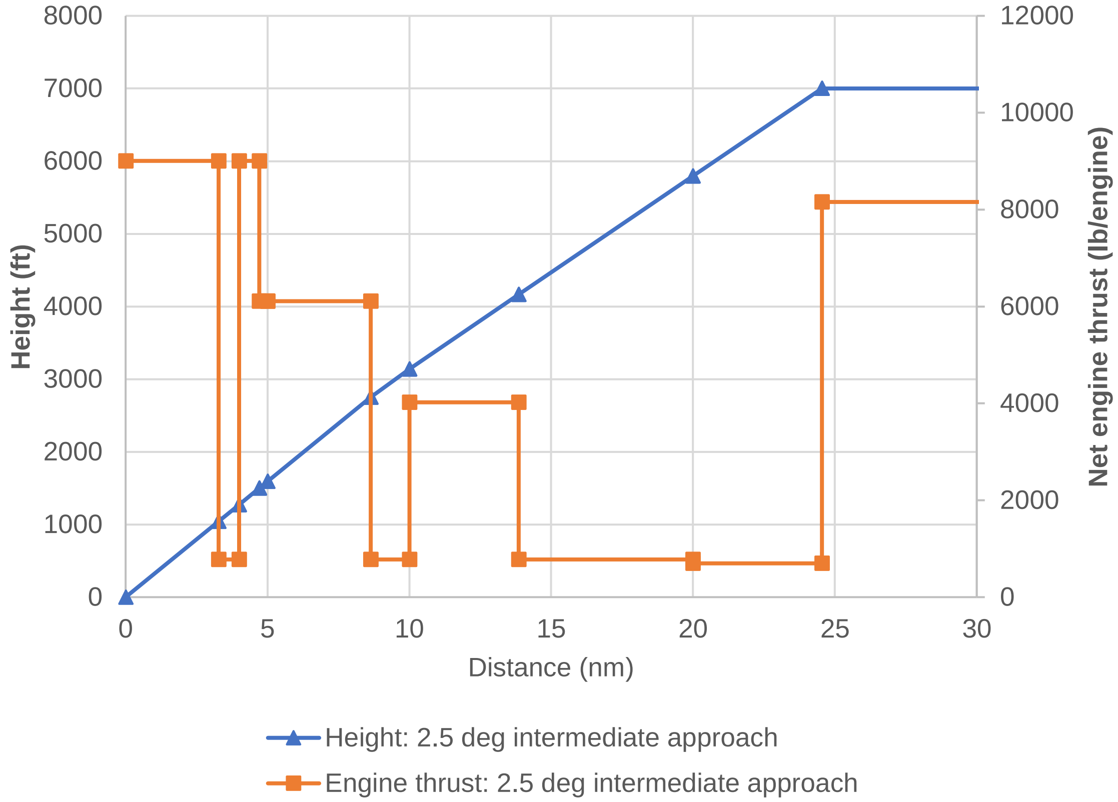
Although this may change in the future as airspace is modernised, an arrival begins at a holding area, where aircraft speed is standardised at 220 kt. Initial descent will begin from level flight at 7,000 ft or passing 7,000 ft in descent from a higher altitude.

Again, although this may change in the future, currently in the initial and intermediate phases between 7,000 ft and 3,000 ft, aircraft speed and height are controlled by air traffic control directing aircraft on a tactical basis based on each aircraft’s position and overall traffic levels. One of the key objectives for this is to maintain an expeditious flow of arriving aircraft and a high landing rate. There is a direct relationship between aircraft flap setting, based on speed, descent angle and the engine thrust required. Steeper descent angles require less thrust for a given aircraft flap setting and speed. Higher flap settings which are required to fly at slower speeds increase drag and therefore require higher thrust to maintain the same descent angle.

Figure 4 illustrates the different phases of an arrival, each of which are described in turn. The lower portion of the figure shows how engine thrust varies in relation to changes in approach angle and speed.

Figure 4: Phases of an arrival





(1) Initial descent and deceleration from 220 to 180 kt

Aircraft leave the holding stack at an altitude of 7,000 ft or higher at a speed of 220 kt. A near 3 degree approach without level flight implies descent begins around 21 NM from touchdown. In practice, descent will be initiated around 23-24nm from touchdown, although this may be longer in some situations in order to sequence arriving aircraft. ATC direct aircraft to decelerate from 220 kt to 180 kt around 20nm from touchdown. The deceleration segment will typically take 3-5 NM, depending on aircraft type and wind conditions. For many aircraft types, especially more modern types, deceleration from 220 kt to 180 kt cannot be achieved in an acceptable distance/time without reducing the descent angle to something less than 3 degrees (as illustrated in **Figure 4**).

(2) Descent at constant speed (180 kt)

Once a speed of 180 kt is reached, speed will be maintained to approximately 10 NM from touchdown to facilitate a sequence of closely spaced aircraft. Descent angle may be steepened (if less than 3 degrees) in order to maintain idle or near idle thrust. All aircraft can achieve a 3 degree descent angle at constant speed.

(3) Interception of the final approach glidepath

The final approach glidepath (typically 3 degrees, but sometimes higher) will be intercepted between 3,000 ft (10 NM from touchdown) and 4,000 ft (12.6 NM from touchdown).

(4) Descent and deceleration to 160 kt

At or shortly after interception of the final approach glidepath, ATC direct aircraft to descend on the ILS and decelerate to 160 kt[8] and then maintain this speed to 4-5 NM from touchdown.

(5) Descent at constant speed (160 kt)

Once a speed of 160 kt is reached, speed will be maintained to 4-5 NM from touchdown. The descent angle is fixed at that of the ILS glideslope (typically 3 degrees) and thrust will be above idle.

(6) Deployment of landing gear

Landing gear deployment will be initiated, around 1,500-2,000 ft (5-6nm from touchdown), in order to prepare the aircraft for the final deceleration segment (phase 7) and ensure that aircraft configuration, speed and rate of descent are stabilised by 1,000 ft; an important safety performance indicator.

(7) Descent and deceleration to final approach speed

Around 4-5 NM from touchdown, aircraft decelerate from 160 kt to the final approach speed, which may vary from as low as 120 kt for smaller aircraft (Airbus A319) to as high as 155 kt for a Boeing 747-400.

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[8] At some airports this speed may be adjusted to better reflect local traffic, e.g. at Stansted 165 kt is used.

Noise variation with different intermediate approach angles

Noise exposure on the ground was calculated for a range of different arrival trajectories, focussing on intermediate approach angles (phases 1 and 2 in Figure 4) between 0.5 and 3.0 degrees at 0.5 degree intervals.

As highlighted in the preceding section, the initial deceleration phase from 220 kt to 180 kt is a key constraint. **Table 1** shows the distance taken to decelerate from 220 kt to 180 kt at idle thrust for different descent angles in zero wind conditions (‘still air’) for the Boeing 787-8.

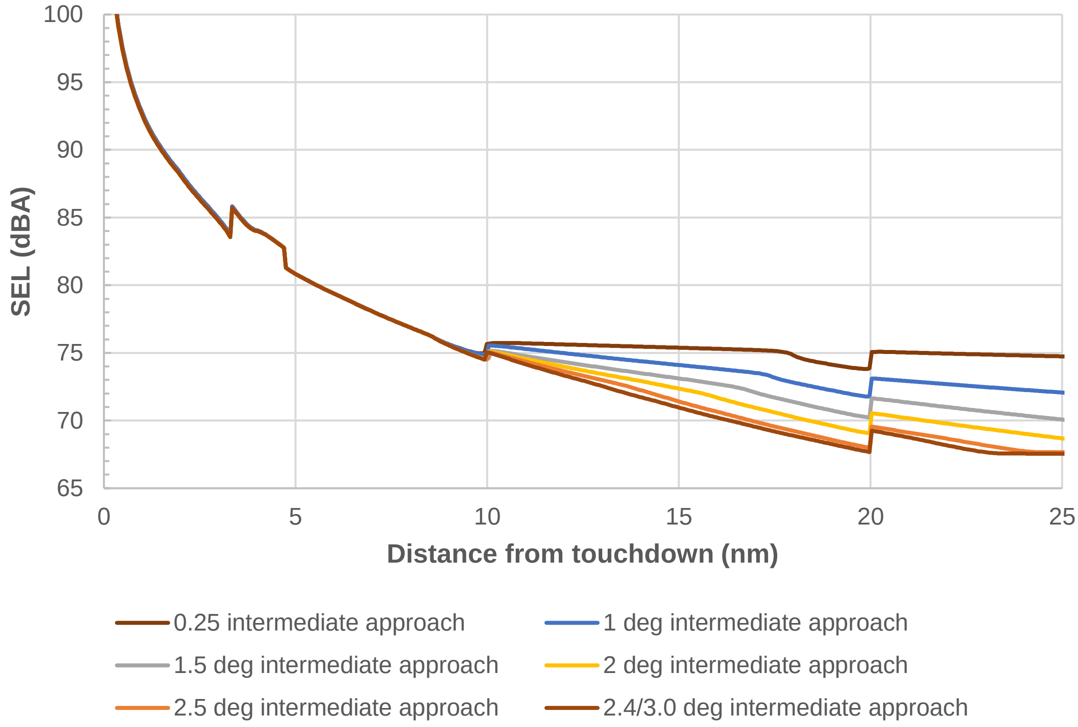
Table 1: Variation in deceleration distance for different descent angles when decelerating from 220 kt to 180 kt in still air

Descent angle (degrees)	Still air deceleration distance (nm)
0	1.9
0.5	2.2
1.0	2.6
1.5	3.2
2.0	4.2
2.5	6.1
3.0	11.4

Whilst the results in **Table 1** are presented for still air conditions, the geographical location of this deceleration phase typically places it downwind of the landing runway and thus the aircraft will experience a tailwind, which in turn, will extend the quoted deceleration distances further. Secondly, windspeeds aloft are much higher than on the ground. At 5,000 ft, the windspeed will be at least double the surface value. The deceleration distance at a descent angle of 2.0 degrees with a 30 kt tailwind will increase by 18% to 5.0nm, and with a 40 kt tailwind the distance will increase by 25%. The results clearly show that modern aircraft, such as the Boeing 787-8, cannot achieve descent angles of 3 degrees whilst maintaining acceptable deceleration distances and meet operational speed constraints.

