London Heathrow Airport Limited

3.2° Slightly Steeper Approach Trial Report

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Executive Summary

1. As part of Heathrow's Blueprint for Noise Reduction[1], they committed to exploring steeper approach angles. Therefore, between 17th September 2015 and 16th March 2016, Heathrow ran a live trial in order to investigate the effect of a slightly steeper 3.2° approach on a number of factors covering safety, the Heathrow operation and the environment.

2. The purpose of the trial was to better understand how an increased glide slope would affect Heathrow operationally whilst at the same time endeavour to measure the benefit in noise reduction that could be achieved.

3. Heathrow declared that a successful trial would be one that enabled sufficient data gathering with no adverse impact on the daily operation. Specifically, Heathrow set out to measure the impact of a slightly steeper approach on Continuous Descent Approach performance, speed adherence on final approach, landing rates, runway occupancy time, numbers of go-arounds, landing gear deployment, aircraft tracks over the ground and to quantify the re-distribution of noise associated with the steeper approach.

4. Heathrow decided to amend their existing 'RNAV' approaches to a 3.2° approach angle leaving the ILS unaffected as the primary landing aid. This eliminated the risk of significant disruption during Low Visibility Procedures as not all aircraft are currently certified to fly 3.2° approaches in CAT III conditions.

5. The majority of the analysis carried out compares the differences between the 3.2° slightly steeper RNAV approach and the existing 3° ILS/MLS approach. However, it is necessary to also understand the several subtle differences between ILS/MLS and RNAV approaches. The result is this trial was not solely a direct comparison between 3° and 3.2° approaches but a comparison between 3° *ILS/MLS* approaches and 3.2° *RNAV* approaches.

Trial Results

6. During the trial, there were c.2500 3.2° RNAV arrivals. The British Airways (BAW) fleet accounted for 85% of all 3.2° RNAV Approaches comprising c2,200 of the RNAV data set.

7. The trial was successful, meeting all objectives with no adverse impact on the daily operation. It is evident that 3.2° approaches would have minimal, if any, negative effect on Heathrow's operation whilst exposing local residents to less aircraft noise.

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[1] http://www.heathrow.com/file_source/HeathrowNoise/Static/heathrow_noise_blueprint.pdf

Objective		Outcome
CDA		3.2º compliance of 85.7% versus 85.9% overall compliance
TBS		No detrimental impact
RoT		No detrimental impact
Go-around		No detrimental impact (3 out of 351 were on a 3.2º approach)
Speed		Slightly improved speed adherence on final approach
Joining point		1.27nm closer to threshold (due to RNAV, not the 3.2º approach angle)
Landing Gear		Med jets: Same but higher / Heavies: Later similar height
Landing Rate		No impact
Height		Low temperature reduced height benefit but as expected
Community		29 out of 50,274 comments, queries and complaints related to trial
Airline		No issues with 3.2º approach angle
ATC		No detrimental impact due to 3.2º approach
Environment		Min: +0.1dBA / Average: -0.5dBA / Max: -1.4dBA (SEL)

Figure 1 – Trial Objective Summary Table

8. The RNAV approach angle is affected by temperature. The higher the temperature, the steeper the approach angle. The lower the temperature the shallower the angle. Owing to this, trial data confirms that the average RNAV approach angle achieved during the trial was 3.14°[2].

9. The A380 self-corrects for this altitude differential due to temperature. Therefore, during the trial, the A380 was the only aircraft achieving the maximum height benefit expected from the 3.2° approach angle. This was likely the reason that the A380 was one of the aircraft offering the best noise reduction (SEL) as a result of the steeper approach.

10. Pre-trial concerns regarding a potential increase in the number of go-arounds, earlier landing gear deployments and poorer speed adherence along final approach did not materialise. On the contrary, the majority of 3.2° RNAV arrivals were able to achieve closer to the ideal 160Kts until 4DME (5DME for the A380) than the 3° ILS/MLS arrivals.

[2] Average temperatures between 0600 and 2230 were 10.11°C producing an average RNAV approach angle of approximately 3.14°.

Next Steps and Issues to Resolve

11. The trial findings will be reported to Heathrow's Airspace Governance and Community Groups and CAA will be engaged to understand what can be done in the short, medium and long term.

12. Should Heathrow wish to consider a permanent introduction of 3.2° approach angles for their Instrument Landing Systems, the following action would likely be required:

- A survey of current and planned Heathrow airlines to understand the number of aircraft that are not certified to perform CAT III approaches with an angle of 3.2°. It is likely that an approach angle of 3.15° would be a more manageable short term step.

- Consideration of the wider impact of CAT II and III approaches with a 3.15° and/or 3.2° angle such as on Runway Occupancy Time and associated breaking distances particularly on wet runways.

- ATC reported a reduction in the number of requests for 3.2° RNAV approaches when there was a tailwind. Consideration should be given to any impact that a slightly steeper approach would have on the ability for crews to accept a tailwind on arrival.

- Subject to the above, assurances will need to be provided to, and accepted by the UK CAA and Heathrow's airline customers as to why an approach angle greater than 3° at Heathrow is an acceptable deviation from ICAO PANS-OPS guidance for CAT II and III precision approaches. This states that descent gradients steeper than 3° should only be used for obstacle avoidance[3].

- An Airspace Change Proposal would then be required providing the necessary justification and evidence to be submitted to the CAA for their consideration. Note future trials may be necessary, prior to this step in order to gather any further evidence required.

[3] PANS OPS 8168 Vol II; Part 1; Section 4; Chapter 5; Subsection 5.3 Descent Gradient; 5.3.1

Introduction

Background

13. Aircraft arriving into London Heathrow follow a Standard Terminal Arrival Route (STAR) via the airways structure into one of the holding stacks. Heathrow has four dedicated stacks for its arriving aircraft.

14. These stacks operate as a holding area for aircraft as they wait for their turn to enter the landing sequence to the active landing runway at Heathrow. The stacks enable Air Traffic Control (ATC) to maintain an optimum landing sequence thus minimising delays to arriving aircraft and their passengers during the busiest times of the day.

15. When it is their turn to make an approach to land, an aircraft is 'vectored[4]' off one of the stacks and directed towards the final approach track via a base leg turn. Generally, this means that the aircraft are vectored in a direction parallel to the runway, in the opposite direction for landing, turn onto a 'base leg' and are then given a closing heading on to the final approach track. These arrivals are not following prescribed routes but follow a vectoring pattern which creates the swathes shown below.

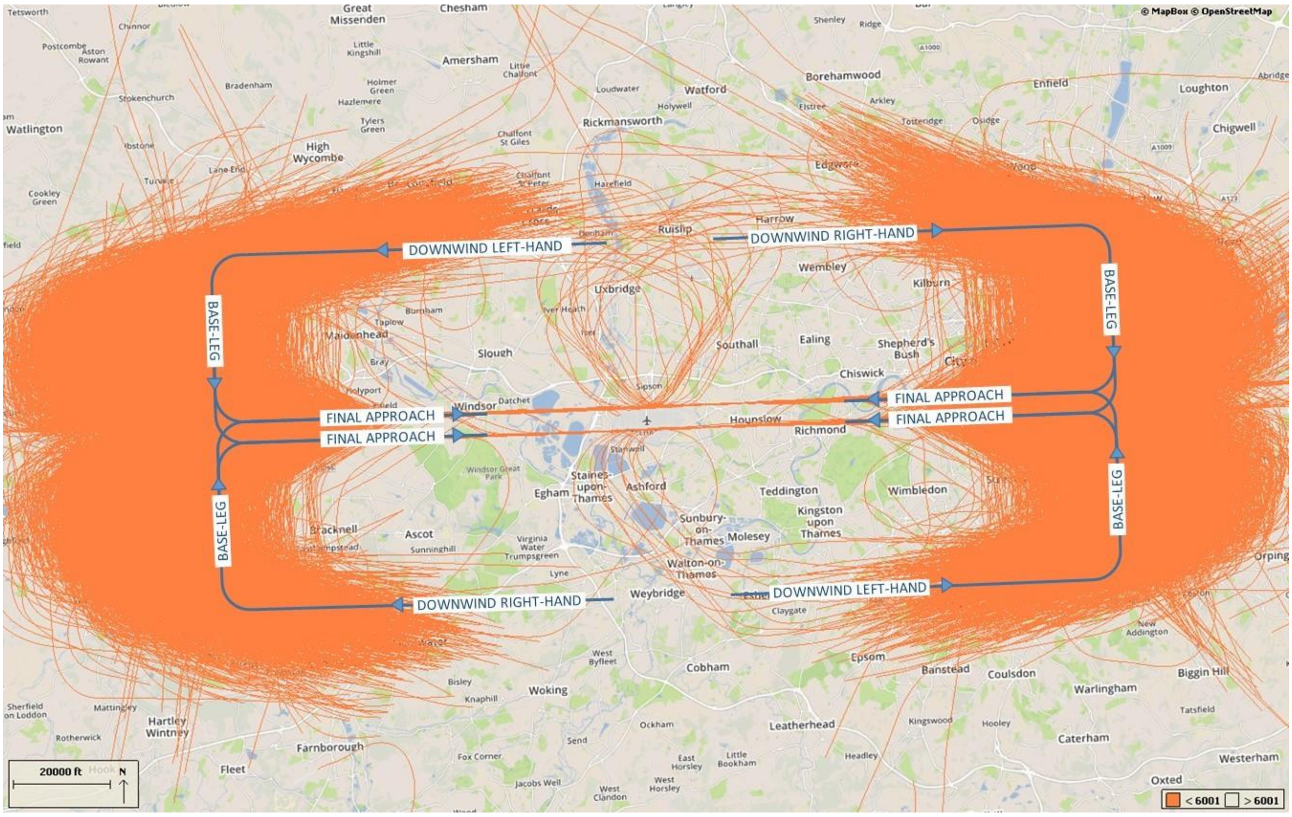

Figure 2: Aircraft approach pattern naming convention

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[4] ATC instructs the pilot to fly a radar heading or 'vector'. The radar heading is given as a compass bearing e.g. an instruction to fly a heading of 090° will result in the aircraft turning towards the East. Headings are generally given in blocks of 5° therefore there are 72 possible vector instructions at the ATCO's disposal. There are no useable published routes between the stacks and final approach therefore vectors are required.

16. The final approach track is a straight, extended line from the runway. Once an aircraft is given a vector to intercept the final approach, the aircraft's systems look to establish on the Instrument Landing System's (ILS) Localiser which ensures the aircraft is aligned correctly with the centreline of the runway. The aircraft systems then descend on the Glide Path which dictates the vertical descent profile and the ILS then guides the aircraft to land safely.

17. Heathrow also has an operational Microwave Landing System (MLS). As there are no differences between ILS and MLS approaches relevant to this trial[5], the comparative 3° approaches are all referred to as just ILS approaches in this report but they may have also included MLS approaches. See Appendix B for description of ILS and associated Categories.

18. When aircraft leave the holding area they are normally at around 7000ft above ground level. During their sequencing onto final approach they are descended to 3000 – 4000ft in order to establish on the ILS glide path and descend to the runway to land.

19. When aircraft descend on the glide path at Heathrow, they do so on a 3° slope i.e. the glide path of the aircraft makes a 3° angle to the ground (Figure 3).

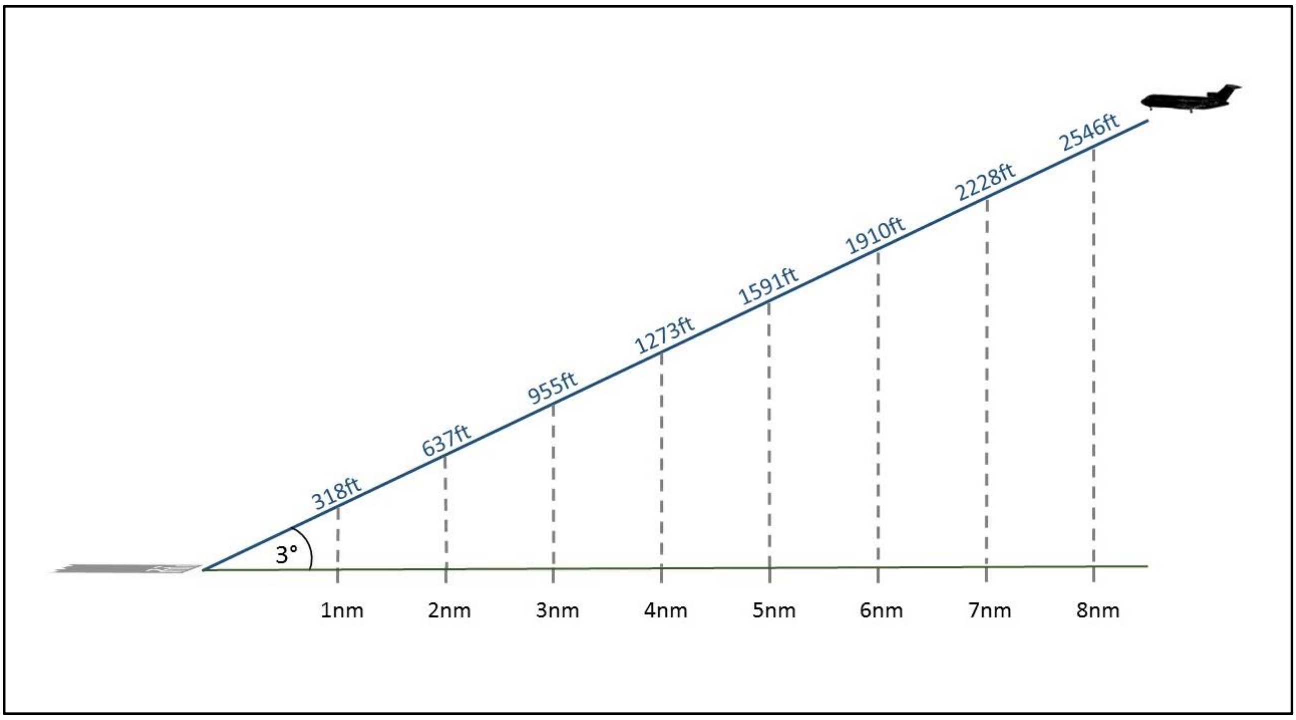


Figure 3: Aircraft height on a 3° approach[6]

5 There is no practical difference in terms of how aircraft are vectored to Heathrow's MLS or ILS. Descent gradients and speeds on final approach are also identical

6 Note that all references in this report refer to Nautical Miles as opposed to Statute Miles which some readers will be more familiar with. 1 nautical mile is 1.15 statute miles.

20. The international standard and optimum angle for approaches since the mid 1970s is 3°. Prior to this, the standard was 2.75° which suited older aircraft types. Descent gradients steeper than the optimum should not be used unless all other means to avoid obstacles have been attempted since these steeper descent gradients may result in rates of descent which exceed the recommended limits for some aircraft on final approach[7].

21. An aircraft's angle of descent has an effect on the noise experienced by people below. An increased final approach angle increases the height of aircraft over the ground thereby increasing the distance the sound has to travel before reaching the population. The steeper the angle, the less time an aircraft spends at low altitudes.

22. As part of Heathrow's Blueprint for Noise Reduction[8], they committed to exploring steeper approach angles. Therefore, between 17th September 2015 and 16th March 2016, Heathrow ran a live trial in order to investigate the effect of a slightly steeper 3.2° approach on a number of factors covering safety, the Heathrow operation and the environment.

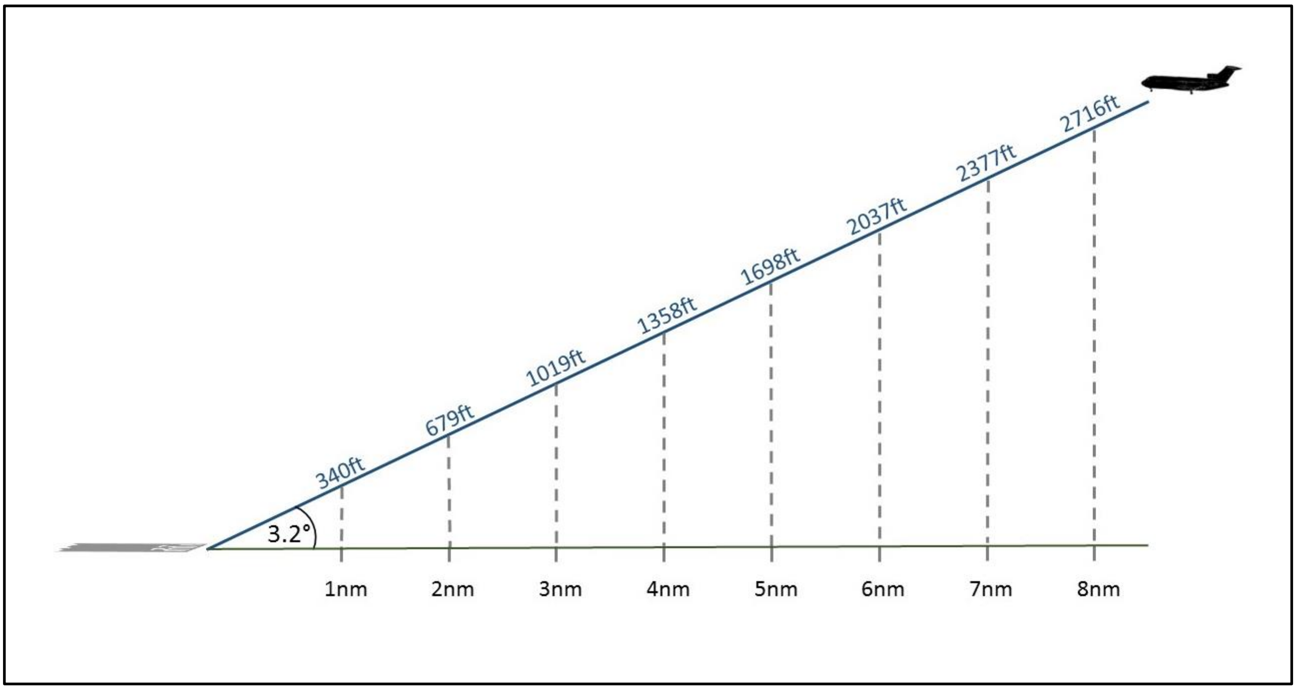


Figure 4: Aircraft height on a 3.2° approach

Why only a 3.2° approach and not steeper?

23. International guidelines state that 3° is the optimum approach angle for precision approaches and that descent gradients steeper than the optimum should not be used unless all other means to avoid obstacles have been attempted since these steeper descent gradients may result in rates of descent which exceed the recommended limits for some aircraft on final approach[9].

[7] PANS OPS 8168 Vol II; Part 1; Section 4; Chapter 5; Subsection 5.3 Descent Gradient; 5.3.1
[8] http://www.heathrow.com/file_source/HeathrowNoise/Static/heathrow_noise_blueprint.pdf
[9] PANS OPS 8168 Vol II; Part 1; Section 4; Chapter 5; Subsection 5.3 Descent Gradient; 5.3.1

24. Some airports in the UK already utilise glide path angles greater than 3° to account for obstacles which prevent the standard 3° flight path being adopted, for example London City's approach is 5.5°. However, aircraft approaching via a Category III ILS system that provide the highest capability to land in poor visibility are, in the majority, limited to maximum approach angles of 3.25°. Some aircraft are constrained to only 3.15° approaches when performing a CAT III autoland[10].

25. The ability to continue operations in low-visibility conditions is a key requirement that would currently dissuade Heathrow from permanently adopting an approach angle of greater than 3.25°.

26. Approach angles in excess of 3.25° can also require aircraft modifications together with additional training for the flight crew which is not practicable at Heathrow owing to the large operation with an extremely diverse airline/aircraft operation.

27. Increasing the angle of approach for arriving aircraft by 0.2 of a degree may seem insignificant. However, there is evidence that strongly indicates that increasing the angle of approach by 0.2° will result in a small reduction of noise for some populations overflown on final approach into Heathrow whilst having negligible impact on the operation.

Why a trial and not just implement 3.2° Approaches?

28. Industry generally accepts that approach angles of up 3.25° are unlikely to pose any significant issues however there is little formal evidence to support this. Frankfurt Airport carried out an operational trial of a 3.2° approach between 2012 and 2014 and have now implemented that approach to one of their runways, during CAT I operations only[11].

29. Although no significant issues were envisaged, Heathrow was keen to ensure they were aware of any potential unintended consequences as a result of making the change which can only be made through a formal application to the UK Civil Aviation Authority (CAA) via an Airspace Change Proposal (ACP). Even so, without any evidence, approval of such an ACP by the CAA would be highly unlikely.

30. Furthermore, ICAO[12] currently urges States not to adopt flight path angles greater than 3° for environmental reasons alone owing to the operational complexities potentially associated with such a change.

31. Civil Aviation Authority CAP1165, 'Managing Aviation Noise' (May 2013) says that "The aviation industry should consider the potential for slightly steeper and reduced landing flap techniques....procedures where appropriate to mitigate noise." Permission to proceed

10 An avionics system that fully automates an aircraft's landing with the flight crew supervising the process
11 See Appendix B
12 International Civil Aviation Organization

with a trial was therefore agreed with the CAA to allow Heathrow and its Stakeholders to gather evidence in order to fully understand the effects associated with an increase to the final approach angle.

Objectives of the trial

32. The purpose of the trial was to better understand how an increased glideslope would impact Heathrow operationally whilst at the same time endeavour to measure the benefit in noise reduction that could be achieved. The output is also expected to feed into SESAR[13] and CAA's Future Airspace Strategy[14].

33. Heathrow declared that a successful trial would be one which enabled sufficient data gathering, with no adverse impact on the daily operation.

34. More specifically, Heathrow set out to understand the impact of a slightly steeper approach on Continuous Descent Approaches, speed adherence on final approach, NATS' Time Based Spacing tool and landing rates, runway occupancy time, number of go-arounds, landing gear deployment, aircraft height on final approach, final approach joining point and tracks over the ground, aircraft noise distribution and the overall suitability of 3.2° approaches to support a high intensity operation.

[13] http://www.sesarju.eu
[14] https://www.caa.co.uk/fas/

The Trial

35. The trial took place between 17th September 2015 and 16th March 2016. During these dates, Heathrow's existing 3° RNAV approaches were withdrawn from service and replaced with 3.2° RNAV approaches.

36. It is the pilot's decision as to which type of approach is flown however, Heathrow encouraged airlines to adopt the 3.2° RNAV approach as much as possible.

37. The RNAV approaches were only available in CAT I conditions. That is there must be a Runway Visual Range[15] of not less than 550 metres and a Decision Height of not less than 200ft. See Appendix B for a description of ILS Categories. There were only 4 days throughout the 6-month trial period where no 3.2° RNAV approaches were performed.

Limitations of the trial

38. The majority of the analysis carried out compares the differences between the 3.2° slightly steeper RNAV approach and the existing 3° ILS approach. However, there are several subtle differences between ILS and RNAV approaches, such as the final approach joining point and the effect of temperature on Baro-VNAV approaches. Therefore, some of the findings from the trial are as a result of comparing RNAV approaches to ILS approaches and not just specifically 3° to 3.2° approaches.

39. The number of RNAV approaches undertaken during the 3 months was low in comparison to the number of ILS approaches but this is as expected. During the trial 3.2° RNAV approaches made up over 2% of all approaches into Heathrow which provided sufficient numbers for trend analysis. RNAV approaches normally make up less than 1% of arrivals. The main reasons for lower number of RNAV arrivals compared to ILS arrivals are:

- ILS has been the standard for over 50 years and crews are much more familiar with them than RNAV approaches, which are relatively new on a global level. With Heathrow's huge and diverse operation, many crews are long-haul[16] meaning that they may only fly into Heathrow once every couple of months. In addition, at the end of a long flight when crews are tired, many will opt for the approach they feel most comfortable. 69% of all the 3.2° RNAV approaches were performed by the A320 family, a short to medium-haul aircraft.

- RNAV approaches are only available in CAT I conditions meaning that during poorer visibility they cannot be used. There were only 4 days throughout the 6 month trial period where no 3.2° RNAV approaches were performed.

[15] Runway Visual Range (RVR) is the range over which the pilot of an aircraft on the centre line of a runway can see the runway surface markings or the lights delineating the runway or identifying its centre line.

[16] Flight duration in excess of 6 hours

- Not all the aircraft using Heathrow have the capability to fly RNAV approaches. Eurocontrol data taken during the last 12 months' signals c.15% of Heathrow's movements were not equipped to fly RNAV approaches.

Trial Participation

40. The 3.2° RNAV dataset covers 2.2% of all arrivals in the six months - comparing 2,469 3.2° RNAV approaches to 112,229 3.0° ILS approaches.

Runway	3.2° RNAV Approaches	%
09L	747	30%
09R	35	1%
27L	854	35%
27R	833	34%
Total	2469	100%

Figure 5: Number of 3˚ and 3.2˚ Approaches during the trial period

41. Figure 6 contains a trend line showing the curved trend based on the number of 3.2° RNAV Approaches each day. As can be seen, after the initial enthusiasm, trial participation levelled off after the first two months albeit to a slightly higher rate than pre-trial.

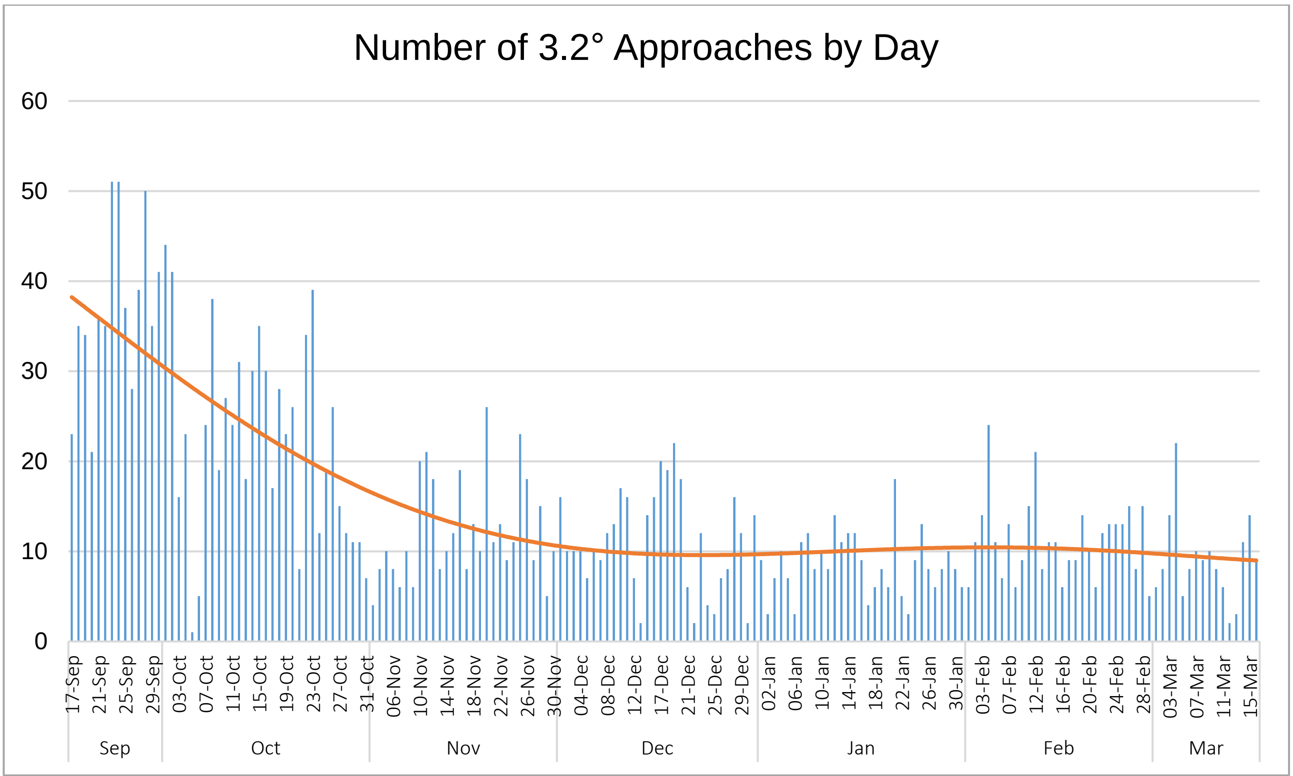


Figure 6: Number of 3.2˚ Approaches per day

Airline Participation

42. The British Airways (BAW) fleet accounts for 85% of all 3.2° RNAV Approaches during the trial.

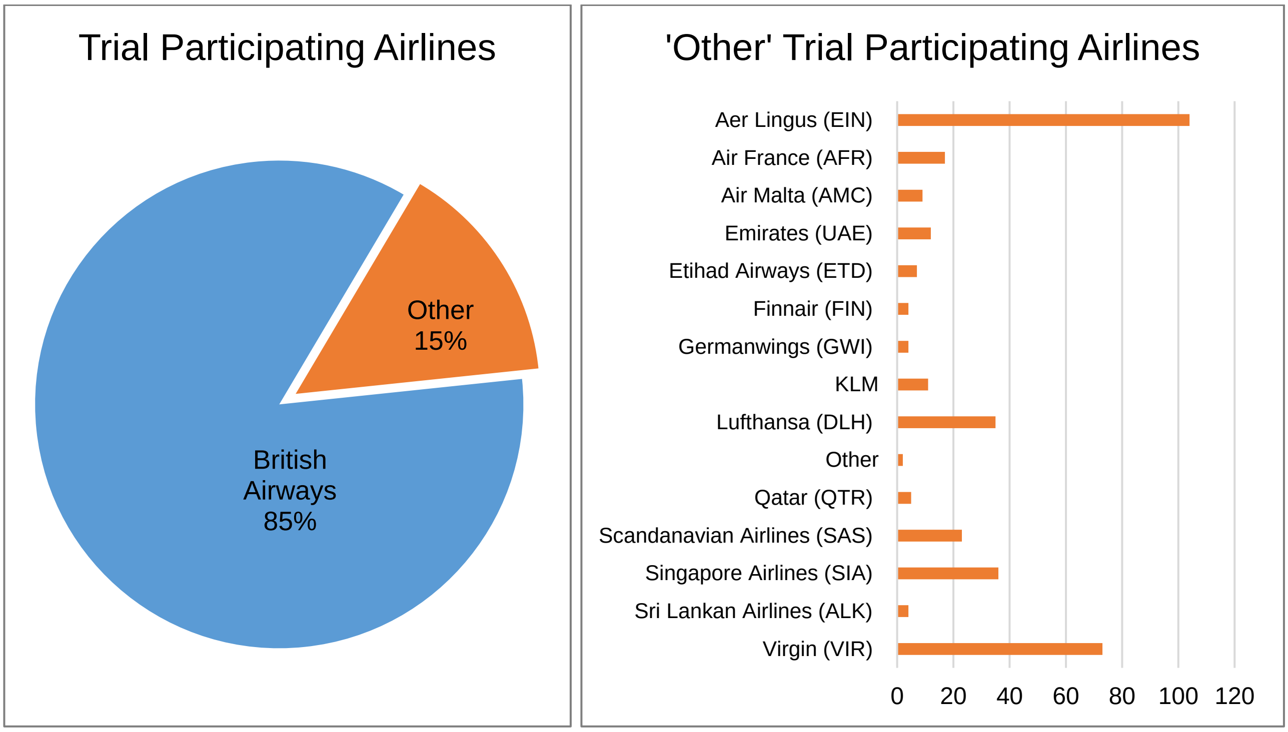


Figure 7: Breakdown of airline participation

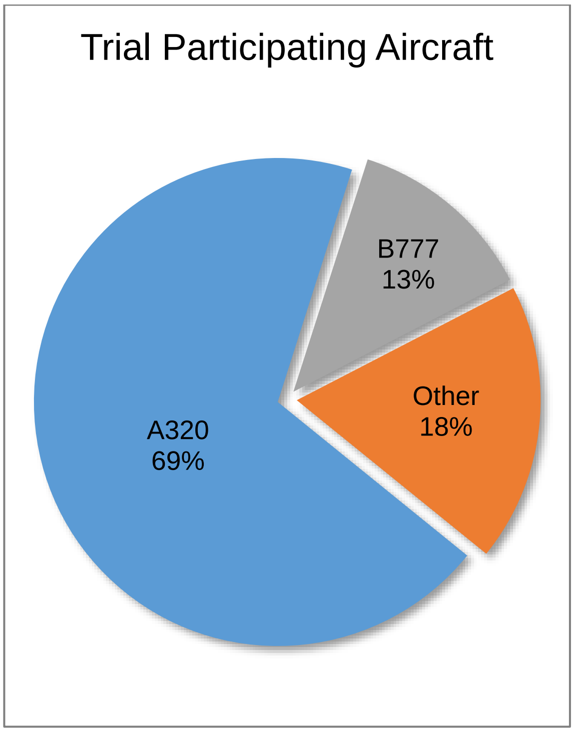
43. Figure 8 below compares the Heathrow fleet mix as a percentage of all movements to the numbers of 3.2° RNAV approaches flown during the trial period.

