

# Departure Noise Mitigation: Main Report

CAP 1691



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## Chapter 1

# Introduction

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Heathrow, Gatwick and Stansted airports are designated for the purposes of section 78 of the Civil Aviation Act 1982. This enables the Secretary of State to impose requirements on departing or landing aircraft for the purpose of mitigating noise. These powers have been used to set noise limits for departing aircraft, which have applied at Heathrow since 1959, at Gatwick since 1968 and at Stansted since 1993.

The original limit values remained effectively unchanged until the government's decision of 18 December 2000 to reduce the limits by 3 dB during the day and 2 dB at night, following a review which was initiated in 1993. The current limits are 94 dBA (day, 0700-2300), 89 dBA (shoulder, 2300-2330 and 0600-0700), and 87 dBA (night, 2330-0600). There was also a revision to relate the limits to a fixed reference distance of 6.5 km from start of roll and a new allowance for departures in a tailwind.

The 2000 decision reaffirmed that the government's general aim in noise monitoring is to help reduce the impact of aircraft noise around airports. Specific objectives and measures include:

- encouraging the use of quieter aircraft and best operating practice;
- deterring excessively noisy movements by detecting and penalising them;
- measuring the effectiveness of noise abatement measures by analysing infringement rates.

The government's 2000 decision included a commitment to commence a further review of the departure noise limits at the designated airports, which was overseen by its Aircraft Noise Monitoring Advisory Committee (ANMAC<sup>1</sup>). ANMAC advises the Department for Transport on technical and policy aspects of aircraft noise mitigation and track-keeping at Gatwick, Heathrow and Stansted airports. Its membership includes representatives of Gatwick, Heathrow and Stansted, those airports' consultative committees, the three airport scheduling committees, the CAA, NATS and the Department for Environment, Food and Rural Affairs (Defra).

The CAA's Environmental Research and Consultancy Department (ERCD) were asked by ANMAC to undertake the technical aspects of the review, which was completed in 2003 and the findings published in ERCD Report 0207<sup>2</sup>. A key conclusion of the review was that

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<sup>1</sup> ANMAC is currently known as the Aircraft Noise Management Advisory Committee, the name changing from Aircraft Noise Monitoring Advisory Committee in 2010/11.

<sup>2</sup> [ERCD Report 0207](#), *Departure Noise Limits and Monitoring Arrangements at Heathrow, Gatwick and Stansted Airports*, Civil Aviation Authority, April 2003

with the current fleets operating during the day and at night, there was little or no scope for reducing the noise limits.

Recognising that the current noise limits had been in place for many years, the government announced in its March 2013 Aviation Policy Framework that ANMAC would review the departure and arrivals noise abatement procedures, including noise limits and use of penalties, to ensure that these remain appropriately balanced and effective. This report describes the work completed in respect of departure noise<sup>3</sup>. A summary report that outlines the main findings is also available as [CAP 1691a](#).

Much of the work in support of this review was carried out by the CAA's Environmental Research and Consultancy Department (ERCD) in close collaboration with other members of the ANMAC Technical Working Group (TWG), whose membership is listed below.

<b>ANMAC Technical Working Group membership</b>	
CAA ERCD (Chair and Secretariat)	Stansted Scheduling Committee
Department for Transport	Technical Adviser to the Scheduling Committees
Gatwick Airport	Gatwick Airport Consultative Committee (GATCOM)
Heathrow Airport	Heathrow Community Engagement Board (HCEB)
Stansted Airport	Stansted Airport Consultative Committee (STACC)
Gatwick Scheduling Committee	NATS
Heathrow Scheduling Committee	

The Technical Working Group's terms of reference were:

- Conduct a review of the existing policy objectives and desired outcomes from a departure noise management regime in order to establish the criteria against which any revised proposals can be assessed. If appropriate, additional or alternative outcomes will be added to the criteria.
- Carry out a systematic review of the current departure noise abatement and monitoring procedures to understand how they help achieve the required outcomes.
- Without prejudice to the review of current procedures, assess the change in infringement rates for an increase in stringency of the current noise limits at Heathrow, Gatwick and Stansted. The current policy of applying uniform noise limits across the three airports should also be reviewed.

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<sup>3</sup> [CAP 1554](#) *Review of Arrival Noise Controls*, published in July 2017, summarises the related work completed by the ANMAC Technical Working Group in respect of arrivals noise.

- On the basis of findings from these investigations, assess the potential for operational changes to mitigate any significant increase in infringement rate for aircraft of similar types.
- Assess the possible impacts of operational changes in terms of noise, emissions and any other significant factors.
- The Technical Working Group should report their findings back to ANMAC.

The report is structured as follows:

- Chapter 2 describes in general terms the different phases of a typical departure and the responsibilities associated with each phase of the operation.
- Chapter 3 summarises the history of the noise limits and other departure noise controls at the designated London airports.
- Chapter 4 provides a comparison of climb profiles across different airports and investigates changes in average aircraft heights over time.
- Chapter 5 considers the effect on noise and emissions of operational changes to departure procedures.
- Chapter 6 considers the potential for providing targeted respite from noise along departure routes through more accurate track keeping.
- Chapter 7 presents the conclusions and recommendation of the study.



## Chapter 2

# Phases of a departure and associated responsibilities

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## Introduction

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To assist the reader with the discussion and interpretation of results in the subsequent chapters, the following sections describe the main phases of a typical UK departure and briefly outline the associated responsibilities. Presentation slides that illustrate each phase of a departure are also available in [CAP 1691b](#).

## Prior to departure

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Prior to departure (this can be hours, days or even months prior) an airline will submit a flight plan<sup>4</sup> to the UK Air Traffic Control (ATC) provider NATS requesting an air traffic routing to its destination. The filed route, as defined in the Standard Route Document (SRD), will specify the route to be flown and airlines will normally use automated optimisation tools to select the most appropriate routing.

In order to get connectivity from airport to airway a designated Standard Instrument Departure (SID) route will be part of the departure. For example, if routing from London Heathrow towards a north-easterly destination such as Copenhagen, the requested SID would normally be “Brookmans Park (BPK)”. If routing to a destination in the south east such as Paris the Midhurst (MID) routing would normally be chosen.

Once the load of passengers, cargo and fuel is known, the take-off mass of the aircraft for the flight will be calculated by the airline and passed to the pilots. For the vast majority of operations, this take-off mass will be used to calculate the required take-off performance, taking account of the available runway length, obstacle requirements, and prevailing meteorological conditions (temperature, wind speed and direction, air pressure and whether the runway is wet or has slush/snow affecting the take-off). These details will be entered into the aircraft’s Flight Management System (FMS).

At this time, the flight crew will also select the take-off noise abatement departure procedure defined in their company procedures. A noise abatement departure procedure defines the height at which the flight crew will reduce engine power after take-off and the height at which acceleration from the take-off speed commences. ICAO guidance, mandated in Europe, requires that an airline has no more than two departure procedures for each aircraft type it operates, no matter where in the world that aircraft type is flown. This is to ensure that a profusion of bespoke, complex departure procedures do not

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<sup>4</sup> See [CAP 694](#) (*The UK Flight Planning Guide*) for further details.

develop which would add to pilot workload and reduce their ability to monitor a safe take-off at what is a critical stage of flight.

An airline will normally set a company policy (for each aircraft type) for which type of procedure to fly, which balances a number of environmental and operational factors. ICAO guidance recommends two types of procedure, within which a large variety of specific procedures could be developed. An airline is not required to select one of each type as its two procedures.

ICAO has identified that Noise Abatement Departure Procedure 1 (NADP 1) generally provides better noise relief directly underneath the flight path very close to the airport and tends to produce less NO<sub>x</sub> below 3,000 feet (because the aircraft climbs to 3,000 feet more quickly), but leads to an increase of carbon dioxide (CO<sub>2</sub>). NADP 2 can provide better noise relief further along the departure track and is better in regard to fuel burn and CO<sub>2</sub>.

There is a common misconception that NADP 1 reduces noise overall but in fact changing procedures simply moves the noise relief to different locations. This can be useful if there are unpopulated areas to concentrate the noise into, but less useful if the take-off path is close to a heavily populated area. Chapter 5 provides a further discussion of NADP 1 and NADP 2 procedures.

The key point is that each airport, indeed each runway, has a different population distribution under its flight paths. These two procedures are incorporated into an airline's Standard Operating Procedures (SOP) manual, which is approved when an airline is issued an Airline Operating License (AOC).

Thereafter, the contents of and adherence to SOPs is assessed through ongoing safety oversight. Thus, there is no current requirement for a national CAA or an airport to be notified of a change to an airline's SOPs. Note also that the UK CAA only has oversight of SOPs for UK airlines (UK AOC holders). The aircraft type, its take-off mass, the departure procedure used and the prevailing meteorological conditions will largely define the aircraft's height profile, although tight turns on some SIDs will have a secondary effect on climb performance.

## **Taxi for take-off**

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The aircraft will taxi out to the designated departure runway, at which point ATC may offer the flight crew either a full-length departure or the option to enter the runway at an inset point, called an intersection take-off, which is used to facilitate expeditious departures. In such cases, aircraft performance will be re-evaluated by the flight crew to comply with the safety requirements associated with a shorter available runway length. Although an aircraft making an intersection take-off may be lower in height at various points after departure than a departure using the full runway length, the flight crew would still have to comply with the same minimum height and climb requirements at all points along the departure route.

## Take-off and climb

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Once the aircraft departs the airport, the tower controller will observe the aircraft on the aerodrome traffic monitor and then transfer the departure from the tower to a radar controller (based at the relevant ATC centre) to take over control. The aircraft will continue to fly the lateral and vertical profiles of the SID.

### Between 800 and 3,000 feet

During this phase, between 800 feet and 3,000 feet, aircraft will accelerate from their take-off speed (as low as 140 knots) to their desired climb speed (210-270 knots) and reduce engine power from the take-off setting to the climb-setting, in accordance with their SOP. Due to the delayed acceleration associated with an NADP 1 departure (compared to NADP 2), the use of a particular Noise Abatement Departure Procedure can, in some instances, affect runway and airspace capacity. For routes involving early turns, aircraft heights may be lower than for straight out routes, due to the reduced climb performance of an aircraft in a turn.

Although the maximum permitted airspeed is 250 knots below 10,000 feet, for some aircraft types at high take-off mass, this is inefficient and higher climb speeds are sometimes approved by the air traffic controller. Note that these are airspeeds. WebTrak (at Heathrow and Stansted), Casper (at Gatwick) and other third party flight tracking websites report ground speed, which can be significantly different due to the effect of wind. Thus it is not possible to ascertain from such sites which flights have been permitted to operate above 250 knots below 10,000 feet.

### 3,000 - 4,000 feet

Unless there is a need for air traffic control to intervene<sup>5</sup> below the vectoring altitude<sup>6</sup>, an aircraft will follow the SID departure clearance, which defines the instructions with regard to the aircraft's lateral or horizontal position. These instructions do not equate to a single line or track over the ground as aircraft turning at different speeds will turn at different rates, leading to variation in the track flown over the ground, even for the same airline service from one day to the next.

### At or above 4,000 feet

At 4,000 feet and above (3,000 feet on some routes<sup>7</sup>) air traffic control are permitted to intervene, if required, and vector the aircraft off the SID (many SIDs extend beyond 4,000 feet), in order to facilitate a continuous climb and also to separate from other aircraft in the vicinity. If ATC do not radar vector the aircraft, it will continue to follow the lateral SID profile.

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<sup>5</sup> Intervention would generally be for weather or to maintain separation from other aircraft.

<sup>6</sup> Vectoring altitude is a minimum altitude at which ATC are permitted to put an aircraft onto a more direct heading, thereby 'vectoring' the aircraft away from its assigned SID.

<sup>7</sup> 4,000 feet at Heathrow. 3,000 or 4,000 feet at Gatwick and Stansted depending on the route.

At many airports SIDs are designed to require aircraft to level out at a specific altitude between 3,000 and 7,000 feet, in order to facilitate crossing of departing and arriving traffic. This restriction is often lifted by ATC on a flight by flight basis as and when conditions permit. Clearly any altitude restrictions applied will affect the altitude attained thereafter at more distant locations from the airport.

UK airspace, particularly in the South East of England, is some of the busiest airspace in Europe. ATC endeavour to give the aircraft the most direct routing to its destination but also need to keep the aircraft at a safe distance from the many other aircraft climbing and descending from and to airports in the South East.

Improved aircraft navigation performance combined with better airspace design should allow the future airspace system<sup>8</sup> to accommodate more direct routing of aircraft from departure to destination and enable more Continuous Climb Operations (CCO). Performance Based Navigation (PBN) offers the potential to tailor departure routes to avoid more densely populated areas and therefore reduce the number of people impacted by aircraft noise (see Chapter 6).

As the aircraft continues to climb towards its cruising altitude the aircraft is transferred from radar controller to radar controller, and is then transferred to neighbouring ATC centres as it makes its way to its destination.

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<sup>8</sup> The Government has tasked the CAA with preparing and maintaining a coordinated strategy and plan for the use of UK airspace for air navigation up to 2040, including for the modernisation of the use of such airspace. In response to that requirement the CAA has published its Draft Airspace Modernisation Strategy for public engagement, which will be open until 10 September 2018 (see <https://consultations.caa.co.uk/policy-development/draft-airspace-modernisation-strategy/>). The finalised Airspace Modernisation Strategy will be published at the end of the year.

## Chapter 2 summary

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- The SID flown on departure is normally planned well in advance by airlines.
- The airline will normally set a company policy for which type of Noise Abatement Departure Procedure (NADP) to fly for each aircraft type, which balances a number of environmental and operational factors.
- At 4,000 feet and above (or 3,000 feet on some SIDs) air traffic control are permitted to intervene if required and vector the aircraft off the SID.
- The SIDs at many airports are designed to require aircraft to level out at a specific altitude below 7,000 feet in order to facilitate crossing of departing and arriving traffic.
- Improved airspace design should allow the future airspace system to accommodate more direct routing of aircraft from departure to destination and enable more Continuous Climb Operations (CCO). Performance Based Navigation (PBN) offers the potential to tailor departure routes to avoid more densely populated areas and therefore reduce the number of people impacted by aircraft noise.

## Chapter 3

## Review of departure noise controls

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### Departure noise limits

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Departure noise limits have applied at Heathrow since 1959, at Gatwick since 1968 and at Stansted since 1993. Fixed noise monitors were installed specifically for enforcing these limits. The original limits were set in PNdB (Perceived noise decibel, the unit considered then to best represent human judgement of the noisiness of aircraft noise events).

The limits were set at 110 PNdB during the day and 102 PNdB at night, at any monitor. These related to the maximum noise levels which it was considered those living in the major built-up areas closest to the airport should be expected to tolerate. When the airports' original Noise and Track Keeping (NTK) systems were installed in 1992-93 the maximum noise levels were defined in terms of dBA (A-weighted decibel), the broad equivalents of the old PNdB limits being 97 dBA (day) and 89 dBA (night).

The original limit values remained effectively unchanged until the government's decision of 18 December 2000 following a review which was initiated in 1993. The reduced limits - 3 dB lower by day and 2 dB lower by night, and a shoulder period when the previous night limit applies - were implemented in February/March 2001. There was also a revision to relate the limits to a fixed reference distance of 6.5 km from start of roll and a new allowance for departures in a tailwind.

The current limits are 94 dBA (day, 0700-2300), 89 dBA (shoulder, 2300-2330 and 0600-0700), and 87 dBA (night, 2330-0600), which apply equally across the three airports.

The lower night and shoulder period limits are intended to reflect the greater disturbance associated with noise at night and are broadly compatible with the night restrictions regime, reflecting what is operationally practicable in that context.

The noise limits are promulgated through a notice<sup>9</sup> published for each airport under Section 78(1) of the Civil Aviation Act 1982. Financial penalties for breaches of the limits by operators of the offending aircraft are levied by the airports under their charging powers and the money collected is given to local projects and charities.

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<sup>9</sup> The notices are published in the UK Aeronautical Information Publication (AIP). See EGLL AD 2.21, EGKK AD 2.21 and EGSS AD 2.21 (Noise Abatement Procedures) for Heathrow, Gatwick and Stansted respectively.

The size of the financial penalties, which are not part of this review, are also set by each airport and are summarised below (as of 2018):

Period	Heathrow	Stansted	Gatwick
Daytime (0700-2300)	£500 per dB	£1,000 up to 3 dB, £250 per dB for 3 dB or more	£500 up to 5 dB, £1,000 for 5 dB or more
Night Shoulder (2300-2330 and 0600-0700)	£1,500 per dB	£1,000 up to 3 dB, £1,000 per dB for 3 dB or more	
Core Night (2330-0600)	£4,000 per dB		

The noise limits are related to a fixed reference distance in relation to the runways and aircraft departure tracks; the distance being 6.5 km from start of roll<sup>10</sup>. This point was chosen as the fixed reference distance for measuring the noise limits because relatively few residential areas lie closer than that to the London airports.

Current generation aircraft will normally be able to reach 1,000 feet before 6.5 km. The government considers that relating noise limits to the 6.5 km distance encourages aircraft operators to climb as quickly as possible immediately after take-off and then reduce engine power (and noise) at the earliest opportunity before reaching the measurement point. A basic requirement is that noise levels diminish along the track after an aircraft passes a monitor.

At each airport, the fixed monitors are sited in an arc as near as practicable to 6.5 km from start of roll at each end of the runway. The spacing of the monitors takes account of the location of the departure routes and the tracks actually flown. To ensure consistency in the noise monitoring arrangements, the limits at individual monitors are adjusted to account for the effects of any displacement from the reference point, with an additional allowance for departures in a tailwind. The locations of the fixed monitors are shown in **Appendix B**.

<sup>10</sup> Start of roll is where aircraft (using the full runway length) typically begin their take-off run. It is approximately 150 metres in from the 'start' end of the runway.

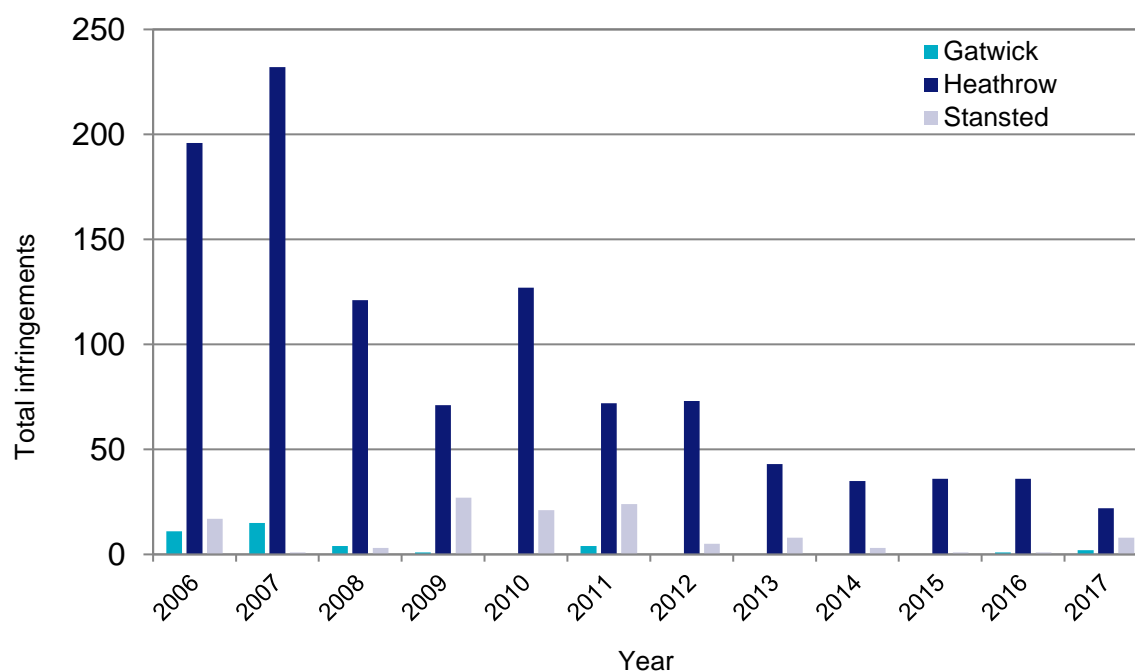
The government has never set noise limits on the basis that they should be operationally achievable by all aircraft irrespective of operating procedures and payload. To reduce the possibility of exceeding the limits airlines are expected to employ operational measures such as:

- use of different departure procedures;
- reduction in take-off weight;
- rescheduling of aircraft within existing fleets;<sup>11</sup>
- use of quieter aircraft generally.

In practice there are now relatively few noise infringements across the three airports, due largely to the gradual retirement and replacement of older aircraft types such as the Boeing 747-400 and Airbus A340-200/300 with newer and quieter types.

A summary of the total number of annual infringements recorded since 2006 is provided below for information. In 2017 less than 0.01% of all departures at Heathrow and Stansted, and 0.001% of departures at Gatwick, exceeded the limits<sup>12</sup>.

**Figure 1** Summary of annual departure noise infringements since 2006



<sup>11</sup> At Stansted, for example, operators have rescheduled MD11 aircraft with particular engine versions to different times of the day to reduce the possibility of exceeding the night limit.

<sup>12</sup> One of the eight noise infringements recorded at Stansted in 2017 was caused by an Ilyushin IL-76TD, which is an older 'Chapter 2' aircraft that is normally banned from operating in EU States. However, on this occasion the aircraft had been issued an exemption (authorised by the Department for Transport) to operate from Stansted during the daytime.



It is immediately apparent that the number of noise infringements at Heathrow historically has been much higher than at Gatwick or Stansted. This is due to the different fleet mixes at each airport and the much greater number of long haul routes that are served from Heathrow.

As mentioned in Chapter 1, ERCD previously published a review of the departure noise limits in 2003<sup>13</sup>. The review concluded that the daytime limit could be reduced by 1 dB, but with current fleets there was little scope for greater reductions. The review also found there was no scope for reducing the shoulder period or night limits, unless a ban on QC/4 departures in the night quota period were to be imposed, in which case a 3 dB reduction of the night limit might be appropriate. Consequently, the noise limits were left unchanged and have therefore been in place since 2000.

The government's 2003 consultation paper on night flying restrictions<sup>14</sup> did however include further discussion of departure noise limits and, in particular, mentioned a proposed trial of differential (or tiered) noise limits. The basis for the proposed scheme was to ensure operators of all types of aircraft, not just the noisiest ones, minimise their noise on take-off.

A trial study was subsequently conducted by Gatwick's Flight Evaluation Unit (FEU) and ERCD between 2003 and 2005, which was overseen by ANMAC. Two possible methods of applying differential limits at the existing fixed monitors were considered:

- (a) a set of limits based on the Departure QC category (termed 'QC-based limits'). The trialled limits were as follows: 94 dBA (QC/8 and QC/16), 91 dBA (QC/4), 88 dBA (QC/2), 85 dBA (QC/1).
- (b) a limit for each aircraft, calculated directly from its certificated flyover noise level (termed 'flyover-based limits'). The trial suggested that the flyover-based dBA limit should be 6 dB less than the flyover certification EPNdB level.

The results of the trial indicated that the number of infringements *per month* at Gatwick would typically be of the order of 10 (QC-based limits), or 25 (flyover-based limits). By comparison, the total number of noise infringements at Gatwick in 2005 was 41.

Based on typical daily movement numbers and the fleet mix at that time, it was considered that the number of infringements at Stansted would likely be similar to Gatwick, but at Heathrow the number of infringements under any new differential scheme, and the consequent administrative workload (in identifying, recording and notifying infringements), could be significantly higher.

A conclusion of the trial was that the trade-off between noise and emissions, whereby reducing noise at a given location might produce increased emissions, would need to be

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<sup>13</sup> [ERCD Report 0207](#), *Departure Noise Limits and Monitoring Arrangements at Heathrow, Gatwick and Stansted Airports*, Civil Aviation Authority, April 2003

<sup>14</sup> *Night Flying Restrictions at Heathrow, Gatwick and Stansted*, Department for Transport, April 2003

further assessed before a fully informed decision could be made on implementing differential departure limits. The results also indicated that only modest noise benefits (of 1 or 2 dB across some fleets) could be gained from proceeding with a differential limits scheme. Given also the increased administrative aspects of the scheme, the work was not pursued further.

Government has stated previously that the primary purpose of the noise limits is to encourage the use of quieter aircraft and best operating practice. On this basis, the relatively low number of noise infringements illustrated in **Figure 1** over more recent years suggests the usefulness of the current limits may have diminished as aircraft have got quieter, and that there may now be scope to lower the limits. To determine the likely effect on infringement rates of successive reductions in the noise limit at each airport a new analysis of operational data has been carried out. Results are presented in **Appendix C**, which indicate that for Heathrow there is limited scope for reductions in the noise limits until the retirement of the remaining Boeing 747-400 fleet.

With 36 aircraft in service, British Airways (BA) is the largest remaining operator of the 747-400, which is expected to continue flying at Heathrow until 2024 (although half of the current BA 747 fleet will be withdrawn by 2021<sup>15</sup>). In the meantime, however, and noting in **Figure 1** that there were approximately 200 noise infringements recorded at Heathrow each year in 2006 and 2007, a small reduction of 1 to 2 dB in the daytime and shoulder limits might be feasible without causing the overall number of infringements to increase above historic levels.

If a corresponding reduction of 1 to 2 dB was applied to the night limit at Heathrow, operational changes might be required, even for a relatively modern aircraft such as the Airbus A380, in order to mitigate any significant increase in infringement rates. Chapter 5 provides further discussion on this issue.

The results for Gatwick and Stansted on the other hand indicate that the current daytime, shoulder and night limits could be lowered, by up to 3 decibels or more in some cases, without significantly impacting the current fleets at those airports. However, it should be noted that any new limits at Gatwick or Stansted could be set at a level that could effectively prohibit noisier aircraft (such as the 747-400) from operating at those airports in the future, which could constitute an operating restriction. A counter argument to this view is that a lowering of the noise limit would provide a backstop, dissuading the re-introduction of the noisiest aircraft types.

In addition to the departure noise limits, a number of other noise controls are promulgated through the Section 78 notices for each London airport, which are summarised below.

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<sup>15</sup> <https://www.flightglobal.com/news/articles/last-ba-747-400-to-leave-fleet-in-early-2024-442859/> (accessed 9 July 2018)

## Height requirement at 6.5 km from start-of-roll

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A height requirement on departure has been set by the government for noise purposes since 1966. The current requirement, for aircraft to be at a height of not less than 1,000 feet above aerodrome level (aal) at 6.5 km from start-of-roll, was introduced following the government's decision of 18 December 2000 (on the noise limits and related noise monitoring arrangements to apply at the London airports). Prior to that decision, the requirement was that aircraft should be at a height of 1,000 feet when passing the nearest noise monitor, some of which were not located close to 6.5 km from start-of-roll.

Although a height requirement has been set for noise purposes for several decades, it has never been enforced. In his December 2000 decision, the Secretary of State confirmed that it accepts that occasional and exceptional breaches of the height requirement would not be expected to lead to the use of his power under Section 78(2) of the Civil Aviation Act 1982 (to direct that the aircraft operator should be refused facilities for using the aerodrome). However, the London airports monitor aircraft against this requirement and work with airlines with regards to their compliance<sup>16</sup>.

Information on the numbers of aircraft that fail to comply with the height requirement over recent years is summarised below in **Figure 2**, which shows a general downward trend over time. In 2017, the compliance rate was 100% at Gatwick, 99.8% at Heathrow and more than 99.9% at Stansted. To account for any uncertainty in the monitored height of aircraft, the airports also monitor against a minimum height requirement of 900 feet. Even with this additional tolerance<sup>17</sup> of 100 feet, the number of height infringements at Heathrow is still relatively high compared to Gatwick and Stansted. This can be explained by the different fleet mix at Heathrow.

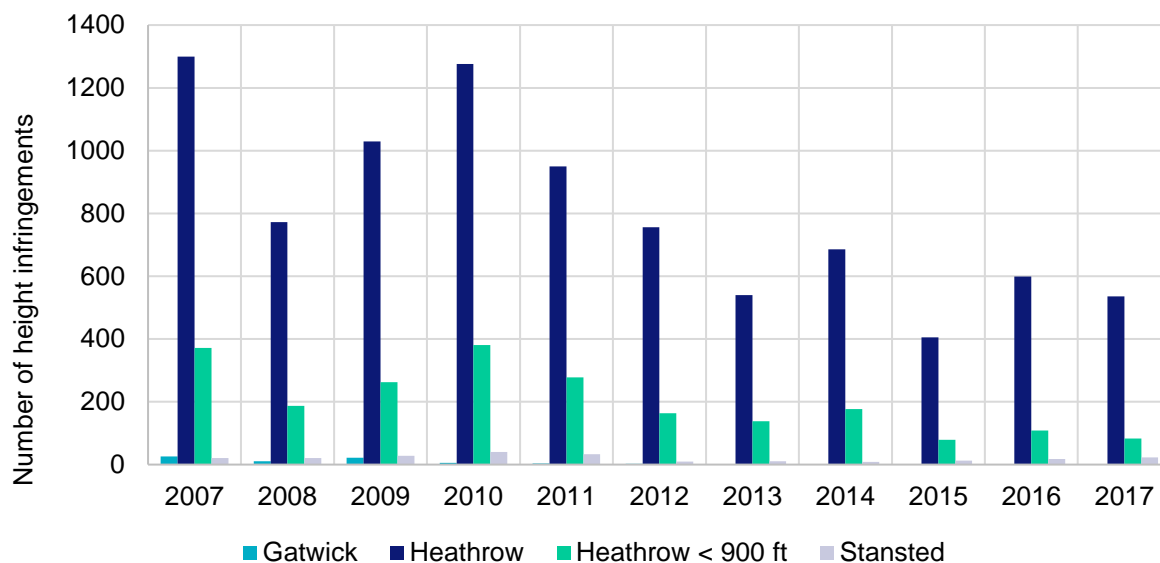
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<sup>16</sup> Gatwick: <https://www.gatwickairport.com/business-community/aircraft-noise-airspace/>.

Heathrow: <https://www.heathrow.com/noise/reports-and-statistics/reports>.

Stansted: <http://www.stanstedairport.com/community/noise/our-noise-performance/> (accessed 9 July 2018)

<sup>17</sup> 100 feet is considered to represent the worst-case (maximum) error in the height measurement for an individual aircraft in the airports' NTK systems.

**Figure 2** 1,000 feet height infringements at Gatwick, Heathrow and Stansted, 2007-2017

Heathrow typically has a greater number of long-haul airline services that tend to operate using larger (and slower-climbing) four-engine aircraft such as the B747-400, A340 and A380.

## 4% climb gradient requirement

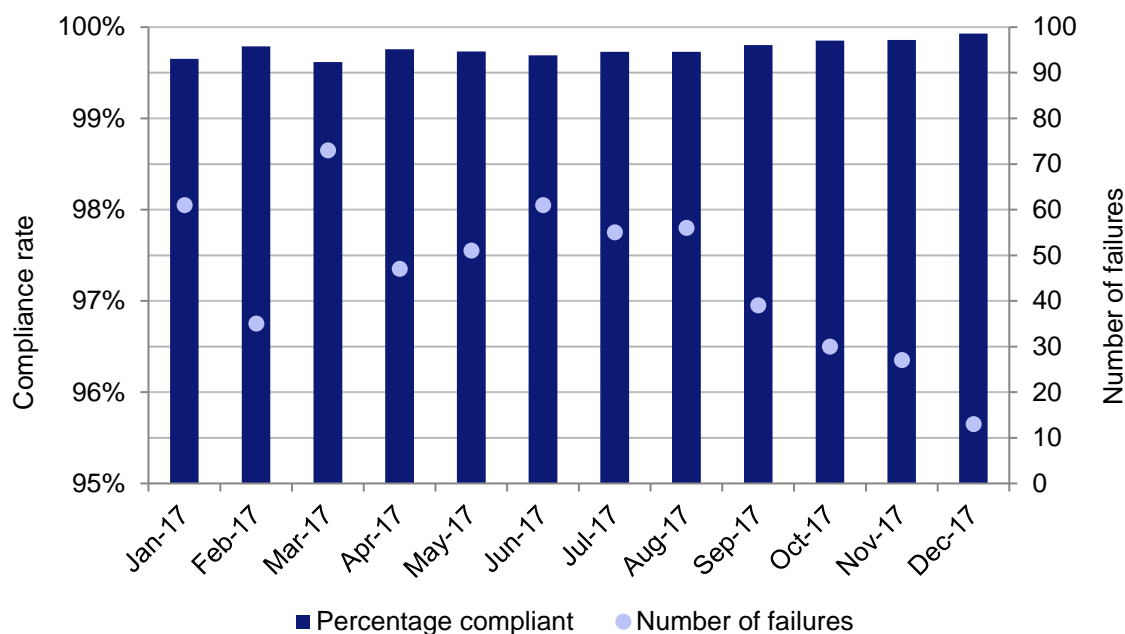
After passing the 1000 feet point (at 6.5 km) referred to above, aircraft are then required to maintain a climb gradient of not less than 4% to an altitude (above mean sea level) of not less than 4,000 feet<sup>18</sup>. The rationale for the climb gradient requirement is to ensure that progressively reducing noise levels at points on the ground are achieved (see the following section). Climb gradients greater than 4% may also be required below 4,000 feet (or 3,000 feet) on some SIDs for ATC purposes in order to safely separate air traffic.

The minimum 4% gradient requirement is another longstanding requirement (dating back to the 1960s), but technology has not existed to enable practical monitoring until recently. Data on minimum climb gradient performance since January 2017 is now being published by Heathrow Airport as part of its regular flight performance reporting<sup>19</sup>. **Figure 3** presents a monthly breakdown of climb gradient performance during 2017<sup>20</sup>. The overall compliance rate in 2017 was 99.8%.

<sup>18</sup> The 4% climb requirement applies up to 3,000 feet at Gatwick at any time, and up to 3,000 feet for daytime departures on the Barkway SID at Stansted.

<sup>19</sup> <https://www.heathrow.com/noise/reports-and-statistics/reports> (accessed 9 July 2018)

<sup>20</sup> Data for the easterly Compton SID are not included in the analysis due to the difficulties associated with flying this route.

**Figure 3** Heathrow minimum 4% climb gradient performance in 2017 for all aircraft types

Whilst the number of departures failing to meet the 4% requirement is small in absolute terms, the majority of the failures are A380 operations. Further analysis of departure climb gradients is provided in Chapter 4.

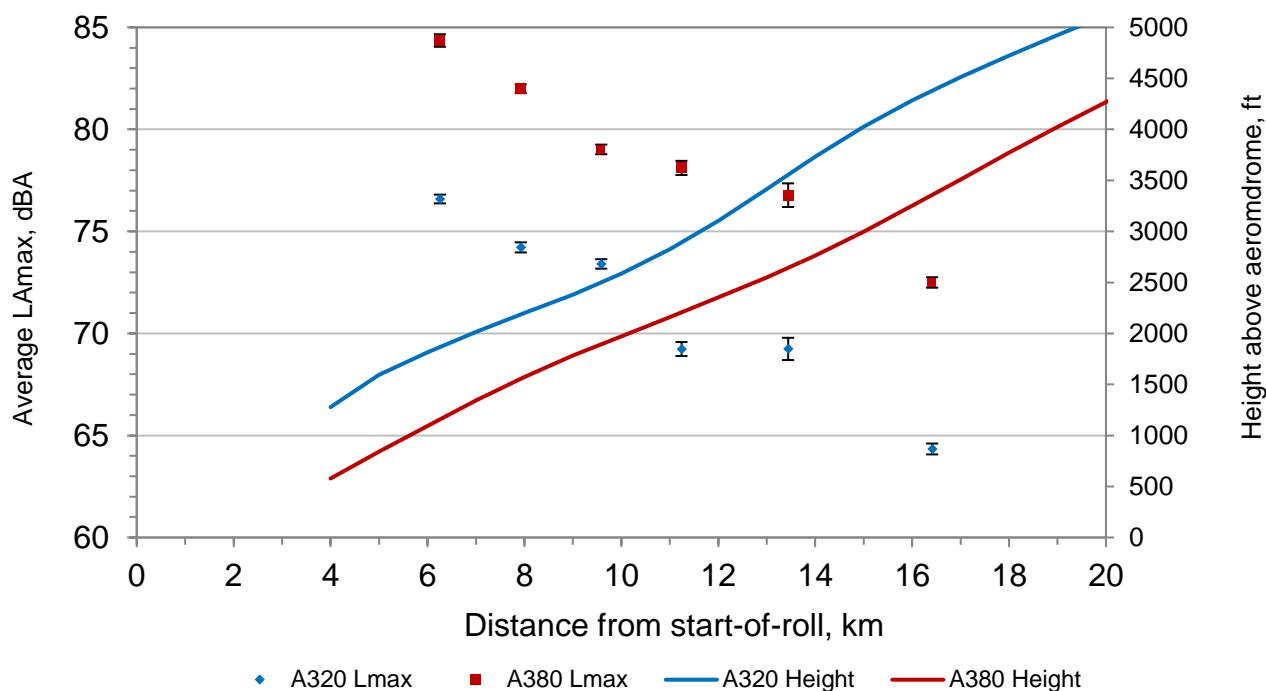
## Progressively Reducing Noise Levels Beyond 6.5 km

In addition to the departure noise limits, the 1,000 feet requirement and the minimum 4% climb gradient, the noise abatement notices for the designated London airports also require that:

*“The aircraft shall be operated in such a way that progressively reducing noise levels at points on the ground under the flight path beyond that point are achieved.”*

There is currently no means of verifying that this requirement is being met, although the minimum 4% climb gradient was intended to contribute to achieving this outcome. Mobile (temporary) noise monitoring carried out on an ad hoc basis over previous years indicates that average noise levels continue to reduce beyond 6.5 km from start of roll.

For example, **Figure 4** shows a general downward trend in the average  $L_{Amax}$  noise levels measured at a number of monitors located along the easterly Detling route at Heathrow for the (faster climbing) twin-engined A320 and (slower climbing) four-engined A380, with error bars representing 95% confidence intervals in each case. The average height profiles for each type are also shown for information, plotted against the right vertical axis. But despite this downward trend in noise, there is undoubtedly still some community discontent with departure noise in general, which suggests that the existing controls may not be sufficient to meet the concerns of the community.

**Figure 4** Average  $L_{Amax}$  departure noise levels along 09R Detling, Summer 2017

In seeking to reduce noise at 6.5 km, procedures could be developed within the ICAO PANS-OPS framework that reduce engine power and noise at 6.5 km to such an extent that engine power would need to be increased at some point beyond 6.5 km, potentially leading to higher noise levels than at the 6.5 km point. An obvious way of mitigating this risk would be to monitor noise on a more continuous basis at one or more additional points beyond 6.5 km.

In addition to considering the number of noise monitoring stations that would be required, other requirements would be that any noise monitoring sites should be free from excessive background (non-aircraft) noise, free of nearby obstructions such as trees and buildings, and also secure enough to reduce the likelihood of vandalism. Whilst deploying additional monitors along departure routes at Gatwick and Stansted could be relatively straightforward, the greater number of routes and geographical layout of the surrounding urban areas at Heathrow could make this more challenging.

Current government guidance to the CAA and wider industry on airspace and noise management acknowledges that noise from aircraft flying at or above 4,000 feet is less likely to affect the key noise metrics used for determining adverse effects, and as aircraft continue to climb above this altitude their noise impact reduces<sup>21</sup>.