Figure 5 shows the effect of intermediate approach angle on noise exposure on the ground for the Boeing 787-8. In order to achieve acceptable deceleration distances, for the highest intermediate approach angle, two different angles are applied, 2.4 degrees whilst decelerating from 220 kt to 180 kt and then either 2.5 or 3.0 degrees for the remainder of the constant speed intermediate descent. The results clearly show that higher descent angles reduce noise, but the results also show the clearly diminishing benefits with increasing angle. Conversely the results show that shallow angles, even with continuous descent, result in disproportionately large increases in noise.

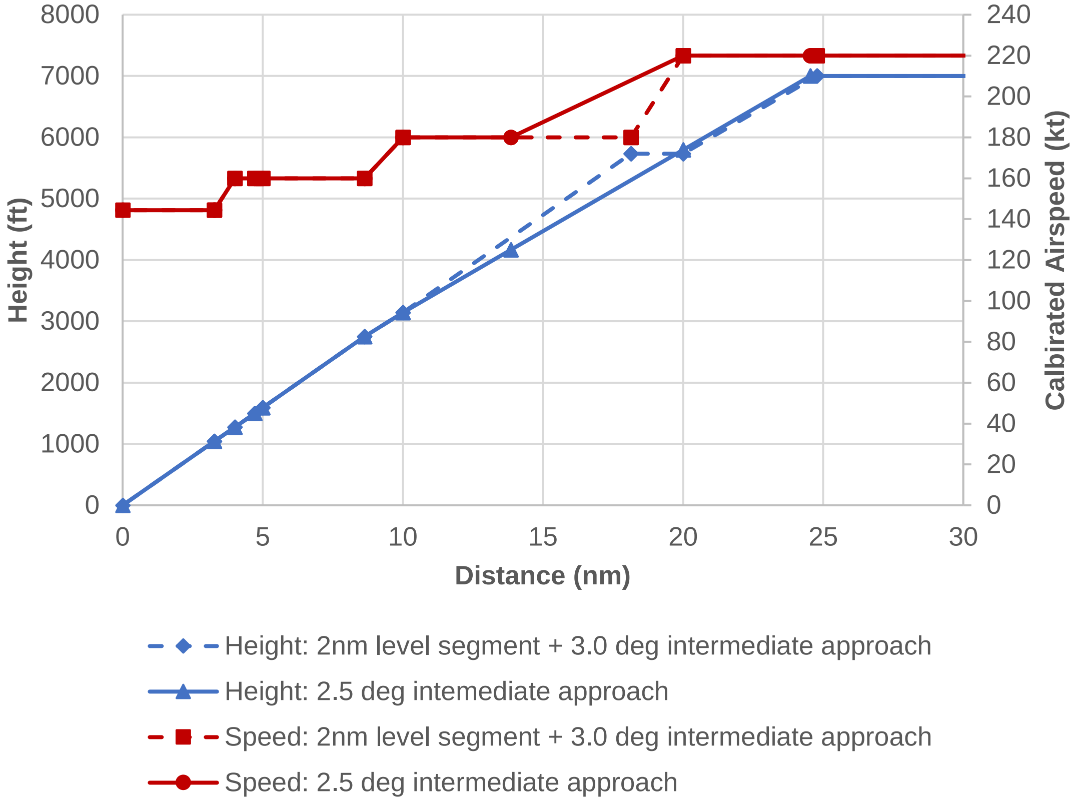
Figure 5: Noise variation for differing intermediate approach angles for Boeing 787-8



Noise variation of different intermediate approach angles with a decelerating level flight segment

It may be necessary, particularly in tailwind conditions to undertake the initial deceleration using a shallower segment or level segment. **Figure 6** illustrates the effect of a 2 NM level segment deceleration from 220 kt to 180 kt on the flight trajectory. The deceleration takes less than half the required distance and can then enable a steeper descent at constant speed to take place for the remainder of the intermediate approach segment, albeit a portion of this segment now has a higher thrust setting, because the deceleration takes less time. The noise consequences of such level segments are shown in **Figure 7**. The level segment does not significantly increase noise as it occurs whilst decelerating with the engines at idle power. The height gain achieved by a short level segment followed by a steeper intermediate approach angle provides a small noise benefit.

Figure 6: Effect of higher altitude level segment to increase intermediate approach angle



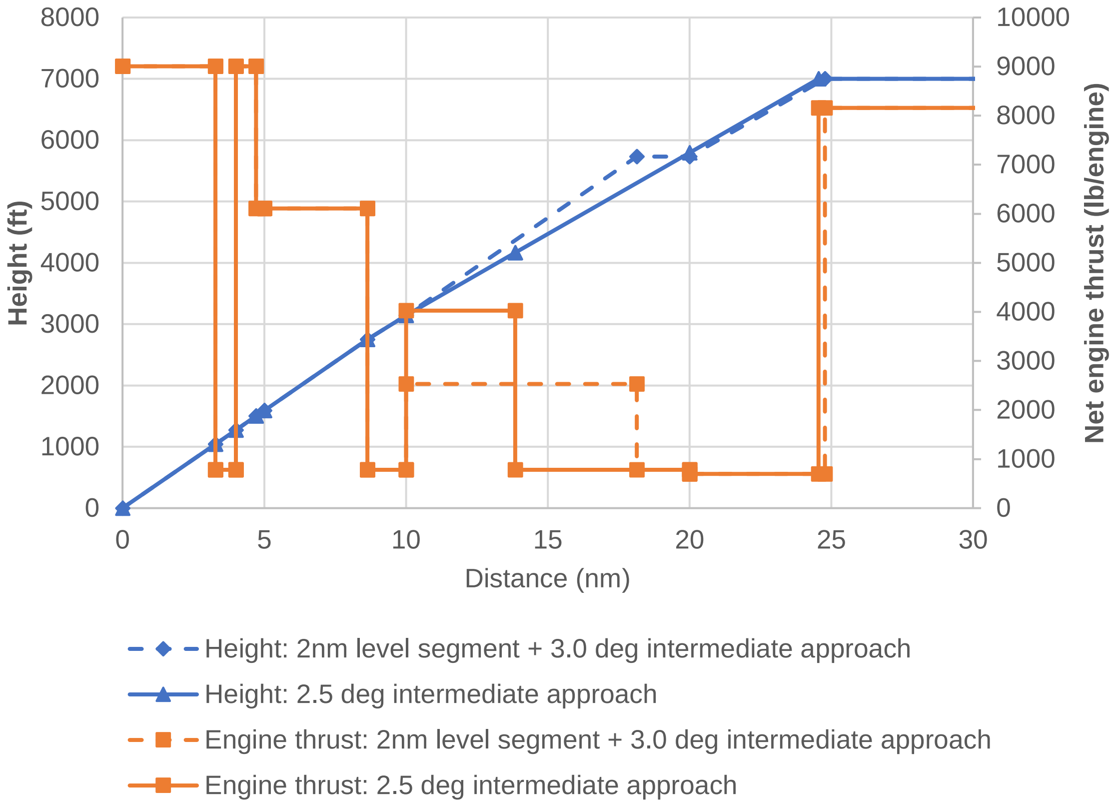
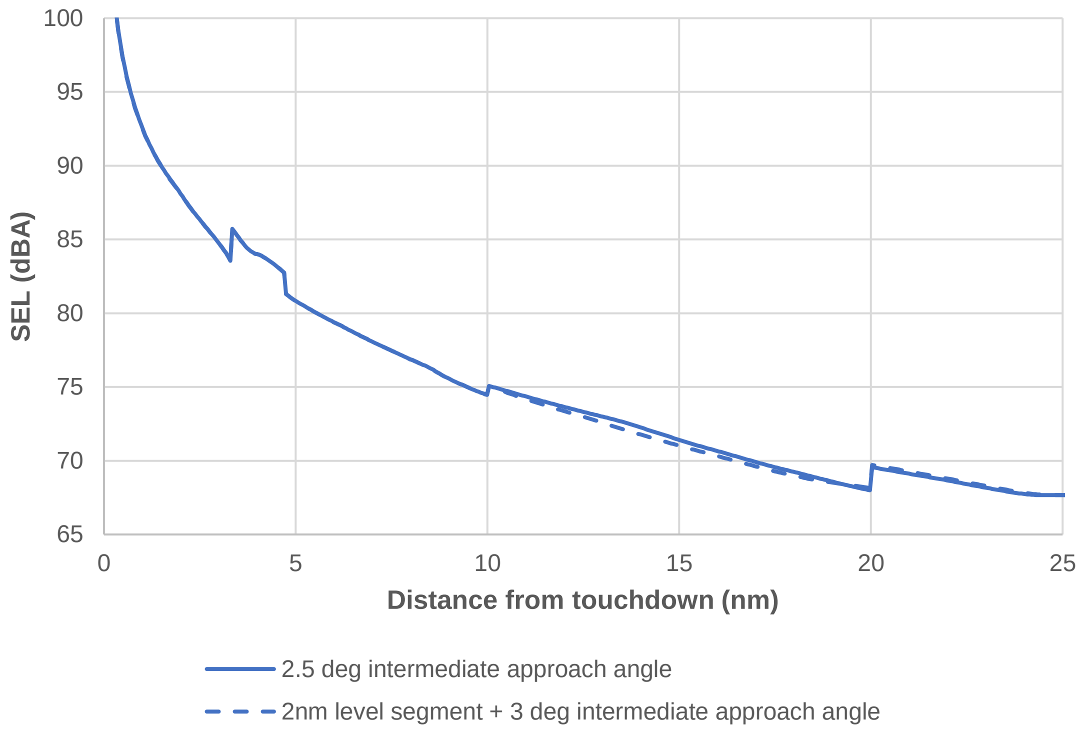