	All		Trial	
Aircraft	**Count**	**%**	**Count**	**%**
A320	63962	56.1%	1706	69.1%
A330	4350	3.8%	20	0.8%
A340	2030	1.8%	28	1.1%
A380	3981	3.5%	88	3.6%
B737 Next Generation	3733	3.3%	10	0.4%
B747	5430	4.8%	119	4.8%
B767	6582	5.8%	8	0.3%
B777	15235	13.4%	308	12.5%
B787	4842	4.3%	177	7.2%
Executive Jet	658	0.6%	5	0.2%
Totals	114036	100.00%	2469	100.0%

Figure 8: Comparison between proportion of aircraft types between all approaches and trial approaches.

Aircraft Participation

44. The A320 family[17] accounted for 69% of all 3.2° RNAV Approaches with the B777 accounting for c.13%.



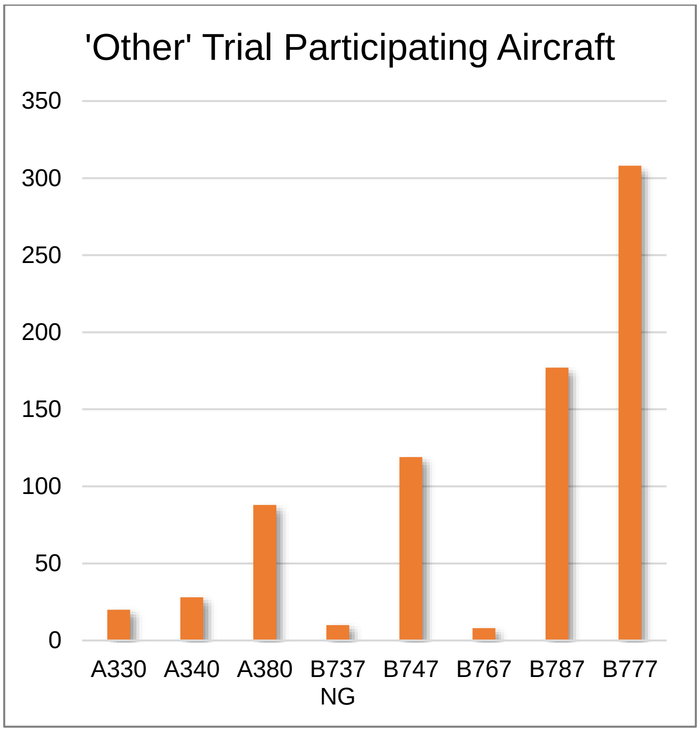


Figure 9: Breakdown of aircraft participation

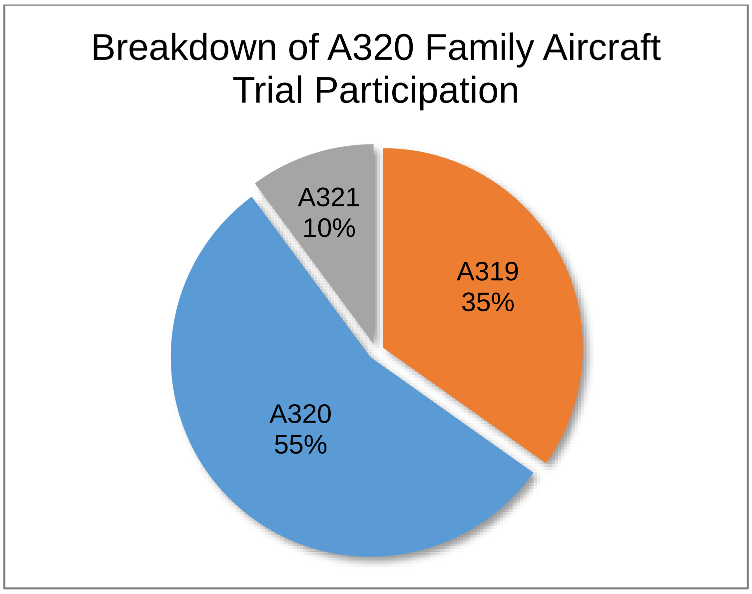


Figure 10: A320 family participation

Type	Count	Percentage
A319	632	35%
A320	999	55%
A321	184	10%

[17] For this report, the A320 family refers to the A319, A320 and A321 aircraft

45. 91 of all 3.2° RNAV Approaches were undertaken by the A380 accounting for c.4% of the RNAV data set.

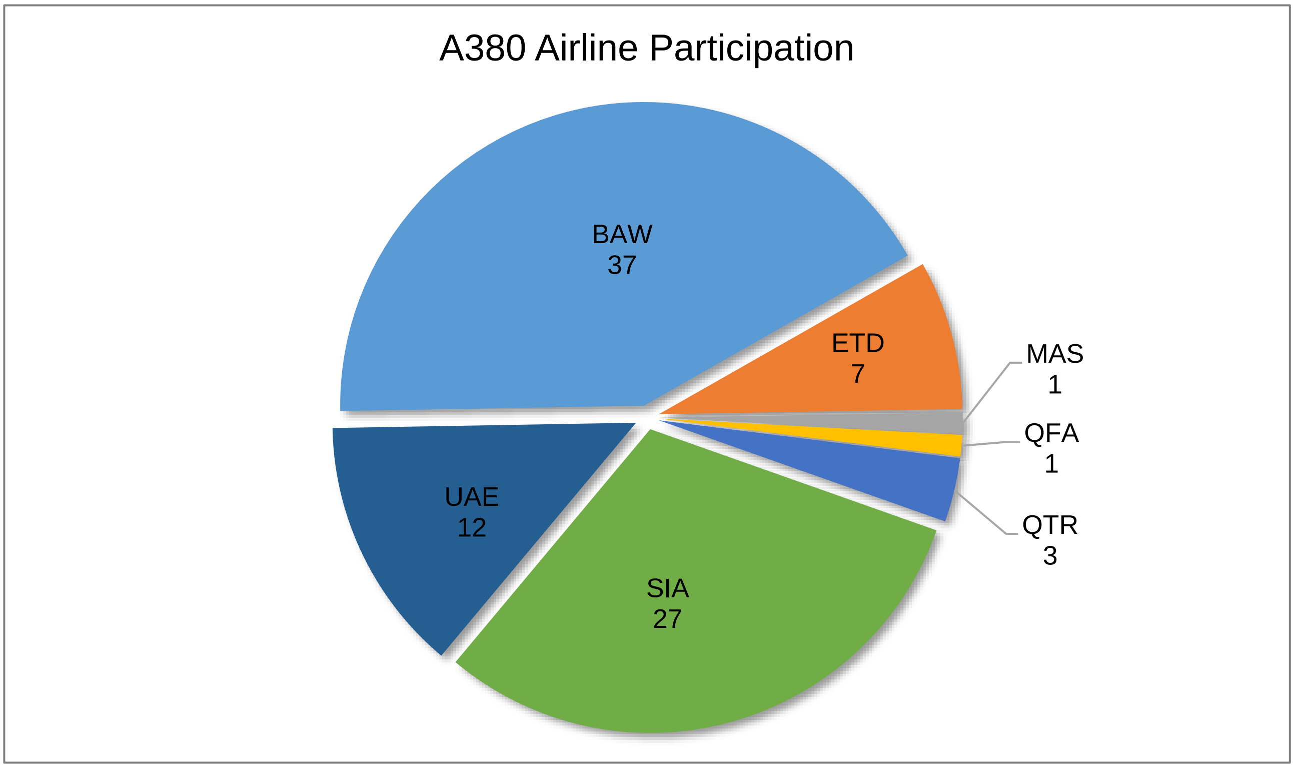


Figure 11: A380 airline participation

46. Seven A380 Airlines participated in the trial: British Airways, Singapore Airlines, Emirates, Etihad Airways, Qantas, Qatar Airways and Malaysian Airlines.

Continuous Descent Arrival (CDA) Performance

47. The data shows that CDA compliance for the 3.2° RNAV arrivals is very slightly lower than the combined CDA compliance for all approaches (all approaches include both 3.2° RNAV and 3° ILS approaches) but only by 0.2%.

48. This could be a difference between comparing RNAV arrivals to ILS arrivals, not necessarily 3.2° approaches to 3.0° approaches. Data to compare CDA performance between RNAV and ILS for another comparative, non-trial, period was not available.

49. However, Figure 12 shows an improving trend in CDA performance over the duration of the trial for 3.2° RNAV approaches with 3.2° becoming significantly greater than 3.0° CDA performance by the end of the trial. This was possibly as a result of the experience gained by crews in flying the approaches.

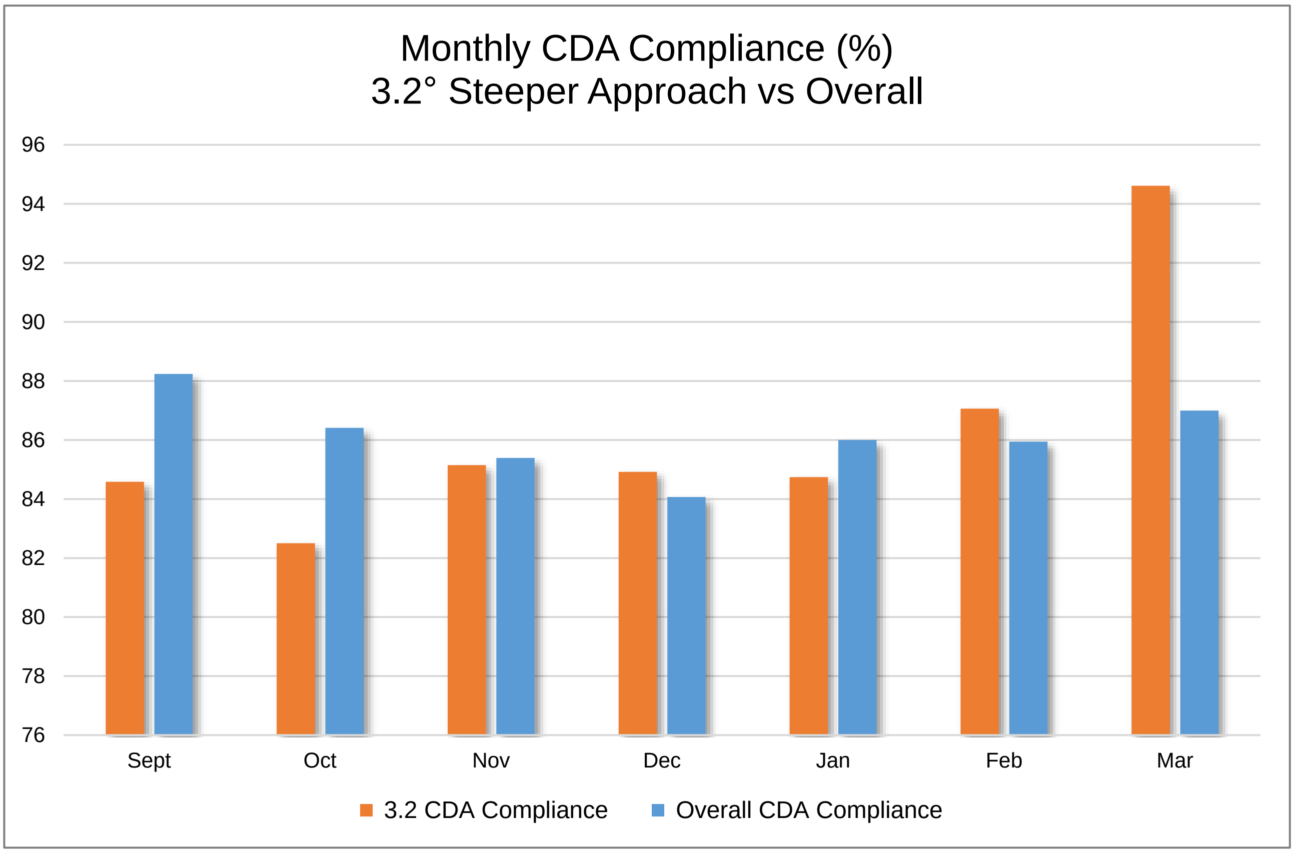


Figure 12: Monthly comparison of 3.2˚ CDA performance

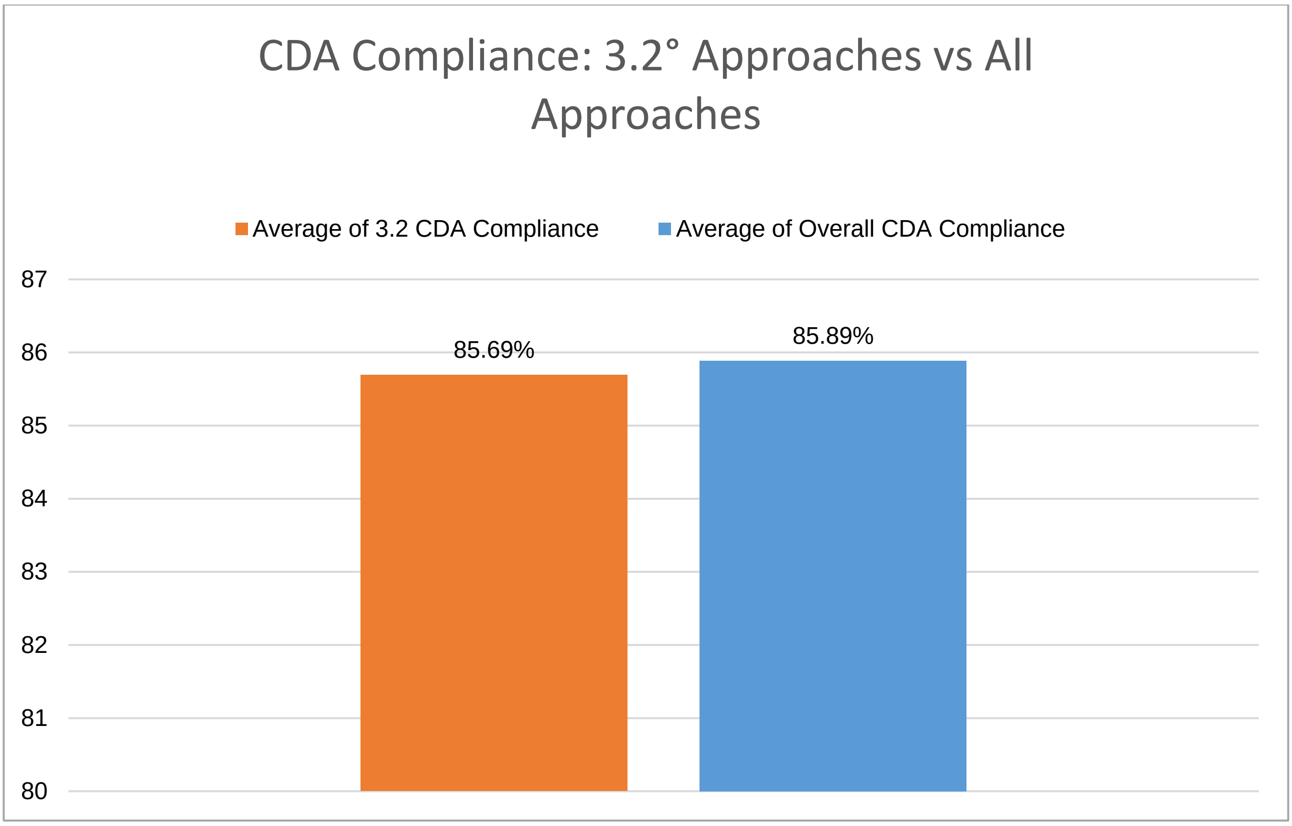


Figure 13: Overall comparison of 3.2˚ approach CDA performance

50. When comparing CDA performance of westerly versus easterly operations, it can be seen that there is a poorer CDA performance with the 3.2° approaches on easterly operations. This reflects the existing situation regarding a slightly poorer overall CDA performance on easterly operations.

Orientation	3.2°RNAV CDA Compliance	Overall CDA Compliance
Easterly	81%	84%
Westerly	87%	86%

Speed Adherence on final approach

51. In order to provide accurate and consistent final approach spacing, all Heathrow arrivals, with the exception of the A380 are instructed to maintain 160Kts until 4nm (4DME) from touchdown. The A380 is instructed to maintain 160Kts until 5nm (5DME). Figure 14 shows that speed adherence at these distances from touchdown was actually slightly closer to optimal on the 3.2° than the 3° approaches.

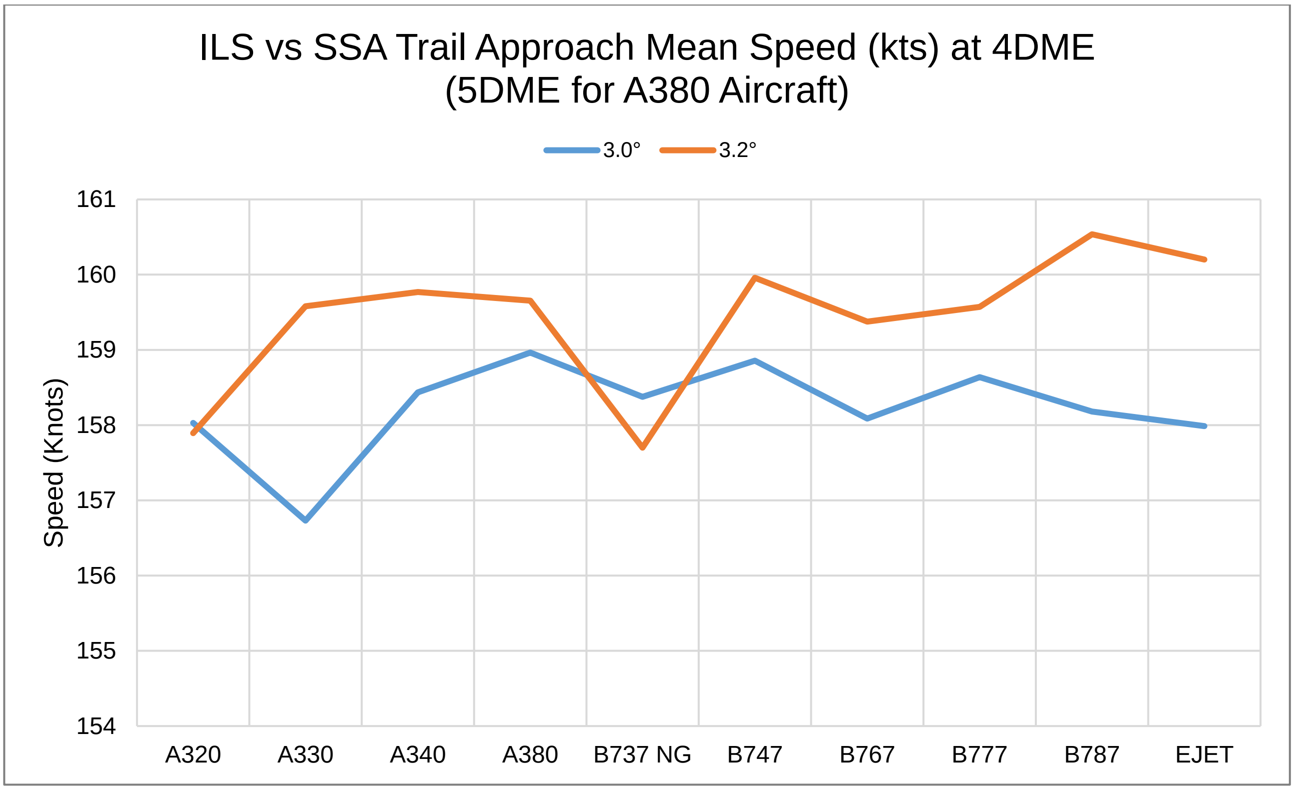


Figure 14: Speed adherence at 4DME all aircraft

52. There is very little difference in the mean speeds at 4DME (5DME for A380s) between the different aircraft types. A 3kt difference for A330 aircraft is the largest difference observed.

53. With the exception of the B737, the 3.2° RNAV arrivals were able to achieve closer to the ideal 160Kts until 4DME than the 3° ILS arrivals.

54. Looking at the mean speeds at 4DME of just the A320 family (Figure 15) There is very little, less than a ¼ of a knot, between the 3° ILS and 3.2° RNAV approaches and the distribution of the 3.2° approaches sits comfortably within and about a similar mean to the 3.0° ILS approach's distribution, suggesting that the difference in type of approach has a negligible effect on adhering to the 4DME speed restriction.

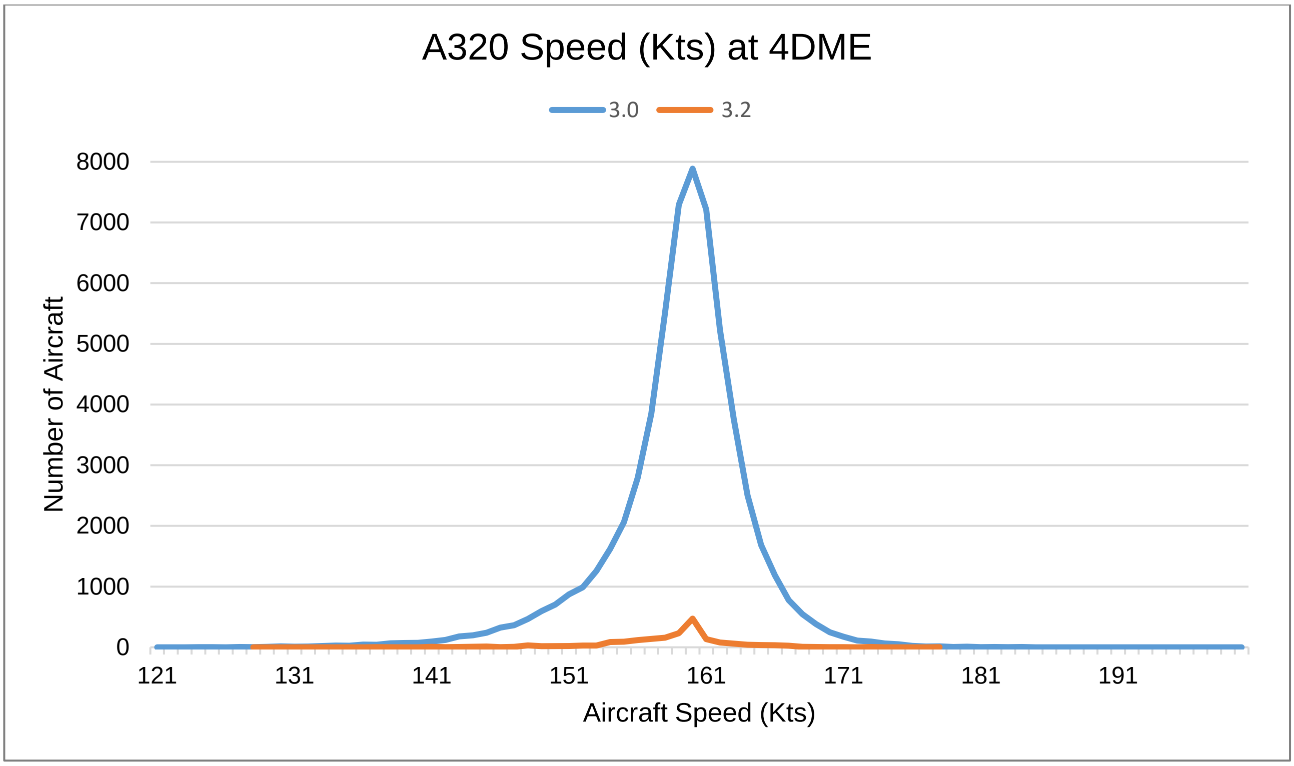


Figure 15: Speed adherence at 4DME for A320 family

55. The impact of poor speed adherence on final approach would be linked to either a drop in landing rates achieved during the trial or an increase in the number of go-arounds neither of which were observed during the trial.

Time Based Spacing (TBC) and Landing Rates

56. In the post-trial ATC workshop, London Terminal Control (LTC) Heathrow Approach controllers did not report any degradation in the ability to react to TBS[18] indicators with 3.2° RNAV approaches compared to 3° ILS approaches.

57. NATS had confirmed, pre-trial, that the steeper approach would have no impact on the functionality of the TBS tool.

58. Landing rates were monitored, via a normal operating process performed by LTC. Figure 16 below shows the average daily landing rates achieved throughout the 6-month trial period, compared to the same period 12 months earlier

59. It can be seen that the average hourly landing rate[19] was exactly the same during the trial period compared to the same period 12 months earlier. It would seem Heathrow did not suffer from any reduction in landing rate during the trial period however it should be noted that the TBS tool was implemented in March 2015 therefore this is a variable which affects a true comparison. Other such variables are wind speed and direction and different aircraft types and landing order which also affects a true comparison.

17th Sep 2014 – 16th Mar 2015			
Month	**Total**	**Av. per day**	**Av. per hour**
Sept	9,260	661	34.8
Oct	19736	658	34.6
Nov	18,935	631	33.2
Dec	18,663	602	31.7
Jan	18,617	601	31.6
Feb	16,299	627	33
Mar	10,241	622	33.7
Av	-	629	33.2

Trial 17th Sep 2015 – 16th Mar 2016			
Month	**Total**	**Av. per day**	**Av. per hour**
Sept	9,464	673	35.5
Oct	20,269	654	34.4
Nov	18,499	623	32.5
Dec	18,543	599	31.7
Jan	18,543	601	31.5
Feb	18,150	631	32.9
Mar	10,852	638	33.6
Av	-	631	33.2

Figure 16: Average landing rates during trial and 12 months prior

[18] Time Based Spacing (TBS) explanation
[19] These figures are for the average hourly landing rate per hour across 19 hours of the day available for landing at Heathrow. Peak hourly landing rates are higher.

Runway Occupancy Times

60. The average Runway Occupancy Time (RoT) is extremely similar between 3° and 3.2° approaches (Figure 17).

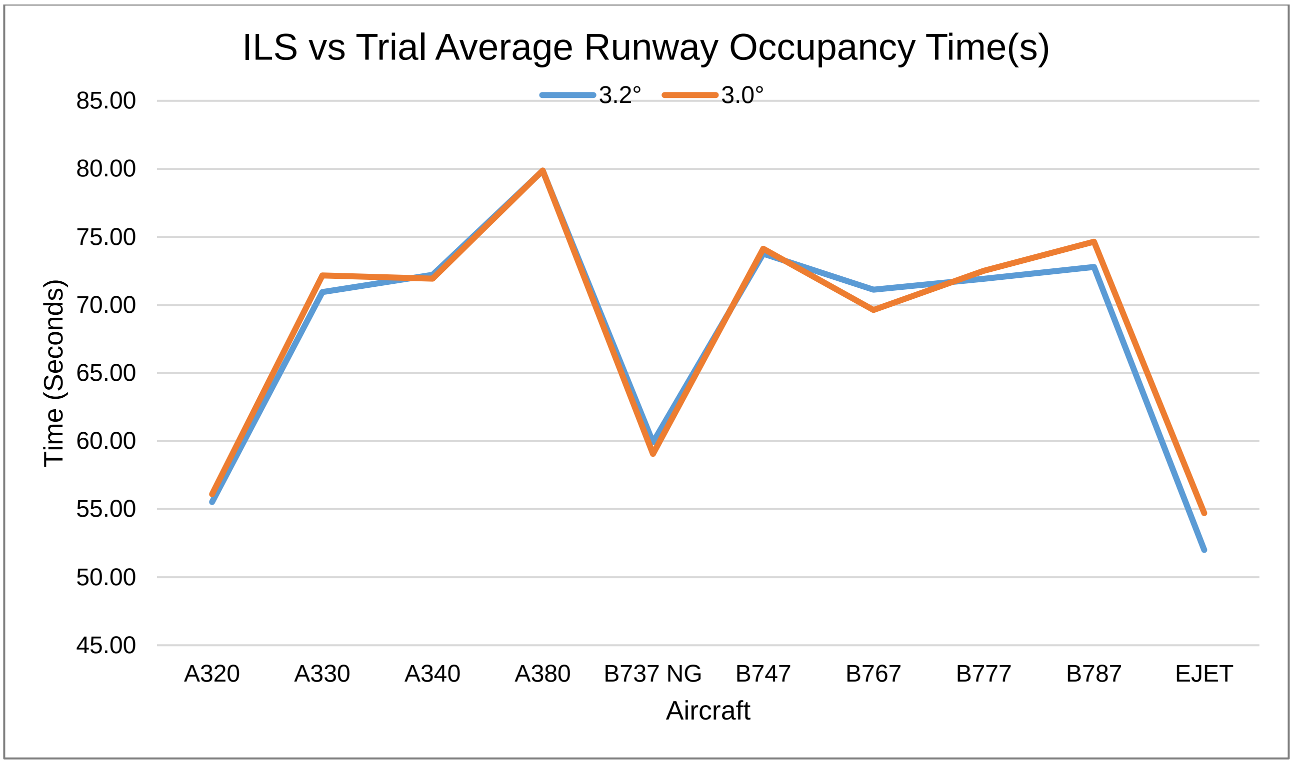


Figure 17: Average RoT all aircraft

61. Looking at the RoTs of just the A320 family (Figure 18) there is very little difference in the means for the respective approaches, approximately ½ of a second, with the distribution of the 3.2° RNAV approaches sitting within the ILS approach distribution suggesting that the difference in type of approach has negligible effect on the runway occupancy time.

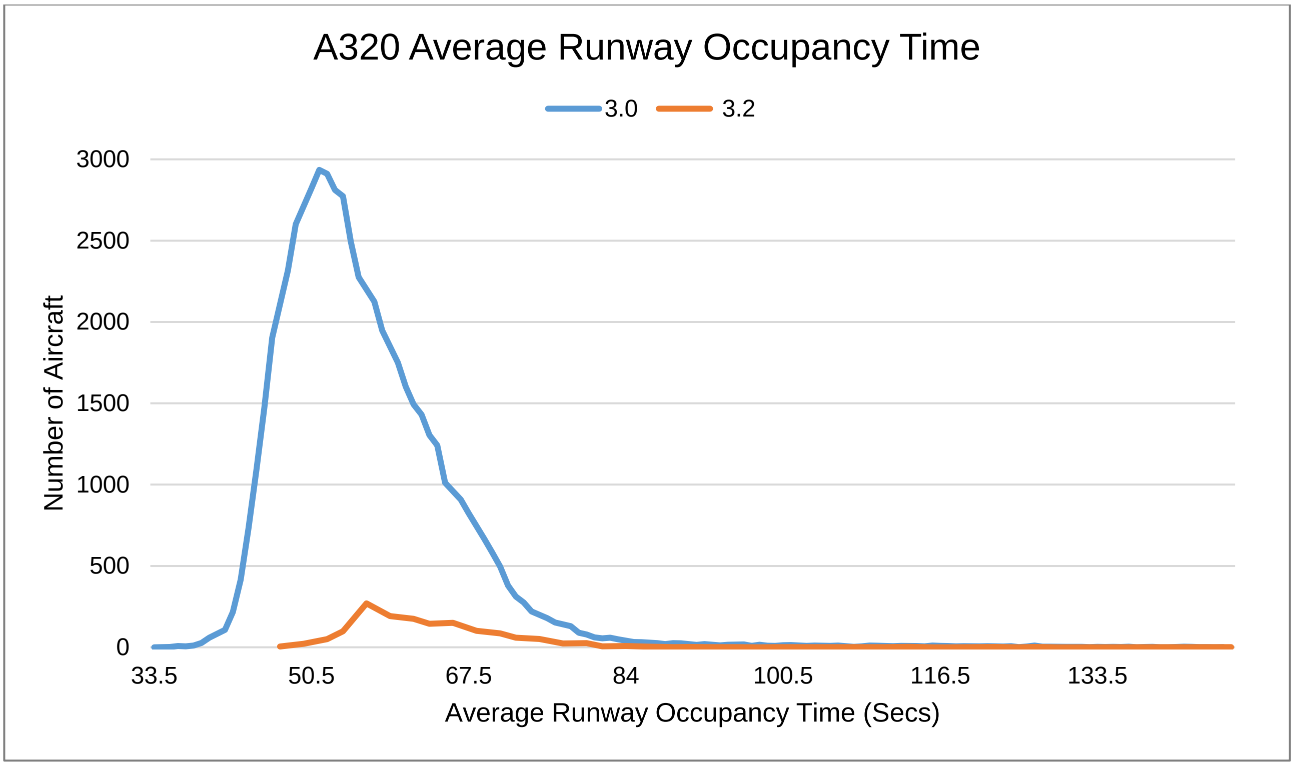


Figure 18: Average RoT of the A320 family

Number of Go-Arounds

62. During the trial period, there were 351 Go-arounds (approximately 2 per day) at Heathrow. Of these, only 3 were performed by aircraft arriving on a 3.2° RNAV approach. None of these were due to the RNAV procedure itself; One was due to an Flight Management Computer issue, one when the previous landing aircraft was slow to vacate the runway and the other was due to windshear[20].

63. Of the 348 remaining go-arounds, none were reported to have been due to an effect from a preceding 3.2° RNAV arrival.

[20] Windshear is a change in wind speed and/or direction over a relatively short distance. This can cause sudden fluctuations in an aircraft's airspeed and destabilise the final approach requiring the pilot to initiate a go-around.

Landing Gear Deployment

64. Deployment of the landing gear is associated with a Standard Operating Procedure (SOP) on the flight deck which, for most airlines including BA, is on passing a certain height. Therefore, with a slightly steeper approach, that height is reached slightly closer to the runway. However, lowering of the landing gear is a manual process and the height differential between 3° and 3.2° is relatively small.