**Figure 4** suggests that, as a minimum, the outermost monitor along other routes at Heathrow could be located somewhere between 10 to 15 km from start-of-roll in order to capture most aircraft still below 4,000 feet. Whilst monitoring significantly beyond this

<sup>21</sup> *Air Navigation Guidance 2017*, Department for Transport, October 2017

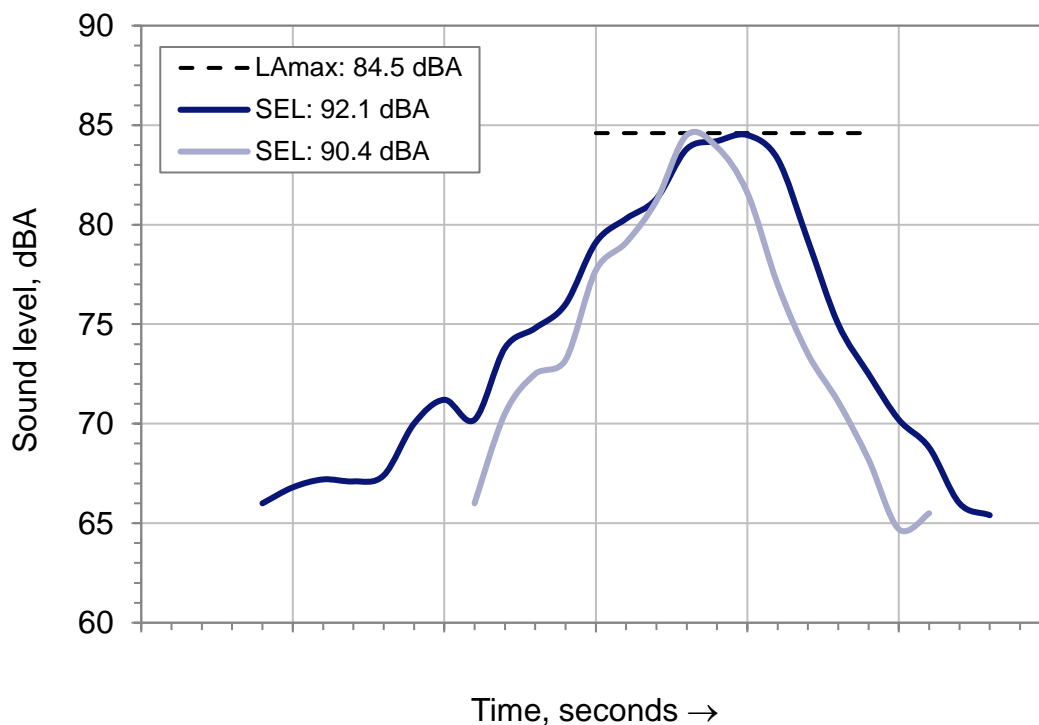
distance should not be ruled out, depending on the level of background sound near the monitoring site, it may be more difficult to reliably measure the departure noise levels for some aircraft types (because aircraft will be at higher altitudes and hence generally quieter).

Depending on the precise location of any new outer noise monitor, a second monitor located approximately midway between the 6.5 km fixed sites and the outermost location could provide a suitable intermediate noise level. Similar locations could also be identified at Gatwick and Stansted based on the local fleet mix and typical climb performance at each airport. A decision would also have to be made as to whether infringement 'limits' or advisory 'levels' should apply at any new monitors. The increased administrative aspects of any new monitoring scheme would also need to be considered.

Another factor for consideration is that the current departure limits are defined in terms of a maximum A-weighted noise level,  $L_{Amax}$ . This is the simplest measure of a noise event such as the overflight of an aircraft and relatively straightforward for the public to understand, since it is simply the maximum sound level recorded during the aircraft fly-by. However, it does not take account of the duration of the noise event (which is influenced by the speed of the aircraft) and hence is possibly less representative of the disturbance the aircraft may cause.

An alternative measure is the A-weighted Sound Exposure Level (SEL), which accounts for the duration of the noise event as well as its intensity. Supplemental reporting of SEL departure levels at a range of distances could enhance community engagement. However, an SEL can be more confusing for the public to understand, since it is the decibel value that would be measured if the entire event energy were uniformly compressed into a reference time of one second.

This means that two different aircraft noise events can have the same  $L_{Amax}$  value but different SEL values if one noise event has a longer duration (or a different profile) than the other. See **Figure 5** for example, which illustrates the noise time histories for two aircraft events (recorded at the same monitor) with the same  $L_{Amax}$  level but different SELs.

**Figure 5** Noise events with the same  $L_{Amax}$  and different SEL

## Track-keeping requirements

The government recognises<sup>22</sup> that at the local level, Noise Preferential Routes (NPRs) can serve a useful purpose to help understand the track-keeping performance of departing aircraft and also as a means to assist in mitigating the impact of aircraft noise. However, whilst existing NPRs can continue, and be updated if agreed at the local level, the government considers that the implementation or retention of NPRs may not always be the most appropriate solution.

Historically, adherence to track-keeping at the noise-designated airports was given practical effect by the Secretary of State's requirement for most departing aircraft to follow NPRs that form the initial part of Standard Instrument Departures (SIDs), which lead from the runways to the upper level airways.

Aircraft are required to follow the NPR relating to the ATC clearance given to them until they reach an altitude of 3,000 or 4,000 feet (depending on the airport and/or route), unless instructed otherwise by an air traffic controller (for example, to maintain safe separation between aircraft). Once above 3,000/4,000 feet, ATC may give pilots a more direct heading to their destination or a tactical heading for integration with other traffic, a practice more commonly referred to as vectoring.

Some local community groups have called for the vectoring altitudes to be raised well above the current levels, effectively extending NPRs along the SIDs, so that aircraft would

<sup>22</sup> *Air Navigation Guidance 2017*, Department for Transport, October 2017



remain on them for longer (rather than being vectored away earlier when faster climbing aircraft have reached the requisite height). However, even if operational constraints within the surrounding airspace were not a factor, any proposed changes to the existing NPRs would need to be approved by the government.

To assist explanation of the government's policy on NPRs and to inform members of the public where they can expect to experience regular overflight by aircraft taking off from Heathrow, the Department of Transport, up until 2000, produced maps illustrating Heathrow's NPRs. There are similar maps for Gatwick and Stansted. Since 2007 the official NPR maps, accredited by the DfT, are held in the designated airports' NTK systems.

The NPRs are represented by nominal centre lines, but aircraft are unable to follow lines over the ground as a train follows a track. Variations in weather (including wind direction relative to an aircraft as it turns) and different piloting procedures and techniques, result in aircraft and their noise being dispersed either side of the nominal centre line. To illustrate this the Department usually describes NPRs in terms of a lateral swathe extending up to 1.5 km either side of the centre line. These are depicted on the NPR maps, with the initial part of each NPR swathe shown as a funnel (see **Appendix B**).

The swathes were adopted provisionally in 1991 in order to better inform people where they could expect to experience regular overflight by departing aircraft; and adopted permanently for track-keeping monitoring in 1993. The UK AIP definition of the swathe is reported in a footnote that does not form part of the Noise Abatement Requirements Notice made under Section 78(1).

The swathes are not a performance standard which pilots are required to achieve, and should not be interpreted as meaning that aircraft outside the swathes are flying in breach of the NPR instructions given in the UK AIP. Aircraft flying outside the swathes are in almost all cases flying an accurate course in terms of the tolerances permitted under internationally agreed (ICAO) navigational standards. However, to encourage greater adherence to the NPRs, the airports may impose a surcharge on aircraft that fly persistently or flagrantly<sup>23</sup> outside the NPRs.

When aircraft are observed significantly off-track (while still below 4,000 feet) they will usually have been given specific instructions to do so by ATC in order to maintain the minimum required safe separation from other traffic, or for other operational reasons such as weather avoidance.

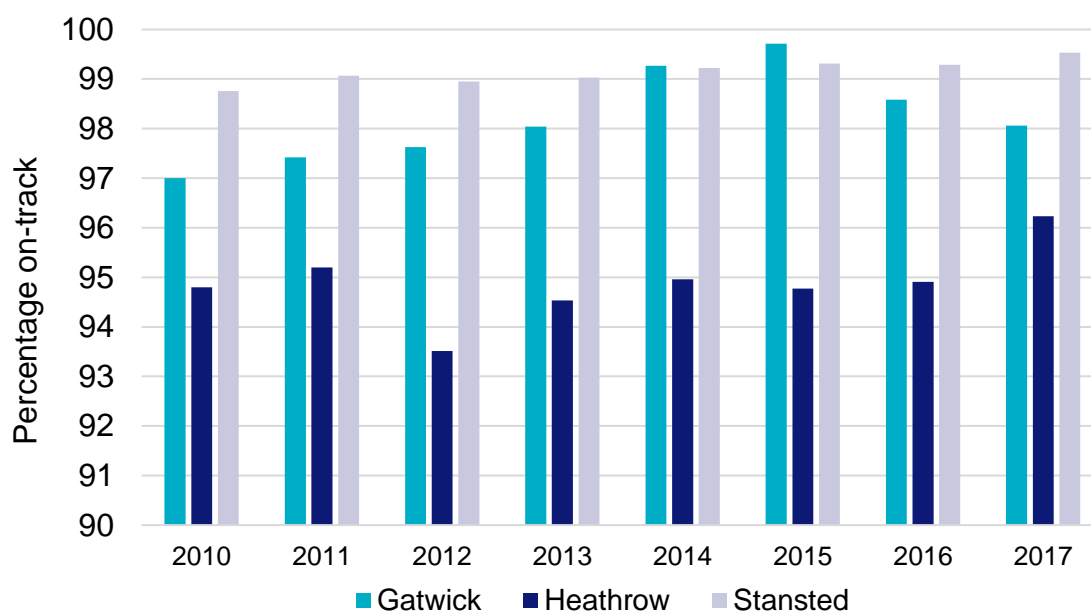
**Figure 6** presents the annual departure track keeping performance for all three airports since 2010. The differences shown between the airports may be explained by the different route designs, fleet mixes, speeds in turns and coding of aircraft navigational databases.

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<sup>23</sup> At Stansted for example, unless the operator can provide a suitable explanation for the deviation, an aircraft is considered "flagrantly" off-track if it has flown more than 750 m beyond the edge of the NPR swathe (2,250 m either side of the centreline).

At Heathrow in particular, most of the track deviations are associated with aircraft ‘ballooning’ outside the NPR. This can be caused by a number of factors, including tight SID radii that were designed for slower aircraft speeds in the 1960s, SID design that is inconsistent with the NPR, navigation database coding issues, airline departure Standard Operating Procedures (SOPs), pilot speed management and high winds<sup>24</sup>. At all three airports, track keeping performance data are shared with individual airlines on a regular basis in order to improve adherence to the NPRs.

**Figure 6** Annual departure track-keeping performance, 2010 to 2017



Over recent years there has been considerable focus on future airspace modernisation, particularly in relation to the replacement of conventional Standard Instrument Departures (SIDs) with Performance-based Navigation (PBN) designs. PBN is the broad term used to describe the technologies (RNAV and RNP) that allow aircraft to fly flexible, accurate, and repeatable flight paths using onboard equipment and capabilities. Therefore, with the introduction of PBN the overall level of departure track-keeping is expected to be greatly improved, resulting in a narrower swathe of tracks.

The transition towards PBN also offers the potential to tailor departure routes to avoid more densely populated areas and therefore reduce the number of people impacted by aircraft noise. Further consideration of this issue is provided in Chapter 6.

Conventional SID designs are still used at the majority of UK airports, including Heathrow and Stansted, and it should be recognised that possible changes in the lateral distribution of flights over time can be caused by different interpretations of conventional SIDs. Further discussion of this issue is provided in **Appendix D** for information.

<sup>24</sup> Investigation into breaches of the Noise Preferential Routes associated with Heathrow Standard Instrument Departures, NATS, June 2017. <https://www.heathrow.com/noise/reports-and-statistics/reports> (accessed 9 July 2018)

## Night time operating restrictions

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Although not specifically to control only departure noise, the government has historically set restrictions on the operation of aircraft at night at the London airports. Under the present Quota Count (QC) system, which was introduced in 1993, aircraft are classified into different categories depending on their noise certification data. The classification for landings is based on the ICAO certificated approach noise level. For departures, it is based on a combination of the certificated lateral and flyover noise levels.

The aircraft QC classifications were, as a matter of policy, based on official certificated noise levels because these are (i) generally considered to be reliable indicators of aircraft noise performance, (ii) available for practically every civil transport aircraft operating in the western world, (iii) openly published and therefore readily applied by administrators of the scheme, and (iv) correlated with noise footprint areas, which were taken to be appropriate measures of 'noise impact'.

The central feature of the classification system is that each aircraft is given a QC rating, which increases by a multiple of two in step with the 3 decibel doubling of noise energy principle (e.g. QC/1, QC/2, QC/4, etc.). The underlying principle of the scheme is to encourage the use of quieter aircraft by making each movement of a noisier type use more of the total available quota set for each airport.

The night restrictions regime recognises both a 'night period' (2300-0700) and a 'night quota period' (2330-0600). During the whole of the night period, the noisiest types of aircraft are banned from operating. During the night quota period aircraft movements are restricted by a movements limit and noise quota, which are set for each summer and winter season.

Previous practice has been for the government to review the night restrictions at Heathrow, Gatwick and Stansted every five or six years, and the present night flying restrictions apply until October 2022<sup>25</sup>.

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<sup>25</sup> *Night flight restrictions at Heathrow, Gatwick and Stansted: decision document*, Department for Transport, July 2017

## Noise related airport charges

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Although commonly referred to as landing charges, noise related airport charges can also be used by airports to incentivise airlines to use quieter aircraft types, which in turn can help to mitigate the effects of noise on departure.

In 2013, following a request made by the DfT in their Aviation Policy Framework, the CAA published CAP 1119 on environmental incentivisation in airport charges<sup>26</sup>. The report set out a series of good practice principles for airports to use when setting charges to encourage quieter and cleaner flights. In July 2017, a follow-up review was published in CAP 1576<sup>27</sup>, which highlighted to what extent airports had followed the CAP 1119 recommendations.

One of the main findings from the review was that at Gatwick and Heathrow, noise certification levels (cumulative margin relative to Chapter 3) were, as recommended in CAP 1119, used to determine which noise charging category an aircraft should be allocated to, whereas at Stansted the ICAO noise certification Chapter and QC values were being used. The report also found that:

- Stansted appeared to have an under-divided set of noise categories that did not provide adequate differentiation in noise performance for the very quietest ('best in class') aircraft.
- Heathrow defined the night period as 0100-0429 (local time), where there is currently a voluntary ban on operations. This definition did not recognise the additional disturbance caused by late departures or arrivals before 0600. Heathrow subsequently aligned its night noise charging period for 2018 with the Night Quota Period.

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<sup>26</sup> [CAP 1119](#), *Environmental charging - Review of impact of noise and NOx landing charges*, October 2013

<sup>27</sup> [CAP 1576](#), *Environmental charging - review of impact of noise and NOx landing charges: update 2017*, July 2017

## Chapter 3 summary

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- The current departure noise limits of 94 dBA (day), 89 dBA (shoulder) and 87 dBA (night) were implemented at the London airports in 2001. The noise limits are related to a fixed reference distance of 6.5 km from start of roll.
- There are now relatively few noise infringements due largely to the gradual retirement and replacement of older aircraft types.
- The number of noise infringements at Heathrow historically has been higher than at Gatwick or Stansted due to the greater numbers of large aircraft serving long-haul destinations.
- There is limited scope for reductions in the noise limits at Heathrow until the retirement of the remaining Boeing 747-400 fleet. Half of the current fleet is expected to be withdrawn by 2021 and the remainder by 2024. A small reduction of 1 to 2 dB in the daytime and shoulder limits might be feasible at Heathrow, without causing the overall number of infringements to increase above historic levels.
- The results for Gatwick and Stansted indicate that the current daytime, shoulder and night limits could be lowered, by up to 3 decibels or more in some cases, without significantly impacting the current fleets at those airports. A lowering of the noise limit would provide a backstop, dissuading the re-introduction of the noisiest aircraft types.
- Other noise controls including minimum height and climb gradient requirements appear to be limiting noise further out, since average measured noise levels continue to reduce beyond 6.5 km from start of roll. The compliance rates with these additional controls are very high. However, continued community discontent with departure noise in general suggests that the existing controls may not be sufficient to meet the concerns of the community.
- Additional departure monitors located beyond 6.5 km from start of roll would help to verify that progressively reducing noise levels under the flight path are being achieved. New infringement 'limits' or advisory 'levels' could be applied at each monitor.
- The current departure limits are defined in terms of  $L_{Amax}$ , the maximum A-weighted noise level.  $L_{Amax}$  does not take account of the duration of a noise event, which can differ as a result of different departure noise abatement procedures. The alternative measure is the A-weighted Sound Exposure Level (SEL), which accounts for the duration of the noise event as well as its intensity but can be more confusing for the public to understand. Nonetheless, supplemental reporting of SEL departure noise levels at a range of distances (as already monitored by the airports' NTK systems) could enhance community engagement.

## Chapter 4

## Departure climb gradients

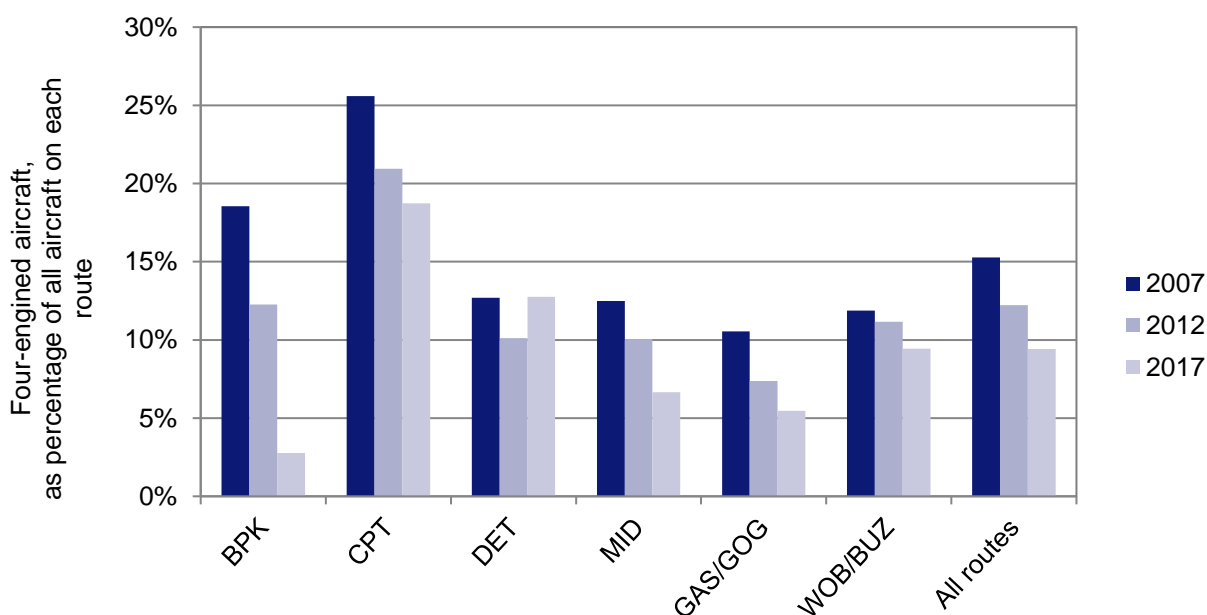
## Introduction

As discussed in Chapter 3, there has been a longstanding requirement for aircraft departing from the designated London airports to maintain a climb gradient of not less than 4% after passing the 1000 feet (at 6.5 km) point, and compliance rates with these controls are very high. The rationale for the climb gradient requirement is to ensure that progressively reducing noise levels at points on the ground under the flight path are achieved.

Safety requirements dictate that twin-engined aircraft need to be more over-powered than four-engined aircraft in order to cope with a single engine failure on take-off, since they would have 50% of their power remaining compared to 75% for a four-engined aircraft. This means that with all engines functioning as normal, twin-engined aircraft can climb faster than four-engined aircraft.

**Figure 7** shows that, with the exception of the Detling (Dover) route<sup>28</sup>, there has been a declining trend in the use of four-engined aircraft by airlines at Heathrow in recent years. This can be explained by the general increased use of more fuel efficient twin-engine aircraft such as the Boeing 777-300ER, Boeing 787-8/9 and Airbus A350.

**Figure 7** Percentage of four-engined aircraft by departure route at Heathrow, 2007-2017



<sup>28</sup> There has been growth to destinations in the Middle East by four-engined aircraft on the Detling route.

Over recent years, there has been increased concern from local communities that climb performance is reducing, particularly for larger, heavier aircraft such as the A380. At Heathrow, recent evidence<sup>29</sup> is available that indicates whilst the number of departures failing to meet the 4% AIP requirement is small in absolute terms, a high proportion of failures are A380 operations.

As part of a monitoring programme conducted through the Heathrow Community Noise Forum, independent flight analysis<sup>30</sup> was undertaken in 2015 to investigate changes in flight patterns over particular communities since 2011. One of the main findings was that aircraft on some routes were flying lower than before<sup>31</sup>.

On one particular route, the easterly Detling SID, the average height of aircraft at approximately 11 km from the start of roll position was found to have decreased from approximately 3,400 feet in 2011 to 3,100 feet in 2015<sup>32</sup>. The study also found that the number and proportion of large 'heavy' aircraft such as the A380 had increased on the Detling route over the same period, consistent with the data presented in **Figure 7**. Heathrow airport has been working with the airlines concerned to try and improve overall compliance with the 4% requirement.

Local community groups have also questioned why the minimum climb gradient at Heathrow is limited to 4% whereas, it is claimed, other international airports specify steeper climb gradients. However, when comparing climb requirements across different airports, care must be taken to ensure that aircraft performance against those requirements is treated in the same way.

For example, unless stated otherwise the minimum climb gradient for a SID is normally measured from an origin which is assumed to be 5 m above Departure End of Runway (DER). By way of illustration, **Figure 8** compares the London 4% minimum climb requirement as currently monitored by Heathrow with a steeper gradient of 5.5% measured from the Departure End of Runway, as applied at Paris Charles de Gaulle for example. Up until approximately 15 km from start of roll and a height of 2,200 feet, the Heathrow 4% climb gradient definition leads to a higher minimum altitude than a 5.5% gradient defined from the Departure End of Runway. A higher quoted gradient may not necessarily translate to a higher minimum altitude requirement at a given location or reduce noise.

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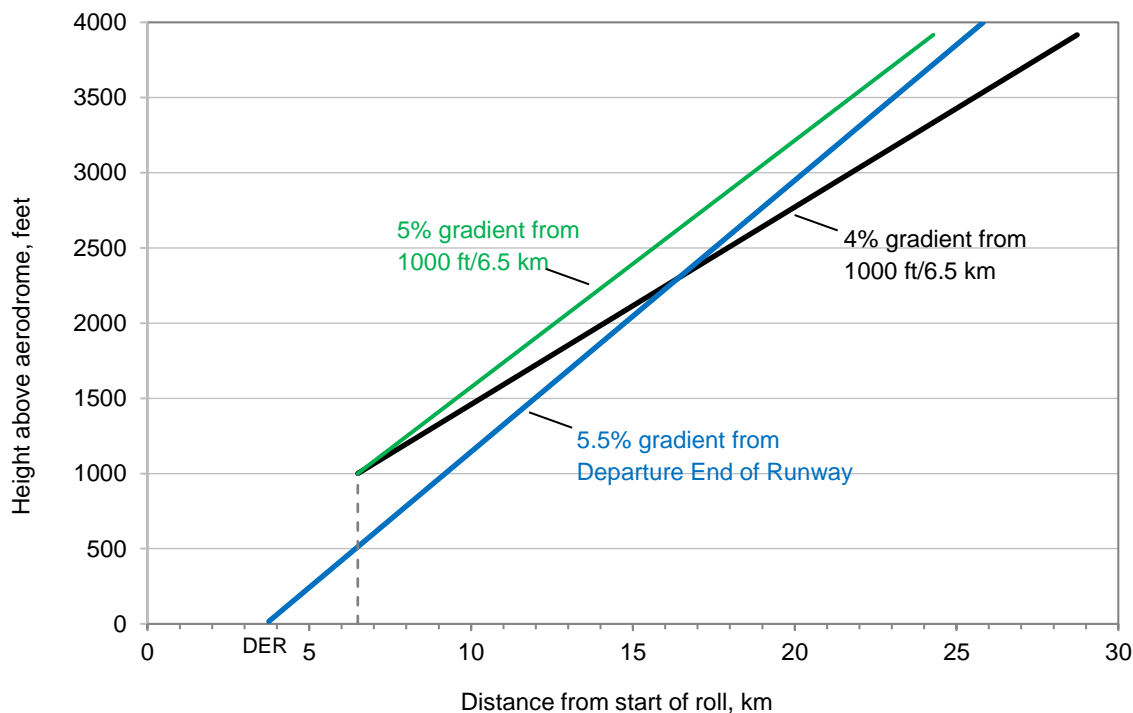
<sup>29</sup>

[http://www.heathrow.com/file\\_source/HeathrowNoise/Static/HCNF\\_WG2\\_Climb\\_profile\\_measurement\\_and\\_performance\\_Apr\\_2017.pdf](http://www.heathrow.com/file_source/HeathrowNoise/Static/HCNF_WG2_Climb_profile_measurement_and_performance_Apr_2017.pdf) (accessed 9 July 2018)

<sup>30</sup> <http://www.heathrow.com/noise/heathrow-community-noise-forum/flight-analysis> (accessed 9 July 2018)

<sup>31</sup> *Teddington Flight Path Analysis Final Report*, PA Knowledge Limited, October 2015

<sup>32</sup> All other things being equal, an aircraft flying at 3,100 feet would be approximately 1 dB noisier under the flight path compared to the same aircraft at 3,400 feet (due to the shorter sound propagation distance).

**Figure 8** Examples of varying climb requirements with different origins

As noted previously, some SIDs are also designed to require aircraft to level out at a specific altitude between 4,000 and 7,000 feet in order to facilitate crossing of departing and arriving traffic. Aircraft may therefore be lower on some routes, or on the same route but at different times of the day.

In response to local community observations that climb performance is reducing, Heathrow airport is conducting a trial between January and December 2018 whereby the minimum climb gradient on the easterly Detling route is increased to 5% from 1,000 feet at 6.5 km from start of roll up to an altitude of 4,000 feet. The trial 5% minimum climb requirement is also shown in **Figure 8** for comparison. In addition to the changes in height profiles, the Detling trial will also consider the trade-offs with other priorities such as noise and fuel burn/carbon emissions.

## International comparisons

Whilst a detailed evaluation of SID climb requirements across different international airports was outside the scope of this study, it has been possible to compare average measured A380 climb profiles from Heathrow in summer 2017<sup>33</sup> with equivalent departure profiles for the same airlines operating at other international airports by making use of freely available ADS-B data. ADS-B is a technology in which an aircraft periodically

<sup>33</sup> On 25 March 2018 Qantas Airways changed the stopover destination for departures on the UK-Australia route from Dubai to Singapore. Because of the longer distance flown, the average Heathrow climb profile for Qantas was instead based on data from 25 March to 12 June 2018.

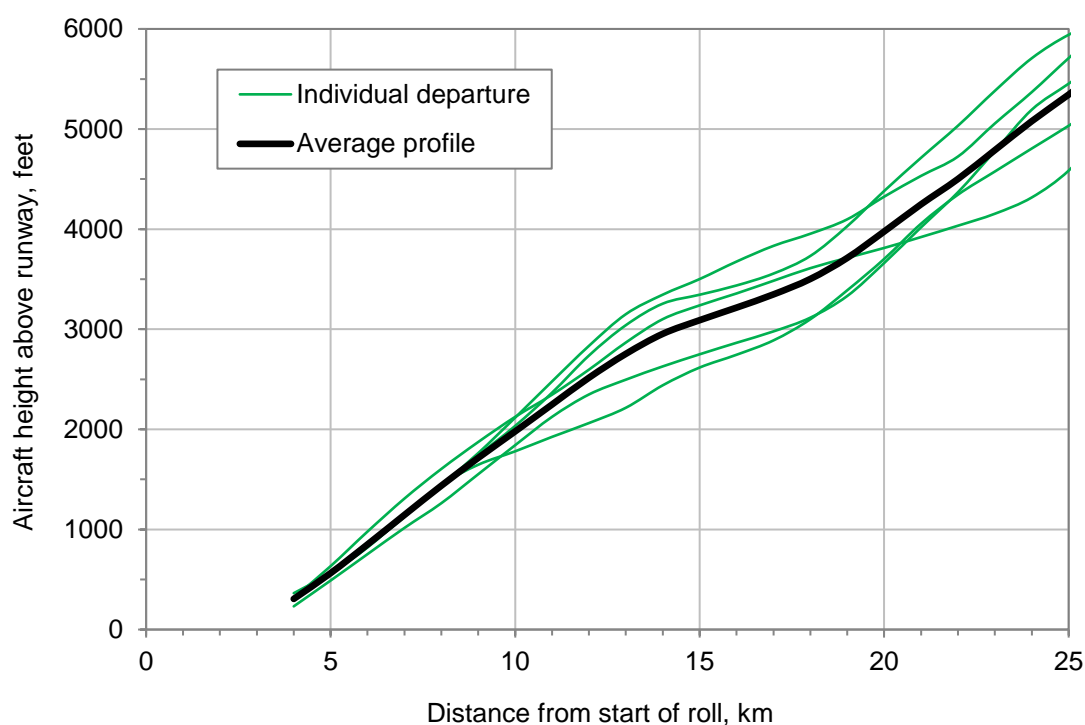


broadcasts its position in three dimensions, allowing it to be tracked using a ground-based ADS-B receiver<sup>34</sup>.

Average flight profiles for A380 departures at Sydney (SYD), Paris Charles de Gaulle (CDG), Frankfurt (FRA), Los Angeles (LAX) and New York John F. Kennedy (JFK) were measured based on samples of ADS-B data collected at intervals between March 2017 and February 2018.

In most cases the average profile for each international airport/airline combination was based on at least 10 individual departures. For cases where the samples sizes were less than 10, the vertical dispersion of the individual departures was such that the average profile was still considered to be representative. **Figure 9**, for example, shows the average Thai Airways profile generated from five individual departures at Frankfurt.

**Figure 9** Individual A380 height profiles compared to the average profile (n = 5)



<sup>34</sup> [ADSbexchange.com](https://adsbexchange.com) makes this data freely available to anyone (for non-commercial use) by relying on a worldwide community of participants that feed in local data using their own ADS-B receivers. Aircraft equipped with suitable transponders can provide altitude reporting in 25 feet intervals and positional data based on the aircraft's GPS receiver, which generally provides position data accurate to within a few metres.

**Figure 10** compares the average Heathrow departure profile for British Airways (BA), the most common A380 operator at Heathrow, with the average BA A380 profile at Los Angeles<sup>35</sup>. The 4% AIP climb requirement is also shown for reference.

**Figures 11 to 16** present similar results for other Heathrow A380 operators that also operate the same aircraft type from one or more of the international study airports mentioned above. **Figures 17 to 19** present the average profiles for other airlines that don't operate the A380 from Heathrow but are common to two or more of the other study airports.

The results in **Figure 10** indicate that BA is using a different departure procedure at Heathrow compared with Los Angeles, causing the aircraft to be higher above the ground, on average, between 8 and 15 km. This difference may be explained by the modification<sup>36</sup> by BA in April 2017 to their existing NADP 2 procedure for A380 departures at Heathrow (which delays the climb thrust and acceleration altitude from 1,000 feet to 1,500 feet).

Whilst the average flight profiles for the other airlines represent a wide range of different departure procedures, the results show no indication that A380 operators at Heathrow are flying the same aircraft significantly lower than at other international airports.

It is interesting to note however that, for the same airline, the average profiles for some LAX departures appear significantly lower compared to other airports. This may be explained by the fact that the LAX departures included in this analysis were all westerly operations (which is the prevailing runway direction). This meant that they all departed directly over the Pacific Ocean, thus possibly having no requirement to climb at any greater rate for noise abatement, obstacle or airspace reasons<sup>37</sup>.

It should also be noted that in some cases, the average stage length flown from each airport by the specific operator may be significantly different. In **Figure 14** for example, the Singapore Airlines A380 departure from JFK to Singapore includes a stopover at Frankfurt, which is approximately 3,400 NM from JFK. Whereas the Singapore Airlines A380 departure from Heathrow flies direct to Singapore (approximately 5,900 NM).

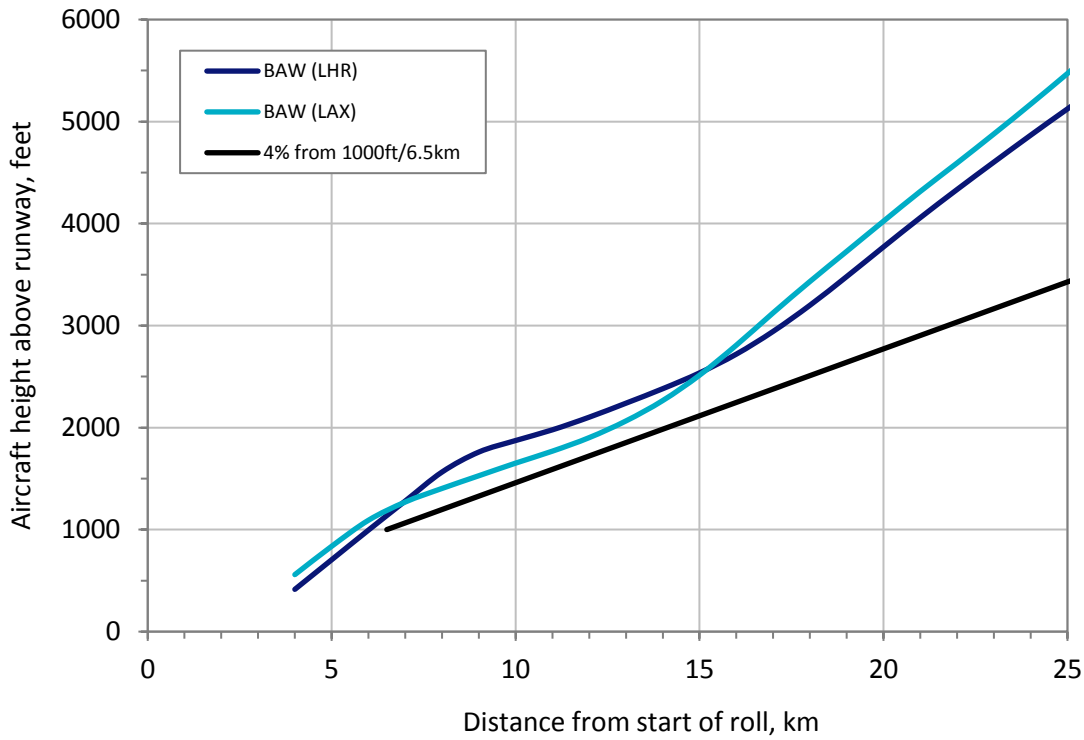
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<sup>35</sup> British Airways did not operate the A380 from the other study airports.

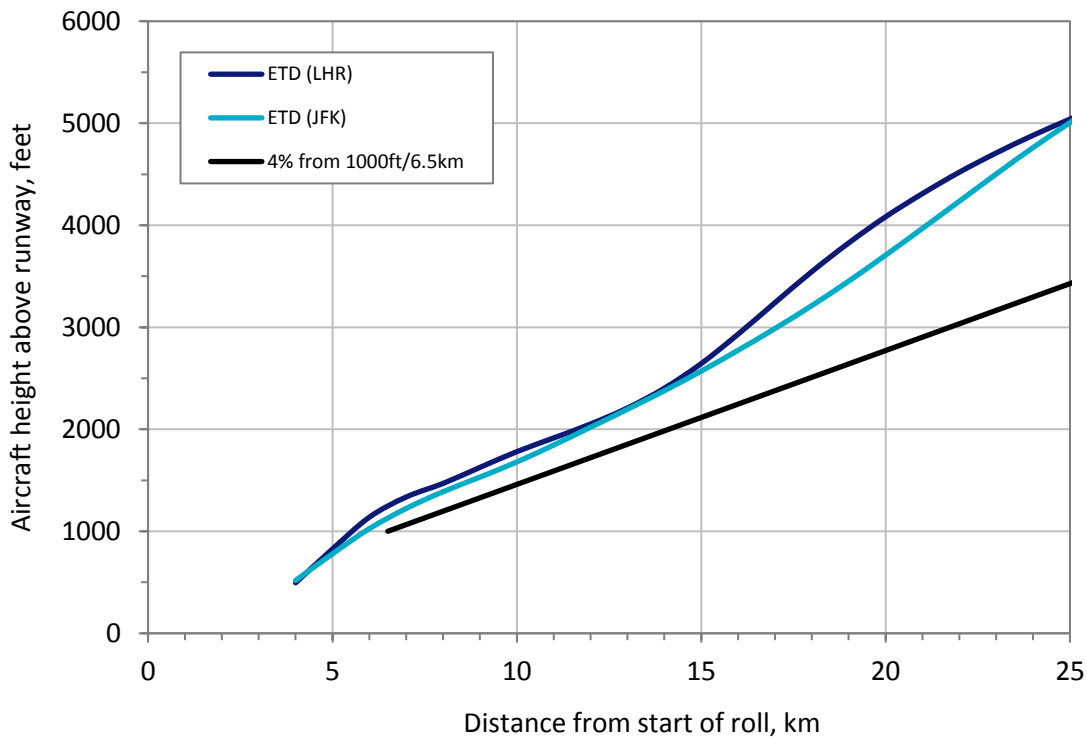
<sup>36</sup> [https://www.heathrow.com/file\\_source/HeathrowNoise/Static/HCNF\\_Climb\\_Gradients\\_May\\_2017.pdf](https://www.heathrow.com/file_source/HeathrowNoise/Static/HCNF_Climb_Gradients_May_2017.pdf) (accessed 9 July 2018)

<sup>37</sup> Whilst a detailed analysis of LAX airspace requirements was not undertaken for this study, the published noise abatement procedures for westerly operation departures at LAX do not specify a minimum climb gradient. See <http://www.losangelesinternationalairport.org/airops.aspx?id=862> (accessed 9 July 2018).