Figure 7: Effect on noise of higher altitude level segment to increase intermediate approach angle



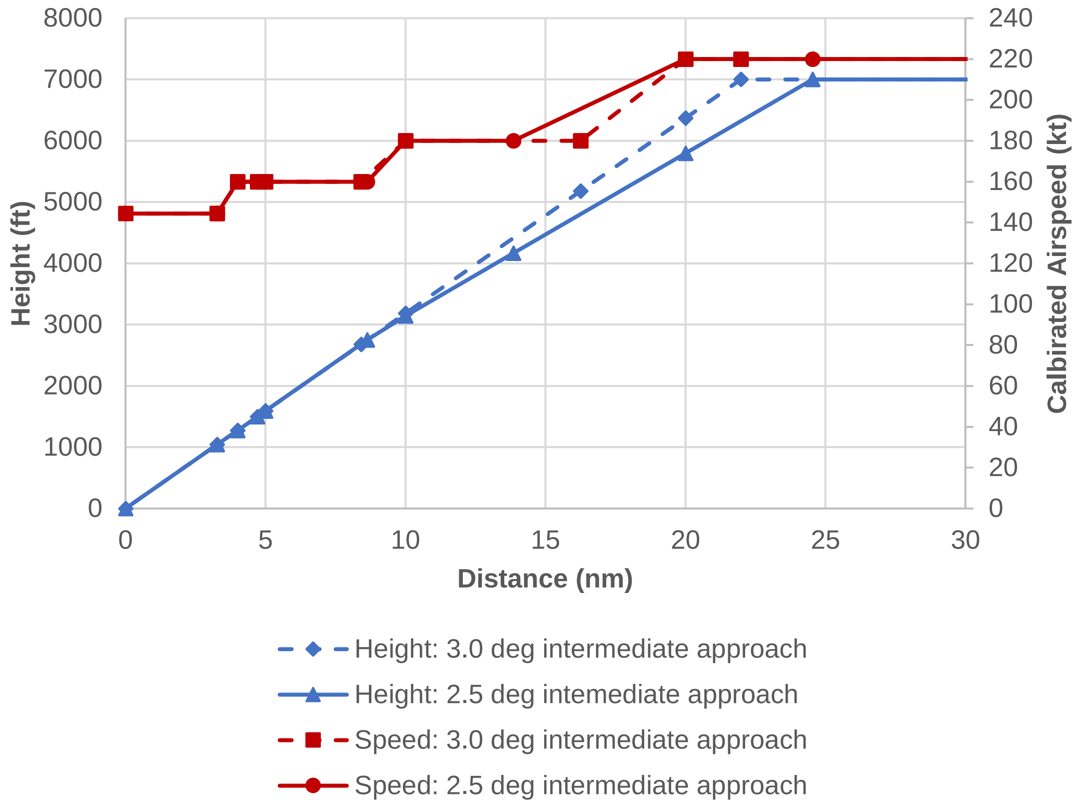
3 degree intermediate approach angle

For the most modern aircraft, intermediate approach angles up to around 2.5 degrees can be achieved within the existing speed constraints requiring deceleration from 220 to 180 kt around 20 NM from touchdown.

Higher intermediate approach angles, whilst maintaining this deceleration requirement, necessitate additional drag. In the example shown in **Figure 8**, in order to achieve an intermediate approach angle of 3 degrees during deceleration, flap 20 was selected instead of flap 5 to achieve an acceptable deceleration distance from 220 to 180 kt. This maximises aircraft height during the intermediate approach segment. However, once the deceleration is complete, the additional flap is unnecessary, resulting in additional engine thrust required whilst descending at constant speed. This adds additional engine noise to the additional airframe noise due to the higher flap angle. The noise consequences of this are shown in **Figure 9**. Noise during the intermediate approach segment increases by 2-7dB despite the aircraft being higher at all points than the shallower 2.5 degree intermediate approach.

This scenario illustrates how for the most modern aircraft, intermediate approach angles above 2.5 degrees, despite increasing aircraft height, do not reduce noise with current speed constraints.

Figure 8: Effect of additional flap drag on approach profile and engine thrust to achieve 3 degree intermediate approach segment



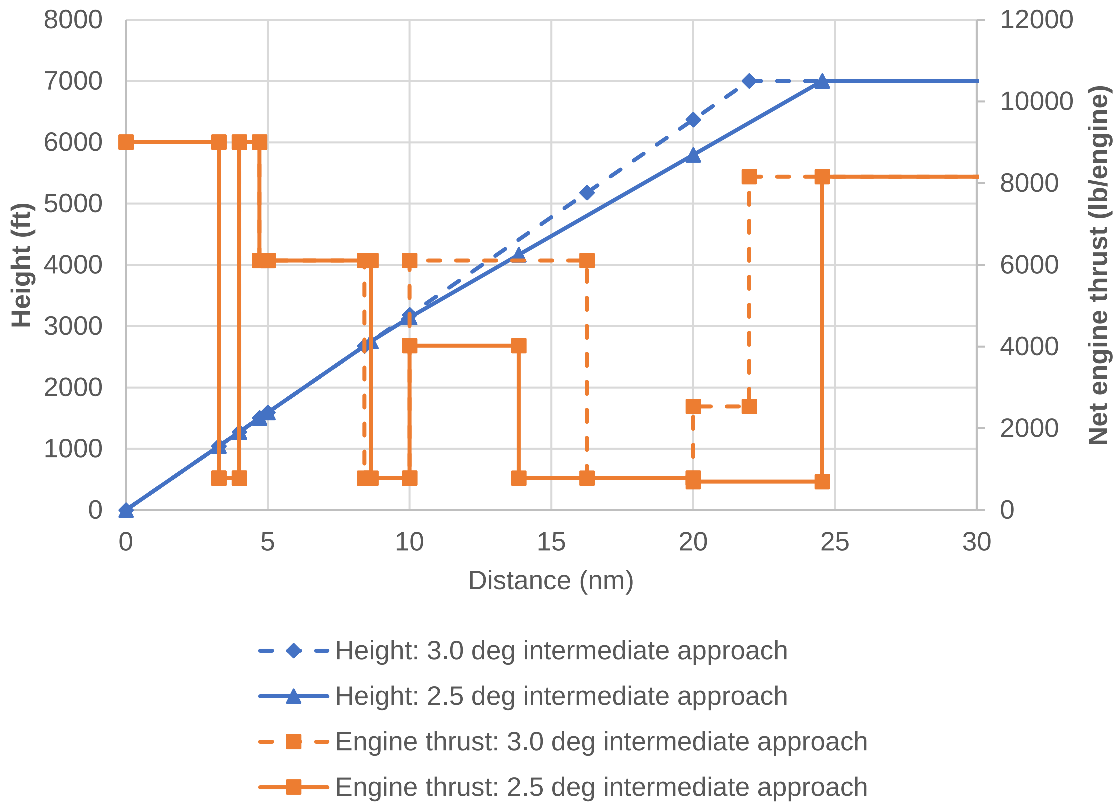
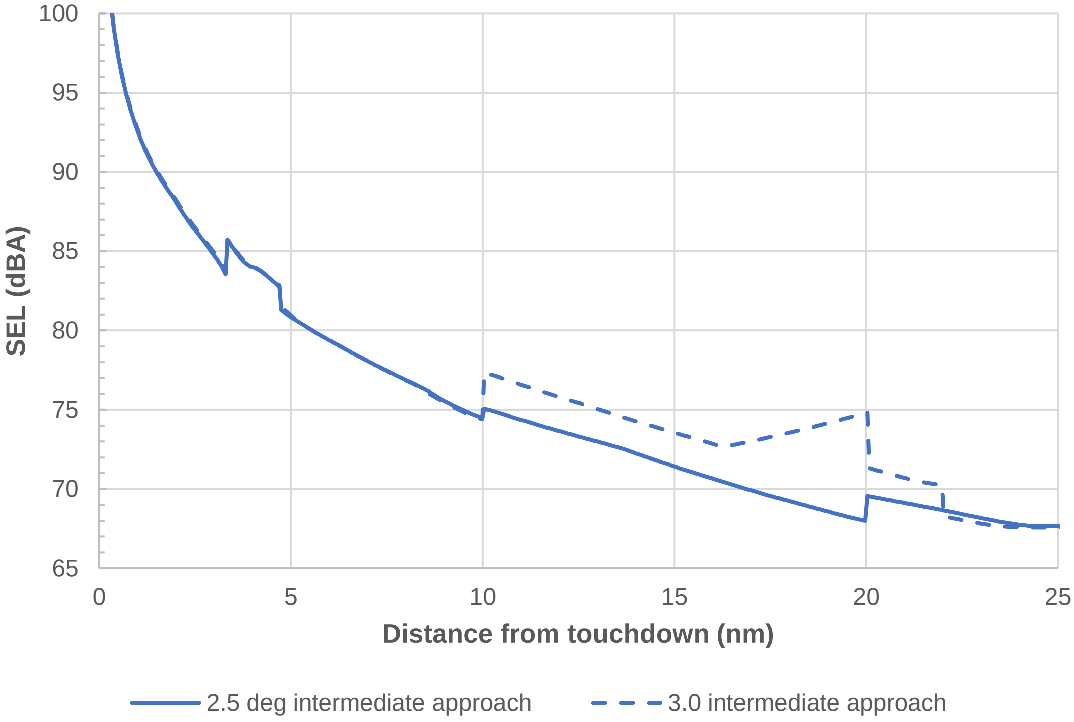


