London Heathrow Airport Limited

DET 09R Steeper Climb Gradient Trial Report

V1.0 May 2019

Heathrow
Making every journey better

Trax

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Section 1: Executive Summary

1. Between 4th January 2018 and 3rd January 2019, the climb gradient of one of Heathrow's departure routes (DET 09R) was raised in order to understand the ability for airlines to achieve that gradient together with the change in noise distribution associated with that change. An additional 12 noise monitors were deployed to provide a comprehensive data set of noise measurements.

2. The trial aimed to increase the DET 1J SID gradient between 1000ft and 4000ft from 4% to 5%. The trial SID was designated DET 2Z.

3. The track data from 2018 was compared with a year's worth of track data from 2017 to undertake a comprehensive analysis enabling the trial objectives to be met and success criteria fulfilled as detailed below.

Table 1. Summary of the trial objectives

Objective	Objective met?
Understand the change in noise distribution associated with aircraft climb gradients	Yes. Noise data was collected and analysed from 12 noise monitors. See section 6 for details.
Validate the modelled variation in noise distribution attributed to differing airline NADP procedures	Yes. Analysis of A380 data shows a reduction in L_{Amax} underneath the centreline with smaller decreases and sometimes increases to the side. See Section 6 for details.
Gather sufficient data against which to compare baseline and trial findings across a wide-range of meteorological and aircraft operating conditions	Yes. Jan – Dec 2018 trial period was compared against Jan-Dec 2017 baseline. However, Full NMT deployment was not completed until June 2017.
Ensure the trial gradient results in an actual change in aircraft climb performance	Yes. In 2017, 97.63% of DET departures achieved at least a 5% gradient between 1000ft and 4000ft. This increased to 98.26% during the trial. See sub-section 5.7 for details.
Enable a steeper climb gradient trial without dictating a change in airline NADP procedure(s)	Yes. The trial did not dictate a change in NADP procedure.
Understand the impact of a steeper climb gradient on airline operations (engine wear/fuel burn/SOPs)	Partially. Actual fuel burn data not provided by airlines however some modelled information and qualitative information was supplied. Analysis confirms that steeper climbs do reduce speed but there was no impact to departure rates during the trial
Understand any impacts on Local Air Quality as a result of the steeper climb gradient.	Yes. No airline reported a change in thrust settings below 1000ft.

Understand all the consequences of increasing the height of aircraft on departure over specific communities. (Similar requests have been made of Heathrow by other industry members for airspace design purposes)	Partially. Noise distribution and climb performance was analysed in detail. However, operational airline data was unavailable for detailed quantitative analysis (fuel burn) due to commercial sensitivities.
Support the establishment of future airspace design principles for Heathrow Airport, shared with industry via FASIIG[1]	Yes.

Table 2. Summary of the trail success criteria

Success Criteria	Success criteria fulfilled?
The trial has not had any direct impact on the safety of aircraft and/or Heathrow operations	Yes. No MORs filed or ATC issues raised.
Total number of DET 2Z departures in 2018 is at least 70% of the total number of DET 1J departures in 2017	Yes. Increase in Easterly operations in 2018 meant that the number of DET 2Z departures during the trial period was significantly more than DET 1J departures in 2017.
Total number of Heavy/Super Heavy DET 2Z departures is at least 80% of the number of Heavy/Super Heavy DET 1J departures in 2017	Yes. Number of Heavy/Super Heavy departures was ~x1.8 more during the trial in 2018 when compared to the 2017.
Sufficient good quality data has been collected for aircraft operations as well as from the noise monitors so as to allow for understanding changes in noise distribution as a direct result of an increased climb gradient	Yes. Note that Qantas supplied data and Emirates supplied modelled data. No data from other airlines.
The trial has not had a detrimental effect on local air quality	Yes. No reports on thrust increases below 1000ft.

1.1 Summary of Results

4. Due to prevailing westerly winds, just under 20% of operations throughout 2017 were Easterly compared to over 35% in 2018.

5. Although the number of A380 operations increased as a result of an increase in easterly operations, as a percentage it was the aircraft type with the biggest reduction in operations on the DET route 2018.

[1] Now known as the Industry Co-ordination for the Airspace Modernisation Strategy (ICAMS) group.

6. It is important to understand a constant climb gradient is not able to be coded into all aircraft Flight Management Computers as part of an Instrument Flight Procedure. The minimum altitude restrictions included in the trial were to help simulate a 5% gradient between 1000ft and 4000ft but aircraft can and did vary their vertical profiles in between the published altitude points. 98.26% of all DET2Z departures achieved at least a 5% climb gradient between 1000ft and 4000ft during the trial.

7. Looking at just the heavy A340/A380/B747/B777 departures, in 2017, before the trial, 92.81% were maintaining a 5% climb gradient between 1000ft and 4000ft. During the trial when the altitude restrictions were added, this number increased to 94.09%.

8. Across all DET09 departures, it saw average height increases at each of the altitude attainment points as shown below in Figure 1 and Table 3.

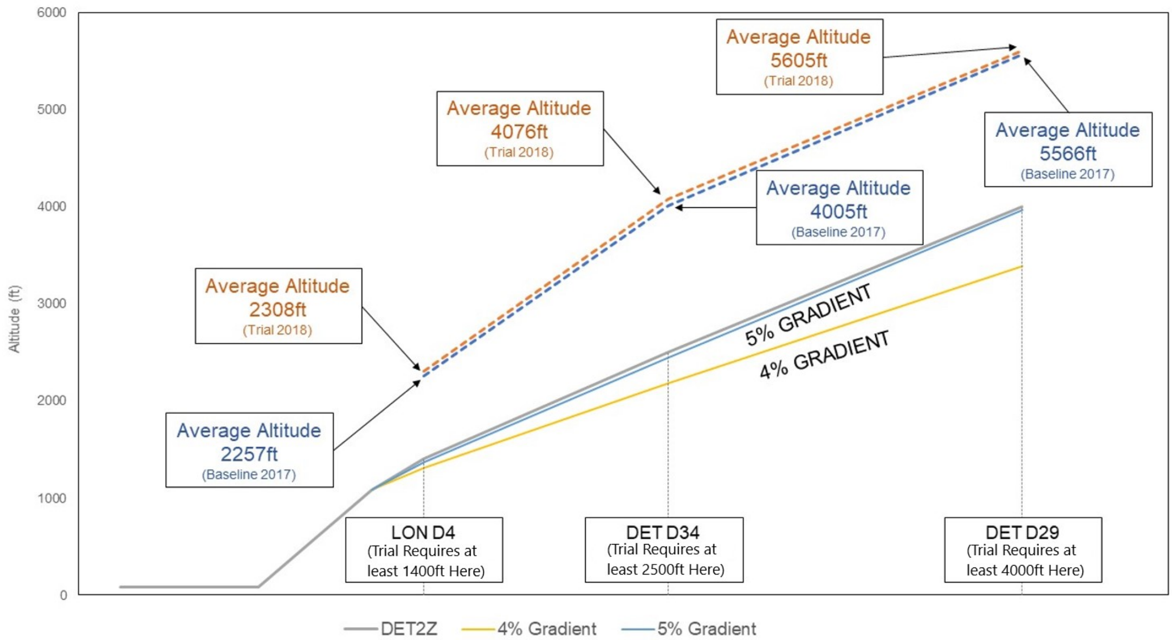

Figure 1. Average altitude vs DET 2Z / 4% / 5% gradients[2]

Table 3. Average altitudes at LON D4, DET D34 & DET D29 (by aircraft category)

	LON D4 (Trial SID Requires at least 1400ft here)			DET D34 (Trial SID Requires at least 2500ft here)			DET D29 (Trial SID Requires at least 4000ft here)		
	2017	**2018**		**2017**	**2018**		**2017**	**2018**	
Super Heavy	1652	1729	↑	3242	3337	↑	5288	5361	↑
Heavy	2163	2213	↑	3796	3859	↑	5573	5601	↑
Upper Medium	3273	3666	↑	5164	5361	↑	5898	5891	↓
Medium	2431	2440	↑	4258	4292	↑	5619	5648	↑
Light	3620	3830	↑	4903	5343	↑	5879	5902	↑
	2257	2308	↑	4005	4076	↑	5566	5605	↑

[2] The 4%/5% gradients are measured from a point 6.5km from the start of take-off roll where aircraft are required to be at least 1000ft, as required by Heathrow's noise abatement procedures.

9. From an Air Traffic Management perspective, an aircraft is deemed to be at or maintaining its level if it is within 200ft of the required level restriction. 26 flights or 0.1% of flights were more than 200ft below any of the published altitude restrictions required by the trial, resulting in an ATM compliance of 99.9%.

10. CAA's Environmental Research Consultancy Department (ERCD) performed the analysis of the noise measurements. The range of noise differences between the DET 1J (2017 baseline) procedure and the DET 2Z (2018 trial) procedure (across all airlines and all monitors) is -3.5 to +1.6 dB for L_{Amax} and -2.7 to +1.0 dB for SEL, although the majority of differences are small in absolute terms (most are less than 1 dB).

11. Whilst the trial did not stipulate a specific Noise Abatement Departure Procedure (NADP) the noise monitor deployment enabled ERCD to analyse the actual noise differential between NADP1 and NADP2 for an individual A380 operator. NADP1 requires an aircraft to start acceleration after 3000ft whereas NADP2 requires acceleration below this level. Figure 2 and Figure 3 below illustrate the difference in the vertical profiles and noise distribution as a result.

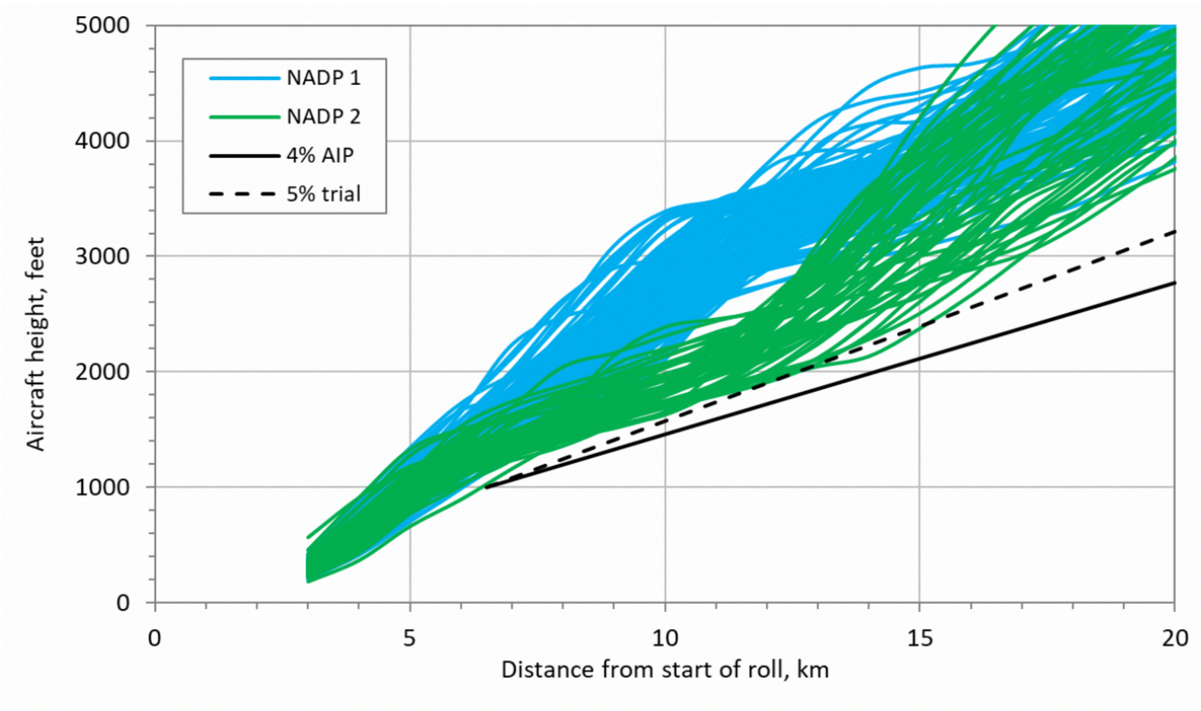

Figure 2. A380 operator NADP 1 and NADP 2 departure height profiles (DET 2Z)

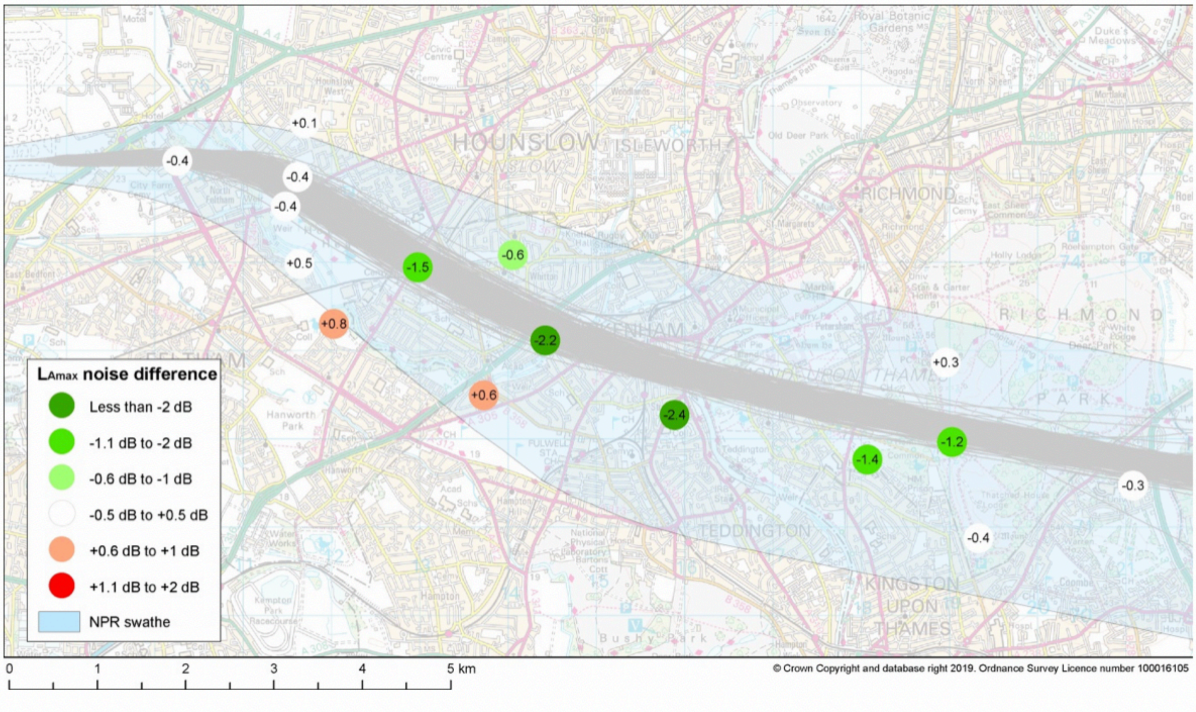

Figure 3. A380 LAmax noise differences, NADP1 minus NADP2 (DET 2Z)

12. It can be seen that the delay in aircraft acceleration (NADP1) resulted in a noticeable reduction in L_{Amax} readings directly underneath the A380 flights with some smaller reductions and sometime increases in noise readings to the side.

13. Whilst the noise readings above could be seen to support a requirement to promote use of NADP1, it should be noted that one airline advised that changing from NADP2 (accelerate below 3000ft) to NADP1 (accelerate above 3000ft) would result in an increase in fuel burn of approximately 80 Kgs per flight, equivalent to 92 tonnes of CO_2 a year for its A380 operation at Heathrow alone. However, airlines were unable to provide quantitative fuel burn data for comprehensive analysis due to commercial sensitivities.

1.2 Lessons learned

14. Although the altitude attainment profiles were required in the published trial Instrument Flight Procedure (IFP), there were still instances of some flights not achieving those levels within the accepted tolerance (-200ft). There were no records of either ATC or airlines reporting any such instances, they were captured through the analysis. In addition, the trial uncovered that most Flight Management Computers will not provide an alert to flight crews unless the aircraft is predicted to be 250ft or more below a published departure restriction. These findings should be used to inform airspace design, particularly where altitude attainment is required for route or obstacle separation purposes.

15. Some stakeholders felt a 5% gradient was not ambitious enough. Whilst this trial was coined a 5% SID trial, if the trial gradient was measured from the Declared End of Runway (DER) as is normal for IFP SID design, the climb gradient for the DET2Z SID would be 8.83% until LON D4, 6.55% to DET D34 and 5.82% until DET D29 (See Figure 4). It is clear that these gradients were potentially too ambitious for a small minority of heavy departures whilst trying to optimise aircraft performance to handle a variety of requirements.

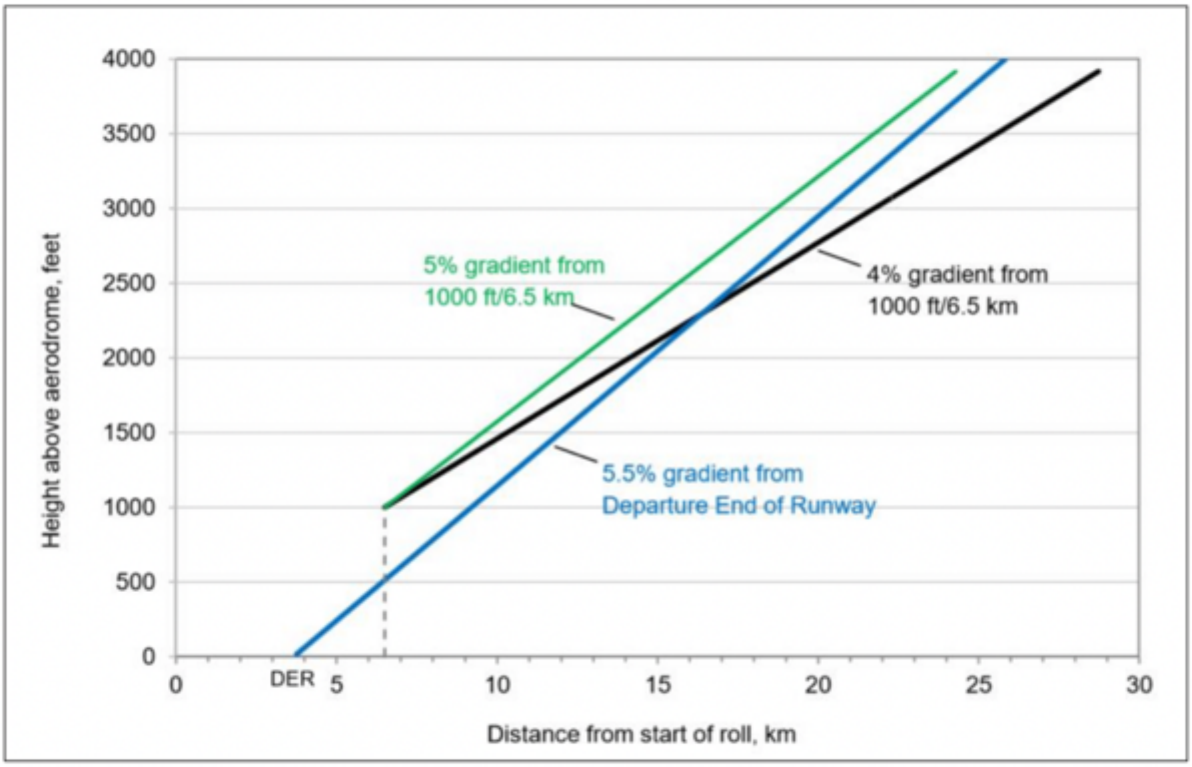

Figure 4. Different methods of measuring gradient

16. Although the trial did not require any change to the lateral flight paths, the detailed analysis highlighted that flight paths can vary significantly owing to the interpretation by Coding Houses. These are the companies who create the flight computer management coding of conventional IFPs. This is not a trend that would be expected with Performance-based Navigation (PBN) SIDs where the standard coding is provided as part of the design process.

17. The small number of failures suggest a 5% gradient from 1000ft to 4000ft is a realistic ambition for Heathrow however, if gradients such as those proposed in this trial were to be taken forward and a 100% adherence is expected, Heathrow may need more direct engagement with operators to help influence operator behaviour.

Section 2: Background to the trial

2.1 Reasons for the trial

18. The Heathrow Community Noise Forum (HCNF), was set up in 2015 and is made up of representatives from 12 local authorities around Heathrow, NATS, BA, DfT, CAA and Heathrow Airport Limited (Heathrow). Heathrow set up the forum in response to local concerns regarding future changes to airspace as a result of the government's Future Airspace Strategy (FAS).

19. Concerns were raised by community representatives of the Operations and Procedures Working Group, a sub-group of the HCNF, that a gradual decrease in climb performance on the DET 09 departures had occurred over previous years, in particular with the performance and operation of the A380.

20. In response to these concerns Heathrow commissioned multiple studies to investigate. One study found that the height of the DVR[3] swath, at a specified point, has decreased both in terms of average height from approximately 3400 feet to 3100 feet, and that the number of low flying aircraft has increased. It should be noted that whilst these aircraft were flying lower, they were still above the minimum 4% climb gradient specified in the AIP.

21. These studies concluded that over the between 2010 and 2015 there has been:

    a) A significant increase in A380 departures from Heathrow;

    b) Approximately 30 more DET departures per day;

    c) A small increase in concentration along SID centrelines;

    d) A small decrease in climb performance: At the point of measurement, average height had reduced by 300ft.

In addition,

    e) Departures significantly outperform the Instrument Flight Procedure (IFP) climb gradient of the SID. The IFP is designed for obstacle clearance and airspace containment however, Heathrow's Noise Abatement procedures require aircraft to climb at gradients well in excess of the IFP gradient.

22. In response to these findings, the local communities asked Heathrow to make these aircraft higher on departure; in essence raising the departure climb gradient.

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[3] Previously DVR/DET SIDs shared this departure route. The route has now been consolidated to just the DET SID.

23. Heathrow were aware that raising the climb gradient is likely to have environmental and operational consequences. Those being a change in noise distribution as well as potential changes to airline Standard Operating Procedures (SOPs) and aircraft thrust settings which may impact fuel burn and engine maintenance.

24. For this reason, Heathrow proposed to trial a steeper Standard Instrument Departure (SID) for runway 09R DET departures to understand the effect of the climb gradient on noise re-distribution as well as any operational effects on their airline customers and Air Traffic Control (ATC).

2.2 Consideration of the trial gradient

25. There are several different factors to consider when determining how to raise the SID gradient:

a) The IFP Procedure Design Gradient, the climb gradient designed for obstacle clearance and airspace containment (overlays of which are coded into each aircraft's FMS).

b) Heathrow's noise abatement climb gradient; the climb gradient required for all departures to meet their noise abatement responsibilities as detailed in the UK's Aeronautical Information Publication (AIP) on departure[4];

c) The actual climb gradient currently achieved by DET departures;

d) An aircraft's maximum theoretical climb gradient under challenging metrological conditions.

e) Any change below 1000ft could affect air quality

26. Analysis and comparison of the above gradients led to a trial proposal of increasing the IFP design gradient of the DET 1J SID in line with achievable aircraft performance whilst adhering to Heathrow's noise abatement requirements. This method was chosen after discussion with FMS coding houses about how the various climb gradients are displayed and used in the cockpit.

2.2.1 Justification

27. Existing studies[5] show the operation of the DET departure has evolved and it is now accepted that the aircraft are operated differently and the A380 is slightly lower than departures were five or more years previously.

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[4] See EGLL-24 http://www.ead.eurocontrol.int/eadbasic/EG_AD_2_EGLL_en_2019-03-28.pdf

[5] Teddington flight path analysis report

28. Requested by the HCNF, this trial aimed to gather aircraft performance and noise data for a pre-trial period and an in-trial period. It enabled a detailed comparison and comprehensive environmental and operational analysis of aircraft operating on the DET 1J (09R) SID before and after the introduction of a steeper IFP design gradient.

29. The trial has allowed Heathrow to analyse the variance in noise profiles associated with different airline Noise Abatement Departure Procedures which are Standard Operating Procedures (SOPs) not within the control of the airport.

30. Heathrow and CAA require such a trial to fully inform the consequences of potentially making a permanent change to the SID design prior to an Airspace Change Process.

31. The detailed analysis of the operation of a vertical departure profile will be the first of its kind within the UK and closely aligns with the CAA strategic environmental area of aiding performance through information.

32. Working with the communities in such a manner aims to enable Heathrow and the UK's Future Airspace Strategy to jointly move forward with regards to modern aircraft performance on Standard Instrument Departures.

2.3 Objectives and system requirements

33. Table 4 below sets out the trial objectives together with the means of verification together with an assessment of if and how the objective was met.

Table 4. Trial objectives together and the means of verification

	Objective	Method of verification	Objective met?
1	Understand the change in noise distribution associated with aircraft climb gradients	NMT measurements, ANOMS data.	**Yes** Noise data was collected and analysed from 15 noise monitors. See Section 6: for details.
2	Validate the modelled variation in noise distribution attributed to differing airline NADP procedures	NMT measurements to validate industry theory of how aircraft noise is distributed as a result of aircraft climb gradients. ANOMS data.	**Yes** Analysis of A380 data shows a reduction in L_{Amax} underneath the centreline with smaller decreases and sometimes increases to the side. See Section 6 for details.
3	Gather sufficient data against which to compare	8-12 month baseline v 12-month trial period. ANOMS data.	**Yes** Jan – Dec 2018 trial period was

	baseline and trial findings across a wide-range of meteorological and aircraft operating conditions		compared against Jan-Dec 2017 baseline. However, Full NMT deployment was not completed until June 2017.
4	Ensure the trial gradient results in an actual change in aircraft climb performance	Pre-trial analysis and 12-month baseline/trial periods.	**Yes** In 2017, 97.63% of DET departures achieved at least a 5% gradient between 1000ft and 4000ft. This increased to 98.26% during the trial. See sub-section 5.7 for details.
5	Enable a steeper SID trial without dictating a change in airline NADP procedure(s)	Pre-trial analysis, airline buy-in.	**Yes** The trial did not dictate a change in NADP procedure.
6	Understand the impact of a steeper SID gradient on airline operations (engine wear/fuel burn/SOPs)	Qualitative unless airlines willing to share quantitative data. Airline workshops.	**Partially** Actual fuel burn data not provided by airlines however some modelled information and qualitative information was supplied. Analysis confirms that steeper climbs do reduce speed but there was no impact to departure rates during the trial
7	Understand any impacts on Local Air Quality as a result of the steeper SID	Should airlines report a change in thrust settings below 1000ft, Heathrow will perform a Local Air Quality assessment.	**Yes** No airline reported a change in thrust settings below 1000ft
8	Understand all the consequences of increasing the height of aircraft on departure over specific communities. (Similar requests have been made of Heathrow by other industry members for	Final report detailing changes in noise distribution and operational consequences.	**Partially** Noise distribution and climb performance was analysed in detail. However, operational airline data was unavailable for detailed quantitative analysis (fuel burn) due to commercial sensitivities.

	airspace design purposes)		
9	Support the establishment of future airspace design principles for Heathrow Airport, shared with industry via FASIIG[6]	Final report.	**Yes**

2.3.1 Success criteria

34. A successful trial was declared as one which enables fact-based evidence that demonstrates the change in noise distribution and associated operational impacts as a direct result of the climb gradients achieved by a wide mix of aircraft types.

35. Table 5 summarises the trial success criteria and methods of how the success criteria is verified.

[6] Now known as the Industry Co-ordination for the Airspace Modernisation Strategy (ICAMS) group.

Table 5. Trial success criteria and corresponding method of verification

	Success Criteria	Method of Verification	Success criteria fulfilled?
1	The trial has not had any direct impact on the safety of aircraft and/or Heathrow operations	No MORs[7] filed with resultant investigation finding DET 2Z a contributory factor	**Yes** No MORs filed or ATC issues raised
2	Total number of DET 2Z departures in 2018 is at least 70% of the total number of DET 1J departures in 2017	Data collection – Trial extension procedure	**Yes** Increase in Easterly operations in 2018 meant that the number of DET 2Z departures during the trial period was significantly more than DET 1J departures in 2017.
3	Total number of Heavy/Super Heavy DET 2Z departures is at least 80% of the number of Heavy/Super Heavy DET 1J departures in 2017	Data collection – Trial extension procedure	**Yes** Number of Heavy/Super Heavy departures was ~x1.8 more during the trial in 2018 when compared to the 2017.
4	Sufficient good quality data has been collected for aircraft operations as well as from the noise monitors so as to allow for understanding changes in noise distribution as a direct result of an increased climb gradient	Final Report findings	**Yes** No airline data on actual fuel burn comparisons.
5	The trial has not had a detrimental effect on local air quality	If an airline reports an increase in thrust settings on departure as a result of DET 2Z it will trigger a Local Air Quality assessment.	**Yes** No reports on thrust increases below 1000ft.

[7] Mandatory Occurrence Report

2.4 Participants and stakeholders

36. The participants of the trial include NATS Heathrow ATC, NATS Swanwick (TC) and all airlines operating on the DET departure route from Heathrow. ANOMS data analysis identified that the airlines listed in Table 6 were most likely to be affected by the steeper climb gradient and were engaged directly.

Table 6. Trial participants: airlines

British Airways	Virgin Atlantic
Singapore Airlines	Qatar Airways
Jet Airways	Thai Airways
Emirates	Etihad

37. Other stakeholders engaged as part of this trial include:

1) Heathrow Airport Limited Airspace Governance Group (Heathrow AGG).

2) Local Heathrow communities as represented by the Heathrow Community Noise Forum (HCNF). See Table 7 below for the list of the HCNF community representatives.

Table 7. Stakeholders: community representatives

Teddington Action Group	AIRCRAFTNOISE3VILLAGES (Lightwater, Windlesham & Bagshot)
Englefield Green	Local Authorities Aircraft Noise Council
Richmond Council	Stanwell Moor Residents Association
The Richmond Heathrow Campaign	Ealing Aircraft Noise Action Group
Hounslow Council	South Bucks District Council
Heathrow Association for the Control of Aircraft Noise (HACAN)	Royal Borough of Windsor and Maidenhead

3) Heathrow Airport Consultative Committee (HACC[8]) members include representatives listed in Table 8 below.

Table 8. HACC Representatives

London Borough of Hounslow	Slough Borough Council
London Borough of Hillingdon	South Bucks District Council
London Borough of Ealing	Spelthorne Borough Council
London Borough of Richmond-on-Thames	Surrey Heath Borough Council
Royal Borough of Windsor & Maidenhead	London Assembly
Bracknell Forest Borough Council	London Councils
Elmbridge Borough Council	Airline Operators Committee
Runnymede Borough Council	IATA / BATA
HACAN/ClearSkies	ABTA
Local Authorities Aircraft Noise Council	London Chamber of Commerce
Thames Valley Chamber of Commerce	Heathrow Area Transport Forum

4) Aircraft Noise Monitoring Advisory Committee (ANMAC). Membership includes representatives from Heathrow, NATS, the Environmental Research and Consultancy Department of the CAA, the Scheduling Committees and their technical advisers, and a representative and technical adviser from the

[8] This group has now been replaced by the Heathrow Community Engagement Board (HCEB)

Consultative Committees of the airport. The committee is chaired by the head of the Aviation Environment Division at the DfT.

5) Heathrow Noise Performance Working Group which consists of local authority technical officers responsible for noise issues.

6) Heathrow Flight Operations Performance Committee (FLOPC). FLOPC is an internal committee of Heathrow Airport. Its membership comprises airlines, pilots, DfT, NATS and Heathrow's Airside Operations team. It reviews noise, track keeping and CDA performance, shares best practice and also advises on noise abatement procedures and new initiatives.

7) UK Flight Safety Committee

8) NATS Swanwick (TC) and Heathrow ATC

9) CAA

10) Department for Transport

2.5 Runway 09R only

38. The prevailing meteorological conditions at Heathrow mean that Easterly operations occur approximately 30% of the time. All runway 09R DET departures were issued with the steeper SID for the duration of the trial although the existing DET 1J was still available on request for those individual departures unable to achieve the trial SID gradient on the day due to aircraft weight and/or meteorological conditions[9].

[9] During 2018, 9 flights elected to depart on the DET1J SID.

Section 3: Selection of the SID gradient

3.1 Existing and the new proposed SID

3.1.1 Current SID

39. Analysis of 1748 heavy DET 1J departures over a 10-month period showed that aircraft are vastly outperforming the vertical profile of the SID. Figure 1 below shows the existing DET 1J SID with the first SID altitude restriction not being required until 3000ft at DET D29.

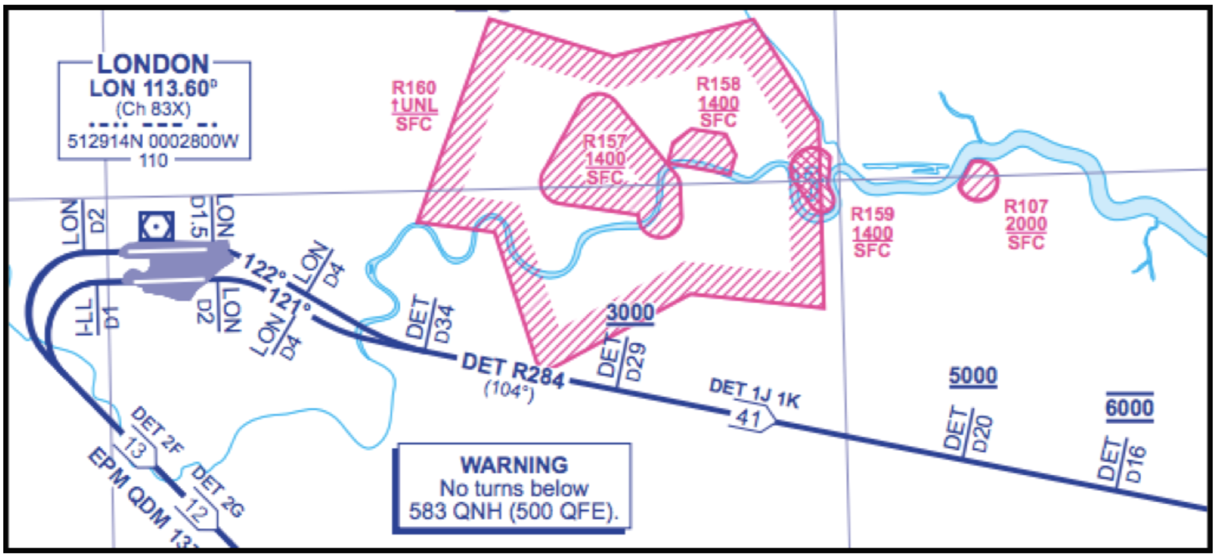

Figure 5. DET 1J

3.1.2 Existing noise abatement requirements

40. In addition to the published SID restrictions, the UK AIP states that 'After take-off the aircraft shall be operated in such a way that it is at a height of not less than 1000ft AAL[10] at 6.5 km from start of roll as measured along the departure track of that aircraft' and also 'Where the aircraft is a jet aircraft, after passing the point referred to in sub-paragraph (1) above, it shall maintain a gradient of climb of not less than 4% to an altitude of not less than 4000ft. 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'

41. The analysis shows that c.99.7% of the 1748 DET 1J departures adhered to the current 1000ft Noise Abatement requirement with c.99% adhering to the 4% to 4000ft requirement.

[10] Above Aerodrome Level

42. Whilst the Noise Abatement requirements are published in the AIP, they do not form part of the IFP Design itself. Furthermore, a minimum gradient is not something which can be coded into an aircraft's Flight Management Computer (FMC). Instead IFPs require aircraft to achieve certain minimum and/or maximum levels at specified points in space.

3.1.3 Proposed gradient change

43. The gradient for the trial was chosen following analysis of 10 months' radar data of heavy departures[11] on the DET 1J SID from runway 09R.

44. The proposed trial SID brought the IFP in line with the existing 1000ft Noise Abatement Procedure but also increased the gradient required between 1000ft and 4000ft from 4% to 5% as shown in Figure 6 below. The analysis revealed that all heavy DET 1J departures climbed in excess of the proposed trial gradient at some point between 1000ft and 4000ft; however, c.17% were at some point, climbing at shallower gradients. This is thought to be largely down to the differing Noise Abatement Departure Procedures (NADP[12]) being executed by a mix of airlines and aircraft types.

45. The analysis demonstrated that the proposed trial SID was achievable and should also result in an actual change in climb performance for a significant sample of DET 09 departures. This provided assurance that the trial would force a change to the climb behaviour of some aircraft against which the baseline data will be compared.

46. Figure 7, highlights how different ways of measuring climb gradients can result in a considerable difference in terms of the actual flight path. From an IFP perspective, SID gradients are designed from the Declared End of Runway (DER)[13]. Whilst this trial was coined as a 5% SID trial, if the trial gradient was measured the same way, from the DER, the climb gradient for the DET2Z SID would be 8.83% until LON D4, 6.55% to DET D34 and 5.82% until DET D29.

[11] A340/A380/B747/B777
[12] NADP is an airline Standard Operating Procedure, not to be confused with Heathrow's Noise Abatement requirements outlined in section 3.1.2.
[13] Technically from 5m above the DER.