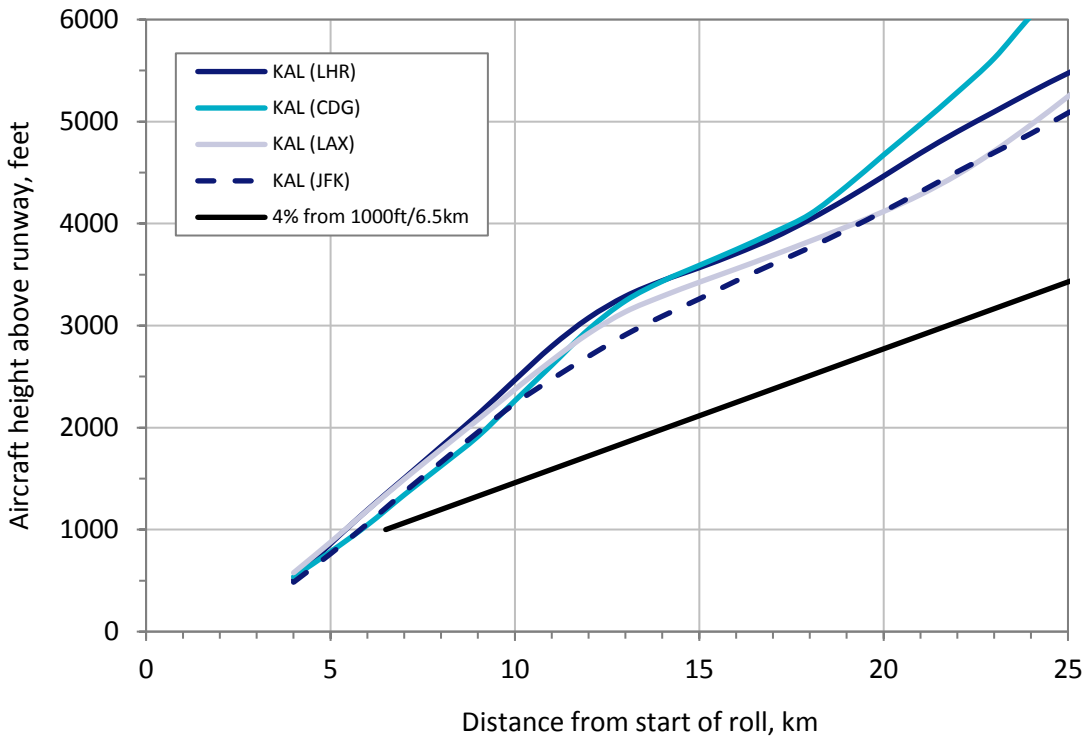
**Figure 10** Average British Airways A380 departure height profiles



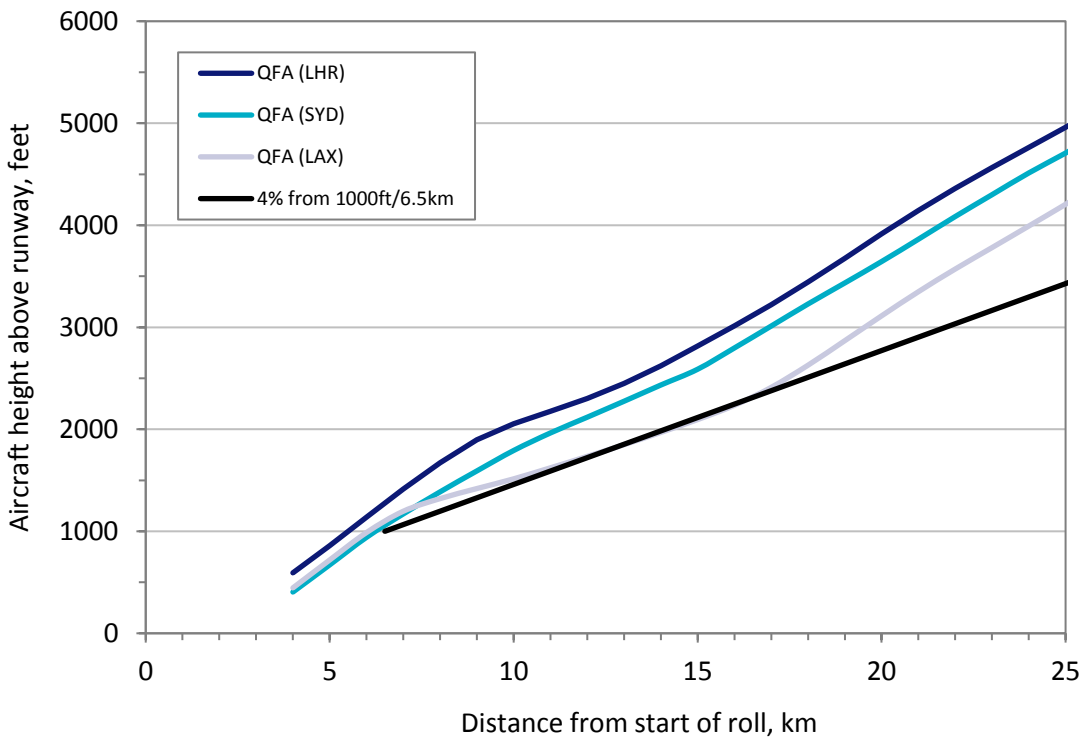
**Figure 11** Average Etihad Airways A380 departure height profiles



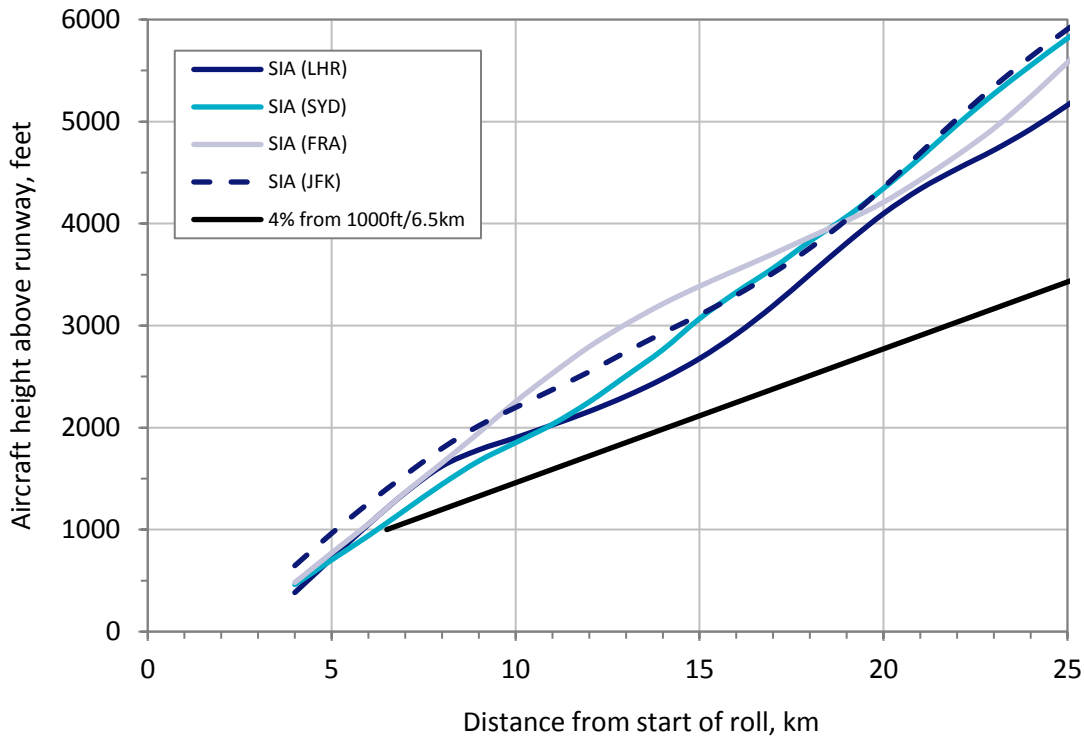
**Figure 12** Average Korean Air A380 departure height profiles



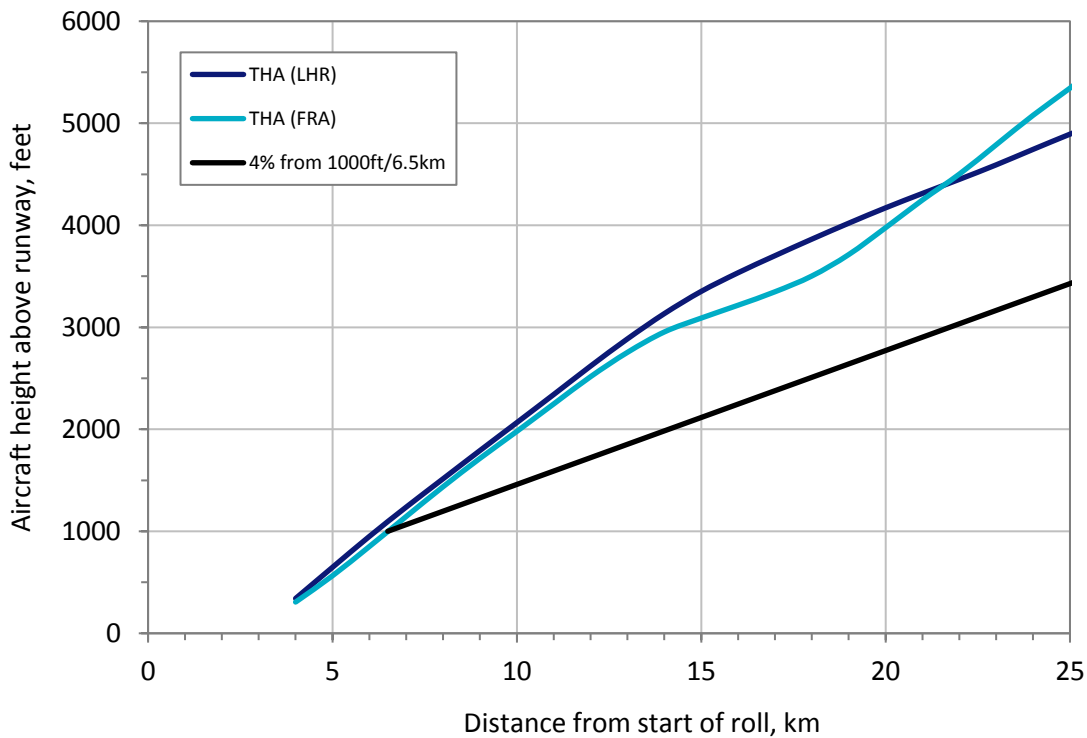
**Figure 13** Average Qantas Airways A380 departure height profiles



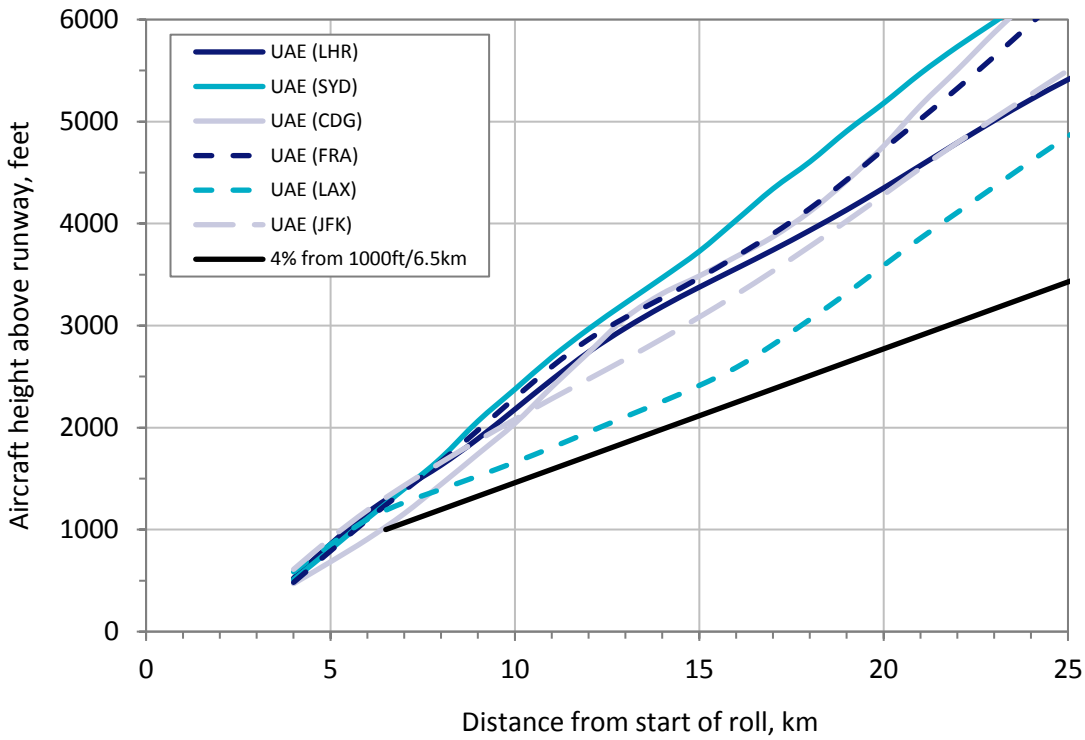
**Figure 14** Average Singapore Airlines A380 departure height profiles



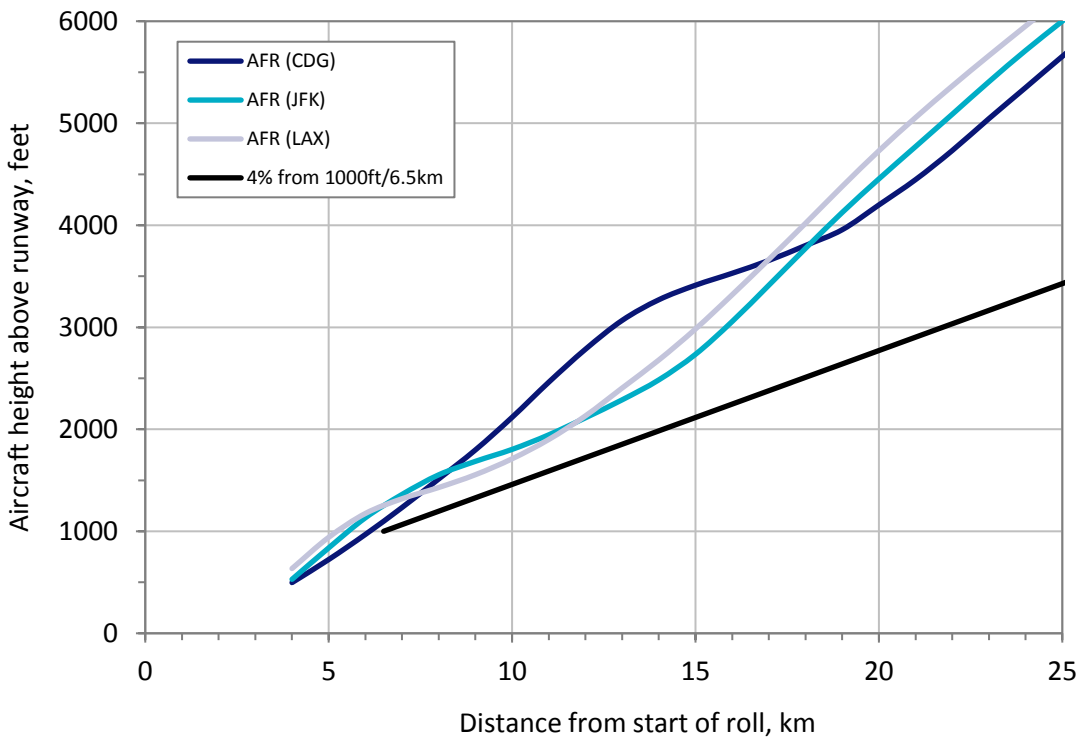
**Figure 15** Average Thai Airways A380 departure height profiles



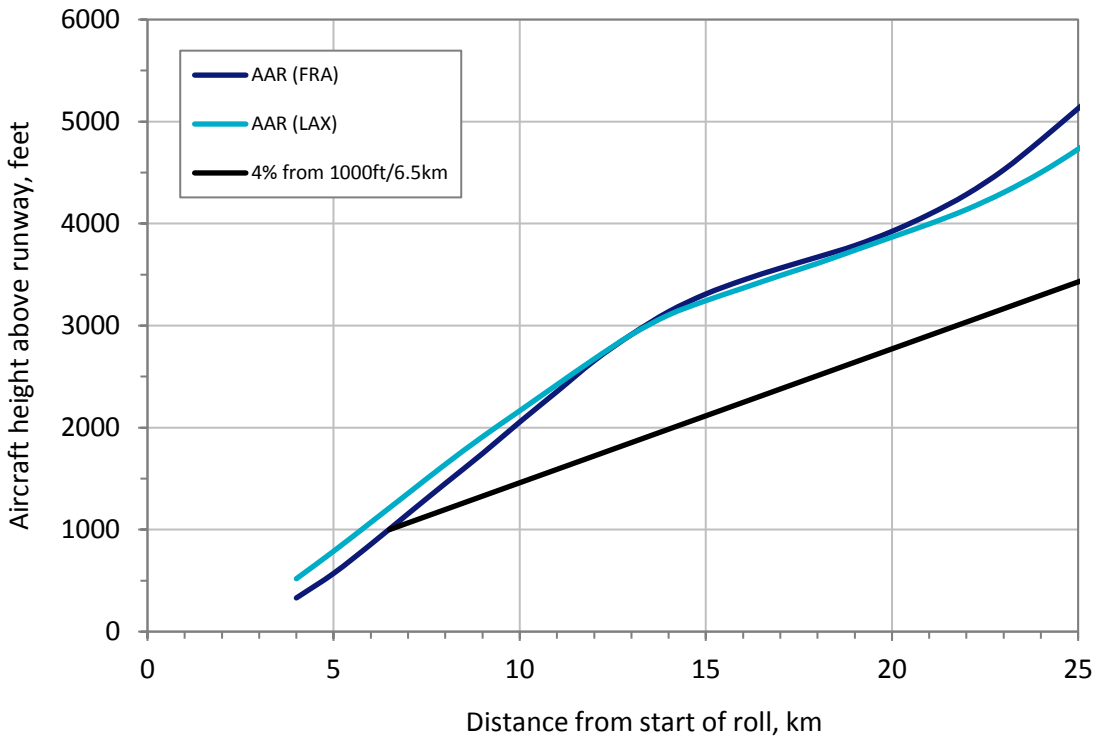
**Figure 16** Average Emirates A380 departure height profiles



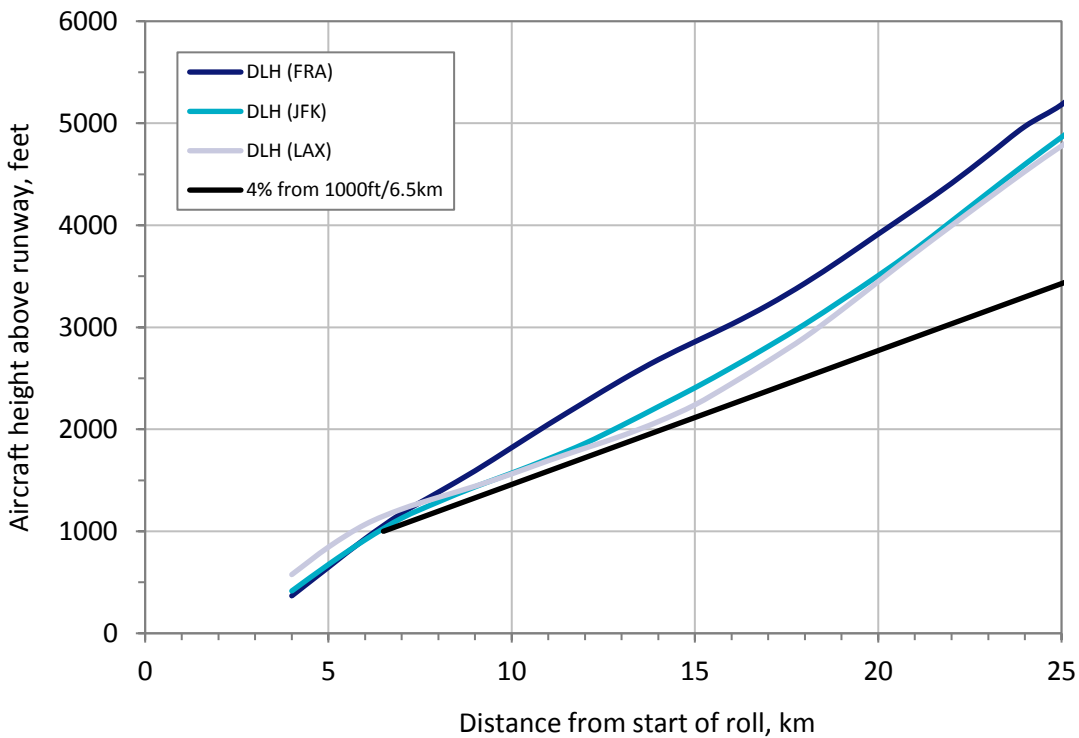
**Figure 17** Average Air France A380 departure height profiles



**Figure 18** Average Asiana Airlines A380 departure height profiles



**Figure 19** Average Lufthansa A380 departure height profiles

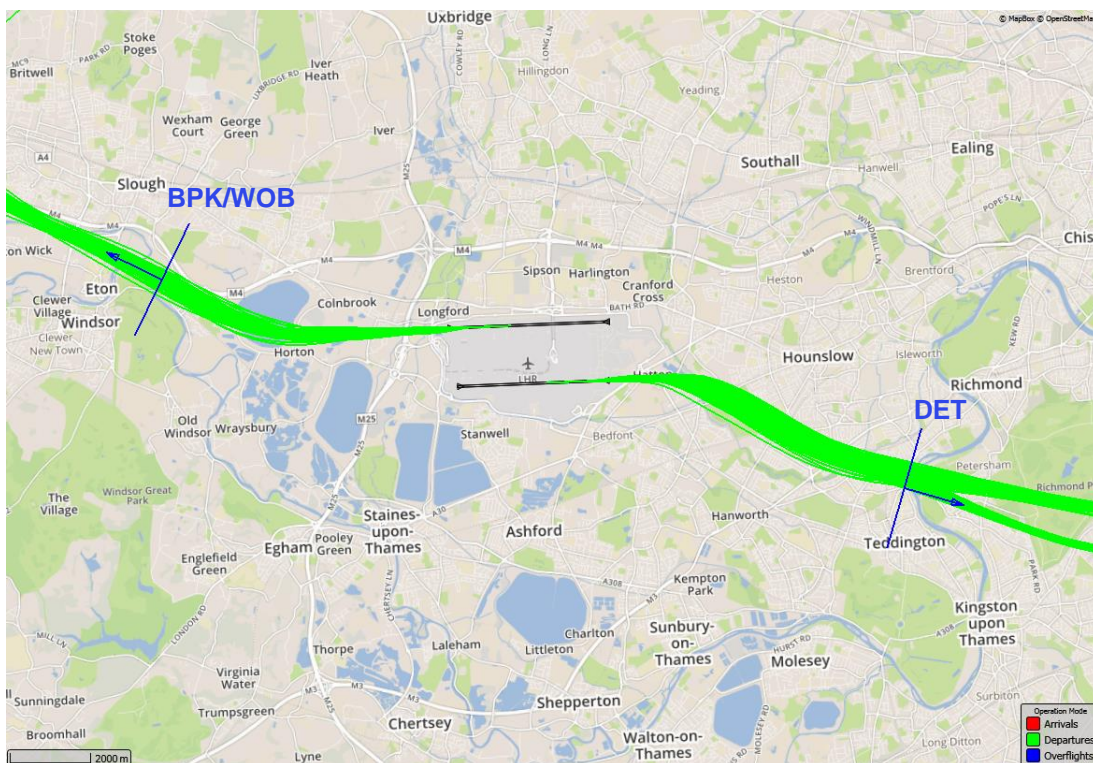


## Average aircraft heights over time

As discussed above, independent flight analysis undertaken on behalf of Heathrow Airport in 2015 found that aircraft on some routes were flying lower than before. To further investigate changes in aircraft heights over time an analysis has been carried out for Heathrow departures on one easterly route and one westerly route between 2000 and 2017.

The heights of all easterly (runway 09R) Detling departures that passed through a 3km-wide analysis gate, centred on the NPR at approximately 11 km (6 NM) from start of roll, were analysed for particular years between 2000 and 2017 (1 June to 30 September). A similar analysis was also carried out for all westerly (runway 27R) Brookmans Park/Wobun departures during the same summer periods. Departures on Brookmans Park/Wobun typically serve different destinations than on Detling and therefore provide a useful comparison. The locations of both analysis gates are shown in **Figure 20**.

**Figure 20** Easterly (DET) and westerly (BPK/WOB) height analysis gates at Heathrow





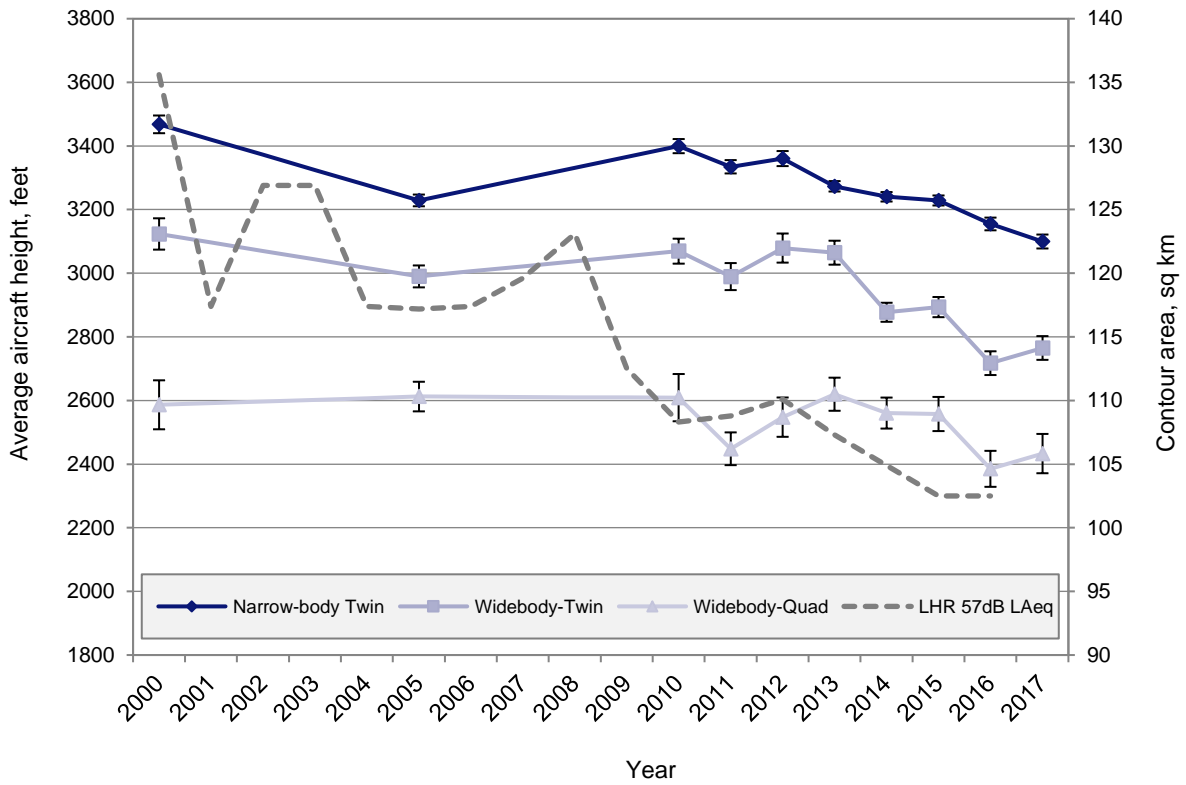
**Figures 21 and 22** presents the corresponding average height data (including 95% confidence intervals), with aircraft grouped into the following categories, based on aircraft size and number of engines:

- Narrow-body twins (e.g. A320 and B737 family)
- Wide-body twins (e.g. A300, A330, B767, B777, B787)
- Wide-body quads (e.g. A340, A380, B747)

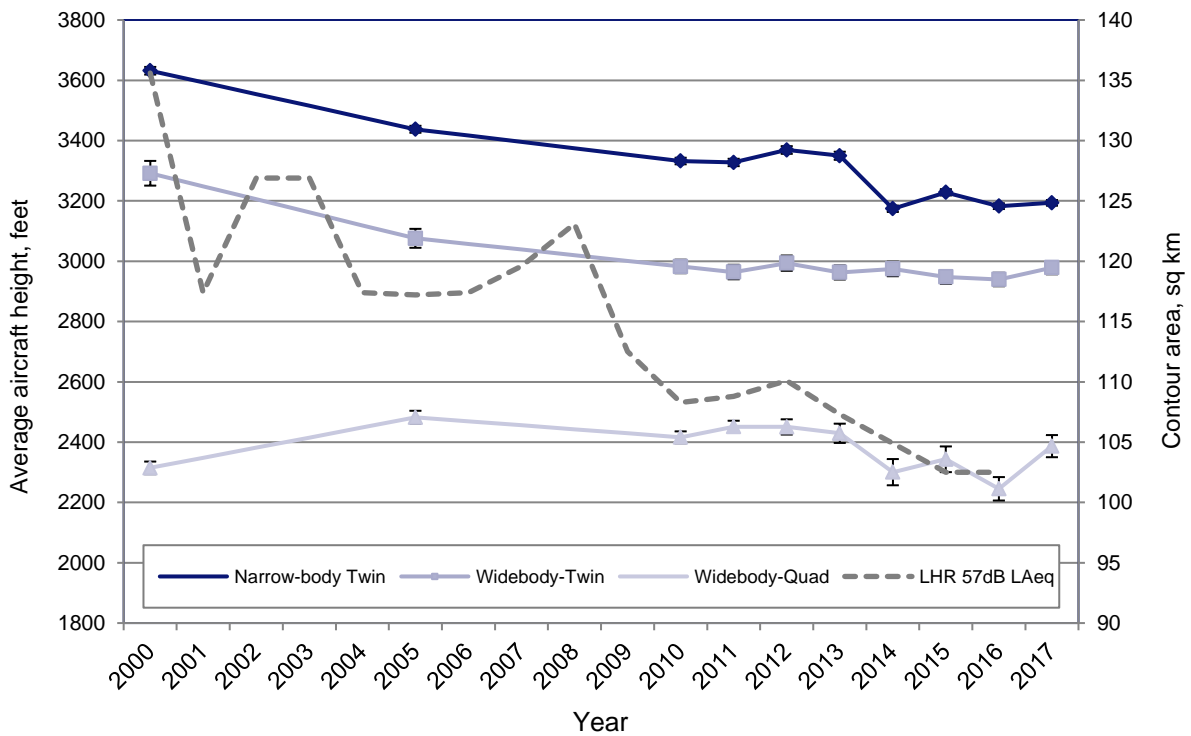
The results for both routes show that there has been a small but gradual decrease in the overall heights of departures at each location since 2000, with a more marked decrease in some cases in recent years. Some year-to-year variation is also apparent in both figures, which is to be expected.

For information purposes, the area of the summer 57 dB  $L_{Aeq, 16hr}$  noise contour is also shown in each figure. It should be emphasised that, due to the continued introduction of quieter aircraft types, an average reduction in aircraft height over the ground does not necessarily correspond to an increase in noise level on the ground.

**Figure 21** Average aircraft heights through easterly DET gate, 2000-2017



**Figure 22** Average aircraft heights through westerly BPK/WOB gate, 2000-2017



Possible reasons for the gradual decrease in average aircraft heights observed over recent years could include one or more of the following:

- aircraft fleets are changing (aircraft are generally getting larger, and therefore heavier),
- passenger loads are increasing (meaning that aircraft are heavier),
- aircraft are flying further (and are therefore heavier because they are carrying more fuel<sup>38</sup>),
- airline departure procedures are changing (new generation aircraft, for example, have a much greater scope for optimisation of the flight profile to maximise fuel efficiency, causing aircraft to be lower over the ground),
- busier airspace in general means that there are more interactions between aircraft. Therefore further climb may be delayed.

Further consideration of the first four of these factors is provided below, and whilst the analysis has focussed on operations at Heathrow, the same general conclusions would be expected to apply for departures at other airports where changes in aircraft heights have been observed over time.

### Changes in aircraft fleets

**Figure 23** shows the percentages of aircraft types at Heathrow within the Narrow-body Twin category, for each year between 2010 and 2017. **Figures 24 and 25** show equivalent data for Wide-body Twins and Wide-body Quads respectively.

The results for the Narrow-body Twins and Wide-body Quads show a general trend towards using larger aircraft, e.g. A320s replacing A319s, and A380s replacing A340s/B747-400s. New larger four-engined aircraft such as the A380 will also climb more slowly compared to the aircraft they are replacing. The A380 has been designed to be developed into a family of larger aircraft and thus has a comparatively large wing giving it a relatively low take-off speed<sup>39</sup>. An A380 will therefore spend more time accelerating to the standard climb speed of 250 knots at a shallower climb gradient.

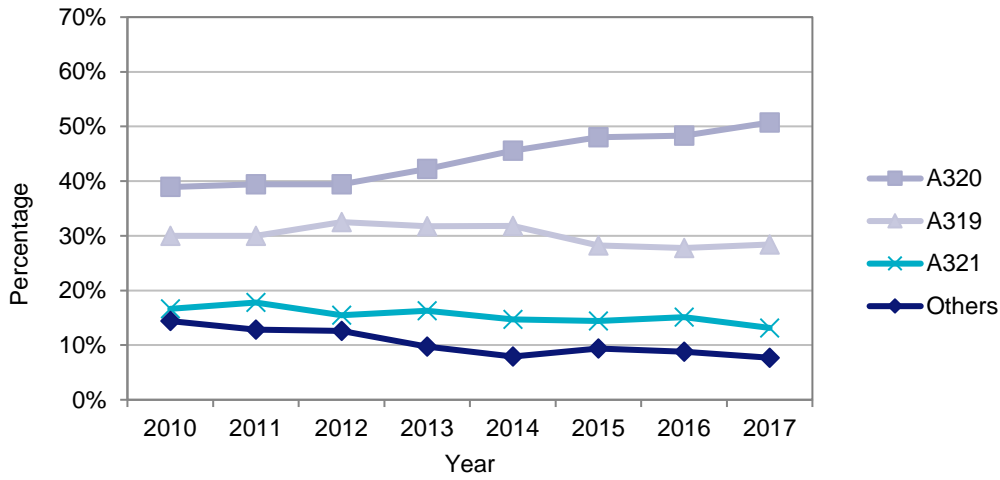
Results for the Wide-body Twins on the other hand suggest that whilst older aircraft such as the B767 are being replaced by newer and quieter types such as the B787 (which are of similar size), there has also been a reduction in the percentage of larger B777s over the same period.

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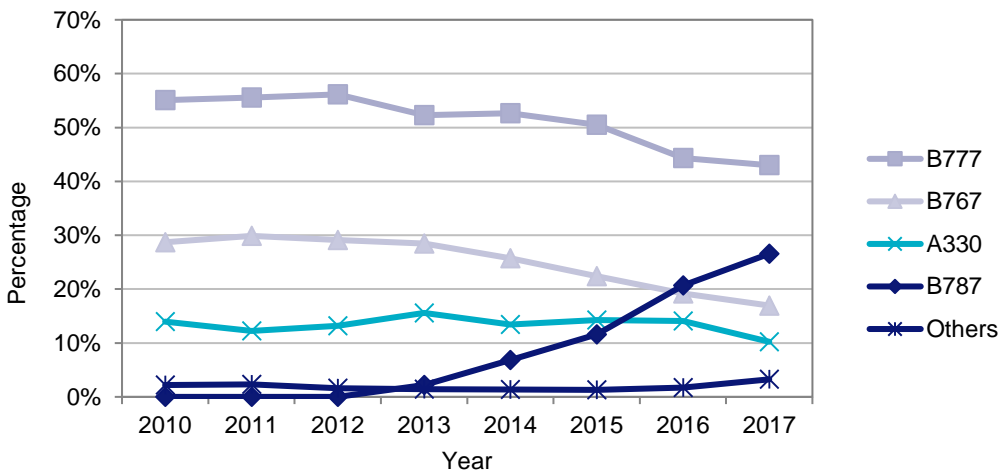
<sup>38</sup> For a long range aircraft, a substantial proportion of the mass is fuel, not passengers/cargo. Since actual take-off weight data are generally unavailable, distance flown (stage length) can be used as a proxy for take-off weight.

<sup>39</sup> Flying to Dubai, for example, the take-off speed for the Airbus A380 is 140 knots compared to a take-off speed as high as 210 knots for a Boeing 777-300ER.

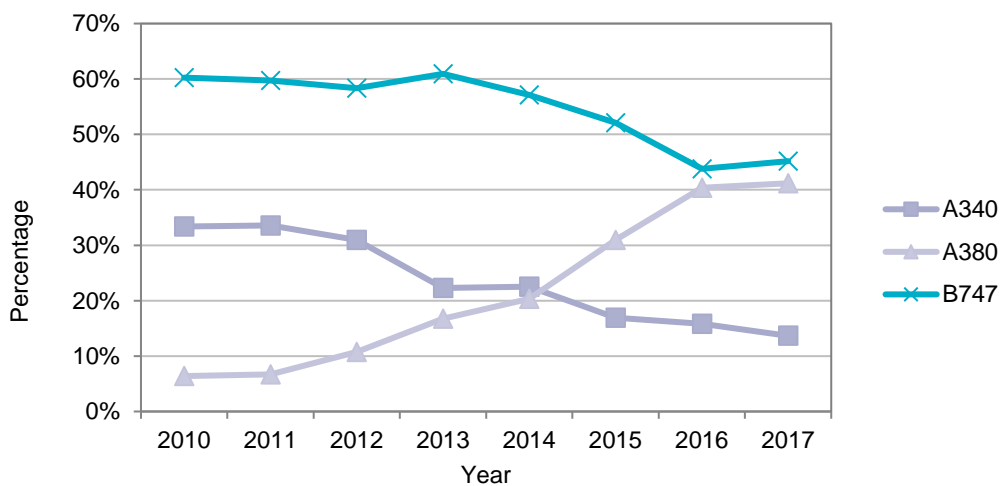
**Figure 23** Narrow-body Twin, percentage by aircraft type at Heathrow



**Figure 24** Wide-body Twin, percentage by aircraft type at Heathrow



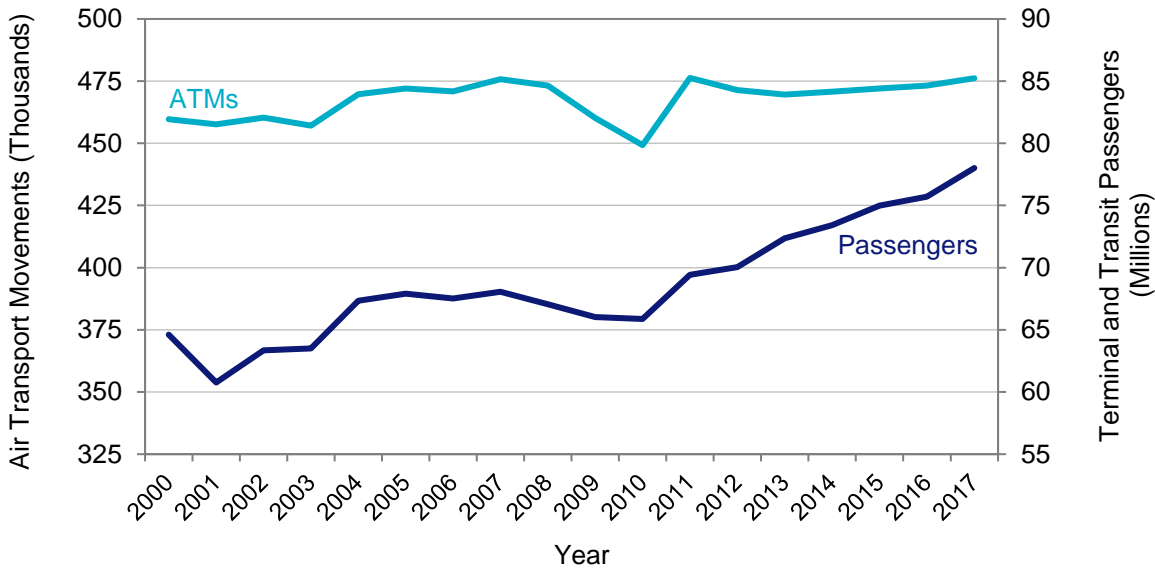
**Figure 25** Wide-body Quad, percentage by aircraft type at Heathrow



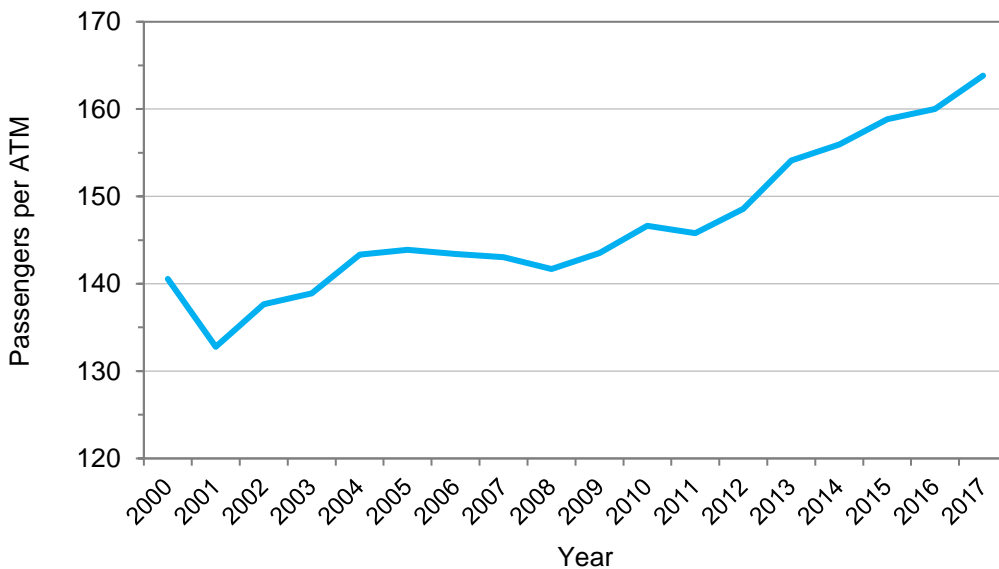
### Changes in passenger load

**Figure 26** presents annual Air Transport Movement (ATM) and passenger statistics for Heathrow for 2000 to 2017<sup>40</sup>. Whilst ATMs have remained relatively stable since 2011, the numbers of passengers carried each year over the same period has steadily increased, resulting in an increase in the average number of passengers per ATM, see **Figure 27**.