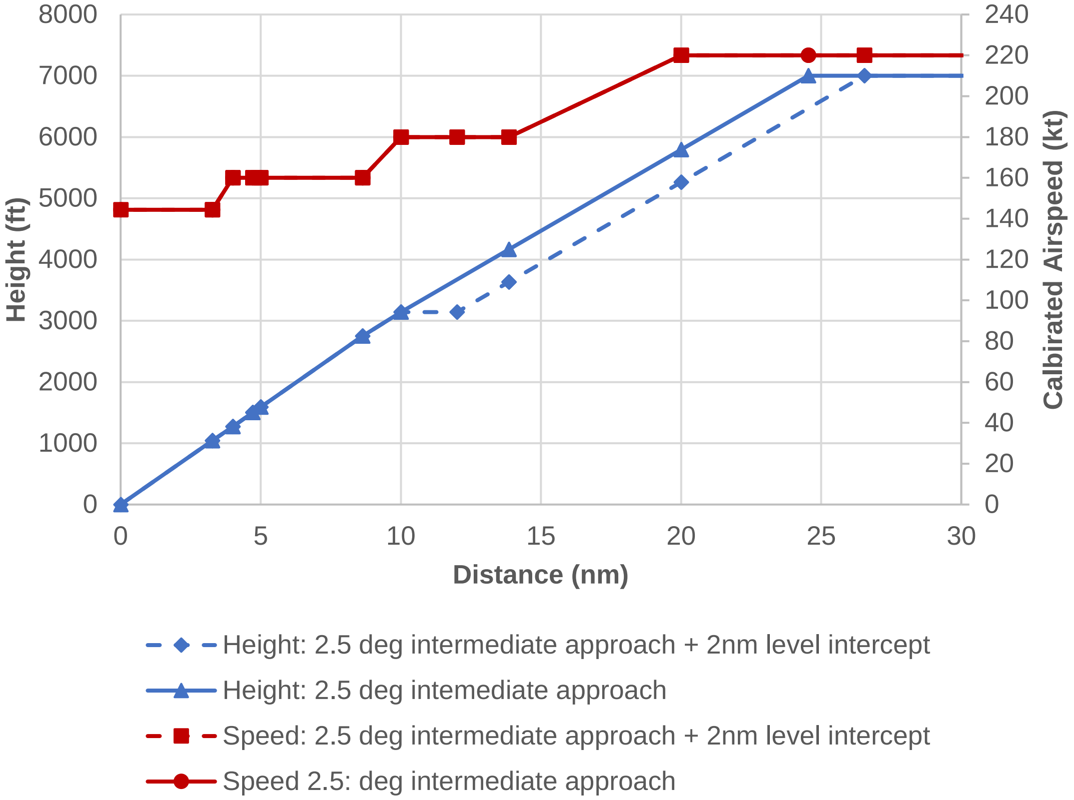
Figure 9: Effect of additional flap drag on noise to achieve 3 degree intermediate approach segment



Constant speed level segment at ILS intercept

Figure 10 shows the effect of level segments just prior to ILS intercept (3,000 ft) on the approach profile. **Figure 11** shows the corresponding effect on noise. A 2 nm level segment at 3,000ft, just prior to glide-path intercept, results in noise increases of 1-2 dB for the entire intermediate approach segment (10-20 NM from touchdown). The earlier analysis showed that level segments of the same length at 5,000 ft to 6,000 ft, aiding the critical deceleration phase (220 to 180 kt), may result in overall noise decreases when coupled with intermediate approach angles above 2.5 degrees for the remainder of the intermediate segment as previously highlighted in **Figure 7**.

Figure 10: Effect of level segment at ILS intercept on flight profile and engine thrust



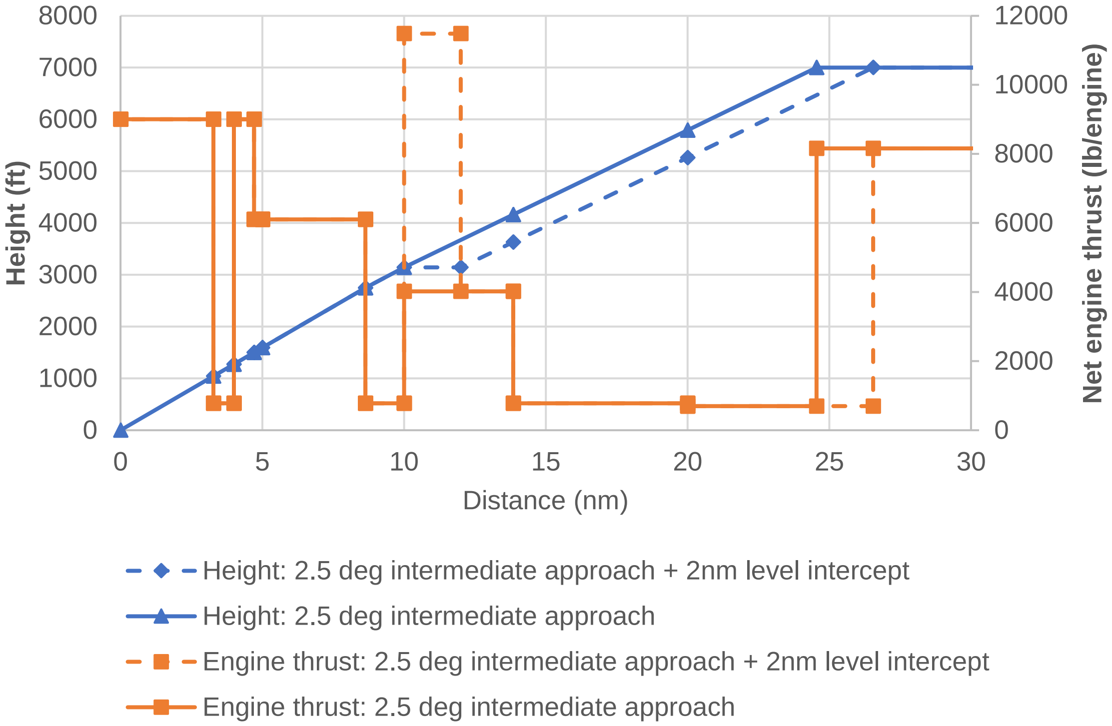
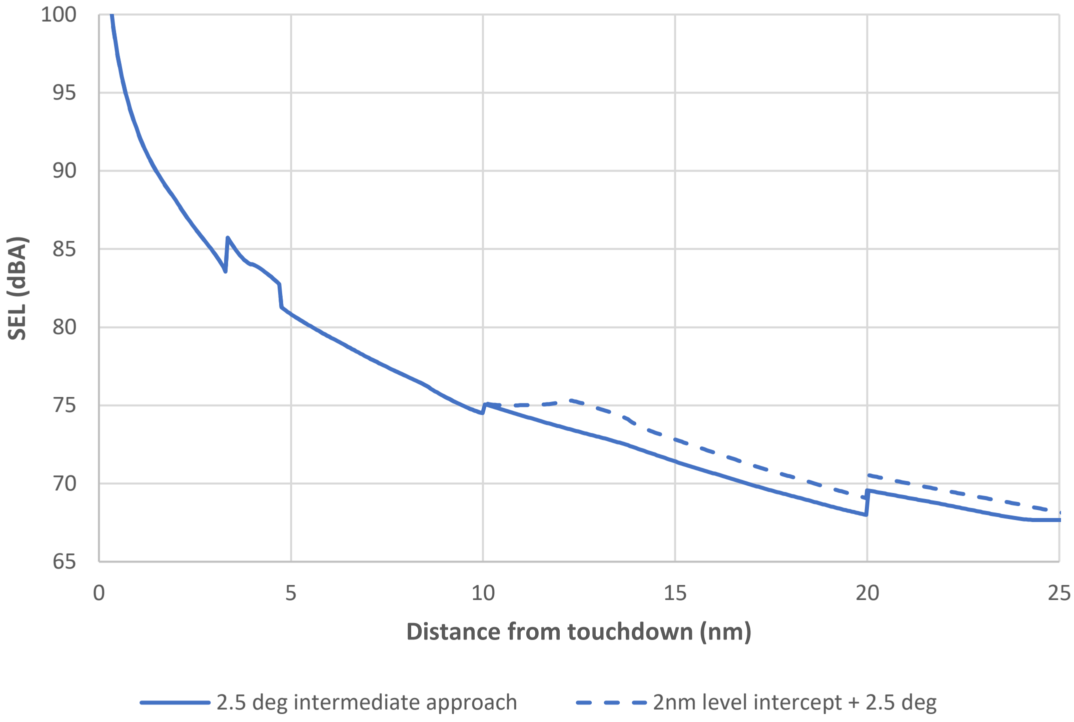