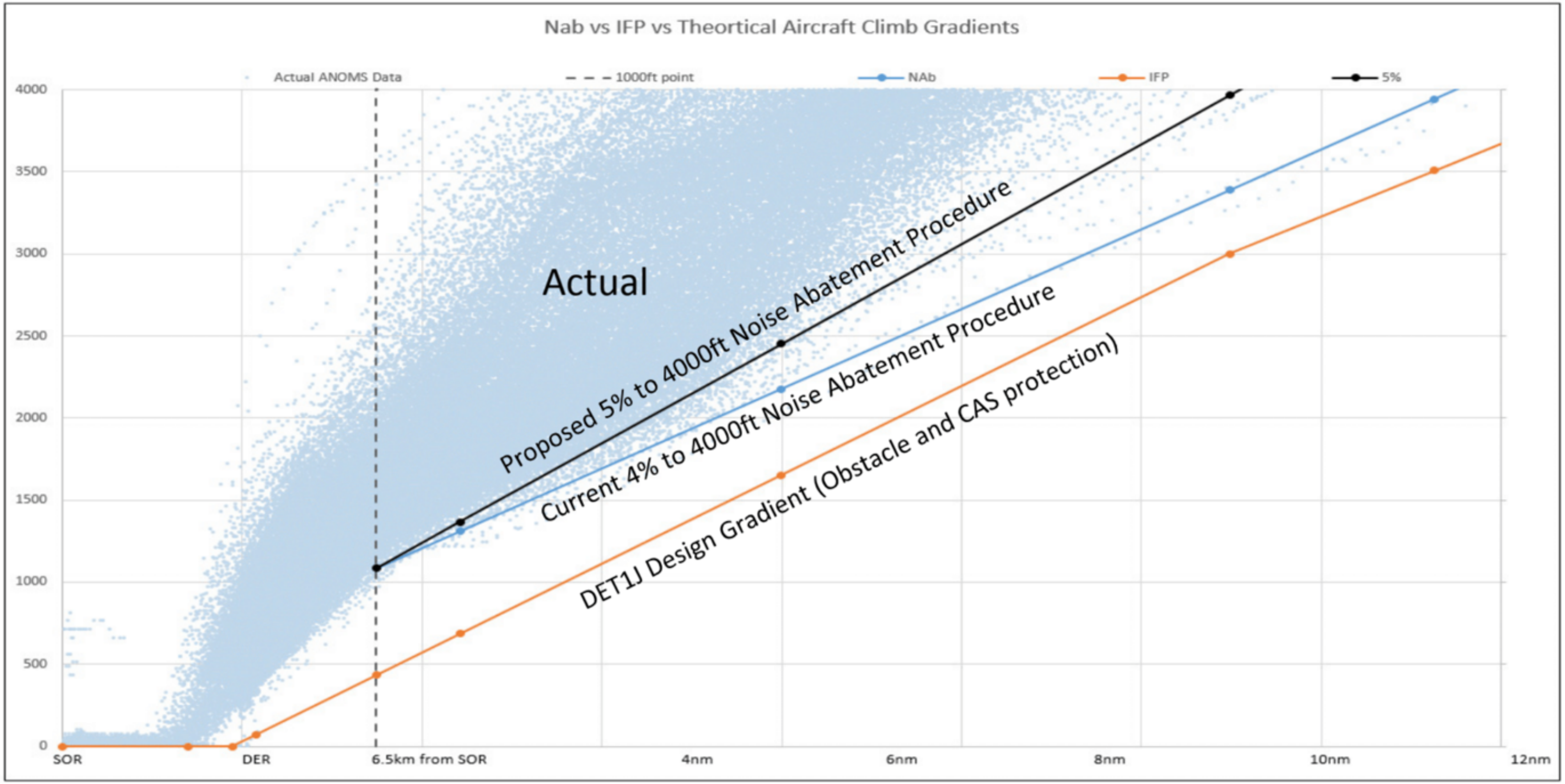

Figure 6. Aircraft climb performance 2016

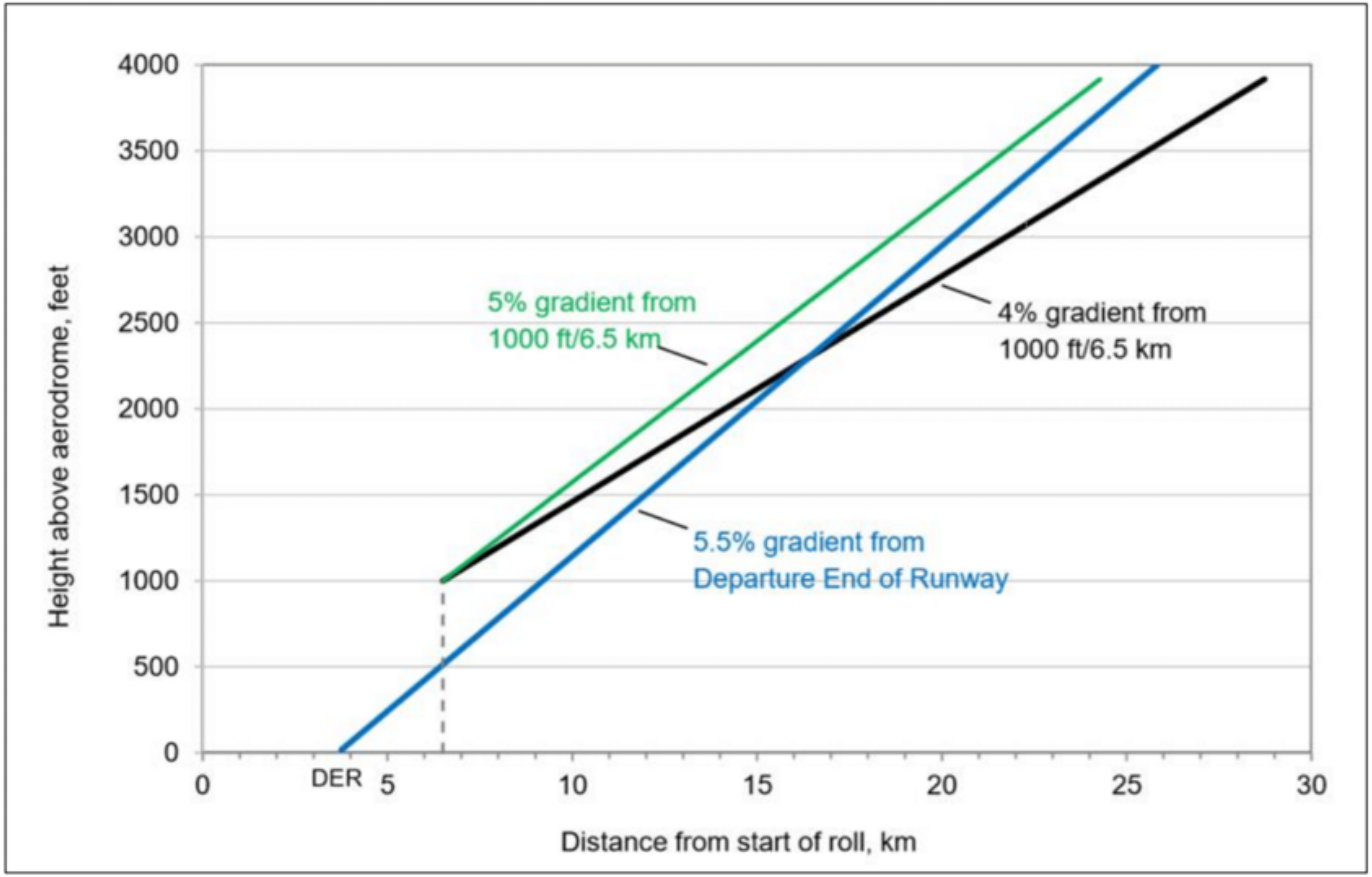

Figure 7. Different methods of measuring gradient

3.2 Conventional or PBN SID

47. In order to ensure that the only variable changed by Heathrow for the trial was the altitude, it was agreed with CAA that the SID should be left as a Conventional SID and not be re-designed to a PBN specification.

3.3 SID Design and validation

48. The trial SID aimed to bring the initial portion of the Instrument Flight Procedure more in line with Heathrow's first Noise Abatement requirement[14] which results in a Procedure Design climb gradient from the DER of c.9% to LON D4. The analysis showed that 99.7% of heavy departures are currently achieving this gradient. Thereafter, the trial SID has added minimum altitude restrictions at LON D4 and DET D34 and an increase at DET D28 which results in a climb gradient of 5% between 1000ft and 4000ft. Figure 8 shows the trial SID as designed by NATS Procedure Designers which we refer to as the DET 1Z.

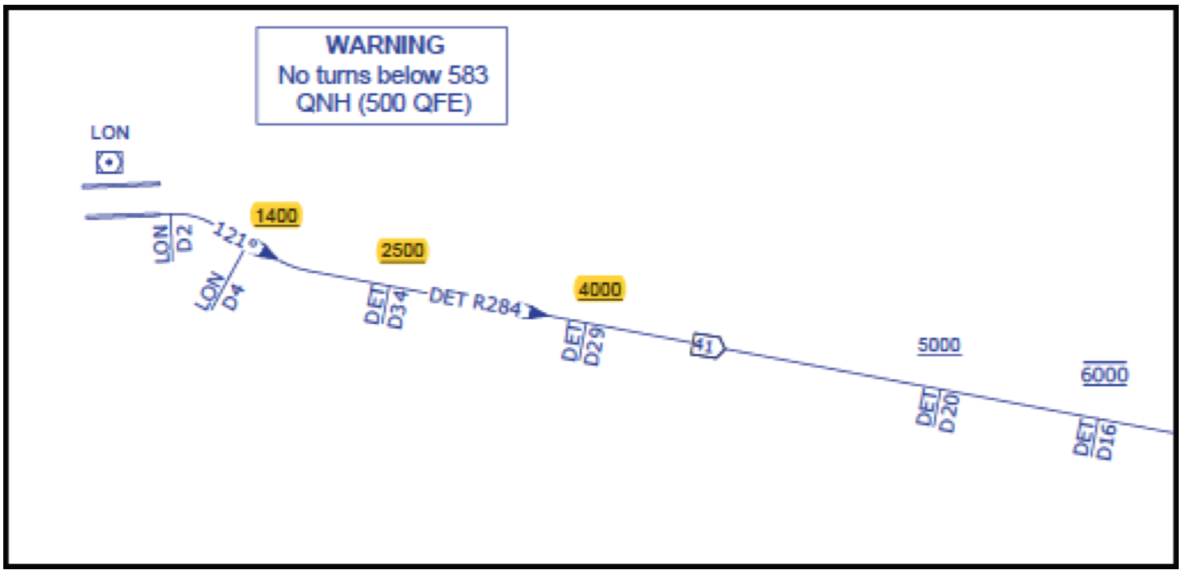

Figure 8. Trial DET 1Z SID profile

49. The DET 2Z Ground Validation was performed in an Etihad A380 Flight Simulator and was also flown in a Singapore B777 simulator in accordance with CAA Policy on the Validation of Instrument Flight Procedures.

50. This trial was initiated by the promulgation of an AIP Supplement which was submitted in October 2017 and published by NATS AIS as part of the AIRAC promulgation

[14] To be 1000ft by 6.5 km after the start of the take-off roll

process. An AIS supplement detailed the Steeper SID trial and included the DET2Z SID chart, which was operated for the duration of the trial.

51. The DET 1Z SID became the default DET departure for runway 09R for the duration of the trial. Any departures unable to accept the DET 1Z SID were offered the extant DET 1J SID on request with ATC.

52. The trial ran for 12 months starting on Thursday 4th January 2018 and ending at 23:59 on Wednesday 2nd January 2019.

3.3.1 ATM system requirements

53. The following Air Traffic Management (ATM) systems were identified as requiring software amendments for the trial:

- Electronic Flight Progress Strips (NATS)
- NATS Supplementary Information System (NATS)
- Airport Noise Monitoring and Management System (Heathrow)

3.4 Pre-trial concerns

54. The nomenclature DET 2Z was to be agreed with CAA who had provisionally proposed DET 1Z. British Airways highlighted that some FMS only display the first 4 characters of the SID selection page. This raised the potential for crews to select the wrong SID in error as DET 1J was still available. Whilst not a safety hazard, it could lead to data collection inaccuracies if small numbers of departures were following the old departure profile unintentionally.

55. ATC and Airlines raised a concern that an increase in climb gradient can result in a slower ground speed which could lead to aircraft catching each other up on departure. This was included in part of the NATS Hazard Analysis and mitigated. The Hazard Analysis was held at NATS (Swanwick) on 31st March 2017. In attendance were two Heathrow Tower Air Traffic Control Officers (ATCOs), a TC Heathrow Approach ATCO, a TC South ATCO, a Heathrow Airspace Performance representative and an airline pilot.

Section 4: Noise monitor deployment

56. Gathering of noise data from aircraft using the extant DET 1J SID began 1st January 2017 from the existing Noise Monitoring Terminals (NMTs) as well as a suite of additional remote NMTs.

57. In total, an additional 12 remote Noise Monitoring Terminals (NMTs) were deployed to collect a baseline[15] against which to compare the steeper SID operations. Full RMT deployment was not completed until June 2017.

58. The purpose of increasing the number of NMTs is to enable the gathering of pre-trial and trial datasets which are large and diverse enough to fully understand the distribution and density of noise energy underneath and to the side of the DET departure route for the extant DET 1J SID and the trial DET 2Z SID.

4.1 ERCD recommendation for Noise Monitor locations

59. Figure 9 below shows the ideal locations for the additional noise monitors locations that were recommended by the CAA's Environmental Research Consultancy Department (ERCD) as well as the existing deployment array.

[15] Jan – Dec 2017

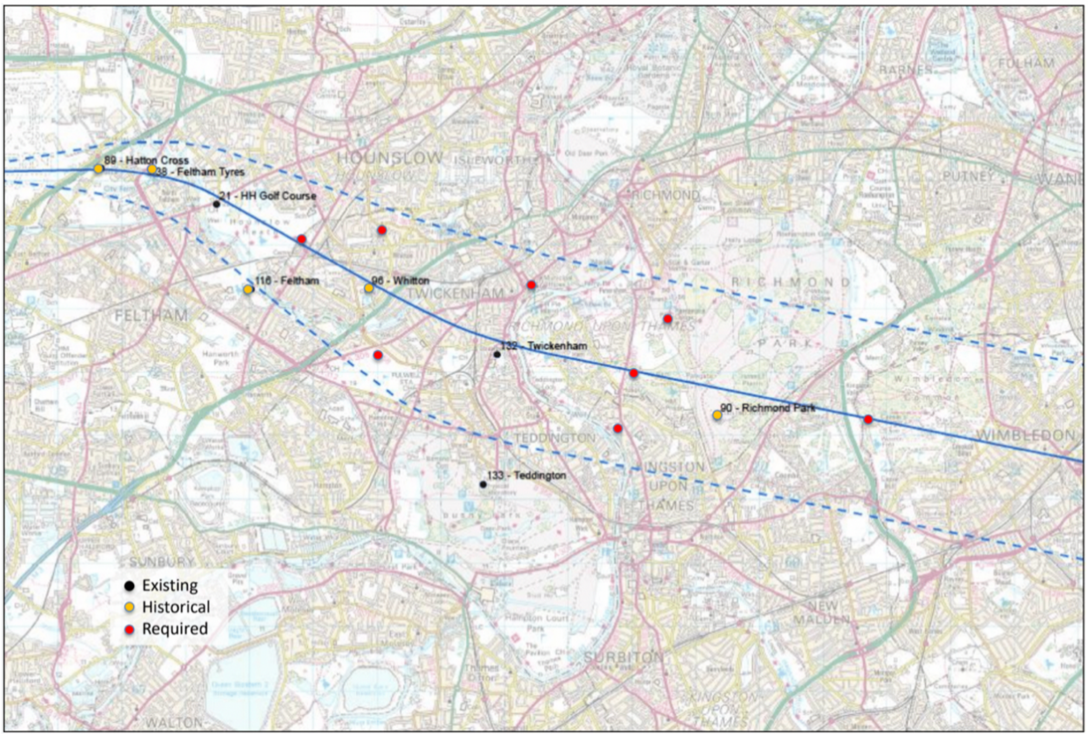

Figure 9. Noise monitors locations recommended by the ERCD

4.2 Actual locations of all monitors

60. Owing the difficulty in finding sites and securing land owner permissions, it was not possible to position all noise monitoring terminals in the ideal locations. Figure 10 below shows the actual locations of the noise monitors.

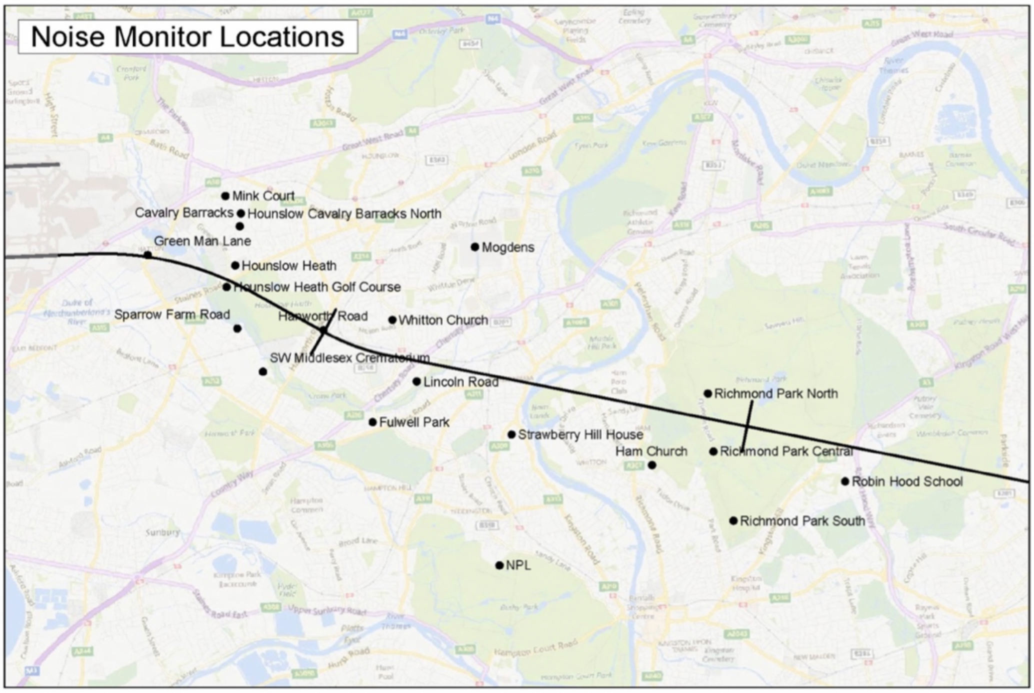

Figure 10. Noise Monitors Locations for the Trial

Section 5: Operational trial analysis

61. This section details the operational analysis which compared the baseline data set (Jan-Dec 2017) to the trial data set (Jan – Dec 2018).

62. For the average altitude summary (Table 39. Average altitudes at LON D4, DET D34 & DET D29), the standard deviation and 95 percent confidence interval (CI) of the average is also reported. The reliability of the measured altitude in each case can be expressed as a 95 percent confidence interval. This is the interval around the sample average within which it is reasonable to assume the 'true' value of the average lies. Due to the relatively large sample size, the 95 percent confidence interval of the altitudes measured in the majority of cases are less than 10ft.

5.1 Easterly versus westerly operations

63. Due to prevailing westerly winds, just under 20% of operations throughout 2017 were Easterly compared to over 35% in 2018 (see Figure 11).

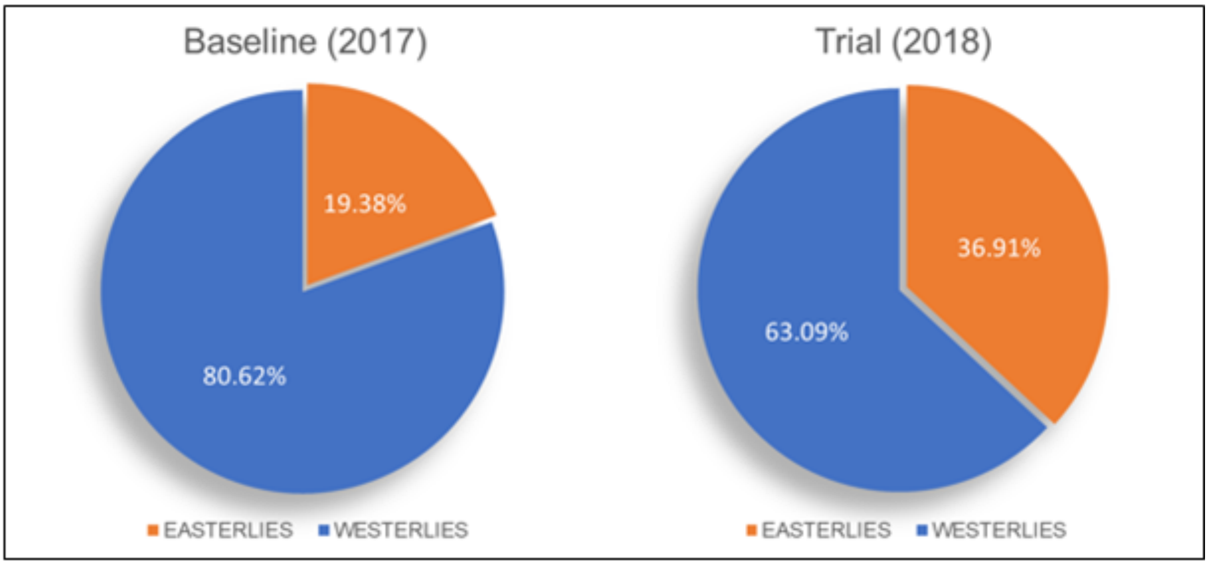

Figure 11. Easterly vs Westerly operations

5.2 Number of DET 09 departures

64. Table 9 below summarises the number of DET departures for 2017 and 2018, showing the difference in each month. It can be seen there were 93% more DET 09 departures in 2018 compared to 2017, largely owing to the increase in easterly operations in 2018.

Table 9. DET Departures (by month)

	Baseline (2017)	Trial (2018)	Difference (%)
Jan	1883	1291	-31.44% ↓
Feb	1548	2009	29.78% ↑
Mar	1130	2912	157.70% ↑
Apr	721	1907	164.49% ↑
May	2207	3188	44.45% ↑
Jun	869	2474	184.70% ↑
Jul	942	1521	61.46% ↑
Aug	514	260	-49.42% ↓
Sep	884	1014	14.71% ↑
Oct	370	1466	296.22% ↑
Nov	53	2922	5413.21% ↑
Dec	311	1116	258.84% ↑
	11432	22080	93.14% ↑

65. As can be seen from Table 10, almost 100% of DET departures in 2018 were following DET 2Z.

Table 10. DET 09 Departures during trial (2018)

	Number of Departures	Percentage of Departures
DET 1J	9	0.04%
DET 2Z	22071	99.96%
	22080	100.00%

66. The average number[16] of daily DET departures increased by 15% during 2018 from 115.5 per day to just over 134 per day.

Table 11. Average DET departures (per day)

	Baseline (2017)	Trial (2018)
DET 1J	115.5	1.1
DET 2Z		133.0
	115.5	134.1

[16] Average based on the number of days with Easterly Operations

5.3 Breakdown of destinations

67. Table 12 shows DET departures broken down by destination groups in 2017 and 2018. Almost all destination regions experienced an increase in the number of DET departures due to the increased proportion of Easterly operations and increase in overall traffic in general caused by a growing market. However only Africa and Europe saw an increase in the overall percentage of traffic with other regions seeing a decrease (see Table 10).

68. As would be expected, an increase in the traffic to Europe is reflected by an increase in short haul traffic (see Table 11).

Table 12. Number of DET departures (by destination)

	Baseline (2017)	Trial (2018)	
Africa	182	396	↑
Europe	5791	12024	↑
Far East	2179	4102	↑
Middle East	3275	5556	↑
UK	5	2	↓
	11432	22080	↑

Table 13. Percentage of DET departures (by destination)

	Baseline (2017)	Trial (2018)	
Africa	1.59%	1.79%	↑
Europe	50.66%	54.46%	↑
Far East	19.06%	18.58%	↓
Middle East	28.65%	25.16%	↓
UK	0.04%	0.01%	↓

Table 14. Percentage of DET departures (by haul)

	Baseline (2017)	Trial (2018)	
Long	42.42%	39.13%	↓
Medium	13.58%	12.62%	↓
Short	43.99%	48.25%	↑

5.4 Passenger numbers and cargo

69. Passenger numbers and cargo data, supplied by Heathrow, is reported as complimentary differences in both could be associated with aircraft climb performance. According to the monthly passenger data summarised in

70. Table 15, there was 2.7% growth in the number of people travelling with April being the only month that had a decline in 2018 compared to 2017.

Table 15. Heathrow passenger numbers

	2017	2018		
	Number of Passengers	Number of Passengers	% Difference	
Jan	5,739,466	5,804,671	1.14%	↑
Feb	5,266,321	5,391,855	2.38%	↑
Mar	6,155,844	6,492,752	5.47%	↑
Apr	6,731,652	6,581,579	-2.23%	↓
May	6,476,024	6,676,963	3.10%	↑
Jun	6,758,018	7,124,524	5.42%	↑
Jul	7,532,422	7,812,309	3.72%	↑
Aug	7,480,285	7,671,950	2.56%	↑
Sep	6,928,800	6,982,147	0.77%	↑
Oct	6,663,671	6,954,019	4.36%	↑
Nov	5,920,389	6,113,761	3.27%	↑
Dec	6,335,860	6,495,487	2.52%	↑
	77,988,752	80,102,017	2.71%	↑

At the same time, volume of cargo reduced by 0.78% with growth only in seven months (see Table 16).

Table 16. Heathrow cargo numbers

	2017	2018		
	Cargo (Metric Tonnes)	Cargo (Metric Tonnes)	% Difference	
Jan	124,401	133,030	6.94%	↑
Feb	126,812	133,140	4.99%	↑
Mar	148,269	150,565	1.55%	↑
Apr	137,979	141,215	2.35%	↑
May	143,511	144,171	0.46%	↑
Jun	142,349	139,329	-2.12%	↓
Jul	143,259	140,241	-2.11%	↓
Aug	139,023	140,738	1.23%	↑
Sep	140,643	142,343	1.21%	↑
Oct	154,492	150,070	-2.86%	↓
Nov	154,364	138,291	-10.41%	↓
Dec	143,353	132,005	-7.92%	↓
	1,698,455	1,685,137	-0.78%	↓

5.5 Airline breakdown

71. Figure 12 below illustrates the proportion of DET departures by airlines in 2017 with 51% dedicated to British Airways and Lufthansa. Figure 13 shows the proportion of DET departures by airline in 2018. As was observed in 2017, the majority of departures were attributed to British Airways and Lufthansa. Austrian Airways replaced Brussels Airways in the top 10 and Germanwings rebranded as Eurowings. No other changes of note were observed. A more detailed breakdown for "Other" category is shown in Figure 14 and Figure 15.

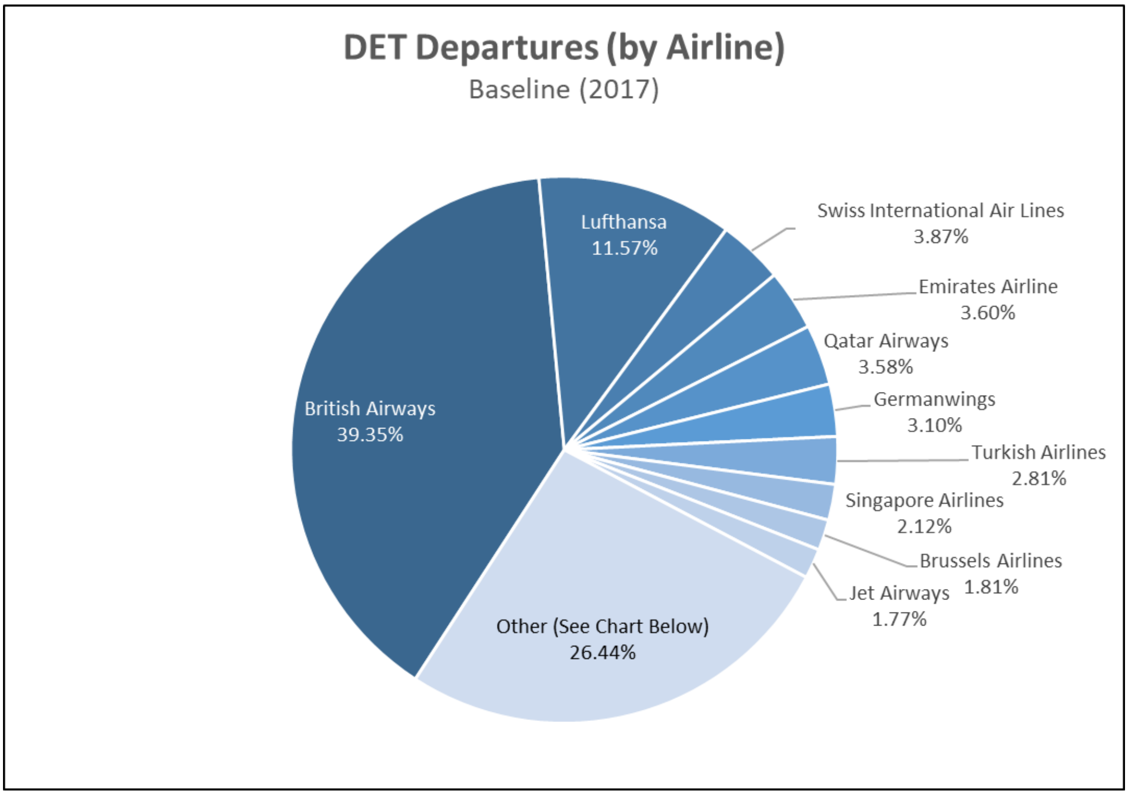

Figure 12. DET Departures (by airline) – baseline

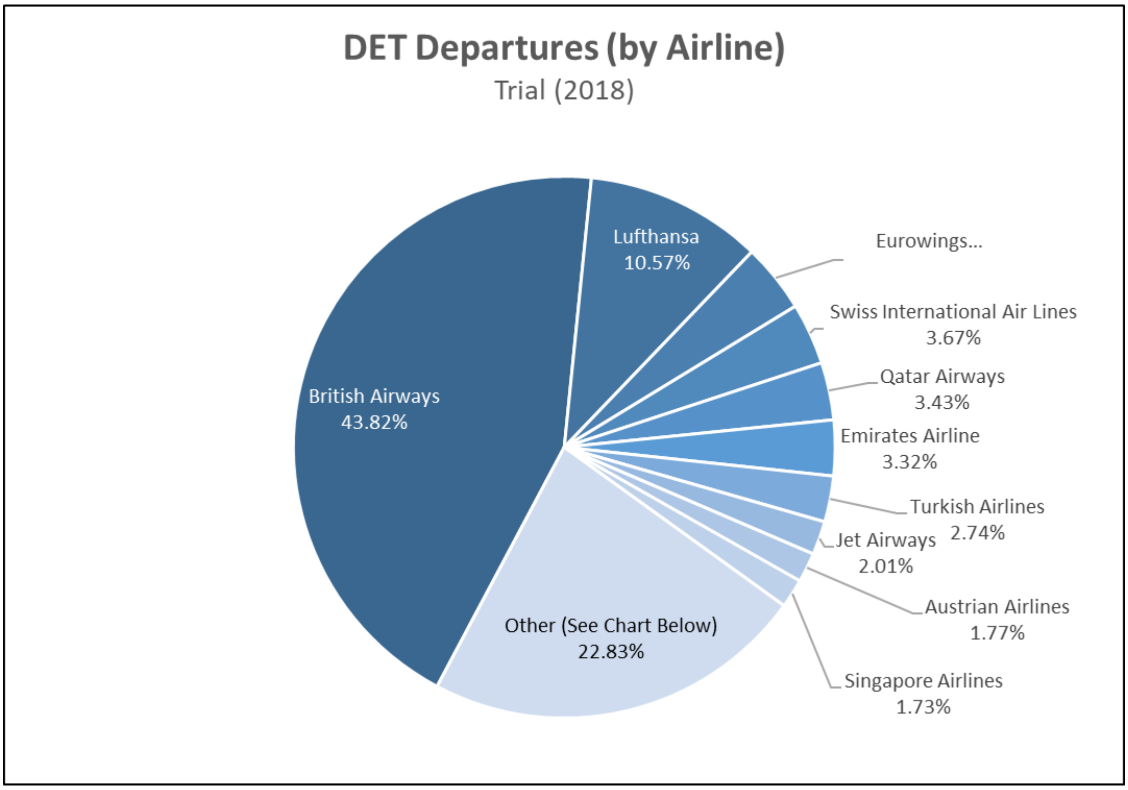

Figure 13. DET departures (by airline) – trial

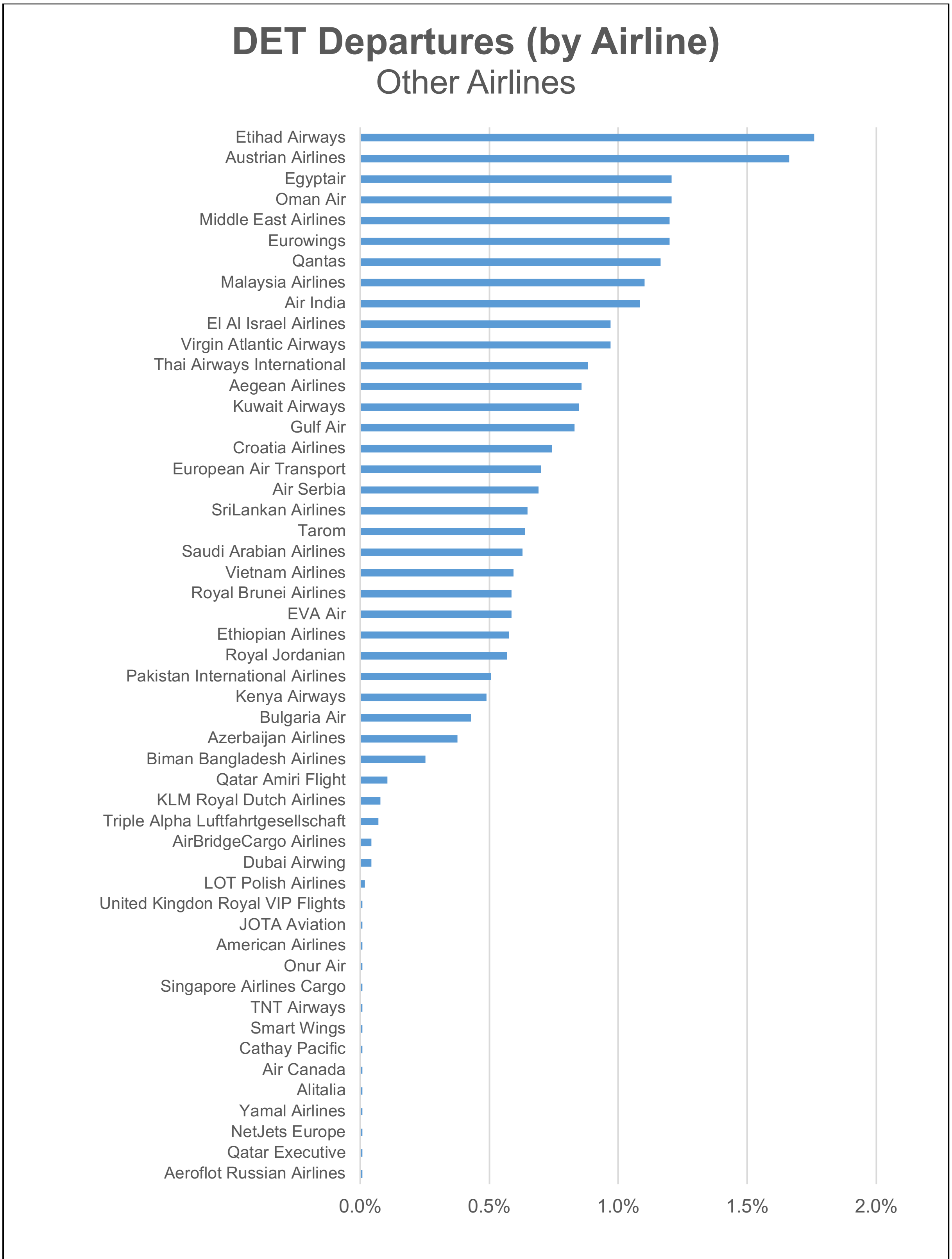

Figure 14. DET Departures (other airlines) – baseline

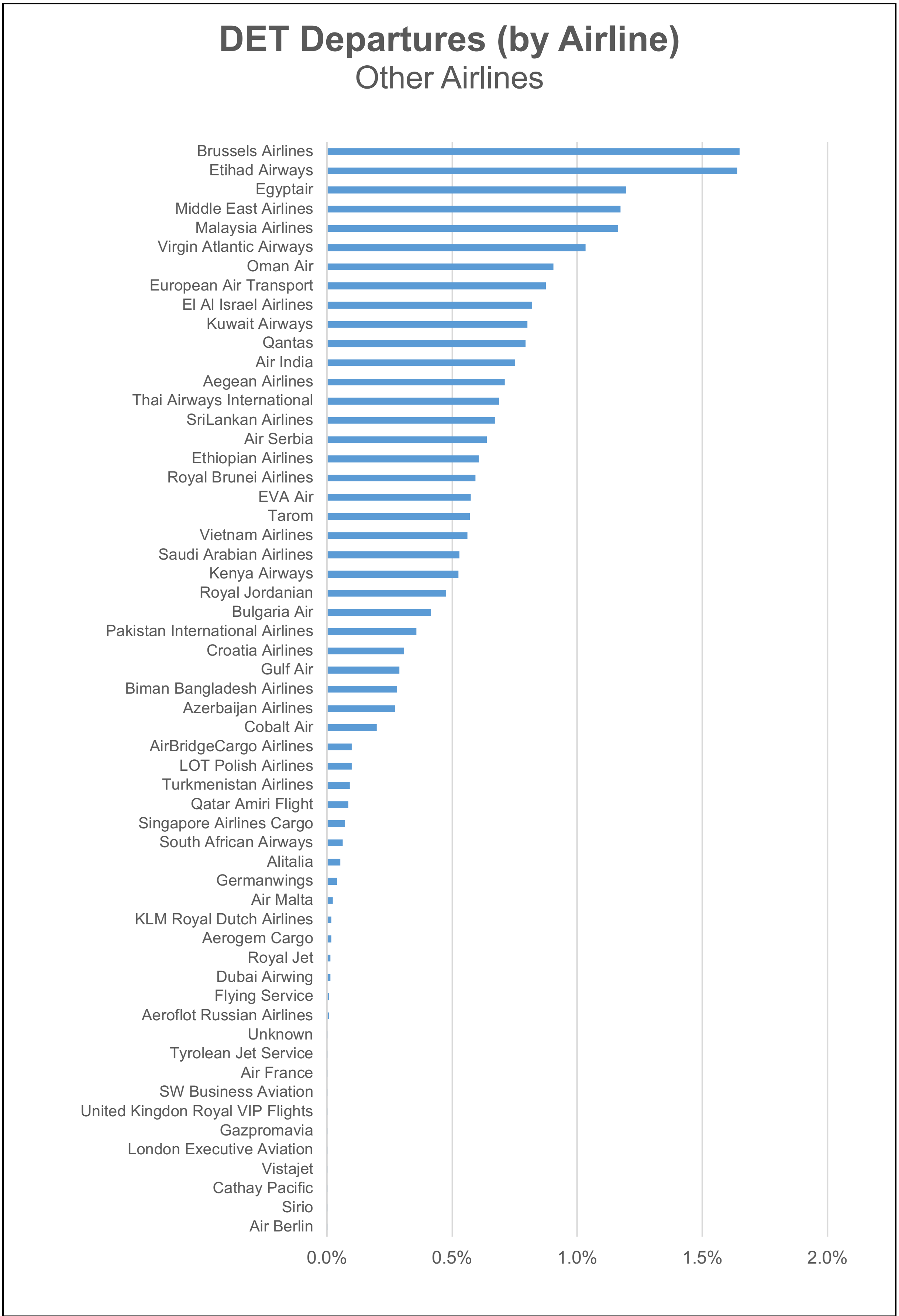

Figure 15. DET Departures (other airlines) – trial

5.6 Aircraft types

72. DET departures by aircraft type comparing 2017 and 2018 are outlined in Table 17

Table 17. DET Departures (by aircraft type)