**Figure 26** Heathrow ATM and passenger statistics, 2000-2017



**Figure 27** Average number of passengers per ATM at Heathrow, 2000-2017



<sup>40</sup> <https://www.caa.co.uk/Data-and-analysis/UK-aviation-market/Airports/Datasets/UK-airport-data/> (accessed 9 July 2018)

All other things being equal, an aircraft's climb gradient is decreased as take-off weight (which can be correlated with passenger load) is increased, meaning that a more heavily loaded aircraft will be lower over the ground compared to a lighter aircraft. In some cases, the higher passenger number per movement will also require an increase in physical aircraft size as well as an increase in load factor, e.g. Airbus A319 to A320, B777-200ER to B777-300ER.

### Changes in distance flown

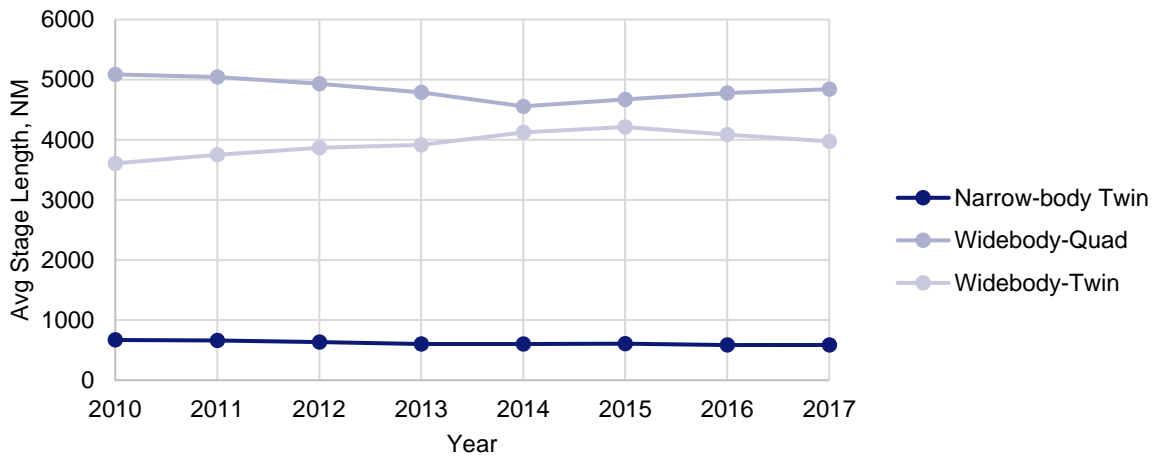
Aircraft that are flying further will generally be heavier because they are carrying more fuel and will therefore be lower, on average, over the ground (all other things being equal). For a long range aircraft in particular, a substantial proportion of the mass is fuel, not passengers or cargo. Since actual take-off weight data are not generally available, the distance flown (stage length) can be used as a proxy for take-off weight.

**Figures 28 to 33** show the average distance flown (stage length, in nautical miles) from Heathrow along each of the airport's six departure routes between 2010 and 2017. As before, results have been grouped into three broad categories of aircraft: Narrow-body Twins, Wide-body Twins and Wide-body Quads.

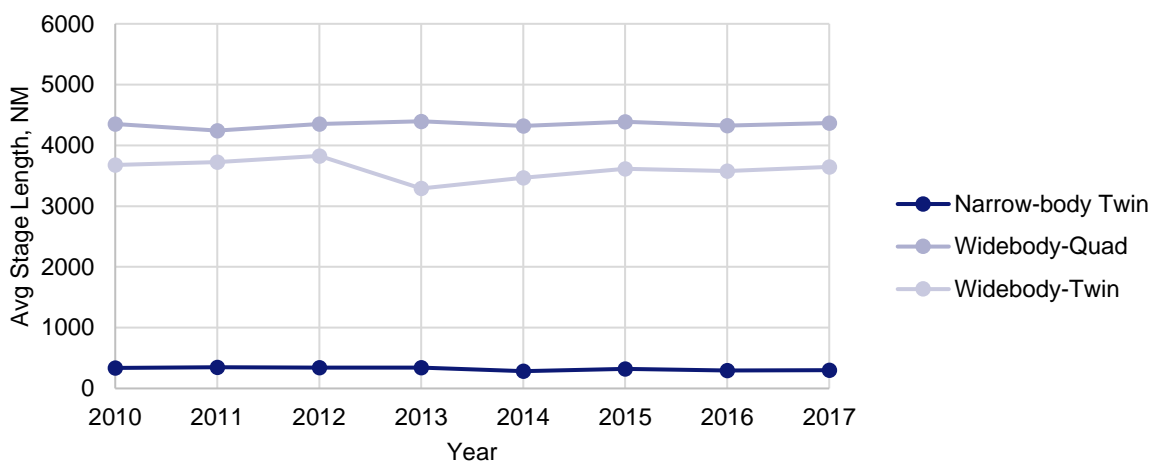
The results for the Narrow-body Twins generally show no significant change in the average distance flown for this category of aircraft at Heathrow. Whilst some year-to-year variation in the average stage length for the Wide-body Twins is visible on some routes, overall the results show no significant change since 2010.

Results for the Wide-body Quads also show no significant change on all but one of Heathrow's routes. The exception is the GAS/GOG route which shows a *decrease* in average stage length flown over time. This is due to a gradual shift towards Wide-body Twins on some of the longer stage lengths and also an increase in the number of Wide-body Quads flying on very short routes (in this case Airbus A340s flying to Madrid). However, Wide-body Quads on GAS/GOG typically account for less than 0.5% of all Heathrow departures and the results should therefore be considered in that context.

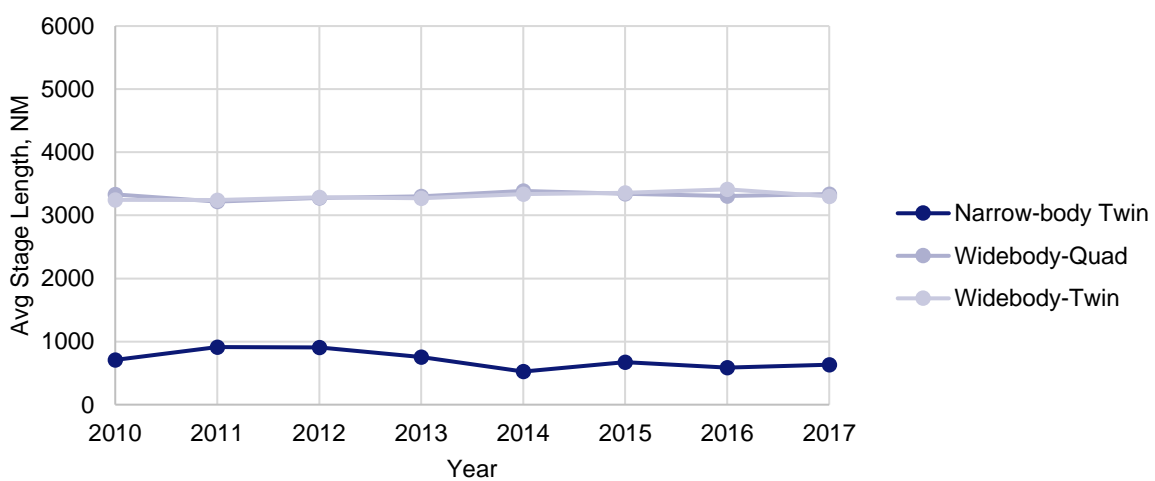
**Figure 28** Average stage length flown, Heathrow BPK



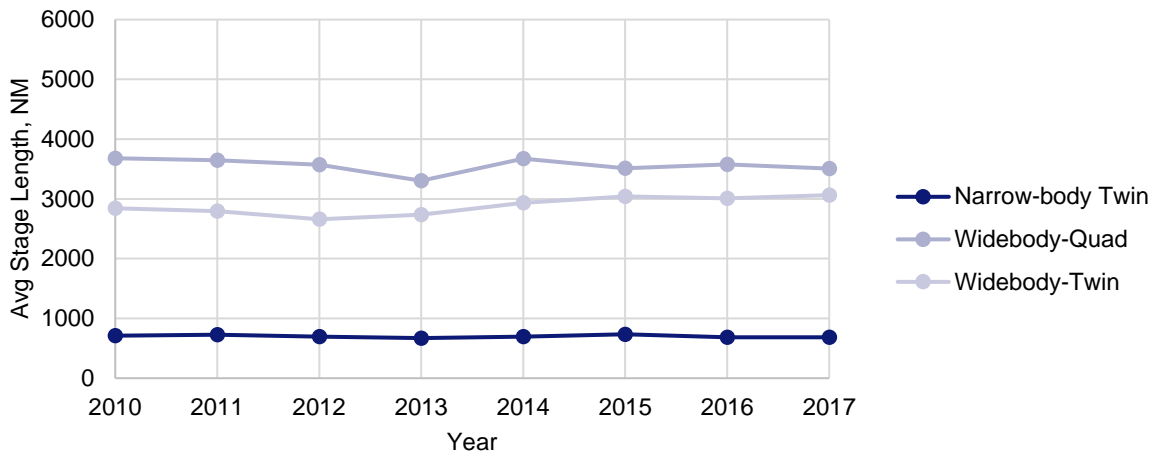
**Figure 29** Average stage length flown, Heathrow BUZ/WOB



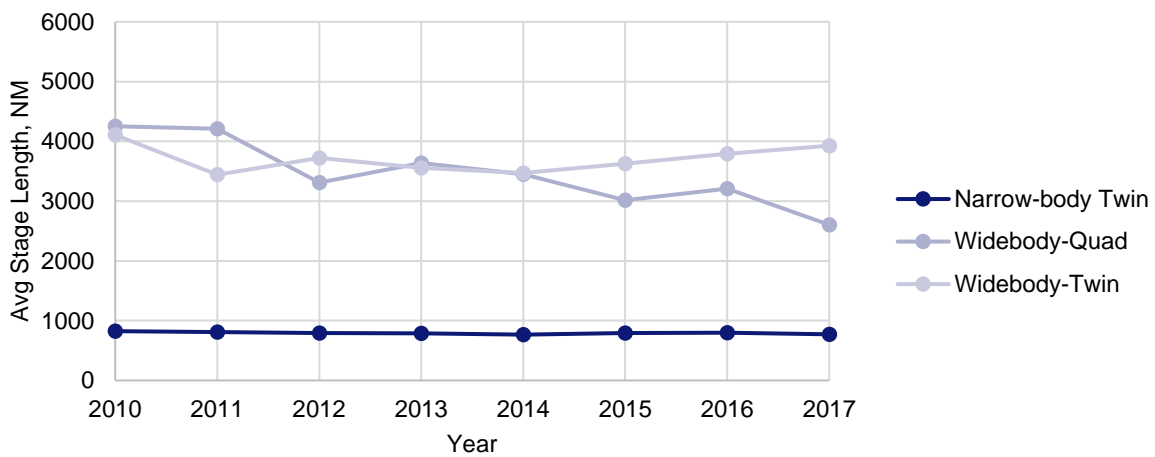
**Figure 30** Average stage length flown, Heathrow CPT



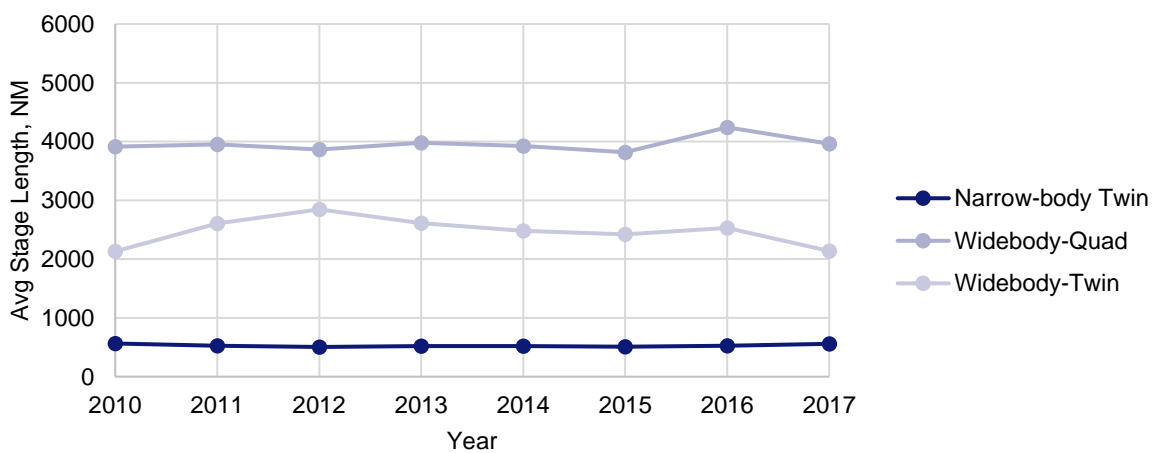
**Figure 31** Average stage length flown, Heathrow DET



**Figure 32** Average stage length flown, Heathrow GAS/GOG



**Figure 33** Average stage length flown, Heathrow MID





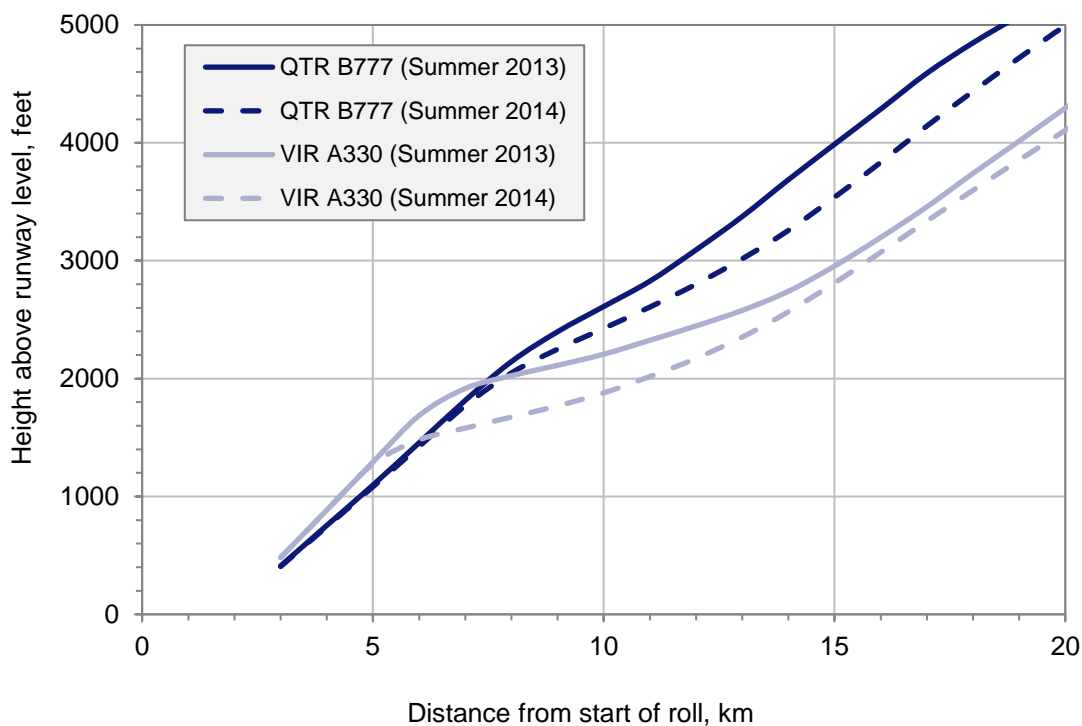
## Changes in aircraft design and airline departure procedures

**Figures 21 and 22** have shown that there has been a gradual decrease in the overall heights of departures on at least two of Heathrow's routes since 2000, with a more marked decrease in some cases in recent years. As discussed previously, aircraft might be flying lower than before because they are getting heavier. This could be because smaller aircraft are gradually being replaced with larger aircraft, passenger loads are increasing, and/or aircraft are flying further.

However, changes in aircraft design and airline operating procedures are likely to be key factors. New generation aircraft and engines have a much greater scope for optimisation of thrust to minimise engine stress, noise, emissions and costs, which may partly explain some of the observed decreases in average aircraft heights in the three broad categories of aircraft over time. Where airlines amend operating procedures on the same aircraft type, this can also influence height profiles.

**Figure 34** presents average height profiles for Qatar B777-300ER and Virgin A330 departures on Heathrow's easterly Detling route during summer 2013 and summer 2014. In the case of the Qatar B777, the aircraft was flying to the same destination in both years. However, the results indicate that between 2013 and 2014 the operator modified its departure procedure for the B777 during the climb segment, causing the aircraft to be up to 400 ft lower, on average, along the departure profile. It is considered less likely that the change in climb profile was caused by higher average take-off weights (due to increased passenger load factors and/or additional cargo) since the initial take-off profile up to 1,500 feet is similar for both years.

**Figure 34** Average height profiles for Qatar B777-300ER and Virgin A330 departures on easterly Detling route

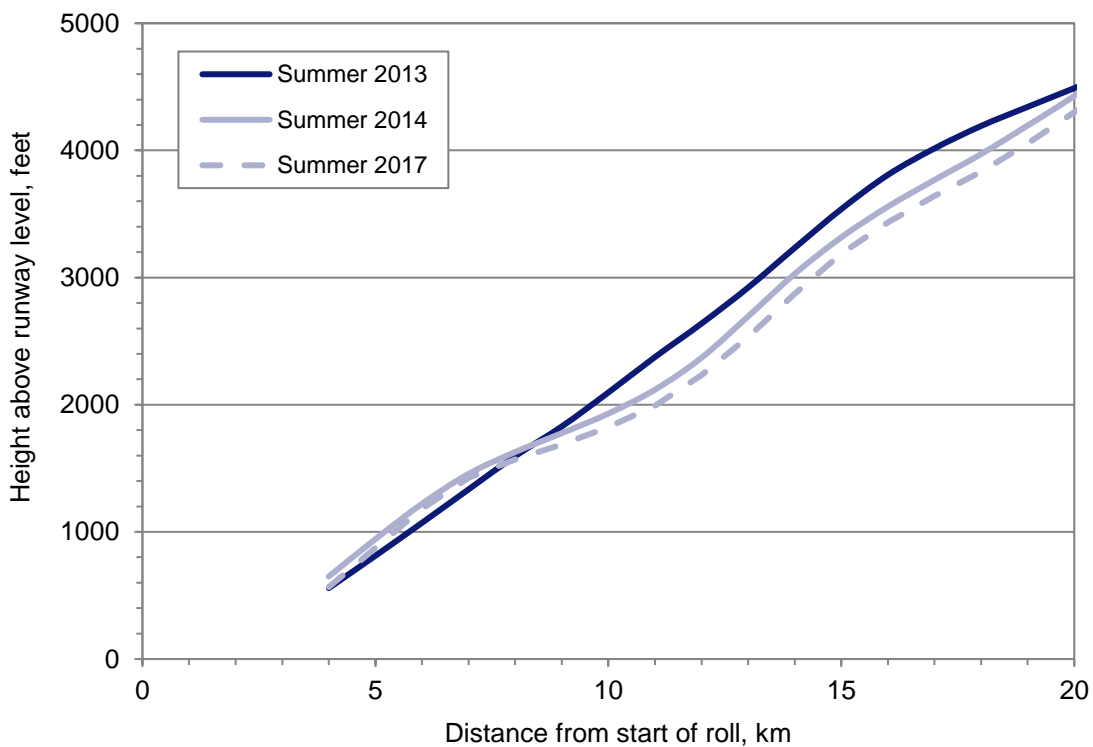


Likewise, the results for the Virgin Atlantic A330 in **Figure 34** show that at some point between 2013 and 2014 the airline operator modified its departure procedure for this type, possibly commencing the initial acceleration and flap retraction phase of the departure earlier than before, causing the aircraft to be lower further along the departure profile.

**Figure 35** presents average height profiles for Qantas A380 departures on the easterly Detling route during summer 2013, 2014 and 2017. In each case the aircraft was flying to the same destination.

The results indicate that between 2013 and 2014 the operator modified its departure procedure for the A380, causing the aircraft to be up to 200 ft lower along the departure route beyond 10 km from start of roll. **Figure 35** also shows that the average profile in summer 2017 was also slightly lower compared to summer 2014. This could be due to an increase in average take-off weight between 2014 and 2017.

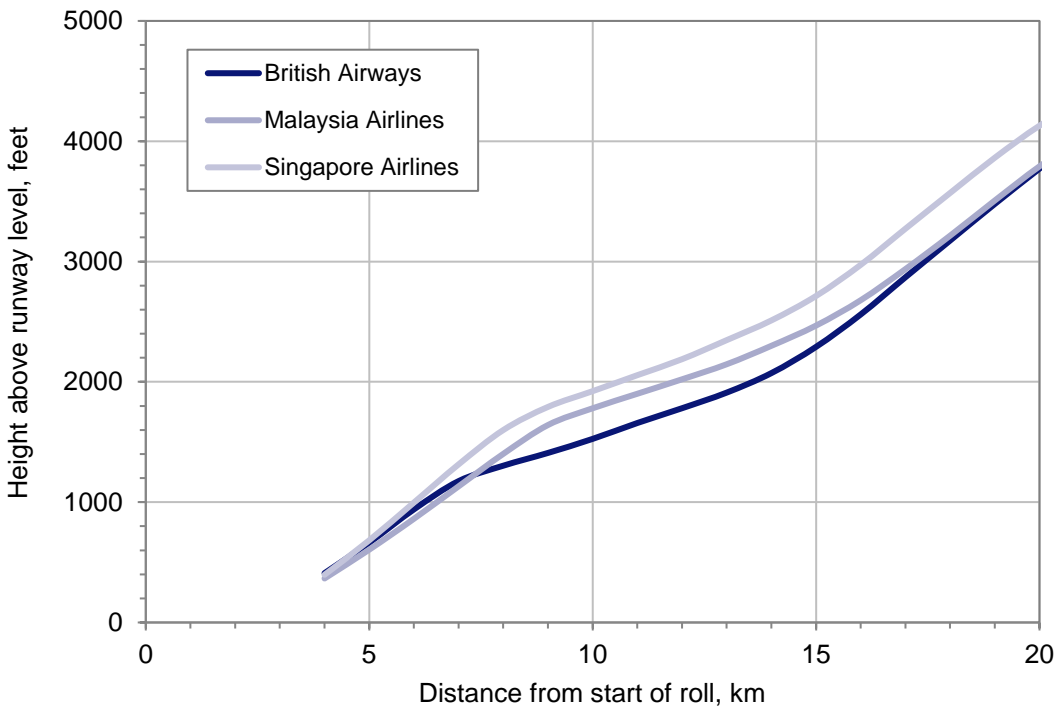
**Figure 35** Average height profiles for Qantas A380 departures on easterly Detling route



**Figure 36** presents the average height profiles in summer 2014 for three common operators of the A380 on the westerly Brookmans Park/Wobun route. The results indicate that each operator is using a different departure procedure, causing markedly different average flight profiles over the ground.

Whilst Malaysia Airlines and Singapore Airlines both operated the A380 on this route in previous years, British Airways commenced A380 services on this route *after* summer 2013. Thus the effect of the introduction of the British Airways A380 on this route was to cause a reduction in the average height profile for all A380s from 2014 onwards<sup>41</sup>. For example, at the location of the westerly BPK/WOB gate (approximately 11 km from start of roll, see **Figure 20**) the average height for all A380s in summer 2014 was approximately 200 feet lower compared to summer 2013.

**Figure 36** Average height profiles for A380 departures in Summer 2014 on westerly Brookmans Park/Wobun route

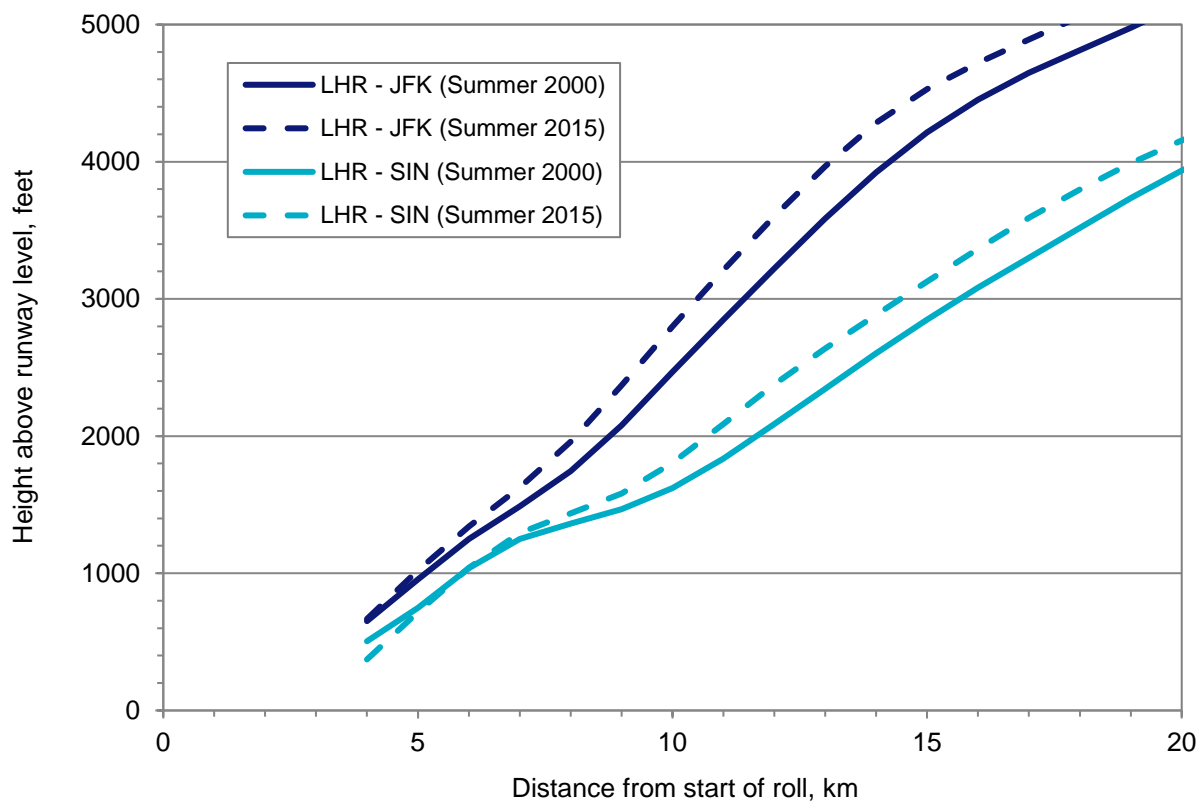


<sup>41</sup> In April 2017 British Airways modified their existing NADP 2 procedure for A380 departures at Heathrow to delay the climb thrust and acceleration altitude from 1,000 feet to 1,500 feet, see [https://www.heathrow.com/file\\_source/HeathrowNoise/Static/HCNF\\_Climb\\_Gradients\\_May\\_2017.pdf](https://www.heathrow.com/file_source/HeathrowNoise/Static/HCNF_Climb_Gradients_May_2017.pdf) (accessed 9 July 2018)

Notwithstanding the general finding that there has been a gradual decrease in the overall heights of departures at Heathrow since 2000, it should also be noted that average aircraft heights have increased in some specific instances.

For example, **Figure 37** presents the average height profiles for all British Airways B747-400 departures flying from Heathrow to John F. Kennedy International Airport (JFK) and Singapore Changi Airport (SIN) in Summer 2000 and Summer 2015. Whilst the flight profiles for the Singapore flights are lower (as expected, due to the longer distance flown), the results indicate that between 2000 and 2015 British Airways may have modified its procedure for the B747-400 during the climb segment, causing the aircraft to be higher on average along the departure profile to both destinations.

**Figure 37** Average height profiles for British Airways B747-400 departures in Summer 2000 and Summer 2015



## Chapter 4 summary

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- The minimum 4% climb gradient requirement on departure is intended to ensure that progressively reducing noise levels at points on the ground under the flight path are achieved.
- Definitions of minimum climb gradient vary from airport to airport – a higher quoted gradient may not necessarily translate to a higher minimum altitude requirement at a given location or reduce noise.
- There has been increased concern from local communities over recent years that climb performance is reducing, particularly for larger, heavier aircraft such as the A380.
- A comparison of average measured A380 climb profiles from Heathrow with equivalent departure profiles at other international airports has shown no indication that A380 operators at Heathrow are flying the same aircraft significantly lower than at other airports.
- A gradual decrease in average aircraft heights at Heathrow has been observed over recent years (up to 400 feet lower in some instances). Lower heights have not led to overall noise increases due to the continued introduction of quieter aircraft types, replacing older, noisier types.
- Three main reasons have been identified for the observed decreases in average aircraft heights on departure over time:
  - New generation aircraft and engines have a much greater scope for optimisation of thrust to minimise engine stress, noise, emissions and costs, which may partly explain some of the observed decreases in average aircraft heights in the three broad categories of aircraft over time.
  - There is some evidence that airline departure procedures have changed over time causing aircraft to be lower than previously.
  - Aircraft are getting larger/heavier. Smaller aircraft are gradually being replaced with larger aircraft and passenger loads are increasing.

## Chapter 5

# Options to reduce departure noise

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## Introduction

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Noise abatement operational procedures to limit aircraft noise exposure form one of the four principal elements of the ICAO Balanced Approach<sup>42</sup> to noise management. They cover a wide variety of techniques, but can be grouped into four areas:

- Operational measures that reduce the amount of noise emitted by the aircraft.
- Operational measures that increase the distance between the aircraft and the ground.
- Operational measures to cause noise to affect less populated areas.
- Operational measures that provide respite from aircraft noise

Depending on how the measure is applied, it may achieve one or more of the above, which may also result in cumulative improvements.

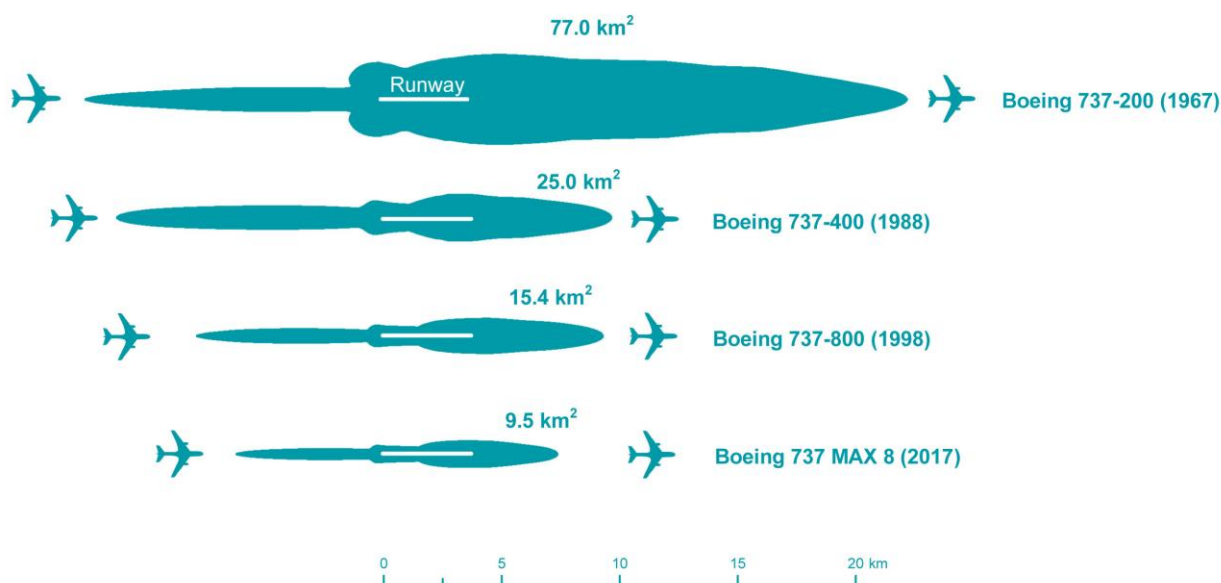
The other three elements of the Balanced Approach cover:

- Reduction of Noise at Source (tighter international noise standards to incentivise quieter aircraft)
- Land-use Planning and Management (limiting new residential development in areas around airports)
- Operating Restrictions (limits on numbers or types of flights during specified periods)

In terms of reduction of noise at source, there is no doubt that over more than fifty years of the jet age, technology has significantly improved aircraft noise performance. By way of example, **Figure 38** illustrates the shape and relative size of the noise footprint (the ground area affected by aircraft noise to a level of 70 dBA) for different generations of the Boeing 737.

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<sup>42</sup> ICAO Doc 9829, Guidance on the Balanced Approach to Aircraft Noise Management (Second Edition), International Civil Aviation Organization, 2008

**Figure 38** Improvement in noise performance for the Boeing 737

**Figure 38** shows that noise performance has improved significantly despite a 40% increase in maximum take-off weight between the 737-200 (58 tonnes) and the 737 MAX 8 (82 tonnes). Evidence of the long-term improvement in aircraft noise performance can also be seen in the historic noise contours for the London airports (see for example the Heathrow contour areas reported in **Figures 21 and 22**).

There is also some evidence that noise-related operating restrictions at airports have influenced the design of new aircraft in order to make them quieter than they otherwise might have been<sup>43</sup>. Over more recent years however, the impact of this technology improvement has been eroded to some extent, in terms of the overall noise exposure, because of the growth in the number of aircraft movements.

Given that aviation rarely has influence over land use and planning and, as the ICAO Balanced Approach sets out, operating restrictions are considered to be a final resort, this means that the management of aviation noise is generally focused on manufacture and operation, the latter of which is discussed below.

## Noise Abatement Departure Procedures

As explained in Chapter 2, the flight crew's primary aim on departure is to accelerate the aircraft to take-off speed and then depart from the runway to climb rapidly. At or above

<sup>43</sup> Although other airlines may have had additional requirements, a condition of Singapore Airlines' order for the Airbus A380 before the aircraft entered service in 2007 was the requirement to comply with the London airports' QC/2 departure noise classification. Changes to the A380 design in order to accommodate noise technology improvements meant that the aircraft incurred a small fuel penalty as a result.



800 feet altitude (the minimum altitude above ground level defined by ICAO), engine power may be reduced in order to preserve an adequate service life for the engines, and to reduce noise. Also at or above 800 feet altitude, the aircraft may be accelerated from the take-off speed. Engine power is therefore used to gain both altitude and speed.

The balance between how much energy is put into gaining altitude and speed, and at what altitudes power reduction and acceleration are initiated, and in what order, are set out in an airline's noise abatement departure procedure(s), that are incorporated into its Standard Operating Procedures (SOPs). These procedures are heavily regulated to ensure that a proliferation of procedures does not lead to confusion and impact on safety levels. ICAO guidance<sup>44</sup> recommends that an airline adopts no more than two procedures for any given aircraft type. This requirement is made mandatory within EU regulations<sup>45</sup>.

The ICAO guidance also provides two examples of Noise Abatement Departure Procedures: NADP 1 which ICAO notes can mitigate noise directly underneath the flight path close to the aerodrome, and NADP 2 which can mitigate noise more distant from the aerodrome. NADP 1 prescribes that at an initial altitude, take-off power is reduced to climb thrust, whilst take-off speed is maintained until a higher altitude, before accelerating. NADP 2 prescribes that at an initial altitude, the aircraft is accelerated to a higher speed, and at the same or higher altitude take-off power is reduced to the climb thrust setting. Close-in noise differences between NADP 1 and NADP 2 are generally bigger than distant noise differences.

Whilst NADP 1 and NADP 2 may each be considered to represent different families of procedures, a generally held view is that the specified altitudes represent a single procedure. For example, two NADP 1 procedures that specify different altitudes for power reduction to climb thrust (e.g. 1,000 feet and 1,500 feet) would be considered separate procedures.

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<sup>44</sup> ICAO Doc. 8168, Aircraft Operations (PANS-OPS), Volume I — Flight Procedures

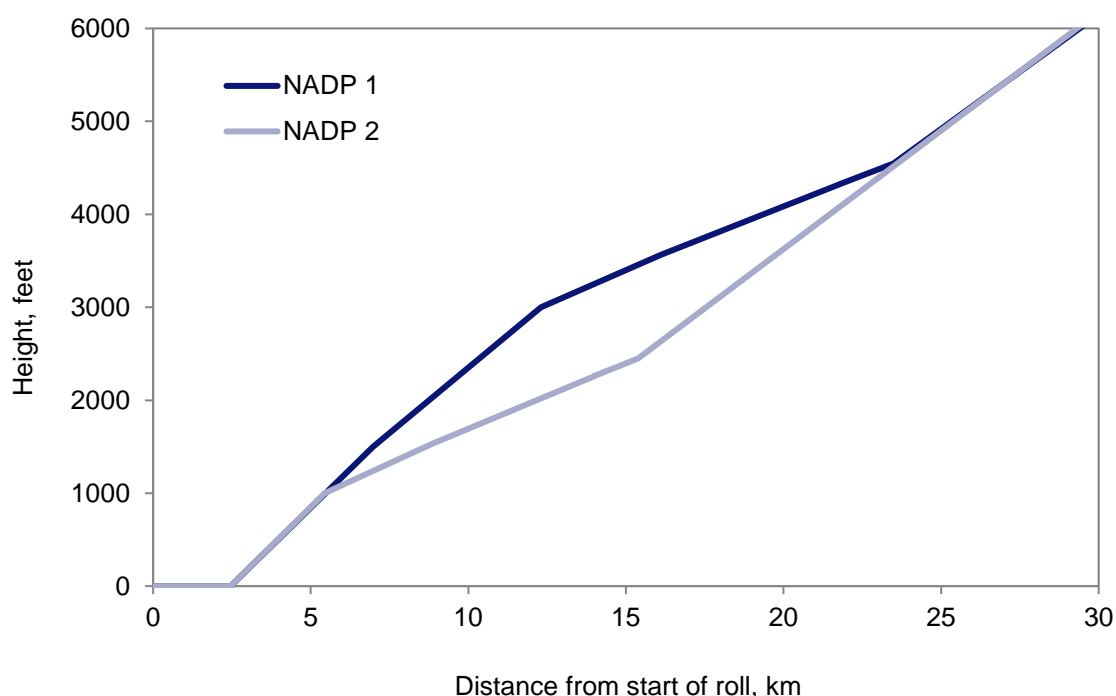
<sup>45</sup> Commission Regulation (EC) No 859/2008 (EU-OPS 1)

Although a wide range of procedures may be developed within the NADP 1 and 2 definitions, the following procedures are commonly implemented by carriers:

- NADP 1: Change to climb thrust at 1,500 feet, accelerate to climb speed at 3,000 feet
- NADP 2: Accelerate to climb speed and change to climb thrust at 1,000 feet

The difference between the height profiles for the two procedures is illustrated below for the Airbus A380.