65. Figures 19 and 20 compare the differences in average distances from touchdown and height across BA's fleet on 3° ILS and the 3.2° RNAV approaches. Note that data for the B747, B767 and B777 fleets was only available from the 1st month of the trial period.

Type	No.3.0°ILS Approaches	No.3.2°RNAV Approaches	3.0°ILS Mean Heights (ft)	3.2°RNAV Mean Heights (ft)	Distance Closer to THR. (m)	Height Diff. (ft)
A319	13,702	441	1525	1564	28	+39
A320	19,177	590	1487	1523	6	+36
A321	5,141	104	1471	1484	201	+13
A380	470	17	2161	2004	1404	-157
B747	873	24	1958	1973	362	+15
B777	1,121	56	2090	2135	495	+45
B787	151	19	2104	2127	109	+23

Figure 19: BA Landing Gear Selection average heights and distances. A319. A320, A321 & A380 data was available for the entire trial period of 6 months. Data for the B747, B767 & B777 fleets was only available from the 1st month of the trial period.

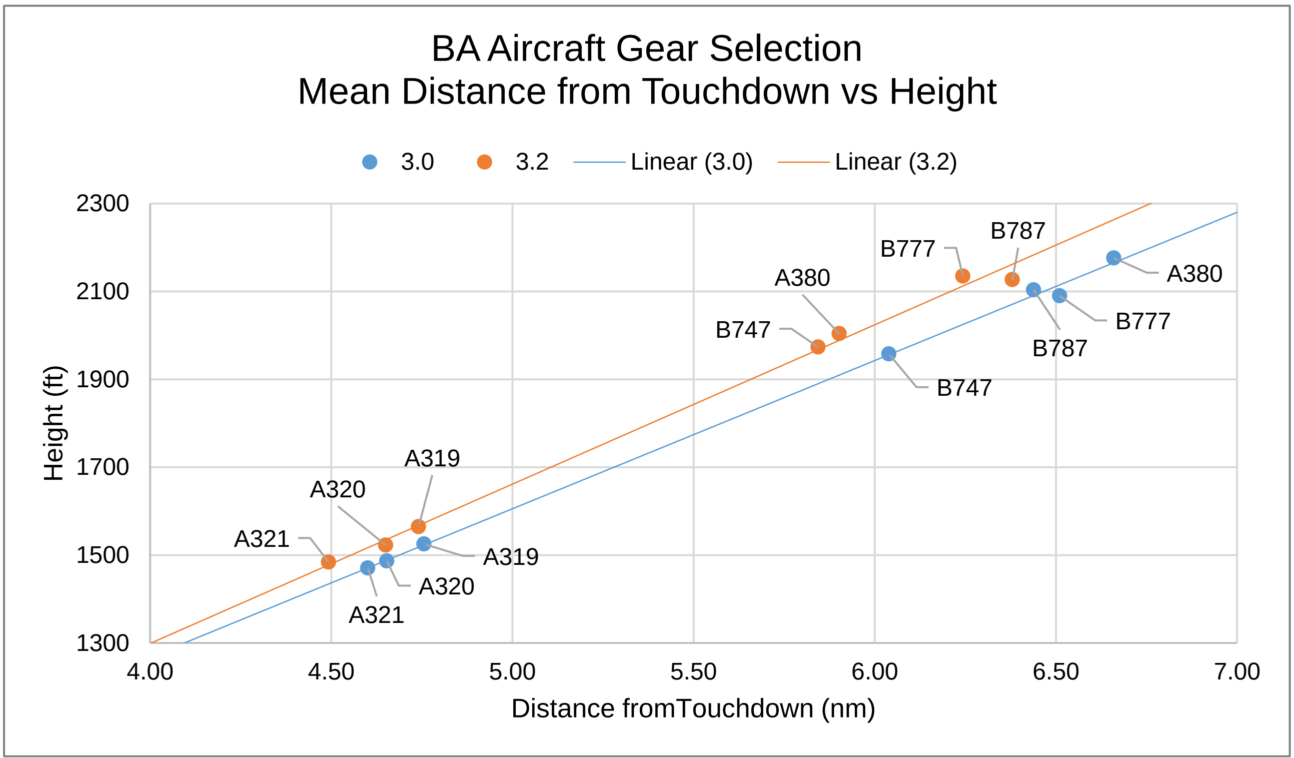


Figure 20: BA Landing Gear Selection average heights and distances. A319. A320, A321 & A380 data was available for the entire trial period of 6 months. Data for the B747, B767 & B777 fleets was only available from the 1st month of the trial period.

66. The medium sized jets were deploying landing gear in almost the same region. Note that at c.4.5nm from touchdown and taking into effect the effect of temperature, the actual height differential during the trial in this location was only c.55ft.

67. The larger, heavy aircraft were clearly deploying their landing gear slightly closer in to the runway at the same approximate height. The most significant difference between 3° and 3.2° landing gear deployment occurred on the A380 with it being, on average, 0.75nm closer to the runway. The A380 self-corrects for the effect of temperature on baro-VNAV approaches therefore as the actual height differential was greater, one would expect this to just move the landing gear selection point closer to the runway but keep the height of deployment the same. However, the height of landing gear deployment is actually slightly lower although the A380 was one of the aircraft offering the greatest noise reduction on the ground during the trial.

68. Note due to the effect of temperature on baro-VNAV approaches, the average RNAV approach angle was actually less than 3.2°. With a fixed 3.2° ILS approach it could be expected that the average landing gear deployment could therefore be slightly closer to the runway.

Aircraft height on Final Approach

69. Figure 21 shows the available height improvement between a 3° and a 3.2° glide slope based on the trigonometric difference at 2NM intervals.

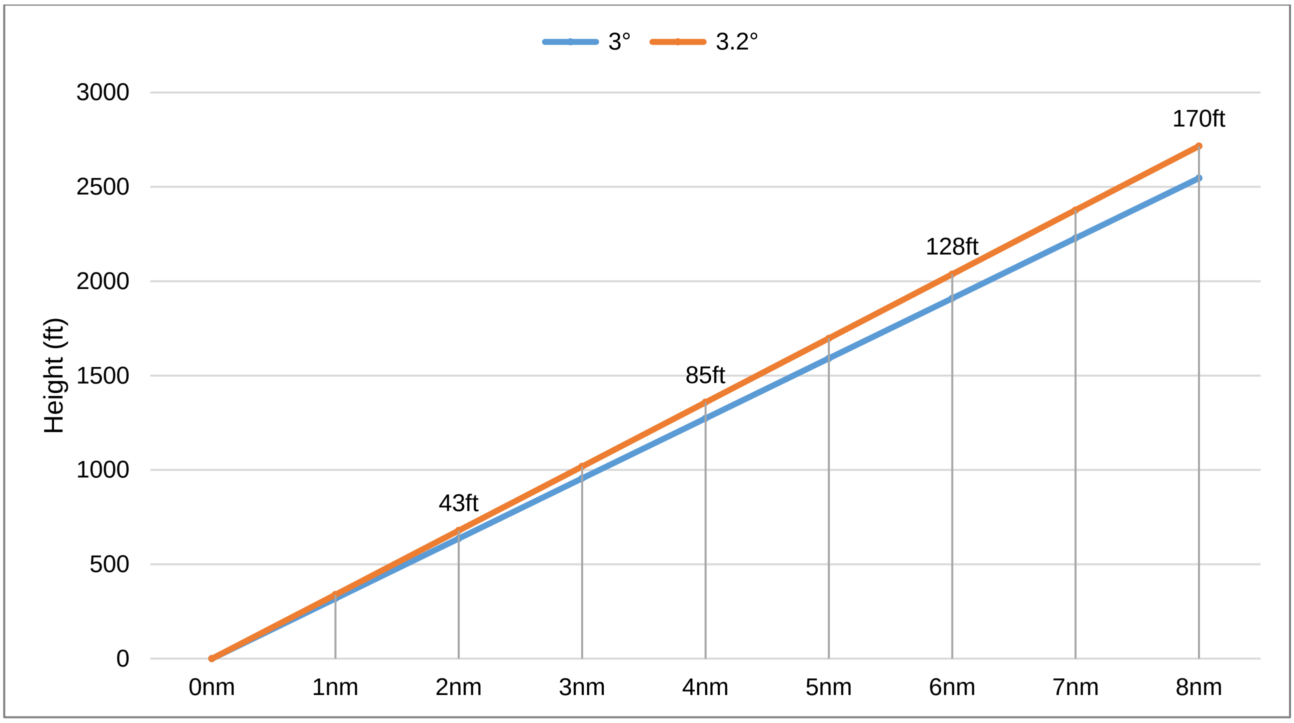


Figure 21: Height differential at 2nm intervals

70. When looking at the average actual height improvement at 4nm, 6nm and 8nm across all 3.2° RNAV Approaches on all aircraft types across the 6-month trial period, the height improvement was lower than the trigonometry would expect (Figure 22).

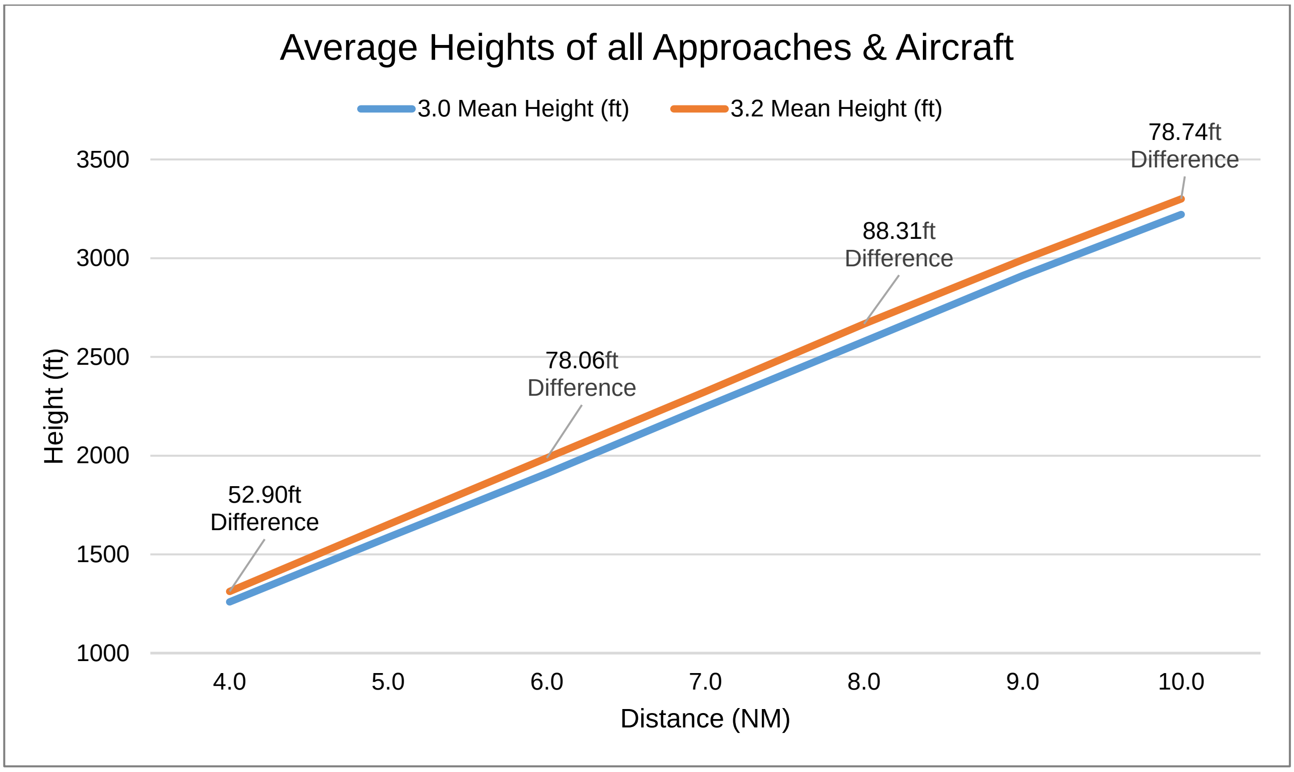


Figure 22: Average height improvement achieved. All runways, all aircraft types.

71. In order to understand this result, it requires a closer look at performance across easterly and westerly operations, specific aircraft types and the effect that the average temperatures during the trial period had on the barometric height of aircraft on the 3.2° (Baro-VNAV) RNAV Approaches.

Westerly V Easterly height differential

72. Comparing separate Westerly (Figure 23) and Easterly (Figure 24) approaches and all aircraft types, there was a much 'better' 3.2° height performance for Westerly arrivals compared to Easterly arrivals.

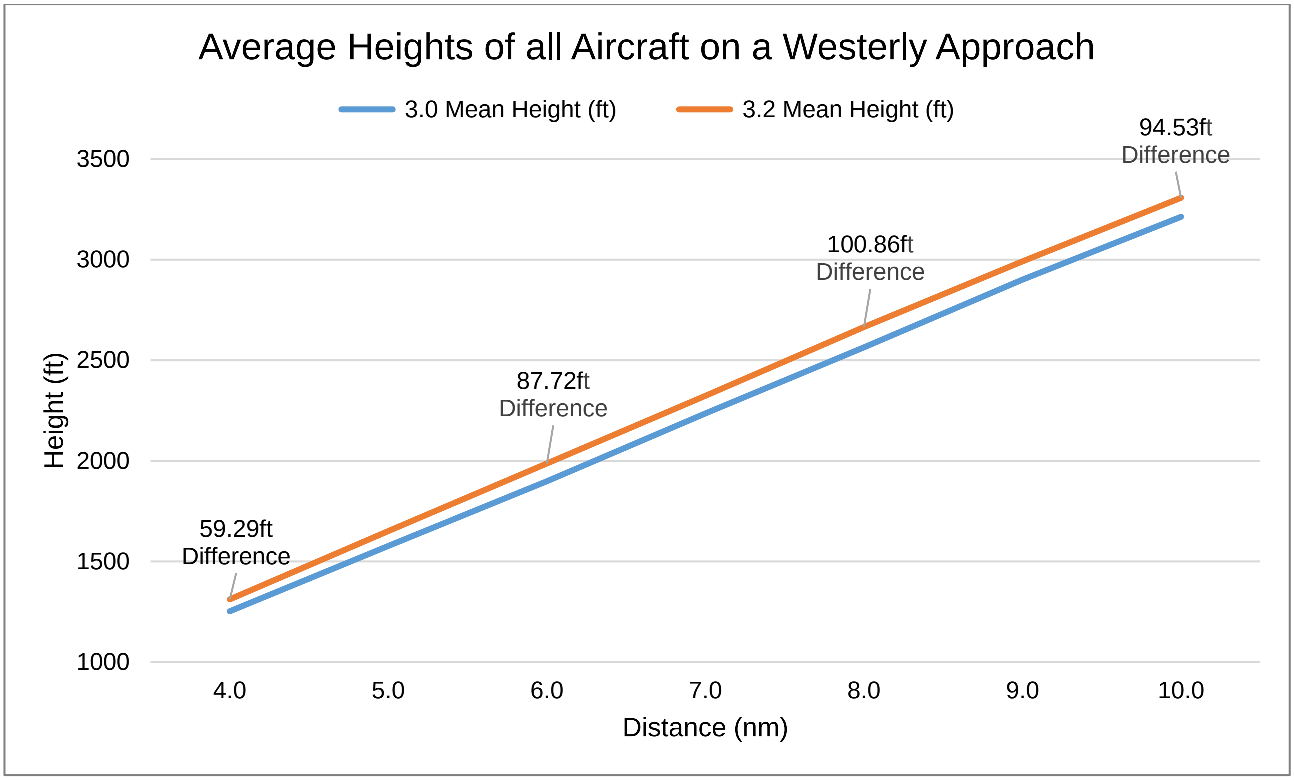


Figure 23: Average height improvement achieved. Westerly approaches all aircraft

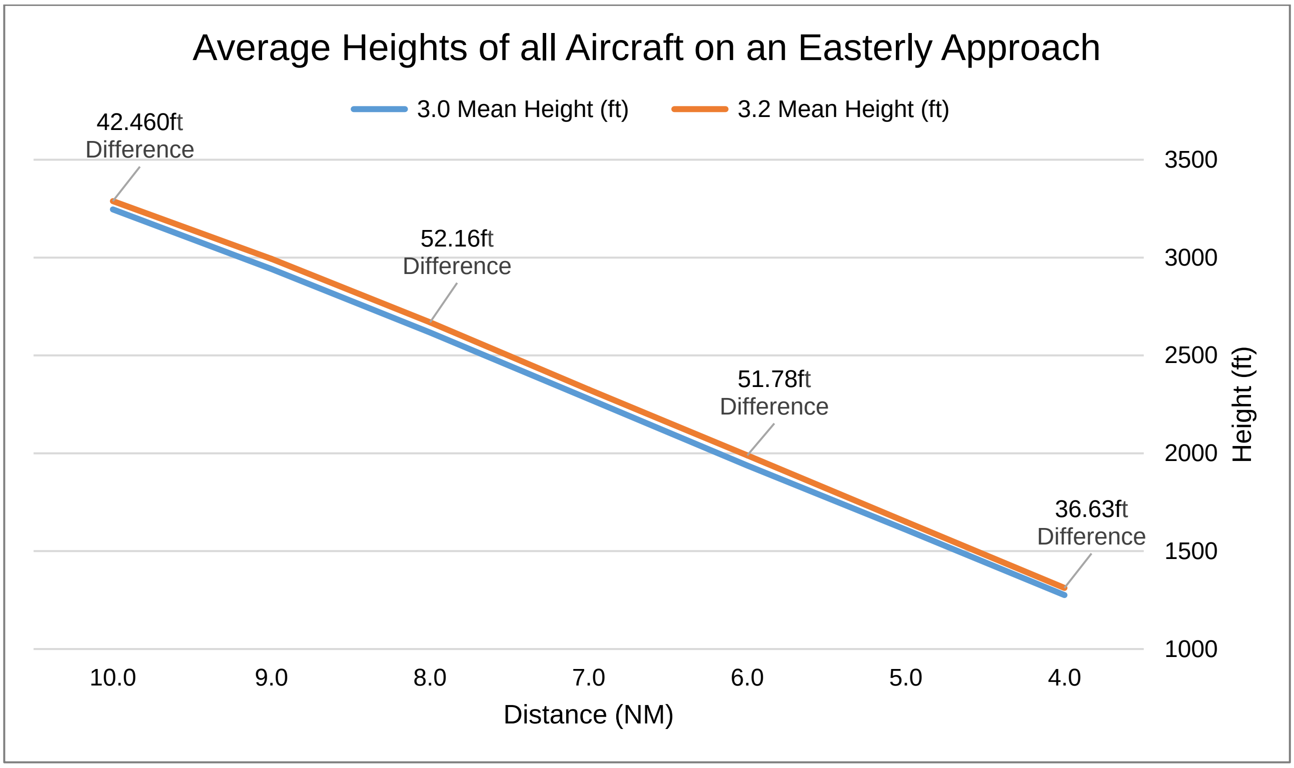


Figure 24: Average height improvement achieved on Easterly approaches. 09L approaches excluded due insufficient data

73. The existing Easterly and Westerly operations are not identical. As already mentioned, there is a poorer CDA performance on Easterly operations compared to

Westerly operations which could be a contributory factor to lower height differential on the easterly 3.2° approach.

The Temperature Effect

74. One important difference between RNAV approaches and ILS approaches is the effect that air temperature has on the RNAV approach slope angle.

75. With ILS, the glide-slope is a physical ‘beam’ that the aircraft is following, both laterally and vertically and that ‘beam’ is unaffected by air temperature. It is constant.

76. With RNAV Approaches, the lateral path of the aircraft is based on a different navigation system (PBN, not conventional) and is also fixed however, the vertical path is based on ‘barometric altitude’. Air temperature has a small effect on the altitude that an aircraft’s altimeter[21] says the aircraft is at compared to the height it *actually* is at. An RNAV Approach’s descent angle is based on the angle at the International Standard Atmosphere (ISA) temperature at mean sea level which is 15°C. When the temperature is not exactly 15°C, the barometric approach angle starts to alter slightly. The colder the temperature, the shallower the approach angle. The warmer it gets, the steeper the approach angle.

77. Data analysed from METARs[22] for Heathrow during the trial period confirm the average temperature across all 6 months (H24) was 9.63°C (Figure 25). This had the effect of producing an average RNAV approach angle of approximately 3.12°. Note that average temperatures between 0600 and 2230 were 10.11°C producing an average RNAV approach angle of approximately 3.14°.

[21] An altimeter or an is an instrument used to measure the altitude of the aircraft above a fixed level
[22] A METAR is a format for reporting weather information to the aviation sector

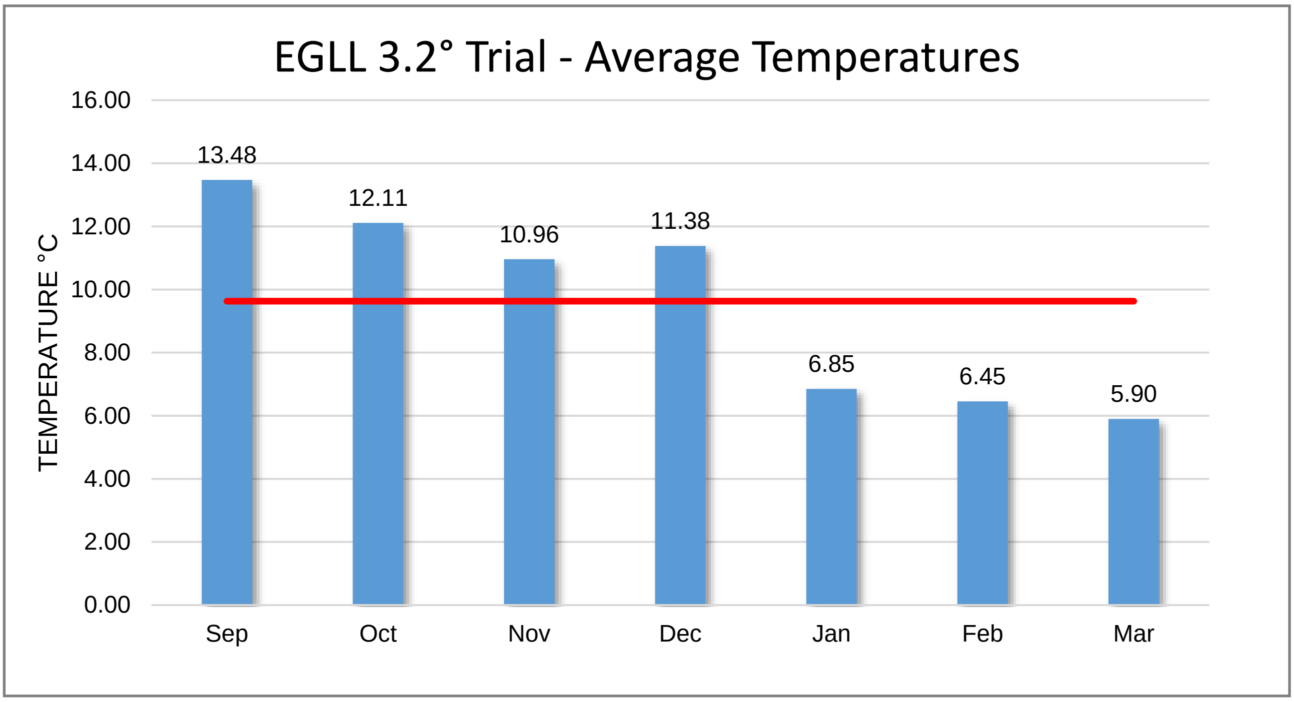
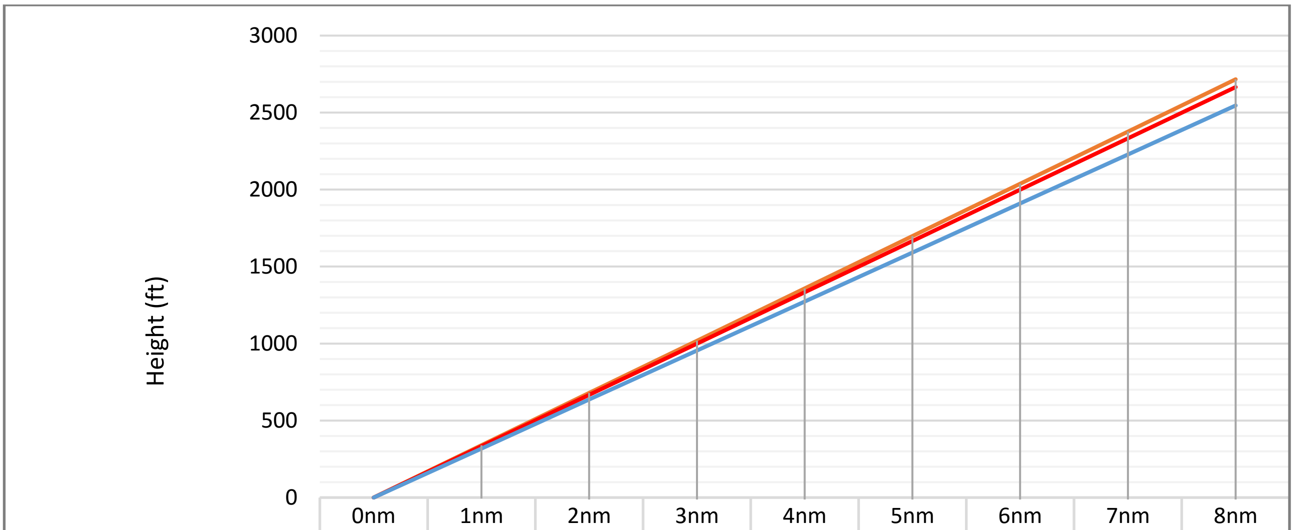


Figure 25: Average temperature of 9.63°C at Heathrow during the trial period

78. Figure 26 below shows the effect that this average temperature reduction alone would have on the height of aircraft along the 3.2° final approach track.



	0nm	1nm	2nm	3nm	4nm	5nm	6nm	7nm	8nm
3.2°	0	339.53	679.06	1018.59	1358.12	1697.65	2037.19	2376.72	2716.25
3.2 ° +/- Temperature	0	333.26	666.50	999.73	1332.94	1666.14	1999.33	2332.49	2665.65
Difference	0	-6.27	-12.56	-18.86	-25.18	-31.51	-37.86	-44.22	-50.60
3°	0	318.27	636.54	954.81	1273.08	1591.35	1909.62	2227.89	2546.16

Figure 26: Effect of an average 9.63°C air temperature on a 3.2° Baro-VNAV approach

79. Figure 26 shows that, at 8nm from touchdown, an average temperature of 9.63°C has the effect of lowering an aircraft's height on a baro-VNAV approach by c.51ft. At 6nm this is c.38ft and at 4nm, c.25ft. Figure 27 below shows the aircraft height achieved by all

3.2° RNAV arrivals across all aircraft and all runways corrected for the deviation due to the average temperature at Heathrow for the trial period.

	4nm	6nm	8nm
Average height increase achieved (all aircraft and runways)	+53ft	+78ft	+88ft
Temperature Correction for 9.63°C	+25ft	+38ft	+51ft
Temperature corrected average height increase achieved	+78ft	+116ft	+139ft
Trigonometrically achievable height improvement	+85ft	+128ft	+170ft
Difference from trigonometrically achievable height improvement	-7ft	-12ft	-31ft

Figure 27: Temperature corrected average height improvement achieved

80. This would suggest that had the average temperature at Heathrow been exactly 15°C for the duration of the trial, the figures shaded in orange would have been the average actual height improvement achieved by 3.2° RNAV approaches.

Warmer months analysis

81. There was a marked reduction in average temperature in Jan-Mar 2016 compared to Sep-Dec 2015 which has brought the overall average temperature down. It should be noted that the number of aircraft performing 3.2° RNAV approaches also fell during these months – only 724 out of the 2,469 occurred in 2016. It is therefore worth looking at average height performance for just Sept-Dec 2015 alone when the average temperature was 11.77°C (Figure 28) which created an RNAV approach angle of approximately 3.16°.

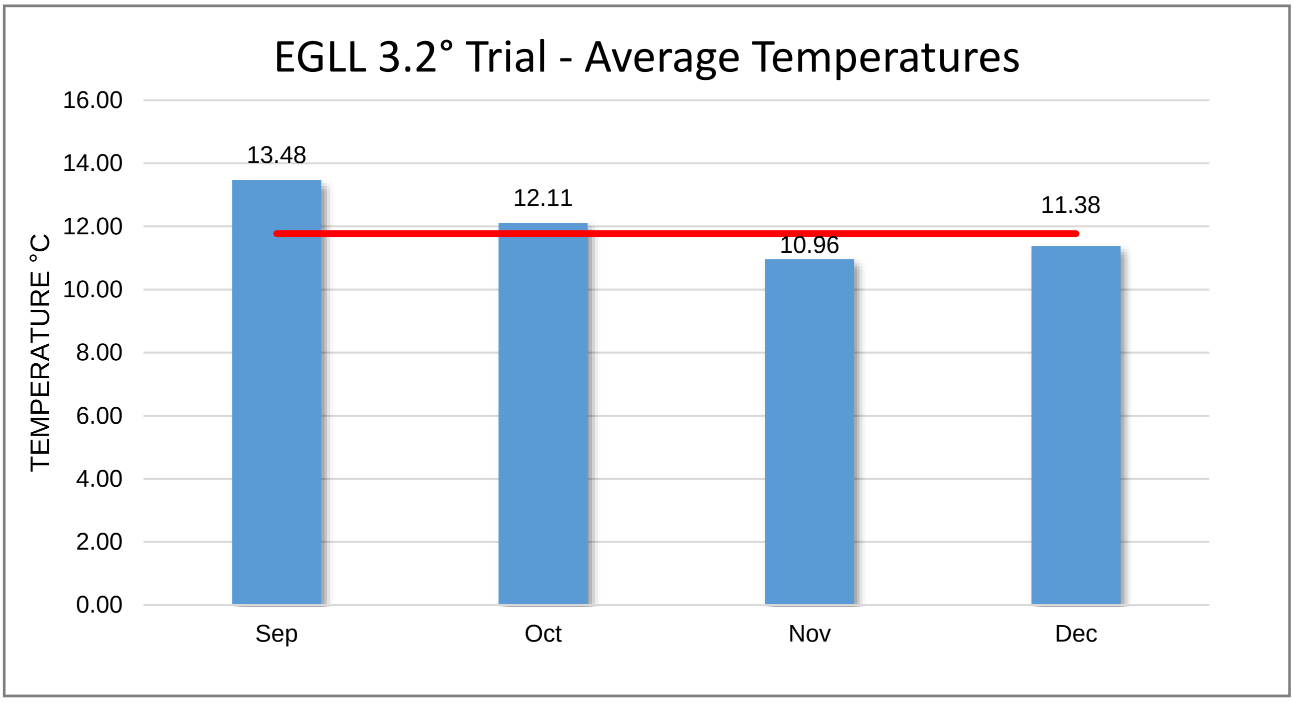


Figure 28: Average temperature of 11.77°C at Heathrow during Sept-Dec 2015

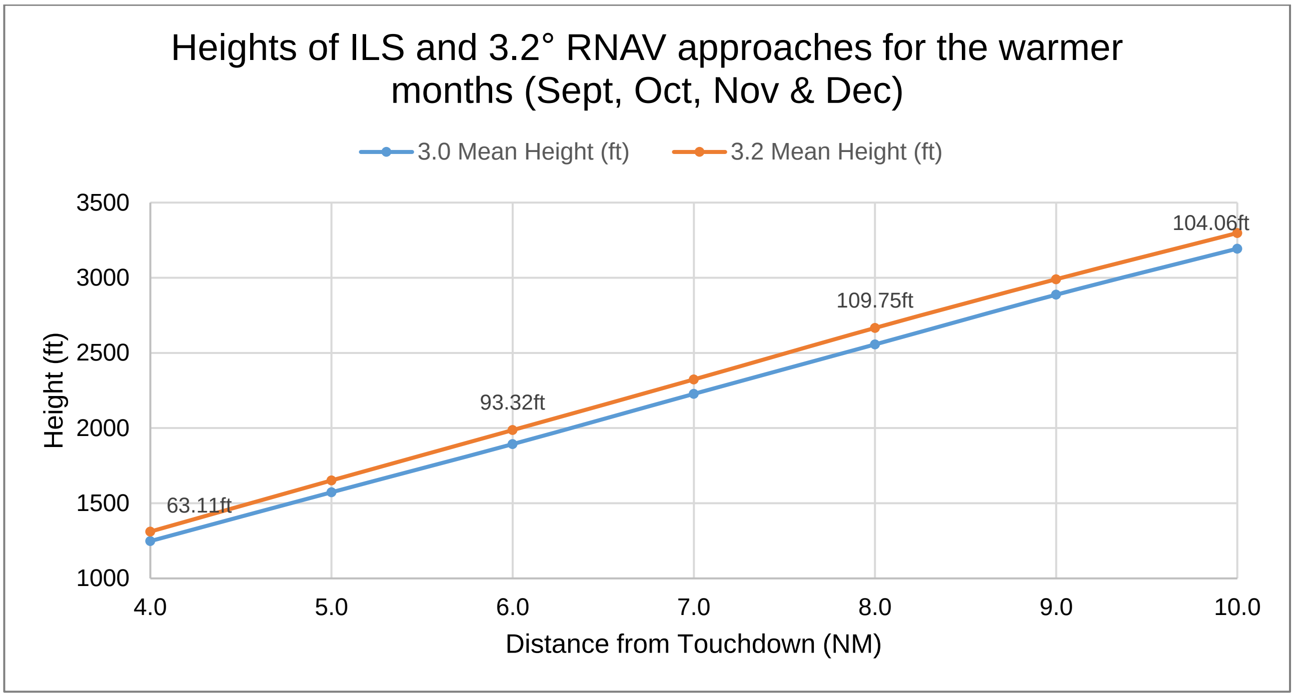
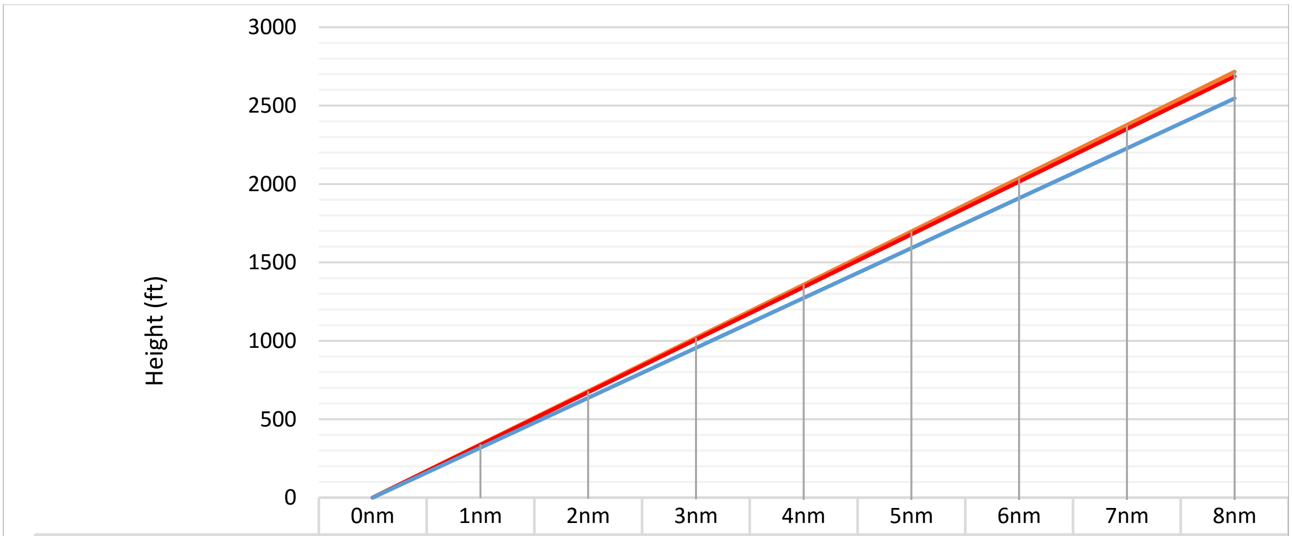


Figure 29: Average height improvement achieved. All runways and aircraft. Average temperature 11.77°C



	0nm	1nm	2nm	3nm	4nm	5nm	6nm	7nm	8nm
3.2°	0	339.53	679.06	1018.59	1358.12	1697.65	2037.19	2376.72	2716.25
3.2 ° +/- Temperature	0	335.86	671.71	1007.55	1343.39	1679.21	2015.03	2350.84	2686.64
Difference	0	-3.67	-7.35	-11.04	-14.74	-18.44	-22.16	-25.88	-29.61
3°	0	318.27	636.54	954.81	1273.08	1591.35	1909.62	2227.89	2546.16

Figure 30: Effect of an average 11.77°C air temperature on a 3.2° Baro-VNAV approach

	4nm	6nm	8nm
Average height increase achieved (all aircraft and runways)	+63ft	+93ft	+110ft
Temperature Correction for 11.77°C	+15ft	+22ft	+30ft
Temperature corrected average height increase achieved	+78ft	+115ft	+140ft
Trigonometrically achievable height improvement	+85ft	+128ft	+170ft
Difference from trigonometrically achievable height improvement	-7ft	-13ft	-30ft

Figure 31: Temperature corrected average height improvement achieved (Sep-Dec 2015 only)

Colder months analysis

82. During Jan 1st and Mar 16th 2016, the average temperature at Heathrow was 6.5°C (Figure 32) which created an RNAV approach angle of approximately 3.1°.