	Baseline (2017)		Trial (2018)		
Light					
Beech B90 King Air	1	0.01%			↓
Cessna Citation 650			1	0.00%	↑
Cessna Citation 680 Sovereign	1	0.01%	2	0.01%	↑
Gulfstream G280	1	0.01%			↓
	3	**0.03%**	**3**	**0.01%**	↓
Medium					
Airbus A318	77	0.67%	124	0.56%	↓
Airbus A319	1869	16.35%	3704	16.78%	↑
Airbus A320	800	7.00%	1781	8.07%	↑
Airbus A320 Neo	188	1.64%	911	4.13%	↑
Airbus A320-100/200	2056	17.98%	4114	18.63%	↑
Airbus A321	126	1.10%	280	1.27%	↑
Airbus A321 Neo			2	0.01%	↑
Airbus A321-100/200	983	8.60%	1554	7.04%	↓
Avro RJ100 Avroliner	3	0.03%			↓
Boeing 737 MAX 8 pax	1	0.01%	21	0.10%	↑
Boeing 737-300 pax	1	0.01%			↓
Boeing 737-400 pax	1	0.01%	1	0.00%	↓
Boeing 737-700 (winglets) pax	6	0.05%	6	0.03%	↓
Boeing 737-800	3	0.03%	4	0.02%	↓
Boeing 737-800 (winglets) pax	74	0.65%	173	0.78%	↑
Boeing 737-800 pax	6	0.05%	10	0.05%	↓
Boeing 737-900 pax	1	0.01%			↓
Bombadier 500 C Series CS300	3	0.03%	55	0.25%	↑
Bombadier Challenger 350	1	0.01%	2	0.01%	↑
Bombadier Challenger 600			2	0.01%	↑
Bombadier Challenger 605			1	0.00%	↑
Bombardier CS100	6	0.05%	14	0.06%	↑
Canadair Global Express	1	0.01%	2	0.01%	↑
Canadair Regional Jet 900	1	0.01%	1	0.00%	↓
Dassault Falcon 2000EX/EASY/LX			1	0.00%	↑
Dassault Falcon 900			1	0.00%	↑
De Havilland Canada DHC-8-400 Dash 8Q			9	0.04%	↑
Embraer 190	23	0.20%	32	0.14%	↓
Embraer E195	1	0.01%	3	0.01%	↑
Fokker 100	8	0.07%	3	0.01%	↓
Gulfstream G650	4	0.03%	1	0.00%	↓
Gulfstream V			1	0.00%	↑
	6243	**54.61%**	**12813**	**58.03%**	↑

Upper Medium					
Boeing 757 Freighter	10	0.09%	19	0.09%	↓
Boeing 757-200			1	0.00%	↑
Boeing 757-200 pax	12	0.10%	12	0.05%	↓
	22	**0.19%**	**32**	**0.14%**	↓
Heavy					
Airbus A330-200	184	1.61%	194	0.88%	↓
Airbus A330-200 Freighter			10	0.05%	↑
Airbus A330-300	325	2.84%	467	2.12%	↓
Airbus A340-200	2	0.02%	4	0.02%	↑
Airbus A340-300			38	0.17%	↑
Airbus A340-500	6	0.05%	1	0.00%	↓
Airbus A340-600	10	0.09%	1	0.00%	↓
Airbus A350-1000			93	0.42%	↑
Airbus A350-900	183	1.60%	483	2.19%	↑
Airbus Industrie A600-600 Freighter	68	0.59%	173	0.78%	↑
Boeing 747-400 Combi	2	0.02%			↓
Boeing 747-400 Freighter	16	0.14%	29	0.13%	↓
Boeing 747-400 pax	219	1.92%	313	1.42%	↓
Boeing 747-800F	8	0.07%	10	0.05%	↓
Boeing 767-300			3	0.01%	↑
Boeing 767-300 pax	230	2.01%	348	1.58%	↓
Boeing 777-200 pax	714	6.25%	1433	6.49%	↑
Boeing 777-200LR	15	0.13%	17	0.08%	↓
Boeing 777-300ER	1029	9.00%	2066	9.36%	↑
Boeing 777F	8	0.07%	30	0.14%	↑
Boeing 787-800	494	4.32%	799	3.62%	↓
Boeing 787-900	491	4.29%	990	4.48%	↑
	4004	**35.02%**	**7502**	**33.98%**	↓
Super Heavy					
Airbus A380-800	1160	10.15%	1730	7.84%	↓
	1160	**10.15%**	**1730**	**7.84%**	↓
	11432	100.00%	22080	100.00%	

73. Of note, although the number of A380 operations increased as a result of an increase in easterly operations, as a percentage it was the aircraft type with the biggest reduction.

74. Table 18 below shows summarises the number of DET departures by Aircraft Category.

Table 18. Summary of DET Departures (by Aircraft Category)

	Baseline (2017)	Trail (2018)	
Light	0.03%	0.01%	↓
Medium	54.61%	58.03%	↑
Upper Medium	0.19%	0.14%	↓
Heavy	35.02%	33.98%	↓
Super Heavy	10.15%	7.84%	↓
	100.00%	100.00%	

5.7 Aircraft heights

75. This section contains the detailed analysis of the heights that aircraft flying the DET 09 departure routes achieved during 2017 and 2018.

76. From an ATC perspective an aircraft is deemed to be at or maintaining its level if it is within 200ft of the required level restriction. It was uncovered from airline feedback during the trial that some aircraft will only provide an alert to the pilot if it is predicted to not meet a level restriction by 250ft or more. In addition, an aircraft can be assessed as being over a specific location if it is within a mile laterally (assuming RNAV1 performance and more if navigating conventionally). Finally, an absolute measure with no tolerance is considered too prescriptive for analysis.

77. For these reasons, the analysis is broken down to show whether aircraft were within -100ft, -200ft and -250ft of the required level restriction.

78. Figure 16 shows the vertical profiles of the DET 2Z trial SID and the existing 4% noise abatement requirement[17].

[17] The noise abatement requirement is monitored with zero tolerance

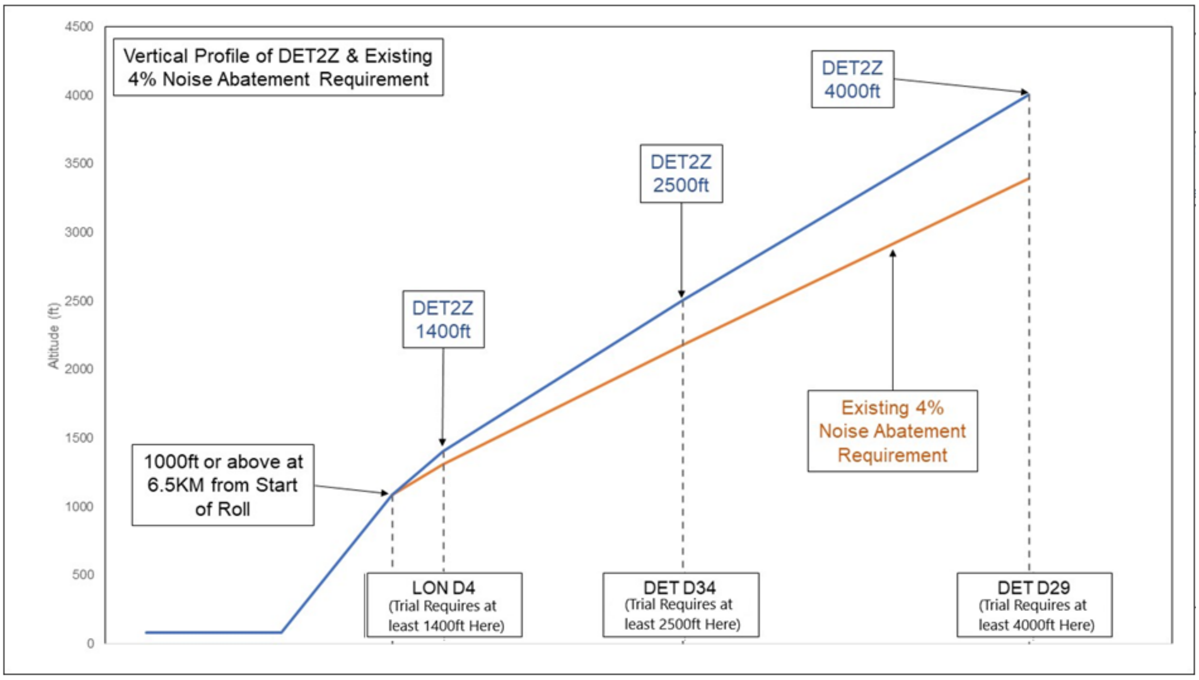

Figure 16. Vertical profiles of the DET 2Z SID and the existing 4% Noise Abatement Requirement

5.7.1 4% and 5% adherence

79. As outlined in section 3.1.2 one of the current requirements for noise abatement at Heathrow is for departures to maintain a climb gradient of at least 4% between 1000ft and 4000ft.

80. It is important to understand a constant climb gradient is not able to be coded into aircraft Flight Management Computers as part of an Instrument Flight Procedure. The minimum altitude restrictions included in the trial were to help simulate a 5% gradient but aircraft can, and did, vary their vertical profiles in between the published altitude points.

81. In 2017, 99.23% of all DET09 departures adhered to the 4% to 4000ft noise abatement requirement. During the trial, this increased to 99.5%.

82. Whilst the trial did not officially change the published noise abatement requirement, the DET 2Z SID aimed to generate a departure profile equivalent to 5% between 1000ft and 4000ft. Analysis shows that pre-trial in 2017, 97.63% of DET departures maintained at least a 5% gradient to 4000ft. This increased to 98.26% during the trial.

83. Looking at just the heavy A340/A380/B747/B777 departures, in 2017, before the trial, 92.81% were maintaining a 5% climb gradient between 1000ft and 4000ft. During the trial when the altitude restrictions were added, this number increased to 94.09%.

5.7.2 LON D4

84. The average altitude at LON D4 increased from 2257ft to 2308ft during the trial. Increases to the minimum and maximum altitudes were also observed (see Table 19).

Table 19. MIN/MAX/AVG Altitude at LON D4

MIN ALTITUDE			AVERAGE ALTITUDE			MAX ALTITUDE		
Baseline	**Trial**		**Baseline**	**Trial**		**Baseline**	**Trial**	
1022	1213	↑	2257	2308	↑	4923	5780	↑

85. This overall improvement in climb performance resulted in a change to the average (mean) location where aircraft reached 1400ft. As can be seen in Figure 17, aircraft achieved 1400ft approximately 150m earlier than they did during 2017.

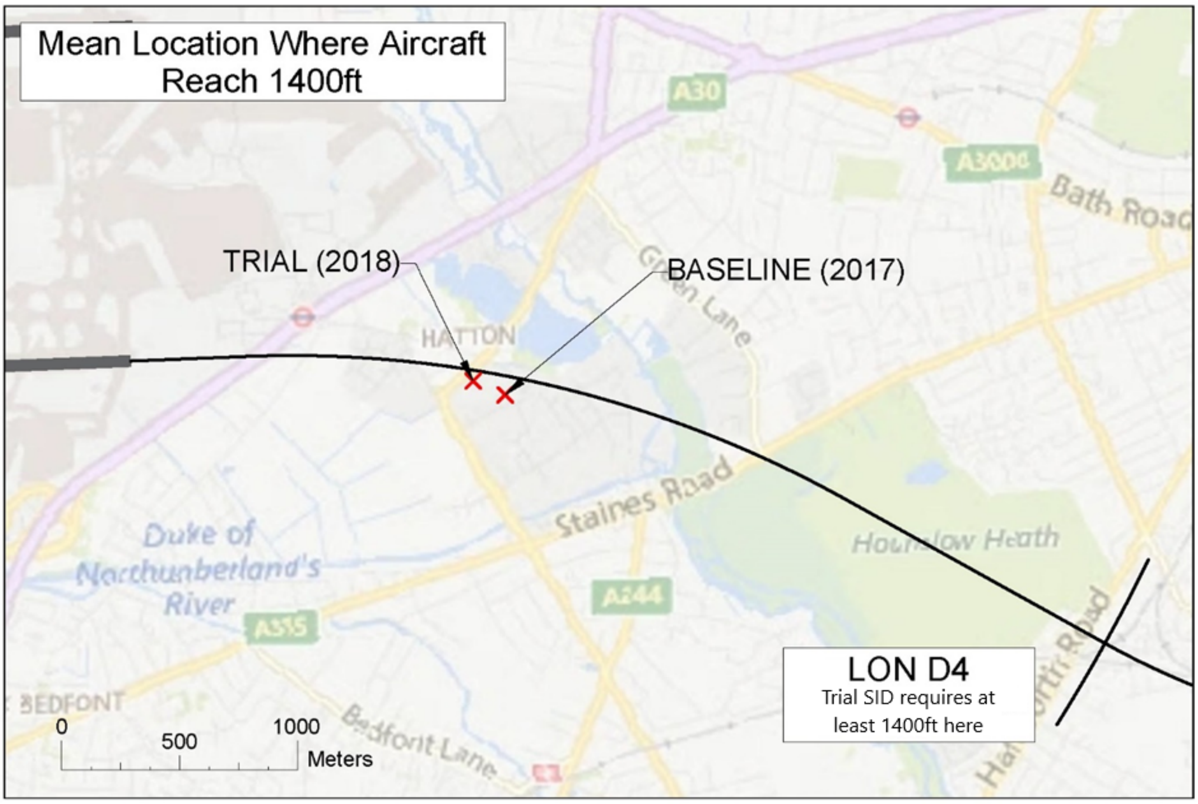

Figure 17. Mean Location Where Aircraft Reach 1400ft

86. Aircraft are required to be 1400 ft or above at LON D4 when departing on the DET 2Z trial SID and all flights were within 200 ft, standard tolerance, of this level. Table 20 summarises % of aircraft that did not make the 1400 ft restriction at D4.

Table 20. Percentage of aircraft below 1400ft at LON D4

	Baseline (2017)	Trial (2018)	
% 100ft Below Level Restriction	0.15%	0.08%	↓
% 200ft Below Level Restriction	0.03%	0.00%	↓
% 250ft Below Level Restriction	0.03%	0.00%	↓

Table 21 shows that the overall minimum, average and maximum altitudes at LON D4 increased for Airbus A380s during 2018.

87. Table 22 shows that the average altitude at LON D4 also increased for long haul flights.

Table 21. MIN/MAX/AVG Altitude at LON D4 (by aircraft type)

	MIN ALTITUDE			AVERAGE ALTITUDE			MAX ALTITUDE		
	2017	2018		2017	2018		2017	2018	
Airbus A318	2116	2071	↓	2562	2663	↑	3786	3816	↑
Airbus A319	1754	1494	↓	2591	2498	↓	4287	4543	↑
Airbus A320	1434	1392	↓	2356	2355	↓	4268	4172	↓
Airbus A320 Neo	1940	1854	↓	2557	2761	↑	4077	4852	↑
Airbus A321	1348	1388	↑	2363	2403	↑	3692	3909	↑
Airbus A321 Neo	-	3120	-	-	3287	-	-	3488	-
Airbus A330	1141	1382	↑	2373	2349	↓	3832	4025	↑
Airbus A340	1390	1388	↓	1932	1981	↑	2711	3075	↑
Airbus A350	1594	1344	↓	2309	2245	↓	3524	3852	↑
Airbus A380	1142	1213	↑	1652	1729	↑	2837	3321	↑
Boeing 737	1996	1654	↓	2832	2732	↓	4093	4159	↑
Boeing 747	1022	1332	↑	2251	2255	↑	4606	4300	↓
Boeing 757	2071	1987	↓	3273	3666	↑	4923	5219	↑
Boeing 767	1426	1503	↑	2034	2024	↓	4159	4185	↑
Boeing 777	1365	1371	↑	2128	2178	↑	3955	4633	↑
Boeing 787	1395	1418	↑	2003	2115	↑	3688	3892	↑
Other	1922	2108	↑	3325	3512	↑	4862	5780	↑

**Denotes the lowest or highest value

Table 22. Average altitude at LON D4 (by haul)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Long	2019	2076	2.83%	↑
Medium	2343	2403	2.57%	↑
Short	2487	2486	-0.06%	↓
	2257	2308	2.27%	↑

88. Table 23 below shows that all but 6 aircraft types improved their average altitude at LON D4 during the trial. The biggest improvement observed was by B757 with a 12% improvement. However, it should be noted that B757 had a very small sample size in both 2017 and 2018 (<0.2%) and therefore the result is not necessarily statistically significant.

Table 23. Average altitude at LON D4 (by aircraft type)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	**Average of Altitude (ft)**	**Improvement**	
Boeing 757	3273	3666	12.02%	↑
Airbus A320 Neo	2557	2761	7.99%	↑
Other	3325	3514	5.69%	↑
Boeing 787	2003	2115	5.60%	↑
Airbus A380	1652	1729	4.67%	↑
Airbus A318	2562	2663	3.92%	↑
Airbus A340	1932	1981	2.52%	↑
Boeing 777	2128	2178	2.34%	↑
Airbus A321	2363	2403	1.67%	↑
Boeing 747	2251	2255	0.15%	↑
Airbus A320	2356	2355	-0.06%	↓
Boeing 767	2034	2024	-0.51%	↓
Airbus A330	2373	2349	-1.02%	↓
Airbus A350	2309	2245	-2.76%	↓
Boeing 737	2832	2732	-3.56%	↓
Airbus A319	2591	2498	-3.58%	↓
Airbus A321 Neo	N/A	3287		
	2257	2308	2.27%	↑

89. By grouping aircraft according to their wake vortex category, we can see that all categories of aircraft, except Medium, made improvements to their average altitude at LON D4.

90. The Upper Medium (B757) category of aircraft had the biggest improvement, followed by Light aircraft, Super Heavies (A380) and finally Heavy.

Table 24. Average altitude at LON D4 (by aircraft category)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Upper Medium	3273	3666	12.02%	↑
Light	3620	3830	5.78%	↑
Super Heavy	1652	1729	4.67%	↑
Heavy	2166	2220	2.49%	↑
Medium	2452	2451	-0.03%	↓
	2257	2308	2.27%	↑

91. This overall improvement in performance is further evident in Figure 18 below which shows the mean location each aircraft type reached 1400 ft during 2017 and 2018.

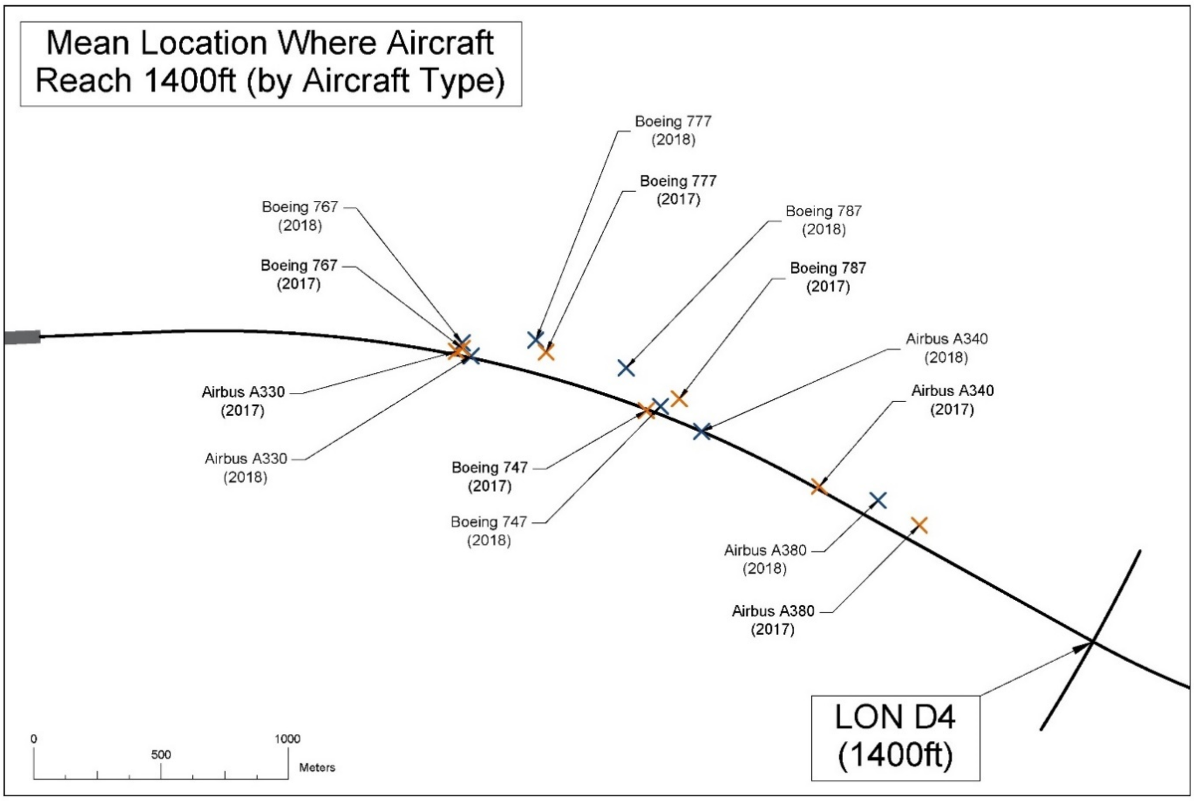

Figure 18. Mean Location Where Aircraft Reach 1400ft (by Aircraft Type)

5.7.3 DET D34

92. The DET 2Z trial SID requires aircraft to be 2500 ft or above at DET D34. The average altitude at DET D34 increased by 71ft during the trial from 4005 ft to 4076 ft. A slight improvement to the maximum average altitude was also observed however the minimum altitude was considerably lower when compared to 2017.

Table 25. MIN/MAX/AVG Altitudes at DET D34

MIN ALTITUDE		AVERAGE ALTITUDE		MAX ALTITUDE	
Baseline	Trial	Baseline	Trial	Baseline	Trial
2203	1803	4005	4076	5991	5994

93. As happened at LON D4, the overall improvement to the climb performance resulted in a small change to the average location where aircraft achieved 2500ft, compared to 2017 (see Figure 19).

Figure 19. Mean location where aircraft reached 2500 ft

94. Data shows that during the trial 20 flights (0.09%) were 200ft or more below of which 9 flights (0.04%) were 250ft or more below (see Table 26).

Table 26. Percentage of aircraft below 2500ft at DET D34

	Baseline (2017)	Trial (2018)
% 100ft Below Level Restriction	0.39%	0.24%
% 200ft Below Level Restriction	0.10%	0.09%
% 250ft Below Level Restriction	0.03%	0.04%

95. Table 27 shows a breakdown of the 20 aircraft that were more than 200ft below 2500ft at DET D34 during the trial.

Table 27. Aircraft more than 200 ft below 2500 ft at DET D34 (2018)

Month	Haul	Destination	Aircraft Type	Altitude (ft)
Mar	Long	Chennai International Airport	Boeing 787	2230
	Long	Dubai International Airport	Airbus A330	2187
	Long	Dubai International Airport	Airbus A380	2290
	Long	OR Tambo International Airport	Airbus A380	2288
Apr	Long	Dubai International Airport	Airbus A380	2218
	Long	Dubai International Airport	Airbus A380	2290
May	Long	Abu Dhabi International Airport	Airbus A380	2277
	Long	Chhatrapati Shivaji International Airport	Boeing 777	2277
	Long	Dubai International Airport	Airbus A380	2249
	Long	Imam Khomeini International Airport	Boeing 777	2260
Jul	Long	Dubai International Airport	Airbus A380	2257
	Long	Dubai International Airport	Boeing 777	1803
	Long	Singapore Changi Airport	Airbus A380	2277
Aug	Long	Abu Dhabi International Airport	Airbus A380	2256
	Long	Indira Gandhi International Airport	Boeing 777	2231
Sep	Long	Dubai International Airport	Airbus A380	2294
Oct	Long	Abu Dhabi International Airport	Airbus A340	2123
	Long	Abu Dhabi International Airport	Airbus A380	2288
Nov	Long	Kuala Lumpur International Airport	Boeing 787	2210
	Long	Rajiv Gandhi International Airport	Boeing 787	2027

96. Figure 16 and Figure 21 articulate that those aircraft that were more than 200ft below the required SID altitude restriction were climbing more steeply before and after this point. This suggest all these aircraft were accelerating between c.1500ft and 2500ft with a resultant decrease in climb performance. This performance can be expected from a NADP2 departure[18] however operators are primarily expected to achieve the requirements of the published SID profile, which these flights did not.

[18] See CAP 1691 for further details on NADP procedures (www.caa.co.uk/CAP1691)

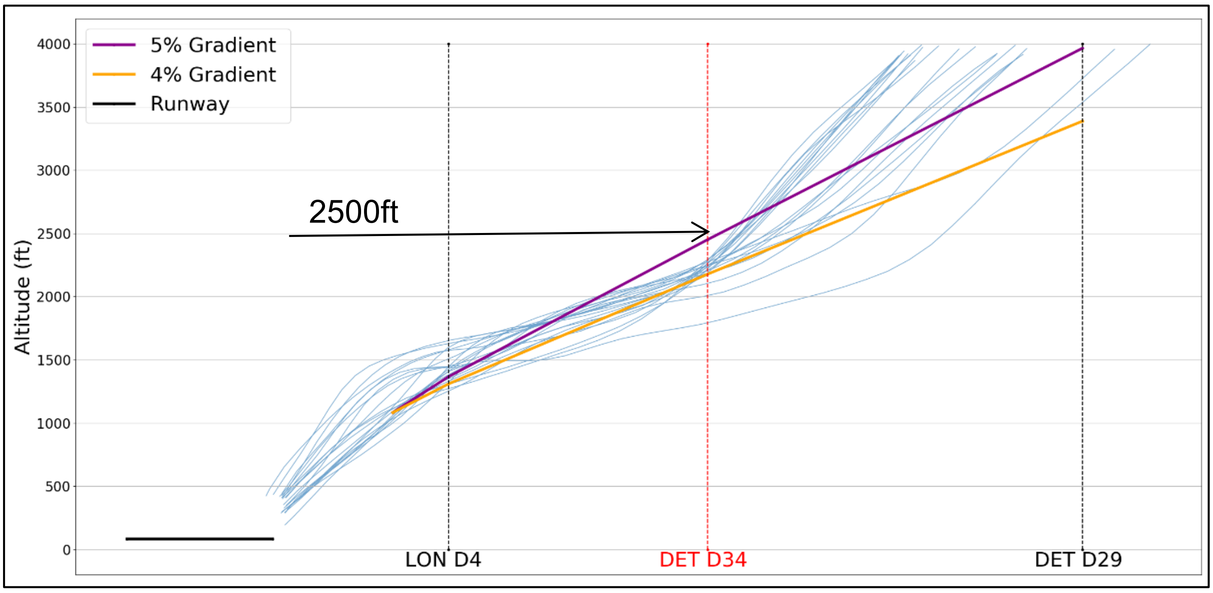

Figure 20. Profile view of aircraft more than 200 ft below 2500 ft at DET D34 (2018)

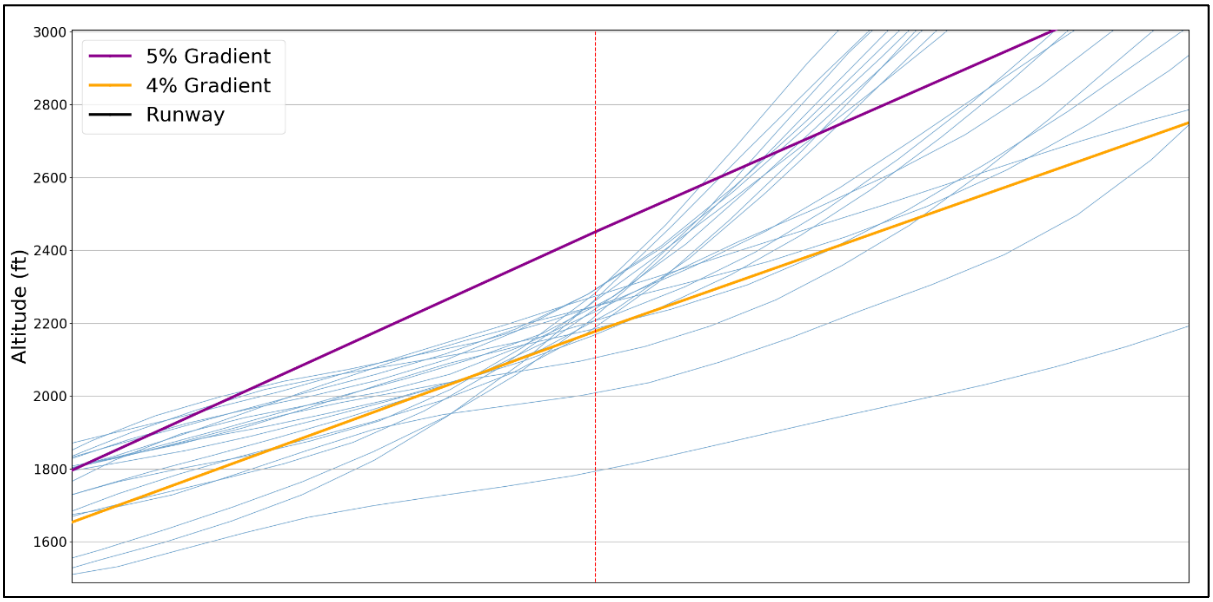

Figure 21. Close-up profile view of aircraft more than 200 ft below 2500 ft at DET D34 (2018)

97. As can be seen, all aircraft more than 200ft below the level restriction were long haul flights and the majority were Heavy or Super Heavy aircraft. Figure 22 shows each aircraft type that failed to make the DET D34 level restriction.

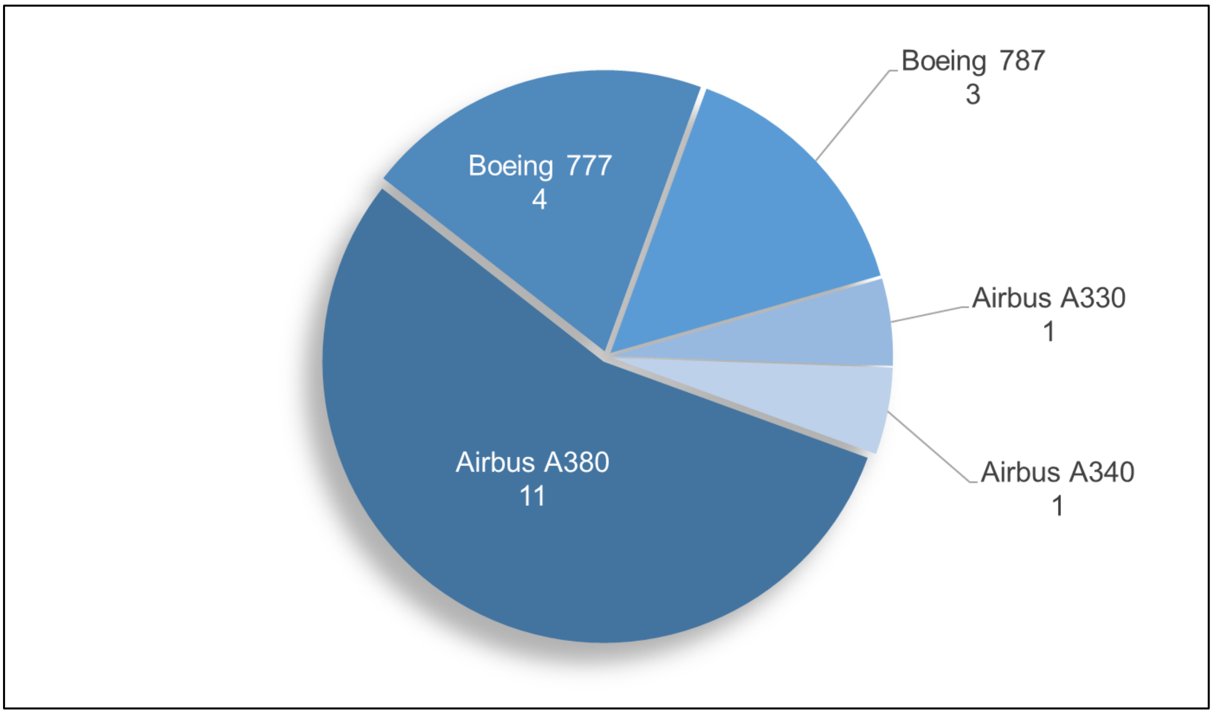

Figure 22. Aircraft types 200 ft or more below 2500 ft at DET D34 (2018)

98. Table 28 and Table 29 show that the overall minimum, maximum and average altitudes at DET D34 increased for all aircraft types.