**Figure 39** Comparison of NADP 1 and NADP 2 height profiles (A380, 3,000 NM trip length, reduced take-off thrust)



Airlines tend to adopt noise abatement departure procedures that are compatible with their dominant base of operation, e.g. their central hub airport. Some airports direct airlines to use preferred procedures, though they have no formal power to enforce this, and in isolated cases it could cause an airline to breach EU regulations if the procedure directed by the airport was not one of the two adopted by the airline on a given aircraft type.

One procedure does not necessarily have a better overall noise impact than another. Instead, changing from one procedure to another may redistribute noise from one location to another, resulting in both noise decreases and noise increases. The procedure selected can also affect how efficiently an aircraft climbs to cruise altitude, and thus affect the overall fuel used for a flight. It should also be recognised that for some airline operations (e.g. at low take-off weights) the change from take-off thrust to climb thrust may in fact result in no change in engine power setting.

It is widely accepted that no single departure procedure minimises overall noise, emissions and engine maintenance costs simultaneously and so airlines have to decide how best to

balance the requirements of all three elements in their operations whilst maintaining consistency across their operations for safety reasons<sup>46,47</sup>.

## NADP case studies

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To study the effects of different Noise Abatement Departure Procedures on noise, local air quality (affected by emissions of oxides of nitrogen (NO<sub>x</sub>)) and carbon dioxide (CO<sub>2</sub>), a number of procedures have been modelled for the Airbus A380 which, following the retirement of the Boeing 747-400, is expected to be one of the noisiest aircraft types in regular airline service.

The noise assessment focussed on changing from a baseline reduced thrust NADP 2 procedure to an alternative procedure that would be expected to achieve a reduction in the maximum noise level recorded at the 6.5 km noise monitor. This could be achieved either by increasing the aircraft height over the monitor (by switching to NADP 1 or full thrust NADP 2) or by reducing the engine power to a minimum climb setting before the aircraft passes over the monitor (implementing a 'deep cutback' to climb power).

A similar but more limited analysis was also carried out for the Airbus A320, Boeing 737-800 and Boeing 777-300ER to cover common narrow and wide-body twin-engine types in current use. Full details are presented in **Appendix E**.

The analysis showed that depending on the alternative departure procedure flown, L<sub>Amax</sub> reductions of up to 2 dB or more might be achieved at the 6.5 km position and other locations under the flight path. However, this benefit was found to be at the expense of an increase in L<sub>Amax</sub> noise elsewhere, in particular to the sides of the flight path due to the difference in the way noise propagates to the side of the flight path as aircraft height increases.

For the A380 departing on the easterly Detling SID at Heathrow, modelling the change from an NADP 2 procedure to an NADP 1 procedure was found to decrease L<sub>Amax</sub> noise levels in some areas and increase L<sub>Amax</sub> levels in other areas. Overall, more people received a decrease in L<sub>Amax</sub> noise when changing from NADP 2 to NADP 1. However, decreases in L<sub>Amax</sub> occur as a consequence of increased height but at the expense of increased noise event duration (because the aircraft speed is held until reaching 3,000 feet), which, when taken account of by the SEL noise metric, results in some people experiencing more noise and no people experiencing less noise.

In conclusion, the analysis shows that there is no single NADP that will reduce departure noise in all locations; a change of NADP simply moves noise from one location to another. Given the varied population distribution underneath the departure flight paths at the

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<sup>46</sup> ICAO Circular 317, *Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions*, International Civil Aviation Organization, 2008

<sup>47</sup> Jones R E, *Airline flight departure procedures — choosing between noise abatement, minimum fuel consumption and minimum cost*, *Aeronautical Journal*, April 1981, pp 154 -166

designated London airports, no single procedure would lead to noise benefits for everyone.

In terms of local air quality, the results showed that changing from an NADP 2 to an NADP 1 procedure causes a decrease in NO<sub>x</sub> up to 3,000 feet, but no change below 1,000 feet. This is because the aircraft using an NADP 1 procedure climbs to 3,000 feet more quickly, but the two procedures are identical up to 1,000 feet. As a result, there is little difference in local air quality impacts. CO<sub>2</sub> (fuel burn) on the other hand increases slightly when switching from NADP 2 to NADP 1 because the aircraft 'cleans up' and accelerates at a later stage during the departure.

The analysis showed practically no change in NO<sub>x</sub> below 3,000 feet when switching to a deep cutback climb procedure, although CO<sub>2</sub> emission was found to increase slightly. The results also showed that a full thrust departure procedure produces more NO<sub>x</sub> up to 3,000 feet but slightly less CO<sub>2</sub> up to the cruise altitude compared to an equivalent reduced thrust procedure.

## Chapter 5 summary

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- Noise abatement operational procedures to limit aircraft noise exposure form one of the principal elements of the ICAO Balanced Approach to noise management.
- ICAO guidance provides two examples of Noise Abatement Departure Procedures: NADP 1 which ICAO notes can mitigate noise directly underneath the flight path close to the aerodrome, and NADP 2 which can mitigate noise more distant from the aerodrome. A wide range of procedures may be developed within the NADP 1 and NADP 2 definitions.
- One procedure does not necessarily have a better overall noise impact than another. Instead, changing from one procedure to another tends to redistribute noise from one location to another, resulting in both noise decreases and noise increases. A reduction in noise level at the 6.5 km location could be achieved through a procedure change but at the expense of an increase in noise elsewhere along or to the side of the flight path.
- For the A380 departing on the easterly Detling SID at Heathrow, modelling the change from an NADP 2 procedure to an NADP 1 procedure was found to decrease  $L_{Amax}$  noise levels in some areas and increase  $L_{Amax}$  levels in other areas. Overall, more people received a decrease in  $L_{Amax}$  noise when changing from NADP 2 to NADP 1. However, decreases in  $L_{Amax}$  occur as a consequence of increased height but at the expense of increased noise event duration, which, when taken account of by the SEL noise metric, results in some people experiencing more noise and no people experiencing less noise.
- The analysis shows that there is no single NADP that will reduce departure noise in all locations; a change of NADP simply moves noise from one location to another. Given the varied population distribution underneath the departure flight paths at the designated London airports, no single procedure would lead to noise benefits for everyone.
- In terms of local air quality, the results showed that changing from an NADP 2 to an NADP 1 procedure causes a decrease in  $NO_x$  up to 3,000 feet, but no change below 1,000 feet. This is because the aircraft using an NADP 1 procedure climbs to 3,000 feet more quickly, but the two procedures are identical up to 1,000 feet. As a result, there is little difference in local air quality impacts.  $CO_2$  increases slightly when switching from NADP 2 to NADP 1 because the aircraft 'cleans up' and accelerates at a later stage during the departure.
- It is widely accepted that no single departure procedure minimises overall noise, emissions and engine maintenance costs simultaneously. Airlines have to decide how best to balance the requirements of all three elements in their operations whilst maintaining consistency across their operations for safety reasons.

## Chapter 6

# Other opportunities to manage departure noise

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## Introduction

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The preceding sections have considered optimisation of the vertical flight profile to reduce noise emission and/or increase the distance between the noise source and the ground, thereby reducing noise exposure on the ground.

Optimising the lateral flight path taken by the departing aircraft on the other hand does not reduce aircraft noise in the same way; instead it redistributes it. Depending on the local population distribution it may be possible to achieve a net reduction in the number of people exposed to certain levels of noise by changing the lateral flight track. However, this net benefit may result in noise exposure increases for some.

Historically the ability to provide optimised lateral paths was limited by the need to navigate using ground-based navigational aids. The transition towards Performance Based Navigation (PBN) provides an opportunity to improve navigational accuracy, so that aircraft follow more precise flight paths resulting in more precise track keeping. PBN also offers the potential to tailor departure (and arrival) routes to avoid more densely populated areas and therefore reduce the number of people impacted by aircraft noise.

For example, in May 2017, following positive feedback and support during an extensive trial and stakeholder engagement process by Stansted Airport<sup>48</sup>, the CAA approved two new RNP1 SIDs (CLN1E and DET1D) to complement existing conventional procedures on the same routes. In making its decision, the CAA acknowledged that their introduction, when fully utilised, should achieve Stansted Airport's stated aim of implementing RNP1 technology and minimising the numbers of people directly overflown<sup>49</sup>.

## Noise mitigation provided by offset routes

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The Government's overall objective on aircraft noise is to limit and, where possible, reduce the number of people in the UK significantly affected by adverse impacts from aircraft noise<sup>50</sup>. Concentrating traffic on single routes will normally reduce the total number of people overflown. However, PBN also offers the opportunity to use multiple routes which can potentially provide relief or respite from noise. Government guidance recognises that

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<sup>48</sup> <http://www.stanstedairport.com/community/local-environmental-impacts/performance-based-navigation/>  
(accessed 9 July 2018)

<sup>49</sup> <https://www.caa.co.uk/Commercial-industry/Airspace/Airspace-change/Decisions/Stansted-Airport-RNP1-RF-SIDs/>  
(accessed 9 July 2018)

<sup>50</sup> *Air Navigation Guidance 2017*, Department for Transport, October 2017

this may mean there will be situations when multiple routes, that expose more people overall to noise but to a lesser extent, may be better from a noise perspective.

Airspace Design Guidance (CAP 1378<sup>51</sup>) published by the CAA in 2016 provides a range of options for consideration when applying PBN and how best to mitigate noise impacts. The guidance recognises that the degree of noise mitigation provided by routes that are offset from one another will depend on the spacing between the routes and the height of the aircraft. **Figure 40**, reproduced from CAP 1378, may be used to determine the spacing required to provide the required noise mitigation. As indicated in **Figure 40**, a difference in noise level of 3 dB is not particularly noticeable ('just perceptible').

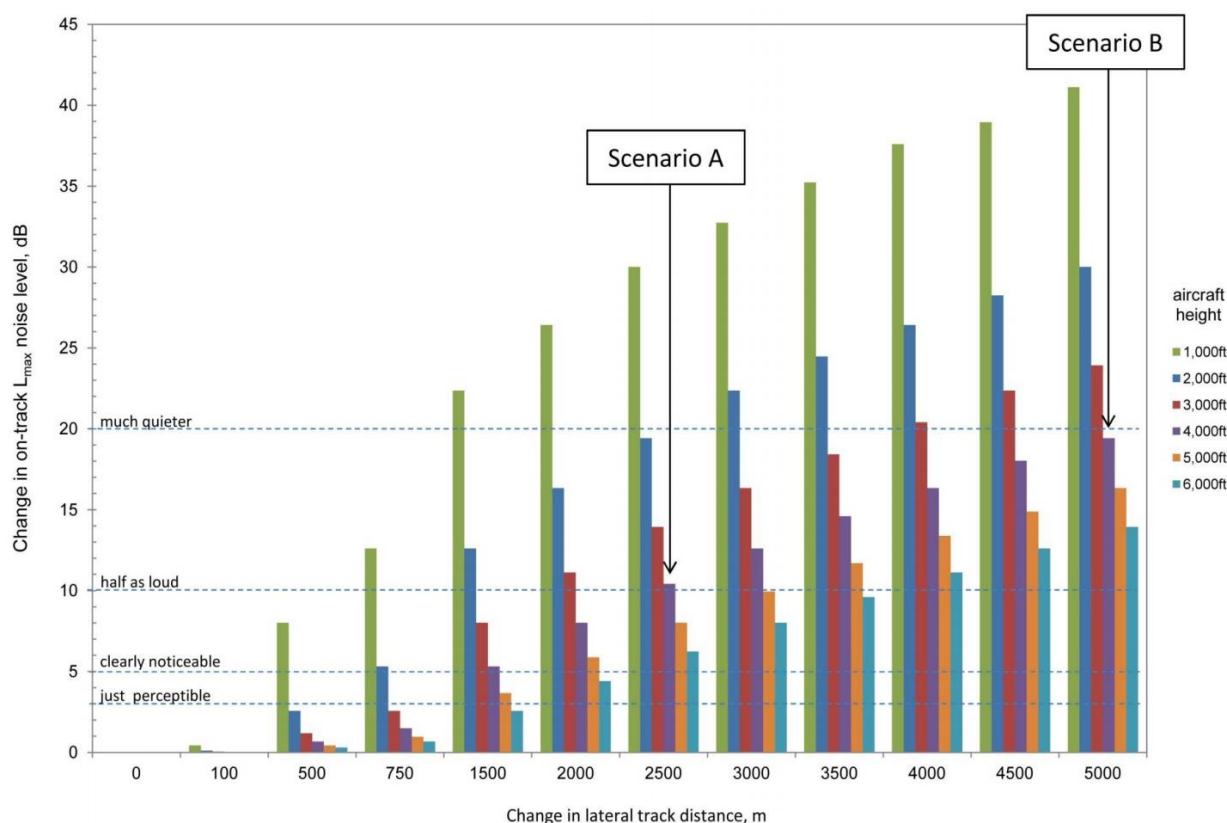
Consider 'Scenario A' for example, where noise mitigation through the need for relief routes is required for routes up to 4,000 feet. If the stakeholder expectation is that relief will mean that the perceived loudness is halved (a 10 dB reduction) when the relief route is active, then the spacing between two routes would need to be at least 2,500 m (where the purple bar which represents impacts from aircraft at 4,000 feet reaches the line for 'half as loud'). If, however, the stakeholder expectation is that relief will mean periods that are 'much quieter' (a 20 dB reduction), then the spacing required would need to be at least 5,000 m, as per 'Scenario B'.

It is also apparent that as aircraft height increases (i.e. at more distant locations from an airport) then the route spacing required to achieve a particular degree of noise mitigation also increases, which may not always be feasible from an airspace design perspective.

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<sup>51</sup> [CAP 1378](#), *Airspace Design Guidance: Noise Mitigation Considerations when Designing PBN Departure and Arrival Procedure*, April 2016

**Figure 40** Changes in on-track noise level due to lateral displacement as a function of aircraft altitude



## Respite from aircraft noise

In February 2018 Heathrow Airport published the results of its commissioned research that is intended to help improve understanding of respite from aviation noise<sup>52</sup>. Listening tests were undertaken during which participants gave feedback on a range of aircraft sounds in terms of whether they noticed differences and whether these could potentially lead to a valuable break from the aircraft noise over a longer period of time. The main findings from the study suggested that, under active listening conditions in the laboratory, on average:

- A 2 to 3 dB difference between successive sounds was not particularly noticeable, although over half of the participants thought that it could lead to a more positive view of the airport, compared to providing no difference at all.
- Differences of 5 to 6 dB between successive sounds may be needed for people to even tell there is a difference.
- But a difference of at least 7 or 8 decibels may be needed between the average sound level of two sequences of aircraft sounds to provide a *valuable* break from aircraft noise.

<sup>52</sup> <https://www.heathrow.com/noise/making-heathrow-quieter/respice-research> (accessed 9 July 2018)



## Chapter 6 summary

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- Performance Based Navigation (PBN) provides an opportunity to improve navigational accuracy and offers the potential to tailor departure routes to avoid more densely populated areas.
- Depending on the local population distribution it may be possible to achieve a net reduction in the number of people exposed to certain levels of noise by changing the lateral flight track. However, this net benefit may result in noise exposure increases for some.
- PBN also offers the opportunity to use multiple routes which can potentially provide relief or respite from noise. This may mean there will be situations when multiple routes, that expose more people overall to noise but to a lesser extent, may be better from a noise perspective.
- A difference in noise level of 3 dB is not particularly noticeable. As aircraft height increases (at more distant locations from an airport) then the route spacing required to achieve a particular degree of noise mitigation also increases, which may not always be feasible from an airspace design perspective.

## Chapter 7

## Conclusions and recommendation

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### Noise limits

The current departure noise limits of 94 dBA (day), 89 dBA (shoulder) and 87 dBA (night) were implemented at the London airports in 2001. The noise limits are related to a fixed reference distance of 6.5 km from start of roll and have been defined in terms of a maximum A-weighted noise level,  $L_{Amax}$  since 1992-93.

Recognising that the noise limits had been in place for many years, the government announced in its March 2013 Aviation Policy Framework that ANMAC would review the departure noise abatement procedures at the London airports, including noise limits and use of penalties, to ensure that these remain appropriately balanced and effective.

The study by the ANMAC Technical Working Group has identified that there is limited scope for reductions in the noise limits at Heathrow until the retirement of the remaining Boeing 747-400 fleet. A small reduction of 1 to 2 dB in the daytime and shoulder limits might be feasible without causing the overall number of infringements to increase above historic levels.

The results for Gatwick and Stansted indicate that the current daytime, shoulder and night limits could be lowered, by up to 3 decibels or more in some cases, without significantly impacting the current fleets at those airports.

A lowering of the noise limits at Gatwick and Stansted would provide a backstop, dissuading the re-introduction of the noisiest aircraft types, but it would mean that the limits would no longer be applied equally across the three airports (which has been a matter of government policy for many years).

The analysis has shown that whilst reductions in noise level at the 6.5 km location could be achieved through changes to airline Noise Abatement Departure Procedures, this would be at the expense of noise increases elsewhere along or to the side of the flight path.

Regarding the wider influence of Noise Abatement Departure Procedures on departure noise, ICAO guidance provides two examples that were originally intended to provide distinct differences in noise exposure between close-in and distant communities from an airport: NADP 1 which ICAO notes can mitigate noise directly underneath the flight path close to the aerodrome, and NADP 2 which can mitigate noise more distant from the aerodrome. A wide range of procedures may be developed within the NADP 1 and 2 definitions.

An NADP 1 procedure for the A380 was found to decrease  $L_{Amax}$  noise levels in some areas and increase  $L_{Amax}$  noise levels in other areas relative to NADP 2, but with more

people overall experiencing less noise on the easterly Detling route at Heathrow. However, decreases in  $L_{Amax}$  occur as a consequence of increased height, but, at the expense of increased noise event duration, which when taken account of by the SEL noise metric, resulted in some people experiencing more noise and no people experiencing less noise.

Variations in the local population distribution along each departure route will therefore influence the resulting noise exposure for a given departure procedure. Identifying the optimum procedure(s), whilst respecting the two procedure EU-OPS limitation, is a matter for individual airports, airlines and their communities. The analysis shows that there is no single NADP that will reduce departure noise in all locations; a change of NADP simply moves noise from one location to another.

Changing from an NADP 2 to an NADP 1 procedure was shown to cause a decrease in  $NO_x$  up to 3,000 feet, but no change below 1,000 feet. This is because the NADP 1 departure climbs to 3,000 feet more quickly, but the two procedures are identical up to 1,000 feet. As a result, there is little difference in local air quality impacts. However,  $CO_2$  (fuel burn) was shown to increase slightly when changing to an NADP 1 procedure because the aircraft cleans up and accelerates at a later stage during the departure.

### **Other noise controls**

In addition to the departure noise limits, a number of other noise controls are promulgated through the Section 78 notices for each designated London airport.

Aircraft are required to be at a height of not less than 1,000 feet at 6.5 km from start-of-roll. After passing the 1,000 feet point (at 6.5 km), aircraft are then required to maintain a climb gradient of not less than 4% to an altitude of 4,000 feet. The compliance rates with these additional controls are very high.

The rationale for the climb gradient requirement is to ensure that progressively reducing noise levels at points on the ground under the flight path are achieved.

### **Aircraft climb performance**

There is continuing community expectation to minimise aircraft noise, and some local communities have expressed concern that aircraft climb performance is reducing, and that this could be sub-optimal for noise in those communities. A gradual decrease in average aircraft heights at Heathrow has been observed over recent years (up to 400 feet lower in some instances). However, lower heights have not led to overall noise increases due to the continued introduction of quieter aircraft types, replacing older, noisier types.

Three main reasons have been identified for the observed decreases in average aircraft heights on departure over time:

- New generation aircraft and engines have a much greater scope for optimisation of thrust to minimise engine stress, noise, emissions and costs, which may partly explain some of the observed decreases in average aircraft heights in the three broad categories of aircraft over time.
- There is some evidence that airline departure procedures have changed over time causing aircraft to be lower than previously.
- Aircraft are getting larger/heavier. Smaller aircraft are gradually being replaced with larger aircraft and passenger loads are increasing.

## Recommendation

Although the current controls appear to be limiting noise further out and compliance rates are very high, continued community discontent with departure noise in general suggests that the existing controls may not be sufficient to meet the concerns of the community.

Given the continued community expectation that departure noise should be minimised, additional departure monitors located beyond 6.5 km from start of roll would help to verify that progressively reducing noise levels under the flight path are being achieved. Additional monitoring could help to further incentivise airline performance, improve transparency and enhance community engagement. The question as to whether the monitors should be subject to supplementary infringement 'limits', advisory 'levels' or simply routine airport monitoring would need to be addressed.

The current departure limits are defined in terms of a maximum A-weighted noise level,  $L_{Amax}$ , which is the simplest measure of a noise event such as the overflight of an aircraft. However, as was highlighted in the NADP analysis, it does not take account of the duration of the noise event and hence is possibly less representative of the disturbance the aircraft may cause. It may therefore be preferable to define any new supplementary levels in terms of SEL, which would complement the existing 6.5 km  $L_{Amax}$  noise limits.

It is recommended that guidance be developed on the application of supplementary departure noise monitoring and associated levels. This could be taken forward through an industry-led group to develop an updated Departures Code of Practice. In the short term however, a voluntary arrangement at each airport may be appropriate.

## APPENDIX A

## Glossary

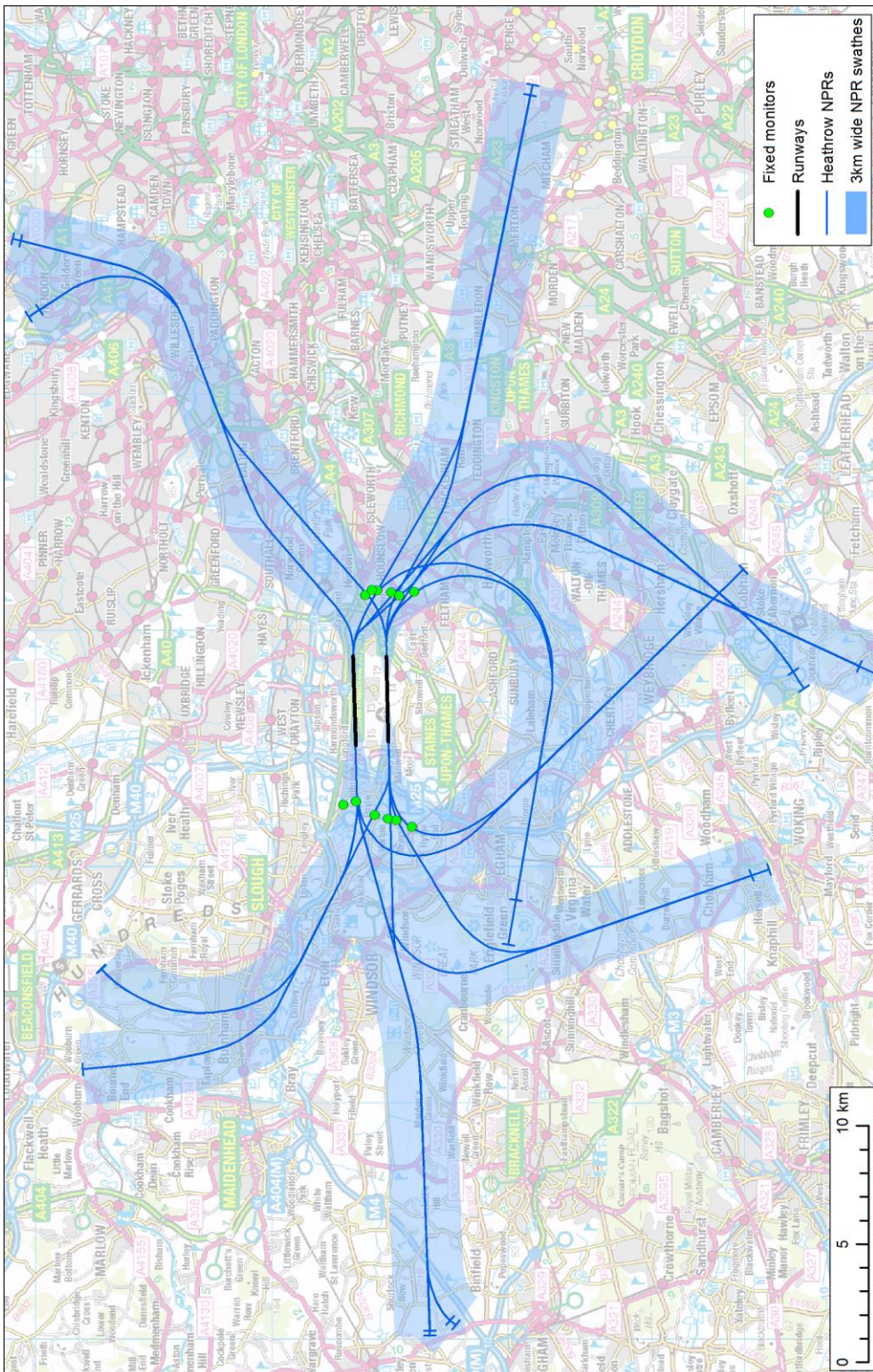
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ATC	Air Traffic Control.
CCO	Continuous Climb Operation. An operation, enabled by airspace design, procedure design and ATC, in which a departing aircraft climbs without interruption, to the greatest possible extent, by employing optimum climb engine thrust, at climb speeds until reaching the cruise flight level.
CO <sub>2</sub>	Carbon dioxide.
dB	Decibel units describing sound level or changes of sound level.
dBA	Units of sound level on the A-weighted scale, which incorporates a frequency weighting approximating the characteristics of human hearing.
ERCD	Environmental Research and Consultancy Department of the CAA.
Knots	Nautical miles per hour. One knot is equal to 1.852 kilometres per hour.
L <sub>Aeq</sub>	Equivalent sound level of aircraft noise in dBA, often called 'equivalent continuous sound level'. For conventional historical contours this is based on the daily average movements that take place within the 16-hour period (0700-2300 local time) over the 92-day summer period from 16 June to 15 September inclusive.
L <sub>Amax</sub>	The maximum sound level (in dBA) measured during an aircraft fly-by.
NADP	Noise Abatement Departure Procedure.
NATS	The UK Air Navigation Service Provider.
NM	Nautical Mile, equivalent to 1,852 metres.
NO <sub>x</sub>	Nitrogen oxide (or oxides of nitrogen).
NPR	Noise Preferential Route. The preferred route for aircraft to fly in order to minimise their noise profile on the ground in the immediate vicinity of the airport. NPRs form the initial part of Standard Instrument Departures (SIDs).
SEL	Sound Exposure Level. A single event noise level that accounts for both the level and duration of an aircraft noise event.
SID	Standard Instrument Departure. A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated air traffic service route, at which the enroute phase of a flight commences.

# APPENDIX B

## Fixed noise monitor positions

Figure B1 Heathrow fixed noise monitor positions



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Figure B2 Gatwick fixed noise monitor positions

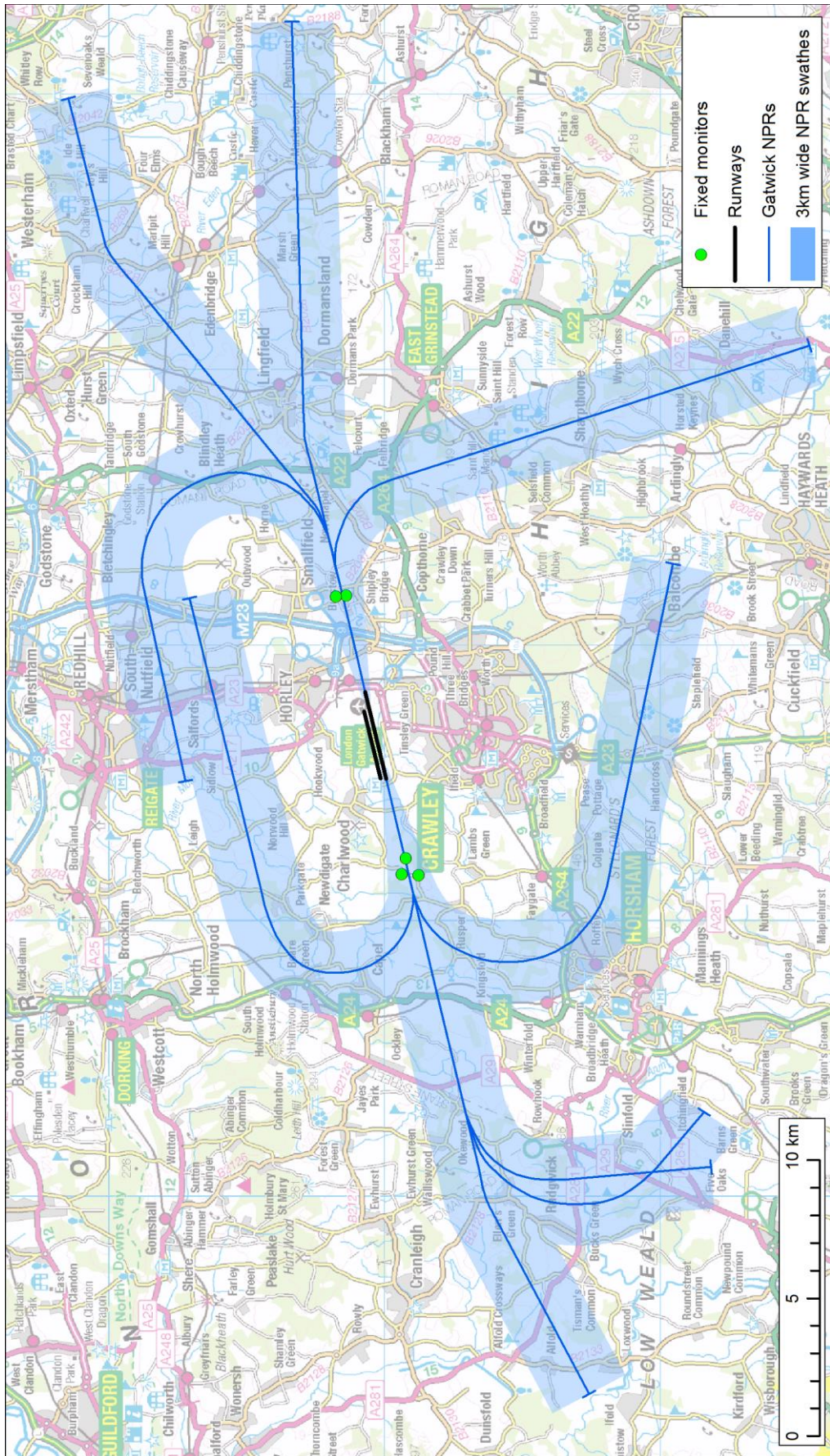
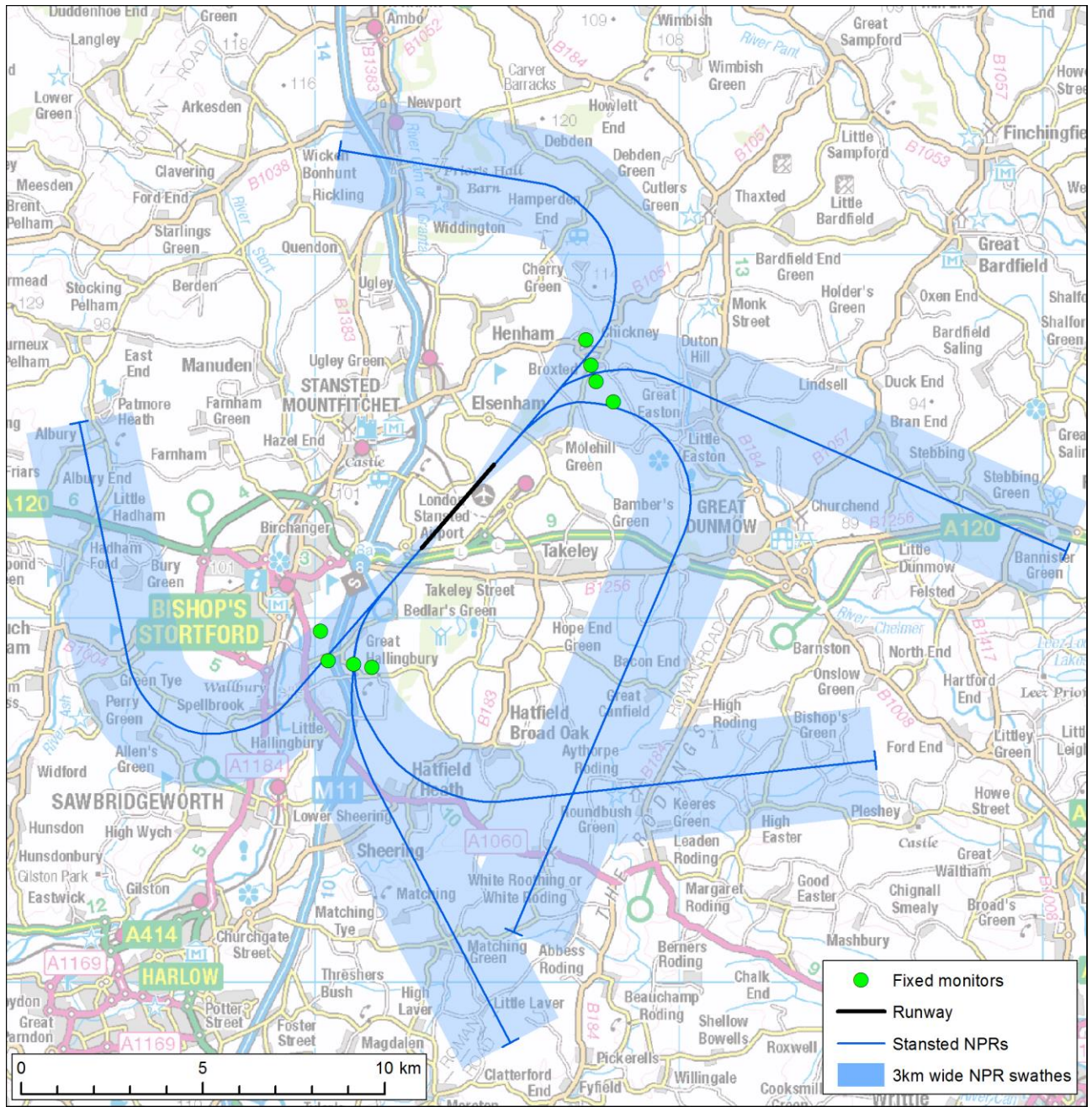


Figure B3 Stansted fixed noise monitor positions



Contains Ordnance Survey data © Crown copyright and database right 2018

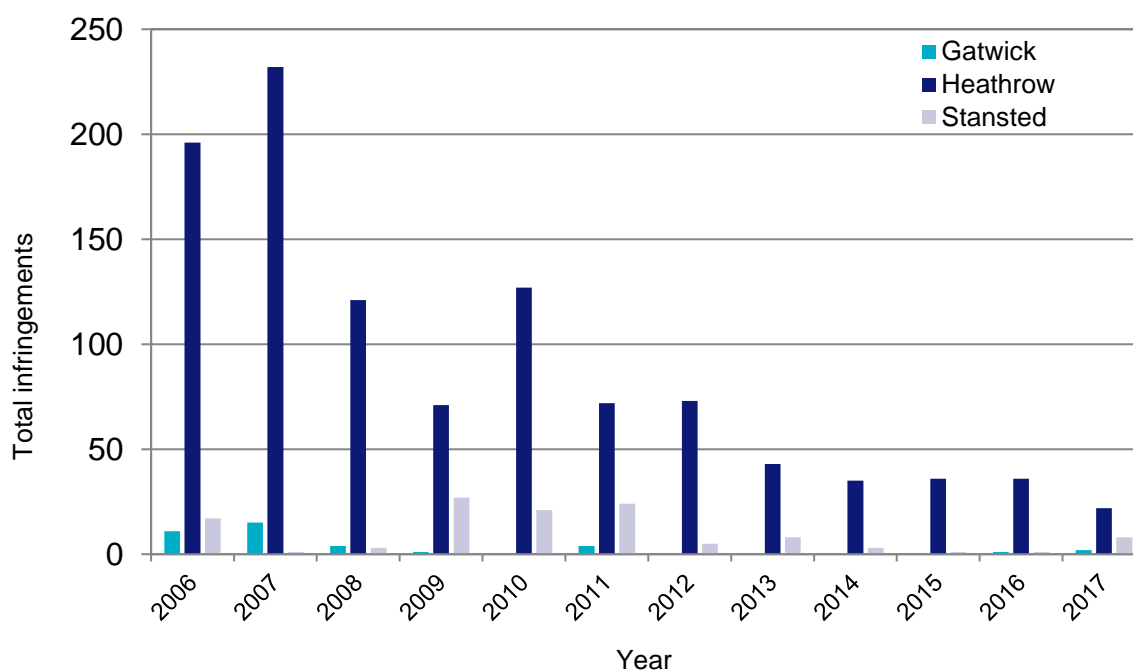


## APPENDIX C

## Empirical analysis of infringement rates

As mentioned in Chapter 3, there are now relatively few departure noise infringements across the three London airports, see **Figure C1**. This is largely due to the gradual retirement and replacement of older aircraft types such as the Boeing 747-400 and Airbus A340-200/300, and the introduction of newer and quieter types such as the Boeing 777-300ER, 787-8/9 and Airbus A380 and A350.

**Figure C1** Summary of annual departure noise infringements since 2006



This appendix presents an empirical analysis of noise measurement data extracted from the London airports' Noise and Track Keeping (NTK) systems in order to estimate the likely effect on infringement rates of successive reductions in the current noise limits at each airport.

**Tables C1, C2 and C3** summarise the numbers of actual infringements of the current limits and the infringement rates<sup>53</sup> over a 12-month period for Heathrow, Gatwick and Stansted respectively. At Heathrow, the analysis covers all departure noise measurements for the calendar year 2016. At Gatwick and Stansted the analysis covers measurements over a 12-month period from November 2011 to October 2012<sup>54</sup>. Results are presented

<sup>53</sup> The infringement rate is the number of infringements as a percentage of the total number of monitored departures of a particular aircraft type or group.

<sup>54</sup> An empirical analysis for the 2011-2012 period was initially carried out for all three airports. However, because of the fleet

separately for each monitoring period: day (94 dBA), shoulder (89 dBA) and night (87 dBA). Also shown in each table are the numbers and percentages of departures that also exceed successive 1 dB reductions in the noise limits, down to 5 dB below the current limits.

For each departure, the measured  $L_{Amax}$  noise level has been adjusted to a reference distance of 6.5 km from start-of-roll using the relevant monitor positional and height adjustments (and tailwind allowance where appropriate) given in the UK AIP. The measurement tolerance of 0.7 dBA that is applied to the noise limits by the airports before determining possible infringements has also been accounted for. Thus, the infringement rates shown in **Tables C1, C2 and C3** are considered to be representative of those that would have occurred had the lower noise limit been in effect during the particular measurement period (assuming aircraft were operating in the same way).

The results for Heathrow indicate there is limited scope for reductions in the noise limits until the retirement of the remaining Boeing 747-400 fleet, which is expected to continue operating until 2024. In the meantime however, and noting in **Figure C1** that there were approximately 200 noise infringements recorded at Heathrow each year in 2006 and 2007, a small reduction of 1 to 2 dB in the daytime and shoulder limits might be feasible without causing the overall number of infringements to increase above historic levels.

If a corresponding reduction of 1 to 2 dB was applied to the night time limit at Heathrow, operational changes might be required, even for a relatively modern aircraft such as the A380, in order to mitigate any significant increase in infringement rates.

The results for Gatwick and Stansted on the other hand indicate that the current daytime, shoulder and night limits could be lowered, by up to 3 dB or more in some cases, without significantly impacting the fleets at those airports.

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differences (compared with Heathrow) it was not considered proportionate to update the Gatwick and Stansted results using 2016 data.