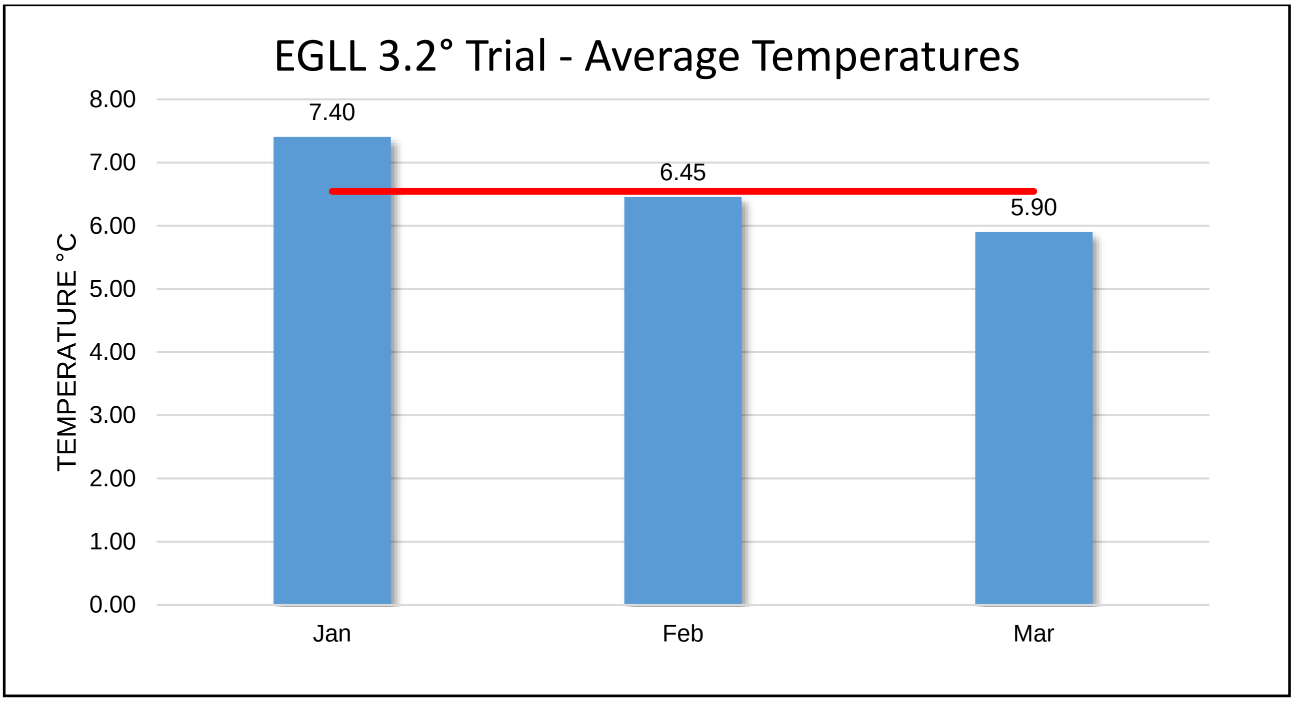


Figure 32: Average temperature of 6.5°C at Heathrow during Jan-Mar 2016

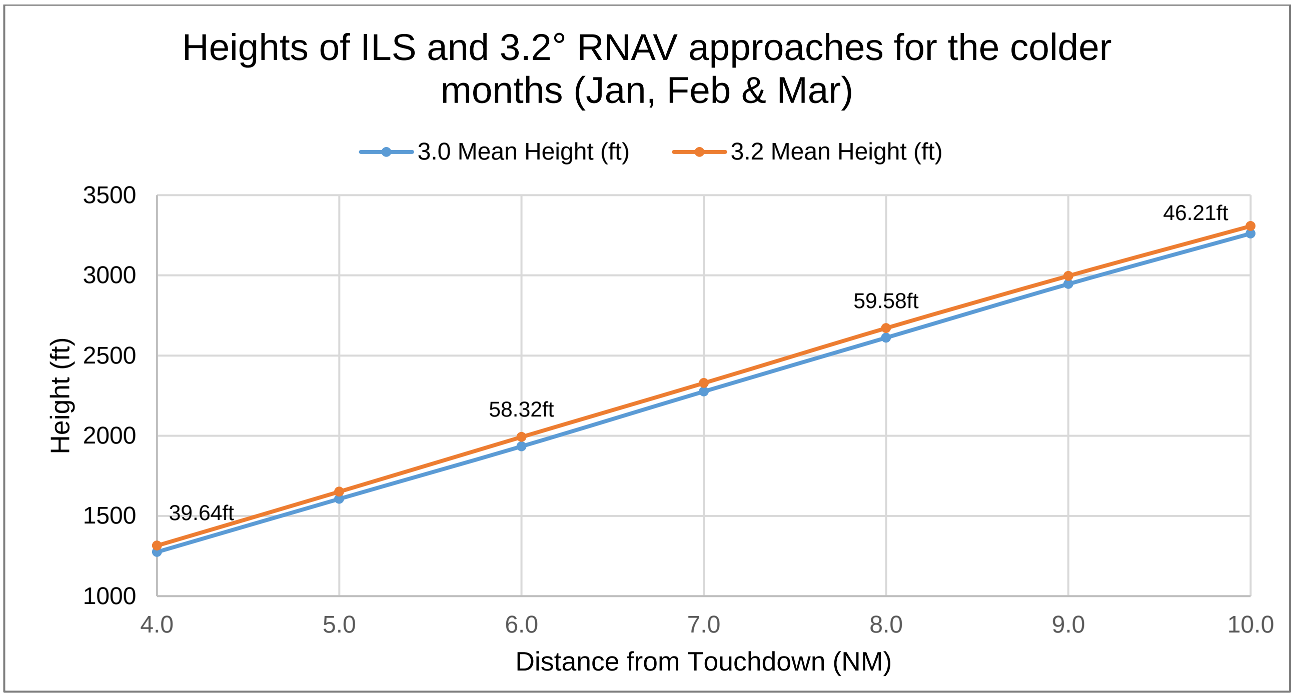
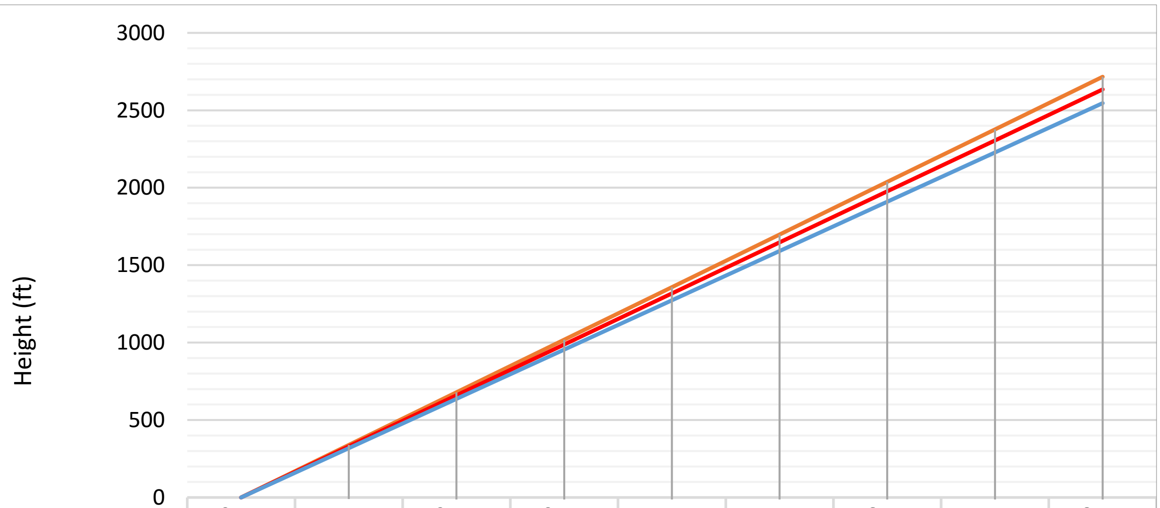


Figure 33: Average height improvement achieved. All runways and aircraft. Average temperature 6.5°C



	0nm	1nm	2nm	3nm	4nm	5nm	6nm	7nm	8nm
3.2°	0	339.53	679.06	1018.59	1358.12	1697.65	2037.19	2376.72	2716.25
3.2 ° +/- Temperature	0	329.43	658.84	988.23	1317.59	1646.93	1976.24	2305.53	2634.79
Difference	0	-10.10	-20.22	-30.36	-40.53	-50.73	-60.94	-71.19	-81.46
3°	0	318.27	636.54	954.81	1273.08	1591.35	1909.62	2227.89	2546.16

Figure 34: Effect of an average temperature of 6.5°C air temperature on a 3.2° Baro-VNAV approach

	4nm	6nm	8nm
Average height increase achieved (all aircraft and runways)	+40ft	+58ft	+60ft
Temperature Correction for 11.77°C	+41ft	61ft	+82ft
Temperature corrected average height increase achieved	+81ft	+119ft	+142ft
Trigonometrically achievable height improvement	+85ft	+128ft	+170ft
Difference from trigonometrically achievable height improvement	-4ft	-9ft	-28ft

Figure 35: Temperature corrected average height improvement achieved (Jan-Mar 2016 only)

83. Figures 27, 31 and 35 show that when corrected for temperature, the difference between the actual height improvement and the improvement available based trigonometry alone is almost identical to within 4ft.

Westerly comparison only

84. Figure 36 shows the temperature corrected average heights for westerly approaches only during the whole trial with an average temperature of 9.63°C.

	4nm	6nm	8nm
Average height increase achieved (all aircraft westerlies only)	+59ft	+88ft	101ft
Temperature Correction for 9.63°C	+25ft	+38ft	+51ft
Temperature corrected average height achieved	+84	+126	+152
Trigonometrically achievable height improvement	+85ft	+128ft	+170ft
Difference from trigonometrically achievable height improvement	-1ft	-2ft	-18ft

Figure 36: Temperature corrected average height improvement achieved. Westerlies all aircraft

85. With the easterly data removed from the sample we saw the temperature-corrected height improvement much closer to the pre-trial trigonometric expectations.

A380 performance

86. It is worth noting that this aircraft automatically corrects its height for temperature. Figure 37 shows that the height improvement of the A380 performing 3.2° RNAV approaches is considerably better than the average and indeed very close to the height improvement expected of a 3.2° final approach angle.

87. It is also worth considering this data when looking at the noise analysis from the 3 Remote Monitoring Terminals (RMTs) as the A380 is one of the aircraft offering the best noise reduction as a result of the 3.2° approach.

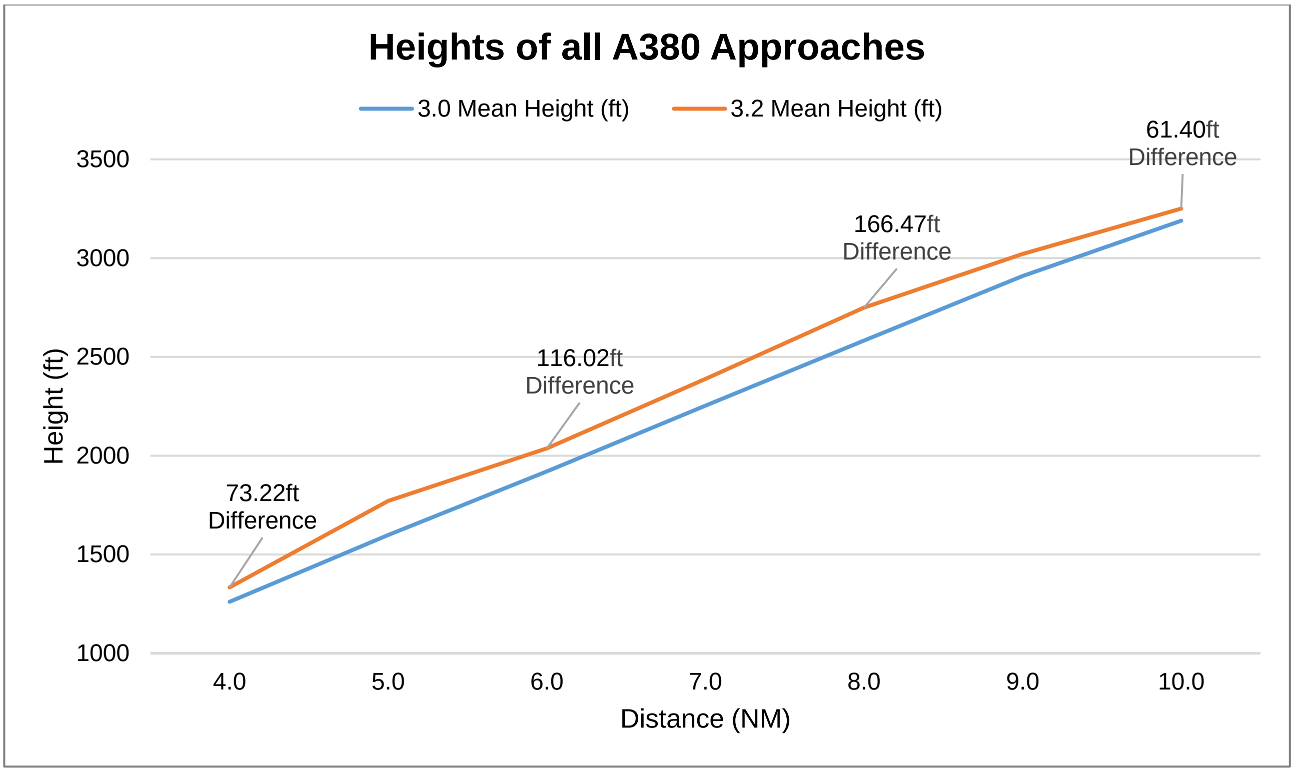


Figure 37: Average height improvement achieved. All runways for A380.

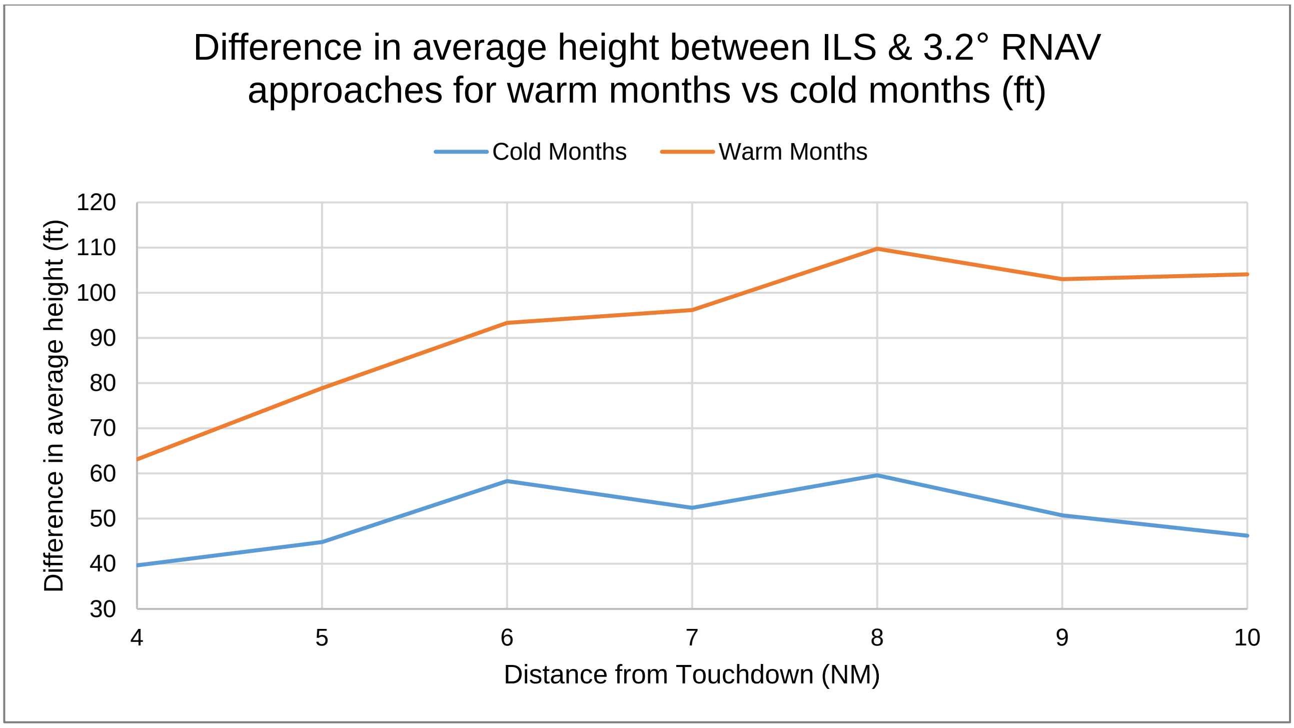


Figure 38: Average height improvement comparing Sept-Dec 2015 (warmer months) to Jan-Mar 2016 (colder months).

88. The height improvement on final approach was lower than mathematically expected from a 3.2° approach which was due to the effect of temperature on the Baro-VNAV approaches.

89. Looking only at average temperatures between 0600 and 2230 throughout the trial period, the average RNAV approach angle was 3.14°.

90. The data confirms however, that had the air temperature been 15°C or had the aircraft been flying 3.2° ILS approaches, the height improvement would have been as expected.

91. The technology on board the A380 self-corrects for the temperature effect. The result being during the trial, the A380 was the only aircraft achieving the maximum height benefit expected from the 3.2° approach angle.

Final Approach joining point

92. On average, across all runways and aircraft types, the 3.2° RNAV arrivals are joining final approach 1.27 NM closer into the threshold than the 3.0° ILS arrivals (Figure 39). The analysis most likely compares RNAV arrivals to ILS arrivals, rather than 3.2° to 3.0° approaches specifically. The change is therefore a symptom of RNAV approaches being put on their own navigation to the Initial Fix, instead of positioning by ATC vectors onto the ILS localiser as described in the section on RNAV approaches.

93. Behaviour is fairly consistent across all runways with average differences being 1.26nm on 27L, 1.52nm on 27R and 1.09nm on 09L. 3.2° approaches to runway 09R made up only 0.01% of the dataset and therefore the average distance between different approaches of only 0.76nm is less reliable.

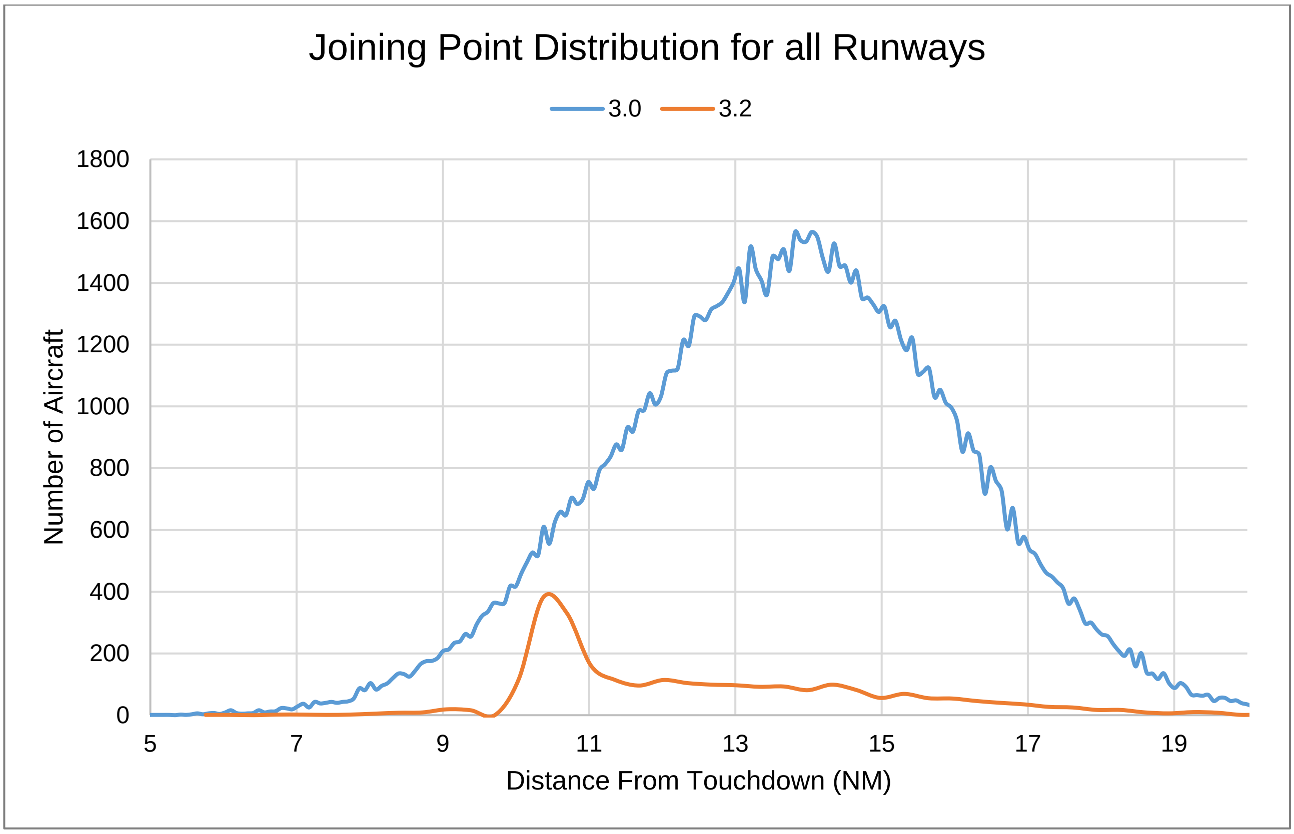


Figure 39: Final approach joining point distribution. All runways, all types.

	Final Approach Joining Point Differential (closer to threshold)
27L	1.26nm
27R	1.52nm
09L	1.09nm
09R	0.76nm

Tracks of aircraft over the ground

94. Figures 40 and 41 show the tracks of the 3° ILS (red) and 3.2° RNAV (purple) arrivals, below 6000ft for both easterly and westerly configurations. The 3° ILS tracks are for 6 days of traffic only[23], compared to the 6-month dataset for the 3.2° RNAV arrivals.

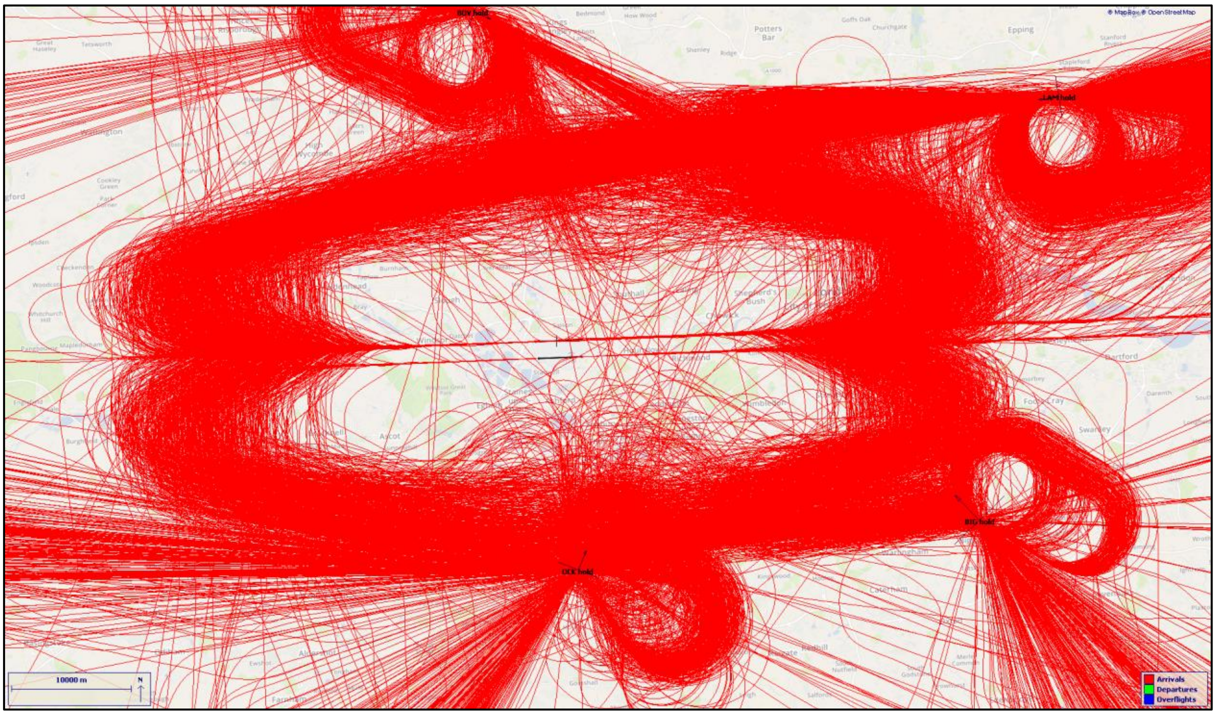


Figure 40: Final approach arrival swathes 3° ILS arrivals only. 6-day sample.

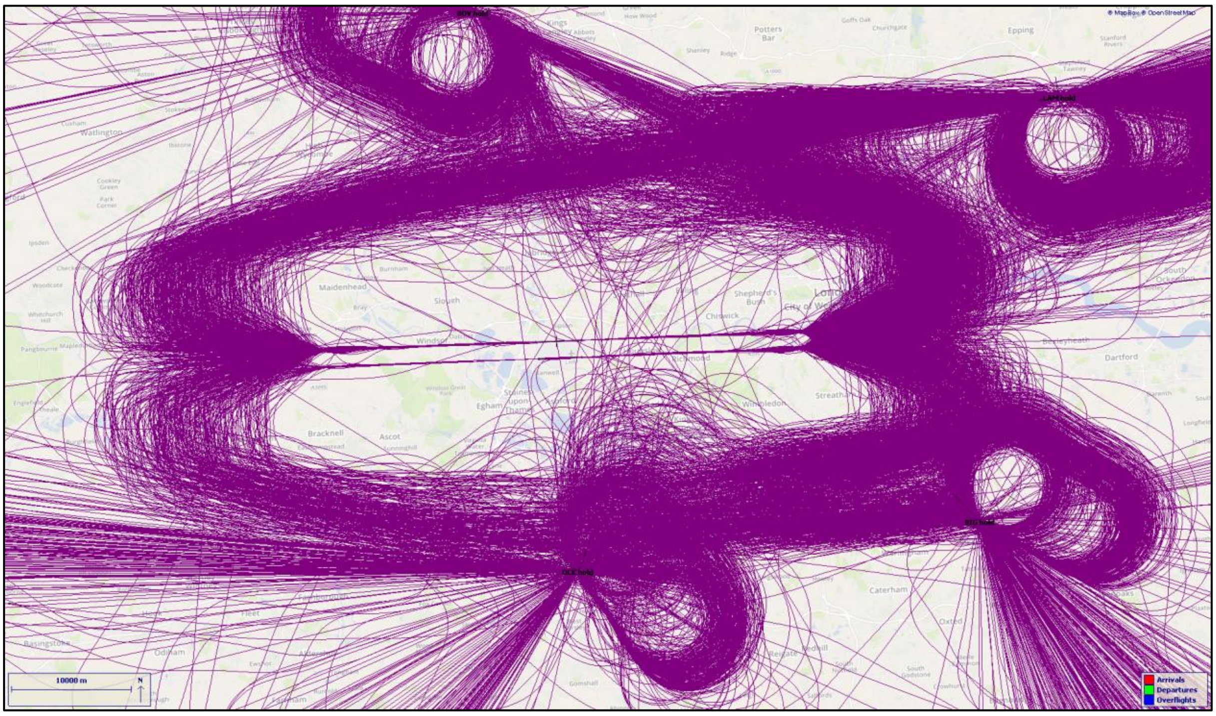


Figure 41: Final approach arrival swathes 3.2° RNAV only. 6-month sample

[23] 6 days of ILS traffic provides a more balanced illustration in terms of comparing similar numbers of movements

95. The variation in the arrival tracks is created by the vectoring of the aircraft by ATC until they are established on final approach, creating a broad 'swathe' of tracks over the ground.

96. Figure 42 shows all Heathrow arrivals for the trial period with the darker swathe representing the 3.2° arrivals. It can be seen that the tracks of the darker 3.2° arrivals are fully encompassed within the 3° ILS arrival swathe.