Table 28. MIN/MAX/AVG Altitudes at DET D34 (by aircraft type)

	MIN ALTITUDE			AVERAGE ALTITUDE			MAX ALTITUDE		
	2017	2018		2017	2018		2017	2018	
Airbus A318	3461	3503	↑	4264	4423	↑	5276	5521	↑
Airbus A319	3156	3139	↓	4492	4433	↓	5974	5945	↓
Airbus A320	2753	2621	↓	4234	4254	↑	5899	5945	↑
Airbus A320 Neo	3639	3591	↓	4526	4708	↑	5684	5984	↑
Airbus A321	2540	2649	↑	4012	4000	↓	5825	5760	↓
Airbus A321 Neo	-	4584	-	-	4863	-	-	5141	-
Airbus A330	2298	2187	↓	3830	3817	↓	5665	5955	↑
Airbus A340	2377	2123	↓	3593	3389	↓	4458	5170	↑
Airbus A350	2886	2438	↓	4012	3809	↓	5008	5528	↑
Airbus A380	2203	2218	↑	3242	3338	↑	5163	5049	↓
Boeing 737	2991	3390	↑	4514	4449	↓	5914	5959	↑
Boeing 747	2643	2757	↑	4525	4495	↓	5913	5956	↑
Boeing 757	4298	3879	↓	5164	5361	↑	5877	5969	↑
Boeing 767	2433	2820	↑	3920	3899	↓	5765	5870	↑
Boeing 777	2277	1803	↓	3700	3810	↑	5782	5937	↑
Boeing 787	2265	2027	↓	3681	3819	↑	5711	5715	↑
Other	3384	3677	↑	4828	5104	↑	5991	5994	↑

**Denotes the lowest or highest value

Table 29. Average altitudes at DET D34 (by aircraft type)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Other	4828	5106	5.78%	↑
Airbus A320 Neo	4526	4708	4.02%	↑
Boeing 757	5164	5361	3.83%	↑
Boeing 787	3681	3819	3.74%	↑
Airbus A318	4264	4423	3.73%	↑
Boeing 777	3700	3810	2.98%	↑
Airbus A380	3242	3337	2.93%	↑
Airbus A320	4234	4254	0.47%	↑
Airbus A321	4012	4000	-0.31%	↓
Airbus A330	3830	3817	-0.35%	↓
Boeing 767	3920	3899	-0.53%	↓
Boeing 747	4525	4496	-0.64%	↓
Airbus A319	4492	4433	-1.30%	↓
Boeing 737	4514	4449	-1.42%	↓
Airbus A350	4012	3809	-5.06%	↓
Airbus A340	3593	3389	-5.68%	↓
Airbus A321 Neo	N/A	4863		
	4005	4076	1.79%	↑

99. Table 30 also shows that long haul flights had the biggest increase on the average altitude at DET D34 with just over a 2% improvement whilst Table 31 shows that all categories of aircraft made overall improvements during the trial.

Table 30. Average altitude at DET D34 (by haul)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Long	3653	3733	2.17%	↑
Medium	4038	4067	0.70%	↑
Short	4362	4385	0.53%	↑
	4005	4076	1.79%	↑

Table 31. Average altitude at DET D34 (by aircraft category)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Light	4903	5343	8.98%	↑
Upper Medium	5164	5361	3.83%	↑
Super Heavy	3242	3337	2.93%	↑
Heavy	3814	3877	1.67%	↑
Medium	4286	4310	0.55%	↑
	4005	4076	1.79%	↑

100. Figure 23 below shows the change in average location where aircraft achieved 2500 ft.

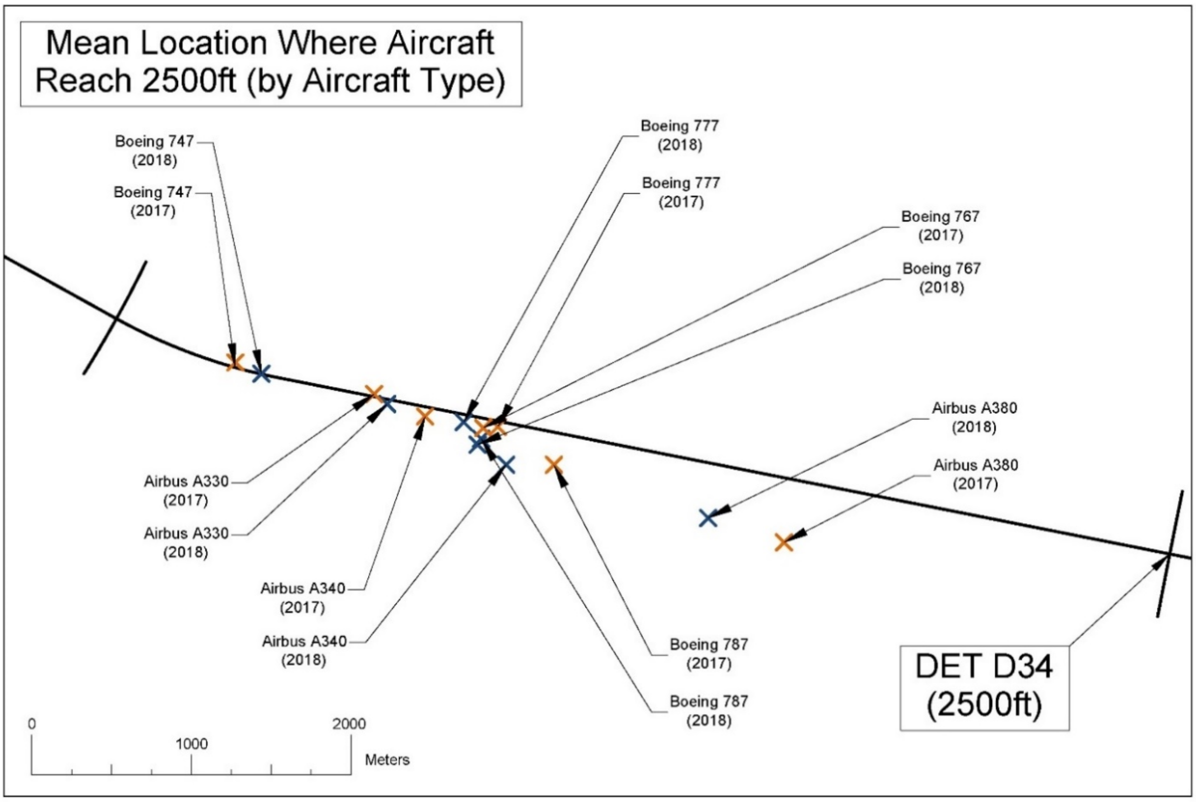

Figure 23. Mean location where aircraft reach 2500 ft (by aircraft type)

5.7.4 DET D29

101. The DET 2Z trial requires aircraft to be 4000ft or above by DET D29. The average altitude at DET D29 increased from 5566 ft to 5605 ft during the trial. The minimum and maximum altitudes also increased (see Table 32).

Table 32. MIN/MAX/AVG Altitude at DET D29

MIN ALTITUDE			AVERAGE ALTITUDE			MAX ALTITUDE		
Baseline	Trial		Baseline	Trial		Baseline	Trial	
3105	3174	↑	5566	5605	↑	5788	5843	↑

102. The result of this improvement is a change to mean location where the aircraft achieved 4000ft, as shown in Figure 24 below.

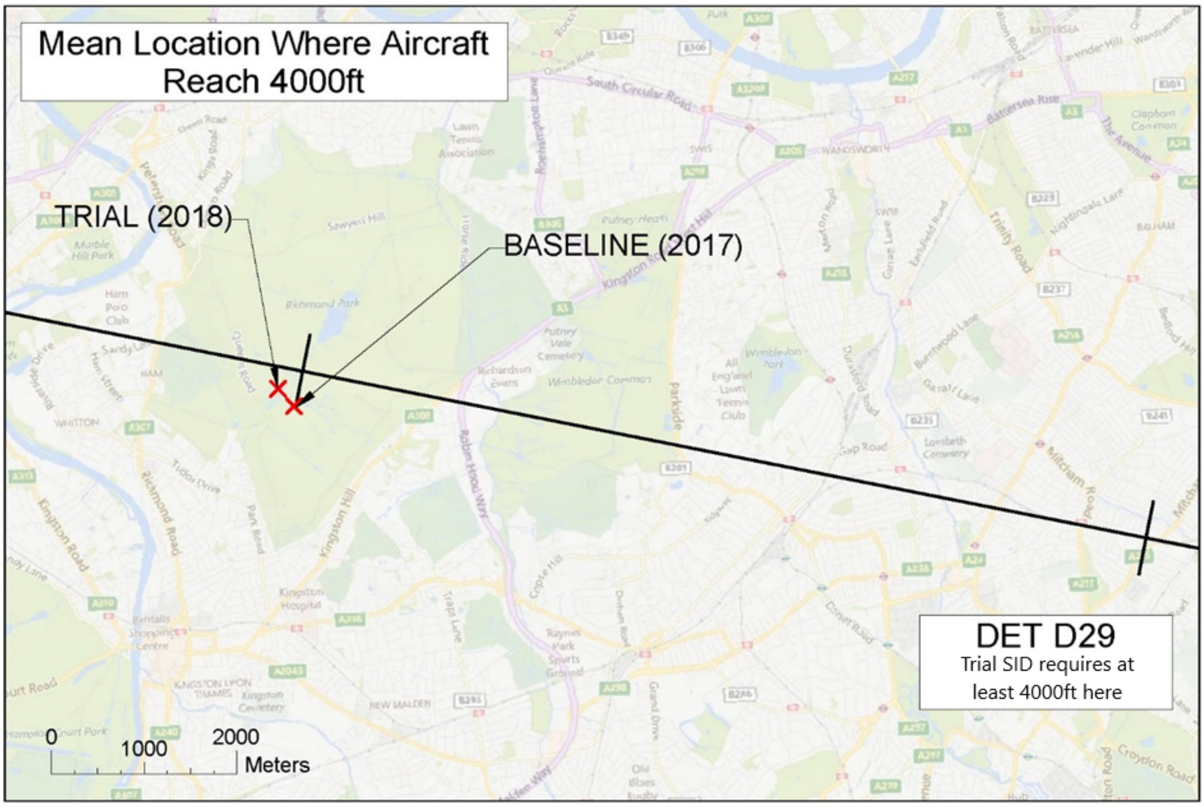

Figure 24. Mean location where aircraft reached 4000ft

103. Trial data shows that 8 flights (0.04%) were 200 ft or more below 2500 ft at DET D34 of which 6 flights (0.03%) were 250 ft or more below. This is an overall improvement on the percentage of aircraft that were less than 4000ft at DET D29 during 2017.

Table 33. Percentage of aircraft below 4000 ft at DET D29

	Baseline (2017)	Trial (2018)	
% 100ft Below Level Restriction	0.11%	0.05%	↓
% 200ft Below Level Restriction	0.07%	0.04%	↓
% 250ft Below Level Restriction	0.07%	0.03%	↓

104. Table 34 shows a breakdown of the 8 aircraft that were more than 200ft below 4000ft at DET D29 during the trial. As can be seen, all flights that failed to meet the DET D29 restriction were long haul and more than 60% of the aircraft were B777's.

Table 34. Aircraft 200 ft or more below 4000 ft at DET D29

Month	Haul	Destination	Aircraft Type	Altitude (ft)
Mar	Long	Hamad International Airport	Boeing 777	3676
	Long	Imam Khomeini International Airport	Boeing 777	3763
	Long	Indira Gandhi International Airport	Boeing 777	3588
Jun	Long	Hamad International Airport	Airbus A380	3174
Jul	Long	Dubai International Airport	Boeing 777	3551
	Long	Imam Khomeini International Airport	Boeing 777	3708
	Long	Singapore Changi Airport	Airbus A380	3798
Sep	Long	Dubai International Airport	Airbus A330	3537

105. Only two flights – the July flight to Dubai and the July flight to Singapore – were also more than 200ft below the 2500ft level restriction at DET D34. This makes the total number of flights that were more than 200ft below any of the DET 2Z altitude restrictions 26.

106. Again, all these flights were climbing more steeply either side of DET D29 but the acceleration of the aircraft resulted in a failure to meet the published level restrictions (see Figure 25 and Figure 26).

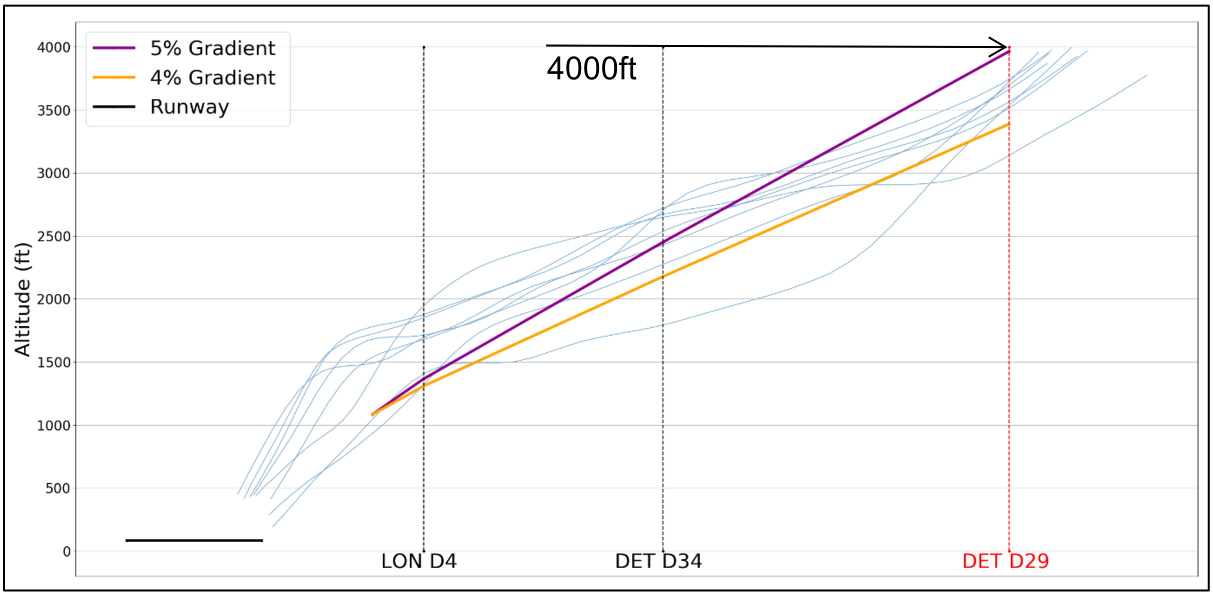

Figure 25. Profile view of aircraft more than 200 ft below 4000 ft at DET D29 (2018)

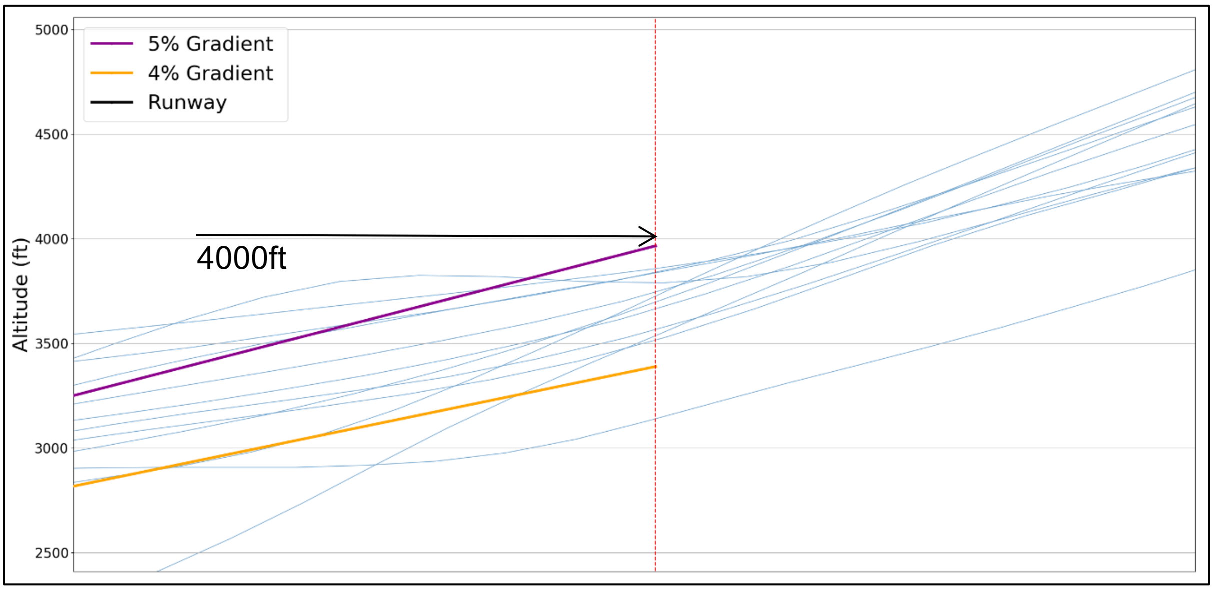

Figure 26. Close-up profile view of aircraft more than 200 ft below 4000 ft at DET D29 (2018)

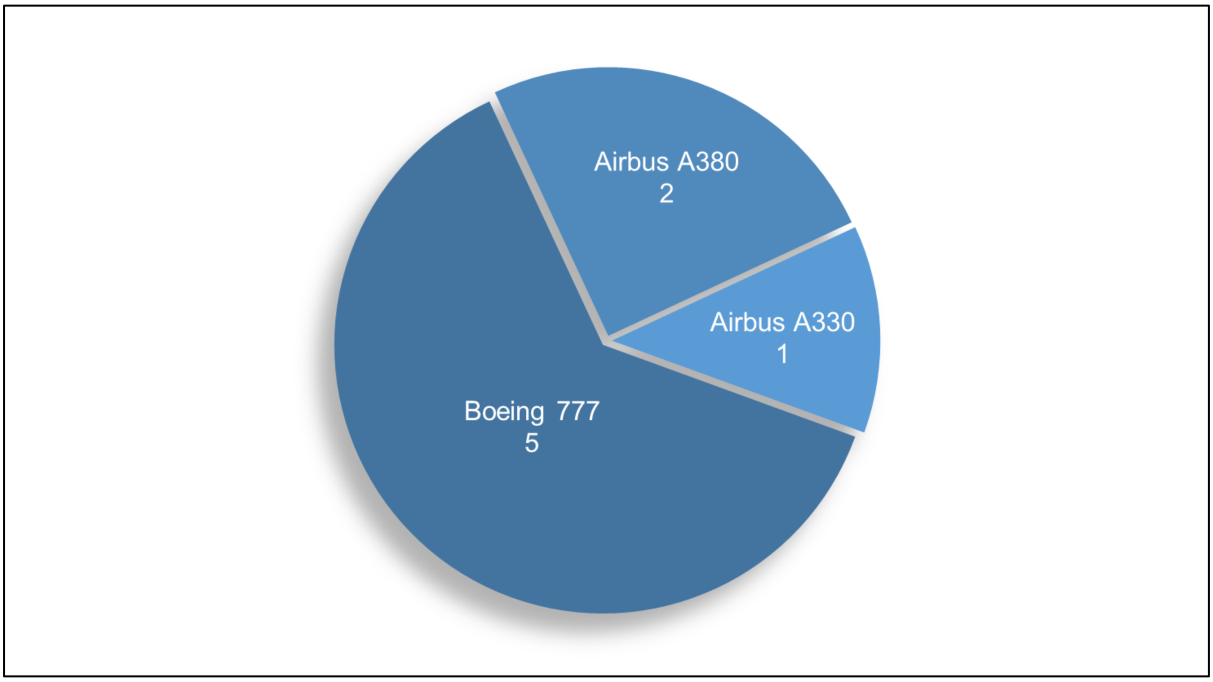

Figure 27. Aircraft types 200 ft or more below 4000 ft at DET D29 (2018)

107. Although the B777's accounted for more than 60% of aircraft that failed to achieve 4000ft at DET D29 by more than 200ft, the overall average altitude at DET D29 improved for that aircraft type, as can be seen in Table 35 and Table 36.

Table 35. MIN/MAX/AVG Altitude at DET D29 (by aircraft type)

	MIN ALTITUDE			AVERAGE ALTITUDE			MAX ALTITUDE		
	2017	2018		2017	2018		2017	2018	
Airbus A318	3890	4603	↑	5569	5646	↑	3890	4603	↑
Airbus A319	4406	4454	↑	5699	5710	↑	4406	4454	↑
Airbus A320	4012	4193	↑	5599	5611	↑	4012	4193	↑
Airbus A320 Neo	4816	4848	↑	5630	5748	↑	4816	4848	↑
Airbus A321	4061	4101	↑	5520	5537	↑	4061	4101	↑
Airbus A321 Neo	-	5765	-	-	5840	-	-	5765	-
Airbus A330	3598	3537	↓	5454	5431	↓	3598	3537	↓
Airbus A340	4606	3854	↓	5429	4945	↓	4606	3854	↓
Airbus A350	4696	4418	↓	5641	5621	↓	4696	4418	↓
Airbus A380	3749	3174	↓	5288	5362	↑	3749	3174	↓
Boeing 737	4670	5167	↑	5710	5717	↑	4670	5167	↑
Boeing 747	4592	4753	↑	5734	5743	↑	4592	4753	↑
Boeing 757	5788	5843	↑	5898	5891	↓	5788	5843	↑
Boeing 767	3866	4561	↑	5579	5603	↑	3866	4561	↑
Boeing 777	3105	3551	↑	5576	5606	↑	3105	3551	↑
Boeing 787	3503	3941	↑	5620	5694	↑	3503	3941	↑
Other	4992	5031	↑	5777	5863	↑	4992	5031	↑

**Denotes the lowest or highest value

Table 36. Average altitude at DET D29 (by aircraft type)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Airbus A320 Neo	5630	5748	2.09%	↑
Other	5777	5863	1.48%	↑
Airbus A318	5569	5646	1.39%	↑
Airbus A380	5288	5361	1.38%	↑
Boeing 787	5620	5693	1.30%	↑
Boeing 777	5576	5606	0.54%	↑
Boeing 767	5579	5603	0.43%	↑
Airbus A321	5520	5537	0.31%	↑
Airbus A320	5599	5611	0.22%	↑
Airbus A319	5699	5710	0.20%	↑
Boeing 747	5734	5743	0.16%	↑
Boeing 737	5710	5717	0.11%	↑
Boeing 757	5898	5891	-0.12%	↓
Airbus A350	5641	5621	-0.35%	↓
Airbus A330	5454	5431	-0.42%	↓
Airbus A340	5429	4945	-8.92%	↓
Airbus A321 Neo	N/A	5840		
	5566	5605	0.69%	↑

108. Trial data also shows that all but the Upper Medium aircraft types improved their average altitude at DET D29 as well as an improvement for long, medium and short haul flights (See Table 37 and Table 38).

Table 37. Average altitude at DET D29 (by aircraft category)

	Baseline (2017)	Trial (2018)		
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement	
Light	5879	5902	0.38%	↑
Medium	5615	5642	0.47%	↑
Upper Medium	5898	5891	-0.12%	↓
Heavy	5584	5614	0.54%	↑
Super Heavy	5288	5361	1.38%	↑
	5566	5605	0.69%	↑

Table 38. Average altitude at DET D29 (by haul)

	Baseline (2017)	Trial (2018)	
	Average of Altitude (ft)	Average of Altitude (ft)	Improvement
Long	5508	5559	0.92%
Medium	5517	5544	0.48%
Short	5643	5666	0.40%
	5566	5605	0.69%

109. Figure 28 below shows the resulting change in average location where aircraft achieved 4000ft.

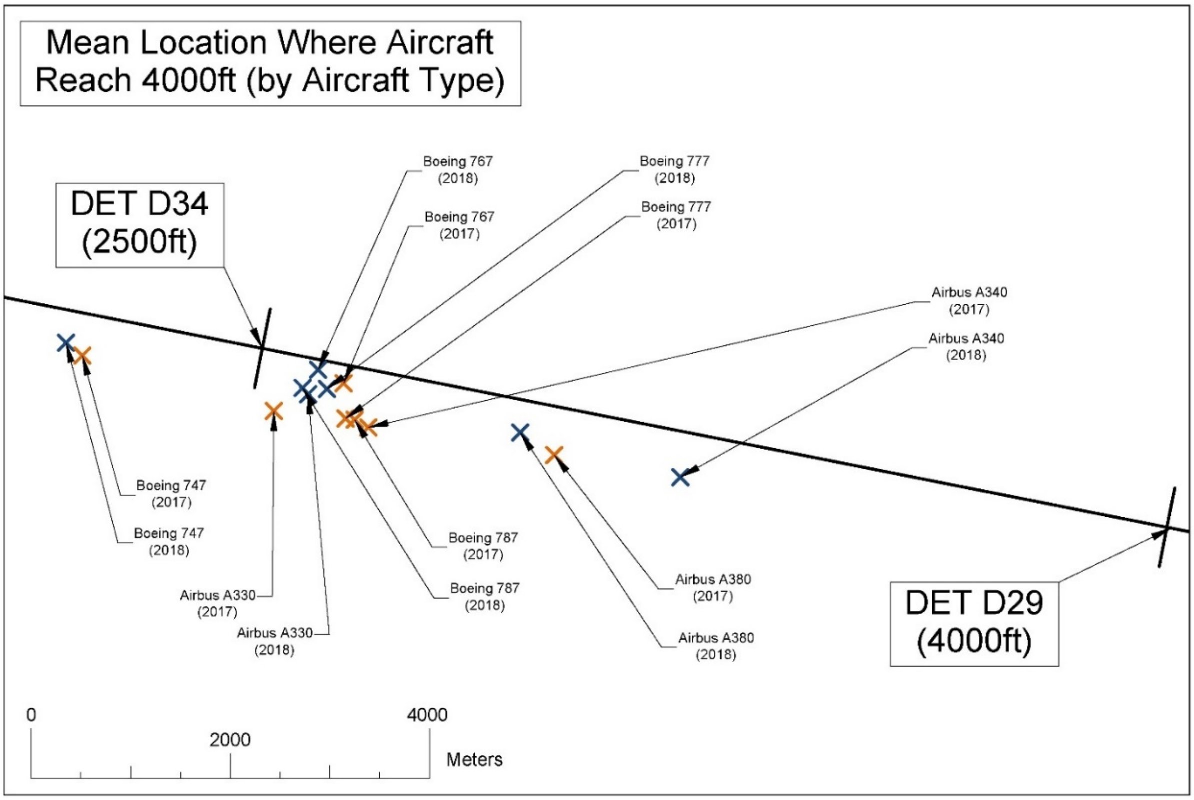

Figure 28. Mean location where aircraft reach 4000 ft (by aircraft type)

5.7.5 Average altitudes

110. Trial data shows that the average altitude achieved at each of the DET 2Z SID altitude attainment points increased during the trial.

Table 39. Average altitudes at LON D4, DET D34 & DET D29

		Baseline (2017)	Trial (2018)	
LON D4	Average Altitude (ft)	2257	2308	↑
	Std Dev	522	516	
	Count	11,431	22,065	
	95% CI	9.57	6.81	
DET D34	Average Altitude (ft)	4005	4076	↑
	Std Dev	673	665	
	Count	11,399	21,979	
	95% CI	12.35	8.79	
DET D29	Average Altitude (ft)	5566	5605	↑
	Std Dev	369	338	
	Count	8,379	15,592	
	95% CI	7.90	5.31	

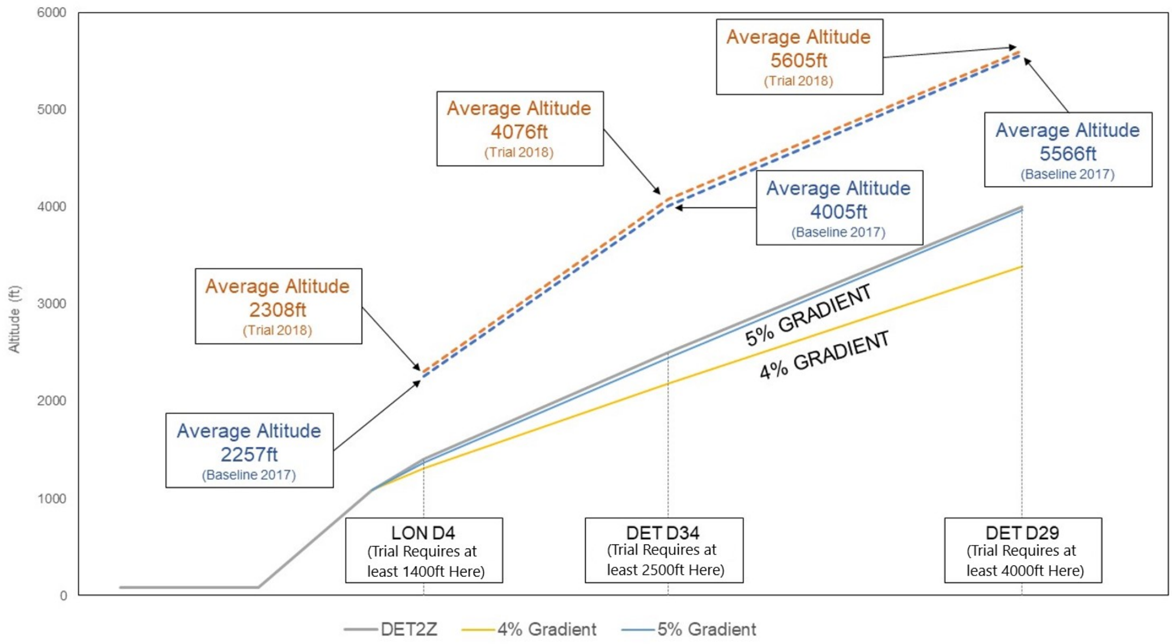

Figure 29. Average altitude vs DET 2Z / 4% / 5% gradients

111. Although some aircraft types achieved a lower average altitude compared to 2017, overall the majority of wake vortex categories of aircraft improved their performance (See Table 40 and Table 41).

Table 40. Average altitudes at LON D4, DET D34 & DET D29 (by aircraft type)

	LON D4 (Trial SID Requires 1400ft here)			DET D34 (Trial SID Requires 2500ft here)			DET D29 (Trial SID Requires 4000ft here)		
	Baseline (2017)	**Trial (2018)**		**Baseline (2017)**	**Trial (2018)**		**Baseline (2017)**	**Trial (2018)**	
Airbus A318	2562	2663	↑	4264	4423	↑	5569	5646	↑
Airbus A319	2591	2498	↓	4492	4433	↓	5699	5710	↑
Airbus A320	2356	2355	↓	4234	4254	↑	5599	5611	↑
Airbus A320 Neo	2557	2761	↑	4526	4708	↑	5630	5748	↑
Airbus A321	2363	2403	↑	4012	4000	↓	5520	5537	↑
Airbus A321 Neo	N/A	3287	-	N/A	4863	-	N/A	5840	-
Airbus A330	2373	2349	↓	3830	3817	↓	5454	5431	↓
Airbus A340	1932	1981	↑	3593	3389	↓	5429	4945	↓
Airbus A350	2309	2245	↓	4012	3809	↓	5641	5621	↓
Airbus A380	1652	1729	↑	3242	3337	↑	5288	5361	↑
Boeing 737	2832	2732	↓	4514	4449	↓	5710	5717	↑
Boeing 747	2251	2255	↑	4525	4496	↓	5734	5743	↑
Boeing 757	3273	3666	↑	5164	5361	↑	5898	5891	↓
Boeing 767	2034	2024	↓	3920	3899	↓	5579	5603	↑
Boeing 777	2128	2178	↑	3700	3810	↑	5576	5606	↑
Boeing 787	2003	2115	↑	3681	3819	↑	5620	5693	↑
Other	3325	3514	↑	4828	5106	↑	5777	5863	↑
	2257	2308	↑	4005	4076	↑	5566	5605	↑

Table 41. Average altitudes at LON D4, DET D34 & DET D29 (by aircraft category)

	LON D4 (Trial SID Requires 1400ft here)			DET D34 (Trial SID Requires 2500ft here)			DET D29 (Trial SID Requires 4000ft here)		
	2017	**2018**		**2017**	**2018**		**2017**	**2018**	
Super Heavy	1652	1729	↑	3242	3337	↑	5288	5361	↑
Heavy	2166	2220	↑	3814	3877	↑	5584	5614	↑
Upper Medium	3273	3666	↑	5164	5361	↑	5898	5891	↓
Medium	2452	2451	↓	4286	4310	↑	5615	5642	↑
Light	3620	3830	↑	4903	5343	↑	5879	5902	↑
	2257	2308	↑	4005	4076	↑	5566	5605	↑

112. Overall improvements were also observed for traffic departing to all regions.

Table 42. Average altitudes at LON D4, DET D34 & DET D29 (by region)

	LON D4 (Trial SID Requires 1400ft here)			DET D34 (Trial SID Requires 2500ft here)			DET D29 (Trial SID Requires 4000ft here)		
	Baseline (2017)	**Trial (2018)**		**Baseline (2017)**	**Trial (2018)**		**Baseline (2017)**	**Trial (2018)**	
Africa	2226	2270	↑	4024	4077	↑	5718	5758	↑
Europe	2470	2473	↑	4332	4354	↑	5635	5656	↑
Far East	1991	2058	↑	3549	3672	↑	5475	5537	↑
Middle East	2095	2164	↑	3769	3823	↑	5507	5548	↑
UK	3138	4820	↑	4202	N/A	-	4839	N/A	-
	2257	2308	↑	4005	4076	↑	5566	5605	↑

5.8 Lateral track distribution

113. To determine if the change to the vertical path affected the lateral distribution of traffic, heatmaps were produced which show the concentration of traffic over the 2-year period.

114. Figure 30 shows all DET traffic up to and including 31st Dec 2017. At approximately 5nm from the end of runway 09R, a fork appears and the traffic forms two streams. Traffic outside of this area is most likely above 4000ft and being tactically vectored by ATC.

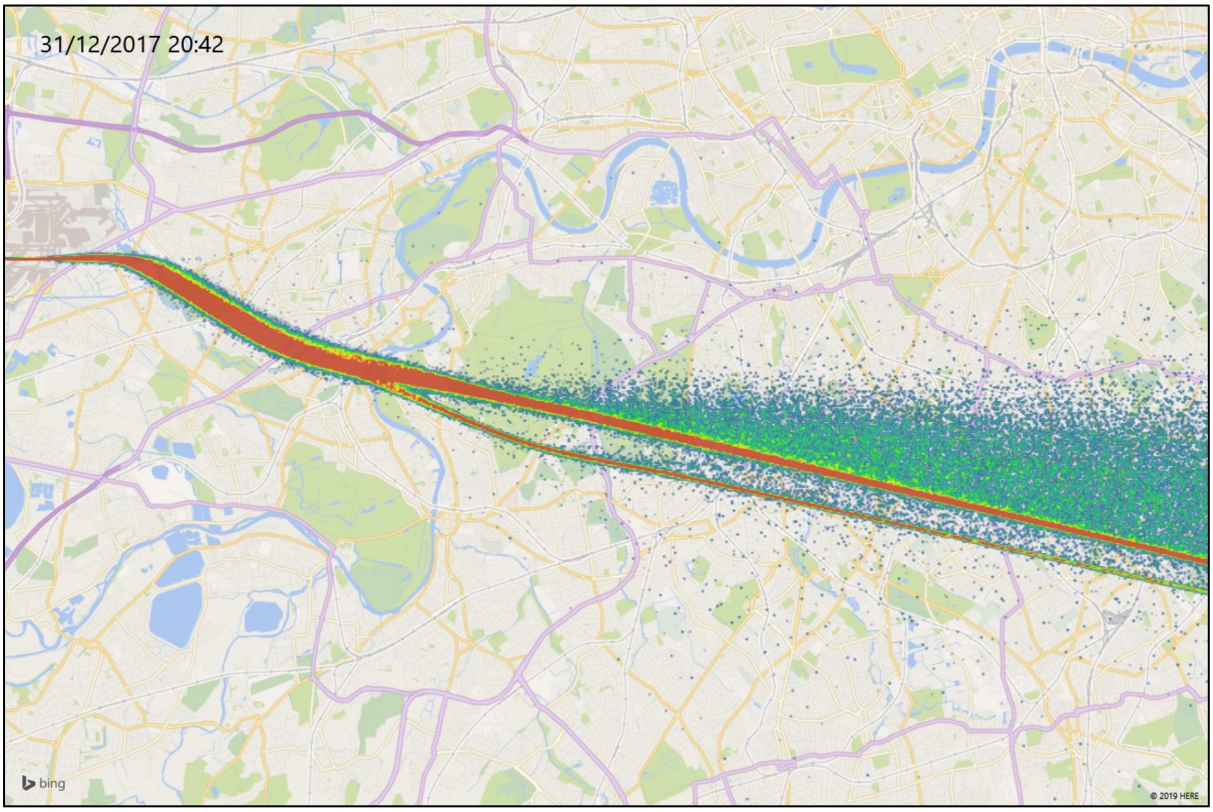

Figure 30. DET 1J Traffic heatmap (2017)

115. The fork is thought to be caused by differences in the way the conventional procedure is coded. There are two major coding houses used by Heathrow airlines; Jeppesen and LIDO. Airlines flying the Jeppesen procedure tend to concentrate in the southern stream whilst airlines flying the LIDO procedure concentrate in the northern stream (see Figure 31 and Figure 32). It should be noted that both streams fall within the Noise Preferential Routing (NPR) area.