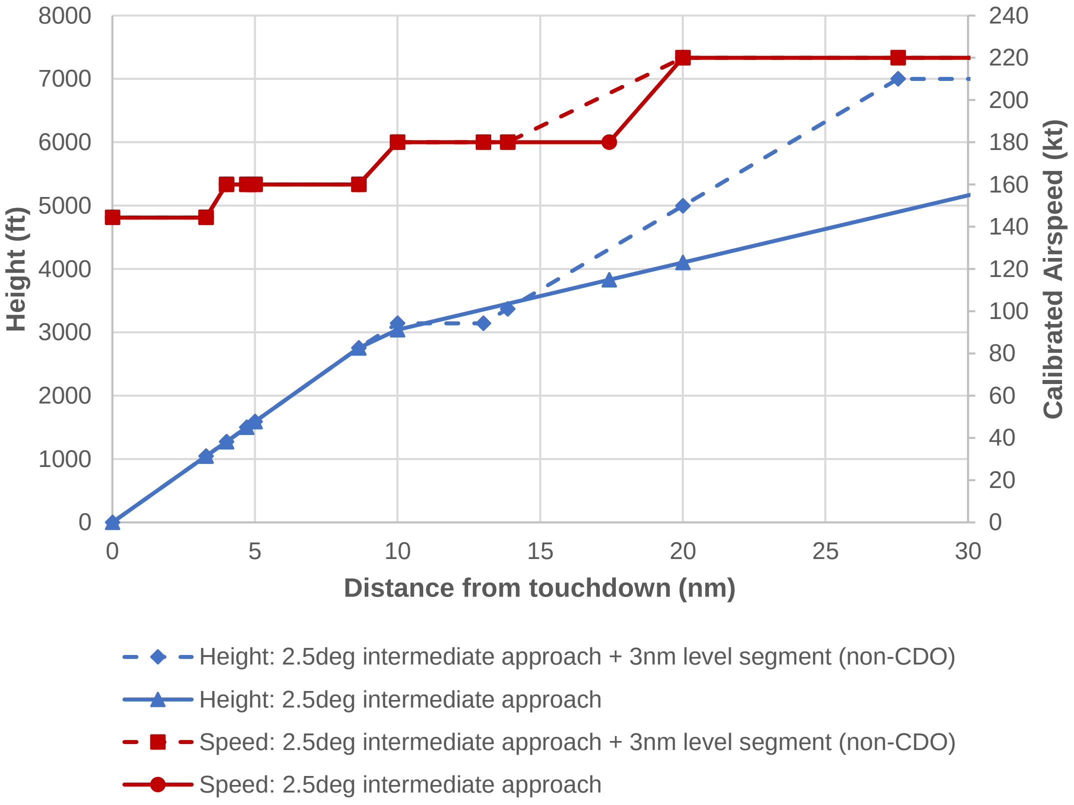
Figure 11: Effect of level segment at ILS intercept on noise

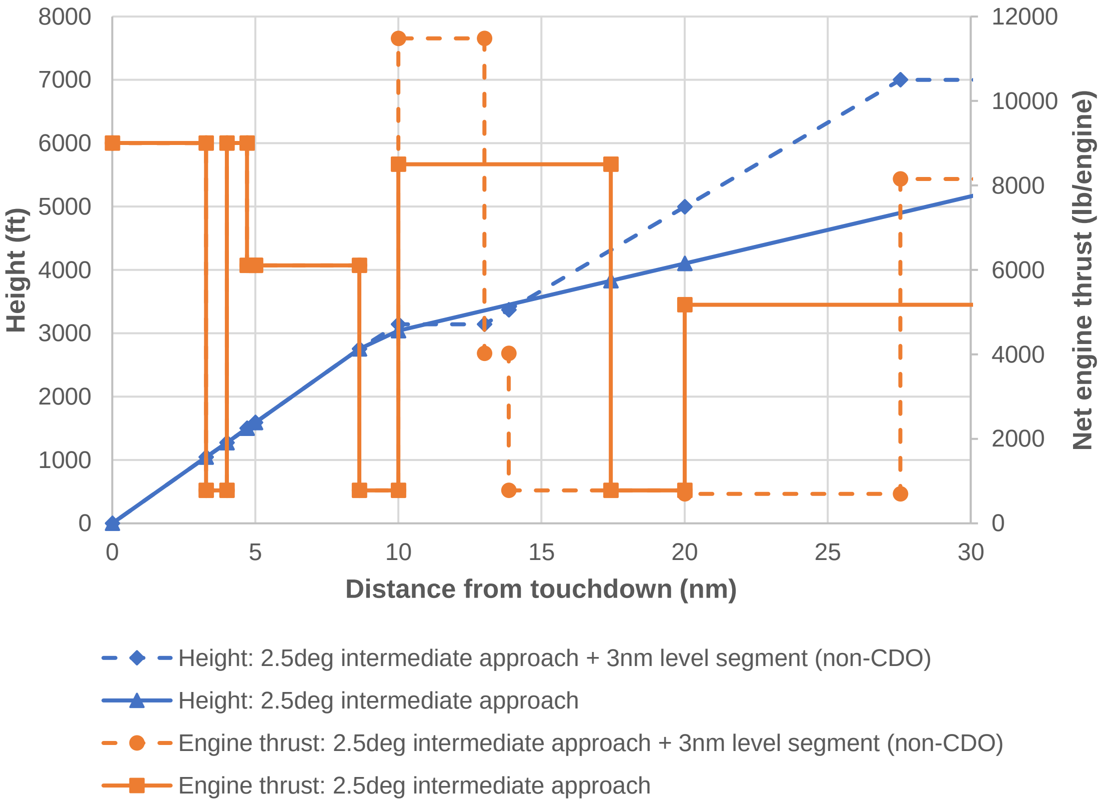


Shallow CDO vs non-CDO approach

Finally, this scenario compares a non-CDO with a 2.5 degree intermediate approach angle and a 3 NM level segment just prior to intercept of the ILS, to a CDO approach with no level flight, but with a shallow 1 degree intermediate approach angle. Beyond 14 NM the shallow angle is lower than the non-CDO (**Figure 12**) and is noisier than the non-CDO approach between 14-20 NM by up to 3 dB (**Figure 13**). The non-CDO approach is noisier around 11-13 NM in the region of the level segment, by up to 1 dB.

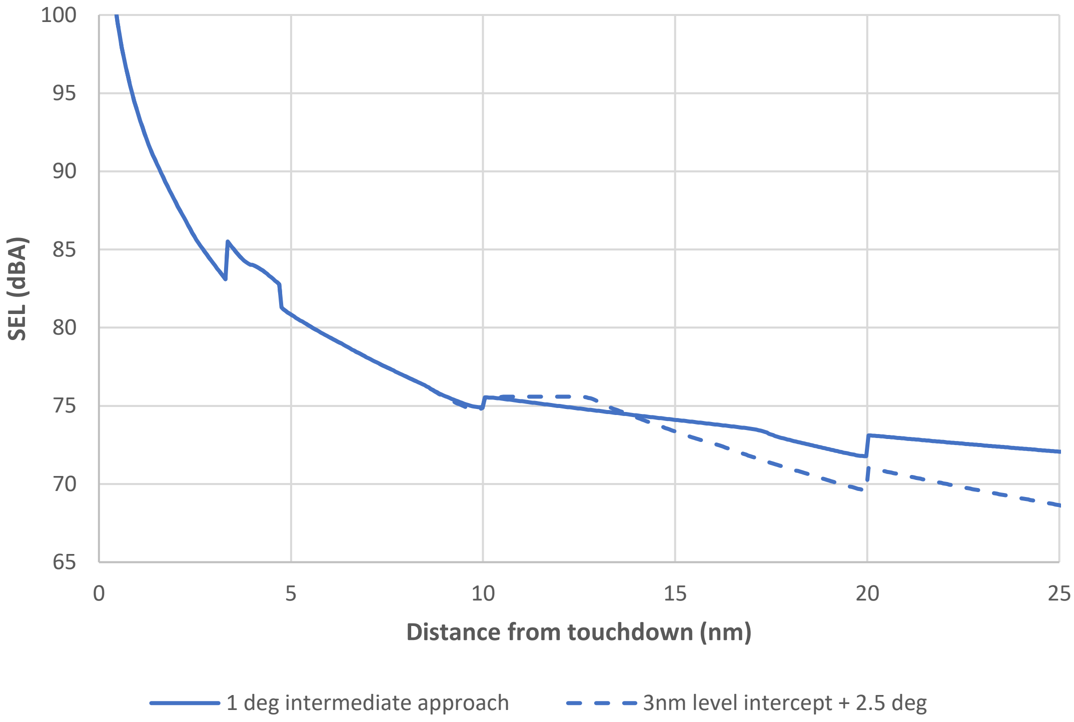
Figure 12: Approach profiles for shallow CDO and non-CDO (3 NM level flight at 3,000 ft)





Figure

Figure 13: Effect on noise of shallow CDO and non-CDO (3nm level flight at 3,000 ft)



Summary

The analysis presented highlights:

- For modern aircraft types and current operational speed constraints, optimum noise is achieved for intermediate approach angles around 2.5 degrees.
- To achieve a 3 degree intermediate angle requires additional drag, which generates additional airframe noise and additional thrust when flying at constant speed, increasing noise when compared with intermediate approach angles of 2.5 degrees.
- Shallow angle CDO profiles significantly increase noise compared with the optimum intermediate approach profile.
- Short level segments around 6,000 ft, when used to decelerate an aircraft at idle power, result in little noise increase relative to the optimum profile, whereas level segments flown at constant speed close to ILS intercept increase noise for the entire intermediate approach phase (10-20 NM from touchdown).
- Shallow angle CDO profiles are noisier than non-CDO approaches with steeper intermediate approach angles.