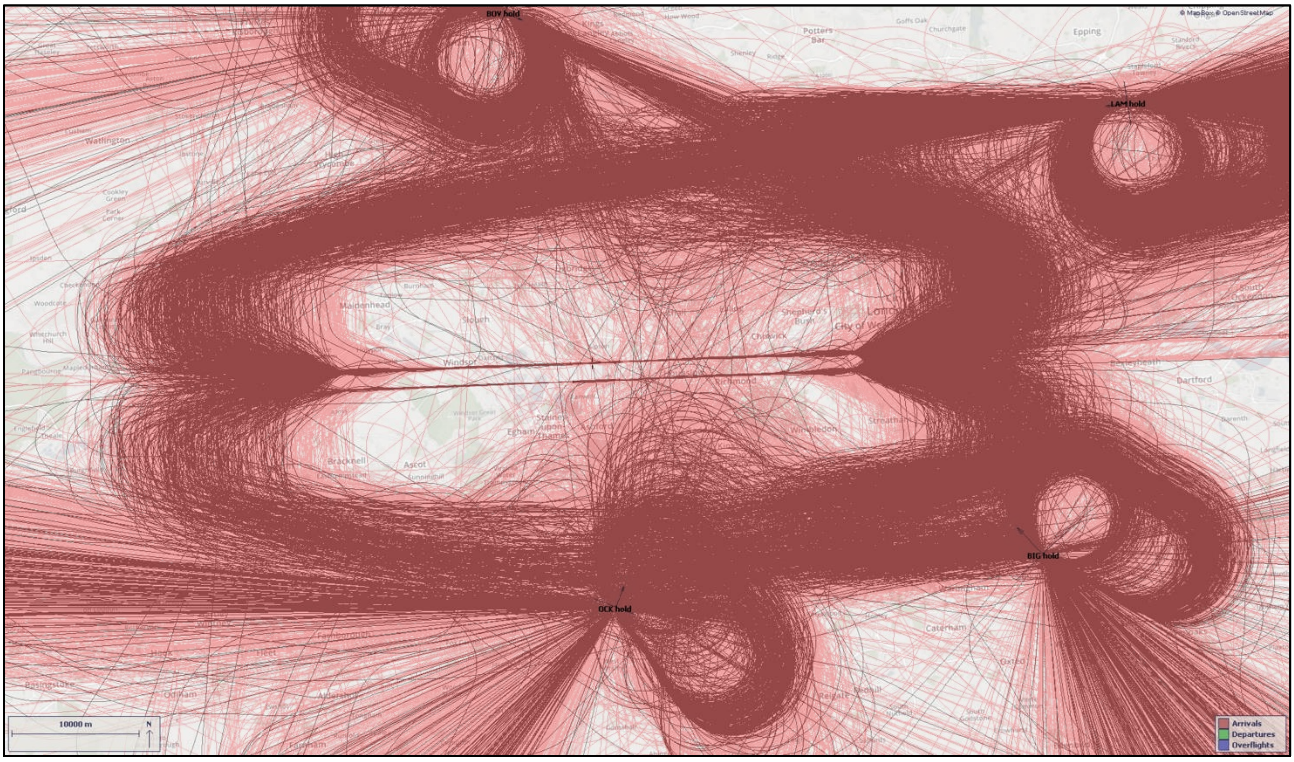


Figure 42: Final approach arrival swathes ILS and RNAV combined

97. There is no noticeable difference in tracks over the ground between the 3° and 3.2° arrivals.

ATC feedback

98. Post-trial, a workshop was held with representatives from Scandinavian Airlines, Heathrow Airport Limited (HAL) Heathrow ATC, LTC Heathrow Approach Controllers, NATS R&D, Eurocontrol and Airbus to share any operational issues from the ATC perspective which had not been raised during the trial or were not covered via the data captured.

99. The main issue was the integration of a higher number of RNAV approaches in with the ILS approaches, particularly during the first 2 months of the trial. ATC felt this was less to do with the steeper approach angle but more the issue of RNAV approaches and their integration with the ILS approaches.

Instrument Flight Procedure Design

100. ATC advised that the technical construction (design) of the RNAV approaches were not ATC friendly largely due to the PANS-OPS requirement to have a level segment prior to the Final Approach Fix. Whilst the vast majority of aircraft do not actually fly the level segment but actually perform a CDA, technically, once ATC clear an aircraft for the RNAV arrival, although unlikely, a crew could descend on the profile as published. This creates a potential conflict with other air traffic in the vicinity which results in higher workload for ATC as an extra verbal instruction to RNAV arrivals is sometimes required to mitigate this risk. This is not an issue specific to Heathrow nor is it an issue as a result of the 3.2° approach angle but is included in this report for completeness.

Workload associated with RNAV approaches in general

101. Together with the issue above, the handling of RNAV approaches by LTC Heathrow Approach Controllers involves more Flight Progress Strip marking, more R/T (verbal instructions to the crews) and less flexibility with regards to positioning towards the Initial Fix as opposed to the ILS.

Workload associated with the trial

102. ATC felt there was no noticeable operational difference between the 3° and 3.2° approaches. Noting, however that RNAV approaches in general create a higher ATC workload, there was concern during the first two months of the trial where requests for RNAV approaches was significantly higher than normal. As the numbers of requests reduced for the remaining 4 months of the trial, the impact on ATC was reduced accordingly.

103. ATC reported that when there was a tailwind, they noticed a reduction in the number of requests for 3.2° RNAV approaches. This was likely due to an uncertainty by the crews of the effect that the steeper approach would have on their landing distance required and therefore opted for the 3° ILS approach which they were more familiar and comfortable with.

Safety Observations

104. There was one report where an aircraft on a 3.2° RNAV approach reported a vortex wake encounter whilst following an aircraft on a 3° ILS approach. ATC felt this was likely not due to the trial.

105. There was one report of an aircraft following an 3.2° RNAV approach which was cleared to route to the Initial Fix via a left turn but the aircraft turned right. The pilot at the time said this was crew error and was therefore not linked to the 3.2° approach. It is however, potentially another highlight of the extra workload associated with RNAV approaches, both in the cockpit and by ATC and is therefore included here for completeness.

Requests going forward

106. The consensus by ATC was that the 3.2° approach angle made very little difference to their operation however the increased use of RNAV approaches did.

Airlines/Pilot Feedback

107. Post-trial, a workshop was held with representatives from British Airways, Virgin Atlantic, Lufthansa, HAL, Heathrow ATC, NATS R&D, Eurocontrol and Airbus to share any operational issues that had not been raised during the trial.

Speed Management

108. Before the trial there had been opinion that speed adherence on the 3.2° approach would be harder to manage which would lead to an increased risk of go-arounds. The pilots reported that this concern had not materialised and the go-around data supports this. In addition, the data demonstrates that speed adherence at 4DME was improved slightly when following the 3.2° RNAV approach. One possible explanation discussed was that the crews were less familiar with RNAV approaches compared to ILS approaches and that actually, the extra time spent briefing the approach and heightened potential concern over speed management actually created a positive result.

109. Anecdotally, the pilots believed that Heathrow's 3.2° RNAV approach made no difference to the ability to manage the aircraft's speed.

Numbers of 3.2° RNAV Approaches

110. Discussing the numbers of 3.2° RNAV approaches compared to 3° ILS approaches, the crews believed this was not related to the slightly steeper approach angle but to do with the greater familiarity with ILS approaches of most crews. Heathrow's runways are very long in comparison to some others (such as Frankfurt's northern runway with a 3.2° approach) therefore any concern with regards to energy management would likely have been alleviated by the large landing distance available. It was therefore likely a Human Factors issue which contributed to the low take up of the trial approaches with pilots preferring the easiest and most familiar/comfortable option, especially at the end of a long flight. RNAV approaches are becoming more common but are still relatively new to a lot of crews.

Landing Gear Deployment

111. The pilots explained that the Standard Operating Procedure (SOP) for the lowering of the landing gear is normally associated with a specific altitude which varies across different airlines and different aircraft types. Therefore, that height is now slightly closer to the runway.

112. Prior to the trial there was some concern that in order to manage the speed of aircraft performing the slightly steeper approach, crews may need to lower the landing gear earlier in order to produce more drag. This was not found to be the case during the trial.

PAPIs

113. Precision Approach Path Indicators (PAPIs) are a visual aid which provides guidance information to pilots to help them maintain the correct vertical profile to a runway. Following consultation with airlines prior to the trial, Heathrow's PAPIs remained configured to a 3°

approach for the duration of the trial and this fact was marked on the published 3.2° RNAV Approach charts.

Figure 43: Precision Approach Path Indicators (PAPIs)

114. The crews had no issues with the PAPIs remaining at 3° when performing 3.2 approaches. It was noted on the RNAV approach charts and crews are used to having PAPIs set at 3°. Note that Frankfurt Airport opted to set their PAPIs at 3.1° on their northern runway to cater for both 3° and 3.2° approaches.

Construction of Heathrow’s 3.2° RNAV Approaches

115. The crews reported that most of the initial feedback from within their airlines was in the lead up to, and during the first month of the trial and most comments were with regards to the design of the RNAV procedures themselves. The following may therefore be considerations for any future RNAV designs for Heathrow:

- A platform height of 3,000ft, as opposed to 2,500ft would be preferable as 3,000ft is the level that ATC clear the aircraft to prior to establishing on final approach. This makes intercepting the RNAV approach angle from above harder to achieve.

- The go-around procedure on the RNAV approaches were based on conventional navigation, it would be preferable if the design could incorporate an RNAV missed approach.

General airline feedback

116. The airline representatives present at the workshop had no other issues with 3.2° RNAV approaches at Heathrow but all agreed a 3.2° ILS approach would be the preferred option.

117. Heathrow's 3.2° approaches did not require a change to pilot behaviour. The stabilisation of the aircraft, landing gear deployment, energy management and the flare[24] prior to touchdown were not affected. However, all the crews agreed that an approach angle above 3.2° starts to create issues.

118. When discussing the potential next steps, it was highlighted that whilst most aircraft can perform an ILS CAT III autoland with approach angles of up to 3.25° there are still aircraft in operation at Heathrow, including the older A320, which are limited to 3.15°. This is an important consideration for Heathrow if they were to consider a permanent introduction of 3.2° ILS Approaches.

[24] The flare follows the final approach phase and precedes the touchdown and roll-out phases of landing. In the flare, the nose of the plane is raised, slowing the descent rate, and the proper attitude is set for touchdown.

Noise Measurements

119. CAA's Environmental Research and Consultancy Department (ERCD) were commissioned to assess the noise effects of the 3.2° slightly steeper approach.

120. Noise measurements were taken from the specific monitoring terminals (RMT129 at Mogden Sewage Works, 130 at Mid Surrey Golf Course and 131 at Roehampton Golf Club. See Figure 44) along the arrival route on runway 27L.

Figure 44: RMT Locations under 27L Final Approach

121. ERCD performed 2 independent tasks in order to support the analysis:

a) Numerical analysis of trial data extracted from RMTs under Heathrow 27L final approach path as detailed in this section.

b) The UK civil Aircraft Noise CONtour model (ANCON[25]) was used to model and create profiles associated with a 3.2° approach, assuming all arrivals were flying 3.2° approaches. The data collected from the RMTs was not used in the modelling of these noise contours. See Appendix C for these results.

Data Validation

122. Weather data for Heathrow, including wind speed and weather events such as precipitation, have been used to discard noise measurements that were recorded at a time when wind speeds were higher than 10 m/s. This is standard practice in order to filter out noise measurements which may have been affected by wind noise at the microphone.

123. Noise events with measured levels within the 95th percentile were used in the analysis. I.e. 2.5% at the top, and at the bottom, of the sampling range in terms of noise level, were discarded to reduce the effect of outliers and some obvious non-aircraft noise.

[25] Features of the ANCON noise modelling process

124. Note: RMT 130 had three periods of outage during November and December 2015 (from 4th to 9th November, 26th November to 1st December and 18th to 21st December), which accounts for the lesser number of noise events recorded at this monitor.

125. The metric used for analysis and comparison is the logarithmic average Sound Exposure Level, SEL (dBA), measured per aircraft type, for each navigational method (ILS and RNAV) and at each monitoring terminal. The minimum, maximum, standard deviation and size of sample were calculated to inform the level of confidence in the results generated from the noise data gathered.

Numerical Analysis of trial data

126. The additional altitude on a 3.2° approach means a greater noise propagation distance between the aircraft noise source and receptors on the ground. Consequently, for ideal trajectories under standard atmospheric conditions, there would be a constant noise reduction at every point directly beneath the approach path for the 3.2° slightly steeper approaches compared with standard 3° approaches[26].

127. Figure 45 shows the different aircraft types assessed, some of which appear more than once to differentiate between the same aircraft types but with different engine manufacturers.

ANCON Aircraft Type	Description
B744R	Boeing 747-400 (RR RB211 engines)
B772G	Boeing 777-200 (GE GE90 engines)
B772R	Boeing 777-200 (RR Trent 800 engines)
B787	Boeing 787-8/9
EA319V	Airbus A319 (IAE-V2500 engines)
EA320C	Airbus A320 (CFM-56 engines)
EA320V	Airbus A320 (IAE-V2500 engines)
EA321V	Airbus A321 (IAE-V2500 engines)
EA38R	Airbus A380 (RR Trent 900 engines)

Figure 45: ANCON aircraft types and their description

128. Figures 46-51 show the logarithmic average Sound Exposure Level (SEL) per aircraft type compared between 3° ILS arrivals and 3.2° RNAV arrivals for each noise monitor. They also show additional statistical parameters to assist in the interpretation of results. These parameters are the minimum and maximum SEL values, the standard deviation, and the number of noise events per aircraft type and noise monitor.

[26] For the mathematical explanation, see Appendix H

RMT129 Mogden Sewage Works

ANCON Aircraft Type	ILS SEL (dBA)	RNAV SEL (dBA)	Noise change (dBA)
B744R (B747)	90.3	90.1	-0.2
B772G# (B777)	86.8	86.7	-0.2
B772R (B777)	87.8	87.5	-0.2
B787	86.0	85.9	-0.1
EA319V (A319)	83.0	82.9	-0.1
EA320C (A320)	84.7	84.3	-0.4
EA320V (A320)	83.6	83.3	-0.2
EA321V (A321)	83.9	83.7	-0.2
EA38R (A380)	88.8	88.2	-0.6

Figure 46: RMT129 – Noise results

ANCON aircraft type	3° ILS				3.2° RNAV			
	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events
B744R	88.3	92.4	0.8	1,300	88.7	91.6	0.8	23
B772G	84.9	88.9	0.7	845	85.5	87.9	0.6	40
B772R	85.5	90.5	1.0	825	86.3	89.0	0.7	28
B787	84.0	87.8	0.8	1,306	84.7	86.9	0.5	42
EA319V	81.1	85.1	0.8	3,994	81.1	84.6	0.8	153
EA320C	82.3	87.4	1.1	3,015	81.6	85.8	1.0	38
EA320V	81.3	86.3	1.1	5,739	81.3	85.9	1.1	233
EA321V	81.4	86.9	1.2	2,049	81.9	86.5	1.2	43
EA38R	86.6	90.7	0.9	593	86.7	89.4	0.9	19

Figure 47: RMT129 – Statistical analysis

RMT130 Mid Surrey Golf Course

ANCON Aircraft Type	ILS SEL (dBA)	RNAV SEL (dBA)	Noise change (dBA)
B744R (B747)	88.8	88.5	-0.2
B772G (B777)	85.3	84.9	-0.4
B772R (B777)	86.4	86.0	-0.5
B787	84.8	84.5	-0.2
EA319V (A319)	80.2	79.8	-0.4
EA320C (A320)	82.8	82.1	-0.7
EA320V (A320)	80.0	79.6	-0.4
EA321V (A321)	81.0	80.2	-0.8
EA38R (A380)	87.9	87.1	-0.8

Figure 48: RMT130 – Noise results

ANCON aircraft type	3° ILS				3.2° RNAV			
	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events
B744R	85.9	90.8	1.0	1,124	85.7	90.7	1.2	20
B772G	80.7	87.3	1.1	726	83.5	85.9	0.6	35
B772R	83.1	89.7	1.2	722	84.1	87.7	1.2	24
B787	80.6	86.9	1.0	1,159	81.4	85.9	0.9	38
EA319V	77.6	83.4	1.3	3,429	77.8	82.6	1.2	131
EA320C	79.2	85.6	1.4	2,558	78.8	84.1	1.5	36
EA320V	77.4	83.7	1.3	4,945	77.4	82.4	1.1	208
EA321V	77.9	84.7	1.7	1,733	78.0	83.1	1.3	35
EA38R	85.4	89.7	0.9	511	85.5	88.6	0.9	17

Figure 49: RMT130 – Statistical analysis

RMT131 Roehampton Golf Club

ANCON Aircraft Type	ILS SEL (dBA)	RNAV SEL (dBA)	Noise change (dBA)
B744R (B747)	82.6	82.7	+0.1
B772G (B777)	78.0	77.3	-0.8
B772R (B777)	79.7	78.4	-1.4
B787	79.8	78.4	-1.3
EA319V (A319)	77.3	77.4	+0.1
EA320C (A320)	78.5	77.4	-1.1
EA320V (A320)	77.1	76.6	-0.5
EA321V (A321)	76.9	76.2	-0.8
EA38R (A380)	83.2	82.2	-1.0

Figure 50: RMT131 – Noise results

ANCON aircraft type	3° ILS				3.2° RNAV			
	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events	SEL_{min} (dBA)	SEL_{max} (dBA)	StDev	Number of Events
B744R	78.4	86.5	1.2	1,265	80.7	84.9	1.1	23
B772G	74.6	82.7	1.7	807	74.9	82.0	1.5	34
B772R	74.6	84.9	2.5	789	74.7	80.5	1.7	25
B787	74.4	83.4	2.3	1,290	75.2	83.9	2.0	40
EA319V	73.3	81.2	1.8	3,879	73.7	81.5	2.0	153
EA320C	75.0	82.1	1.6	2,953	73.7	79.7	1.5	38
EA320V	73.3	81.0	1.8	5,591	72.9	80.3	1.7	223
EA321V	73.6	80.7	1.5	2,001	73.6	78.5	1.0	40
EA38R	79.8	86.4	1.3	585	78.9	84.6	1.3	18

Figure 51: RMT131 – Statistical analysis

Analysis of trial data

129. The results in Figures 46, 48 and 50 suggest that, in the majority of cases, 3.2° approaches do indeed provide noise reductions compared to 3° approaches. However, these are not constant, as the science would suggest[27], at each of the monitoring points considered in this study. Instead, noise attenuation appears to be greater at receptors further away from the airport. The variability, expressed as standard deviation in Figures 47, 49 and 51, also increases with increasing distance from the 27L threshold.

130. To address the variability first, this is likely due to the variation of different aircraft joining the ILS or the RNAV procedure at different places on their final approach. The variability observed in the statistical analyses for the selected aircraft types in each monitor ranges, on average, from 1.0 dB to 1.7 dB. 3.2° RNAV sample variability has been found to be marginally lower than that of 3° ILS, despite the low number of samples on RNAV compared to ILS. As described above, there is more variability in the positioning of aircraft onto the ILS compared to the more defined positioning of aircraft onto the RNAV approach, which could support these figures.

131. Turning to the differences in noise levels at monitor positions, the average noise changes vary between:

- -0.1 dB and -0.6 dB at RMT129,
- -0.2 dB to -0.8 dB at RMT 130,
- +0.1 to -1.4 dB at RMT 131

132. Two-sample t tests[28] were used to compare the average noise levels for each aircraft type at each monitoring position that operated using ILS and RNAV to test whether differences are statistically significant. With a 95% confidence, the tests showed that sample data was statistically significant for each type and monitor combination with the exception of the B747 at monitors RMT 130 and RMT 131, and the A319 at RMT 131. It is concluded that the ILS and RNAV distributions for those combinations of aircraft types and monitor location are not significantly statistically different.

133. **Therefore, all the measurement results that are considered show valid reductions in measured noise level for 3.2° slightly steeper approaches.**

134. For ideal trajectories under standard atmospheric conditions, we would expect that the 3.2° steeper approaches would give constant noise reductions at receptors directly

[27] See page Appendix H

[28] A T-test is a statistical comparison of two samples of data, in this case, with different mean, standard deviation and sample size. It determines, in this study, whether the two samples of data are statistically significant (real difference) or different by chance or bias.

below the aircraft approach path of around -0.7 dB (including atmospheric absorption attenuation in addition to the distance dependent attenuation). The noise events analysis shows modest noise reductions that fall short of this expectation in terms of consistency and magnitude. There are a number of factors that could contribute to this, among them:

- The sound level meter devices of RMTs are designed to meet a tolerance, i.e. sound level meters are expected to have a small error. A study[29] has recommended that 0.4 dB should be allowed for any error in the instrumentation which may contribute to variation in the measured results.

- Monitoring positions are in locations affected by variability in operational procedures. I.e. aircraft may or may not have their landing gear down, and there will be differences in thrust and flap settings. These will have an effect on the amount of noise produced by the aircraft which is not directly related to the approach angle.

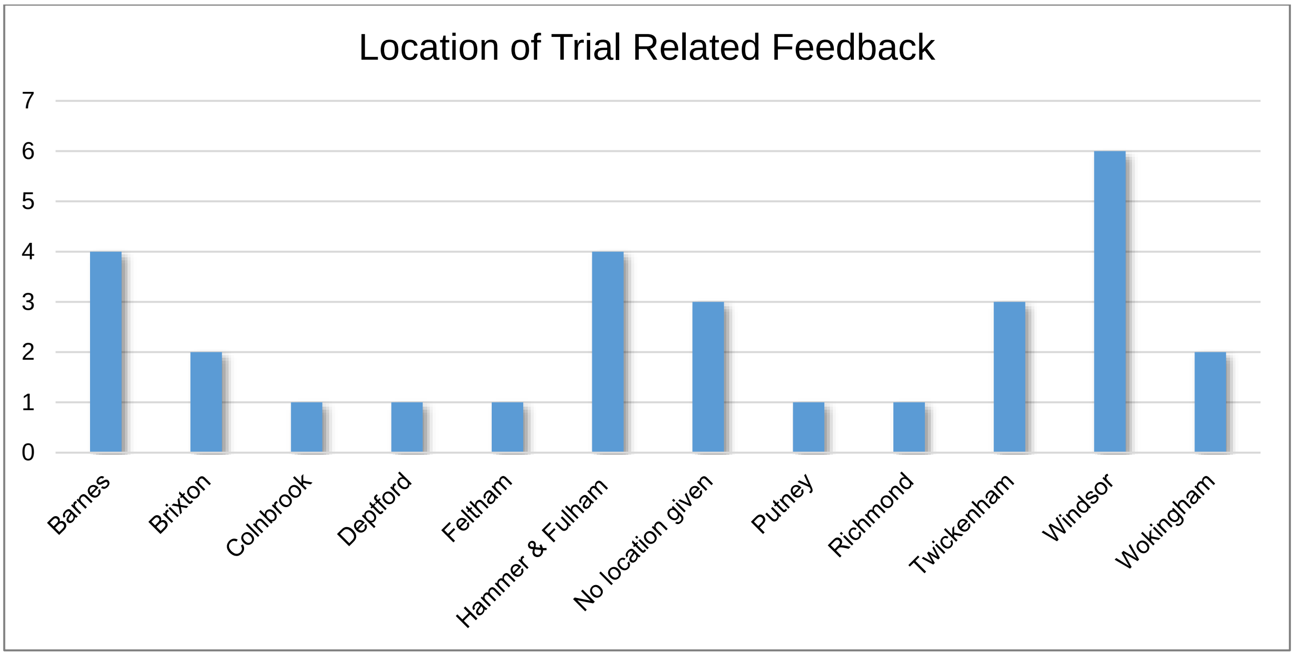
- Non-aircraft noise local to a noise monitor may artificially increase aircraft event noise levels as recorded. The causes of the extraneous noise may vary, and have been reported to include road traffic, construction or demolition works and birds at some of the monitoring positions. This may introduce variation in the results and could affect the differences between the results.

- The effect of a temperature lower than 15°C during the trial period resulted in aircraft being lower than expected of a mathematical 3.2° approach angle.

[29] NPL REPORT DQL-AC 002 Uncertainties associated with the use of a sound level metre

Community Feedback during the trial

135. During the trial period, Heathrow received 50,274 pieces of feedback made by 2,718 people. Of these, there were only 29 (0.06%) comments, queries and complaints received from approximately 23 people in respect of the 3.2° slightly steeper approach trial.



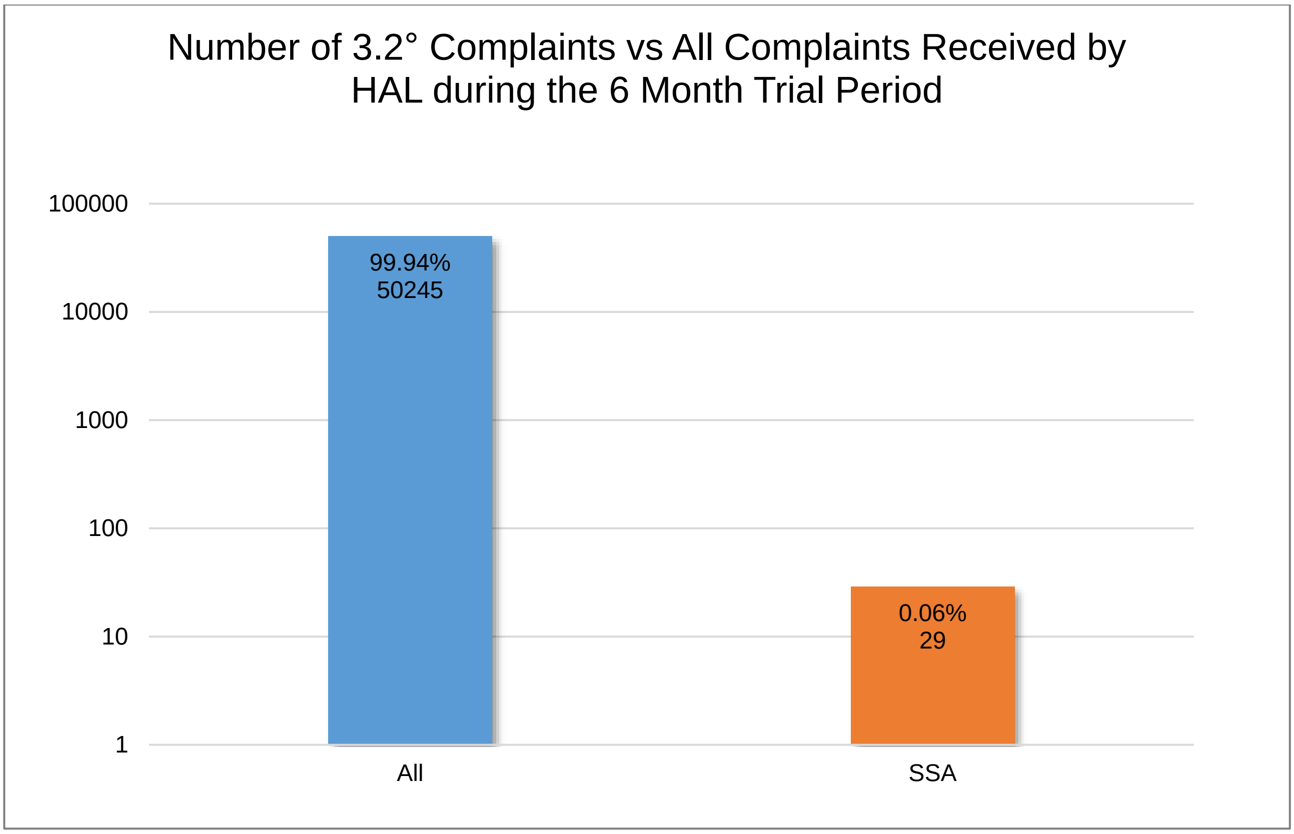


Figure 52: Community feedback during the trial

Unintended Consequences

136. There did not appear to be any unintended consequences as a result of the 3.2° steeper approaches however, a marked increase in the numbers of RNAV approaches does have a direct impact on ATC workload.

Trial conclusions and next steps

137. Heathrow declared that a successful trial would be one which enabled sufficient data gathering with no adverse impact on the daily operation. Specifically, Heathrow set out to measure the impact of a slightly steeper approach on CDA performance, speed adherence on final approach, landing rates, runway occupancy time, numbers of go-arounds, landing gear deployment, aircraft tracks over the ground and to quantify the re-distribution of noise associated with the steeper approach.

138. With this in mind, the trial met all objectives with no adverse impact on the daily operation. It is evident that 3.2° approaches would have minimal, if any, negative effect on Heathrow's operation whilst exposing local residents to less aircraft noise and is unlikely to change the track of Heathrow arrivals over the ground.

Objective	Outcome
CDA	3.2º compliance of 85.7% versus 85.9% overall compliance
TBS	No detrimental impact
RoT	No detrimental impact
Go-around	No detrimental impact (3 out of 351 were on a 3.2º approach)
Speed	Slightly better speed adherence on final approach
Joining point	1.27nm closer to threshold (due to RNAV, not the 3.2º approach angle)
Landing Gear	Med jets: Same but higher / Heavies: Later similar height
Landing Rate	No impact
Height	Low temperature reduced height benefit but as expected
Community	29 out of 50,274 comments, queries and complaints related to trial
Airline	No issues with 3.2º approach angle
ATC	No detrimental impact due to 3.2º approach
Environment	Min: +0.1dBA / Average: -0.5dBA / Max: -1.4dBA (SEL)

Figure 53 – Trial Objective Summary Table

139. The noise benefit was not as much as mathematically available in test conditions, which was most likely due to the aircraft being lower due to the temperature effect of baro-VNAV approaches.

140. The noise analysis and modelling confirms that 3.2° approaches do provide a small noise benefit to local communities. It should be noted that the magnitude of that benefit is small (c.-0.5dBA) and unlikely to be perceptible on the ground[30]. However, 3.2° approaches would actively progress a reduction in Heathrow's noise footprint and could be seen as a necessary incremental step towards even steeper approaches in the future.

141. This trial has not provided evidence as to the effect of 3.2° approaches during poor meteorological conditions. It is unlikely that 3.2° ILS approaches would create any adverse impacts to Heathrow's operation for those aircraft that can perform CAT II/III approaches at an angle of up to 3.2°. Potentially, 3.2° CAT II/III ILS landings could have a small impact on Runway Occupancy Times which is worthy of consideration.

[30] A reduction in the order of 3 dBA is widely considered to be required in order to be 'just perceptible'. See CAP1378 Page 99 and Planning Policy Guidance 24 (Glossary)

Issues to resolve before considering a permanent introduction of 3.2° ILS approach angles at Heathrow

142. Should Heathrow wish to consider a permanent introduction of 3.2° approach angles for their Instrument Landing Systems, the following action would likely be required:

- A survey of current and planned Heathrow airlines to understand the number of aircraft that are not certified to perform CAT III approaches with an angle of 3.2°. It is likely that an approach angle of 3.15° would be a more manageable short term step.

- Consideration of the wider impact of CAT II and III approaches with a 3.15° and/or 3.2° angle such as on Runway Occupancy Time and associated breaking distances particularly on wet runways.

- ATC reported a reduction in the number of requests for 3.2° RNAV approaches when there was a tailwind. Consideration should be given to any impact that a slightly steeper approach would have on the ability for crews to accept a tailwind on arrival.

- Subject to the above, assurances will need to be provided to, and accepted by the UK CAA and Heathrow's airline customers as to why an approach angle greater than 3° at Heathrow is an acceptable deviation from ICAO PANS-OPS guidance for CAT II and III precision approaches.

- An Airspace Change Proposal would then be required providing the necessary justification and evidence to be submitted to the CAA for their consideration. Note future trials may be necessary, prior to this step in order to gather any further necessary evidence.

Appendix A - Trial Preparation

143. Heathrow runs an intensive operation, regularly achieving 98% of their theoretical capacity. Any reduction in the ability to operate at these levels, such as through a reduction in landing rate[31] can quickly lead to significant delays.

144. Altering the ILS glide slope to a 3.2° approach angle is not a quick process and involves engineering support followed by aircraft flight calibration. In the event of any unforeseen issue materialising, reversion to a 3° glide slope is just as time consuming. Without the evidence to assure Heathrow that re-calibrating their ILS glide paths to 3.2° would have no undesirable consequences, for example by limiting the ability for CAT III approaches during poor visibility, doing so on even one runway was not an option.

145. The only efficient option was for Heathrow to amend their existing 'RNAV' approaches to a 3.2° approach angle leaving the ILS unaffected as the primary landing aid.

RNAV Approaches

146. RNAV stands for aRea NAVigation which is one specification of the Performance-based Navigation (PBN) concept[32]. Heathrow implemented 3° RNAV approaches in 2008 in order to add resilience to the operation as it provides another commonly used approach procedure which could be used in the event of an ILS failure or unavailability.

147. As opposed to the physical infrastructure required on the airfield for the ILS', Heathrow's RNAV approaches use Satellite technology to provide the navigational accuracy required to enable aircraft to be guided to the runway for landing. Once established on Final Approach, there is no difference to the track over the ground, laterally or vertically, between Heathrow's ILS approaches and 3.0° RNAV approaches.

148. RNAV approaches require certain technology to be available on aircraft compared to that required for ILS landings. RNAV approaches are also not as precise as ILS approaches which means in very poor visibility, RNAV approaches become redundant and ILS (CAT II/III) approaches are required in order to continue to land safely.

149. However, RNAV approaches do offer some benefit over ILS approaches – that is they do not rely on the physical ground infrastructure of ILS and are therefore not susceptible to interference of the signal by obstacles on the airfield.