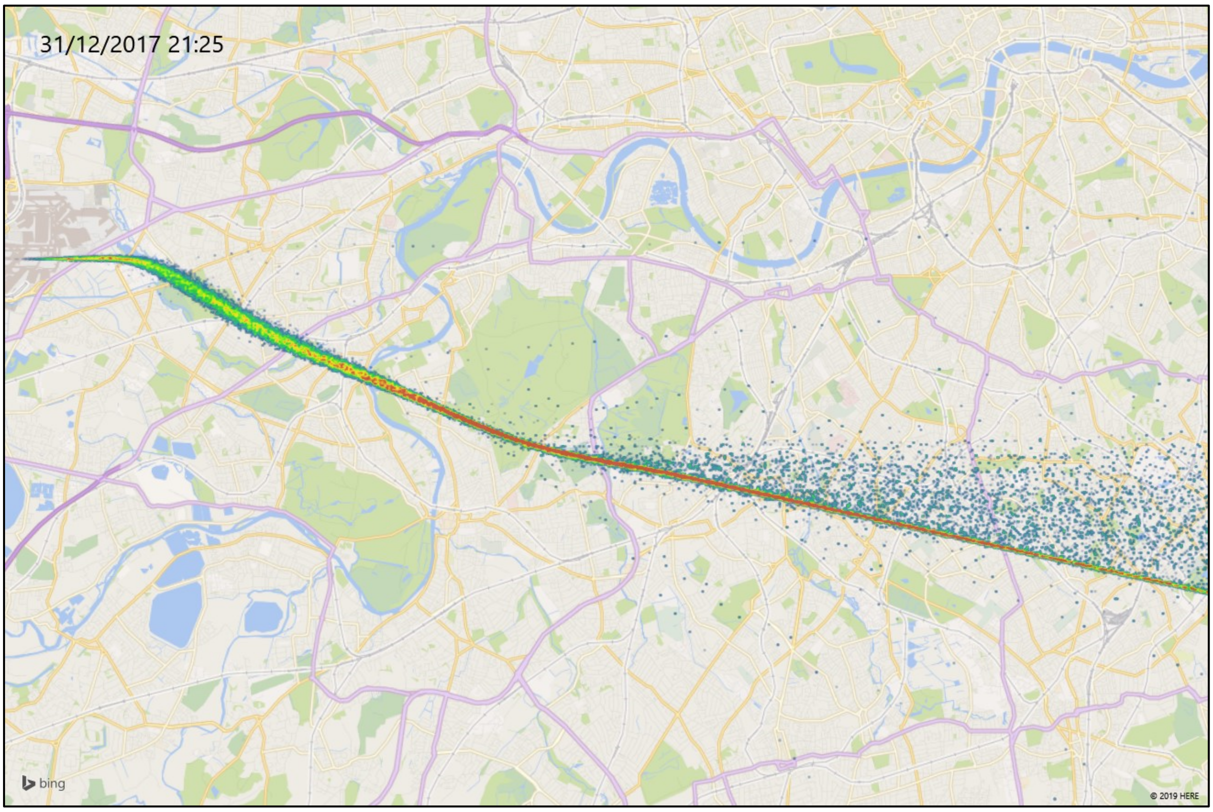

Figure 31. DET 1J Traffic heatmap (2017) - Jeppesen

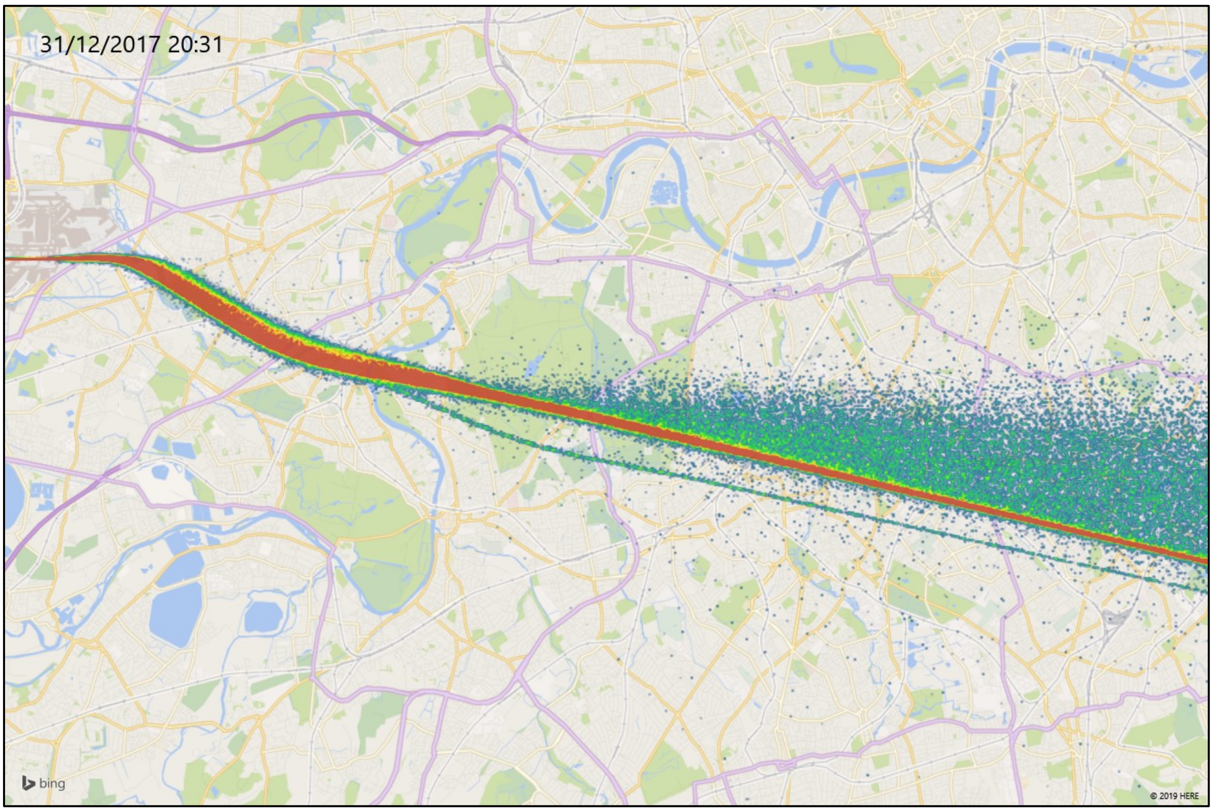

Figure 32. DET 1J Traffic heatmap (2017) - LIDO

116. The higher concentration of traffic in the north stream is due to more airlines on the DET departure using LIDO coding. Table 43 shows that 60.69% of DET departures in 2017 are confirmed as using the LIDO procedure whilst only 7.99% were confirmed to be using the Jeppesen procedure. The remainder was unknown.

Table 43. Percentage of DET departures (2017) by coding house

	2017
LIDO	60.69%
Unknown	31.32%
Jeppesen	7.99%
	100.00%

117. Comparing the 2017 heatmap to 2018 it is evident that a change to the concentration of traffic has occurred with a 'bulge' appearing in 2018 in the vicinity of where the traffic forks.

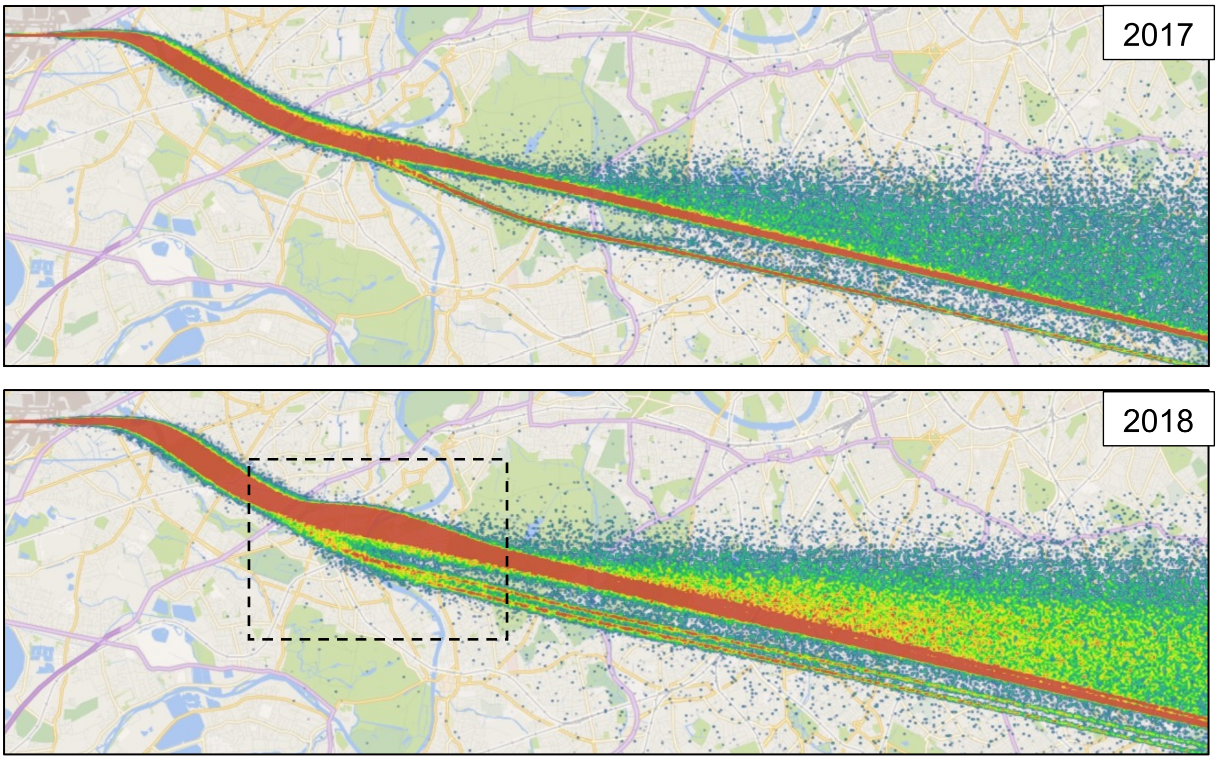

Figure 33. DET Departures heatmap comparison

118. Between 7th January and 28th March 2018, aircraft flying with Jeppesen coding began to fly further south before turning left creating a 'bulge' to the south. (see Figure 35).

Figure 34. Jeppesen DET 1J traffic 2017

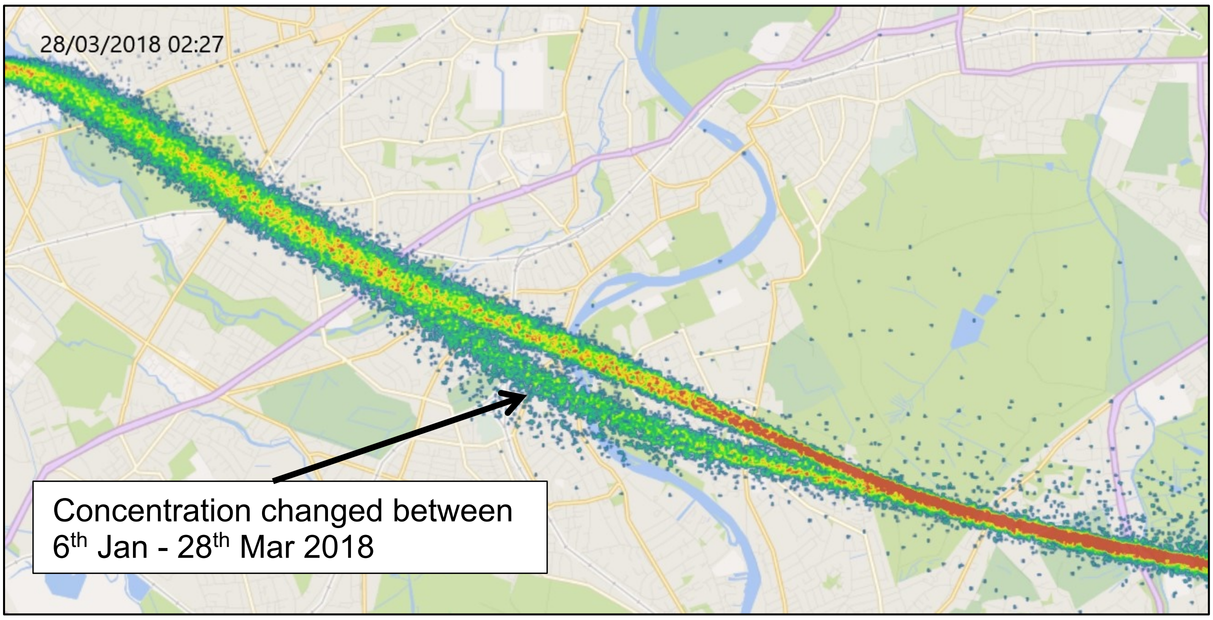

Figure 35. Jeppesen DET 2Z traffic between 6th Jan - 28th Mar 2018

119. After the 28th March 2018 the concentration changed once again with Jeppesen traffic appearing to turn left earlier creating a northern stream (see Figure 36).

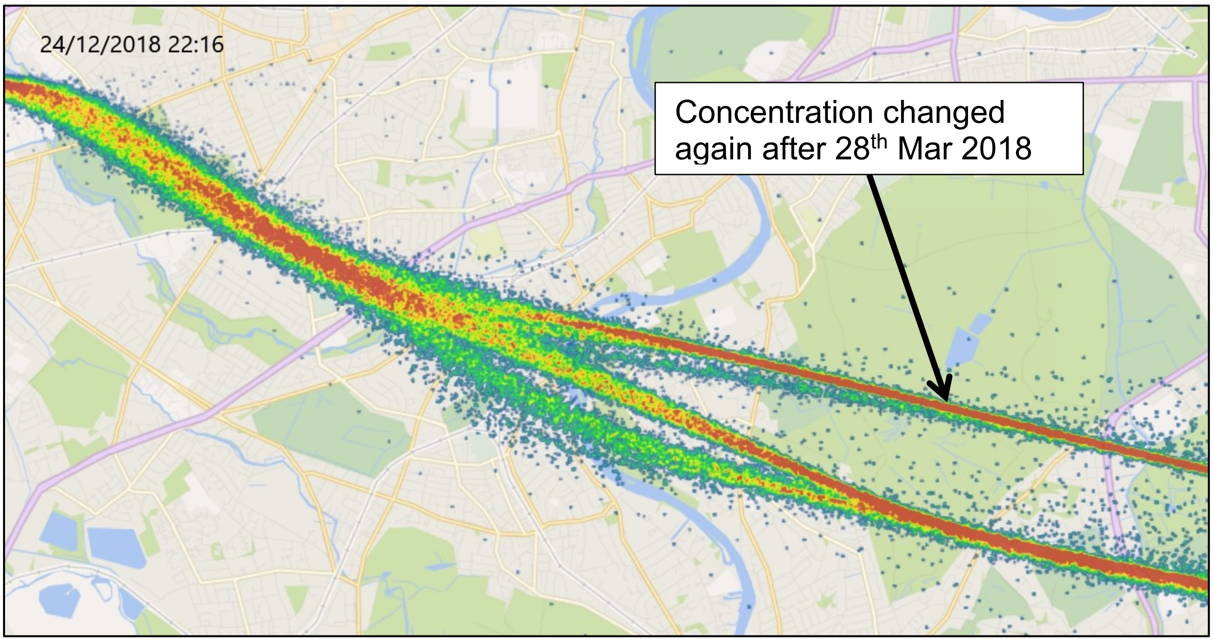

Figure 36. Jeppesen DET 2Z traffic after 28th Mar 2018

120. Heathrow contacted Jeppesen and were informed that they changed the procedure coding at the end of March 2018. Jeppesen reported:

> "One change was changing the recommended VOR for the DET D34 leg from LON to DET. This change was done to ensure the navaid used for all points on DET R284 are using the same recommended navaid. Most systems don't really use the recnav for much, but there are some systems that use the recnav to determine the MagVar for the track. LON currently is coded with a Var of 1W while DET is coded with a Var of 0W. These systems may have used the recnav information for the Var on the track. The fix for DET34 was also moved slightly as it was found that while it was within tolerance of R284 (+/- 1°), it was not exactly on the DET R284."

121. This coding change did not affect the vertical flightpath but did realign the lateral flightpath more closely with the DET nominal centreline. It is not known however, if this change was responsible for the change in concentration evident between Jan and Mar 2018.

122. Interestingly, analysis shows that there was a change in lateral distribution of the LIDO traffic too from 7th January 2018 onwards.

Figure 37. LIDO DET 2Z Traffic 2017

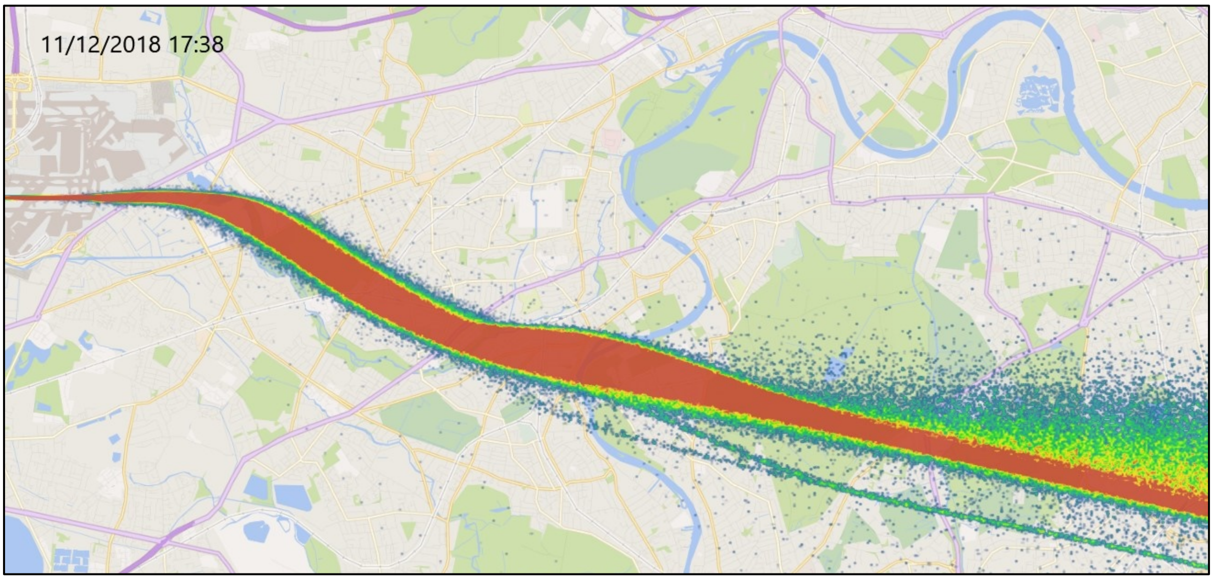

Figure 38. LIDO DET 2Z Traffic 7th Jan 2018 onwards

123. After the 7th January 2018, LIDO aircraft appear to take a sharper left turn then adjust right to establish on the nominal centreline. This results in a bulge to the north.

124. After the 11th December 2018, LIDO aircraft appear to change flight path once again. The heatmap shows that aircraft continue further south before turning left which creates a stream to the south of the nominal centreline. This is shown in Figure 36.

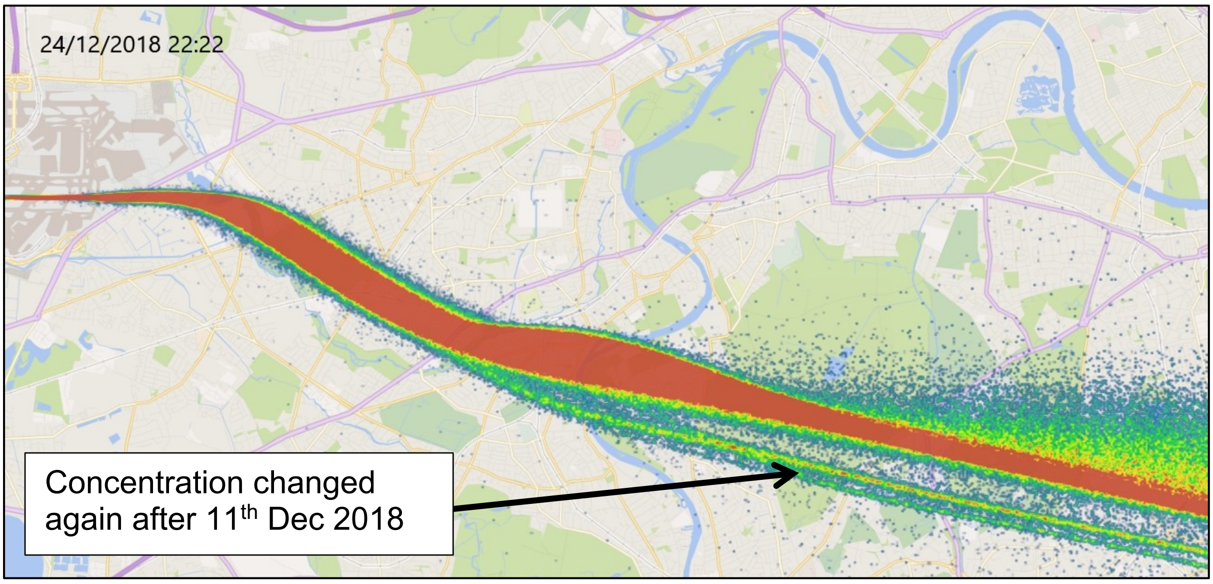

Figure 39. LIDO DET 2Z Traffic 11th Dec 2018 onwards

125. Whilst the change in coding did not affect the vertical path, it may have impacted the noise levels recorded in the vicinity and has been taken into account when comparing noise data from 2017 and 2018 (see Section 6:).

5.9 Average monthly temperature

126. Average monthly temperatures for 2017 and 2018 are shown in Figure 40. For the trial period it appears that the summer was warmer than in the previous year, whereas winter had a mix of warmer and colder months in 2018 when compared to 2017. The main influence of air temperature in relation to noise is on the aircraft climb gradient rather than on the propagation of noise itself. All other things being equal, as temperature rises the air density reduces, which causes reduced wing lift and consequently aircraft may be lower over the monitors (see Figure 41).

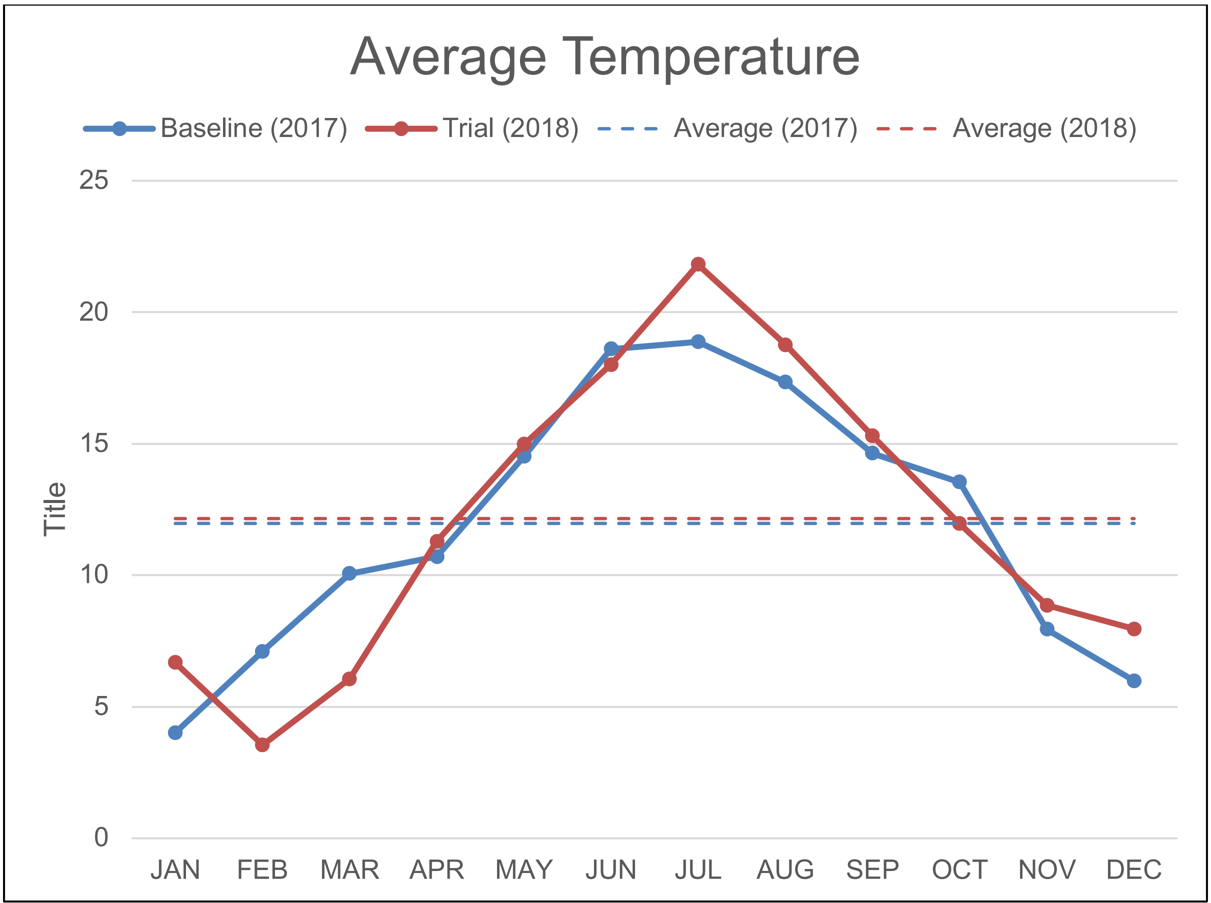

Figure 40. Average monthly temperatures

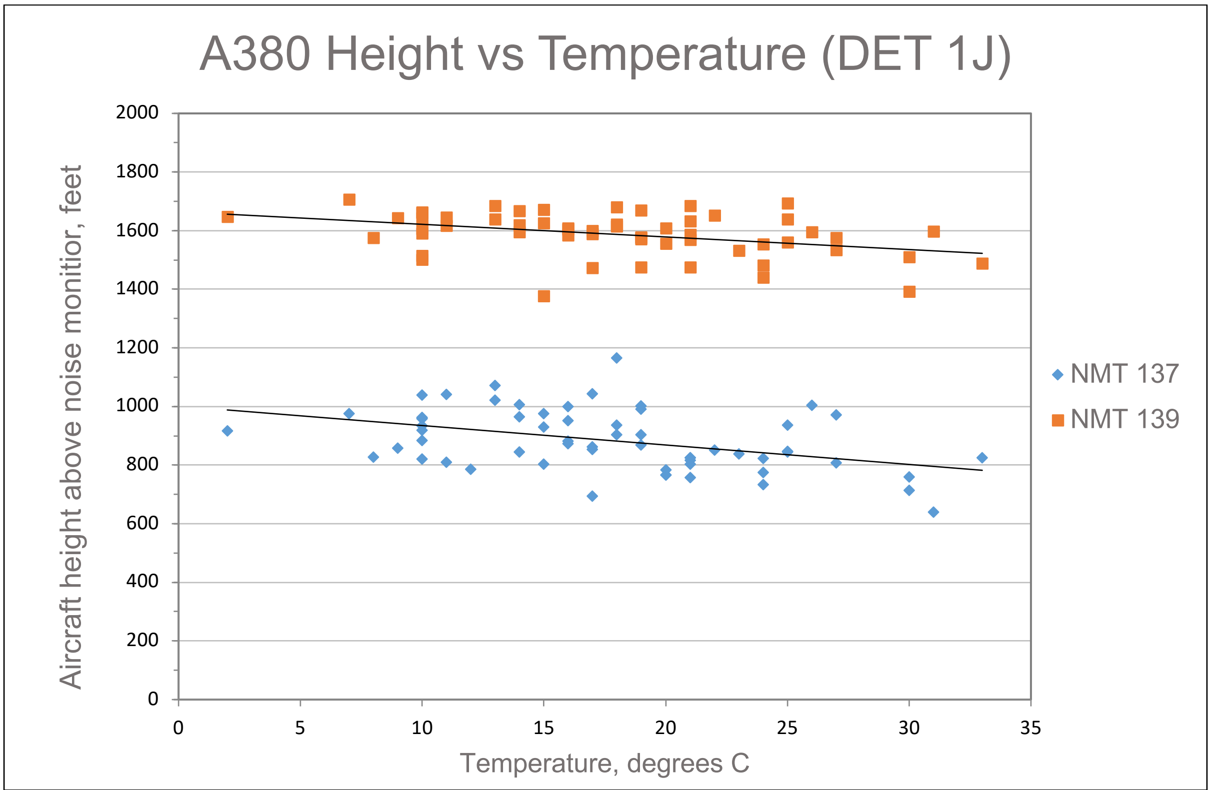

Figure 41. A380 Height vs temperature graph

5.10 Airline feedback

127. Following some interim analysis of trial data for the first half of the trial, those airlines that had flight operations more than 200 ft below the required DET 2Z level restrictions were contacted and feedback was requested on the reasons for the failures.

128. The feedback was complex and covers a wide range of variable factors including aircraft type, weight (passengers, cargo, fuel (destination)), air temperature, air pressure, wind speed and direction, the NADP being flown, Standard Operation Procedures, thrust reduction altitude, flap reduction, acceleration profiles and the expectation from ATC at high density operations to accelerate to 250kts as soon as possible.

129. To summarise, airlines strive for standardisation across their fleets wherever possible but are met with competing demands and they cannot always adhere to every requirement. Particularly, the need to both accelerate and climb in a manner that best balances requirements are at conflict.

130. Figure 42 below, provided by an A380 operator shows how a difference in the acceleration altitude from 1000ft (blue line) to 1500ft (orange line) can be a deciding factor in whether it meets the 5% gradient (red line) or not. However, this performance is relevant only to an exact weight, at an exact air temperature and in nil wind. Change any one of those variables and the actual performance achieved on the day will be different.

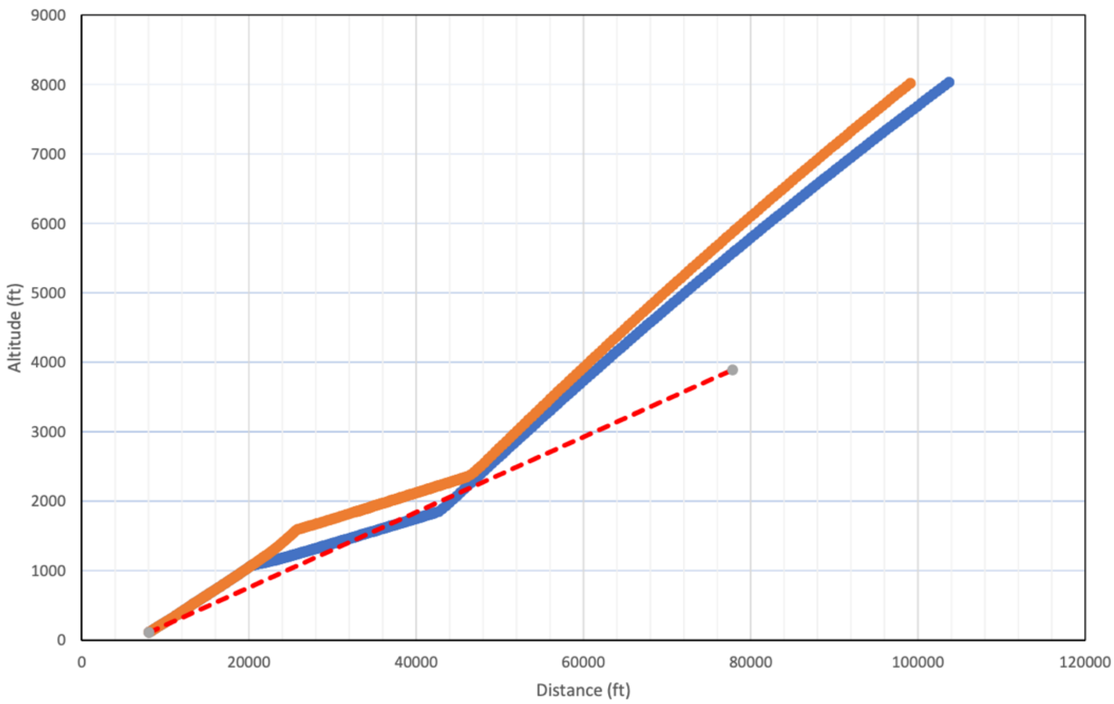

Figure 42. Difference in the acceleration altitude from 1000ft (blue line) to 1500ft (orange line)

131. Another airline advised that changing from NADP2 (accelerate below 3000ft) to NADP1 (accelerate above 3000ft would result in an increase in fuel burn of approximately 250Kgs per day or 92 Tonnes of CO_2 a year.

132. The following tables show that this contact by Heathrow stimulated a notable improvement in airline climb performance in Q4 of 2018.