**Table C1** Number and percentage of Heathrow departures exceeding certain Reference levels, 2016

## i) Day, 0700-2300

Aircraft Type	Number of departures	94 dBA		93 dBA		92 dBA		91 dBA		90 dBA		89 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	9,591	-	-	-	-	-	-	1	0.0%	1	0.0%	4	0.0%
A319/A320/A321	128,277	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	966	-	-	1	0.1%	3	0.3%	10	1.0%	28	2.9%	73	7.6%
A340-500/600	2,635	-	-	1	0.0%	1	0.0%	3	0.1%	4	0.2%	4	0.2%
A350	352	-	-	-	-	-	-	-	-	-	-	-	-
A380	8,992	-	-	2	0.0%	7	0.1%	13	0.1%	21	0.2%	40	0.4%
B737/B757	10,556	-	-	-	-	-	-	-	-	-	-	-	-
B747-200/300	3	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	9,998	2	0.0%	18	0.2%	91	0.9%	304	3.0%	777	7.8%	1,879	19%
B747-8	58	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	42,084	-	-	-	-	1	0.0%	6	0.0%	11	0.0%	22	0.1%
B787	13,496	-	-	-	-	-	-	-	-	-	-	-	-
Others	2,438	-	-	-	-	-	-	1	0.0%	1	0.0%	1	0.0%

## ii) Shoulder, 2300-2330 and 0600-0700

Aircraft Type	Number of departures	89 dBA		88 dBA		87 dBA		86 dBA		85 dBA		84 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	641	-	-	-	-	-	-	2	0.3%	4	0.6%	9	1.4%
A319/A320/A321	3,536	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	126	10	7.9%	11	9%	21	17%	37	29%	52	41%	74	59%
A340-500/600	62	-	-	1	1.6%	1	1.6%	1	1.6%	2	3.2%	8	13%
A350	3	-	-	-	-	-	-	-	-	-	-	-	-
A380	87	2	2.3%	3	3.4%	3	3.4%	5	5.7%	15	17%	30	34%
B737/B757	626	-	-	-	-	-	-	-	-	-	-	-	-
B747-200/300	-	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	191	6	3.1%	13	6.8%	20	10%	35	18%	44	23%	63	33%
B747-8	1	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	1,187	-	-	1	0.1%	3	0.3%	17	1.4%	53	4.5%	115	10%
B787	218	-	-	-	-	-	-	-	-	-	-	-	-
Others	90	-	-	-	-	-	-	-	-	-	-	-	-

## iii) Night, 2330-0600

Aircraft Type	Number of departures	87 dBA		86 dBA		85 dBA		84 dBA		83 dBA		82 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	61	-	-	-	-	0	0.0%	2	3.3%	6	9.8%	8	13%
A319/A320/A321	105	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	22	4	18%	7	32%	11	50%	15	68%	15	68%	18	82%
A340-500/600	22	-	-	-	-	-	-	1	4.5%	2	9%	7	32%
A350	1	-	-	-	-	-	-	-	-	-	-	-	-
A380	30	1	3.3%	3	10%	10	33%	14	47%	19	63%	22	73%
B737/B757	36	-	-	-	-	-	-	-	-	-	-	1	2.8%
B747-200/300	-	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	57	11	19%	17	30%	20	35%	22	39%	30	53%	39	68%
B747-8	1	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	215	-	-	1	0.5%	7	3.3%	21	10%	59	27%	86	40%
B787	46	-	-	-	-	-	-	-	-	-	-	-	-
Others	7	-	-	-	-	-	-	-	-	-	-	-	-

**Table C2** Number and percentage of Gatwick departures exceeding certain Reference levels, November 2011 to October 2012

i) Day, 0700-2300

Aircraft Type	Number of departures	94 dBA		93 dBA		92 dBA		91 dBA		90 dBA		89 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	3,077	-	-	-	-	-	-	-	-	-	-	-	-
A319/A320/A321	54,342	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	135	-	-	-	-	-	-	-	-	2	1.5%	2	1.5%
A340-500/600	10	-	-	-	-	-	-	-	-	-	-	-	-
A380	1	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	34,057	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	1,835	-	-	-	-	-	-	1	0.1%	4	0.2%	21	1.1%
B767/B777	5,735	-	-	-	-	-	-	-	-	-	-	-	-
MD80	20	-	-	-	-	-	-	-	-	-	-	-	-
Others	14,254	-	-	-	-	-	-	-	-	-	-	-	-

ii) Shoulder, 2300-2330 and 0600-0700

Aircraft Type	Number of departures	89 dBA		88 dBA		87 dBA		86 dBA		85 dBA		84 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	126	-	-	-	-	-	-	-	-	-	-	-	-
A319/A320/A321	6,304	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	10	-	-	1	10%	2	20%	2	20%	3	30%	3	30%
A340-500/600	-	-	-	-	-	-	-	-	-	-	-	-	-
A380	-	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	1,691	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	-	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	76	-	-	-	-	-	-	-	-	-	-	-	-
MD80	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	46	-	-	-	-	-	-	-	-	-	-	-	-

iii) Night, 2330-0600

Aircraft Type	Number of departures	87 dBA		86 dBA		85 dBA		84 dBA		83 dBA		82 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	42	-	-	-	-	-	-	-	-	-	-	-	-
A319/A320/A321	839	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	14	1	7.1%	1	7.1%	2	14%	5	36%	6	43%	8	57%
A340-500/600	-	-	-	-	-	-	-	-	-	-	-	-	-
A380	-	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	300	-	-	-	-	-	-	-	-	-	-	1	0.3%
B747-400	-	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	30	-	-	-	-	-	-	-	-	-	-	-	-
MD80	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	73	-	-	-	-	-	-	-	-	-	-	-	-

**Table C3** Number and percentage of Stansted departures exceeding certain Reference levels, November 2011 to October 2012

i) Day, 0700-2300

Aircraft Type	Number of departures	94 dBA		93 dBA		92 dBA		91 dBA		90 dBA		89 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	218	-	-	-	-	-	-	-	-	-	-	-	-
A319/A320/A321	14,651	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	14	-	-	-	-	-	-	-	-	-	-	-	-
A340-500/600	2	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	37,535	-	-	-	-	-	-	-	-	-	-	-	-
B747-200/300	22	-	-	-	-	-	-	-	-	-	-	2	9.1%
B747-400	364	-	-	-	-	1	0.3%	3	0.8%	5	1.4%	10	2.7%
B747-8	450	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	677	-	-	-	-	-	-	-	-	-	-	-	-
MD11	662	-	-	-	-	-	-	-	-	-	-	-	-
MD80	5	-	-	-	-	-	-	-	-	-	-	-	-
Others	3,410	-	-	1	0.0%	2	0.1%	3	0.1%	4	0.1%	7	0.2%

ii) Shoulder, 2300-2330 and 0600-0700

Aircraft Type	Number of departures	89 dBA		88 dBA		87 dBA		86 dBA		85 dBA		84 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	10	-	-	-	-	-	-	-	-	-	-	-	-
A319/A320/A321	1,108	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	-	-	-	-	-	-	-	-	-	-	-	-	-
A340-500/600	-	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	5,265	-	-	-	-	-	-	-	-	-	-	-	-
B747-200/300	1	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	13	1	8%	1	7.7%	1	7.7%	4	31%	5	38%	5	38%
B747-8	6	-	-	-	-	-	-	-	-	-	-	-	-
B767/B777	271	-	-	-	-	-	-	-	-	-	-	-	-
MD11	9	1	11%	1	11%	1	11%	1	11%	1	11%	3	33%
MD80	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	303	-	-	-	-	-	-	-	-	1	0.3%	1	0.3%

iii) Night, 2330-0600

Aircraft Type	Number of departures	87 dBA		86 dBA		85 dBA		84 dBA		83 dBA		82 dBA	
		N	%	N	%	N	%	N	%	N	%	N	%
A300/A330	260	-	-	-	-	-	-	-	-	-	-	1	0.4%
A319/A320/A321	111	-	-	-	-	-	-	-	-	-	-	-	-
A340-200/300	1	-	-	-	-	-	-	-	-	1	100%	1	100%
A340-500/600	-	-	-	-	-	-	-	-	-	-	-	-	-
B737/B757	1,304	-	-	-	-	-	-	-	-	-	-	-	-
B747-200/300	-	-	-	-	-	-	-	-	-	-	-	-	-
B747-400	3	-	-	-	-	-	-	-	-	-	-	-	-
B747-8	63	-	-	-	-	-	-	1	1.6%	1	1.6%	7	11%
B767/B777	109	-	-	-	-	-	-	-	-	-	-	-	-
MD11	55	-	-	3	5.5%	14	25%	22	40%	36	65%	42	76%
MD80	-	-	-	-	-	-	-	-	-	-	-	-	-
Others	456	1	0.2%	1	0.2%	2	0.4%	2	0.4%	2	0.4%	2	0.4%

## APPENDIX D

# Variation of departure tracks caused by different interpretations of conventional routes

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## Background

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Over recent years there has been considerable focus on future airspace modernisation, particularly in relation to the replacement of conventional Standard Instrument Departures (SIDs) with PBN designs. For example, in November 2013 the conventional departure SIDs from Gatwick Airport were replicated with RNAV SID designs. In addition, during 2013 and 2014 a number of temporary departure trials were undertaken across all three London airports to test PBN design procedures. A number of these trials involved newly designed SID route structures that resulted in aircraft overflying new areas, causing a significant rise in complaints from local communities in some instances.

Since the trials were terminated, local communities have claimed that some of the conventional departure routes either did not revert to their original designs or that the distribution of flights on some routes has changed subsequently.

Whilst changes in weather conditions, aircraft type, take-off weight and magnetic variation can all cause a noticeable shift in the distribution of flights over the ground, different airline interpretations of the conventional departure route centreline, as programmed into the coded RNAV 'overlay' procedures which are loaded into an aircraft's Flight Management System (FMS), can also be a factor.

A coded overlay is a conventional instrument procedure that has been interpreted by a commercial aeronautical navigation database provider (a 'Coding House'), contracted to the airlines, and a coding produced for loading into the aircraft's FMS. A coded overlay falls outside of the CAA's regulatory oversight.

Whilst the CAA regulates the design of Instrument Flight Procedures (IFP) up to their notification in the UK AIP, their transposition into an FMS coding table is the responsibility of an airline operator. The operators commercially employ, in accordance with their own quality management systems, Coding Houses to take the regulated information in the UK AIP and turn it into something their aircraft FMS can use. In endeavouring to replicate the conventional procedure design, the FMS coding can be subtly different according to the airline's operational procedures and aircraft types.

Track changes caused by changes in the coded overlays may not always be detected by the airports' flight monitoring systems if they are contained within the boundaries of the NPR swathes, but they may be noticeable to residents under the flight paths.

## Variation of departure track by airline

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**Figure D1** presents the ground tracks of all easterly Midhurst departures at Heathrow between 1 April and 30 June 2016 in relation to the route centreline and NPR monitoring swathe. Also shown in **Figure D1** is the location of a theoretical 3 km-wide vertical gate, which has been positioned across the NPR swathe at a point where most aircraft will have completed their initial turn to the south-west.

**Figure D2** shows the positions of all easterly Midhurst departures that passed through the gate during that period. The vertical axis in the gate plot is aircraft height in feet above runway level, and the horizontal axis is the distance in metres from the route centre, as viewed in the direction of travel. **Figures D3 and D4** present equivalent data for the period 1 July to 31 October 2016.

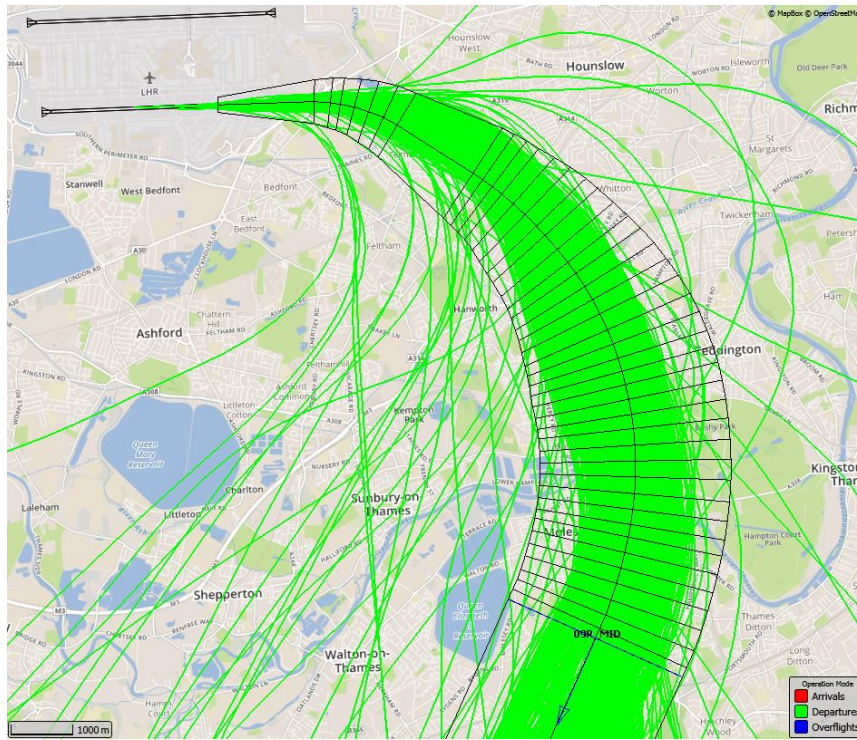
It is apparent from these plots that a marked change in the lateral distribution for some flights on the easterly Midhurst route occurred at some point between June and July 2016. Further investigation has shown that the change occurred for some airlines and aircraft types but not for others<sup>55</sup>.

For example, **Figures D5, D6 and D7** compare the gate plots for three different airlines that each operate a different aircraft type along this particular route. In each case a track displacement of approximately 800 m is apparent. **Figure D8** on the other hand shows equivalent data for the dominant home-based carrier that exhibits no such change.

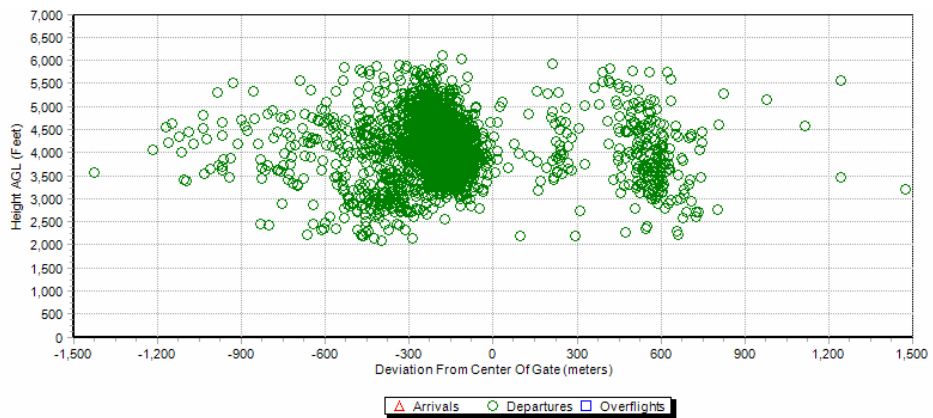
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<sup>55</sup> A review of the Midhurst SID chart in the UK AIP (AD 2-EGLL-6-2) indicates that the SID instruction did not change in 2016.

**Figure D1** Heathrow easterly Midhurst departures  
1 April to 30 June 2016

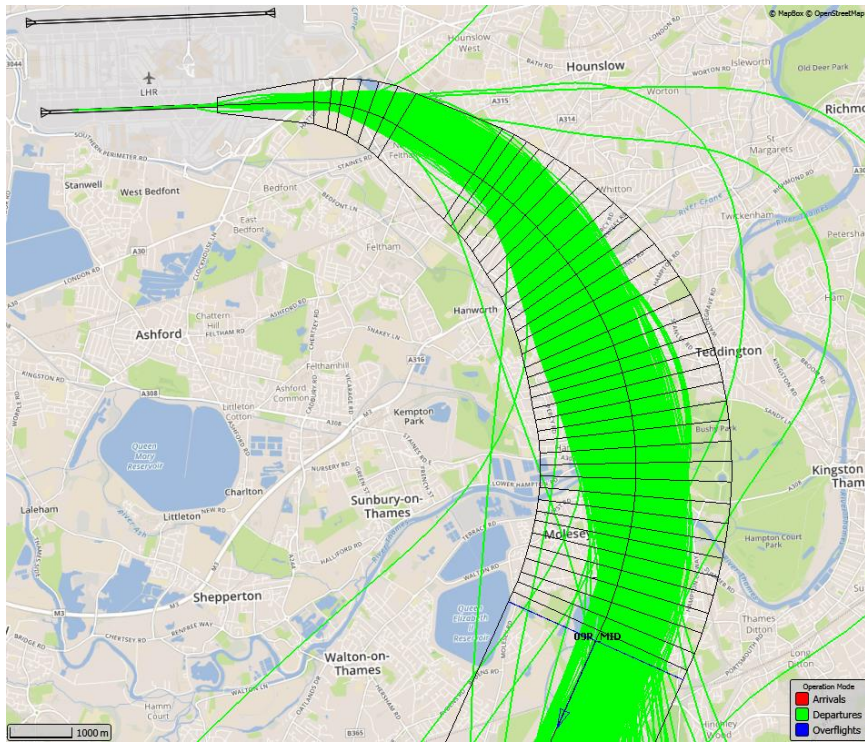


**Figure D2** Gate plot of all easterly Midhurst departures  
1 April to 30 June 2016

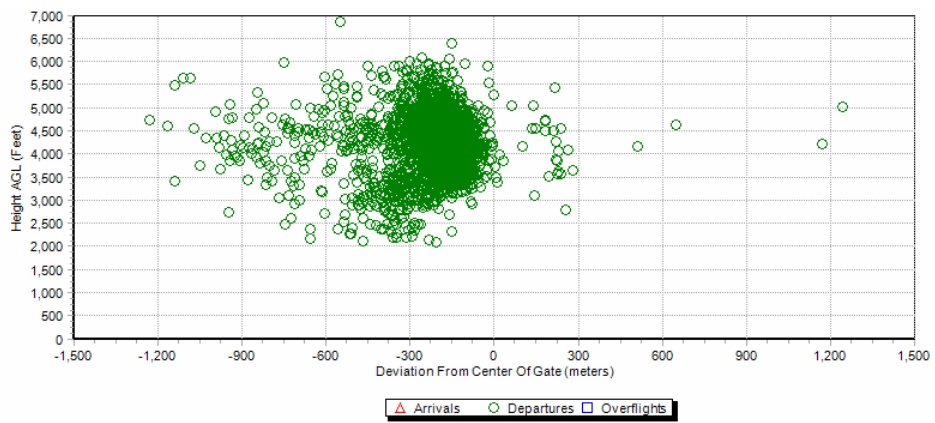




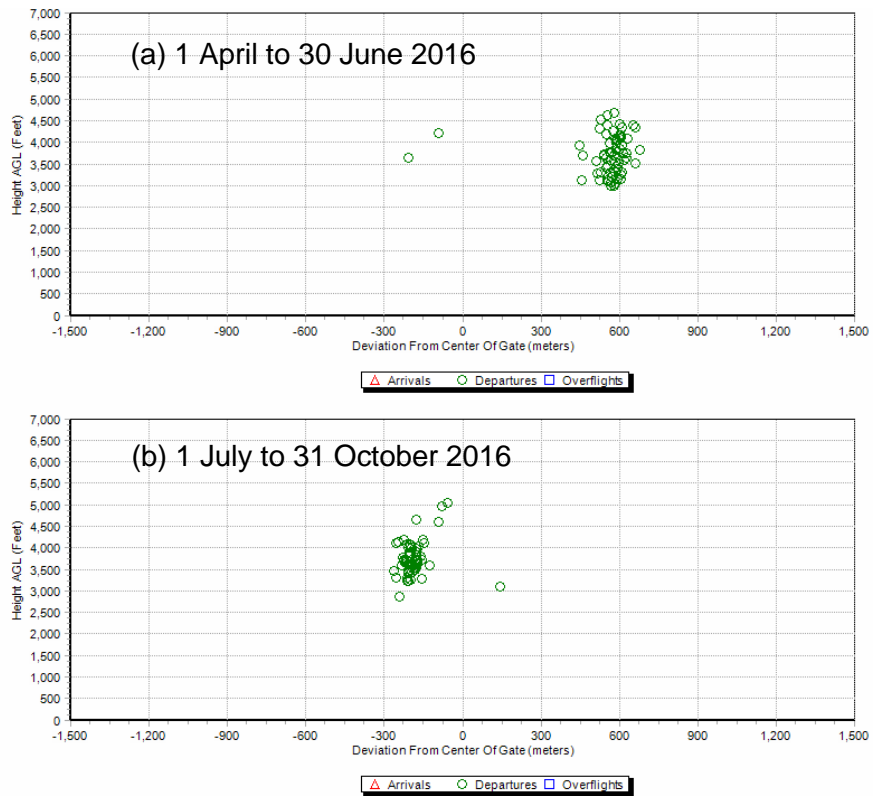
**Figure D3** Heathrow easterly Midhurst departures  
1 July to 31 October 2016



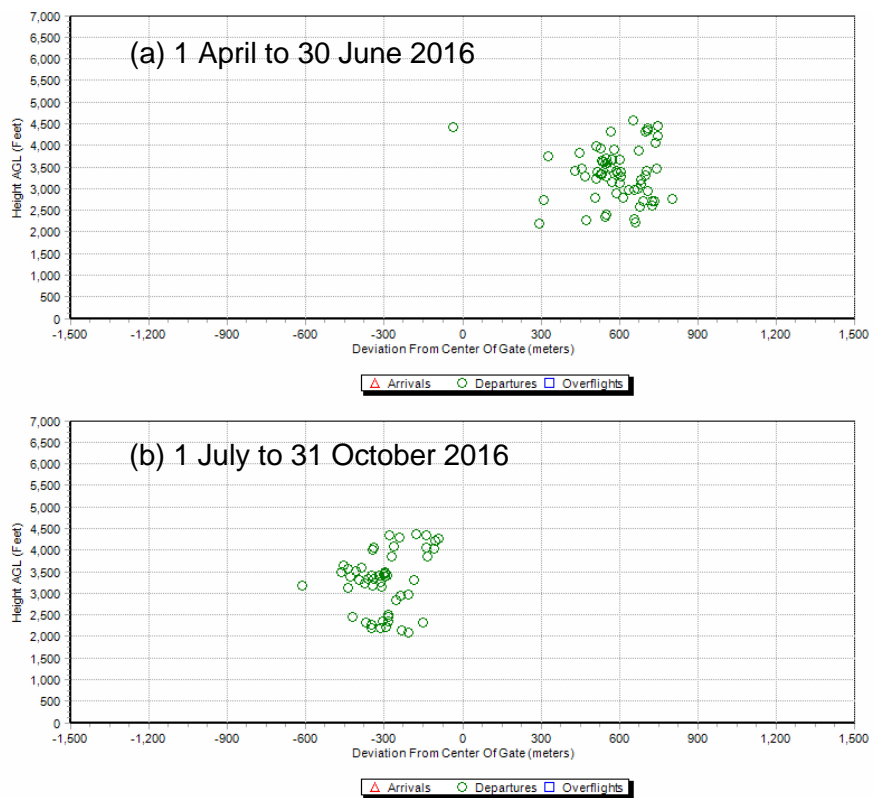
**Figure D4** Gate plot of all easterly Midhurst departures  
1 July to 31 October 2016



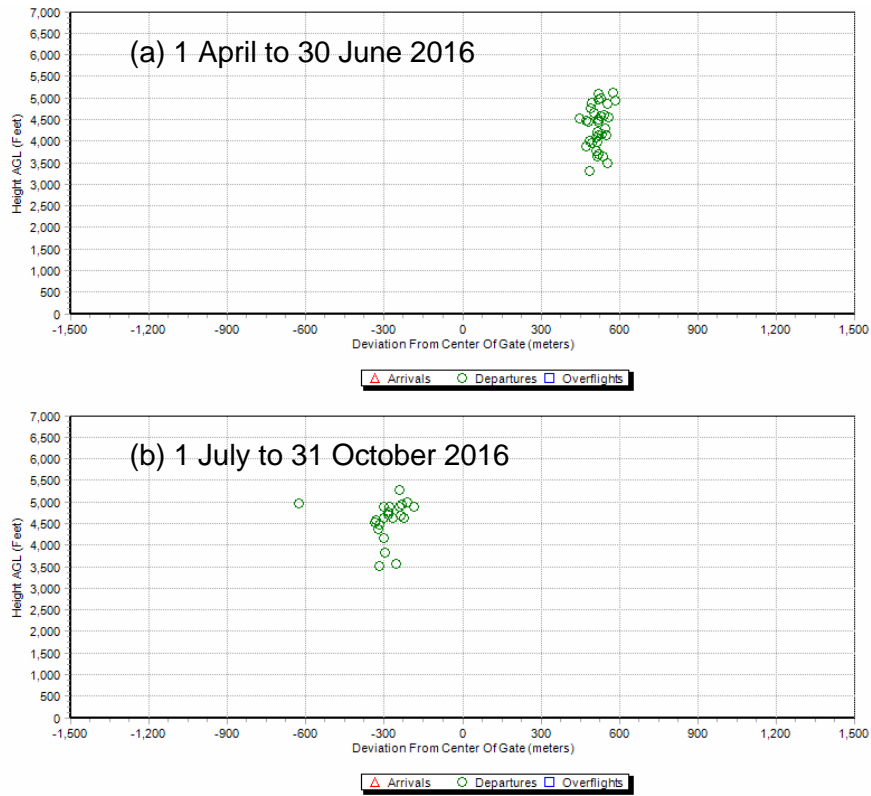
**Figure D5** Gate plot of AMC A319/A320 easterly Midhurst departures



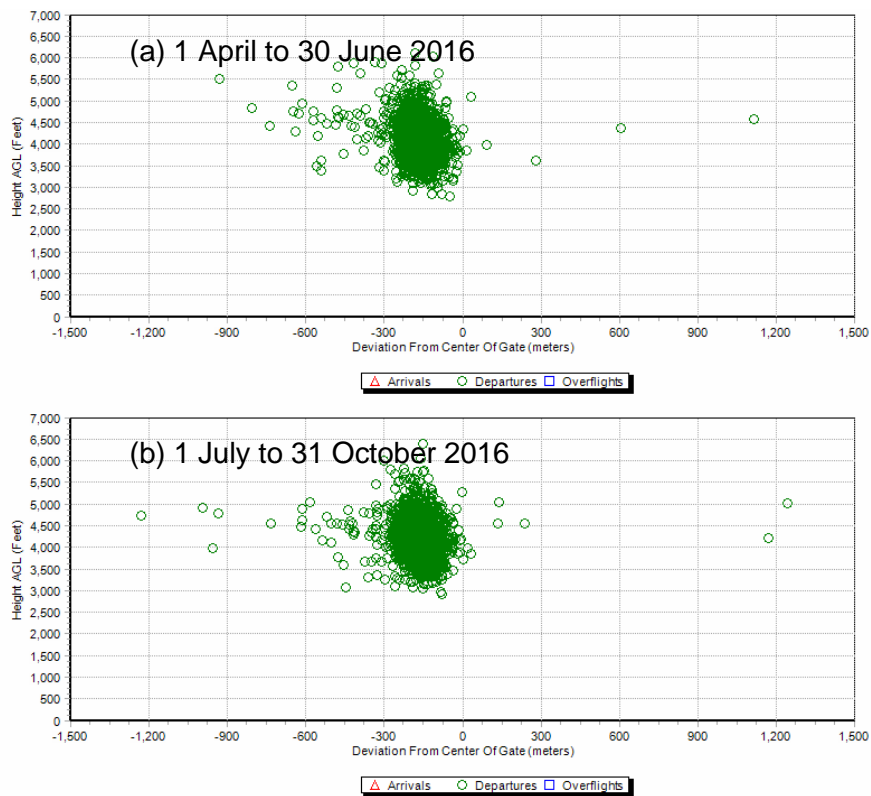
**Figure D6** Gate plot of SAA A330/A340 easterly Midhurst departures



**Figure D7** Gate plot of SVA B777 easterly Midhurst departures



**Figure D8** Gate plot of BAW A319/A320/A321 easterly Midhurst departures



## APPENDIX E

# NADP case studies

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## Introduction

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To study the effects of different Noise Abatement Departure Procedures on noise, local air quality (NO<sub>x</sub>) and CO<sub>2</sub>, a number of procedures have been modelled for the Airbus A380 which, following the retirement of the Boeing 747-400, is expected to be one of the noisiest aircraft types in regular airline service.

The analysis includes comparisons of reduced thrust departure procedures (which are intended to represent normal airline operation), full thrust procedures and also a 'deep cutback' (of climb power) procedure to assess the extent of any possible noise reductions.

A similar but more limited analysis was also carried out for the Airbus A320, Boeing 737-800 and Boeing 777-300ER to cover common narrow and wide-body twin-engine types in current use.

Flight profiles for each procedure were generated using data taken from the ICAO Aircraft Noise and Performance (ANP) database<sup>56</sup>. Performance Limited Take-off Weights were also used to take account of the aircraft performance at the reduced take-off weights and thrusts applicable to stage lengths typically flown (in nautical miles) from the London airports.

## Noise validation

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Before the noise modelling could be undertaken for the A380 it was first necessary to validate the CAA aircraft noise model through a detailed analysis of flight tracks, flight profiles and noise measurements for summer 2017 operations. SEL and L<sub>Amax</sub> noise events were extracted from the Heathrow Noise and Track Keeping System and the noise model parameters were then adjusted to obtain a good correlation between the noise predictions and measurements.

The validation exercise was based on data from an array of 15 noise monitors positioned along the easterly Detling route between approximately 6.5 and 16 km from start of roll<sup>57</sup>. A similar validation exercise was also carried out for the B777-300ER using Heathrow data, and for the A320 and B737-800 using data from Gatwick and Stansted.

The A380 validation exercise was carried out separately for Emirates middle east (3,000 NM stage length) and Malaysia/Singapore far east departures (>5,500 NM stage

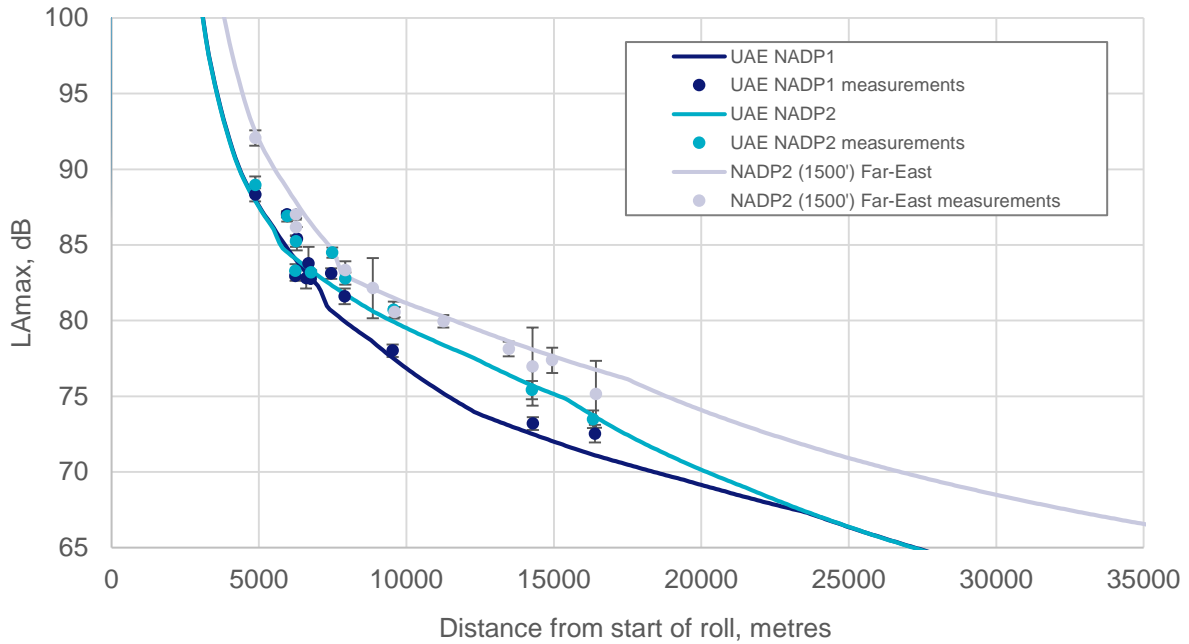
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<sup>56</sup> <https://www.aircraftnoisemodel.org/>

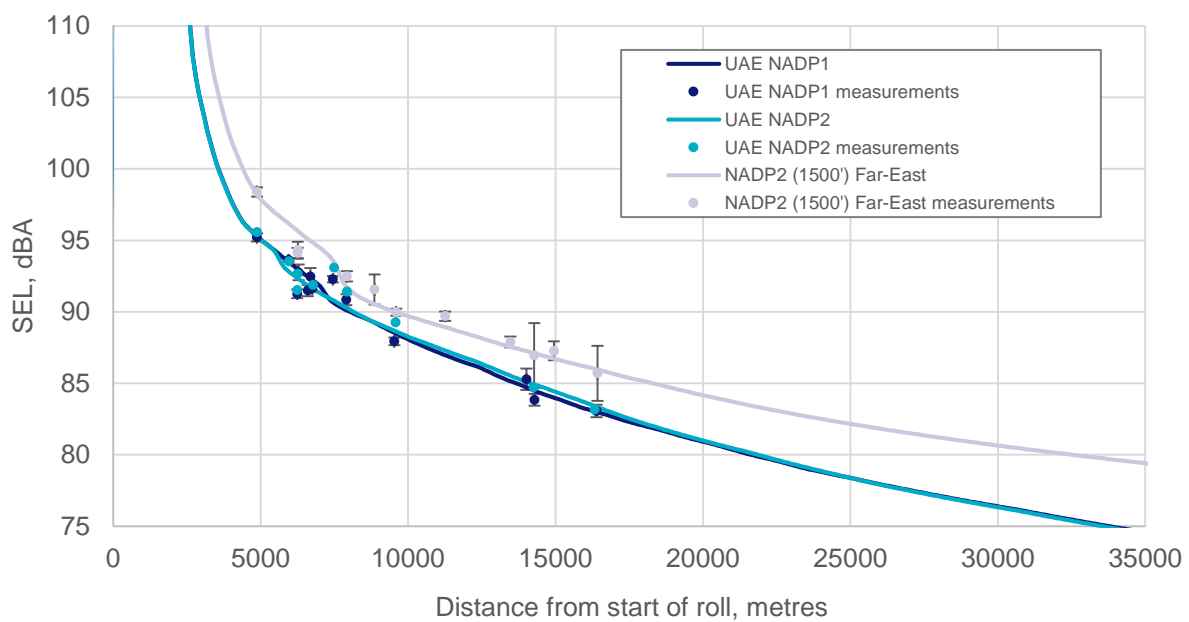
<sup>57</sup> CAP 1149, *Noise monitor positions at Heathrow, Gatwick and Stansted Airports*, Civil Aviation Authority, May 2018

length), see **Figures E1 and E2**. Emirates data were used because the airline operates both NADP 1 and NADP 2 departures from Heathrow and their measurements therefore serve as a useful dataset for validation of both types of procedure at similar take-off weights. Malaysia and Singapore airlines were selected because they fly similar stage lengths and both operate a similar NADP 2 type procedure (with an acceleration and climb thrust altitude of 1,500 feet, based on visual inspection of their height profiles).

**Figure E1**  $L_{Amax}$  noise validation for the A380 at Heathrow



**Figure E2** SEL noise validation for the A380 at Heathrow



## A380 case study

### Effect of A380 departure procedure on noise level

Two common (baseline) departure procedures for A380 operators at Heathrow are:

- Reduced thrust NADP 2, with an acceleration and thrust reduction altitude of 1,000 feet, and
- Reduced thrust NADP 2, with an acceleration and thrust reduction altitude of 1,500 feet.

The A380 noise assessment has therefore focussed on changing from a baseline NADP 2 procedure to an alternative procedure that would be expected to achieve a reduction in the maximum noise level recorded at the 6.5 km noise monitor.

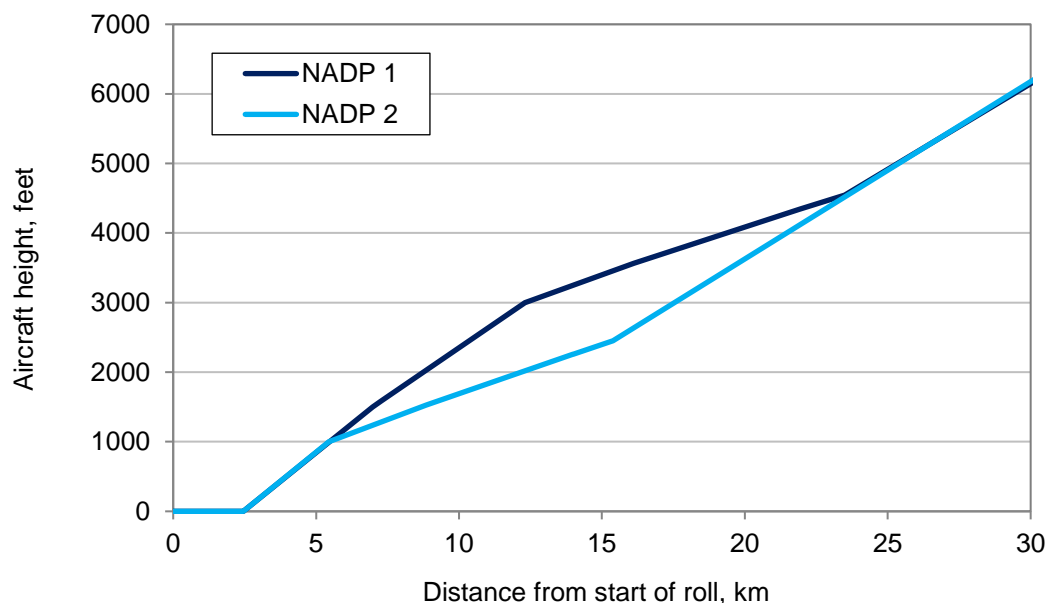
This could be achieved either by increasing the aircraft height over the monitor (by switching to NADP 1 or full thrust NADP 2) or by reducing the engine power to a minimum climb setting before the aircraft passes over the monitor (implementing a 'deep cutback' to climb power). **Table E1** summarises the four specific case studies investigated.

**Table E1** Assessment of A380 Noise Abatement Departure Procedures

Case Study	Baseline procedure	Alternative procedure	Stage length
1	Reduced thrust NADP 2 (1,000 ft)	Reduced thrust NADP 1 (1,500 ft)	3,000 NM
2	Reduced thrust NADP 2 (1,000 ft)	Reduced thrust NADP 2 with deep cutback (1,000 ft)	3,000 NM
3	Reduced thrust NADP 2 (1,000 ft)	Full thrust NADP 2 (1,000 ft)	3,000 NM
4	Reduced thrust NADP 2 (1,500 ft)	Full thrust NADP 2 (1,500 ft)	>5,500 NM

The NADP 2 (baseline) and NADP 1 (alternative) height profiles for case study 1 are shown for comparison in **Figure E3**.

**Figure E3** A380 height profiles, case study 1 (3,000 NM stage length)



The modelled noise level differences for case study 1 are presented in **Figures E4 and E5** for  $L_{Amax}$  and SEL respectively. These diagrams show the areas within the noise footprint<sup>58</sup> for a nominal 'straight-out' departure that experience a change in noise level as a result of the procedure change. Increases or decreases ( $\pm$ ) of less than 1 dB are not shown. The change in the  $L_{Amax}$  level (of -0.3 dB) at 6.5 km is also shown in **Figure E4**.