150. Heathrow already have RNAV Approaches with a 3° approach angle so they were re-designed in order to create a 3.2° approach angle for the duration of the trial. The existing 3° RNAV approaches were removed from service for the duration of the trial therefore, any aircraft performing an RNAV arrival was doing so on the published 3.2° approach angle.

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[31] The number of aircraft landing in a set period, usually measured per hour.
[32] Eurocontrol Introducing PBN.pdf

151. With RNAV arrivals, aircraft are vectored from the stacks in exactly the same manner as ILS arrivals; downwind and onto base-leg before being put on their own navigation to the Initial Fix (IF). The IF is at a set distance from touchdown and therefore arrivals following the RNAV approach always join on track to the IF as opposed to an ILS arrival, which can be vectored more freely onto the final approach to establish on the localiser. The IFs for Heathrow's RNAV 3.2° approaches are at 10nm from touchdown on all runways. On average, at Heathrow, ILS arrivals are vectored onto final approach at between 11 and 16nm from touchdown.

Effect of Air Temperature on Baro-VNAV RNAV Approaches

152. With regards this trial, one important difference between RNAV approaches and ILS approaches is the effect that air temperature has on the RNAV approach slope angle.

153. With ILS, the glide-slope is a physical 'beam' that the aircraft is following, both laterally and vertically and that 'beam' is unaffected by air temperature. It is constant.

154. With RNAV Approaches, the lateral path of the aircraft is based on a different navigation system (PBN, not conventional) and is also fixed however, the vertical path is based on 'barometric altitude'. Air temperature has a small effect on the altitude that an aircraft's altimeter[33] says the aircraft is at compared to the height it *actually* is at. An RNAV Approach's descent angle is based on the angle at the International Standard Atmosphere (ISA) temperature at mean sea level which is 15°C. When the temperature is not exactly 15°C, the barometric approach angle starts to alter slightly. The colder the temperature, the shallower the approach angle. The warmer it gets, the steeper the approach angle.

Runway configuration

155. Heathrow have 4 runway ends available for landing; 27L, 27R, 09L and 09R. The direction planes land at Heathrow depends on the direction of the wind. Aircraft preference is to take off and land into the wind for safety reasons.

156. In the UK, the wind usually blows from the west. As aircraft preference is to land into the wind, the majority of aircraft therefore arrive from the east (over London) and take off towards the west (over Berkshire/Surrey). This is known as westerly operations. Westerly operations occur for about 70% of the year.

157. When the wind blows from the east, the reverse happens. Aircraft arrive from the west (over Berkshire) and depart towards London. This is called easterly operations and Heathrow are 'on easterlies' for about 30% of the year[34].

[33] An altimeter or an is an instrument used to measure the altitude of the aircraft above a fixed level
[34] The actual percentage of westerly and easterly operations varies from week to week and month to month according actual to wind direction

158. In order to share the burden of noise produced by arriving aircraft, Heathrow use a mechanism known as runway alternation to give local communities periods of relief from aircraft noise when they are on westerly operations. For part of the day Heathrow use 27L for landings and halfway through the day they switch over to land on 27R, or vice-versa. Therefore, on average over a year, approximately 35% of arrivals land on 27L and 35% land on 27R.

159. On easterly operations, runway alternation as above was not historically permitted because of an agreement between Heathrow and the local residents of Cranford. The Cranford Agreement was established in the 1950s, although it was abolished in 2010. It prevented planes from taking off over the village of Cranford, which is at the eastern end of the northern runway. The Cranford Agreement only applied when Heathrow was on easterly operations but the result is that, when on 'easterlies' aircraft tend to only depart Heathrow from 09R which meant arrivals must land on 09L.

160. However, because Heathrow's taxiway infrastructure has been developed in the context of the Cranford Agreement, alterations to it are necessary before the northern runway can be used for departures on easterly operations. This includes building new access taxiways which require planning approval which has not yet been granted. So whilst the Cranford Agreement no longer exists, departures from 09L are still limited. For this reason, the number of arrivals to 09R is still much lower than compared to 09L.

Noise Monitor locations

161. In order to capture data of the impact of aircraft noise distribution, Heathrow deployed three additional noise monitors, or Remote Monitoring Terminals (RMTs), under the approach to 27L. This runway was chosen for the positioning of the RMTs (RMT129 at Mogden Sewage Works, 130 at Mid Surrey Golf Course and 131 at Roehampton Golf Club. See Figure A1) as it was anticipated that the majority on RNAV arrivals would take place for aircraft arriving to 27L than any of the other 3 runway ends. The locations for the RMTs were determined by an independent acoustics specialist.

Figure A1: RMTs under 27L Final Approach

Benefit of RNAV arrivals onto 27L

162. During periods of high arrival stack delay, Heathrow have the ability to use both the arrival and departure runway in order to land more aircraft.

163. As described in Appendix B, obstacles in the vicinity of the ILS infrastructure on the airfield can interfere with the signal to landing aircraft. This is the case with Runway 27L. Aircraft waiting to enter 27L for departure infringe the protected area of the 27L ILS which can interfere with the ILS signal for aircraft approaching to land on the same runway. For this reason, aircraft landing on 27L are not permitted to use the ILS glidepath for landing when the runway is also being used for departures and so in this circumstance, most aircraft will use the RNAV arrival to 27L. It was therefore assumed that 27L would experience the greatest use of the 3.2° RNAV arrival and was the chosen runway centreline for the placement of the RMTs, this is supported by the findings.

Stakeholder Engagement Prior to the Trial

164. In the 12 months prior to the beginning of the trial, Heathrow formally engaged with multiple stakeholders affected by the trial. Namely:

- CAA
- NATS
- A selection of Heathrow Airlines (British Airways, Air France, American Airlines, Delta Airlines, Swiss Air, United Airlines, Virgin Atlantic and Lufthansa)
- Local communities via the Heathrow Community Noise Forum and Heathrow Airport Consultative Committee (HACC)[35]
- Department for Transport (DfT)
- UK Flight Safety Committee (UKFSC)

Safety assurance

165. In additional to the above stakeholder engagement and the design and validation of the 3.2° approach procedures, a number of activities took place to provide assurance that the trial was safe to be introduced:

- Following evidence supplied to the CAA from Frankfurt Airport's 3.2° approach trial and also NATS' Research and Development department, CAA accepted that there would be no change to the ICAO Wake Vortex[36] separations between consecutive arrivals on final approach during the trial.

[35] Heathrow Community Noise Forum
[36] This is the turbulence that forms behind an aircraft as it passes through the air, which can be extremely hazardous to the following aircraft on final approach. An adequate minimum distance must be provided to ensure this turbulence has dissipated before the next aircraft reaches that position. The minimum distance varies from 3-8nm depending on the types of aircraft in each pair.

- NATS stated that there would be no impact on the functionality of their Time Based Spacing (TBS) tool[37].

- A successful Hazard Identification workshop was held by Heathrow in January 2015. The experts in the room were from HAL, CAA, NATS (Tower and London Terminal Control), British Airways, Virgin Atlantic and Lufthansa.

- An additional safety assessment was undertaken by NATS to ensure that the trial was acceptably safe to introduce into the operation and there would be no change to the way that ATC would vector the aircraft for a 3.2° RNAV approach compared to the current 3° RNAV approach.

Timeline for trial preparation

166. Formal preparation for the live trial started in August 2014 when Heathrow notified CAA of their intention to stage the trial and design their 3.2° RNAV approaches. Design and validation[38] of the new RNAV approaches took place between September 2014 and February 2015. The 3.2° procedures were submitted to the CAA for promulgation in the UK Aeronautical Information Publication (AIP) in May 2015 in order for the live trial to commence 17th September 2015.

Continuous Descent Approaches (CDAs)

167. When a CDA procedure is flown the aircraft stays higher for longer, descending continuously from as high as possible and avoiding any level segments of flight prior to intercepting the final approach. A continuous descent requires significantly less engine thrust than prolonged level flight.

168. All Heathrow arrivals endeavour to perform CDAs from 6000ft with a current success rate of around 85%. The objective was to measure the impact of the slightly steeper approach on the aircraft's ability to perform a CDA. Aircraft CDA performance was collected from Heathrow's Airport Noise MOnitoring and Management System (ANOMS) for all arrivals.

Speed Adherence on Final Approach

169. In order for Heathrow to achieve consistently high landing rates on one runway, adherence to speed instructions by ATC is critical to allow Heathrow Approach radar controllers to achieve the minimum safe distance between consecutive landing pairs of aircraft.

170. Prior to the trial there was some opinion that the extra energy the aircraft would have owing to their slightly steeper descent path may mean that the ability to adhere to ATC speed instruction on final approach could be harder. Any degradation in speed adherence

[37] Time Based Spacing (TBS) explanation
[38] Demonstrating that the procedures are safe and fit for purpose for the aircraft types that will use them

could have a direct impact on the spacing achieved between successive arrivals and therefore affect the landing rate. The aircraft speed at 4nm and 5nm from touchdown was provided by NATS.

NATS' Time Based Spacing Tool and Landing Rates

171. NATS implemented a State-of-the-art system in March 2015, which allowed ATC to space pairs of consecutive arrivals on final approach according to a Time-Based Separation (TBS), rather than by a distance-based separation. TBS enables Heathrow to land more arrivals when there are strong head winds which, when applying a distance-based separation, dramatically reduces the landing rate.

172. Prior to the start of the trial, NATS confirmed that the steeper approach would have no impact on the functionality of the TBS tool however, landing rates achieved during the trial were also monitored to measure any potential degradation in throughput. Landing rates achieved were taken from NATS' Terminal Control Daily Reports.

Runway Occupancy Time (RoT)

173. For the purposes of this trial, the Runway Occupancy Time (RoT) was assessed only for the arrivals and times compared between 3° and 3.2° arrivals. RoT is defined as the time the aircraft touches down on the runway until the time is has fully vacated.

174. It was possible that owing to the extra energy that the aircraft had whilst flying the slightly steeper approaches, they would take longer to reduce speed and vacate the runway.

175. In the UK, an aircraft cannot be cleared to land whilst another aircraft is still on the runway therefore, a longer RoT could require the minimum spacing between successive arrivals to have to increase in order to create more time for the landing aircraft to receive its landing clearance. This would have a direct impact on the landing rate achieved.

176. RoT data was supplied by NATS.

Numbers of Go-arounds

177. A go-around, also known as a missed approach, is a standard procedure followed by a pilot when the approach to the runway cannot be completed to a full stop landing. It can be initiated by Pilot or ATC for any number of reasons including:

- The runway is not in sight by the point required by the Instrument Approach Procedure
- An obstruction on the runway
- Landing clearance issued too late or is not forthcoming
- The aircraft is unstable (too high, too low or too fast)
- The aircraft is not configured for landing correctly (e.g. Landing gear not down and locked)
- A dangerous meteorological activity (e.g. Excessive cross-winds)

- Any other unsafe condition

178. Whilst a standard and rehearsed occurrence, a go-around is statistically a 'wasted landing' and results in delay for the go-around aircraft, all the aircraft is it re-sequenced ahead of as well as increased fuel burn and CO_2 emissions. Data is continuously collected by ATC on the numbers of, and reasons for go-around occurrences however this report assesses whether there was an increase in go-arounds owing to the 3.2° RNAV Approaches.

179. The number of, and reasons for, go-arounds was supplied via the Heathrow ATC Watch log.

Landing Gear Deployment

180. In order to keep the aircraft in a clean configuration[39], airlines endeavour to lower their undercarriage during the final stages of the approach, subject to compliance with ATC speed control requirements and the safe operation of the aircraft. As well as being obviously essential for landing, landing gear deployment is a technique used by pilots to reduce the aircraft's speed which is affected by the aircraft's rate of descent.

181. Data was supplied by British Airways[40] so as to compare the point at which landing gear was deployed on all their arrivals during the trial in order to understand if the 3.2° approach had an effect on this.

Aircraft height on final approach

182. The steeper approach means that aircraft will be higher at any point over the ground (on final approach) for the 3.2° arrivals compared to the 3° arrivals. Figure A2 below shows the mathematical increase in height expected based on trigonometry alone.

[39] Landing gear and flap/slats are not deployed and therefore the aircraft is producing minimal drag together with its associated minimal noise.
[40] Data automatically captured by the Flight Data Recorder for all British Airways arrivals excluding the B767.

	1nm	2nm	3nm	4nm	5nm	6nm	7nm	8nm
3°	318ft	636ft	955ft	1273ft	1591ft	1909ft	2228ft	2546ft
3.2°	339ft	679ft	1018ft	1358ft	1697ft	2037ft	2377ft	2716ft
Difference	+21	+43	+63	+85	+106	+128	+149	+170

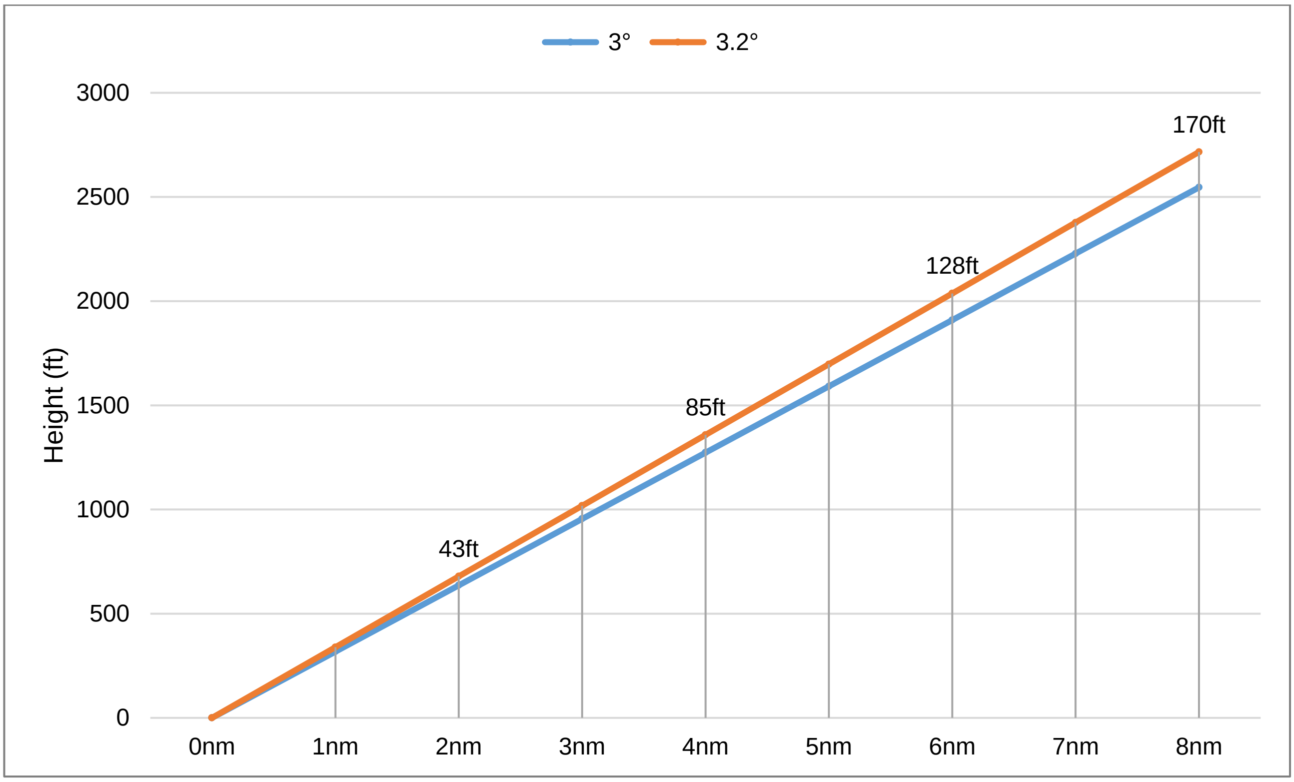

Figure A2: Trigonometric height differential between a 3° and 3.2° glideslope

183. As detailed in the section above, air temperature has an effect on the actual angle of a Baro-VNAV arrival, as is Heathrow's 3.2° RNAV arrival. This combined with other variables effects the amount of height improvement actually experienced.

184. Aircraft height data was collected from ANOMS for all arrivals. ANOMS indicated which arrivals were following the 3.2° RNAV arrival. This information was fed into ANOMS via the Heathrow ATC Electronic Flight Progress Strip (EFPS) system.

185. Importantly, the height information received was height above the ground as determined by the radar, not the height reported by the aircraft. The height data is therefore the 'true' height of the aircraft and not the barometric height reported via the aircraft's altimeter which contains the small variation for temperature.

Final approach joining points and track over the ground

186. Heathrow required to understand if the introduction of 3.2° approaches would create any shift in the average track over the ground of arrivals from the 4 holding stacks until established on Final Approach.

187. Data was collected from ANOMS in order to compare the tracks of 3˚ and 3.2˚ arrivals below 6000ft together with their Final Approach joining points.

Noise Measurements and Modelling

188. In order to quantify the re-distribution of noise associated with the steeper approach, measurements were collected throughout the trial from 3 Remote Monitoring Terminals under the final approach to 27L.

189. The CAA's Environmental Research and Consultancy Department (ERCD) have carried out all independent analysis of trial data from the RMTs. In addition, they modelled the likely impacts on noise distribution should Heathrow implement 3.2˚ approaches for all arrivals, using their ANCON model.

Unintended Consequences

190. A trial with a clear start and end date allows Heathrow to assess if there are any other impacts, positive or negative, which emerge as a result of the introduction of slightly steeper approaches and limits any negative consequences to a defined period as opposed to a permanent introduction.

Overall suitability of the 3.2° RNAV approaches to support a high intensity operation

191. The overarching intention for the trial was for all the objectives above to provide sufficient data to collectively support or discredit a case for the permanent introduction of 3.2° approaches at Heathrow.

Pre-trial expectations

192. Following Frankfurt Airport's operational 3.2° approach trial and also with noise modelling carried out by the Airports Commission into the impact of such approaches, it was anticipated that the operational impacts of a 3.2° approach would be minimal in order to provide, an albeit small, noise benefit to the communities under the approach paths.

193. Based on Frankfurt's experience, the size of the Sound Exposure Level[41] (SEL) noise reduction was expected to be in the order of 1dB (decibel[42]) based on a trigonometric difference between a 3° and 3.2° approach angle.

Independent Analysis

194. All operational data was provided by Heathrow's ANOMS system, NATS Business Information, NATS London Terminal Control Operations, NATS Heathrow ATC and British Airways. The data has been independently analysed by Trax International Ltd with the noise

[22] The single event Sound Exposure Level is the sound level in dBA which, if maintained for a period of one second, would cause the same A-weighted sound energy to be received as is actually received from a given sound event.
[42] Decibel units describing sound level or changes of sound level

measurement analysis and modelling performed independently by CAA's Environmental Research and Consultancy Department.

Appendix B - Instrument Landing System

195. The ILS is a radio navigation system which provides aircraft with horizontal and vertical guidance just before and during landing.

196. The ILS has 2 main components; the localiser and the glideslope. The localiser is the lateral component of the ILS which ensure the aircraft is aligned with the centreline of the landing runway. The localiser aerial which emits the radio signal is situated at the far end of the landing runway. The glideslope provides the vertical guidance allowing the aircraft to descend at a rate which keeps it above obstacles and reach the runway at the correct touch down point. The glideslope aerial is situated to the side of the landing runway (Figure B1).

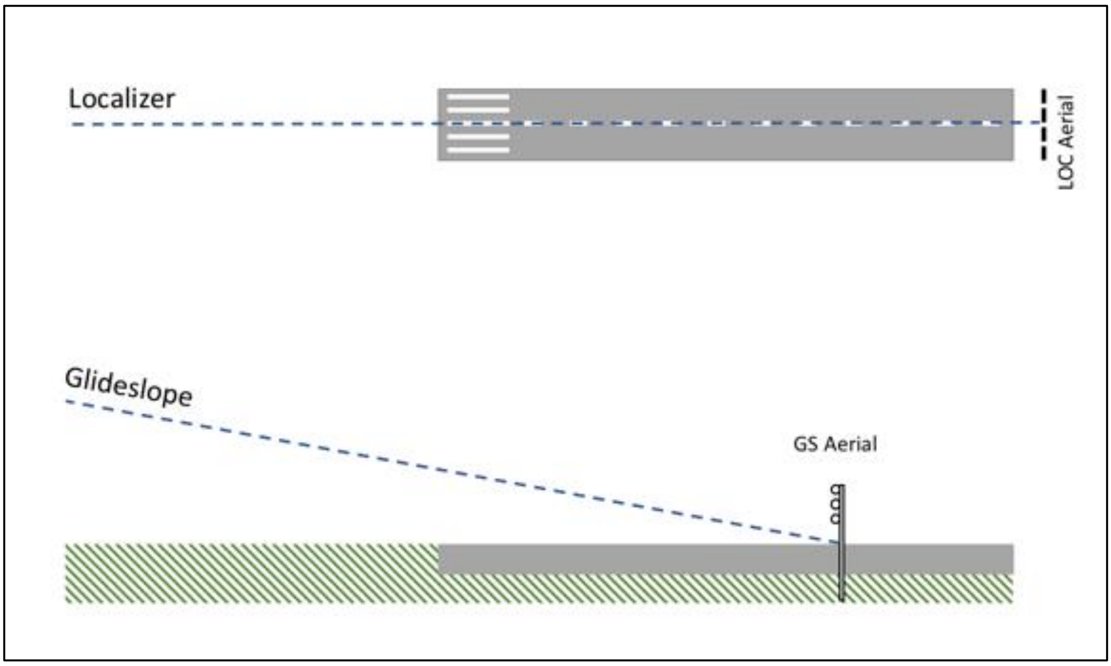

Figure B1: Components of an ILS

197. The ILS emits physical signals (radio waves) which can be distorted by objects, close to the ILS infrastructure. Operations on the airfield in the vicinity of the devices are strictly controlled when the ILS is in use to ensure the signals are not distorted for arriving aircraft, for example, by departing aircraft preparing to use or cross the same runway.

198. There are three categories of ILS equipment each operated with varying amounts of operational integrity. The category of the ILS equipment dictates the tolerances (mainly meteorological) of their use. The category affects various operational limits such as the height by which the pilot can see the runway (known as the 'Decision Height'), the visible distance along the runway (the Runway Visual Range (RVR)), the lighting system available on the runway and also the restrictions in positioning of aircraft on the airfield whilst the ILS is in use. Every ILS system has an associated Category; CAT I, CAT II or CAT III with CAT III being the highest specification which permits aircraft to continue landing even in extremely poor visibility. A CAT III ILS system allows some aircraft to land 'automatically', with pilot supervision as opposed to having tactical control.

199. An approach may not normally be continued unless the runway visual range (RVR) is above the specified minimum. The pilot follows the ILS guidance until the decision height (DH) is reached. At the DH, the approach may only be continued if the specified visual reference is available, otherwise, a go-around must be flown.

- Category I permits a DH of not lower than 200ft and an RVR not less than 550 m
- Category II permits a DH of not lower than 100 ft and an RVR not less than 300 m;
- Category IIIA permits a DH below 100 ft and an RVR not below 200 m;
- Category IIIB permits a DH below 50 ft and an RVR not less than 50 m;
- Category IIIC is a full auto-land with roll out guidance along the runway centreline and no DH or RVR limitations apply.

Appendix C- Full airport noise modelling

200. This section details the results of modelling performed by CAA's ERCD into what the likely effect would be on noise distribution in the vicinity of Heathrow arrivals should all aircraft be arriving via a 3.2° approach angle to each runway.

201. This modelling did not use data from the trial and was an additional, independent activity commissioned by Heathrow.

202. The profile development involved calculating average aircraft heights and speeds at points along the approach paths based on radar track data. Arrival flight profiles were developed with a 3.2° approach angle to represent the slightly steeper approaches. Measurements taken at noise monitors during the trial were not used in the development of these profiles.

203. The most recent published average summer day noise contours for Heathrow are the 2014 LAeq,16h contours, calculated using the validated 2014 standard aircraft profiles. To assess the effect of the steeper approaches, these contours were recalculated using the new 3.2° RNAV arrival profiles, keeping everything else (traffic, routes and departure profiles) the same. The resulting output was then compared to the published noise contours, and any effects of the changes were quantified.

204. The published Heathrow 2014 average summer day scenario will be referred to in this section as *'Heathrow 2014 actual'*, and the new scenario, which incorporates the 3.2° RNAV approaches, will be referred to as '*Heathrow 2014 with 3.2° approach angle'*.

205. The areas, population and households enclosed by the Heathrow 2014 actual contours, and the Heathrow 2014 with 3.2° approach angle contours are given in Figure C1 and Figure C2 respectively. The contours are calculated in 3 dB steps from 54 dB to 72 dB.

Contour Level	Area (km^2)	Population	Households
54 dB	199.6	616,000	249,800
57 dB	106.6	266,700	104,100
60 dB	58.2	120,500	45,800
63 dB	33.7	46,000	17,300
66 dB	19.9	13,400	5,100
69 dB	9.6	3,600	1,400
72 dB	5.1	200	100

Figure C1: Heathrow 2014 actual contour area, population and households (rounded to nearest hundred)

Contour Level	Area (km^2)	Population	Households
54 dB	197.1	594,900	240,600
57 dB	104.8	255,200	99,200
60 dB	57.6	119,400	45,300
63 dB	33.4	43,700	16,400
66 dB	19.7	12,300	4,700
69 dB	9.5	3,500	1,300
72 dB	5.1	200	100

Figure C2: Heathrow 2014 with 3.2° approach angle contour area, population and households (rounded to nearest hundred)

206. Figure C3 shows the numbers of households enclosed by the particular noise bands for both scenarios[43]. This enabled us to see the numbers of households that would be exposed to more or less noise as a result of 3.2° approaches for all Heathrow arrivals.

Households			Heathrow 2014 with 3.2° approach angle							
	Noise Band (dB)		51-54	54-57	57-60	60-63	63-66	66-69	69-72	>72
		Total per band	245,700	143,500	54,000	29,200	11,800	3,500	1,200	100
Heathrow 2014 actual	51-54	243,500	235,500	400	-	-	-	-	-	-
	54-57	147,500	9,700	137,600	100	-	-	-	-	-
	57-60	58,900	-	5,500	53,200	300	-	-	-	-
	60-63	28,700	-	-	700	27,900	100	-	-	-
	63-66	12,200	-	-	-	1,000	11,300	-	-	-
	66-69	4,000	-	-	-	-	500	3,500	-	-
	69-72	1,200	-	-	-	-	-	-	1,200	-
	>72	100	-	-	-	-	-	-	-	100

Figure C3: Number of households per noise contour band for both Heathrow 2014 actual and Heathrow 2014 with 3.2° approach angle (rounded to nearest hundred)

207. Reading this table: The data in columns refer to the steeper approach scheme (Heathrow 2014 with 3.2° approach angle) while the data in rows refer to Heathrow 2014 actual contour. Reading, for instance, noise band 60-63 dB for Heathrow 2014 actual, the total given is 28,700 households. The same row shows that, of the total 28,700 households, 700 households are in a lower noise band (57-60 dB shaded green) in the steeper approach

[43] The number of households presented in Figure 60 have been calculated using a different mathematical algorithm than that used to calculate the accepted definitive population and households presented in Figures 58 and 59. There is a difference of around 1% for the outer contours; this is typical and within the modelling tolerances.

scheme, 27,900 still remain in the same noise band, and 100 households fall in a higher noise band (63-66 dB shaded red). Totals may not sum exactly due to rounding.

208. Figure C4 shows the Heathrow 2014 actual (red) and Heathrow 2014 with 3.2° approach angle (black) noise contours, plotted in 3 dB steps from 54 dB to 72 dB.

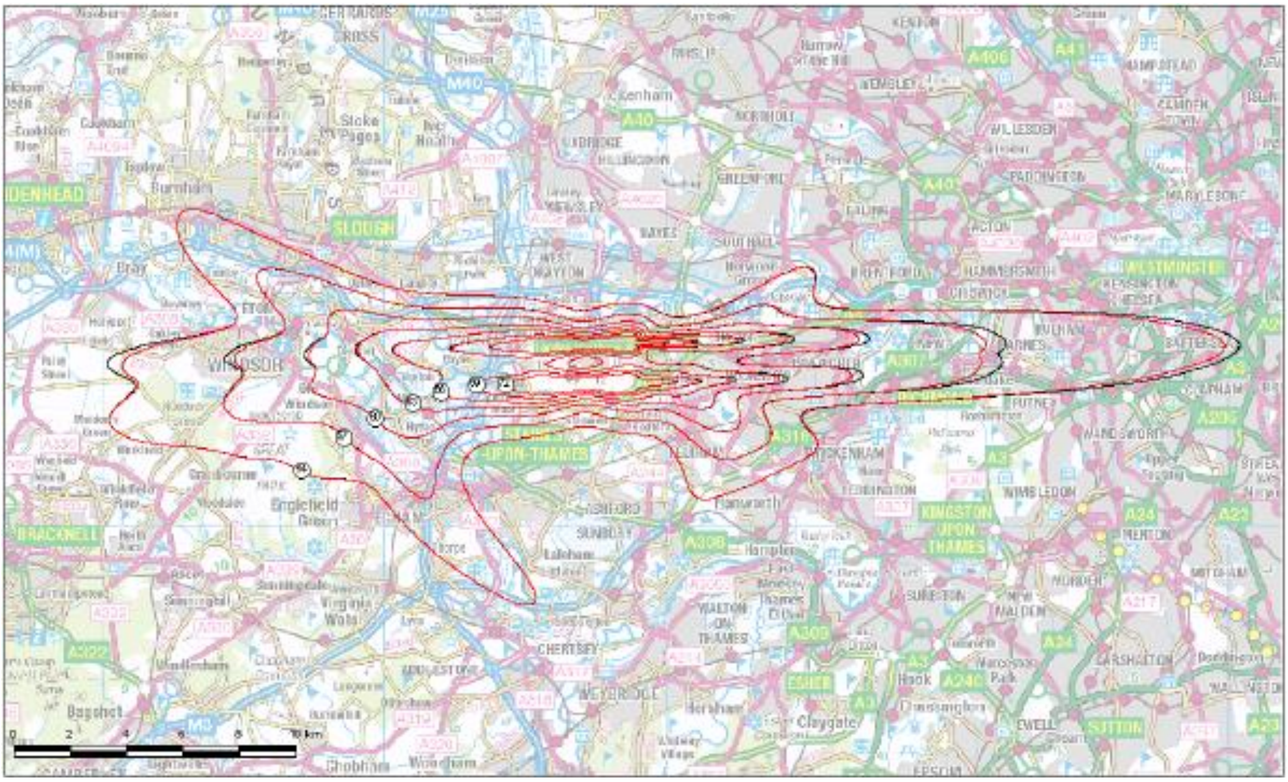

Figure C4: LHR 2014 LAeq,16h (black) and Heathrow 2014 with 3.2 approach angle (red) contours

209. Figure C5 and Figure C6 show the differences (in dB) between the arrivals-only contours for the two scenarios where the arrivals-only noise level is 54 dB or above.