Chapter 5

Low Noise Arrival Metric

Description

From the preceding analysis it is clear that a low noise arrival metric should be informed by aircraft height and descent angle during the initial/intermediate approach phase. Whilst the analysis has also highlighted how aircraft configuration, i.e. flap settings and landing gear influence aircraft noise exposure on the ground, the current inability to monitor flap settings and landing gear exclude them from being components of a near-term low noise arrival metric. However, it is recognised that at least one UK airport is developing systems to identify and monitor when the landing gear is lowered; this could be incorporated into future developments.

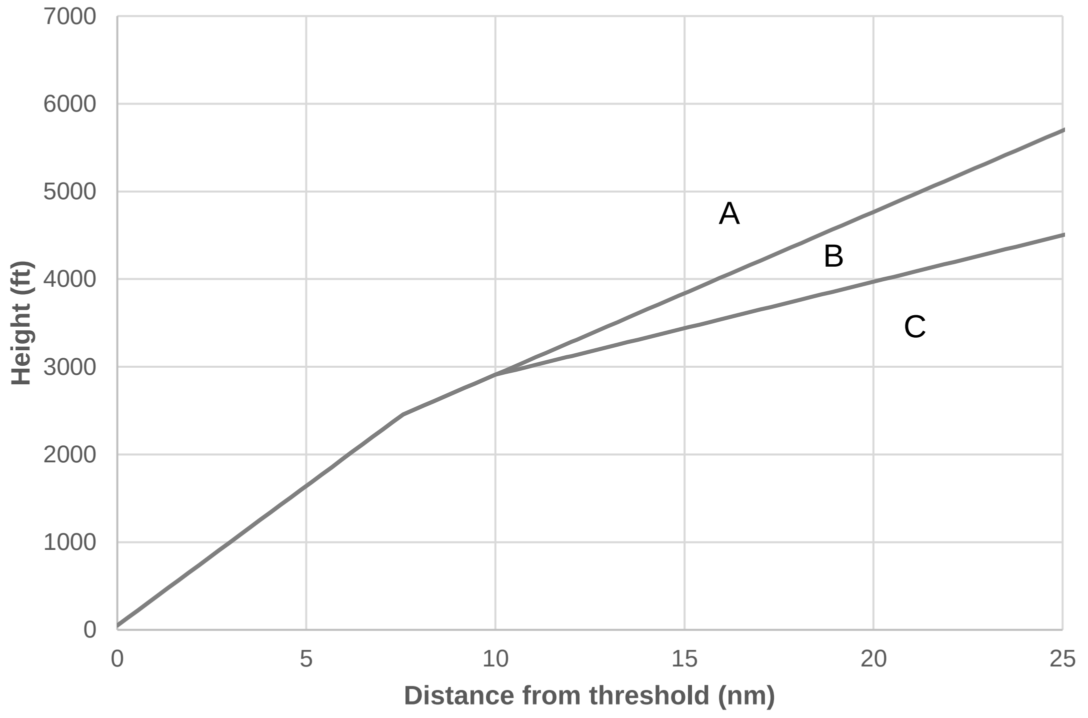
Based on this and the results of the preceding chapter, the following objectives for a Low Noise Arrival Metric were identified:

- Make the criteria simple, and avoid overly complex criteria that may delay implementation of monitoring systems and communication to stakeholders.
- Progressively dissuade level segments lower to the ground as this would naturally incentivise lower noise approaches.
- Provide more flexibility for level segments at higher altitudes than the current CDO metric permits, whilst progressively discouraging level segments at lower altitudes.

Proposed Low Noise Arrival Metric

The proposal is to define two height criteria as a function of distance from landing to define three zones as shown in **Figure 14**.

Figure 14: Proposed Low Noise Arrival Metric Height Zones



The two boundaries that demarcate Zones A, B and C are defined as:

Upper (A/B) boundary:

- A line starting at 50 ft height above the landing runway threshold, extending out to 7.5 NM at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5 NM and 10 NM[9]
- A line at an angle of 1.75 degrees between 10 nm and 5,500 ft[10]

Lower (B/C) boundary:

- A line starting at 50 ft height above the landing runway threshold, extending out to 7.5 nm at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5 nm and 10 nm[9]
- A line at an angle of 1 degrees between 10 nm and 5,500 ft

[9] Initially an angle of 2.5 degrees was selected, however, it was found that a large number of flights failed the criteria by a small margin at the ILS intercept point and thus the angle was revised to 1.75 degrees.

[10] 5,500 ft is proposed as the upper limit, for consistency with the upper limit of the current CDO definition.

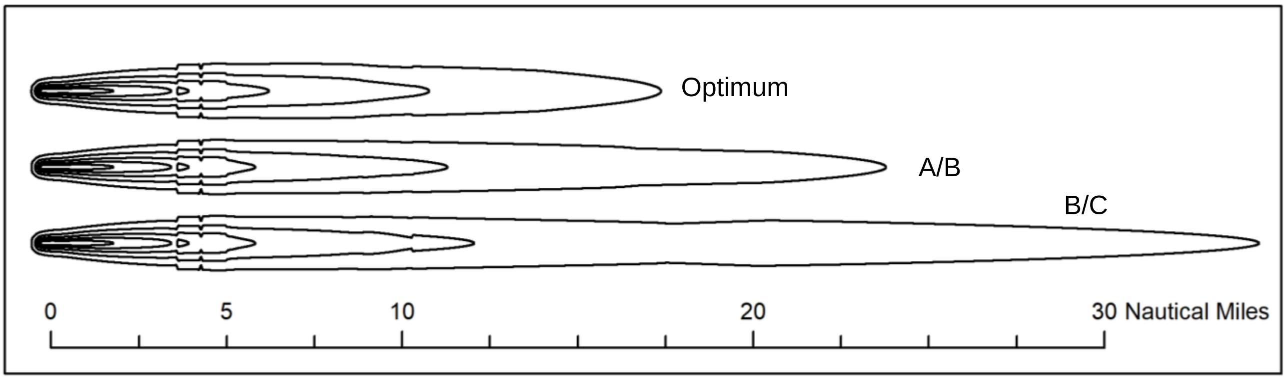
Radar data[11] from an airport's Noise and Track Keeping system would be used to determine the distance from touchdown and check whether the height of each radar point placed the aircraft in either zone A, B or C. It is proposed that the lowest zone associated with any single radar point should define the low noise rating for each flight. Because of the uncertainty associated with individual radar returns, it is proposed that a 100ft tolerance is applied to the criteria defined above. This leads to the minimum height values presented in **Appendix C**.

To produce noise comparisons, the category boundaries, i.e. upper (A/B) boundary and lower (B/C) boundary, are compared against the optimum approach. The intermediate descent angles are thus:

- Optimum approach: 2.5 degrees
- Upper (A/B) boundary: 1.75 degrees
- Lower (B/C) boundary: 1.0 degrees

Noise analysis was undertaken for each of the three descent profiles and from this noise footprints and noise footprint areas were calculated for the Boeing 787-8 (**Figure 14** and **Table 2** respectively). The increase in noise footprint area below noise levels of 75 dB SEL (equivalent to 65 dB L_{Amax}) is apparent. **Figure 15** presents the SEL noise increase in decibels for upper (A/B) boundary and lower (B/C) boundary arrival profiles relative to a category A optimum approach.

Figure 14: Noise footprints for B787-8 aircraft with descent profiles for an optimum approach and the upper (A/B) boundary and lower (B/C) boundary profiles respectively (contours plotted from 70 to 90 dB SEL in 5dB steps)



[11] It recognised that some airport Noise and Track Keeping systems can record and display both raw and smoothed (interpolated) radar data. For the purposes of routine compliance monitoring, it is proposed that raw radar points be used.

Figure 15: Noise increase under flight path for category boundaries A/B and B/C relative to a category A optimum approach