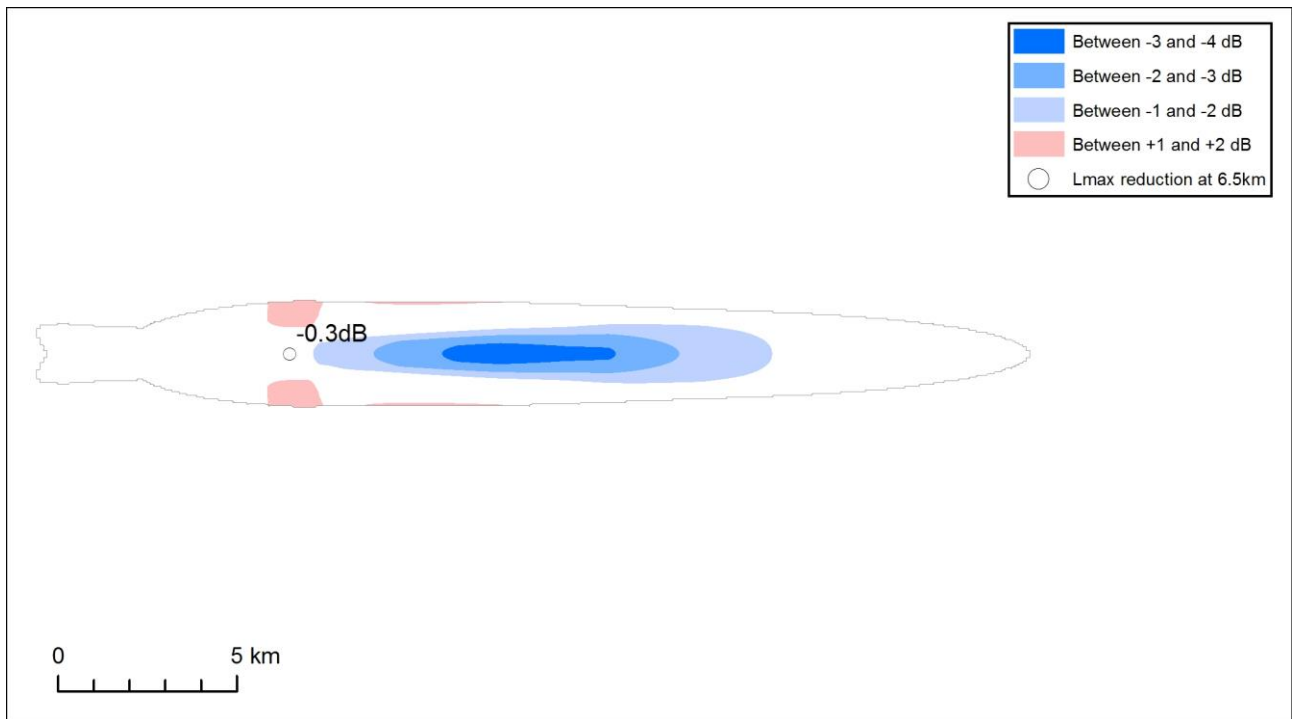
Due to recent focus of the Heathrow Community Noise Forum<sup>59</sup> on particular A380 operations, **Figures E6 and E7** present the same results for case study 1 overlaid on the easterly Detling route. The number of households and population within each noise region are also shown. Whilst the  $L_{Amax}$  results show an overall noise benefit along the centre of the route relatively close to the airport going from NADP 2 to NADP 1 (due mainly to the increase in height over the ground), the SEL results only show areas of increased noise to the sides of the flight path (albeit at lower absolute noise levels).

Although this result may seem counterintuitive, it can be explained by the longer noise duration caused by the NADP 1 procedure (because the aircraft speed is held until reaching 3,000 feet), and also by the difference in the way noise propagates to the side of the flight path as aircraft height increases (noise is attenuated more rapidly at lower angles of elevation).

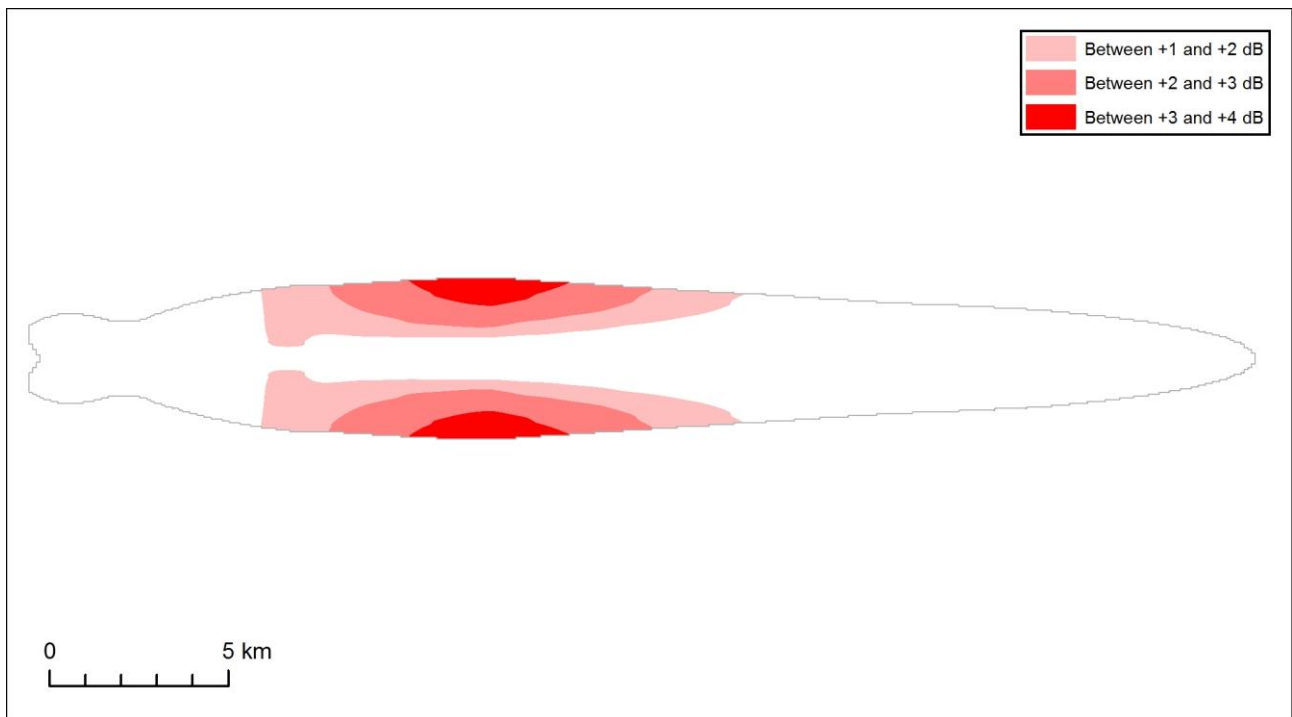
<sup>58</sup> Noise level differences for levels below 65 dB  $L_{Amax}$  or 75 dBA SEL are not shown.

<sup>59</sup> <https://www.heathrow.com/noise/heathrow-community-noise-forum> (accessed 9 July 2018)

**Figure E4** A380  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 3,000 NM stage length

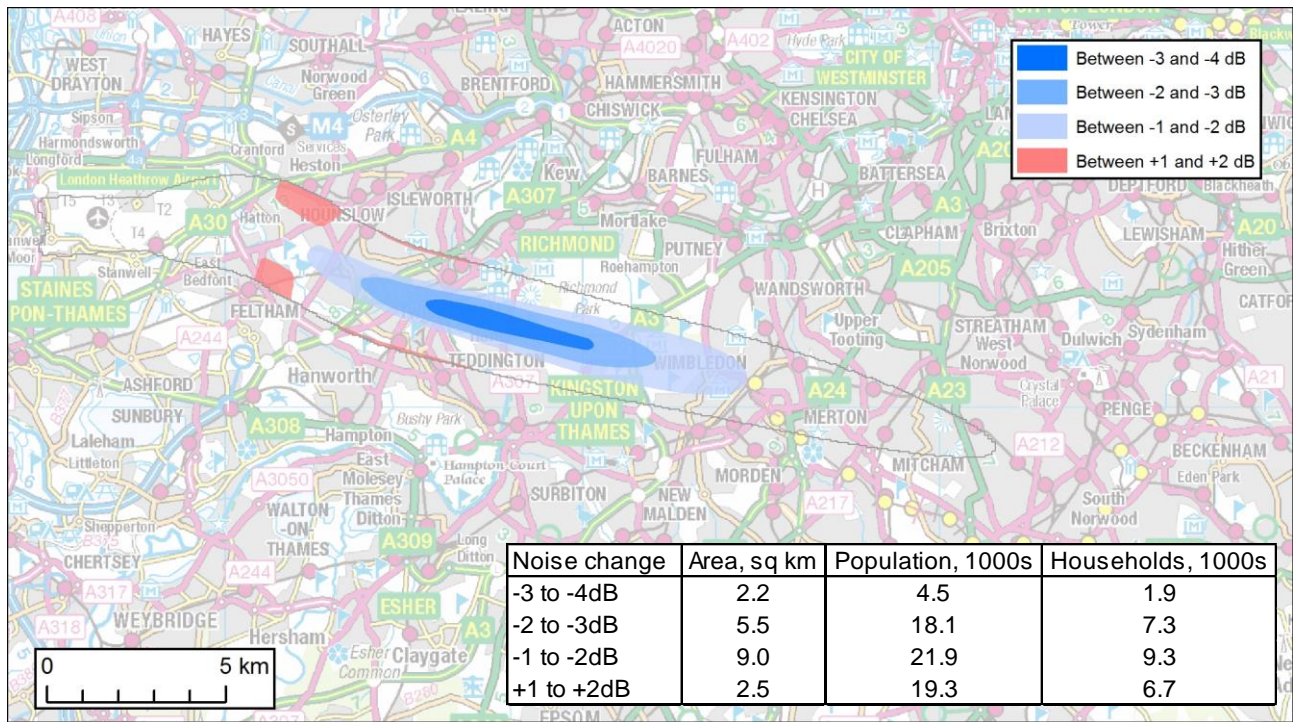


**Figure E5** A380 SEL noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 3,000 NM stage length



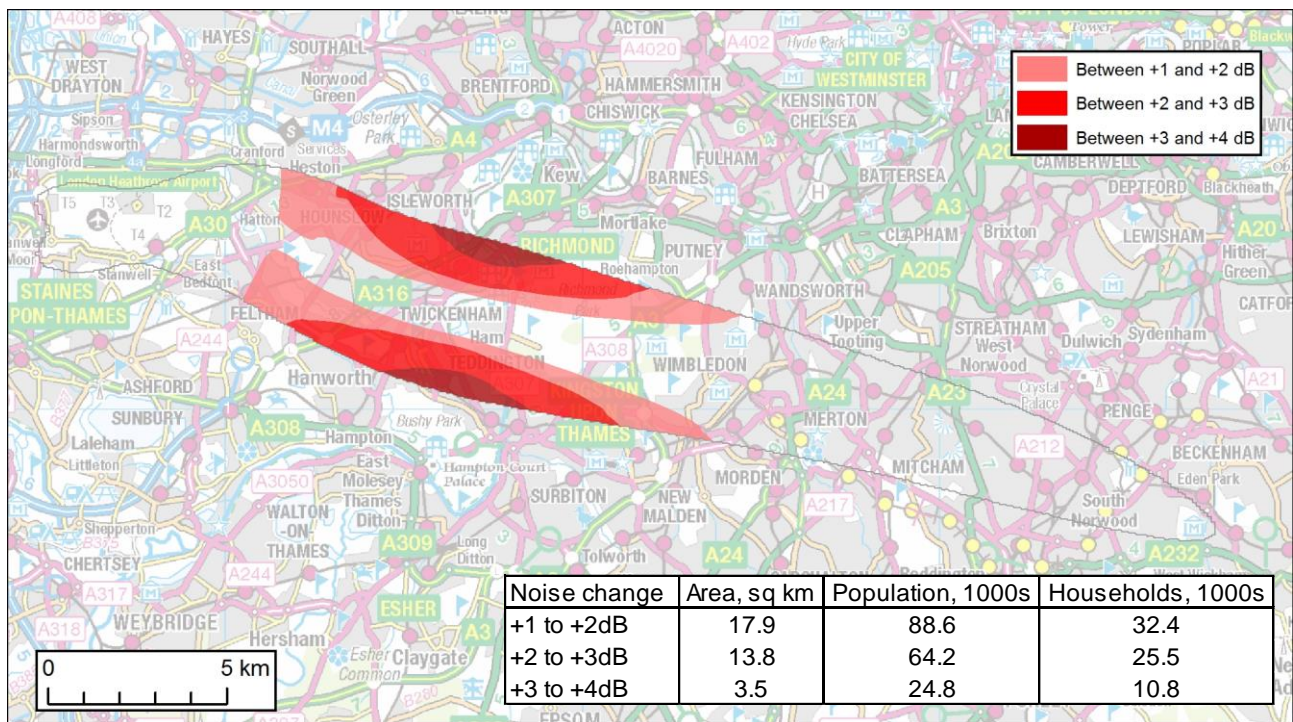


**Figure E6** A380  $L_{max}$  noise differences on easterly Detling route for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 3,000 NM stage length



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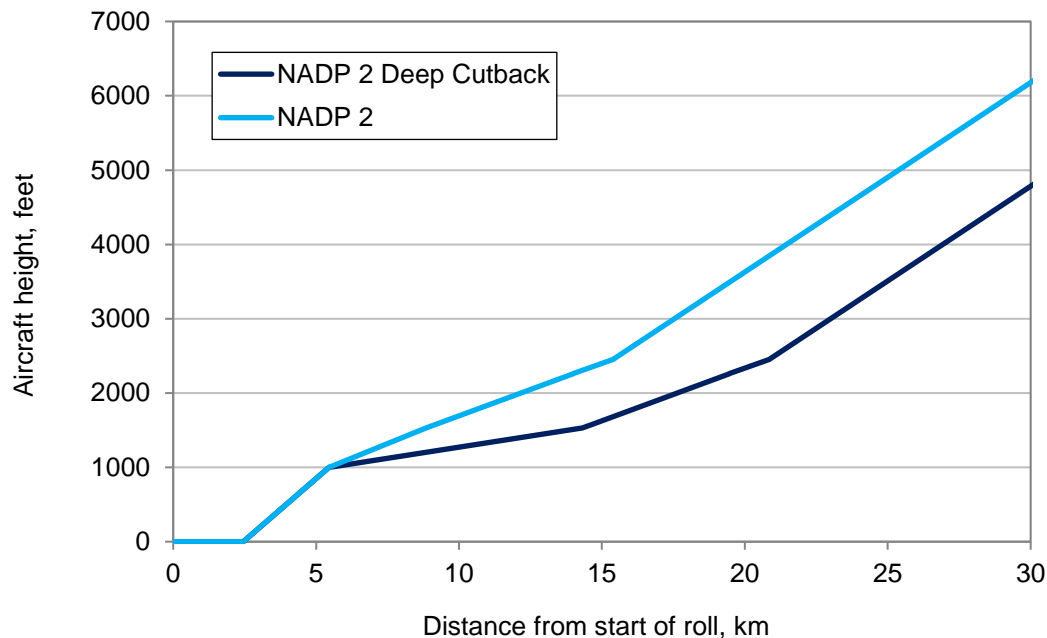
**Figure E7** A380 SEL noise differences on easterly Detling route for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 3,000 NM stage length



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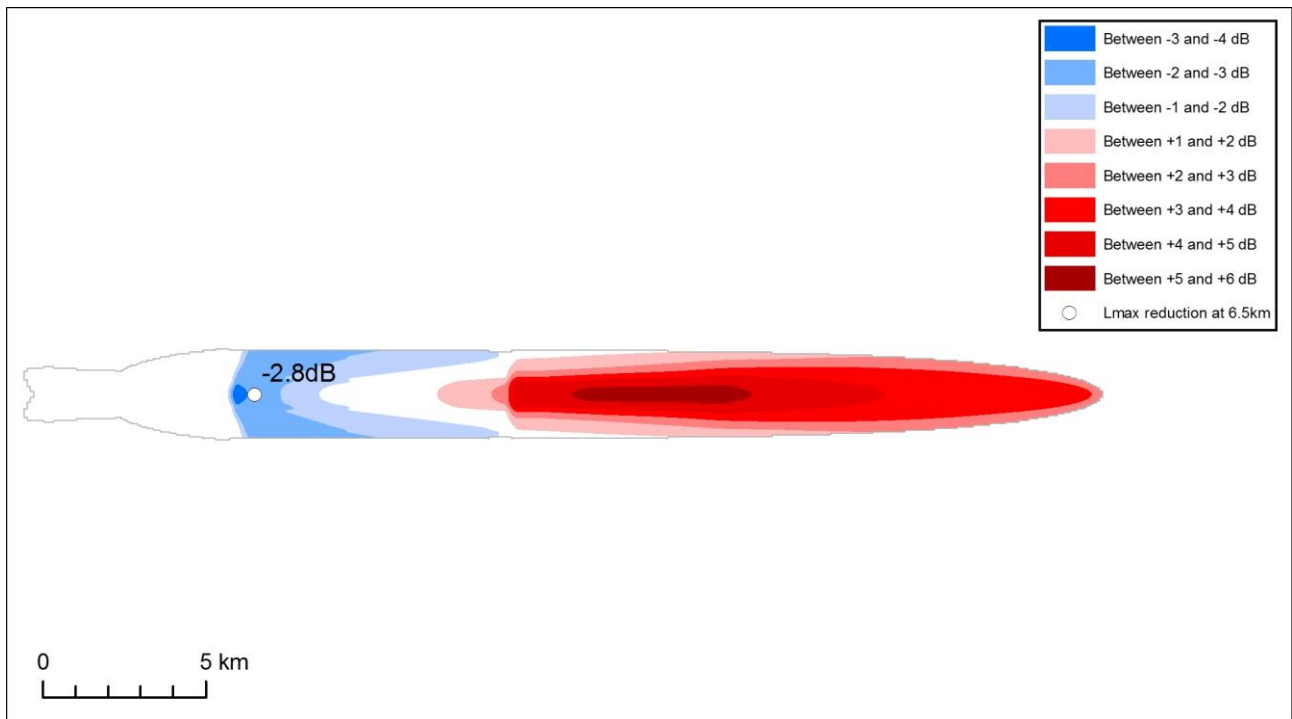
The NADP 2 (baseline) and NADP 2 with deep cutback (alternative) height profiles for case study 2 are shown in **Figure E8**.

**Figure E8** A380 height profiles, case study 2 (3,000 NM stage length)

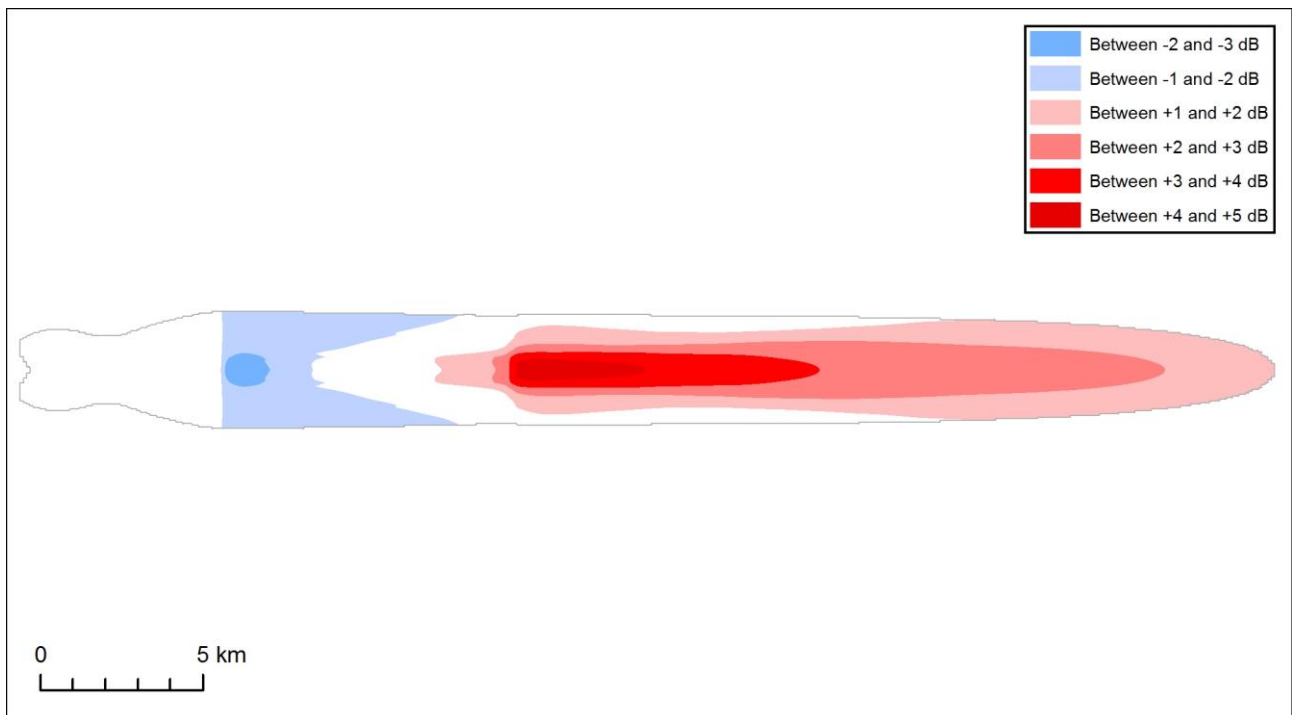


**Figures E9 and E10** present the modelled noise level differences for case study 2, which includes a deep cutback to a reduced climb power setting at a height of 1,000 feet, resulting in a larger reduction of  $L_{Amax}$  (-2.8 dB) at 6.5 km compared to the previous example. Although greater noise reductions are achieved closer in compared to case study 1, there are significant noise increases further along the route caused by the lower height of the aircraft over the ground.

**Figure E9** A380  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 2 with deep cutback (1,000 ft), 3,000 NM

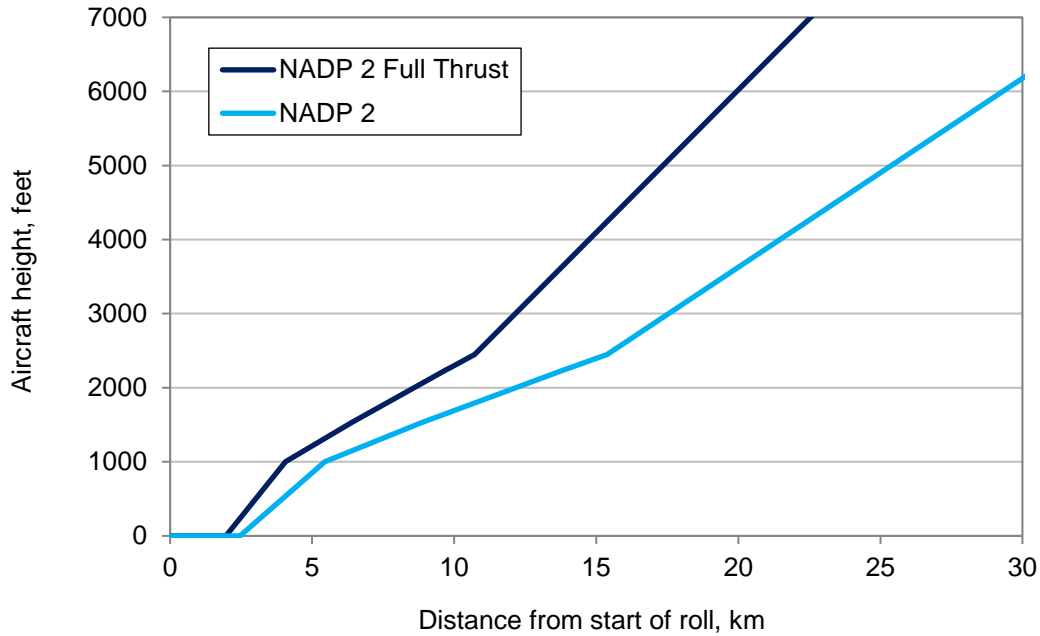


**Figure E10** A380 SEL noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 2 with deep cutback (1,000 ft), 3,000 NM

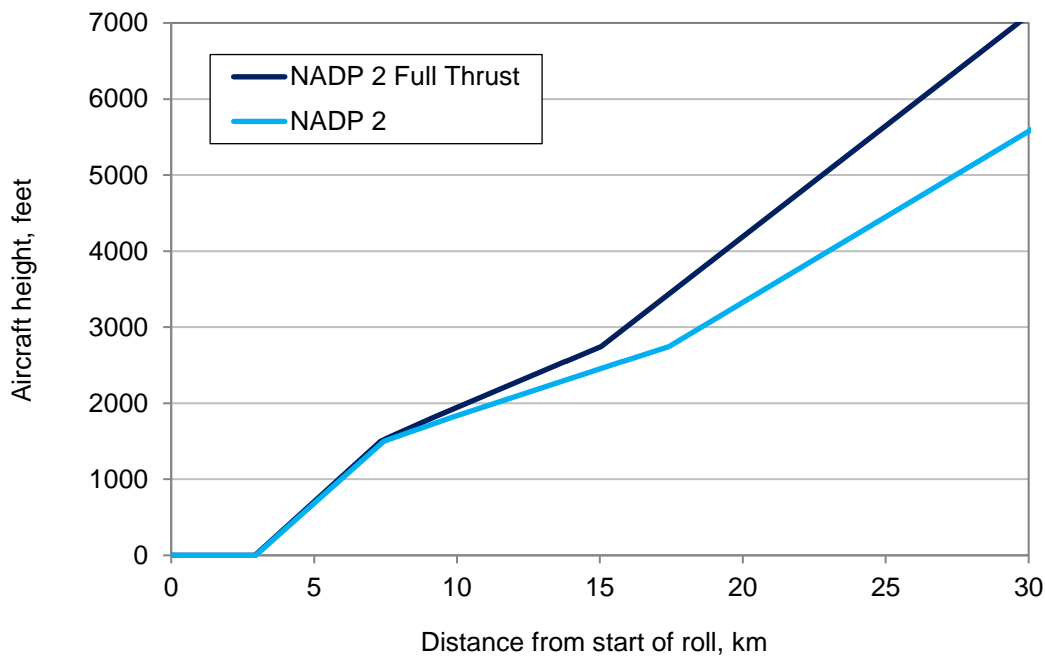


The NADP 2 (baseline) and full thrust NADP 2 (alternative) height profiles for case studies 3 and 4 are shown in **Figures E11 and E12** respectively.

**Figure E11** A380 height profiles, case study 3 (3,000 NM stage length)

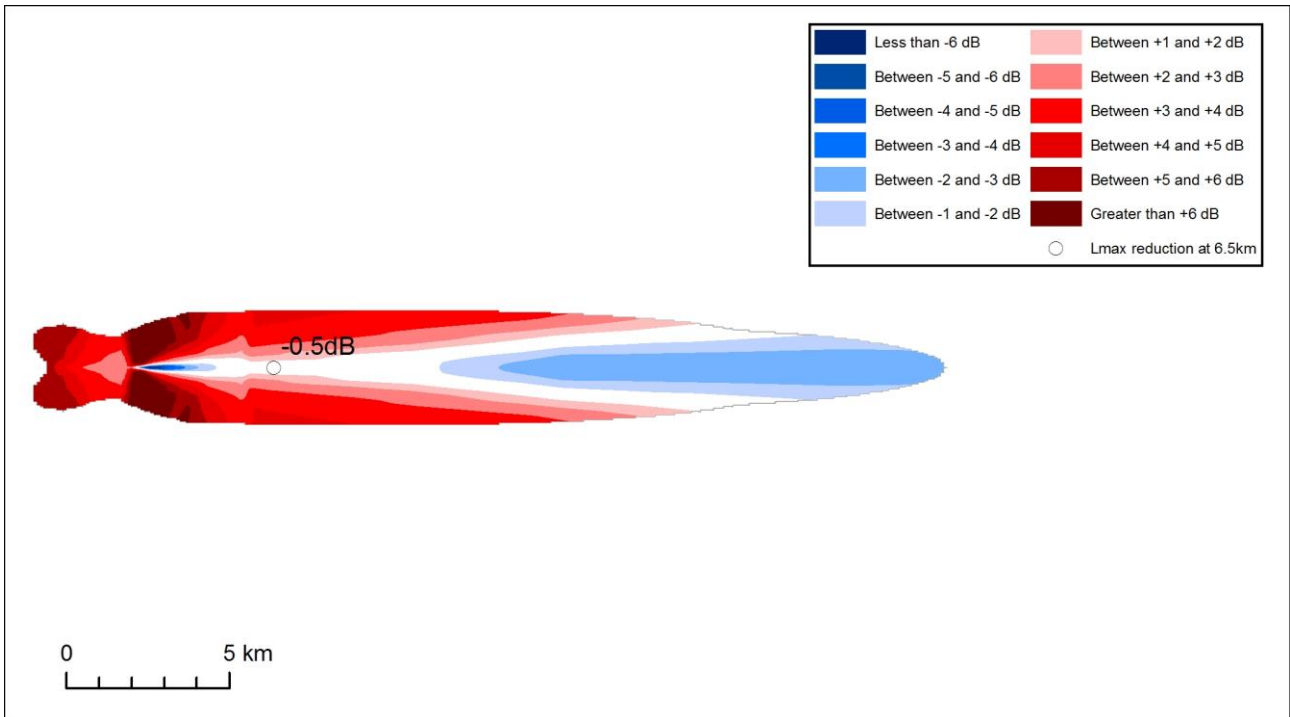


**Figure E12** A380 height profiles, case study 4 (>5,500 NM stage length)

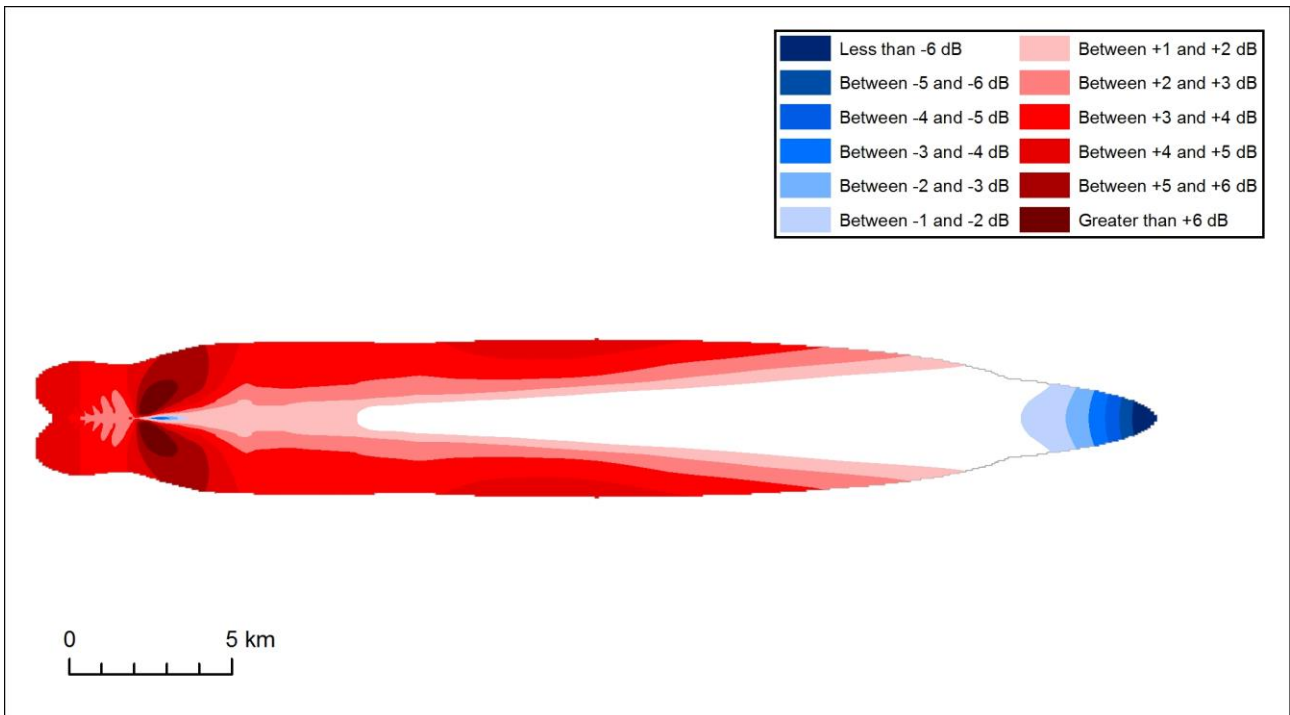


The results for case studies 3 and 4 in **Figures E13 to E16** show that whilst a slight reduction in  $L_{Amax}$  level close to the 6.5 km location (and also underneath the flight path further along the route) may be achieved by using full thrust on take-off rather than reduced thrust (causing the aircraft to be higher over the ground), there are large areas to the side of the flight path that would experience an increase in noise. Again, these increases are due mainly to the difference in the way noise propagates to the side of the flight path as aircraft height increases (noise is attenuated more rapidly at lower angles of elevation).

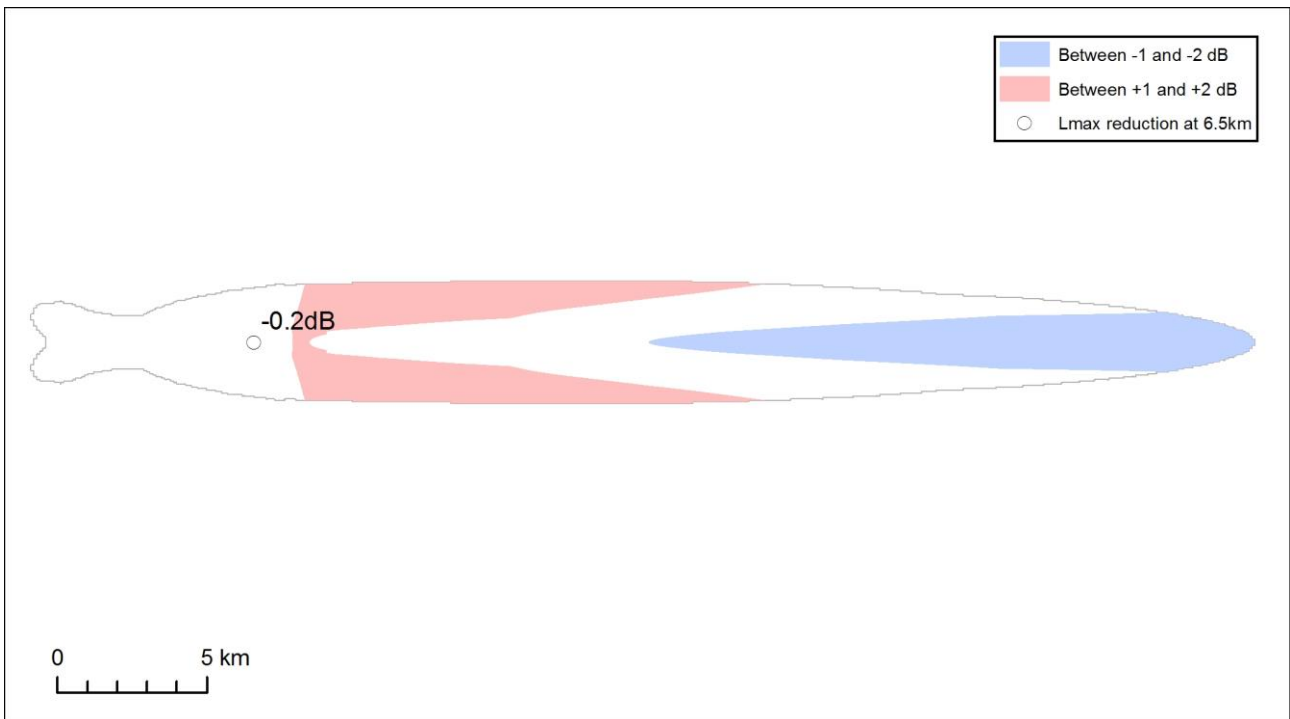
**Figure E13** A380  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft) vs. full thrust NADP 2 (1,000 ft), 3,000 NM



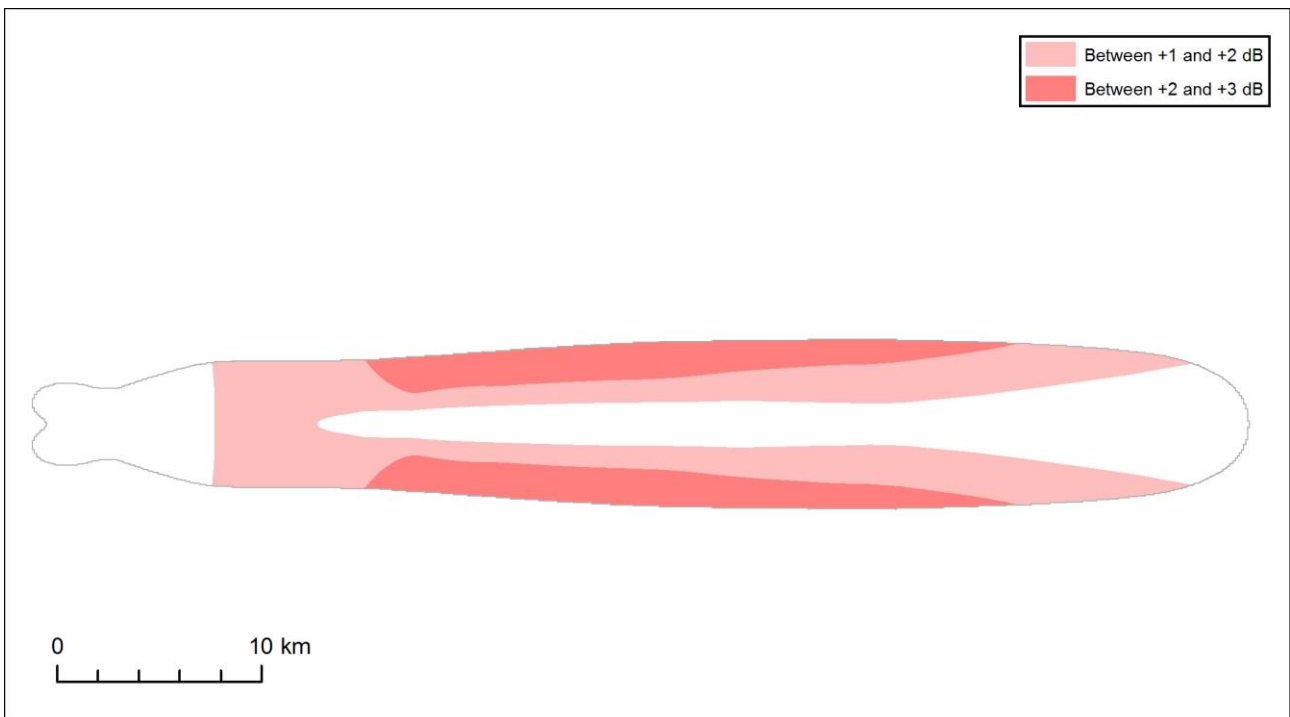
**Figure E14** A380 SEL noise differences for reduced thrust NADP 2 (1,000 ft) vs. full thrust NADP 2 (1,000 ft), 3,000 NM



**Figure E15** A380  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,500 ft) vs. full thrust NADP 2 (1,500 ft), >5,500 NM



**Figure E16** A380 SEL noise differences for reduced thrust NADP 2 (1,500 ft) vs. full thrust NADP 2 (1,500 ft), >5,500 NM



## Effect of A380 departure procedure on noise event duration

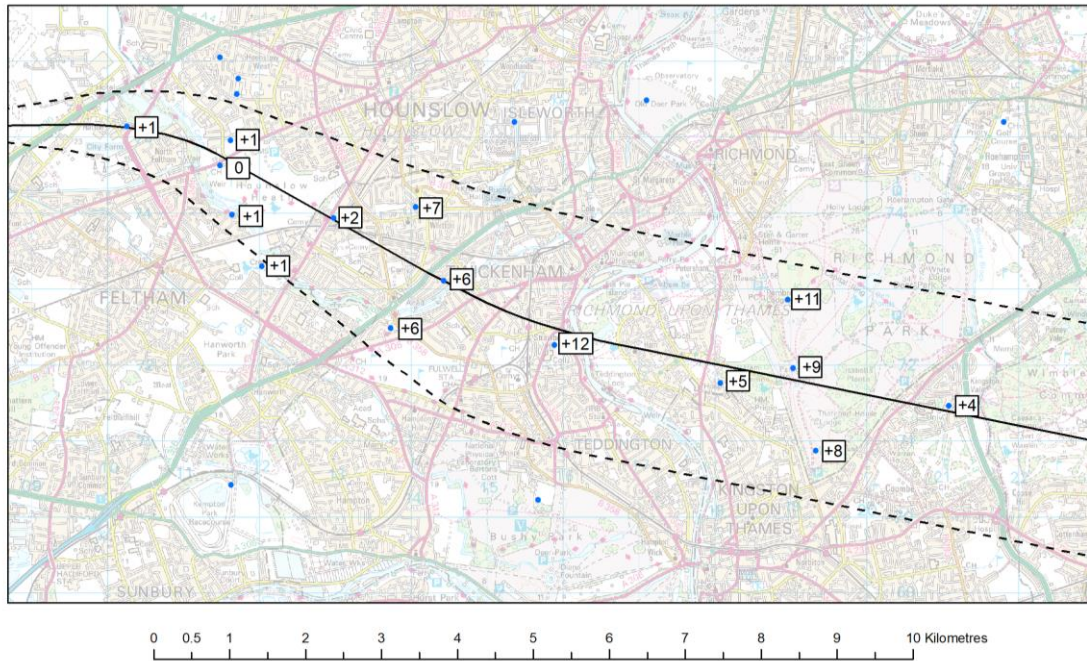
It is currently not possible to model the duration of noise events with sufficient accuracy. Instead, to assess possible changes in the duration of events due to a change in procedure (that in turn causes a change in the speed of the aircraft over the ground) an analysis of noise measurements has been made using data collected for Emirates A380 departures. As noted previously, Emirates operates both NADP 1 and NADP 2 departures from Heathrow and their noise measurements (recorded on the array of 15 noise monitors positioned along the easterly Detling route during summer 2017) serve as a useful dataset for this study.