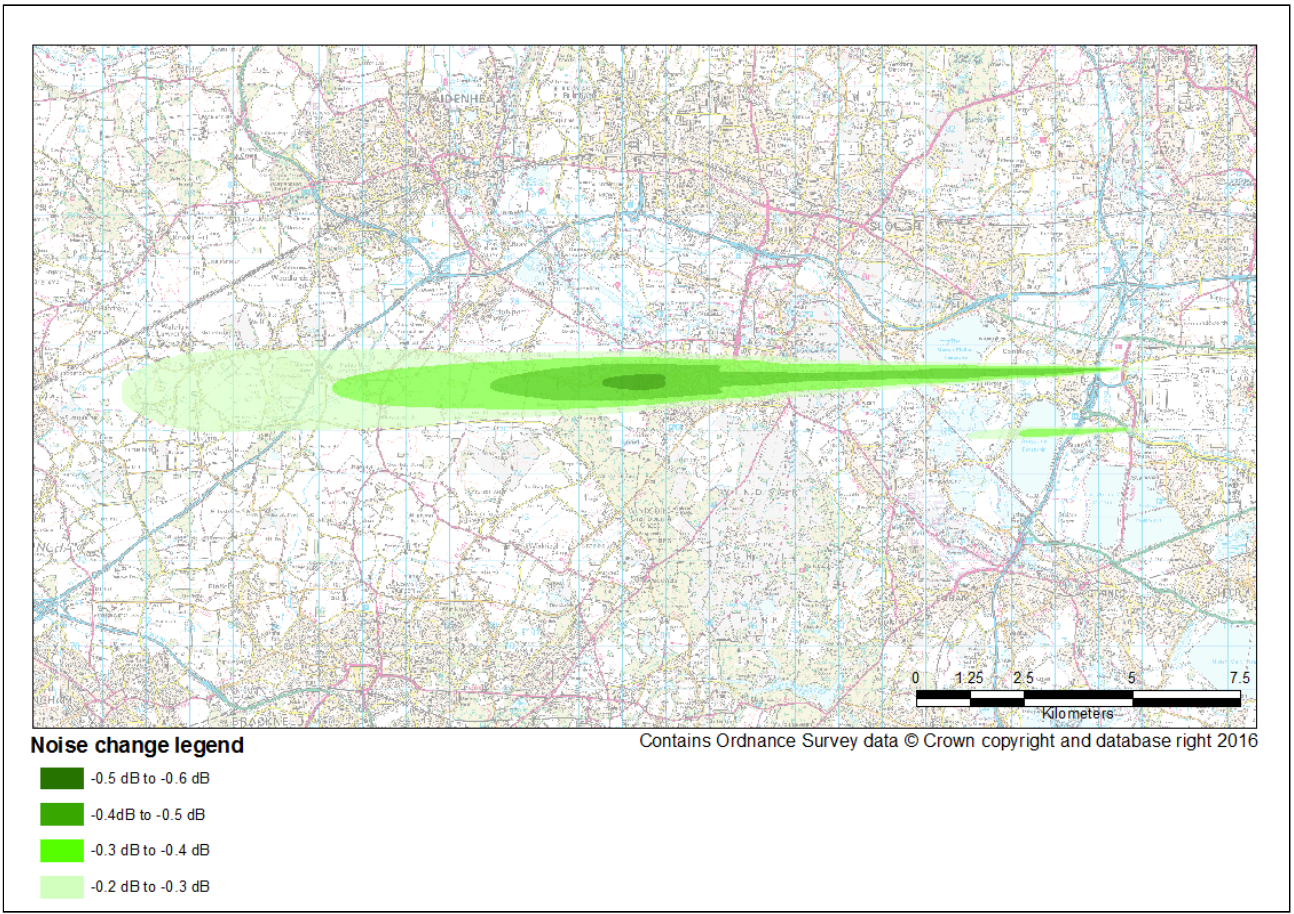

Figure C5: Differences between LHR 2014 Arrivals $L_{Aeq,16h}$ and Heathrow 2014 Arrivals with 3.2° approach angle, when operations are 100% Easterly, within the arrivals-only 54 dB contour

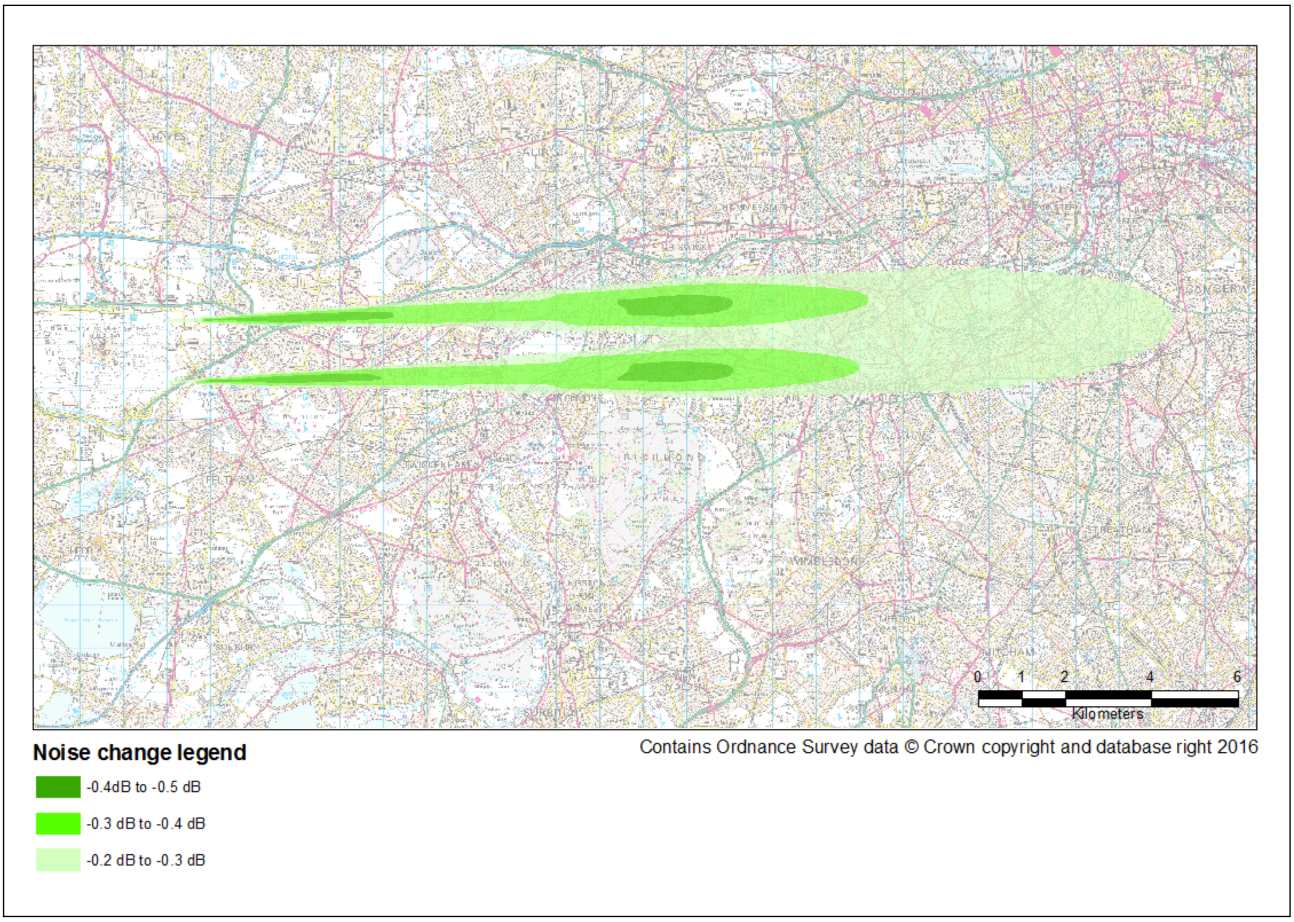

Figure C6: Differences between LHR 2014 Arrivals $L_{Aeq,16h}$ and Heathrow 2014 Arrivals with 3.2° approach angle, when operations are 100% Westerly, within the arrivals-only 54 dB contour

210. The ANCON noise model predicts reductions of 1.3% and 1.7% in the area of the 54 dB and 57 dB LAeq,16h contours[44] respectively for the Heathrow 2014 with 3.2 approach angle scenario compared with the Heathrow 2014 actual scenario (see Figures C3 and C4).

211. Figure C5 shows differences between LHR 2014 Arrivals LAeq, 16h and Heathrow 2014 Arrivals with 3.2° approach angle, when operations are 100% Easterly, within the arrivals-only 54 dB contour; and Figure C6 shows differences between LHR 2014 Arrivals LAeq,16h and Heathrow 2014 Arrivals with 3.2° approach angle, when operations are 100% Westerly, within the arrivals-only 54 dB contour. As can be seen in Figure C5, the maximum difference calculated in the 100% Easterly scenario is a reduction of 0.52 dB that occurs in the western part of Windsor. The maximum calculated difference in the 100% Westerly scenario is 0.45 dB, which occurs in the Barnes/Mortlake areas beneath the approach to 27L, and in Chiswick beneath the approach to 27R (see Figure C6)[45].

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[44] The Government has used 57dBA Leq as the level of daytime noise marking the approximate onset of significant community annoyance. In the consultation document for the South East, the 54dBA Leq contours were also shown as a sensitivity indicator. (White Paper on The Future of Air Transport. Page34. Department for Transport 2003)

[45] The slightly higher reduction on easterlies is a result of the higher number of approaches on 09L compared to westerlies where they are shared between 27L and 27R

212. Despite this modest reduction in noise, the effect of moving the contour lines is to change the number of households exposed to different noise bands. Figure C3 shows that approximately 9,700 households that were in the 54-57 band under the Heathrow 2014 actual scenario, fall within the 51-54 band under the Heathrow 2014 with 3.2° approach angle scenario. Likewise, approximately 5,500 households that were in the 57-60 band, are now in the 54-57 band.

213. Figure C3 also identifies that a 3.2° approach would result in approximately 900 households moving to an immediately higher noise band. This corresponds to less than 0.4% of the population enclosed by the 54 dB LAeq,16h Heathrow 2014 actual noise contour. Similarly, approximately 17,400 households would move to an immediately lower noise band, corresponding to just less than 7% of the population enclosed by the 54 dB LAeq,16h noise contour.

214. Figure C7 includes those areas exposed to a very small increase of up to 0.1 dB as identified in Figure C3.

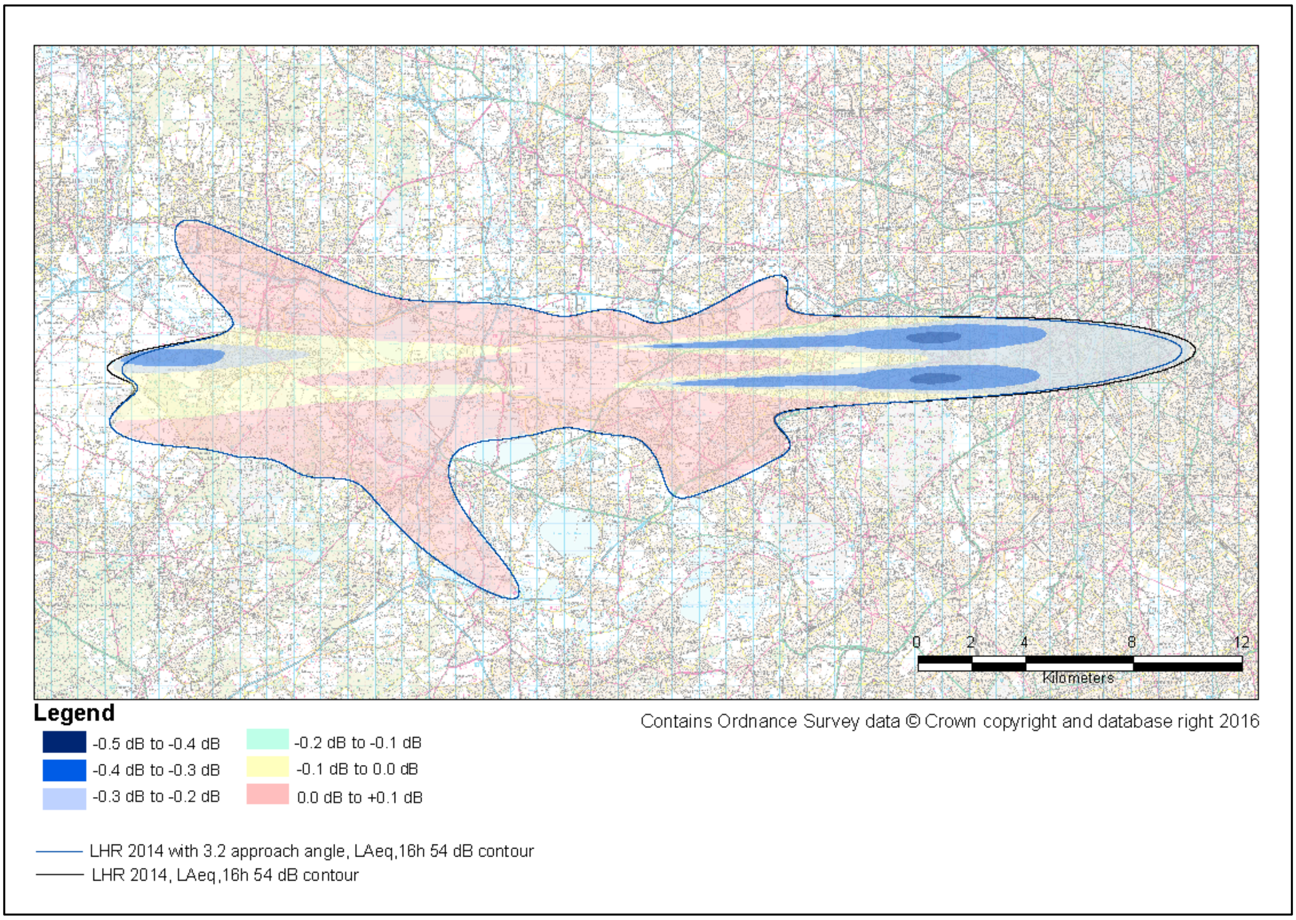


Figure C7: Modelled differences between LHR 2014 LAeq,16h and Heathrow 2014 with 3.2 approach angle, within the 54 dB contour

215. Note that the small level of change identified in the predicted results is less than the modelling error that is typical of an airport noise model. Therefore, these results should be treated as indicative.

216. The small reductions may help in lowering the numbers of people/households in some contour bands; the net effect being to expose local residents to less aircraft noise. The model calculated a maximum reduction of 0.52 dB when considering arrivals only.

Appendix D – 3° ILS/DME Charts

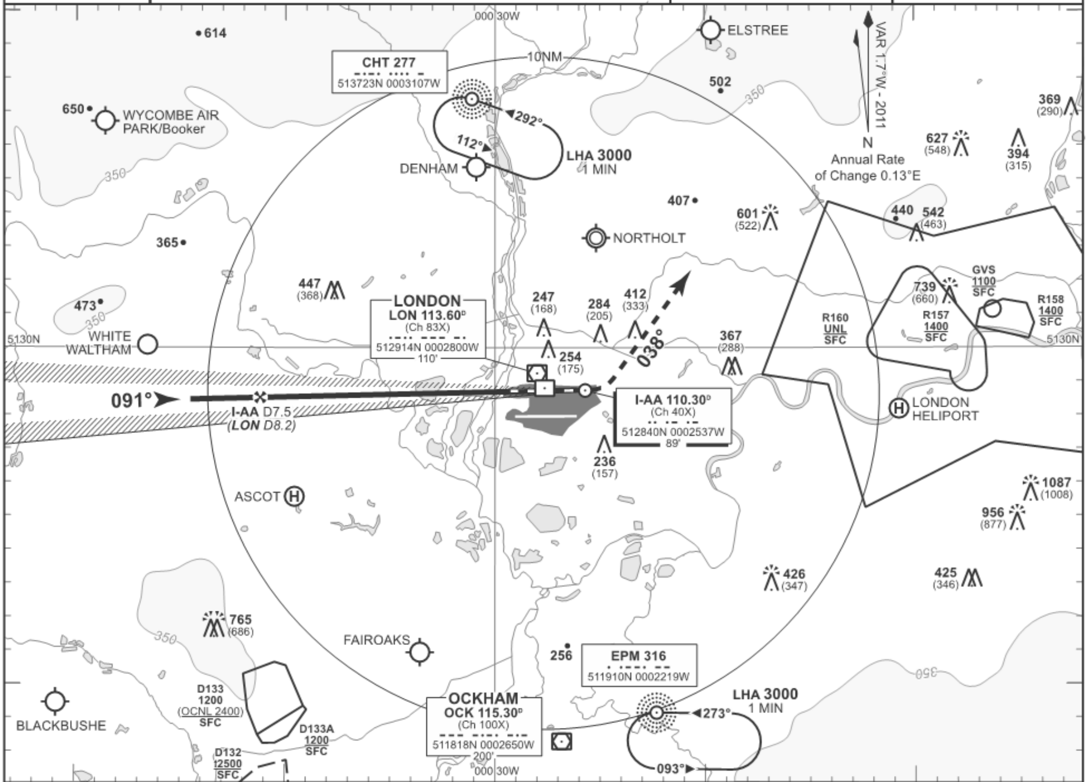
UK AIP **(10 Mar 11) AD 2-EGLL-8-1**

INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW
ILS/DME I-AA
RWY 09L
(ACFT CAT A,B,C,D)

MSA 25NM LON VOR				
2₂ 2₁ 2₁ 2₁ 180° 270° 090° 360°	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	79
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1008) (ABOVE THR)	
	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	

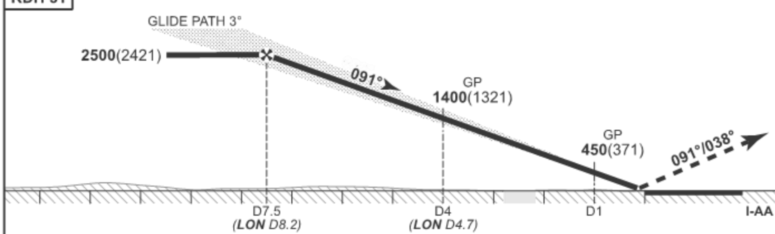
TRANSITION ALTITUDE **6000**



RECOMMENDED PROFILE GLIDE PATH 3.0°, 318FT/NM

DME I-AA	7	6	5	4	3	2
ALT(HGT)	**2360**(2281)	**2040**(1961)	**1720**(1641)	**1400**(1321)	**1080**(1001)	**770**(691)

RDH 51



Climb to **3000** - straight ahead until passing **1580** or **I-AA DME** zero inbound whichever is later, then left onto track 038°. Continue as directed.
RCF: On passing **LON DME** 10 proceed to **NDB CHT** at **3000**.

Aircraft Category		A	B	C	D
OCA (OCH)	CAT I	**221**(142)	**232**(153)	**243**(164)	**257**(178)
	CAT II	**134**(55)	**145**(66)	**158**(79)	**174**(95)
VM(C)OCA (OCH AAL)	Total Area	**750**(667)	**750**(667)	**850**(767)	**850**(767)

Rate of descent						
	G/S KT	160	140	120	100	80
	FT/MIN	850	740	640	530	420

AIRCRAFT UNABLE TO RECEIVE DME I-AA
Advise ATC. Equivalent radar ranges will be provided when established on the localiser approaching the nominal FAP and 4NM points.

NOTES 1 Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
2 Ranging information is provided by ILS-dedicated DME facilities. DME values derived to the nearest 0.1NM from VOR DME LON are also provided for the FAP and 4NM check altitude/height.

CHANGE: MAG VAR. BUR NDB REMOVED.

AERO INFO DATE 29 OCT 10

Civil Aviation Authority AMDT 3/11

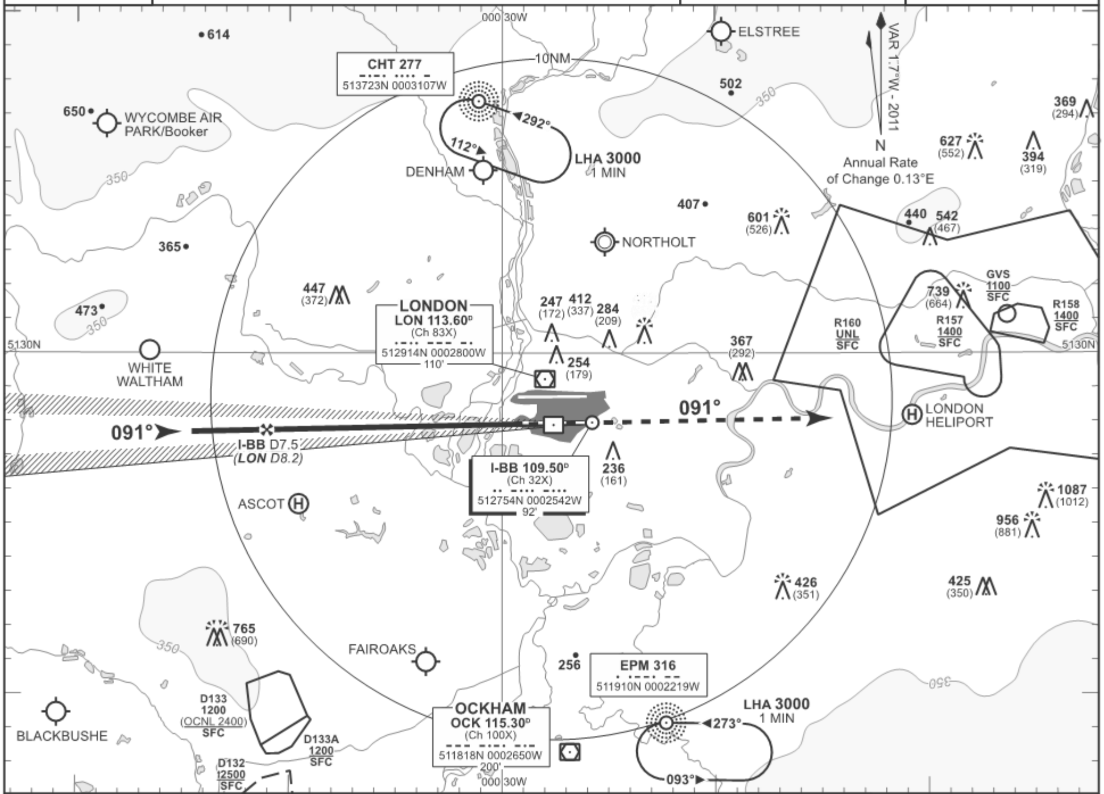
INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW ILS/DME I-BB RWY 09R

(ACFT CAT A,B,C,D)

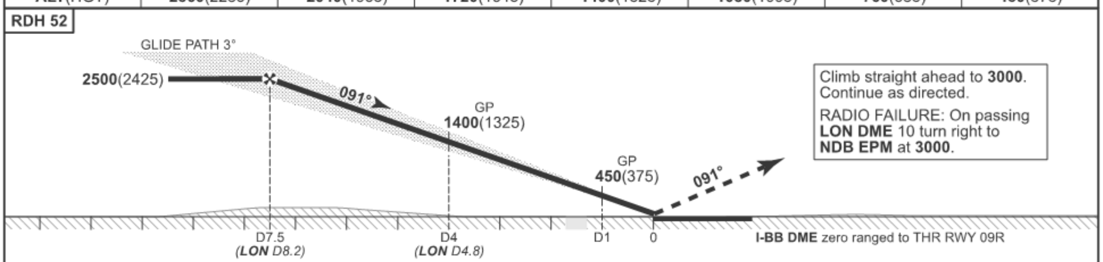
MSA 25NM LON VOR			
APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	75
RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1012) (ABOVE THR)	
ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	

TRANSITION ALTITUDE 6000



RECOMMENDED PROFILE GLIDE PATH 3.0°, 318FT/NM

DME I-BB	7	6	5	4	3	2	1
ALT(HGT)	2360(2285)	2040(1965)	1720(1645)	1400(1325)	1080(1005)	760(685)	450(375)



Aircraft Category		A	B	C	D
OCA (OCH)	CAT I	215(140)	225(150)	237(162)	251(176)
	CAT II	123(48)	134(59)	146(71)	160(85)
VM(C)OCA (OCH AAL)	Total Area	750(667)	750(667)	850(767)	850(767)

Rate of descent						
	G/S KT	160	140	120	100	80
	FT/MIN	850	740	640	530	420

AIRCRAFT UNABLE TO RECEIVE DME I-BB
Advise ATC. Equivalent radar ranges will be provided when established on the localiser approaching the nominal FAP and 4NM points.

NOTES
1 Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
2 Ranging information is provided by ILS-dedicated DME facilities. DME values derived to the nearest 0.1NM from VOR DME LON are also provided for the FAP and 4NM check altitude/heights.

CHANGE: MAG VAR. BUR NDB REMOVED.

AERO INFO DATE 1 NOV 10

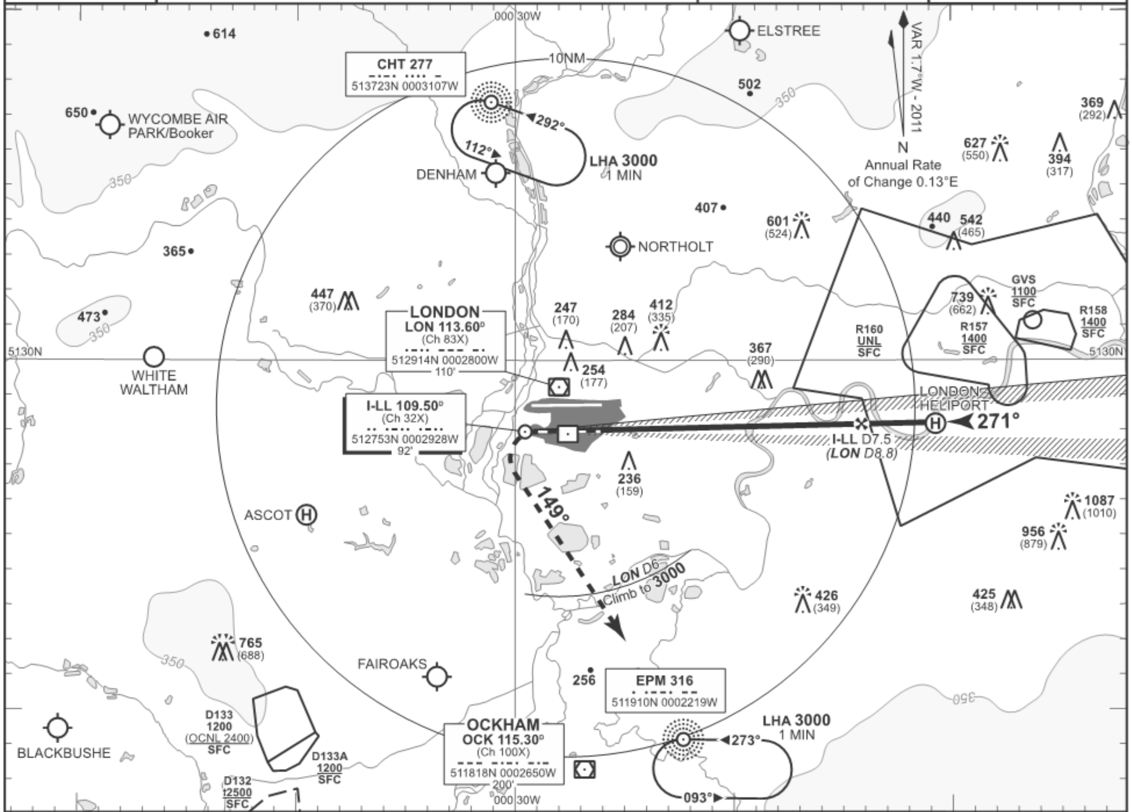
Civil Aviation Authority AMDT 3/11

INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW ILS/DME I-LL RWY 27L

(ACFT CAT A,B,C,D)

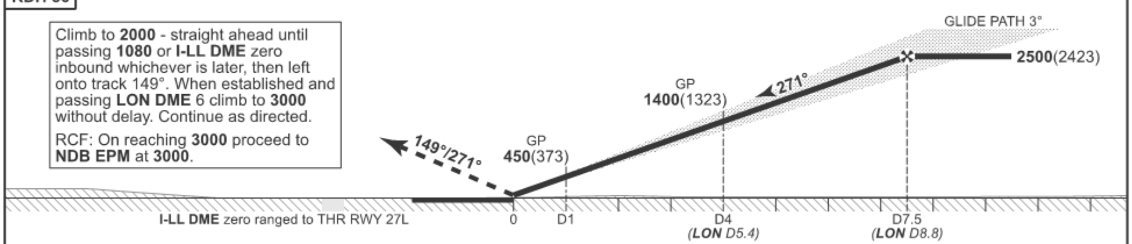
MSA 25NM LON VOR	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	77
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1010) (ABOVE THR)	
	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION		
			BEARINGS ARE MAGNETIC	TRANSITION ALTITUDE 6000



RECOMMENDED PROFILE GLIDE PATH 3°, 318FT/NM

DME I-LL	7	6	5	4	3	2	1
ALT(HGT)	**2360**(2283)	**2040**(1963)	**1730**(1653)	**1410**(1333)	**1090**(1013)	**770**(693)	**450**(373)

RDH 56



Aircraft Category		A	B	C	D
OCA (OCH)	CAT I	229(152)	238(161)	248(171)	260(183)
	CAT II	137(60)	146(69)	159(82)	172(95)
VM(C)OCA (OCH AAL)	Total Area	750(667)	750(667)	850(767)	850(767)

Rate of descent						
	G/S KT	160	140	120	100	80
	FT/MIN	850	740	640	530	420

AIRCRAFT UNABLE TO RECEIVE DME I-LL
Advise ATC. Equivalent radar ranges will be provided when established on the localiser approaching the nominal FAP and 4NM points.

NOTES 1 Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
2 Ranging information is provided by ILS-dedicated DME facilities. DME values derived to the nearest 0.1NM from VOR DME LON are also provided for the FAP and 4NM check altitude/heights.

CHANGE: MAG VAR. BUR NDB REMOVED.

AERO INFO DATE 29 OCT 10

Civil Aviation Authority AMDT 3/11

UK AIP (26 Jul 12) AD 2-EGLL-8-13

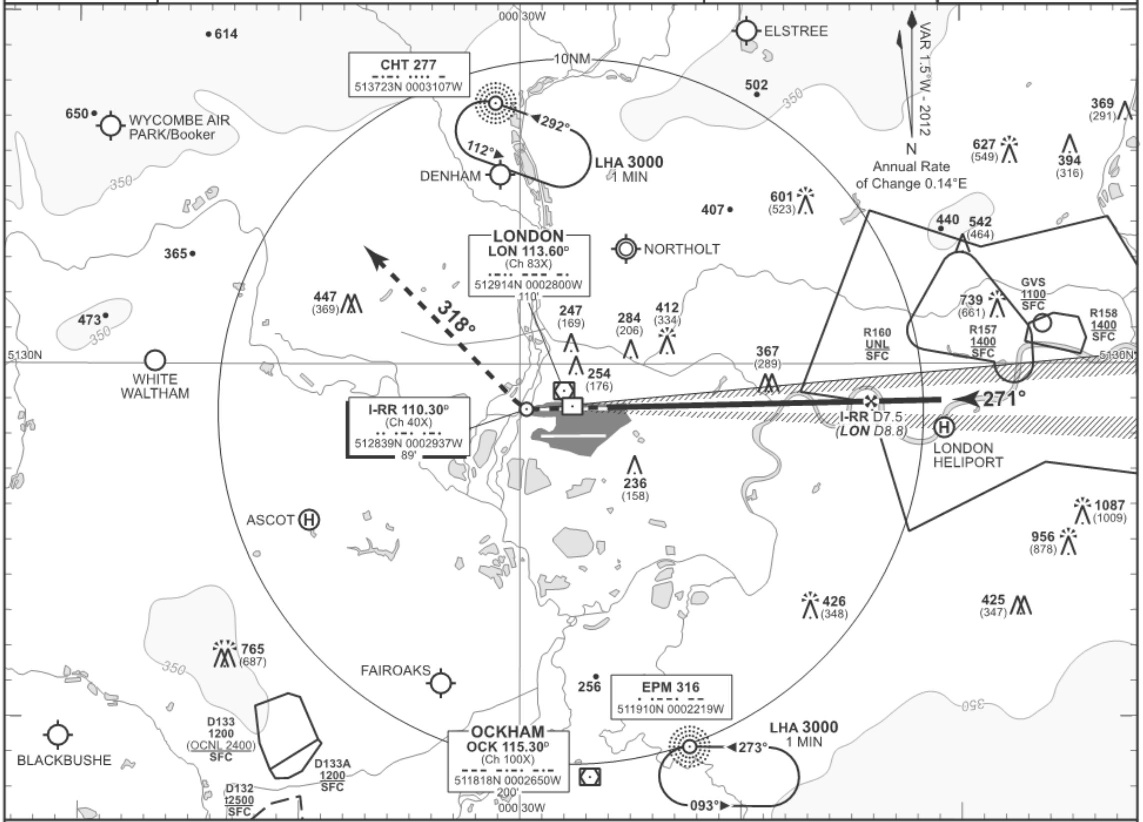
INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW ILS/DME I-RR RWY 27R

(ACFT CAT A,B,C,D)

MSA 25NM LON VOR				
	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	78
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1009) (ABOVE THR)	
	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION		
			BEARINGS ARE MAGNETIC	

TRANSITION ALTITUDE 6000

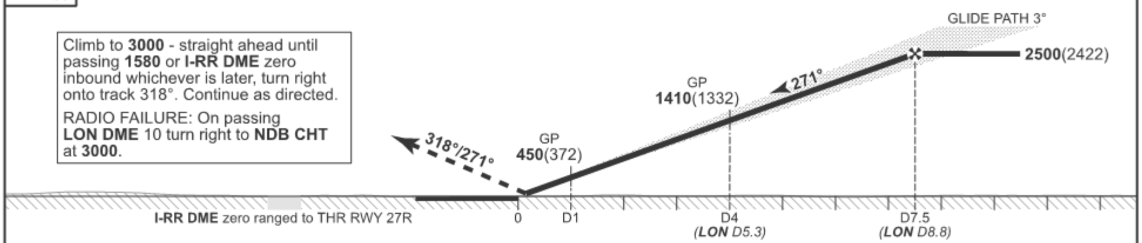


RECOMMENDED PROFILE GLIDE PATH 3°, 318FT/NM							
DME I-RR	7	6	5	4	3	2	1
ALT(HGT)	**2370**(2292)	**2050**(1972)	**1730**(1652)	**1410**(1332)	**1090**(1012)	**770**(692)	**450**(372)

RDH 58

Climb to **3000** - straight ahead until passing **1580** or **I-RR DME** zero inbound whichever is later, turn right onto track 318°. Continue as directed.

RADIO FAILURE: On passing **LON DME** 10 turn right to **NDB CHT** at **3000**.