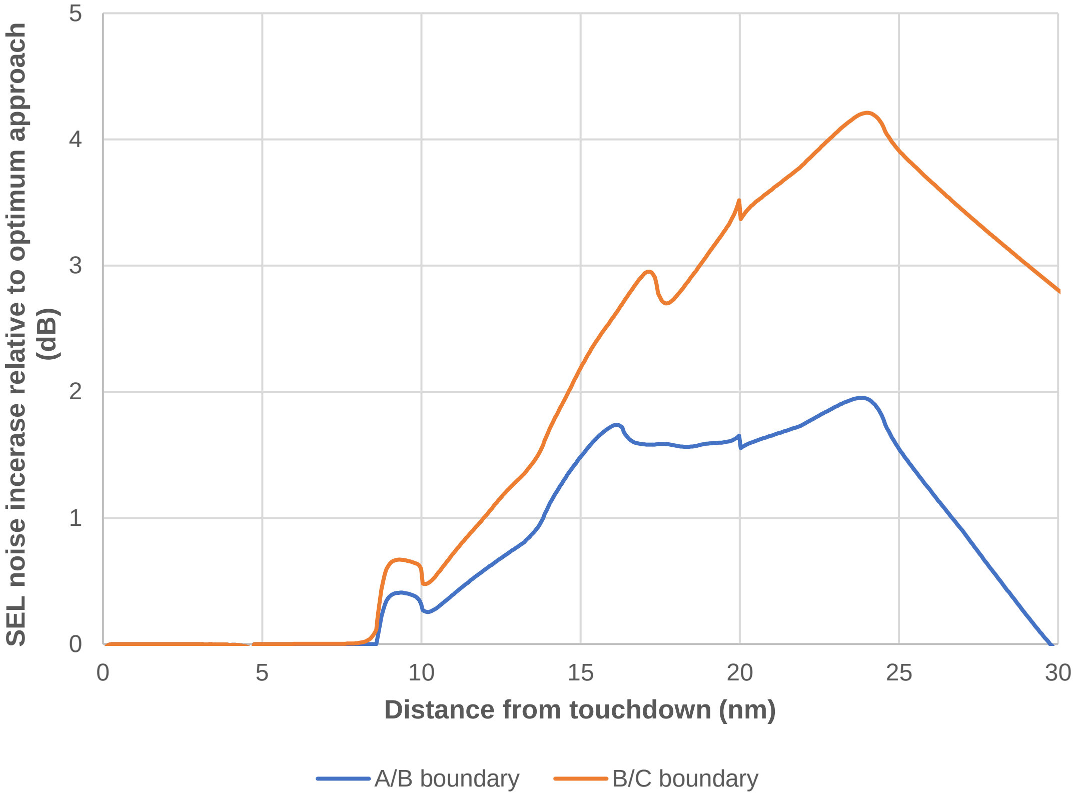


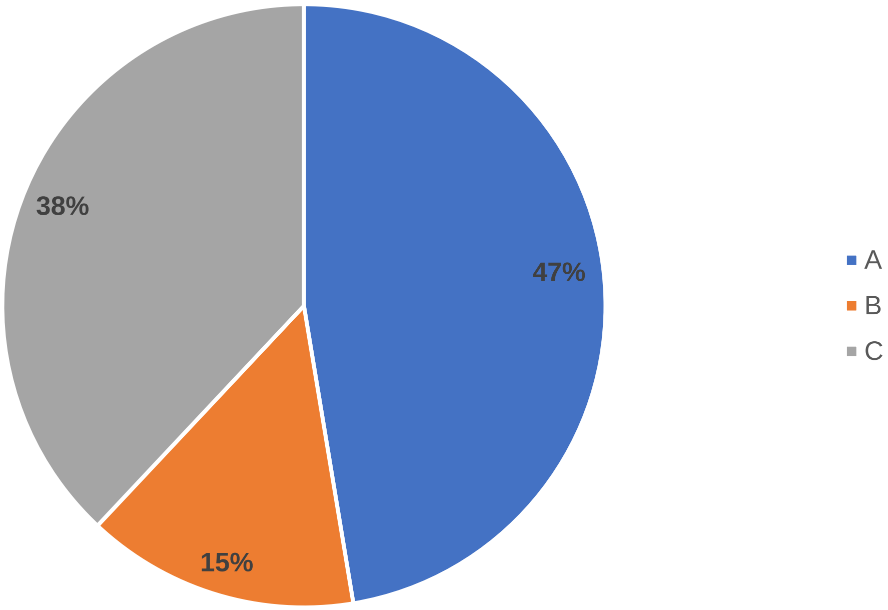
Table 2: Noise footprint areas for B787-8 approach profiles at A/B and B/C category boundaries compared to optimum approach

	Contour area (km²)		
SEL Contour Level (dB)	Optimum	A/B boundary	B/C boundary
70	73.5	95.6	135.6
75	27.3	27.3	28.5
80	9.9	9.4	9.4
85	3.3	3.3	3.3
90	0.8	0.8	0.8

Testing to Date

Testing was undertaken by NATS to identify the distribution and percentage of flights within each category. In total, 1.06 million flights across all UK airfields were analysed and categorised into A, B and C based on the newly defined criteria. **Figure 16** below illustrates the split in flights over the three categories.

Figure 16: Distribution of flights within each category (A, B, and C)



Testing Methodology

A descent categoriser was used by NATS to categorise the descent of aircraft at airports against the predefined thresholds set by the CAA.

The data sources used were:

- Airport & runway location data
- Aircraft arrival runway usage data
- MET Pressure data
- Radar trajectory data

To begin with, a subset of Gatwick arrival flights was run through the tool. The results were compared mathematically and visually against manually calculated profiles. Subsequent to this, they were checked against the predefined CAA thresholds.

NATS ran the tool for a number of example aircraft and validated the outputs against the CAA’s data, who had previously analysed the same radar data. Following this, a further five airports were modelled: Heathrow, Glasgow, Southampton, Manchester and Stansted. The results were verified using spot checks including flights from each airport. User validation was conducted through a session with key stakeholders.

The tool was developed to include all 22 Sustainable Aviation airports and interim testing and additional spot checks were completed to verify that the process remained consistent.

Chapter 6
Conclusions and Recommendations

Almost 20 years have passed since the first Arrivals Code of Practice was published in 2002, which defined a standard metric for a continuous descent operation and recommended monitoring of CDO performance at UK airports. Since publication, CDO performance has steadily improved to levels approaching 90%.

However, it has become apparent that not all CDOs have as low noise levels as were envisaged with the original definition.

Since this time, the fleet has also modernised with aircraft becoming quieter and more aerodynamically efficient such that, in some cases, it can make achievement of an approach close to the ideal 3 degree approach angle more challenging.

The study analysed aircraft approach performance for four aircraft:

- Airbus A320
- Airbus A380
- Boeing 787-8
- Bombardier Dash 8

This found that the Boeing 787-8 is the most difficult aircraft to slow down whilst descending because it has the lowest drag of the aircraft assessed. As a result, further analysis was only undertaken for the Boeing 787-8 and is presented in the report.

In order to maintain high landing rates, aircraft speeds for all but the final approach phase are managed by air traffic control, constraining the management of deceleration and decent angle. Noise emission, a by-product of the aircraft trajectory, is increasingly a function of airframe noise, as well as engine noise which is strongly related to aircraft speed. Whilst the development of internationally agreed airframe noise models and data is still some way off, this study incorporated the latest understanding of airframe theoretical prediction in order to develop an airframe noise component that could be incorporated into an ECAC Doc. 29[12] compliant model, such as the UK ANCON[13] model.

[12] ECAC Document 29 is the international agreed method for the calculation of noise contours around civil airports. The fourth Edition was published by the European Civil Aviation Conference (ECAC) in December 2016.

[13] The ANCON aircraft noise contour model is developed and maintained by ERCD on behalf of the Department for Transport (DfT).

A number of different arrival trajectories were assessed in order to understand what factors have the most significant effect on noise exposure. The results showed:

- how modern aircraft cannot decelerate and descend at angles of 3 degrees – for some aircraft, angles may need to be as low as 2.4 degrees in still air and even lower in tailwind conditions.
- the importance of initial/intermediate approach descent angle
- how the noise effects of level flight segments become less important with increasing height.

These insights led to the development of height-based criteria for a low noise arrival metric that would incentivise increased initial/intermediate descent angles, but not to the extent that would necessitate any changes in speed control or aircraft configuration. To better incentivise low noise arrival performance, two height boundary conditions are proposed, creating three height zones or low noise categories:

Upper boundary:

- A line starting at 50ft height above the landing runway threshold, extending out to 7.5nm at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5nm and 10nm
- A line at an angle of 1.75 degrees between 10nm and 5,500ft

Lower boundary:

- A line starting at 50ft height above the landing runway threshold, extending out to 7.5nm at an angle of 3 degrees
- A line at an angle of 1.75 degrees between 7.5nm and 10nm
- A line at an angle of 1.0 degrees between 10nm and 5,500ft

Testing indicates that the criteria would rate 45-50% of arrivals in the best category, with around 15-20% of arrivals in the second category and 35-40% in the lowest category.

The following recommendations are made:

- Monitoring systems should be developed to implement the rating of arrival operations against the proposed low noise arrival metric definitions and be appropriately validated.
- Concurrent monitoring of CDO and low noise metric performance should be undertaken. The identification of proportions of flights classified as both CDO and non-CDO, within the three low noise arrival categories should be assessed and reviewed with a view as to whether the existing CDO criteria should be incorporated into the proposed low noise arrival metric definitions or remain separate.
- Recognising the current inability to monitor LP/LD performance, encourage development of automated systems to monitor landing gear deployment.

APPENDIX A

Abbreviations

Abbreviations	
ANMAC	Aircraft Noise Management Advisory Committee
ATC	Air Traffic Control
CAA	Civil Aviation Authority
CDA	Continuous Descent Approach
CDO	Continuous Descent Operation
ERCD	Environmental Research and Consultancy Department
FAS	Future Airspace Strategy
ICAO	International Civil Aviation Organization
LP/LD	Low Power Low Drag
PBN	Performance Based Navigation
SA	Sustainable Aviation

APPENDIX B

Development of an enhanced arrival noise model

Current international best practice guidance on the calculation of aircraft noise relies on a methodology and associated database that integrates engine and airframe noise together. For strategic airport noise assessment this is sufficient. However, for the assessment and identification of low noise procedures, particularly in areas where engine thrust will be at or close to idle and thus airframe noise will dominate, it was recognised that airframe noise needs to be better accounted for separately of engine noise.

The surfaces of an aircraft (the fuselage, the wings, but particularly the flaps and landing gear) generate turbulence which produces noise. In the landing configuration, when flaps are extended and landing gear is deployed, engine power settings are low. In this instance airframe noise can exceed that of the engines.

One of the first airframe noise prediction methods published was by Fink[14] in 1977. Prediction methods have been developed by increasing awareness that has led to manufacturers undertaking dedicated airframe flight test and noise measurement programmes.

One of the latest methods for the calculation of airframe noise is published by the IHS ESDU as HIS ESU 90023: Airframe Noise Prediction[15]. The method uses information on the geometric characteristics of the airframe, combined with aircraft speed, height and angular position to predict one-third octave band sound pressure levels. These were compiled into Noise-Distance relationships for different aircraft speeds and configurations (landing gear/flap angles).