Table 44. Change in aircraft performance during latter part of the trial (LON D4)

	LON D4 (Trial SID Requires at least 1400ft here)		
	Q1-Q3 (2018)	**Q4 (2018)**	**Improvement**
% 100ft Below Level Restriction	0.09%	0.04%	-59.84%
% 200ft Below Level Restriction	0.00%	0.00%	N/A
% 250ft Below Level Restriction	0.00%	0.00%	N/A

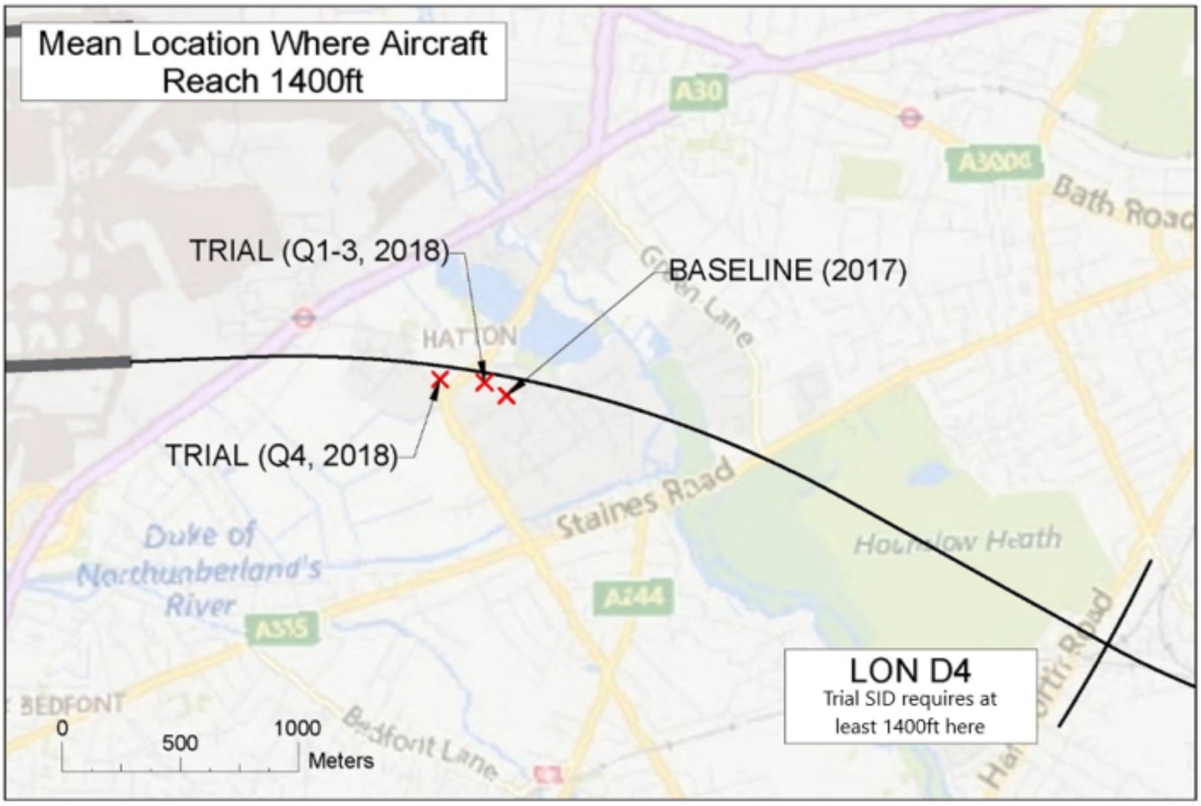

Figure 43. Mean location where aircraft reach 1400 ft – improvements during Q4 (2018)

Table 45. Change in aircraft performance during latter part of the trial (DET D34)

	DET D34 (Trial SID Requires at least 2500ft here)		
	Q1-Q3 (2018)	Q4 (2018)	Improvement
% 100ft Below Level Restriction	0.27%	0.15%	-46.45%
% 200ft Below Level Restriction	0.10%	0.07%	-24.70%
% 250ft Below Level Restriction	0.04%	0.05%	50.60%

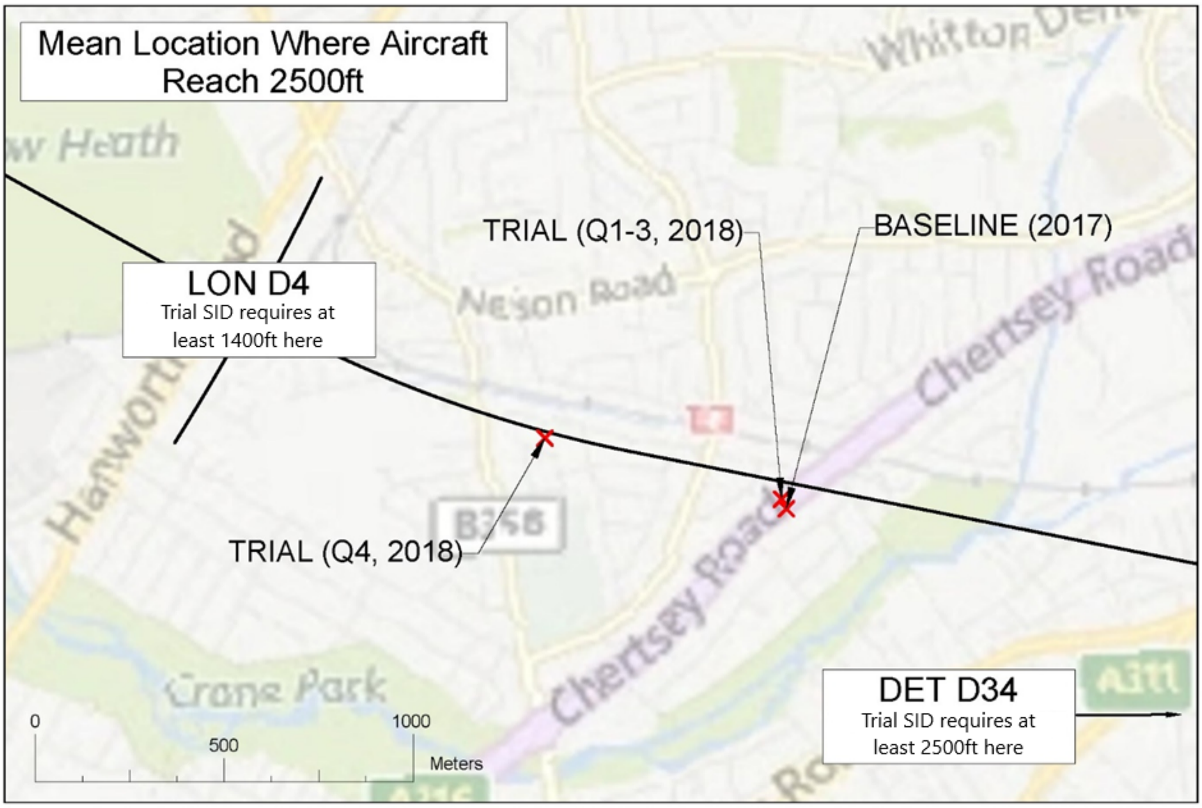

Figure 44. Mean location where aircraft reach 2500 ft – improvements during Q4 (2018)

Table 46. Change in aircraft performance during latter part of the trial (DET D29)

	DET D29 (Trial SID Requires at least 4000ft here)		
	Q1-Q3 (2018)	Q4 (2018)	Improvement
% 100ft Below Level Restriction	0.07%	0.02%	-72.62%
% 200ft Below Level Restriction	0.05%	0.00%	-100.00%
% 250ft Below Level Restriction	0.04%	0.00%	-100.00%

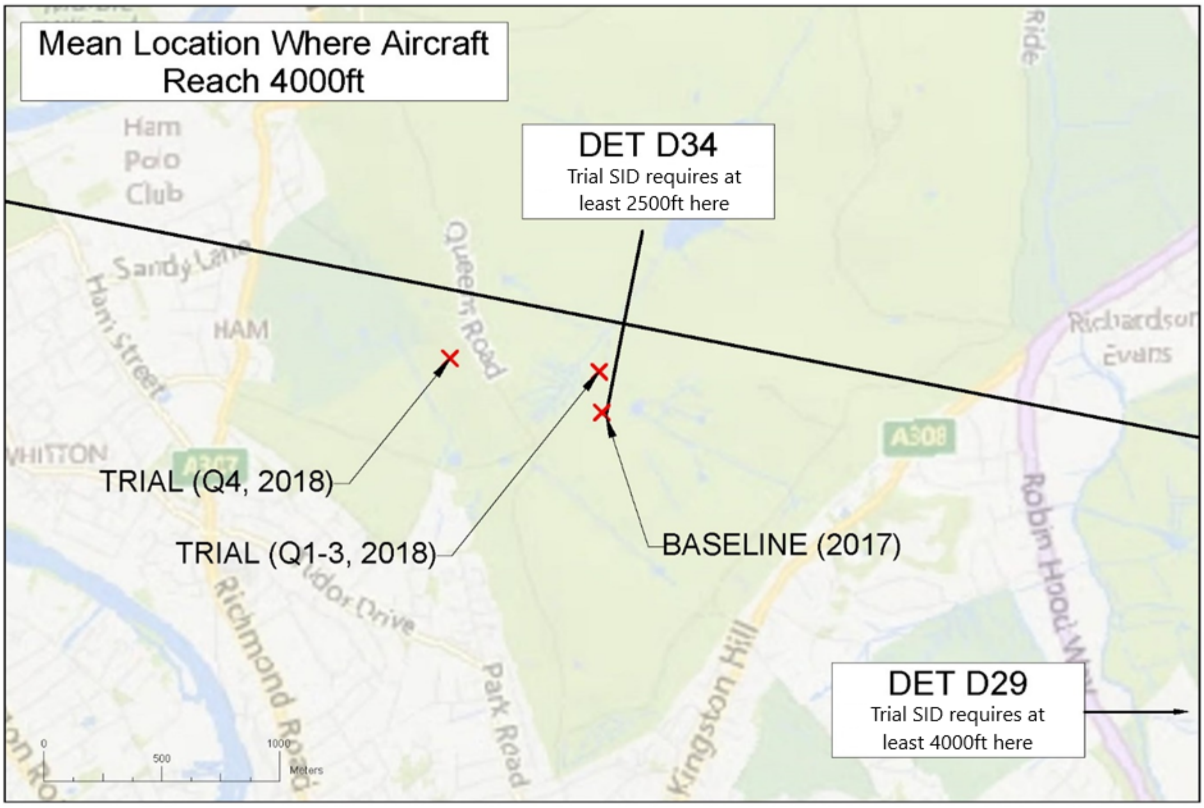

Figure 45. Mean location where aircraft reach 4000 ft – improvements during Q4 (2018)

5.11 ATC feedback

133. No comments were received from ATC during the trial.

Section 6: Noise analysis (ERCD)

6.1 Data collection

134. The objective of the noise study was to understand any changes in the noise distribution along the DET 09 route as a result of the increased climb gradient requirement during the trial period. Noise data was collected and analysed from both fixed and mobile noise monitors that were deployed between 1 January 2017 to 3 January 2019, covering both the baseline DET 1J procedure and the trial DET 2Z procedure.

135. As well as monitoring noise directly beneath the NPR, because of the difference in the way noise propagates to the side of the flight path as aircraft height increases (compared to directly below), noise monitors were also positioned to the sides of the nominal route centreline (see Figure 46). Although the collection of baseline data commenced on 1 January 2017, the full array of noise monitors[19] was not deployed until June 2017.

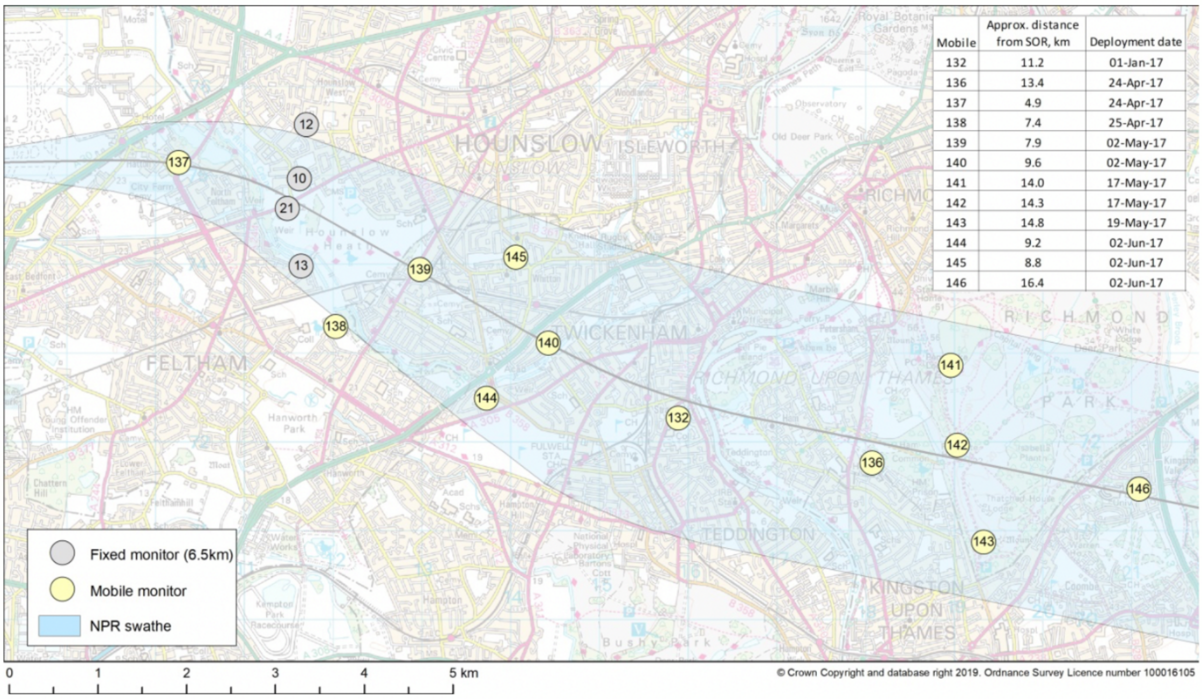

Figure 46. DET 09 noise monitor array

[19] Aircraft noise events recorded at other more distant side-line monitors (that were positioned more than 2 km away from the route centreline) were not used for the final noise analysis. This was due to the increased likelihood of noise event contamination at these more distant locations, since aircraft events were significantly quieter and therefore more difficult to measure.

6.2 Noise analyses methodology

136. Noise monitors for this study were positioned directly below and to the sides of the nominal DET 09 route centreline in order to understand any changes in the noise distribution as a result of an increased climb gradient during the trial period.

137. Figure 47 presents the average difference in maximum noise level (L_{Amax}) at each noise monitor between the DET 1J procedure and the DET 2Z procedure for all wide-body aircraft types, which includes the Airbus A330, A340, A350 and A380 as well as the Boeing 747, 767, 777 and 787.

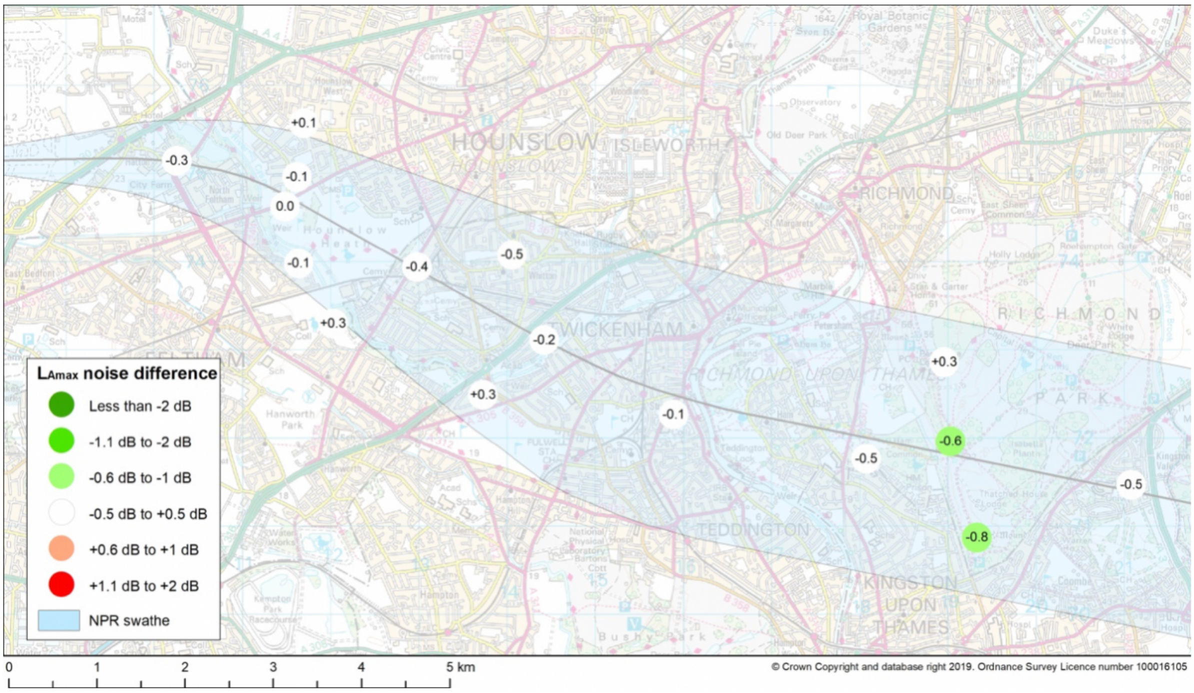

Figure 47. Average L_{Amax} noise differences for all wide-body aircraft (DET 2Z minus DET 1J)

138. When averaged in this way across all aircraft types (and operators) the results generally show no significant change in noise. This is unsurprising since the height analysis presented in Section 5.7 showed both increases *and* decreases in average height between the baseline and trial periods depending on the aircraft type.

139. With the exception of the A380, many of the wide-body types were also significantly higher than the DET 2Z minimum height requirements before the start of the trial and were therefore less likely to have required any change in procedure to meet the trial requirements. The noise analysis has therefore focussed on A380 and 787-9 departures, since these two types were generally lower than all other types in the study.

140. In addition, conventional instrument procedures are commonly programmed as coded RNAV 'overlays' which are then loaded into an aircraft's Flight Management System (FMS). In endeavouring to replicate a conventional procedure design, the FMS coding

(as interpreted by a commercial aeronautical navigation database provider, or 'coding house') can be subtly differ from airline to airline (depending on the coding house used) and the aircraft type used. Different interpretations of the same conventional departure route by the coding houses can therefore cause variations in the departure tracks flown along that route.

141. An analysis of A380 radar tracks before and during the trial showed that beyond approximately 10 km from start-of-roll there were typically two distinct streams of tracks flown; one to the north of the nominal route centreline and the other to the south, approximately 1 km apart from each other at their widest separation. And within each main stream of tracks (north or south), there was also some additional variation depending on the particular FMS coding.

142. Figure 48 illustrates the variation in tracks flown for one particular A380 operator. In this case, changes to the coded overlay at the start of the trial and during the trial resulted in three different average ground tracks to be flown over the noise monitors. Similar differences were also observed for other aircraft types and operators. An exploration of the different coding is covered in more detail in Section 5.8.

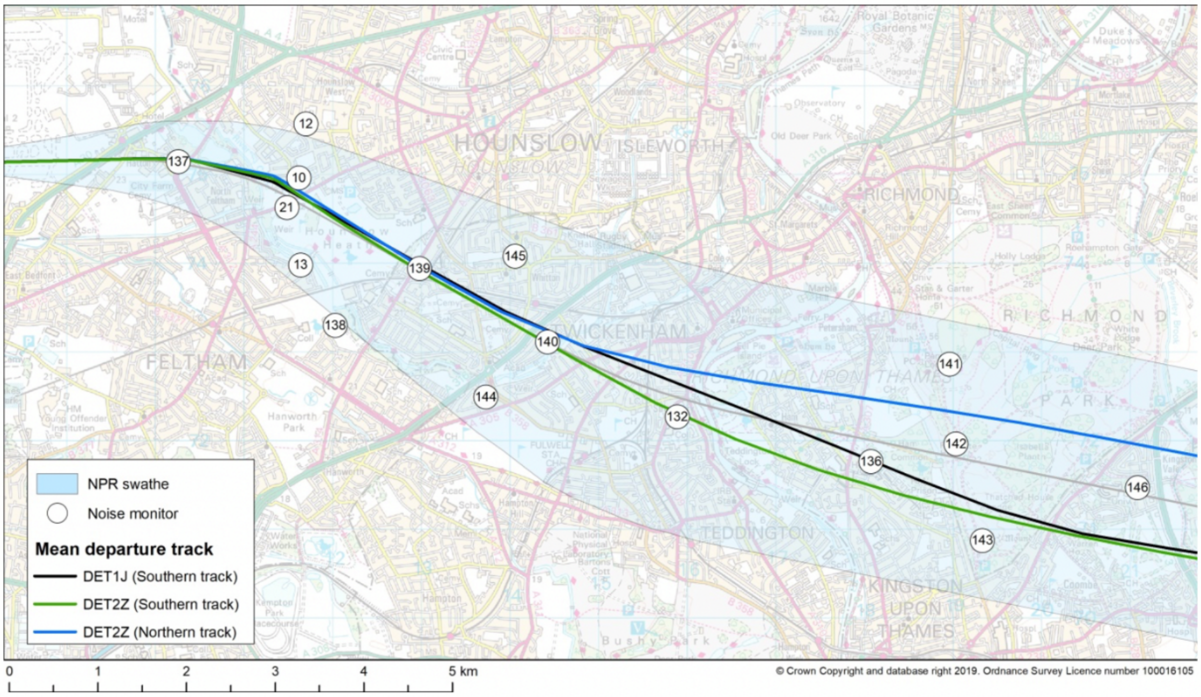

Figure 48. Variation in mean departure ground track for one A380 operator

143. Changes to the lateral ground track during the course of the study, such as those illustrated in Figure 47, therefore meant it was not possible to directly compare noise measurements between the baseline and trial study periods, since it would be difficult to then attribute any measured change in noise solely to the change in required climb gradient. For example, a noise change measured at a particular location could be

influenced to a greater extent by a change in the ground track relative to the monitor rather than by any change in height or noise emission (thrust).

144. Before analysing the data further, it was therefore necessary to take the following steps:

a) In each case where a change from the main northern track to the southern track (or vice versa) occurred part way through the measurement period, the lateral track corresponding to the largest sample size was selected for that particular operator, i.e. the dominant track. For five of the seven A380 operators (ETD, MAS, QTR, THA and UAE, who all use one particular coding house) this was the northern track, and for the remaining two A380 operators (QFA and SIA, who both use a different coding house to the other operators) this was the southern track[20]. For the two 787-9 operators (BAW and VIR), this was the northern track.

b) Noise data for operations on the dominant track were then selected for analysis for both the baseline and trial periods. (In the example shown in Figure A2, noise data for operations on the blue track were excluded)

c) To account for any remaining difference in the lateral ground track between the baseline and trial periods (in the example shown in Figure A2, the black and green lines), the average baseline DET 1J measurements were then adjusted using industry-supplied Noise-Power-Distance (NPD) relationships[21] to estimate what the noise levels at each monitor would have been had the aircraft flown the same average DET 2Z lateral ground track over the array. This was done separately for each aircraft type and operator as it requires adjustment for both slant distance and elevation, both of which are dependent on aircraft height, which varies from operator to operator.

145. Approximately 15% of all noise measurements were rejected due to unacceptable weather conditions, i.e. wind speeds greater than 10 m/s (22 mph) or during periods of precipitation, in accordance with recommended international guidance on aircraft noise monitoring[22].

146. Whilst baseline and trial data were collected for a number of different aircraft types, the noise analysis in this report has focused on Airbus A380 and Boeing 787-9 departures only. As reported previously[23], a relatively high proportion of A380

[20] For QFA and SIA, this also meant that trial data during the summer months were not analysed, since a coding change occurred at the start of the summer 2018 season causing the lateral ground track to shift to the northern position. However, an analysis of noise data collected for QFA and SIA during the baseline period showed a weak relationship between temperature and noise level. Therefore the omission of trial data over the summer months is considered unlikely to affect the conclusions of the study.

[21] https://aircraftnoisemodel.org/

[22] ISO 20906:2009, Acoustics - Unattended monitoring of aircraft sound in the vicinity of airports.

[23] http://www.heathrow.com/file_source/HeathrowNoise/Static/HCNF_WG2_Climb_profile_measurement_and_performance_Apr_2017.pdf

departures fail to meet the current 4% AIP minimum climb gradient requirement, whereas the proportion failing for all other types is significantly lower. The 787-9 has also been included since the height analysis presented in Section 5.7 indicated the 787 is generally climbing at shallower gradients compared to other similar (wide-body) aircraft types. Annex A provides further information on the noise measurements captures during the trial.

6.3 Results

147. Noise measurement data were collected and analysed for the following 787-9 operators[24]:

- British Airways (BAW)
- Virgin Atlantic (VIR)

148. Noise measurement data were collected and analysed for the following A380 operators[25]:

- Etihad Airways (ETD)
- Malaysia Airlines (MAS)
- Qantas (QFA)
- Qatar Airways (QTR)
- Singapore Airlines (SIA)
- Thai Airways (THA)
- Emirates (UAE)

149. For each operator, the average difference in noise level between the DET 1J procedure and the DET 2Z procedure has been calculated at each noise monitor. Results for the A380 are reported in Figure 49 to Figure 62, both in terms of the maximum sound level (L_{Amax}) as well as the Sound Exposure Level (SEL) metric, which accounts for the duration of the noise event as well as its intensity. Corresponding results for the 787-9 are presented in Figure 63 to Figure 66[26].

150. A positive difference at any monitor indicates the trial procedure was noisier, on average, at that location; a negative difference indicates the trial procedure was quieter. Also illustrated in each figure is a sample of DET 2Z departure tracks for the

[24] British Airways did not routinely operate the A380 on the DET 09 Route during 2017 and was therefore excluded from the noise analysis due to the paucity of baseline data. Likewise, although other 787-9 operators departed on the DET 09 route during the baseline and trial periods, British Airways and Virgin Atlantic accounted for the significant majority of 787-9 departures during both periods.

[25] British Airways did not routinely operate the A380 on the DET 09 Route during 2017 and was therefore excluded from the noise analysis due to the paucity of baseline data. Likewise, although other 787-9 operators departed on the DET 09 route during the baseline and trial periods, British Airways and Virgin Atlantic accounted for the significant majority of 787-9 departures during both periods.

[26] Results at sideline monitor 138 are not shown for the 787-9 since this aircraft type was generally too quiet to register noise events at that location.

relevant airline. The range of noise differences across all airlines and all monitors is -3.5 to +1.6 dB for L_{Amax} and -2.7 to +1.0 dB for SEL, although the majority of differences are small in absolute terms (most are less than 1 dB).

151. In a few cases the measured noise reductions cannot be explained by changes in aircraft height or speed. For example, the results for Malaysia Airlines (Figure 51 and Figure 52) show noise reductions of more than 2 dB at a number of the close-in and more distant noise monitors. The changes at the close-in monitor position (NMT 137) are associated with aircraft heights of approximately 800 feet, below which changes to noise abatement departure procedures are not permitted. It is therefore likely that reductions of either average take-off weight or engine thrust may also have occurred for some A380 operators during the trial period, most likely due to other unrelated operational changes[27].

152. The results for Qantas and Singapore Airlines (Figure 53-Figure 54 and Figure 57-Figure 58) both show an increase in noise level of +1.2 and +1.6 dB respectively at 9.6 km from start-of-roll (at NMT 140) and a reduction of -1.0 and -0.8 dB respectively at 11.2 km from start-of-roll (at NMT 132). Whilst it must be acknowledged that for outdoor environmental noise measurements these changes are not much larger than the inherent measurement uncertainty, it is possible that these noise changes relate to procedural changes associated with the DET 2Z 2,500 ft minimum height requirement, which occurs at 15 km from start-of-roll[28].

153. Whilst the results for the British Airways 787-9 (Figure 63 and Figure 64) generally show no change in noise during the trial period, the results for the Virgin Atlantic 787-9 (Figure 65 and Figure 66) indicate possible noise changes related to procedural changes associated with the DET 2Z minimum height requirements[29]. It should again be recognised however that the majority of the differences are small in absolute terms.

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[27] Take-off weight data, which is normally considered commercially sensitive information, was not available for this study. Specific airline Noise Abatement Departure Procedure (NADP) information was also not available, despite attempts made by Heathrow to obtain relevant information.

[28] Qantas and Singapore Airlines both use a different coding house to the other A380 operators in the study, see

Annex A.

[29] There was no significant difference in the average British Airways 787-9 height profile during the baseline and trial periods. The average Virgin Atlantic 787-9 height profile on the other hand was approximately 100-200 ft higher during the trial compared to the baseline period (beyond 8km from start-of-roll).

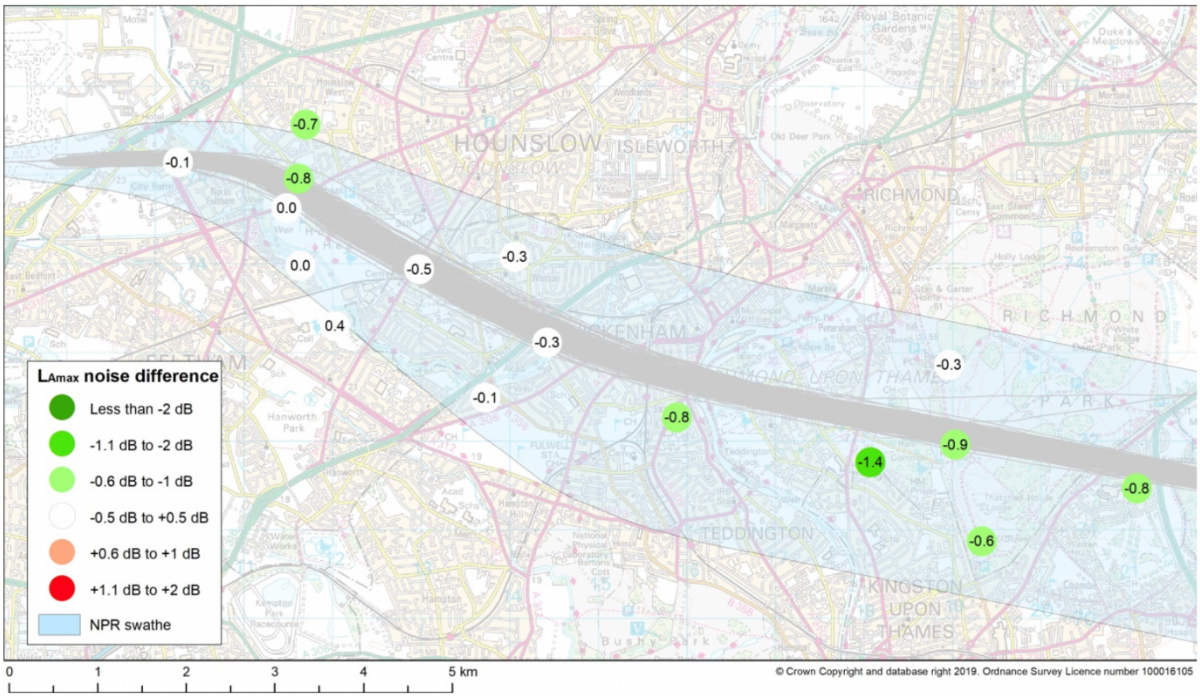

Figure 49. ETD A380 L_{Amax} noise differences on DET 09 route (DET 2Z minus DET 1J)

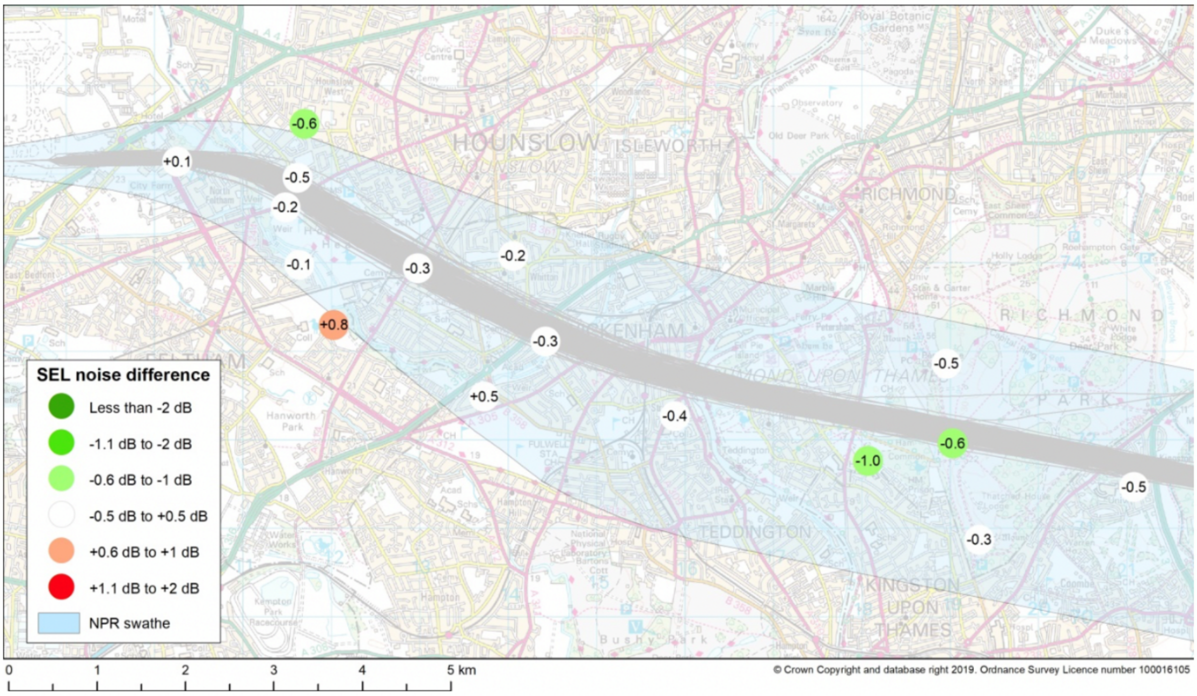

Figure 50. ETD A380 SEL noise differences on DET 09 route (DET 2Z minus DET 1J)

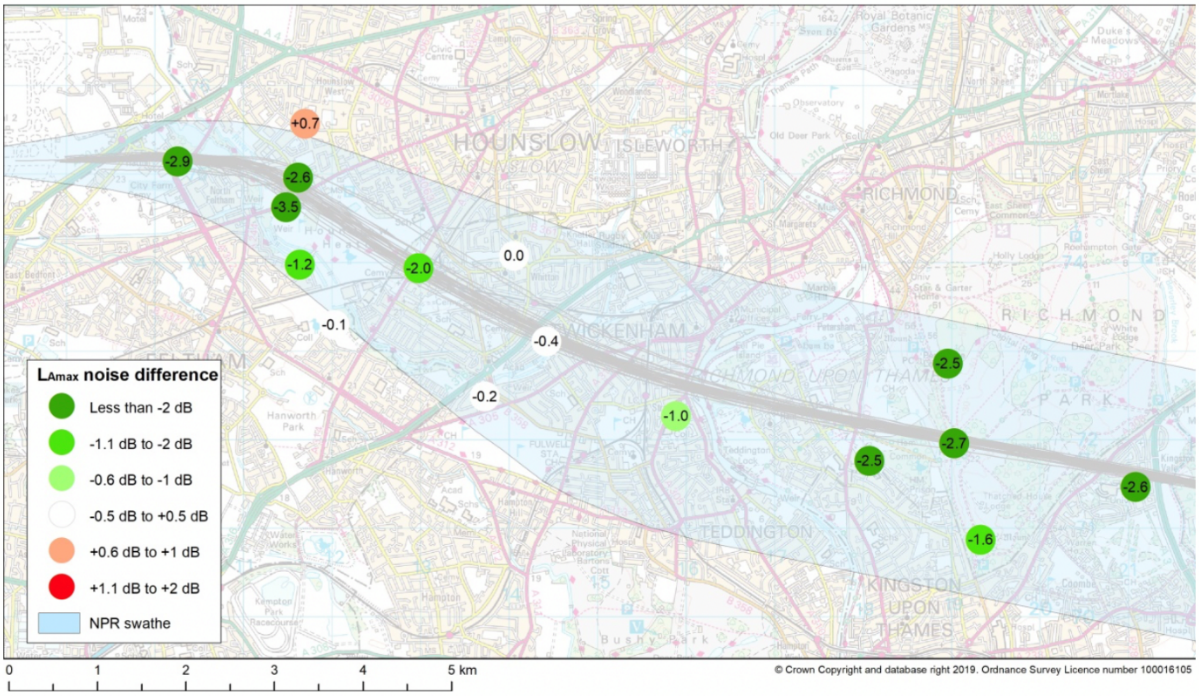

Figure 51. MAS A380 L_{Amax} noise differences on DET 09 route (DET 2Z minus DET 1J)

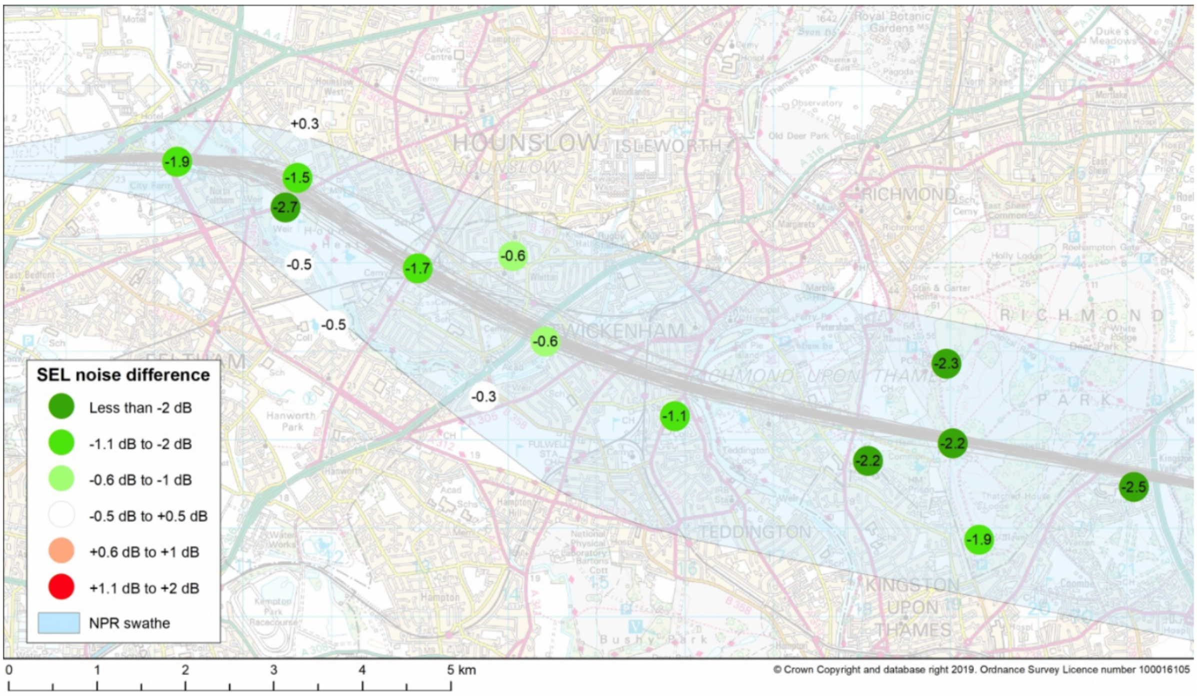

Figure 52. MAS A380 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

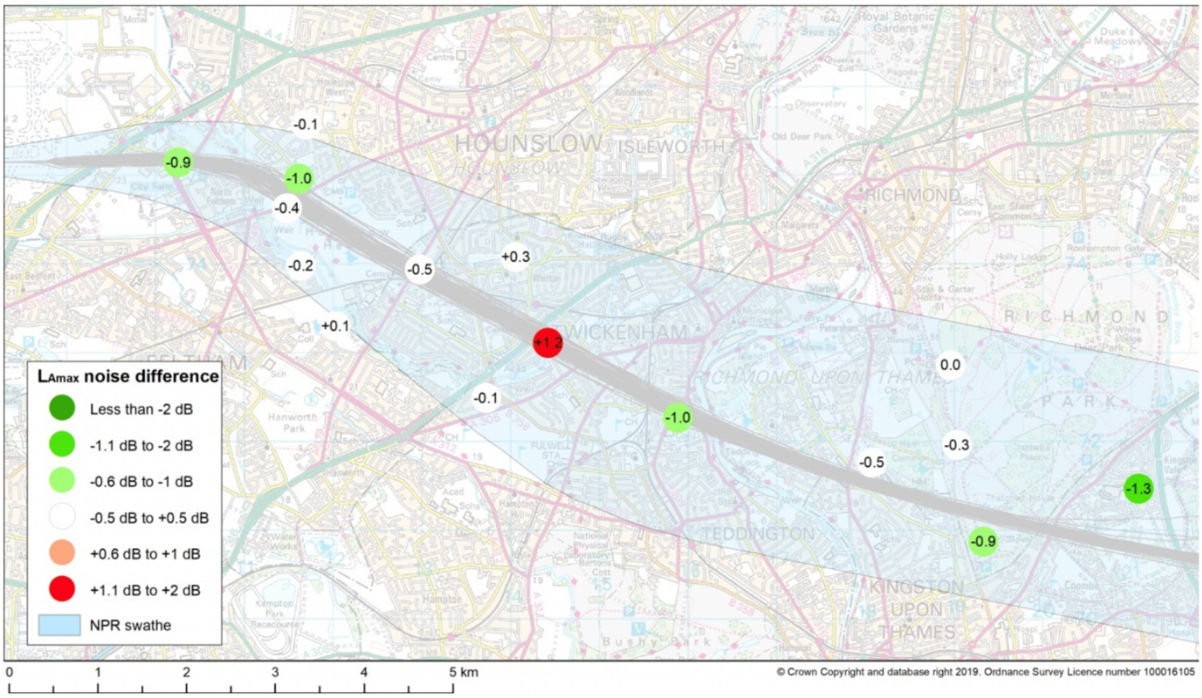

Figure 53. QFA A380 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

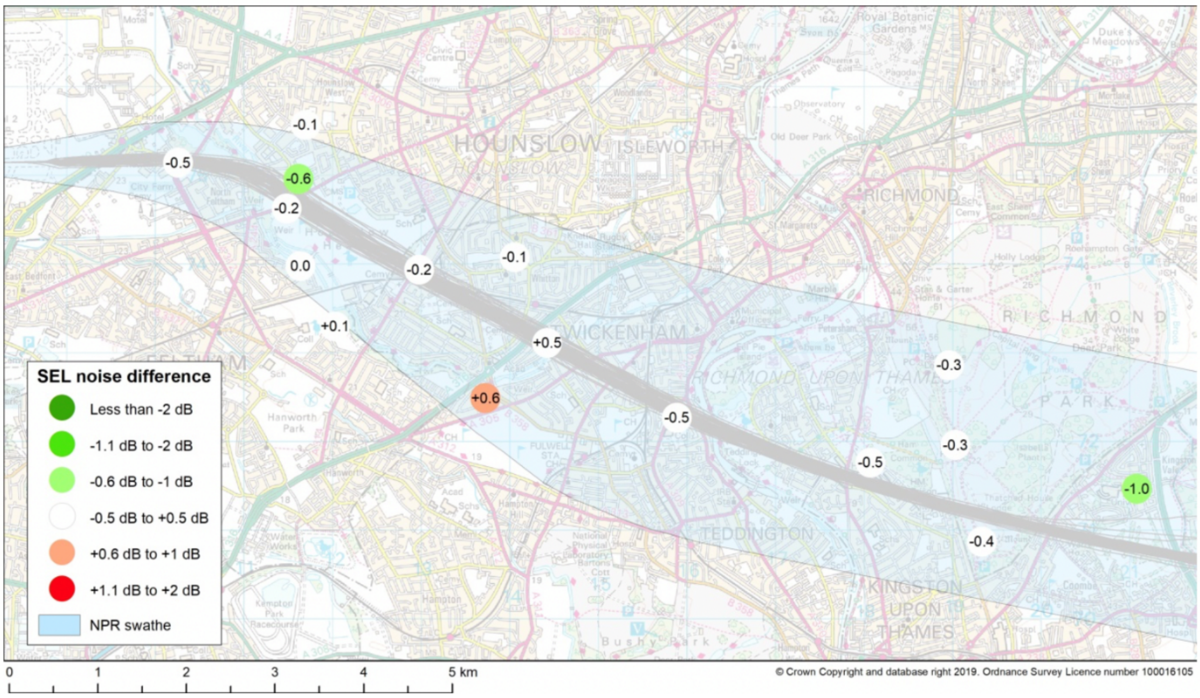

Figure 54. QFA A380 SEL noise differences on easterly DET 09 (DET 2Z minus DET 1J)