**Figure E17** shows the average difference (in seconds) between the time that the noise level for each NADP 1 and NADP 2 A380 departure remained above 60 dB  $L_{Amax}$ .

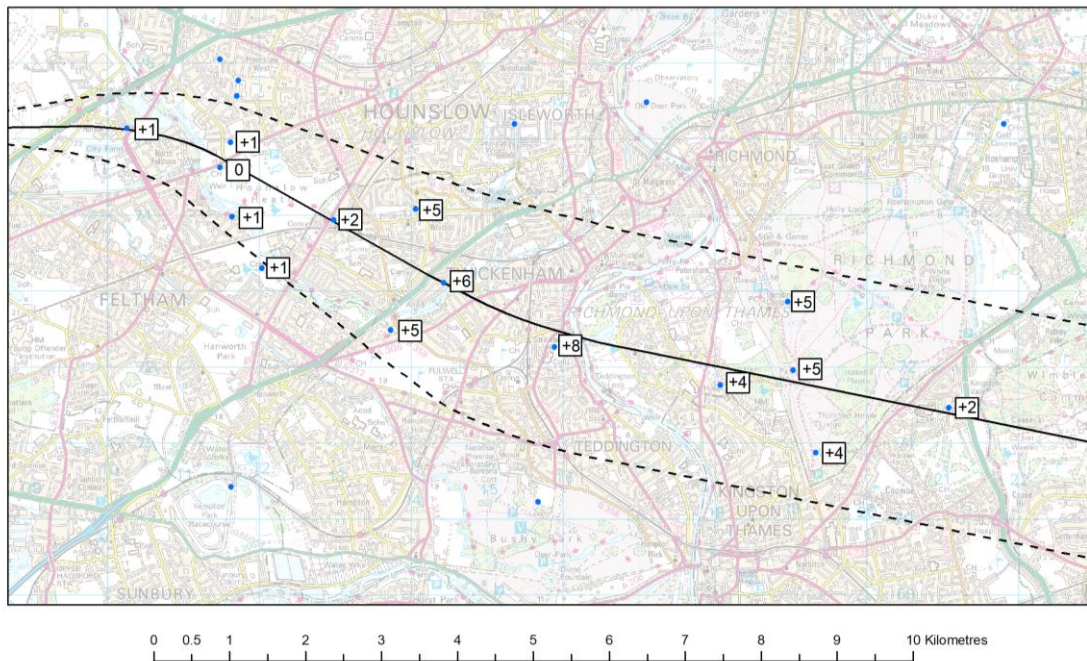
**Figure E18** shows the equivalent measured differences in duration for the time above 65 dB  $L_{Amax}$ . The results show that the average event durations for NADP 1 departures are, in all cases, equal to or greater than the durations for NADP 2 departures. This is due to the slower speeds of the NADP 1 departures as they pass over the noise monitors.



**Figure E17** Difference (in seconds) between the time above 60 dB L<sub>Amax</sub> for A380 NADP 1 and NADP 2 departures



**Figure E18** Difference (in seconds) between the time above 65 dB L<sub>Amax</sub> for A380 NADP 1 and NADP 2 departures



## Effect of A380 departure procedure on emissions

Emissions of NO<sub>x</sub> for each take-off procedure discussed above have been estimated up to a height of 1,000 feet and 3,000 feet using emissions indices provided in the ICAO Engine Emissions Databank. Studies have shown that, due to the effects of mixing and dispersion, emissions from aircraft above 1,000 feet are unlikely to have a significant impact on local air quality. However, results to 3,000 feet are included as a sensitivity analysis.

The total CO<sub>2</sub> emissions produced for each take-off procedure have also been estimated (from fuel flow<sup>60</sup>) using the Aircraft Noise and Performance (ANP) model<sup>61</sup> to 10,000 ft and the Eurocontrol BADA model<sup>62</sup> from 10,000 ft up to a common point at cruise altitude.

**Table E2** summarises the differences in emissions for each case study<sup>63</sup>.

**Table E2** Changes in A380 emissions going from one procedure to another  
(+ve indicates baseline procedure is better; -ve indicates alternative procedure is better)

Case study: Baseline procedure vs. alternative procedure	NO <sub>x</sub> difference to 1,000 ft (percent)	NO <sub>x</sub> difference to 3,000 ft (percent)	CO <sub>2</sub> difference to cruise (percent)
1) R/T NADP 2 (1,000 ft) vs. R/T NADP 1 (1,500 ft) 3,000 NM stage length	None	-11%	+2%
2) R/T NADP 2 (1,000 ft) vs. R/T NADP 2 deep c/b (1,000 ft) 3,000 NM stage length	None	+1%	+2%
3) R/T NADP 2 (1,000 ft) vs. F/T NADP 2 (1,000 ft) 3,000 NM stage length	+47%	+49%	-2%
4) R/T NADP 2 (1,500 ft) vs. F/T NADP 2 (1,500 ft) >5,500 NM stage length	+5%	+8%	>-1%

The results for case study 1 indicate that changing from an NADP 2 to an NADP 1 procedure causes a decrease in NO<sub>x</sub> up to 3,000 feet. This is because the aircraft climbs to 3,000 feet more quickly. Note there is no change in NO<sub>x</sub> below 1,000 feet because both NADP profiles are identical up to this height.

CO<sub>2</sub> (fuel burn) on the other hand increases slightly when switching from NADP 2 to NADP 1 because the aircraft 'cleans up' and accelerates at a later stage during the departure. However, when considering the change in CO<sub>2</sub> relative to an entire flight, the differences would be smaller still.

<sup>60</sup> Based on the Boeing Fuel Flow Method 2.

<sup>61</sup> <https://www.aircraftnoisemodel.org/>

<sup>62</sup> <http://www.eurocontrol.int/services/bada>

<sup>63</sup> It should be noted that the input parameters used in the modelling of emissions of NO<sub>x</sub> and CO<sub>2</sub> have associated uncertainties, and that no attempt has been made to quantify these uncertainties for this study.

For case study 2, there is practically no change in NO<sub>x</sub> below 3,000 feet when switching to a deep cutback procedure, although CO<sub>2</sub> emissions increase slightly. The results for case studies 3 and 4 indicate that a full thrust departure procedure produces more NO<sub>x</sub> up to 1,000 feet and 3,000 feet but slightly less CO<sub>2</sub> up to the cruise altitude when compared to an equivalent reduced thrust procedure.

## A320 case study

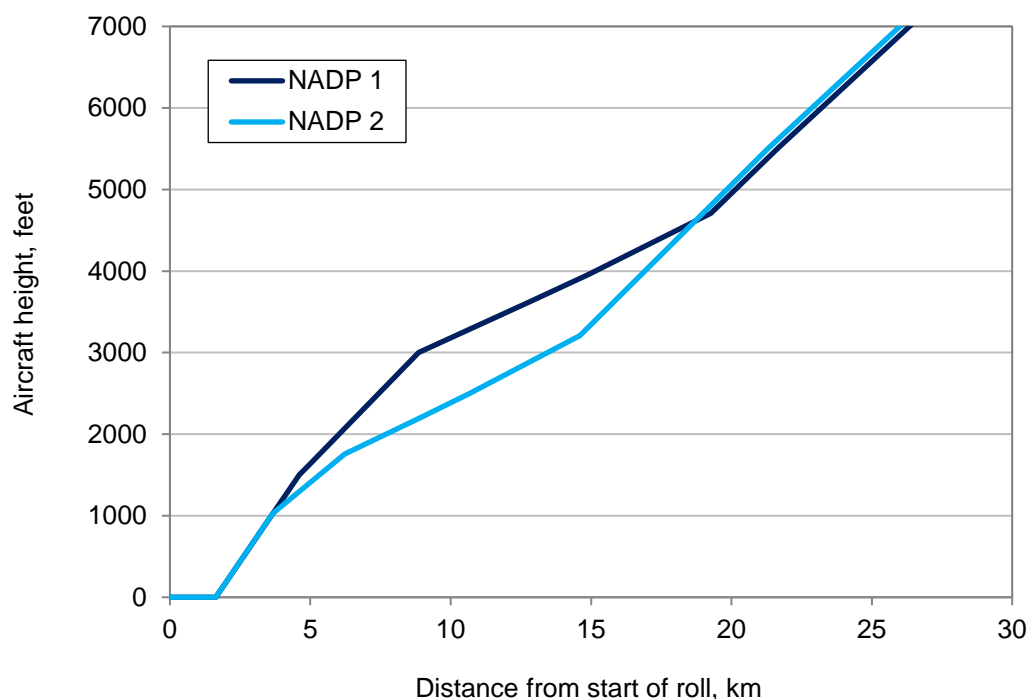
### Effect of A320 departure procedure on noise level

A common (baseline) departure procedure for A320 departures at Gatwick and Stansted is:

- Reduced thrust NADP 2, with an acceleration and thrust reduction altitude of 1,000 feet.

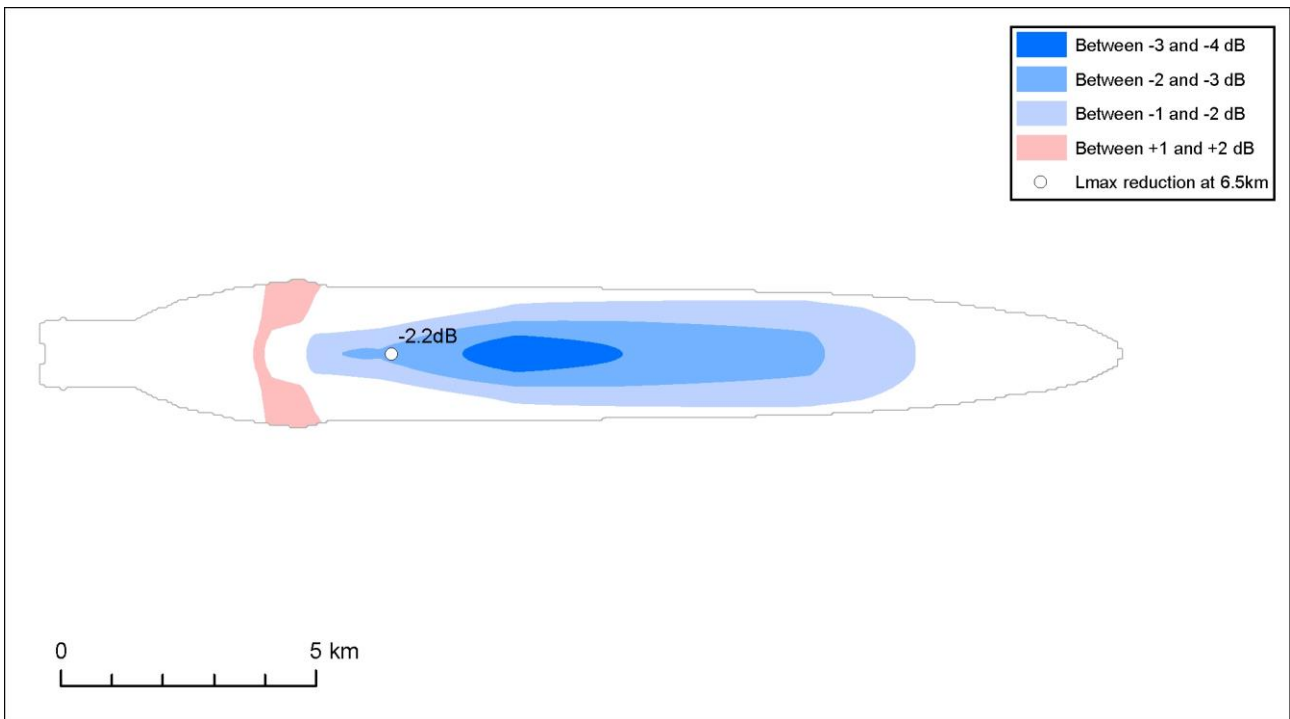
The A320 noise assessment has focussed on changing from this baseline NADP 2 procedure to an alternative NADP 1 (1,500 feet) procedure. The height profiles for the A320 are shown in **Figure E19**.

**Figure E19** A320 height profiles (1,000 NM stage length)

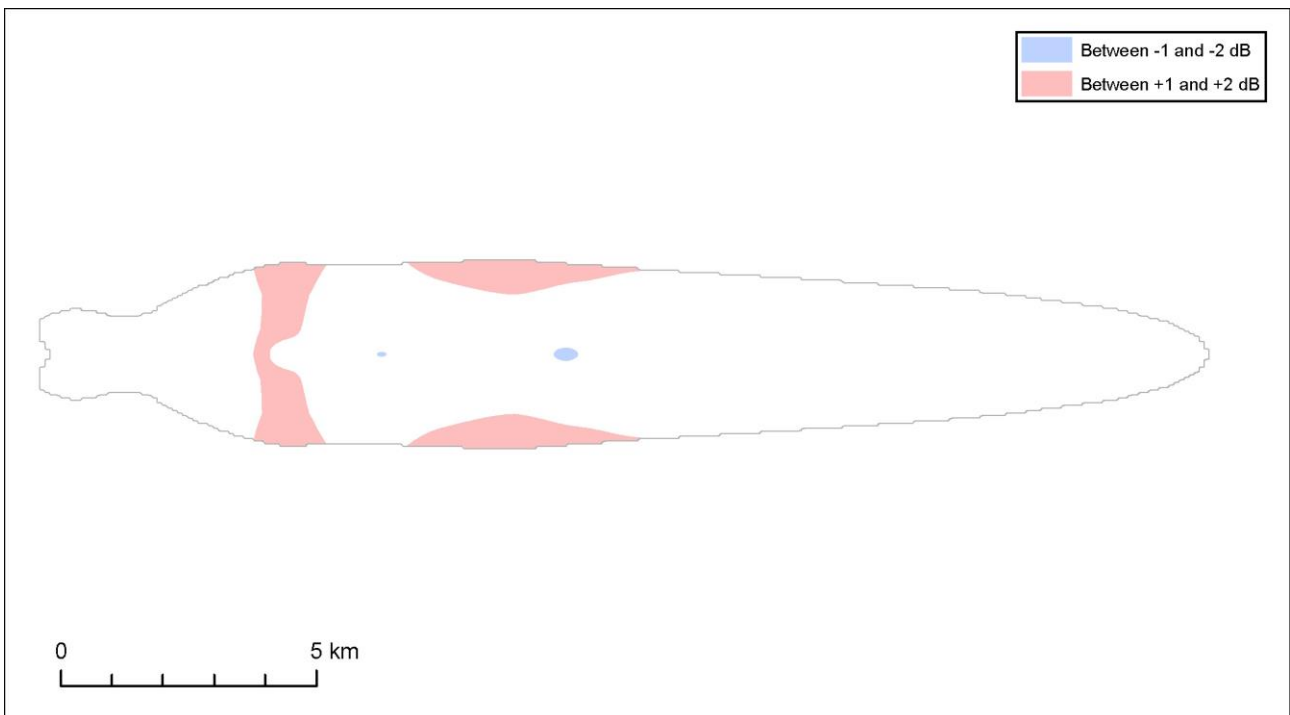


The modelled noise level differences for the A320 are presented in **Figures E20 and E21** for L<sub>Amax</sub> and SEL respectively. The change in the L<sub>Amax</sub> level (-2.2 dB) at 6.5 km is also shown in **Figure E20**. The results show that a notable reduction in L<sub>Amax</sub> under the flight path may be achieved switching to an NADP 1 procedure (due to the increased height of the aircraft over the ground), although similar benefits are not realised in SEL (due to the longer event duration of the NADP 1 procedure in that region of the departure).

**Figure E20** A320  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 1,000 NM stage length



**Figure E21** A320 SEL noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), 1,000 NM stage length



## Effect of A320 departure procedure on emissions

**Table E3** summarises the differences in modelled emissions for A320. The results indicate that changing from a reduced thrust NADP 2 procedure to a reduced thrust NADP 1 procedure causes a decrease in NO<sub>x</sub> up to 3,000 feet but a slight increase in CO<sub>2</sub> up to cruise.

**Table E3** Changes in A320 emissions going from NADP 2 to NADP 1  
(+ve indicates baseline procedure is better; -ve indicates alternative procedure is better)

Baseline procedure vs. alternative procedure	NO <sub>x</sub> difference to 1,000 ft (percent)	NO <sub>x</sub> difference to 3,000 ft (percent)	CO <sub>2</sub> difference to cruise (percent)
NADP 2 (1,000 ft) vs. NADP 1 (1,500 ft)	None	-22%	+2%

## B737-800 case study

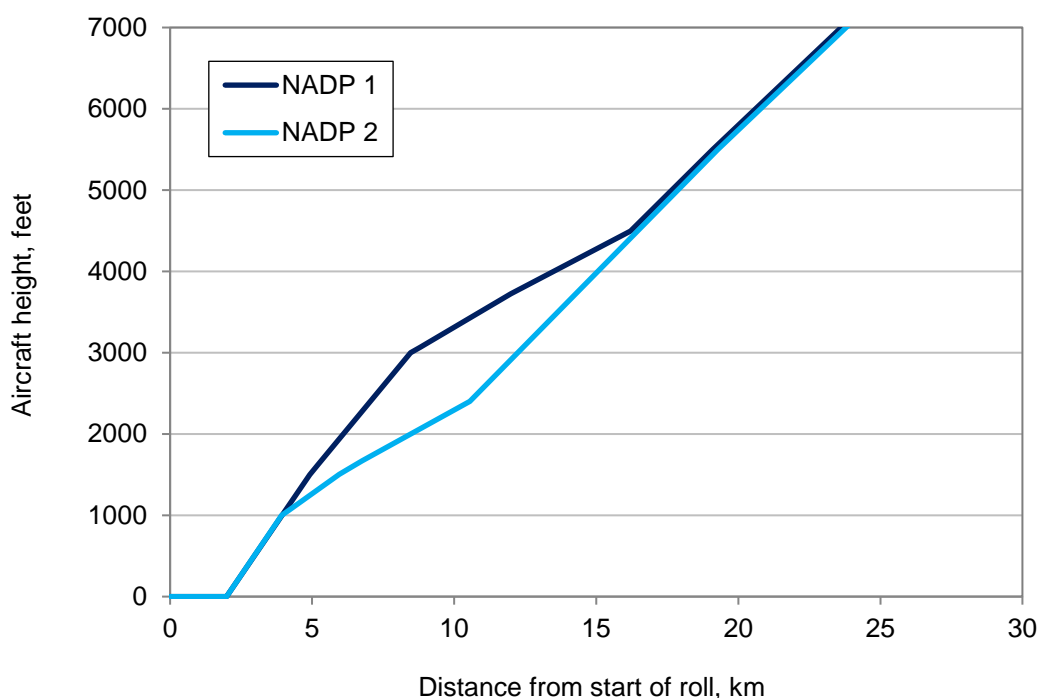
### Effect of B737-800 departure procedure on noise level

A common (baseline) departure procedure for B737-800 departures at Stansted is:

- Reduced thrust NADP 2, with an acceleration altitude of 1,000 feet and a thrust reduction altitude of 1,500 feet.

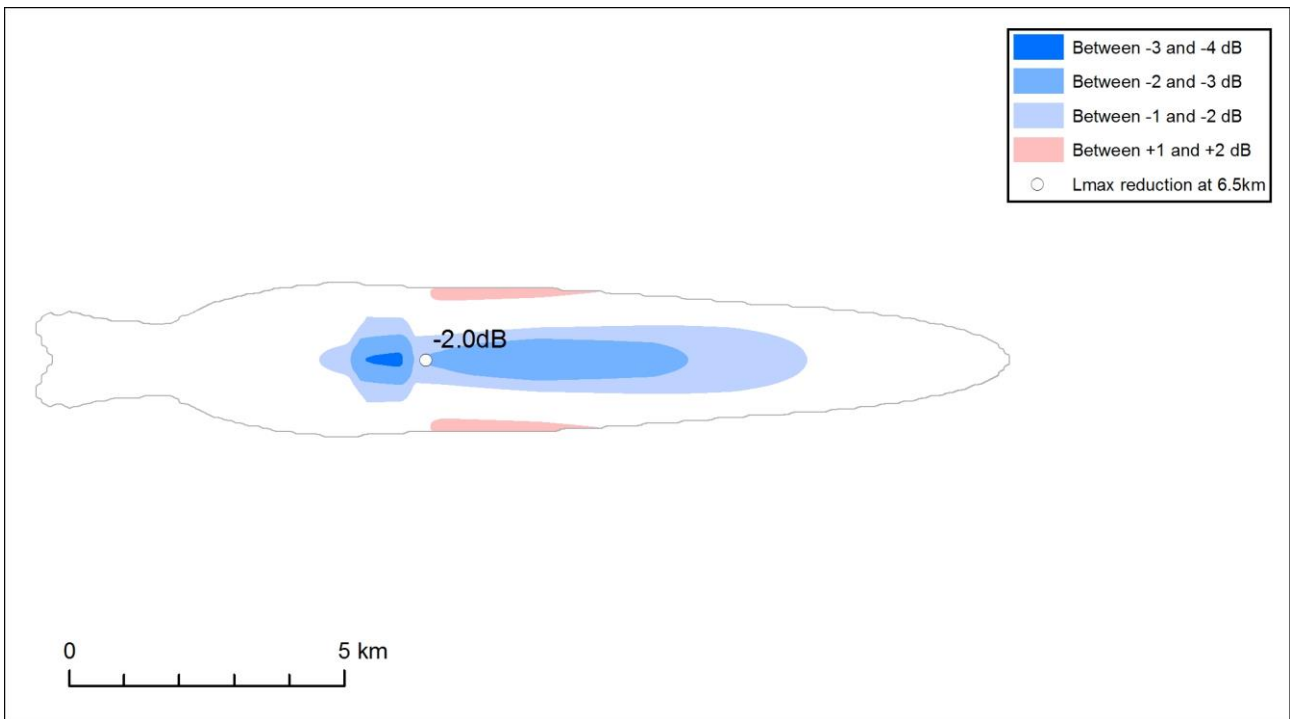
The B737-800 noise assessment has focussed on changing from this baseline NADP 2 procedure to an alternative NADP 1 (1,500 feet) procedure. The height profiles for the B737-800 are shown in **Figure E22**.

**Figure E22** B737-800 height profiles (1,000 NM stage length)

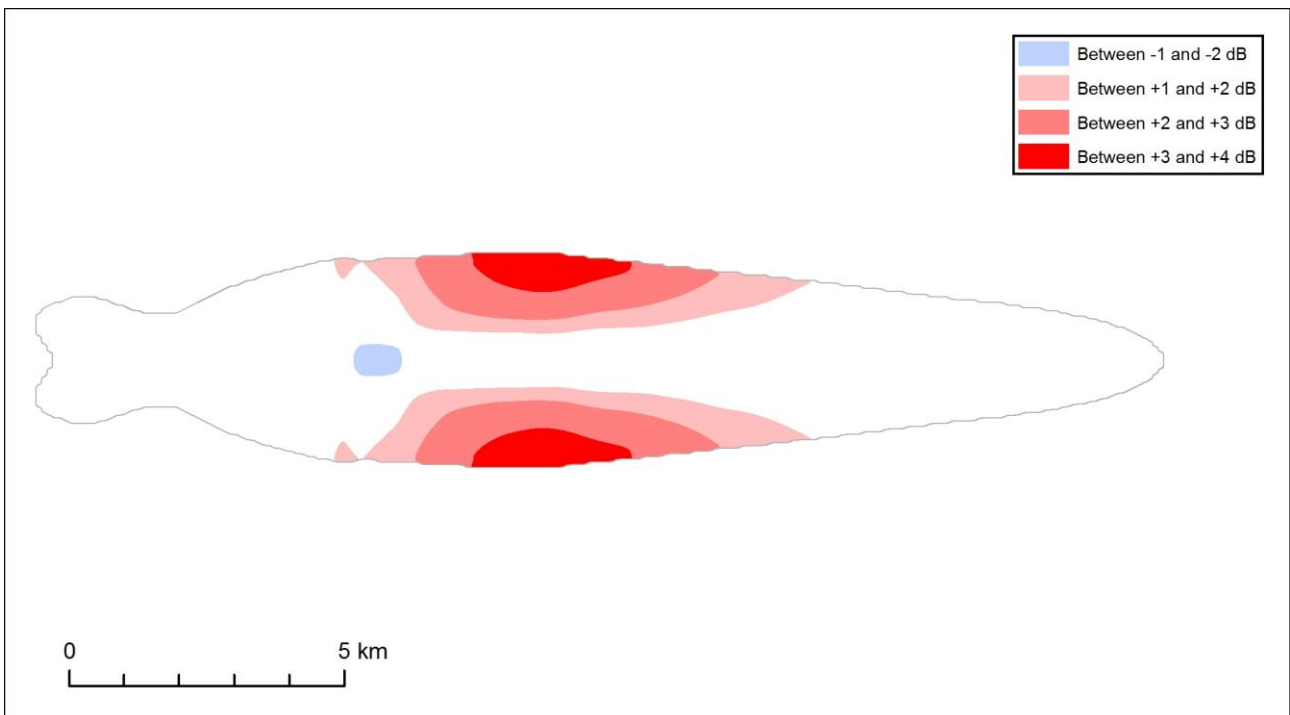


The modelled noise level differences for the B737-800 are presented in **Figures E23 and E24** for  $L_{Amax}$  and SEL respectively. The change in the  $L_{Amax}$  level (of -2.0 dB) at 6.5 km is also shown in **Figure E23**. Like the A320 results, the results for the B737-800 show that a notable reduction in  $L_{Amax}$  under the flight path may be achieved switching to an NADP 1 procedure although the SEL increases significantly to the side of the flight path.

**Figure E23** B737-800  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft accel., 1,500 ft thrust reduction) vs. reduced thrust NADP 1 (1,500 ft), 1,000 NM stage length



**Figure E24** B737-800 SEL noise differences for reduced thrust NADP 2 (1,000 ft accel., 1,500 ft thrust reduction) vs. reduced thrust NADP 1 (1,500 ft), 1,000 NM stage length



## Effect of B737-800 departure procedure on emissions

**Table E4** summarises the differences in modelled emissions for B737-800. The results indicate that changing from a reduced thrust NADP 2 procedure to a reduced thrust NADP 1 procedure causes a decrease in NO<sub>x</sub> up to 3,000 feet but a slight increase in CO<sub>2</sub> up to cruise.

**Table E4** Changes in B737-800 emissions going from NADP 2 to NADP 1  
(+ve indicates baseline procedure is better; -ve indicates alternative procedure is better)

Baseline procedure vs. alternative procedure	NO <sub>x</sub> difference to 1,000 ft (percent)	NO <sub>x</sub> difference to 3,000 ft (percent)	CO <sub>2</sub> difference to cruise (percent)
NADP 2 (1,000 ft accel., 1,500 ft thrust reduction) vs. NADP 1 (1,500 ft)	None	-22%	+2%



## B777-300ER case study

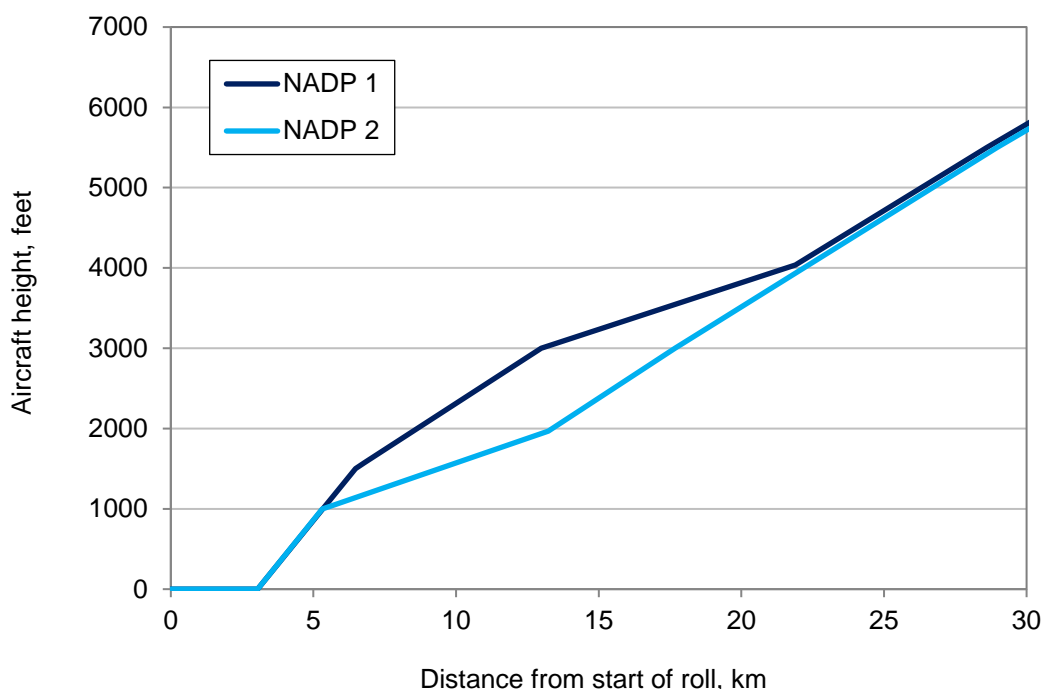
### Effect of B777-300ER departure procedure on noise level

A common (baseline) departure procedure for B777-300ER departures at Heathrow is:

- Reduced thrust NADP 2, with an acceleration and thrust reduction altitude of 1,000 feet.

The B777-300ER noise assessment has focussed on changing from this baseline NADP 2 procedure to an alternative NADP 1 (1,500 feet) procedure. The height profiles for the B777-300ER are shown in **Figure E25**.

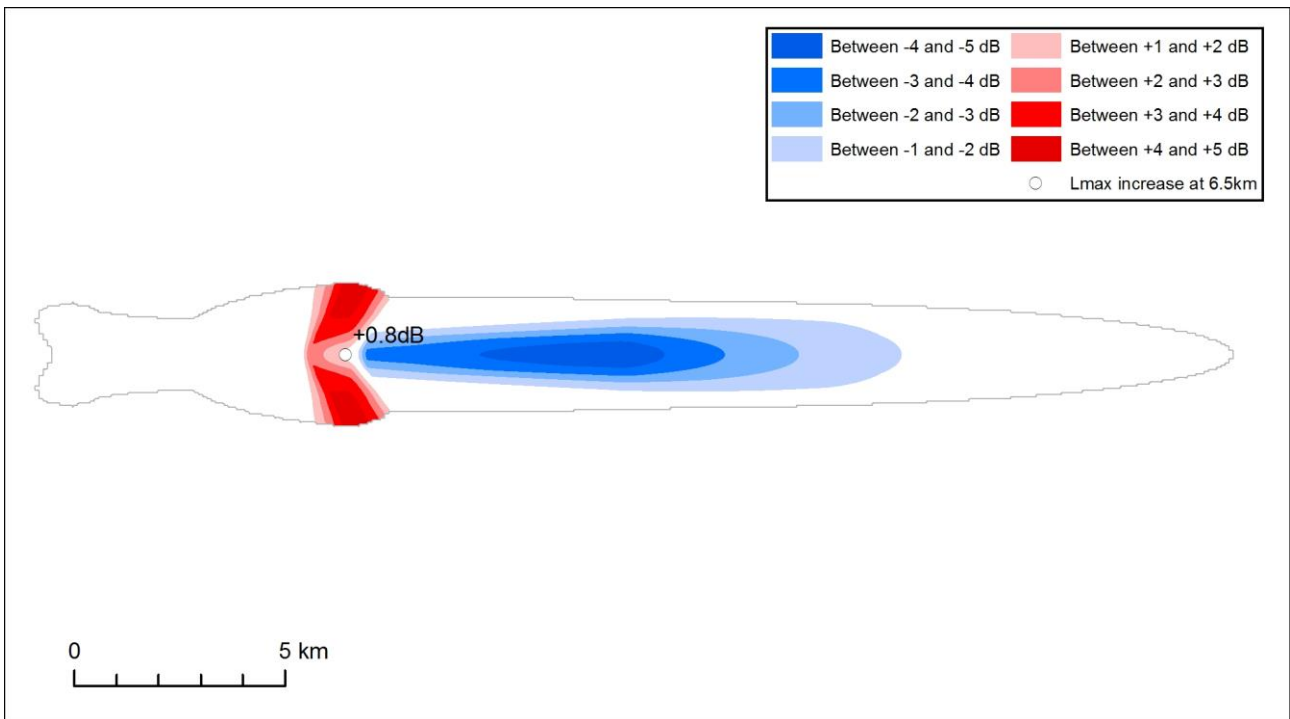
**Figure E25** B777-300ER height profiles (>5,500 NM stage length)



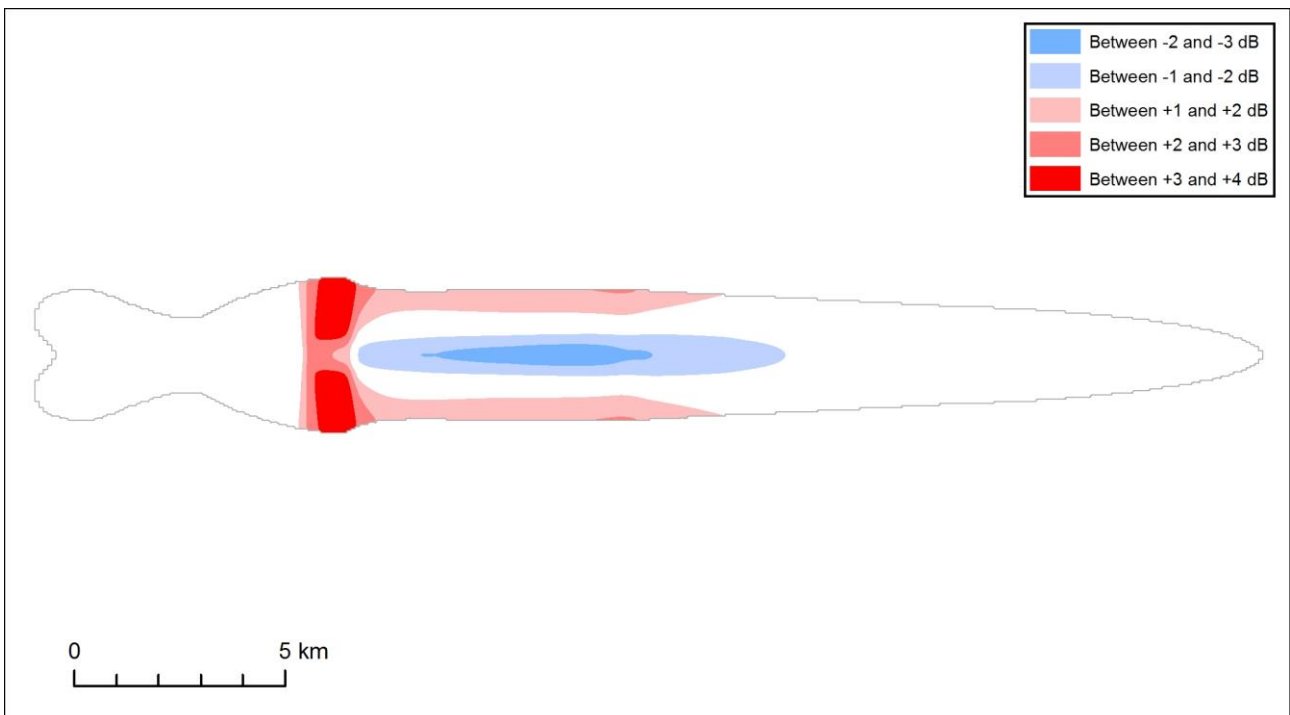
The modelled noise level differences for the B777-300ER are presented in **Figures E26 and E27** for  $L_{Amax}$  and SEL respectively. The change in the  $L_{Amax}$  level (+0.8 dB) at 6.5 km is also shown in **Figure E26**. The results for the B777-300ER show that a notable reduction in noise under the flight path may be achieved switching to an NADP 1 procedure (particularly in  $L_{Amax}$ , as a result of the extra height that is gained in that region), although there are increases in noise in other regions.

It should also be noted that in this example, the  $L_{Amax}$  level at the 6.5 km position is still lower for NADP 2 (despite the extra height that is gained using NADP 1). This is due mainly to the difference between the higher take-off thrust of the NADP 1 procedure compared to the (significantly) lower climb thrust of the NADP 2 procedure in that region.

**Figure E26** B777-300ER  $L_{Amax}$  noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), >5,500 NM stage length



**Figure E27** B777-300ER SEL noise differences for reduced thrust NADP 2 (1,000 ft) vs. reduced thrust NADP 1 (1,500 ft), >5,500 NM stage length



## Effect of B777-300ER departure procedure on emissions

**Table E5** summarises the differences in modelled emissions for B777-300ER. The results indicate that changing from a reduced thrust NADP 2 procedure to a reduced thrust NADP 1 procedure causes a decrease in NO<sub>x</sub> up to 3,000 feet but a slight increase in CO<sub>2</sub> up to cruise.

**Table E5** Changes in B777-300ER emissions going from NADP 2 to NADP 1  
(+ve indicates baseline procedure is better; -ve indicates alternative procedure is better)

Baseline procedure vs. alternative procedure	NO <sub>x</sub> difference to 1,000 ft (percent)	NO <sub>x</sub> difference to 3,000 ft (percent)	CO <sub>2</sub> difference to cruise (percent)
NADP 2 (1,000 ft) vs. NADP 1 (1,500 ft)	None	-9%	+2%