The results of the combined engine/airframe noise model were then combined with a range of arrival trajectories and resulting noise predictions compared with measurements and where necessary, adjustments made.

[14] Fink M, R. Airframe Noise Prediction Method, DOT/FAA Report, FAA-RD-77-29, March 1977.

[15] IHS ESDU 90023: Airframe Noise Prediction, Amendment E, 01 Dec 2008, ISBN 978 0 85679 749 1

Figure B1: Noise estimation for Boeing 787-8 for different arrival profiles compared with measurements

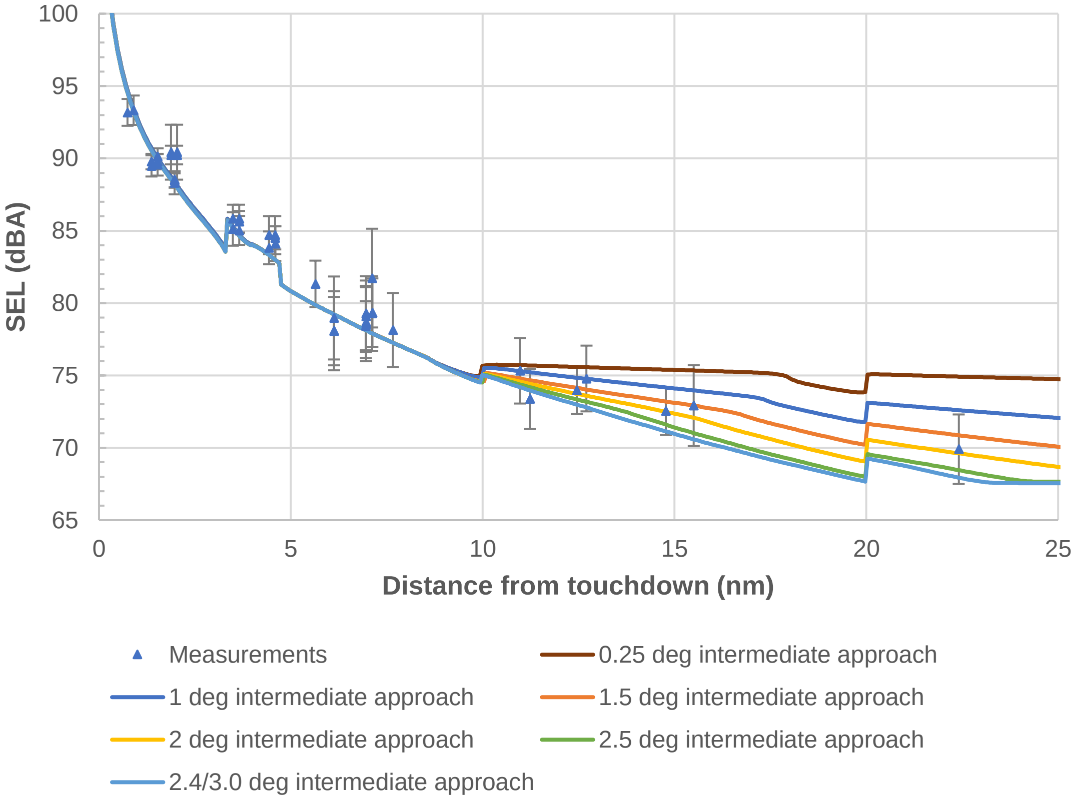
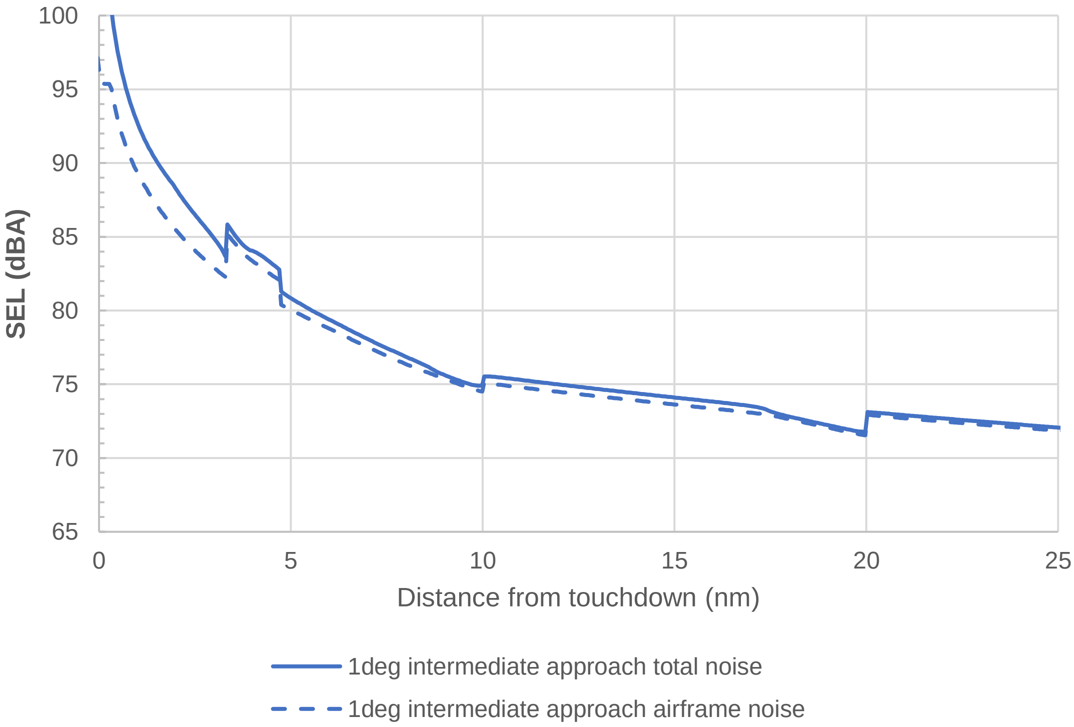


Figure B2: Estimated airframe and engine noise for Boeing 787-8 for a selected arrival profile



APPENDIX C

Minimum Height Values with Tolerance Applied

Table C1

Distance from landing threshold (nm)	Min height with tolerance A/B boundary (ft)	Min height with tolerance B/C boundary (ft)
0	0	0
0.27	36	36
0.54	122	122
0.81	208	208
1.08	294	294
1.35	380	380
1.62	466	466
1.89	552	552
2.16	638	638
2.43	724	724
2.70	810	810
2.97	896	896
3.24	982	982
3.51	1068	1068
3.78	1154	1154
4.05	1240	1240
4.32	1326	1326
4.59	1412	1412
4.86	1497	1497
5.13	1583	1583
5.40	1669	1669
5.67	1755	1755
5.94	1841	1841
6.21	1927	1927
6.48	2013	2013
6.75	2099	2099
7.02	2185	2185
7.29	2271	2271
7.56	2357	2357
7.83	2407	2407
8.10	2457	2457
8.37	2508	2508

Distance from landing threshold (nm)	Min height with tolerance A/B boundary (ft)	Min height with tolerance B/C boundary (ft)
8.64	2558	2558
8.91	2608	2608
9.18	2658	2658
9.45	2708	2708
9.72	2758	2758
9.99	2808	2808
10.26	2837	2858
10.53	2866	2908
10.80	2894	2959
11.07	2923	3009
11.34	2951	3059
11.61	2980	3109
11.88	3009	3159
12.01	3023	3184
12.15	3037	3209
12.42	3066	3259
12.69	3095	3309
12.96	3123	3360
13.23	3152	3410
13.50	3180	3460
13.77	3209	3510
14.04	3238	3560
14.31	3266	3610
14.58	3295	3660
14.85	3324	3710
15.12	3352	3761
15.39	3381	3811
15.66	3410	3861
15.93	3438	3911
16.20	3467	3961
16.47	3495	4011
16.74	3524	4061
17.01	3553	4111
17.28	3581	4161
17.55	3610	4212
17.82	3639	4262
18.09	3667	4312
18.36	3696	4362
18.63	3725	4412

Distance from landing threshold (nm)	Min height with tolerance A/B boundary (ft)	Min height with tolerance B/C boundary (ft)
18.90	3753	4462
19.17	3782	4512
19.44	3810	4562
19.71	3839	4613
19.98	3868	4663
20.25	3896	4713
20.52	3925	4763
20.79	3954	4813
21.06	3982	4863
21.33	4011	4913
21.60	4040	4963
21.87	4068	5014
22.14	4097	5064
22.41	4125	5114
22.68	4154	5164
22.95	4183	5214
23.22	4211	5264
23.49	4240	5314
23.76	4269	5364
24.03	4297	5414
24.30	4326	5465
24.57	4354	5515
24.84	4383	-
25.11	4412	-
25.38	4440	-
25.65	4469	-
25.92	4498	-
26.19	4526	-
26.46	4555	-
26.73	4584	-
27.00	4612	-
27.27	4641	-
27.54	4669	-
27.81	4698	-
28.08	4727	-
28.35	4755	-
28.62	4784	-
28.89	4813	-
29.16	4841	-

Distance from landing threshold (nm)	Min height with tolerance A/B boundary (ft)	Min height with tolerance B/C boundary (ft)
29.43	4870	-
29.70	4899	-
29.97	4927	-
30.24	4956	-
30.51	4984	-
30.78	5013	-
31.05	5042	-
31.32	5070	-
31.59	5099	-
31.86	5128	-
32.13	5156	-
32.40	5185	-
32.67	5213	-
32.94	5242	-
33.21	5271	-
33.48	5299	-
33.75	5328	-
34.02	5357	-
34.29	5385	-
34.56	5414	-
34.83	5443	-
35.10	5471	-
35.37	5500	-