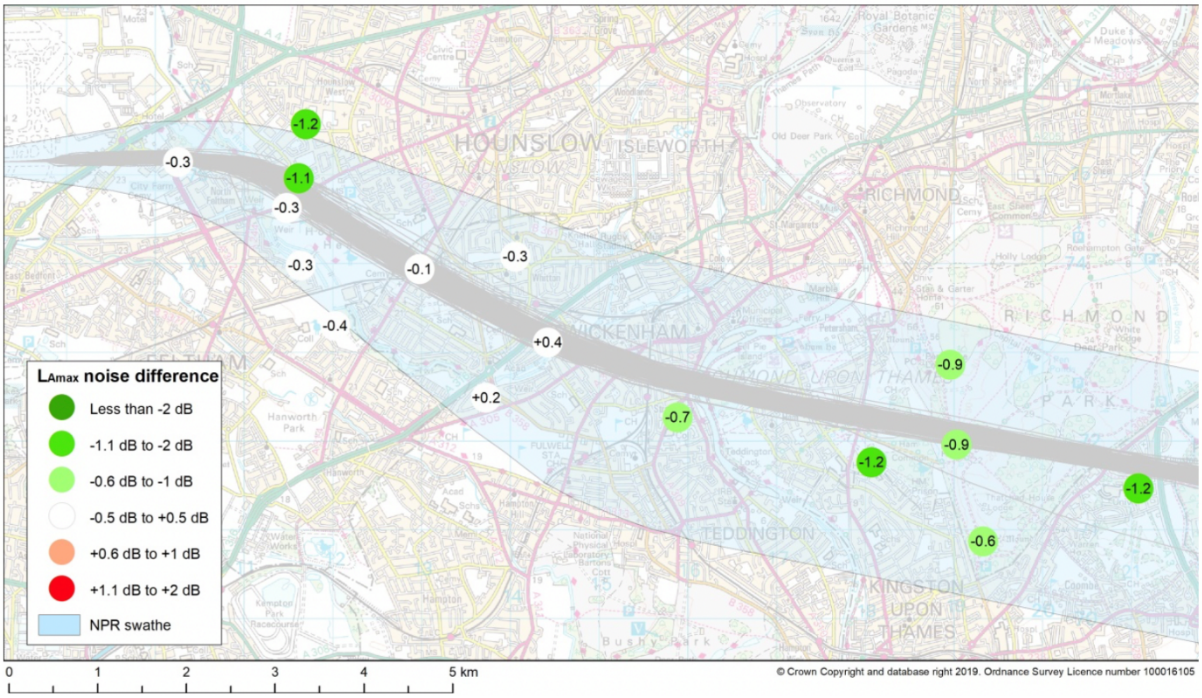

Figure 55. QTR A380 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

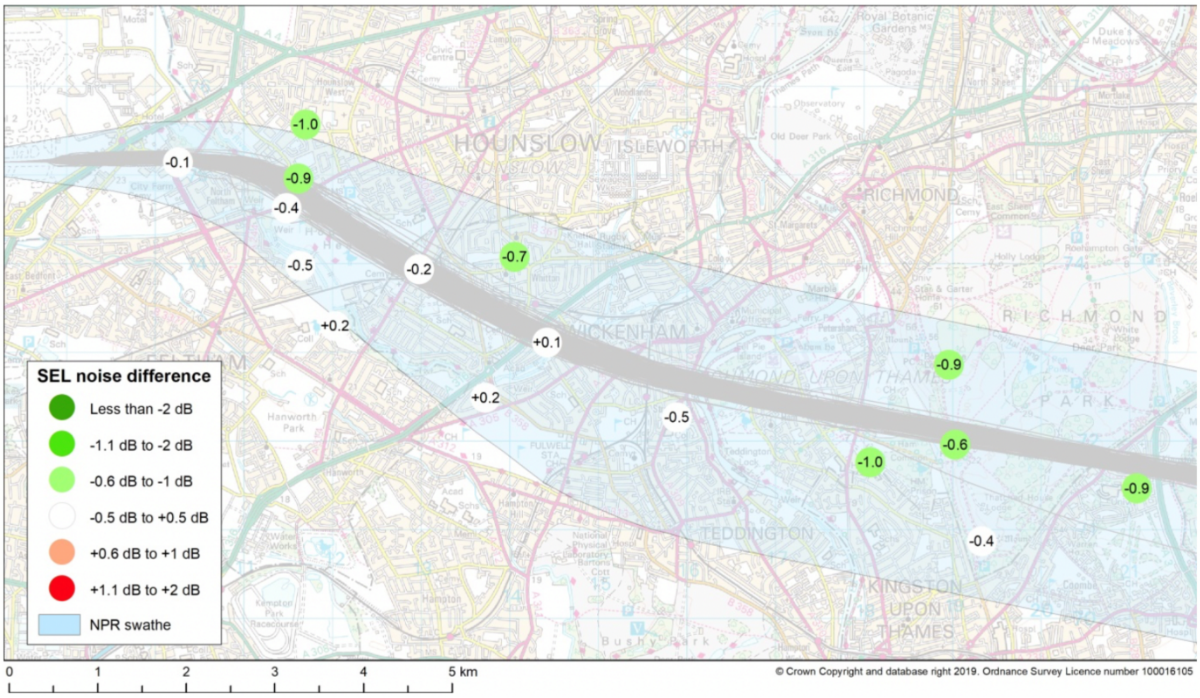

Figure 56. QTR A380 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

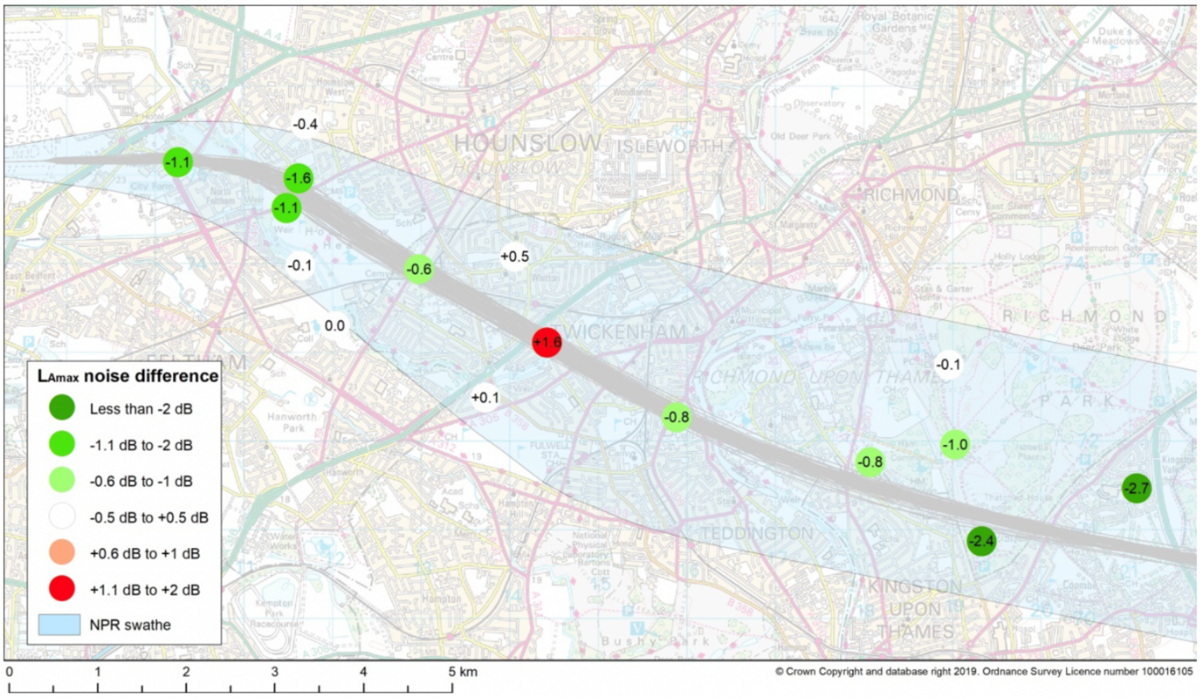

Figure 57. SIA A380 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

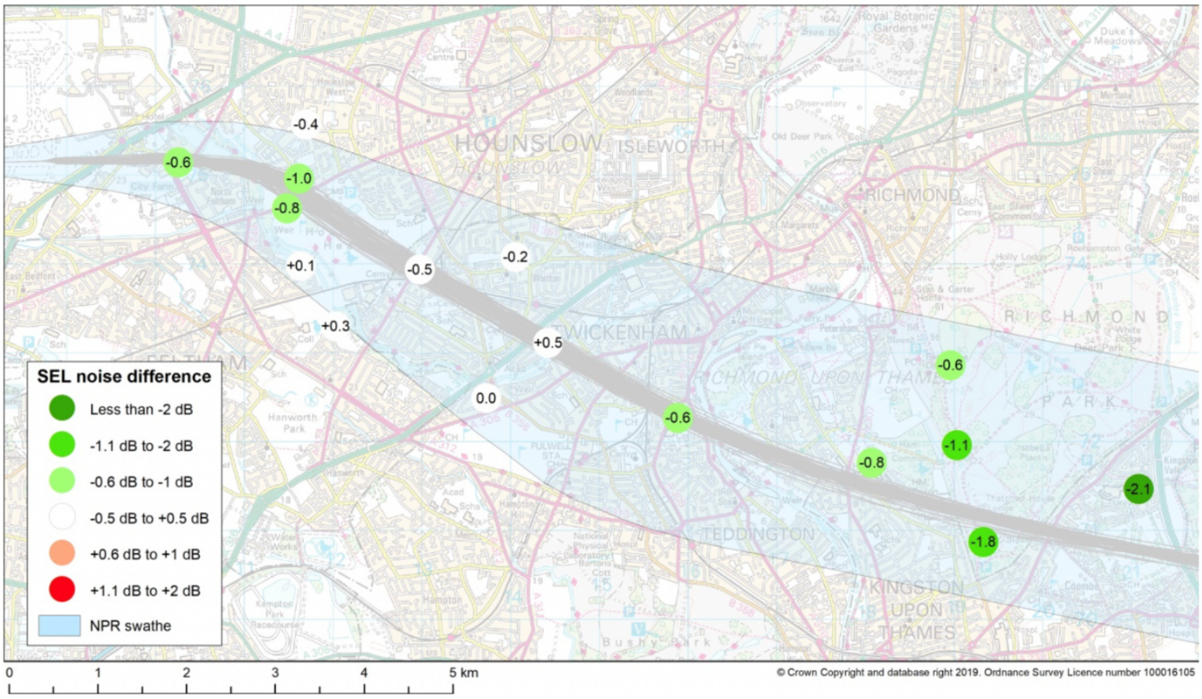

Figure 58. SIA A380 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

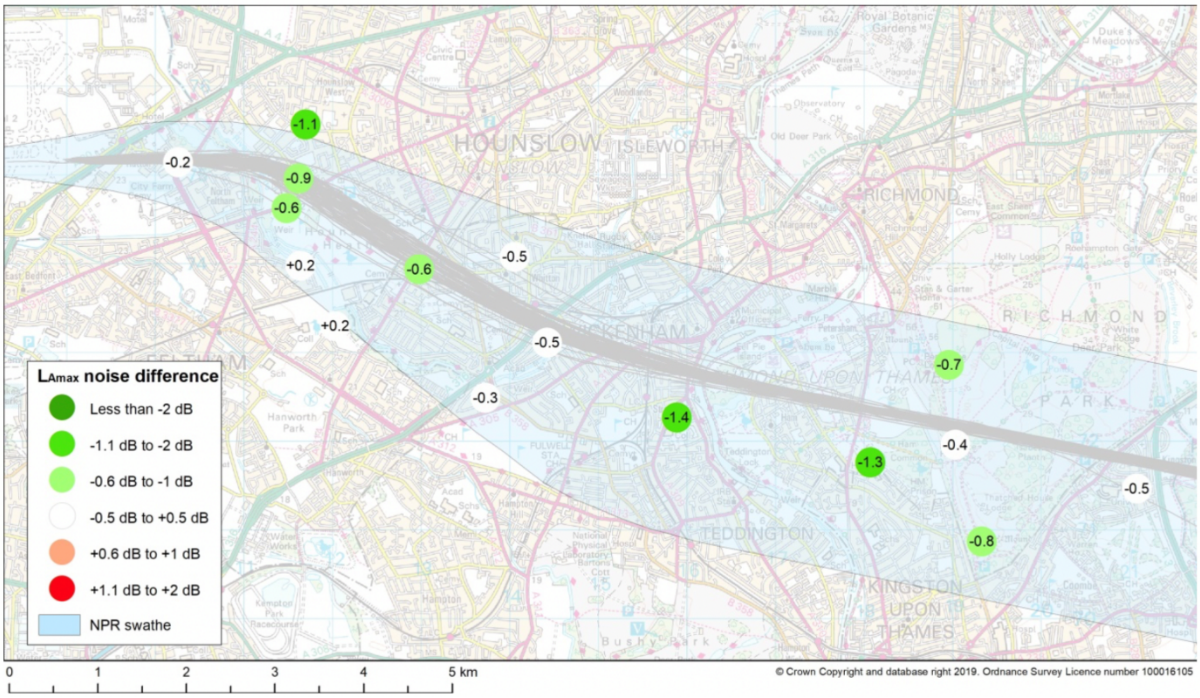

Figure 59. THA A380 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

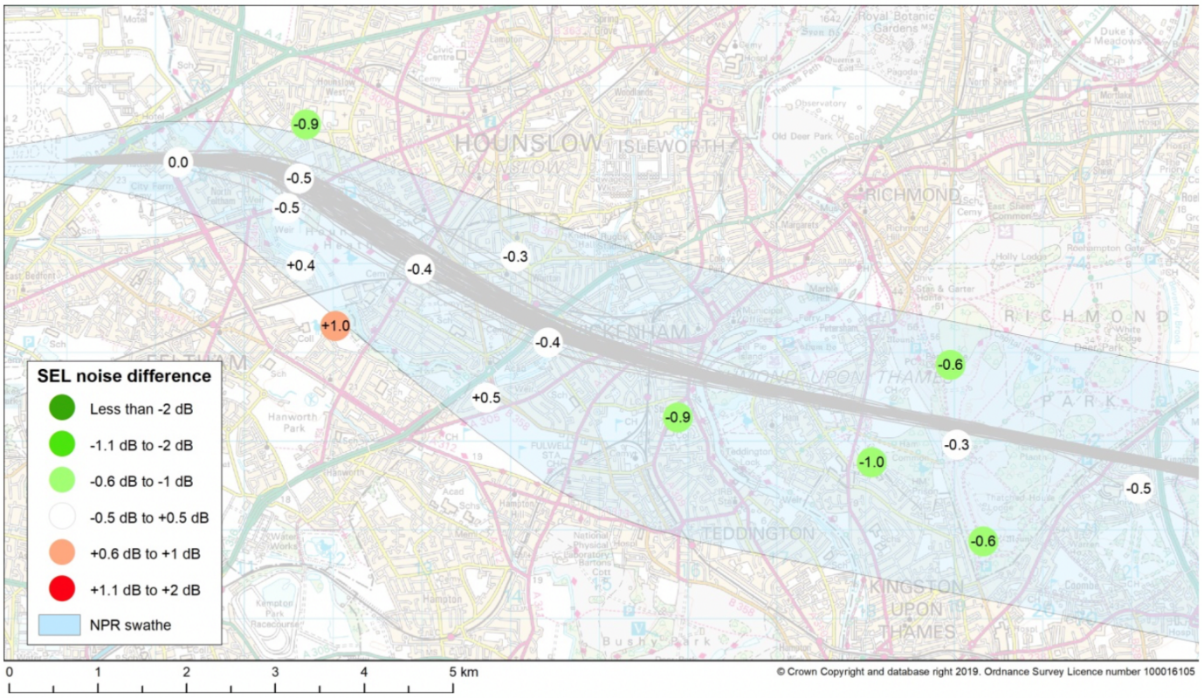

Figure 60. THA A380 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

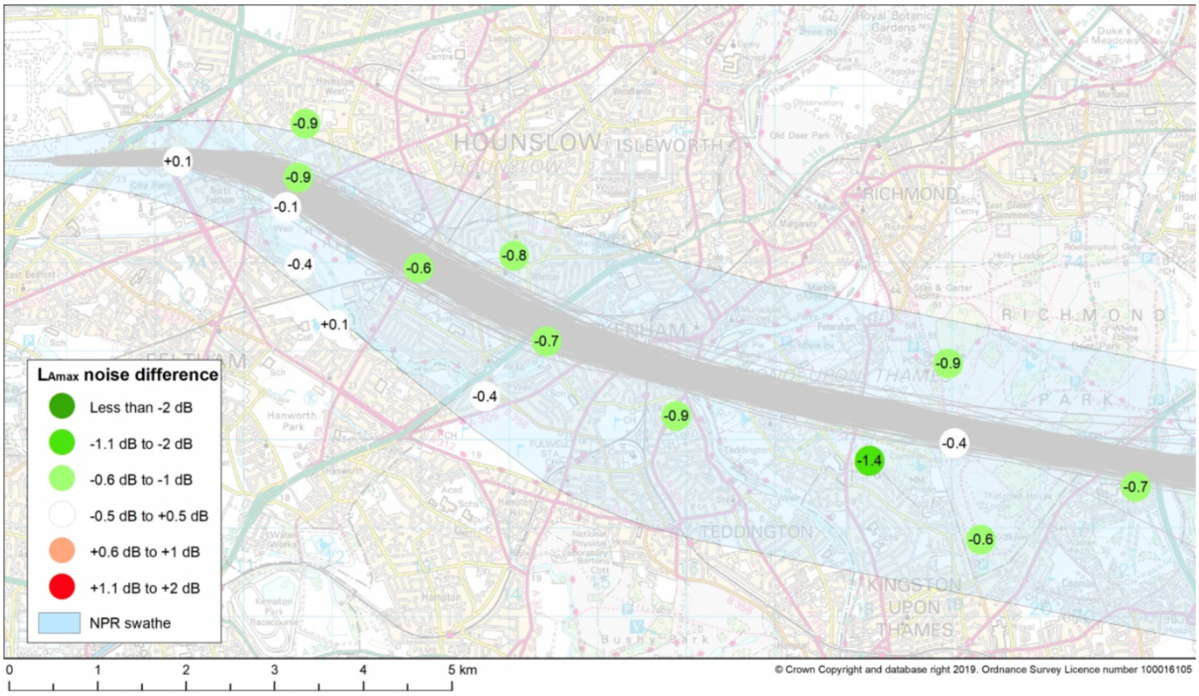

Figure 61. UAE A380 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

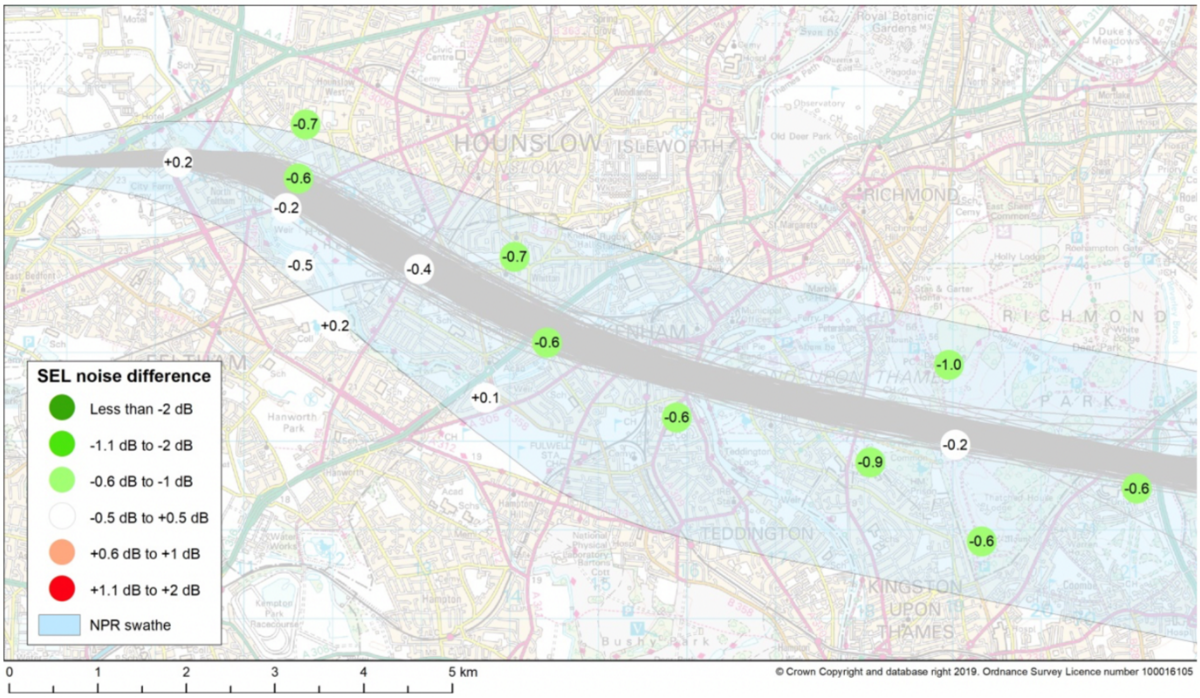

Figure 62. UAE A380 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

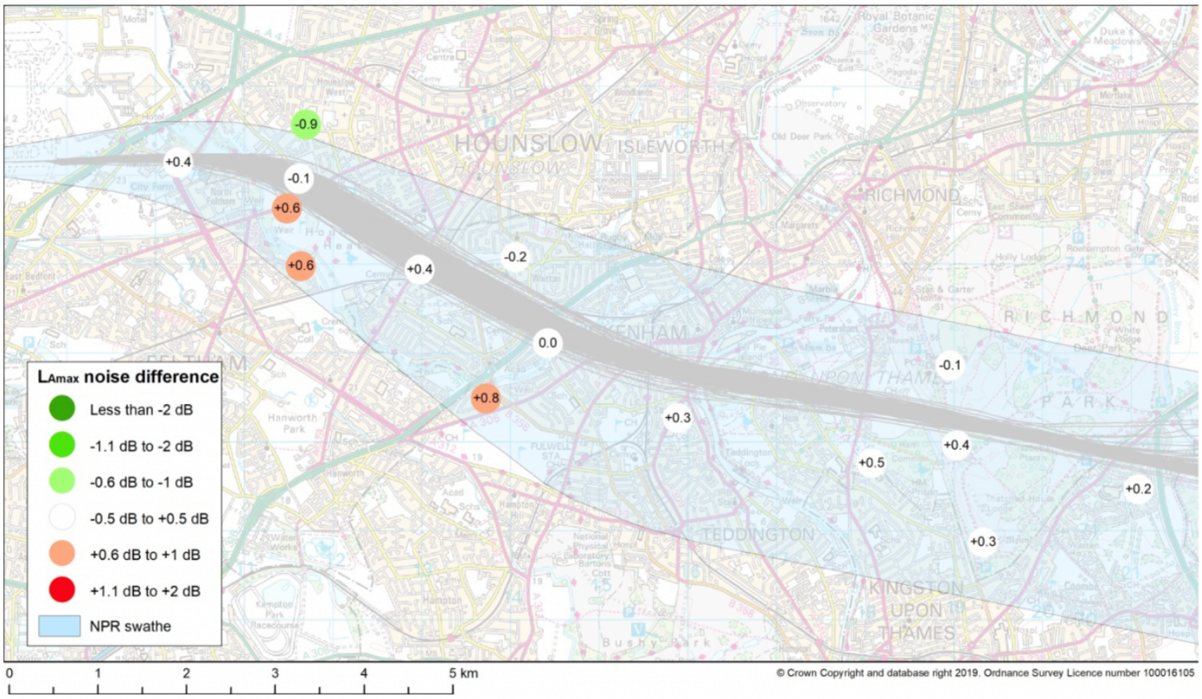

Figure 63. BAW 787-9 L_{Amax} noise differences on DET 09 route (DET 2Z minus DET 1J)

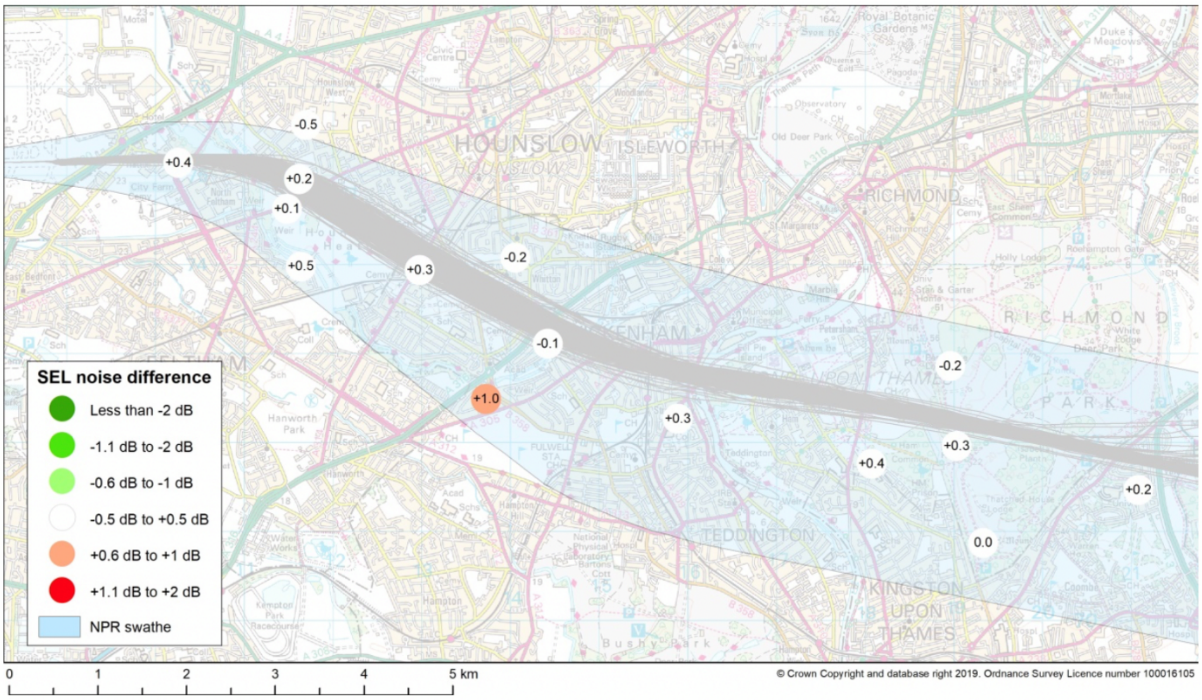

Figure 64. BAW 787-9 SEL noise differences on DET 09 (DET 2Z minus DET 1J)

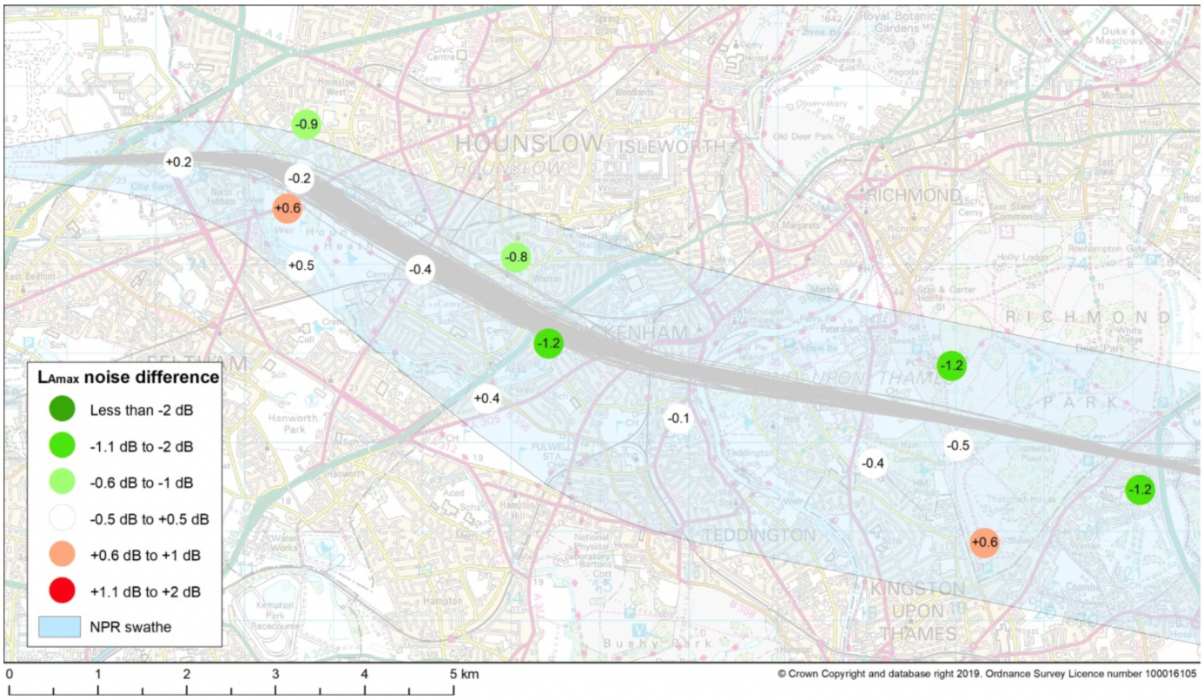

Figure 65. VIR 787-9 L_{Amax} noise differences on DET 09 (DET 2Z minus DET 1J)

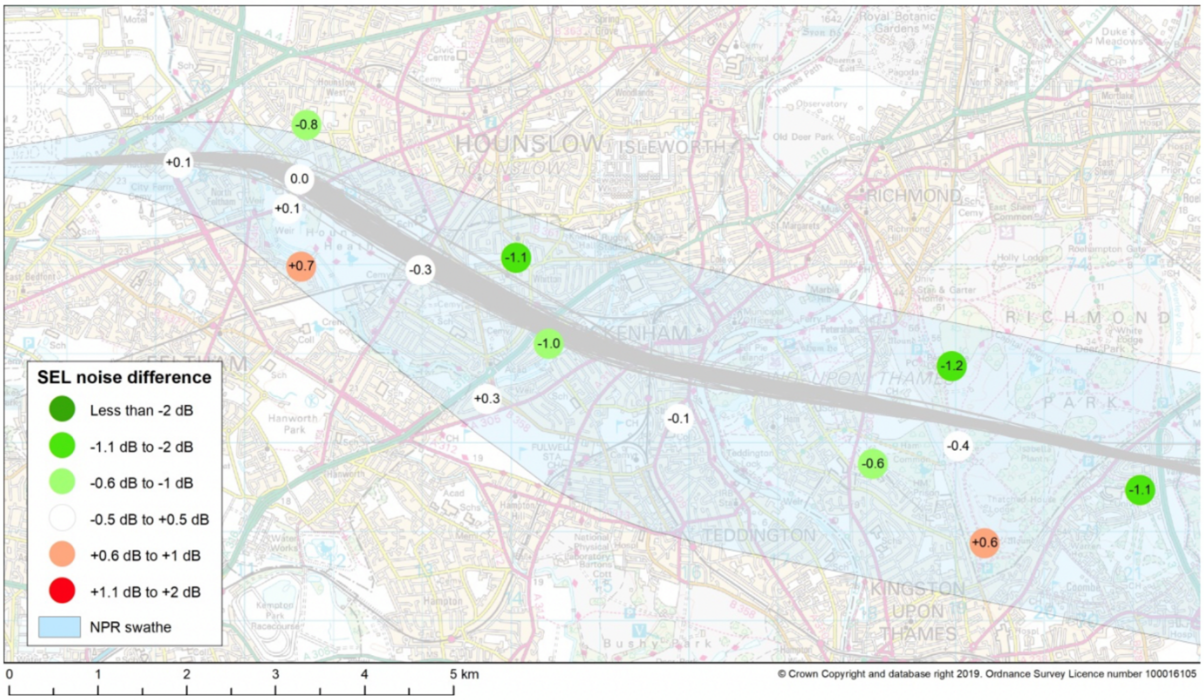

Figure 66. VIR 787-9 SEL noise differences on DET 09 route (DET 2Z minus DET 1J)

6.4 A380 noise differences for NADP 1 and NADP 2 procedures

154. This section provides a separate analysis of the noise differences between NADP1 and NADP2 procedures for one A380 operator, which routinely uses both types of NADP procedures at Heathrow.

155. For some A380 operations, the increased climb gradient requirement during the trial did not necessitate any change to the airline's standard operating procedure on take-off, since their NADP 1 and NADP 2 procedures already resulted in flight profiles that were higher than the minimum requirement.

156. Figure 67 illustrates the relative height differences between the flight profiles and the minimum climb requirements for one particular operator which operates both NADP 1 and NADP2 departures[30] from Heathrow. Based on an analysis of flight profiles, the operator did not appear to alter the proportion of procedures flown during the trial, with NADP1 continuing to be flown more frequently (for approximately 60% of their departures, although there is some variation year-to-year).

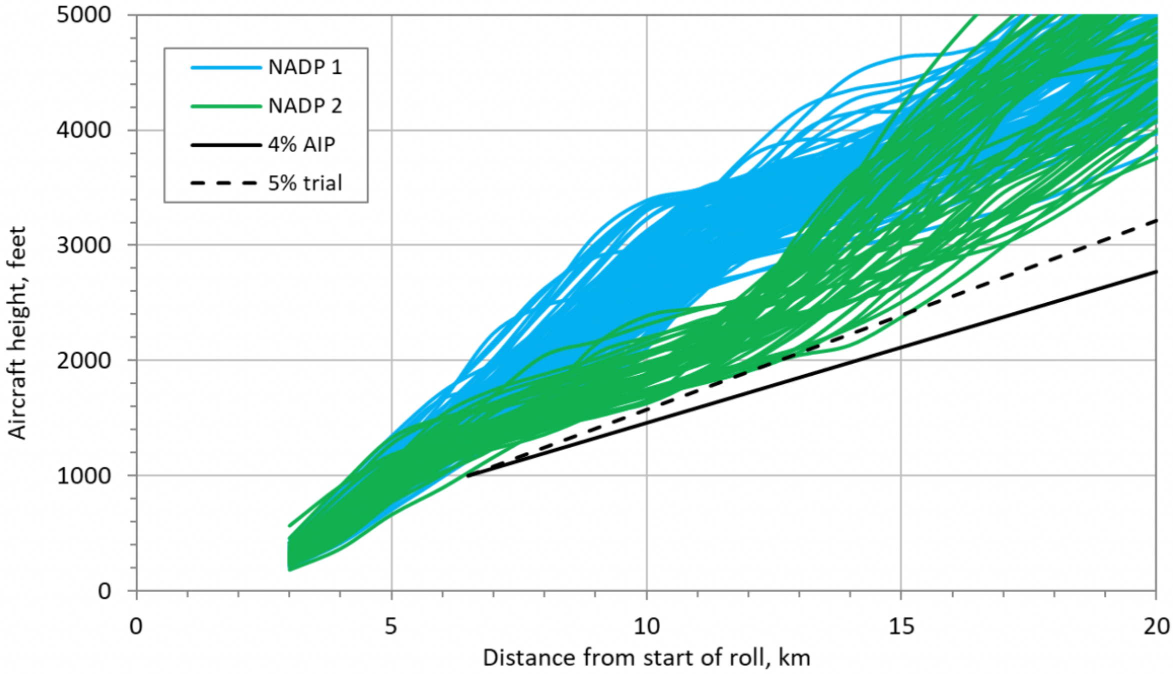

Figure 67. A380 operator NADP 1 and NADP 2 departure height profiles (DET 2Z)

157. Since the operator uses both NADP 1 and NADP 2 departures from Heathrow to a single destination, and therefore at similar take-off weights, their noise measurements serve as a useful dataset for comparing one NADP procedure against the other.

158. The measured noise level differences between NADP1 and NADP2 departures during the DET 2Z trial period are presented in Figure 68 and Figure 69 for L_{Amax} and SEL respectively. Whilst the results show a noise benefit along the centre of the route

[30] See CAP 1691 for further details on NADP procedures (www.caa.co.uk/CAP1691)

between approximately 8 to 14 km from start-of-roll going from NADP 2 to NADP 1 (due mainly to the increase in height over the ground), the results also show areas of increased noise to the sides of the flight path, particularly for SEL which accounts for the duration of the noise event as well as its intensity.

159. These results can be explained by the longer noise duration caused by the NADP1 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).

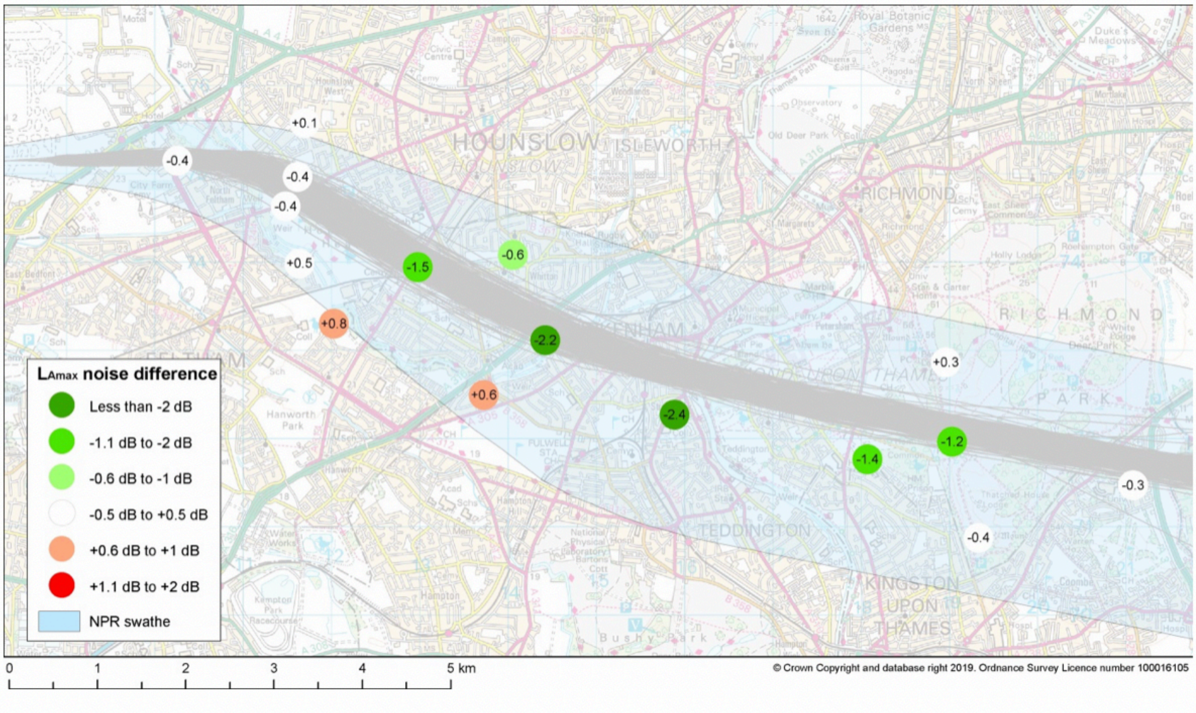

Figure 68. A380 L_{Amax} noise differences, NADP1 minus NADP2 (DET 2Z)

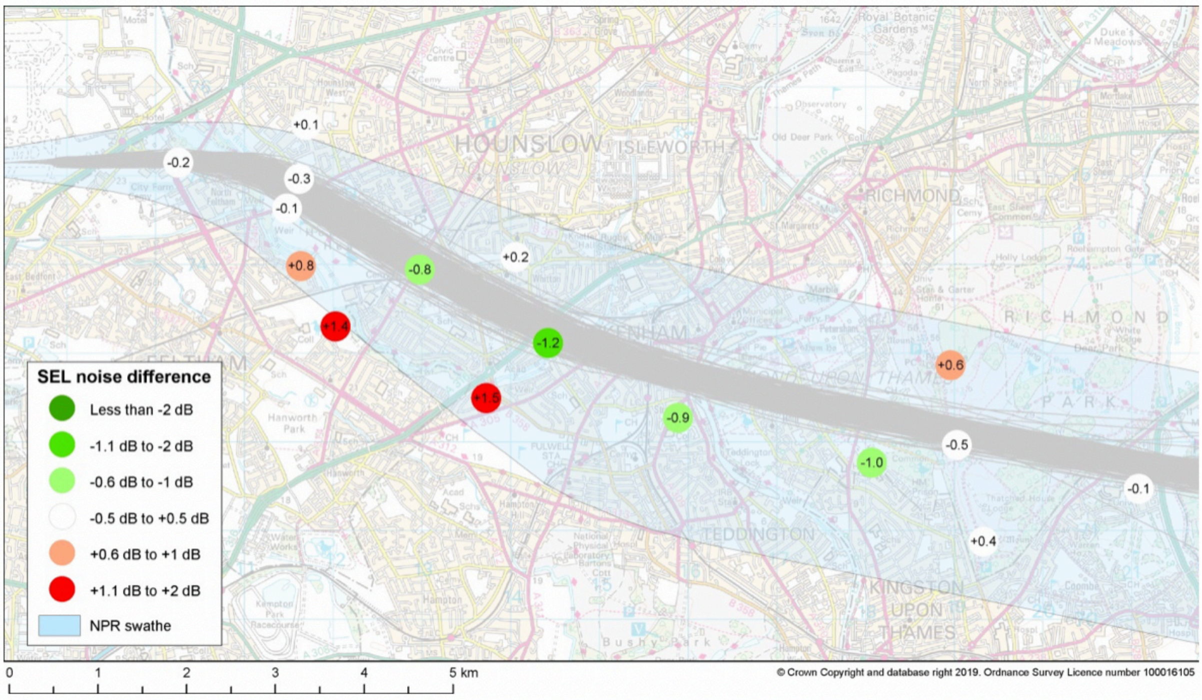

Figure 69. A380 SEL noise differences, NADP1 minus NADP2 (DET 2Z)

6.5 Summary of Key Findings

160. The analyses lead to the following findings:

a) The range of noise differences between the DET 1J procedure and the DET 2Z procedure (across all airlines and all monitors) is -3.5 to +1.6 dB for L_{Amax} and -2.7 to +1.0 dB for SEL, although the majority of differences are small in absolute terms (most are less than 1 dB).

b) In a few cases the measured noise reductions cannot be explained by changes in aircraft height or speed. It is therefore likely that reductions of either average take-off weight or engine thrust may also have occurred for some A380 operators during the trial period, most likely due to other unrelated operational changes, such as those covered in subsection 5.10.

c) The results for two A380 operators (which both use the same FMS coding house) show similar increases in noise level at 9.6 km from start-of-roll and similar reductions in noise level at 11.2 km from start-of-roll. It is possible that these noise changes relate to procedural changes associated with the DET 2Z 2,500 ft minimum height requirement, which occurs at 15 km from start-of-roll.

Section 7: Conclusion

161. Although the altitude attainment profiles were required in the published trial Instrument Flight Procedure (IFP), there were 26 instances of some flights not achieving those levels within the accepted tolerance (-200ft). There were no records of either ATC or airlines reporting these failures, they were captured through the analysis. In addition, the trial uncovered that most Flight Management Computers will not provide an alert to flight crews unless the aircraft is predicted to be 250ft or more below a published departure restriction. These findings should be used to inform airspace design, particularly where altitude attainment is required for route or obstacle separation purposes.

162. Some stakeholders felt a 5% gradient was not ambitious enough. Whilst this trial was coined as a 5% SID trial, if the trial gradient was measured from the Declared End of Runway (DER) as is normal for IFP SID design, the climb gradient for the DET2Z SID would be 8.83% until LON D4, 6.55% to DET D34 and 5.82% until DET D29. It is clear that these gradients were potentially too ambitious for a small minority of heavy departures whilst also trying to optimise their aircraft performance to handle a variety of requirements.

163. Noting that SID gradients cannot be coded into all Flight Management Computers, when measuring 5% gradient compliance as an absolute (with no tolerance) there were 120 failures.

164. Although the trial did not require any change to the lateral flight paths, the detailed analysis highlighted that flight paths can vary significantly owing to the interpretation by the companies who create the flight computer management coding of conventional IFPs. This is not a trend that would be expected with Performance-based Navigation (PBN) SIDs where the standard coding is provided as part of the design process.

165. The noise analysis suggests there are associated reductions in noise with increased climb gradients. However, although the vertical profile was the only variable changed by Heathrow during the trial there were many other variables outside of Heathrow's control that do change: aircraft type, weight (passengers, cargo, fuel (destination)), air temperature, air pressure, wind speed and direction, the NADP being flown, Standard Operation Procedures, thrust reduction altitude, flap reduction, acceleration profiles and the expectation from ATC at high density operations to accelerate to 250kts as soon as possible.

166. All these variables make identifying the optimum SID gradient for an airport with a varied fleet mix challenging. Whilst only 0.1% of flights were more than 200ft below an altitude restriction they were all climbing in excess of the required gradients at times during the SID. This suggest aircraft are capable of achieving the gradients proposed in this trial but not whilst trying to balance all other operating requirements.

167. The small number of failures suggest a 5% gradient from 1000ft to 4000ft is a realistic ambition for Heathrow however, if gradients such as those proposed in this trial were to be taken forward and a 100% adherence is expected, Heathrow may need more direct engagement with operators to help influence behaviour.

Annex A

168. Table A1 presents the measured A380 results for each airline in terms of the average maximum sound level (L_{Amax}) at each monitor location. Table A2 presents the corresponding A380 results in terms of the average Sound Exposure Level (SEL). Tables A3 and A4 present the equivalent results for the 787-9.

169. For each measured result, the standard deviation and 95 percent confidence interval (CI) of the mean level is also reported. The reliability of the measured noise level in each case can be expressed as a 95 percent confidence interval. This is the interval around the sample mean within which it is reasonable to assume the 'true' value of the mean lies. Due to the relatively large sample sizes obtained, the 95 percent confidence intervals of the departure noise levels in the majority of cases are very small, i.e. less than 0.5 dB.

Table A1. Average A380 L_{Amax} departure noise levels for baseline (DET 1J[31]) and trial (DET 2Z) periods

		ETD		MAS		QFA		QTR		SIA		THA		UAE	
Monitor		DET 1J	DET 2Z	DET 1J	DET 2Z	DET 1J	DET 2Z	DET 1J	DET 2Z	DET 1J	DET 2Z	DET 1J	DET 2Z	DET 1J	DET 2Z
10	Mean LAmax	82.8	82.0	85.9	83.3	81.6	80.6	83.4	82.3	84.7	83.1	85.5	84.6	82.8	81.9
	Std Dev	1.1	1.2	1.4	1.8	1.2	1.6	1.1	1.6	1.4	1.7	1.6	1.8	1.6	1.5
	Count	163	287	15	33	109	49	120	203	99	61	47	64	331	558
	95% CI	0.2	0.1	0.8	0.6	0.2	0.5	0.2	0.2	0.3	0.4	0.5	0.5	0.2	0.1
12	Mean LAmax	74.2	73.5	75.6	76.3	74.9	74.8	75.2	74.0	77.2	76.8	78.3	77.2	74.7	73.8
	Std Dev	1.5	1.4	1.1	1.8	1.3	1.8	1.5	1.5	1.3	1.6	2.0	1.7	1.6	1.6
	Count	162	288	15	34	108	49	119	203	99	61	47	65	329	558
	95% CI	0.2	0.2	0.6	0.6	0.2	0.5	0.3	0.2	0.3	0.4	0.6	0.4	0.2	0.1
13	Mean LAmax	76.0	76.0	77.9	76.7	77.0	76.8	77.5	77.2	78.0	77.9	74.6	74.8	76.5	76.1
	Std Dev	1.7	1.8	1.7	1.4	1.5	1.4	1.6	1.5	1.5	1.0	1.9	2.0	1.9	1.9
	Count	163	286	15	33	109	49	121	203	99	61	47	64	330	559
	95% CI	0.3	0.2	0.9	0.5	0.3	0.4	0.3	0.2	0.3	0.3	0.6	0.5	0.2	0.2
21	Mean LAmax	84.2	84.2	88.0	84.5	83.1	82.7	84.8	84.5	85.9	84.8	83.9	83.3	84.0	83.9
	Std Dev	1.2	1.1	1.6	1.7	1.5	1.4	1.7	1.9	1.6	2.1	1.9	1.9	1.4	1.5
	Count	163	164	15	32	109	49	118	124	99	53	47	44	327	316
	95% CI	0.2	0.2	0.9	0.6	0.3	0.4	0.3	0.3	0.3	0.6	0.5	0.6	0.2	0.2
132	Mean LAmax	77.4	76.6	78.6	77.6	78.1	77.1	76.5	75.8	79.9	79.1	76.8	75.4	75.9	75.0
	Std Dev	1.3	1.4	0.9	1.5	1.4	2.0	1.5	1.5	1.2	1.4	1.4	2.3	2.0	1.8
	Count	158	284	13	33	107	48	116	200	95	60	45	64	316	545
	95% CI	0.2	0.2	0.6	0.5	0.3	0.6	0.3	0.2	0.2	0.4	0.4	0.6	0.2	0.2
136	Mean LAmax	75.1	73.7	77.6	75.1	73.6	73.1	74.3	73.1	76.9	76.1	74.9	73.6	74.2	72.8
	Std Dev	1.3	1.6	1.2	1.8	1.6	1.6	1.3	1.5	1.5	2.2	1.6	1.3	1.5	1.6
	Count	92	284	15	31	61	49	66	199	54	60	30	63	187	543
	95% CI	0.3	0.2	0.7	0.7	0.4	0.5	0.3	0.2	0.4	0.6	0.6	0.3	0.2	0.1
137	Mean LAmax	88.1	88.0	92.3	89.4	87.1	86.2	87.7	87.4	90.5	89.4	90.5	90.3	87.8	87.9
	Std Dev	2.1	1.5	1.4	1.7	1.3	1.9	1.3	1.4	1.4	1.3	1.5	1.7	1.5	1.7
	Count	93	285	15	32	61	49	67	202	53	61	30	65	188	556
	95% CI	0.4	0.2	0.8	0.6	0.3	0.5	0.3	0.2	0.4	0.3	0.6	0.4	0.2	0.1
138	Mean LAmax	70.9	71.3	72.2	72.1	71.9	72.0	72.2	71.8	72.7	72.7	70.9	71.1	71.3	71.4
	Std Dev	1.6	1.9	1.1	1.4	1.6	1.6	1.5	1.6	1.4	1.5	1.4	1.8	1.6	1.8
	Count	72	227	11	29	53	49	62	190	52	61	14	45	160	459
	95% CI	0.4	0.2	0.7	0.5	0.4	0.5	0.4	0.2	0.4	0.4	0.8	0.5	0.2	0.2
139	Mean LAmax	82.6	82.1	83.6	81.6	81.1	80.6	80.7	80.6	82.5	81.9	82.7	82.1	81.8	81.2
	Std Dev	1.0	1.5	1.3	1.1	0.7	1.5	1.1	1.4	1.2	1.2	1.0	1.2	1.4	1.8
	Count	83	288	15	33	57	49	61	202	49	61	26	65	171	559
	95% CI	0.2	0.2	0.7	0.4	0.2	0.4	0.3	0.2	0.3	0.3	0.4	0.3	0.2	0.1
140	Mean LAmax	79.7	79.4	80.6	80.2	79.5	80.7	78.0	78.4	80.7	82.3	79.0	78.5	78.7	78.0
	Std Dev	1.3	1.5	1.0	1.3	1.0	1.8	0.9	1.5	0.9	1.4	1.1	1.3	1.6	1.8
	Count	83	286	15	33	56	48	61	203	48	60	26	65	172	557
	95% CI	0.3	0.2	0.5	0.5	0.3	0.5	0.2	0.2	0.3	0.4	0.5	0.3	0.2	0.1
141	Mean LAmax	72.8	72.5	75.8	73.3	68.3	68.3	73.1	72.2	69.2	69.1	74.8	74.1	73.7	72.8
	Std Dev	1.3	1.9	1.0	2.2	1.4	1.9	1.3	1.7	1.5	1.8	1.9	1.5	1.3	1.8
	Count	64	286	15	32	41	45	46	200	33	55	18	64	122	557
	95% CI	0.3	0.2	0.6	0.8	0.4	0.6	0.4	0.2	0.5	0.5	1.0	0.4	0.2	0.1
142	Mean LAmax	74.7	73.8	77.3	74.6	72.0	71.7	74.0	73.1	75.0	74.0	74.6	74.2	73.6	73.2
	Std Dev	1.3	2.1	0.8	2.7	1.3	1.9	1.1	1.8	1.5	2.0	1.5	1.2	1.6	1.8
	Count	64	287	15	33	43	49	46	202	34	61	18	65	124	557
	95% CI	0.3	0.2	0.4	1.0	0.4	0.5	0.3	0.2	0.5	0.5	0.7	0.3	0.3	0.2
143	Mean LAmax	70.2	69.6	72.5	70.9	73.4	72.5	70.0	69.4	76.9	74.5	71.0	70.2	70.0	69.4
	Std Dev	1.7	1.9	0.9	2.5	1.3	1.9	1.8	2.1	1.6	1.9	1.8	1.9	1.5	2.1
	Count	64	280	15	33	43	49	46	201	34	61	18	64	122	552
	95% CI	0.4	0.2	0.5	0.9	0.4	0.6	0.5	0.3	0.6	0.5	0.9	0.5	0.3	0.2
144	Mean LAmax	72.6	72.5	73.5	73.3	73.1	73.0	72.7	72.9	74.3	74.4	72.2	71.9	73.0	72.6
	Std Dev	1.5	1.9	1.6	1.5	1.3	1.7	1.4	1.6	1.5	1.8	1.6	2.0	1.7	1.9
	Count	54	287	15	32	36	49	40	203	27	61	15	65	101	555
	95% CI	0.4	0.2	0.9	0.5	0.5	0.5	0.4	0.2	0.6	0.5	0.9	0.5	0.3	0.2
145	Mean LAmax	77.2	76.9	77.9	77.9	77.1	77.4	76.4	76.1	77.5	78.0	78.9	78.4	77.6	76.8
	Std Dev	1.3	1.4	1.1	1.2	1.3	1.6	1.2	1.4	1.2	1.3	1.9	1.6	1.6	1.6
	Count	53	288	15	33	36	49	40	203	27	61	15	65	101	557
	95% CI	0.4	0.2	0.6	0.4	0.4	0.5	0.4	0.2	0.5	0.3	1.0	0.4	0.3	0.1
146	Mean LAmax	72.2	71.4	75.0	72.4	72.8	71.5	71.8	70.6	74.8	72.1	73.3	72.8	72.3	71.6
	Std Dev	1.1	2.3	1.4	2.2	1.4	2.2	1.7	2.2	1.8	2.1	2.0	1.5	1.4	1.9
	Count	53	290	15	33	36	49	40	203	27	61	15	65	101	554
	95% CI	0.3	0.3	0.8	0.8	0.5	0.6	0.5	0.3	0.7	0.5	1.1	0.4	0.3	0.2

[31] DET 1J noise levels adjusted to account for differences in average lateral ground track between DET 1J and DET 2Z.

Table A2. Average A380 SEL departure noise levels for baseline (DET 1J[32]) and trial (DET 2Z) periods

Monitor		ETD DET 1J	ETD DET 2Z	MAS DET 1J	MAS DET 2Z	QFA DET 1J	QFA DET 2Z	QTR DET 1J	QTR DET 2Z	SIA DET 1J	SIA DET 2Z	THA DET 1J	THA DET 2Z	UAE DET 1J	UAE DET 2Z
10	Mean SEL	91.3	90.8	94.2	92.7	91.6	91.0	92.0	91.1	93.8	92.8	93.7	93.2	91.5	90.9
	Std Dev	0.9	0.8	0.9	1.2	0.9	1.2	0.8	1.3	0.8	1.1	1.1	1.1	1.2	1.1
	Count	163	287	15	33	109	49	120	203	99	61	47	64	331	558
	95% CI	0.1	0.1	0.5	0.4	0.2	0.3	0.1	0.2	0.2	0.3	0.3	0.3	0.1	0.1
12	Mean SEL	84.5	83.9	85.9	86.2	85.5	85.4	85.2	84.2	87.6	87.2	87.7	86.8	85.0	84.3
	Std Dev	1.2	1.3	0.8	2.3	1.1	1.3	1.3	1.4	0.9	1.2	1.9	1.3	1.4	1.4
	Count	162	288	15	34	108	49	119	203	99	61	47	65	329	558
	95% CI	0.2	0.1	0.4	0.8	0.2	0.4	0.2	0.2	0.2	0.3	0.6	0.3	0.2	0.1
13	Mean SEL	85.8	85.7	87.6	87.1	87.7	87.7	87.5	87.0	88.5	88.6	84.6	85.0	86.6	86.1
	Std Dev	1.5	1.7	1.8	1.5	1.4	1.1	1.6	1.5	1.3	0.9	1.9	2.1	1.7	1.8
	Count	163	286	15	33	109	49	121	203	99	61	47	64	330	559
	95% CI	0.2	0.2	1.0	0.5	0.3	0.3	0.3	0.2	0.3	0.2	0.6	0.5	0.2	0.2
21	Mean SEL	92.1	91.9	95.8	93.1	92.1	91.9	92.7	92.3	94.3	93.5	92.6	92.1	92.1	91.9
	Std Dev	1.0	0.8	1.4	1.2	1.7	1.1	1.5	1.5	1.4	2.0	1.4	1.5	1.0	1.3
	Count	163	164	15	32	109	49	118	124	99	53	47	44	327	316
	95% CI	0.2	0.1	0.8	0.4	0.3	0.3	0.3	0.3	0.3	0.6	0.4	0.5	0.1	0.1
132	Mean SEL	87.1	86.7	89.0	87.9	88.2	87.7	86.6	86.1	90.0	89.4	87.5	86.6	86.6	86.0
	Std Dev	1.2	1.2	0.8	1.3	1.3	1.6	1.3	1.3	1.1	1.3	1.1	2.3	1.4	1.4
	Count	158	284	13	33	107	48	116	200	95	60	45	64	316	545
	95% CI	0.2	0.1	0.5	0.5	0.2	0.5	0.2	0.2	0.2	0.3	0.3	0.6	0.2	0.1
136	Mean SEL	84.5	83.5	87.7	85.5	84.4	83.9	83.9	82.9	87.3	86.5	85.2	84.2	84.0	83.1
	Std Dev	1.2	1.9	0.8	1.7	1.6	2.2	1.2	1.7	1.1	2.0	1.3	1.2	1.4	1.7
	Count	92	284	15	31	61	49	66	199	54	60	30	63	187	543
	95% CI	0.3	0.2	0.4	0.6	0.4	0.6	0.3	0.2	0.3	0.5	0.5	0.3	0.2	0.1
137	Mean SEL	94.9	95.0	98.7	96.8	95.3	94.8	94.7	94.6	97.7	97.1	97.3	97.3	95.0	95.2
	Std Dev	2.1	1.0	0.9	1.1	0.9	1.3	0.9	0.9	0.9	1.0	1.1	1.1	1.0	1.2
	Count	93	285	15	32	61	49	67	202	53	61	30	65	188	556
	95% CI	0.4	0.1	0.5	0.4	0.2	0.4	0.2	0.1	0.2	0.2	0.4	0.3	0.1	0.1
138	Mean SEL	79.5	80.3	82.2	81.7	81.6	81.7	81.3	81.5	82.6	82.9	79.4	80.4	80.5	80.7
	Std Dev	2.0	2.3	1.0	1.3	1.6	1.7	1.8	1.6	1.5	1.5	1.9	2.1	1.8	2.3
	Count	72	227	11	29	53	49	62	190	52	61	14	45	160	459
	95% CI	0.5	0.3	0.7	0.5	0.4	0.5	0.5	0.2	0.4	0.4	1.1	0.6	0.3	0.2
139	Mean SEL	91.3	91.0	93.0	91.3	90.8	90.6	90.3	90.1	92.2	91.7	91.9	91.5	91.0	90.6
	Std Dev	0.7	1.2	1.2	1.1	0.6	1.3	0.9	1.1	0.8	1.0	0.8	1.0	1.0	1.3
	Count	83	288	15	33	57	49	61	202	49	61	26	65	171	559
	95% CI	0.1	0.1	0.6	0.4	0.2	0.4	0.2	0.2	0.2	0.3	0.3	0.2	0.1	0.1
140	Mean SEL	88.7	88.4	90.1	89.5	89.0	89.5	87.4	87.5	90.2	90.7	88.8	88.4	88.3	87.7
	Std Dev	0.8	1.1	0.7	0.9	0.6	1.3	0.7	1.2	0.7	0.9	0.9	1.0	1.0	1.4
	Count	83	286	15	33	56	48	61	203	48	60	26	65	172	557
	95% CI	0.2	0.1	0.4	0.3	0.2	0.4	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.1
141	Mean SEL	83.2	82.7	86.4	84.1	79.6	79.3	83.3	82.4	81.0	80.4	85.9	85.3	84.3	83.3
	Std Dev	1.1	1.9	0.8	2.2	1.2	1.9	1.2	1.7	0.9	1.8	1.5	1.3	1.3	1.8
	Count	64	286	15	32	41	45	46	200	33	55	18	64	122	557
	95% CI	0.3	0.2	0.4	0.8	0.4	0.6	0.4	0.2	0.3	0.5	0.7	0.3	0.2	0.1
142	Mean SEL	84.5	83.9	87.4	85.2	83.8	83.5	83.8	83.2	86.3	85.2	85.5	85.2	84.0	83.8
	Std Dev	1.1	1.9	0.6	2.6	1.2	1.7	1.1	1.7	1.0	1.8	1.4	1.2	1.3	1.7
	Count	64	287	15	33	43	49	46	202	34	61	18	65	124	557
	95% CI	0.3	0.2	0.3	0.9	0.4	0.5	0.3	0.2	0.3	0.5	0.7	0.3	0.2	0.1
143	Mean SEL	80.4	80.1	83.6	81.7	84.2	83.8	80.2	79.8	87.4	85.6	82.2	81.6	81.0	80.4
	Std Dev	1.4	1.9	0.5	2.7	1.2	2.0	1.6	2.2	1.1	2.0	1.6	1.8	1.6	2.0
	Count	64	280	15	33	43	49	46	201	34	61	18	64	122	552
	95% CI	0.4	0.2	0.3	1.0	0.4	0.6	0.5	0.3	0.4	0.5	0.8	0.4	0.3	0.2
144	Mean SEL	81.7	82.2	83.8	83.5	83.1	83.7	82.6	82.8	84.7	84.7	81.6	82.1	82.5	82.6
	Std Dev	1.4	1.8	1.7	1.2	1.4	1.4	1.4	1.6	1.1	1.3	1.4	1.9	1.7	1.9
	Count	54	287	15	32	36	49	40	203	27	61	15	65	101	555
	95% CI	0.4	0.2	1.0	0.4	0.5	0.4	0.4	0.2	0.4	0.3	0.8	0.5	0.3	0.2
145	Mean SEL	87.3	87.1	89.1	88.5	88.0	87.9	87.3	86.6	88.9	88.7	89.4	89.1	88.2	87.5
	Std Dev	0.9	1.3	0.8	1.3	0.8	1.4	1.0	1.2	1.0	1.3	1.6	1.4	1.3	1.3
	Count	53	288	15	33	36	49	40	203	27	61	15	65	101	557
	95% CI	0.3	0.1	0.4	0.5	0.3	0.4	0.3	0.2	0.4	0.3	0.9	0.3	0.3	0.1
146	Mean SEL	82.4	81.9	85.9	83.4	83.6	82.6	82.0	81.1	85.7	83.6	84.6	84.1	83.0	82.4
	Std Dev	1.1	2.2	0.9	2.1	1.3	2.1	1.5	2.2	1.1	2.2	1.9	1.4	1.2	1.9
	Count	53	290	15	33	36	49	40	203	27	61	15	65	101	554
	95% CI	0.3	0.3	0.5	0.7	0.4	0.6	0.5	0.3	0.4	0.6	1.1	0.3	0.2	0.2

[32] DET 1J noise levels adjusted to account for differences in average lateral ground track between DET 1J and DET 2Z.

Table A3. Average 787 9 LAmax departure noise levels for baseline (DET 1J[33]) and trial (DET 2Z) periods

		BAW		VIR	
	Monitor	DET 1J	DET 2Z	DET 1J	DET 2Z
10	Mean LAmax	76.6	76.5	77.6	77.4
	Std Dev	1.4	1.5	1.2	1.5
	Count	298	424	41	108
	95% CI	0.2	0.1	0.4	0.3
12	Mean LAmax	71.5	70.6	72.3	71.4
	Std Dev	1.6	1.8	1.6	1.5
	Count	279	395	40	108
	95% CI	0.2	0.2	0.5	0.3
13	Mean LAmax	69.8	70.4	70.1	70.6
	Std Dev	1.5	1.7	1.7	1.7
	Count	273	391	41	103
	95% CI	0.2	0.2	0.5	0.3
21	Mean LAmax	77.0	77.6	77.4	78.0
	Std Dev	1.2	1.4	1.3	1.4
	Count	294	278	40	76
	95% CI	0.1	0.2	0.4	0.3
132	Mean LAmax	69.0	69.3	70.0	69.9
	Std Dev	2.0	2.0	1.6	1.7
	Count	294	423	39	108
	95% CI	0.2	0.2	0.5	0.3
136	Mean LAmax	68.3	68.8	67.9	67.5
	Std Dev	1.5	1.7	1.2	1.0
	Count	44	77	18	34
	95% CI	0.5	0.4	0.6	0.3
137	Mean LAmax	82.4	82.8	84.0	84.2
	Std Dev	2.0	2.2	1.9	1.5
	Count	194	423	24	108
	95% CI	0.3	0.2	0.8	0.3
138	Mean LAmax	No data		No data	
	Std Dev				
	Count				
	95% CI				
139	Mean LAmax	75.7	76.1	76.5	76.1
	Std Dev	1.0	1.3	0.7	1.4
	Count	181	423	22	108
	95% CI	0.1	0.1	0.3	0.3
140	Mean LAmax	73.1	73.1	74.5	73.3
	Std Dev	1.5	1.8	1.2	1.8
	Count	180	423	22	106
	95% CI	0.2	0.2	0.5	0.3
141	Mean LAmax	67.9	67.8	69.3	68.1
	Std Dev	1.4	1.9	1.3	1.5
	Count	130	412	15	107
	95% CI	0.2	0.2	0.7	0.3
142	Mean LAmax	67.2	67.6	68.4	67.9
	Std Dev	1.7	1.9	1.3	1.6
	Count	130	410	15	107
	95% CI	0.3	0.2	0.7	0.3
143	Mean LAmax	63.6	63.9	62.9	63.5
	Std Dev	2.1	2.0	1.6	1.6
	Count	50	176	11	68
	95% CI	0.6	0.3	1.1	0.4
144	Mean LAmax	66.2	67.0	66.9	67.3
	Std Dev	1.3	1.8	1.5	1.6
	Count	77	319	11	96
	95% CI	0.3	0.2	1.0	0.3
145	Mean LAmax	73.0	72.8	73.9	73.1
	Std Dev	1.5	1.8	1.0	1.6
	Count	110	425	12	108
	95% CI	0.3	0.2	0.7	0.3
146	Mean LAmax	65.9	66.1	67.5	66.3
	Std Dev	1.5	2.2	1.1	1.5
	Count	108	388	12	104
	95% CI	0.3	0.2	0.7	0.3

[33] DET 1J noise levels adjusted to account for differences in average lateral ground track between DET 1J and DET 2Z.

Table A4. Average 787 9 SEL departure noise levels for baseline (DET 1J[34]) and trial (DET 2Z) periods

		BAW		VIR	
Monitor		DET 1J	DET 2Z	DET 1J	DET 2Z
10	Mean SEL	85.4	85.6	86.4	86.4
	Std Dev	1.3	1.3	0.9	1.0
	Count	298	424	41	108
	95% CI	0.1	0.1	0.3	0.2
12	Mean SEL	80.5	80.0	81.6	80.8
	Std Dev	1.9	2.2	1.6	1.5
	Count	279	395	40	108
	95% CI	0.2	0.2	0.5	0.3
13	Mean SEL	78.6	79.1	79.1	79.8
	Std Dev	1.7	2.0	1.8	1.8
	Count	273	391	41	103
	95% CI	0.2	0.2	0.6	0.4
21	Mean SEL	85.5	85.6	86.1	86.2
	Std Dev	1.1	1.3	1.0	1.1
	Count	294	278	40	76
	95% CI	0.1	0.2	0.3	0.2
132	Mean SEL	78.9	79.2	80.2	80.1
	Std Dev	1.8	2.0	1.5	1.4
	Count	294	423	39	108
	95% CI	0.2	0.2	0.5	0.3
136	Mean SEL	76.4	76.8	75.9	75.3
	Std Dev	2.2	2.4	1.7	1.3
	Count	44	77	18	34
	95% CI	0.7	0.6	0.8	0.5
137	Mean SEL	89.9	90.3	91.2	91.3
	Std Dev	1.5	1.6	1.3	1.0
	Count	194	423	24	108
	95% CI	0.2	0.2	0.6	0.2
138	Mean SEL	No data		No data	
	Std Dev				
	Count				
	95% CI				
139	Mean SEL	84.7	85.0	85.6	85.3
	Std Dev	1.0	1.3	0.6	1.2
	Count	181	423	22	108
	95% CI	0.1	0.1	0.3	0.2
140	Mean SEL	81.9	81.8	83.4	82.4
	Std Dev	1.6	1.8	0.8	1.6
	Count	180	423	22	106
	95% CI	0.2	0.2	0.4	0.3
141	Mean SEL	77.5	77.3	79.1	77.9
	Std Dev	1.6	1.9	1.1	1.4
	Count	130	412	15	107
	95% CI	0.3	0.2	0.6	0.3
142	Mean SEL	76.9	77.2	78.2	77.8
	Std Dev	1.6	1.9	1.0	1.5
	Count	130	410	15	107
	95% CI	0.3	0.2	0.5	0.3
143	Mean SEL	73.8	73.8	73.4	74.0
	Std Dev	1.9	1.9	1.1	1.5
	Count	50	176	11	68
	95% CI	0.5	0.3	0.7	0.4
144	Mean SEL	74.6	75.6	75.8	76.1
	Std Dev	1.0	2.1	1.5	1.6
	Count	77	319	11	96
	95% CI	0.2	0.2	1.0	0.3
145	Mean SEL	82.7	82.5	84.1	83.0
	Std Dev	1.3	1.7	0.8	1.2
	Count	110	425	12	108
	95% CI	0.2	0.2	0.5	0.2
146	Mean SEL	75.9	76.1	77.6	76.5
	Std Dev	1.4	2.1	0.8	1.5
	Count	108	388	12	104
	95% CI	0.3	0.2	0.5	0.3

[34] DET 1J noise levels adjusted to account for differences in average lateral ground track between DET 1J and DET 2Z.