Aircraft Category		A	B	C	D
OCA (OCH)	CAT I	**224**(146)	**234**(156)	**247**(169)	**262**(184)
	CAT II	**131**(53)	**141**(63)	**154**(76)	**168**(90)
VM(C)OCA (OCH AAL)	Total Area	**750**(667)	**750**(667)	**850**(767)	**850**(767)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	850	740	640	530	420

AIRCRAFT UNABLE TO RECEIVE DME I-RR
Advise ATC. Equivalent radar ranges will be provided when established on the localiser approaching the nominal FAP and 4NM points.

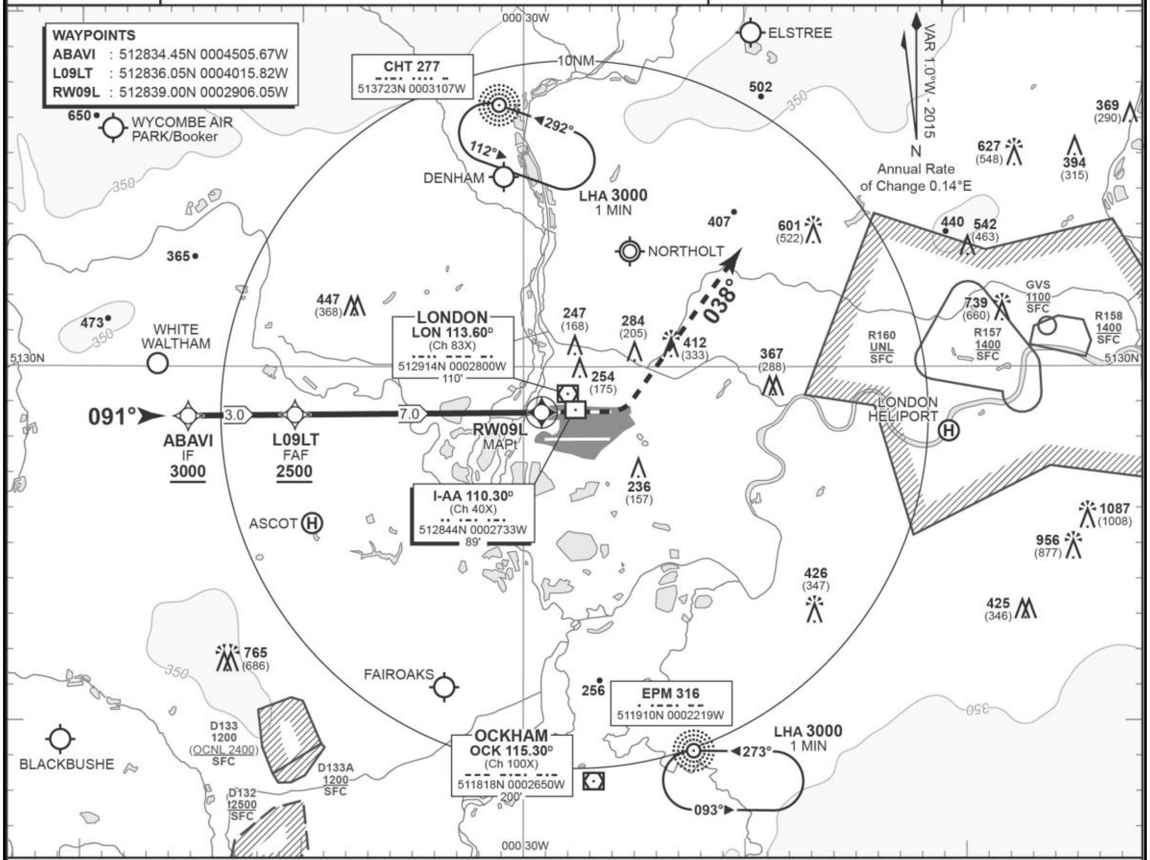
NOTES
1. Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
2. Ranging information is provided by ILS-dedicated DME facilities. DME values derived to the nearest 0.1NM from VOR DME LON are also provided for the FAP and 4NM check altitudes/heights.

CHANGE (8/12): MAG VAR. PAGE NUMBER. ANNUAL RATE OF CHANGE.

AERO INFO DATE 23 APR 12

Civil Aviation Authority AMDT AIRAC 8/12

Appendix E– 3.2° RNAV Charts



INSTRUMENT APPROACH CHART - ICAO | **LONDON/HEATHROW**

RNAV (GNSS) Y RWY 09L (ACFT CAT A,B,C,D)

23 / MSA 25NM ARP	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	79
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1008) (ABOVE THR)	MIN TEMP -10°C
	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	TRANSITION ALTITUDE 6000

RECOMMENDED PROFILE VERTICAL PATH ANGLE 3.2° (5.6%), 340FT/NM

RANGE (NM)	6	5	4	3	2
ALT(HGT)	**2170**(2091)	**1830**(1751)	**1490**(1411)	**1150**(1071)	**810**(731)

MAPt (LNAV): RW09L
Climb to **3000** - straight ahead until passing **1580** or **I-AA DME** zero inbound whichever is later, then turn left onto track 038°. After passing **1580** revert to conventional navigation. Continue as directed.
RCF: On passing **LON DME** 10 proceed to **NDB CHT** at **3000**.

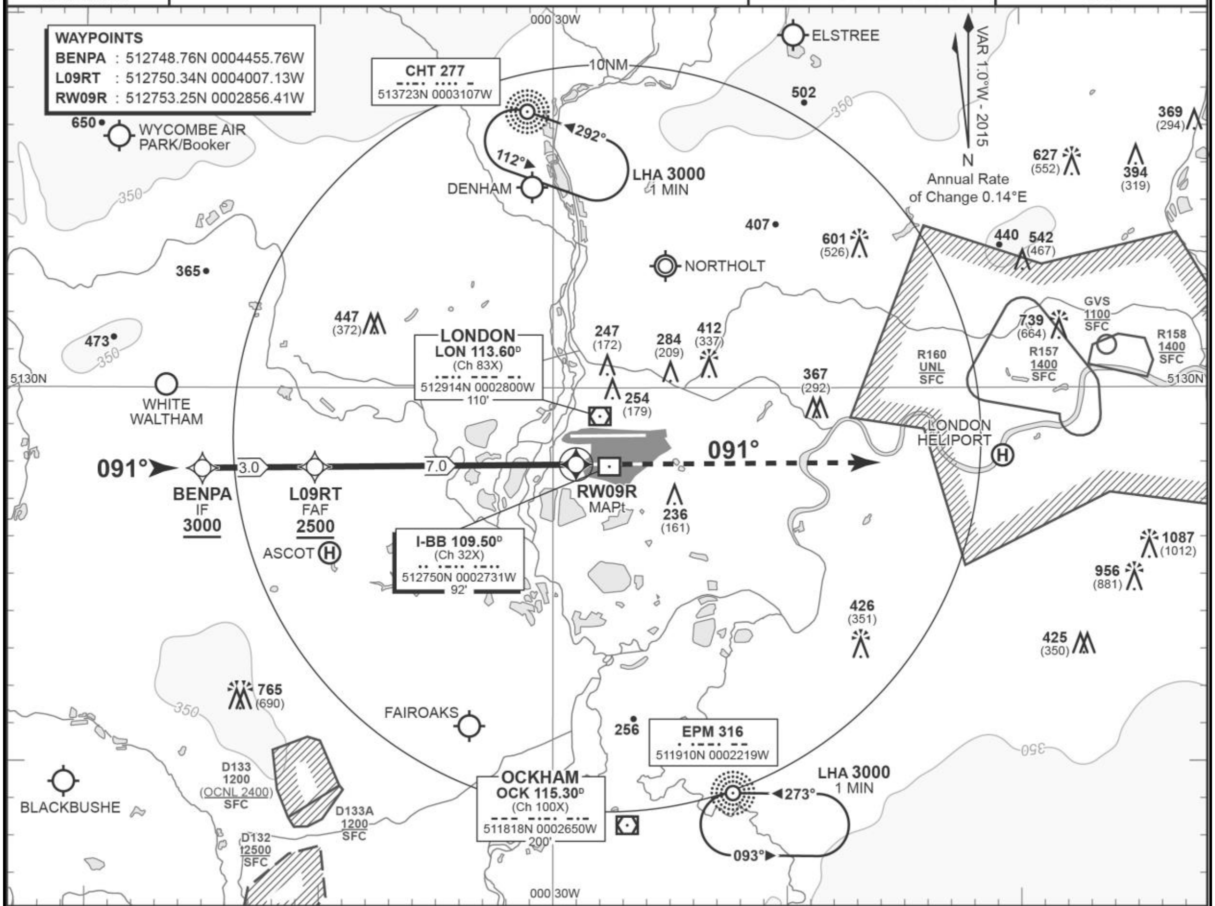
Aircraft Category		A	B	C	D
OCA (OCH)	LNAV/VNAV	**450**(371)	**460**(381)	**470**(391)	**540**(461)
	LNAV	**620**(541)	**620**(541)	**620**(541)	**620**(541)
VM(C)OCA (OCH AAL)	Total Area	**670**(587)	**720**(637)	**820**(737)	**830**(747)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	910	790	680	570	450

NOTES
1. Pilots should 'Request RNAV Y Approach' on first contact with Heathrow Director.
2. Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
3. Missed Approach Procedure and RCF use conventional navigation aids and are not available without DME I-AA, DME LON and NDB CHT.
4. PAPI angle is 3.0°.

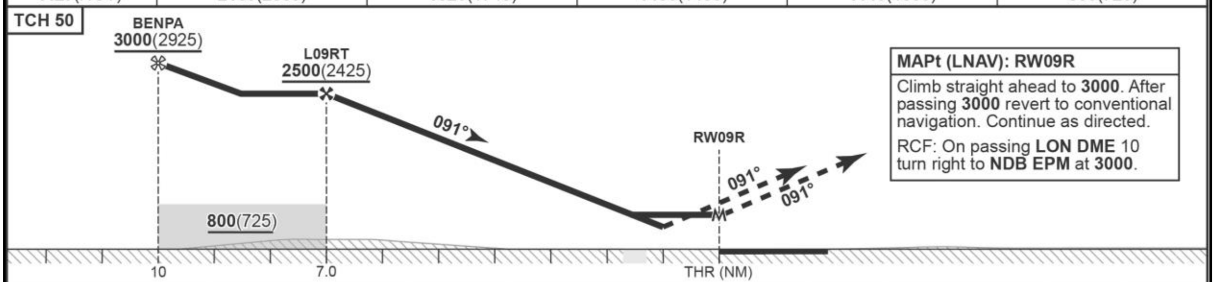
2015/62 LONDON HEATHROW RNAV (GNSS) Y RWY 09L 29 MAY 15

INSTRUMENT APPROACH CHART - ICAO			LONDON/HEATHROW
MSA 25NM ARP: 23	APP 119.725, 120.400, 127.525, 134.975 / HEATHROW DIRECTOR	AD ELEVATION 83	RNAV (GNSS) Y RWY 09R (ACFT CAT A,B,C,D)
	TWR 118.500, 118.700, 124.475 / HEATHROW TOWER	THR ELEVATION 75	
	RAD 125.625, 127.525 / HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1012) (ABOVE THR)	MIN TEMP -10°C
	ATIS 128.075, 113.750, 115.100 / HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	TRANSITION ALTITUDE 6000



RECOMMENDED PROFILE VERTICAL PATH ANGLE 3.2° (5.6%), 340FT/NM

RANGE (NM)	6	5	4	3	2
ALT(HGT)	**2160**(2085)	**1820**(1745)	**1480**(1405)	**1140**(1065)	**800**(725)



MAPt (LNAV): RW09R

Climb straight ahead to **3000**. After passing **3000** revert to conventional navigation. Continue as directed.

RCF: On passing **LON DME** 10 turn right to **NDB EPM** at **3000**.

Aircraft Category		A	B	C	D
OCA (OCH)	LNAV/VNAV	**400**(325)	**410**(335)	**430**(355)	**540**(465)
	LNAV	**620**(545)	**620**(545)	**620**(545)	**620**(545)
VM(C)OCA (OCH AAL)	Total Area	**670**(587)	**720**(637)	**820**(737)	**830**(747)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	910	790	680	570	450

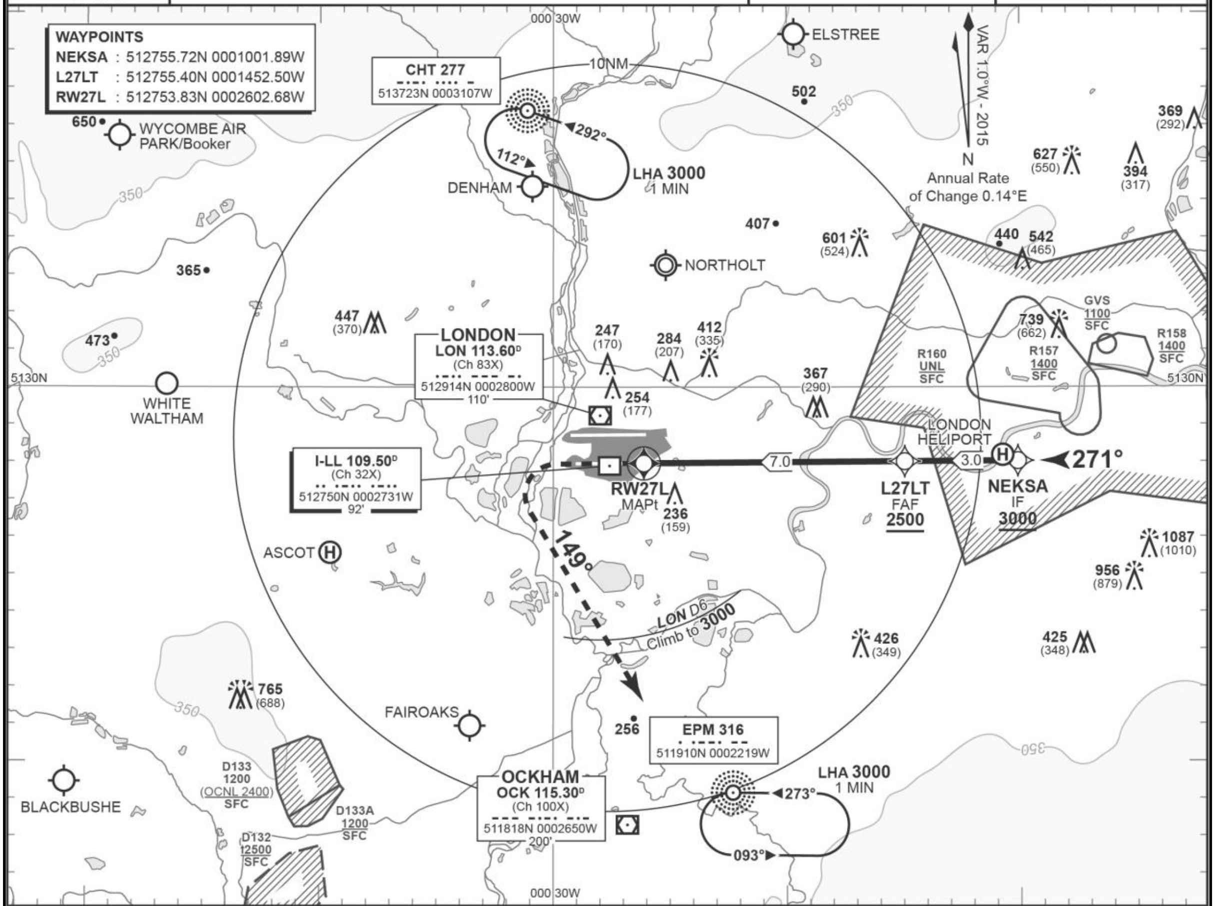
NOTES
1. Pilots should 'Request RNAV Y Approach' on first contact with Heathrow Director.
2. Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
3. Missed Approach Procedure and RCF use conventional navigation aids and are not available without DME LON and NDB EPM.
4. PAPI angle is 3.0°.

2015/62 LONDON HEATHROW RNAV (GNSS) Y RWY 09R 29 MAY 15

INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW RNAV (GNSS) Y RWY 27L (ACFT CAT A,B,C,D)

23	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	77
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1010) (ABOVE THR)	MIN TEMP -10°C
MSA 25NM ARP	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	TRANSITION ALTITUDE 6000



RECOMMENDED PROFILE VERTICAL PATH ANGLE 3.2° (5.6%), 340FT/NM

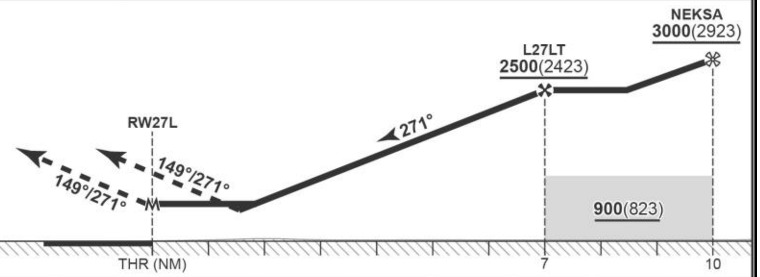
RANGE (NM)	6	5	4	3	2
ALT(HGT)	**2170**(2093)	**1830**(1753)	**1490**(1413)	**1150**(1073)	**810**(733)

TCH 50

MAPt (LNAV): RW27L

Climb to **2000** - straight ahead until passing **1080** or **I-LL DME** zero inbound whichever is later, then turn left onto track 149°. After passing **1080** revert to conventional navigation. When established and passing **LON DME** 6 climb to **3000** without delay. Continue as directed.

RCF: On reaching **3000** proceed to **NDB EPM** at **3000**.



Aircraft Category		A	B	C	D
OCA (OCH)	LNAV/VNAV	**380**(303)	**390**(313)	**400**(323)	**410**(333)
	LNAV	**560**(483)	**560**(483)	**560**(483)	**560**(483)
VM(C)OCA (OCH AAL)	Total Area	**670**(587)	**720**(637)	**820**(737)	**830**(747)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	910	790	680	570	450

NOTES
1. Pilots should 'Request RNAV Y Approach' on first contact with Heathrow Director.
2. Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
3. Pilots should not expect descent clearance below **4000** until 13NM from touchdown.
4. Missed Approach Procedure and RCF use conventional navigation aids and are not available without DME I-LL, DME LON and NDB EPM.
5. PAPI angle is 3.0°.

2015/62 LONDON HEATHROW RNAV (GNSS) Y RWY 27L 29 MAY 15

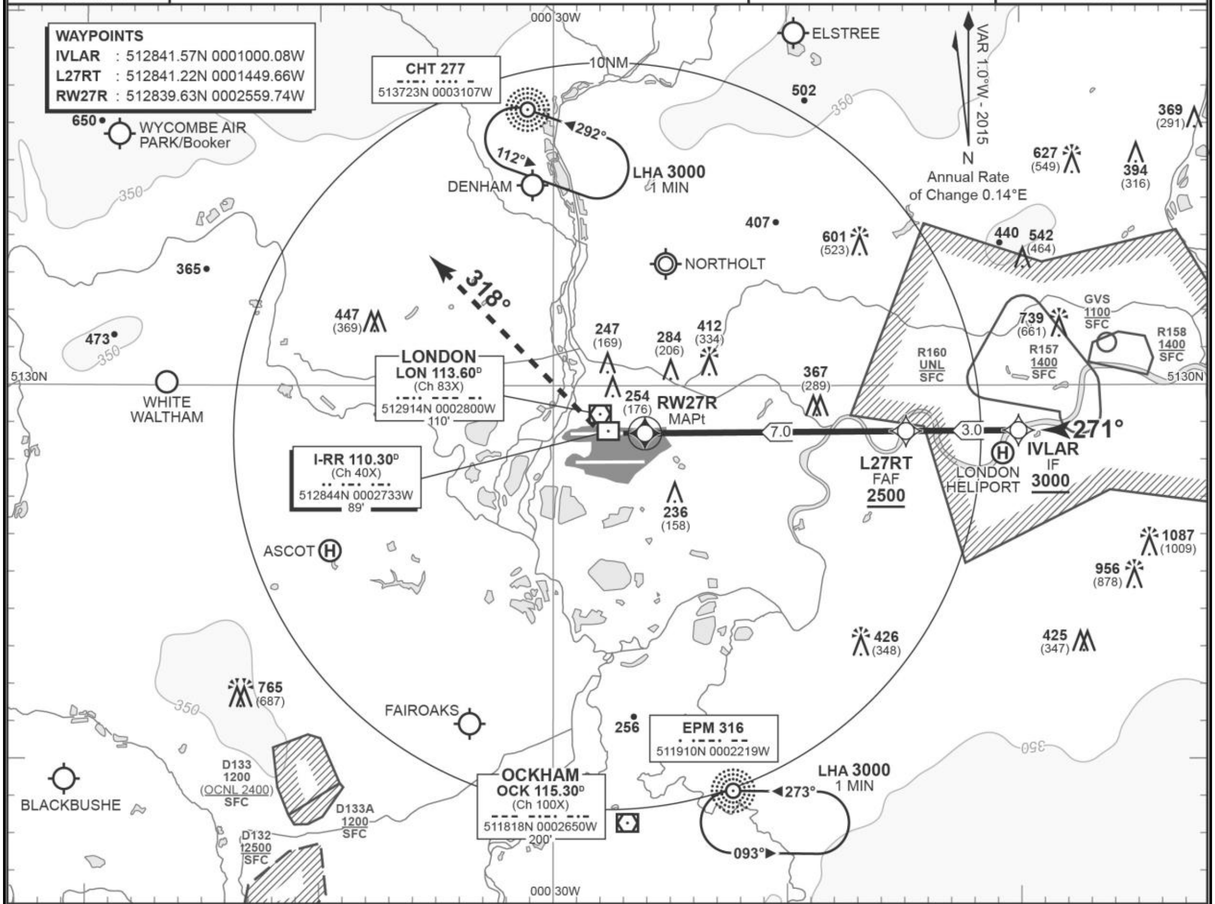
INSTRUMENT APPROACH CHART - ICAO

LONDON/HEATHROW
RNAV (GNSS) Y RWY 27R
(ACFT CAT A,B,C,D)

MSA 25NM ARP: 23	APP 119.725, 120.400, 127.525, 134.975	HEATHROW DIRECTOR	AD ELEVATION	83
	TWR 118.500, 118.700, 124.475	HEATHROW TOWER	THR ELEVATION	78
	RAD 125.625, 127.525	HEATHROW RADAR	OBSTACLE ELEVATION 1087 AMSL (1009) (ABOVE THR)	
	ATIS 128.075, 113.750, 115.100	HEATHROW INFORMATION	BEARINGS ARE MAGNETIC	

MIN TEMP **-10°C**

TRANSITION ALTITUDE **6000**



RECOMMENDED PROFILE VERTICAL PATH ANGLE 3.2° (5.6%), 340FT/NM

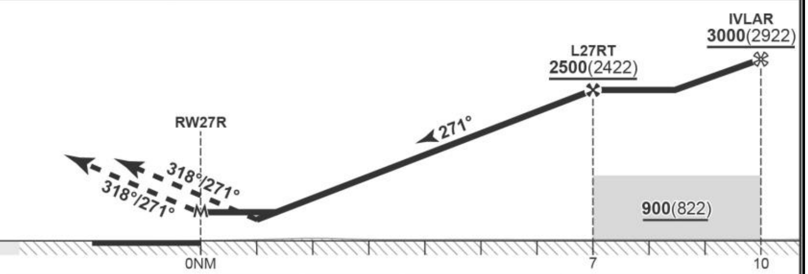
RANGE (NM)	6	5	4	3	2
ALT(HGT)	**2170**(2092)	**1830**(1752)	**1490**(1412)	**1150**(1072)	**810**(732)

TCH 50

MAPt (LNAV): RW27R

Climb to **3000** - straight ahead until passing **1580** or **I-RR DME** zero inbound whichever is later, then turn right onto track 318°. After passing **1580** revert to conventional navigation. Continue as directed.

RCF: On passing **LON DME** 10 turn right to **NDB CHT** at **3000**.



Aircraft Category		A	B	C	D
OCA (OCH)	LNAV/VNAV	**380**(302)	**390**(312)	**400**(322)	**410**(332)
	LNAV	**550**(472)	**550**(472)	**550**(472)	**550**(472)
VM(C)OCA (OCH AAL)	Total Area	**670**(587)	**720**(637)	**820**(737)	**830**(747)

Rate of descent	G/S KT	160	140	120	100	80
	FT/MIN	910	790	680	570	450

NOTES
1. Pilots should 'Request RNAV Y Approach' on first contact with Heathrow Director.
2. Aircraft will normally be radar vectored from the STAR Holding/Initial Approach Fixes.
3. Pilots should not expect descent clearance below **4000** until 13NM from touchdown.
4. Missed Approach Procedure and RCF use conventional navigation aids and are not available without DME I-RR, DME LON and NDB CHT.
5. PAPI angle is 3.0°.

2015/62 LONDON HEATHROW RNAV (GNSS) Y RWY 27R 29 MAY 15

Appendix F – ICAO PANS-OPS Approach Gradients

5.3 DESCENT GRADIENT

5.3.1 Gradient/angle limits

5.3.1.1 *Minimum/optimum descent gradient/angle.* The minimum/optimum descent gradient is 5.2 per cent for the final approach segment of a non-precision approach with FAF (3° for a precision approach or approach with vertical guidance). Descent gradients steeper than the optimum should not be used unless all other means to avoid obstacles have been attempted since these steeper descent gradients may result in rates of descent which exceed the recommended limits for some aircraft on final approach.

5.3.1.2 *Maximum descent gradient/angle.* This paragraph provides guidance regarding the maximum descent gradient/angle to be applied for approach procedures. When, because of obstacle clearance reasons, an approach procedure meeting the maximum descent gradient/angle requirement as specified in this paragraph cannot be implemented, then consideration should first be given to more advanced types of approaches that provide vertical guidance and may allow the descent/angle to stay within the limits. If this is not feasible for operational reasons and it is opted for an approach procedure that exceeds the maximum descent gradient/angle then the approach procedure shall be subject to an aeronautical study and requires special approval by the national competent authority. See Appendix B to this chapter for guidance on steep angle non-precision approaches. See Appendix B to Part II, Section 1, Chapter 1 for guidance on steep angle precision approaches.

The maximum descent gradient/angle is:

a) for non-precision procedures with FAF:

   6.5 per cent for a non-precision approach for Cat A and B aircraft;

   6.1 per cent for Cat C, D and E aircraft; and

   10 per cent for Cat H aircraft. However, where an operational need exists and the magnitude of turn at the FAF is less than or equal to 30°, a gradient of as much as 13.2 per cent may be authorized, provided the final approach speed is restricted to a maximum of 130 km/h IAS (70 kt IAS), and provided the gradient used is depicted on approach charts.

b) for a non-precision approach with no FAF, see Table I-4-5-2;

c) 3.5° for an approach with vertical guidance; and

d) for precision approaches:

   3.5° for a Cat I precision approach; and

   3° for Cat II and III precision approaches.

Appendix G – Excerpts from Airport Commission Interim Report Appendix 1 and DfT's Night Noise Consultation 2013

	Airspace operations options	The Commission's view
22	*Steeper approaches into airports, including both continuous and stepped:* This measure would increase the height of aircraft as they make their final approach to the airport, thereby reducing noise. Approach paths could either be at a continuous approach angle (between 3.2 and 3.5 degrees) or be stepped at different angles (with a steeper intermediate approach followed by the standard 3 degree airport approach).	The Commission supports the principle of steeper approaches but has not been able to prove a strong noise benefit from the introduction of 3.2 degree approaches at Heathrow. Steeper approaches at steeper angles do not appear feasible at Heathrow due to the current fleet mix, with the impact on the landing rate unknown. The Commission considers these issues should form part of any future trials of steeper approaches and, if the benefits can be proved, that steps be taken to implement them.

Increased angle of descent

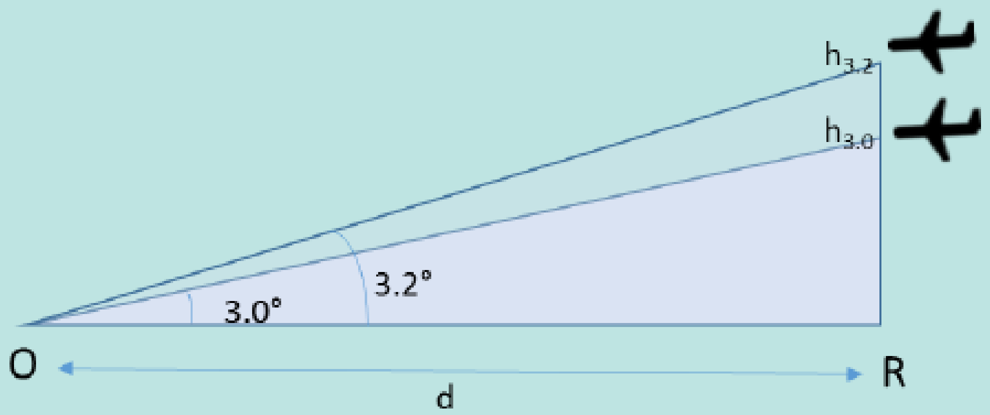
5.12 We have noted the willingness of the aviation industry to explore steeper approaches up to 3.25 degrees[47]. Given the possible noise benefits this would bring, we would encourage these efforts and would like to see trials to assess fully the operational implications and changes in noise. We believe it is realistic to implement such trials over the course of the next regime but recognise that this would require regulatory support and would have to be carefully developed. Looking beyond the next regime, we encourage the industry to explore the operational and technical feasibility of greater angles of approach along with their environmental costs and benefits.

[47] See for example the Sustainable Aviation Noise Road-Map and 'A Quieter Heathrow'

Appendix H – Noise Propagation

A steeper approach results in aircraft remaining at a higher altitude above any ground location until touch-down than if it were following a 3.0° approach. This additional altitude means a greater noise propagation distance between the aircraft noise source and receptors on the ground. Consequently, for ideal trajectories under standard atmospheric conditions, there would be a constant noise reduction at every point directly beneath the approach path for steeper approaches compared with standard approaches.

Technical brief: The effect of distance on noise attenuation



The propagation of noise from an airborne aircraft can be simplified by considering it as a spherical spreading from a point source. In this case, the difference in sound pressure level (SPL) at receptor R given by the same noise source when at height $h_{3.0}$ ($SPL_{3.0}$) and $h_{3.2}$ ($SPL_{3.2}$) is given by the following equation:

$$SPL_{3.2} - SPL_{3.0} = -20\log(h_{3.2}/h_{3.0}) \qquad [1]$$

[Source: Watson, R. and Downey, O. TheLittle Red Book of Acoustics. A practical Guide. Pags73-76. Second edition. Blue Tree Acoustics 2008]

Using trigonometry, $h_{3.0}$ and $h_{3.2}$ can be expressed as follows:

$h_{3.0}$= d*tan(3°) and

$h_{3.2}$= d*tan(3.2°)

By substituting $h_{3.0}$ and $h_{3.2}$ in Equation [1], the difference in sound pressure level is expressed as:

$$SPL_{3.2} - SPL_{3.0} = -20\log(\tan(3.2°)/\tan(3.0°)) = -0.56 \text{ dB}$$

The difference in sound pressure level calculated at R between the noise source at $h_{3.2}$ and $h_{3.0}$ is a constant that depends only on the angle of approach. It does not depend on distance (d) from origin (O).

Appendix I – Frankfurt Airport's 3.2° Approach Summary

Trial operations for approaches to runway northwest started on 18 October 2012. The German Federal Ministry of Transport and Digital Infrastructure (BMVI) has since approved the procedure, on a permanent basis for regular operations.

Measurements carried out by the German Aerospace Centre at seven monitoring stations operated by Fraport and the Environment and Community Centre showed a reduction in the maximum Sound Exposure Level (SEL) ranging between 0.5 and 1.5 dBA depending on the monitoring station and the aircraft type. The measurements were conducted over the entire period of the trial operations.

Between October 2012 and December 2014, approximately 145,000 aircraft landed using the increased glide angle, representing 71% of all landings on that runway. During this time, the new procedure neither caused a higher number of go-arounds nor any delays for arriving aircraft.

For the trial and ensuing permanent introduction, Frankfurt airport's new runway, 07L-25R was required to have two ILS to enhance operational resilience. Since the existing 3° ILS was already CAT III, the airport also installed a CAT I system at 3.2° degrees.

Both systems operate simultaneously. In low-visibility operations, the CAT III 3° system is used, however, when conditions are appropriate, aircraft are directed to use the 3.2° system. In the case of Frankfurt, this was deemed necessary as the Northern Runway only and an available landing distance of 2800m[46] which added to the complexities of aircraft performing CAT III approaches with an angle of 3.2°.

The additional instrument landing system (ILS) and the required relocation of the glide path transmitter cost €3.2m. The operating costs amount to €300,000 per year.

[46] Heathrow's available landing distances are 3882m(27R), 3658m(27L), 3350m(09R) and 3592m(09L) which, in the post-trial airline workshop were considered to provide more than adequate landing distances to compensate for any potential increased breaking distance required for 3.2° approaches. Note: Apart from for the B767, Runway Occupancy Time did not increase for landing aircraft during Heathrow's trial but this was only assessed during CAT I conditions.

Appendix J: Technical Glossary

ACP	Airspace Change Proposal
AIP	Aeronautical Information Publication
ANCON	Aircraft Noise Contour model
ANOMS	Airport Noise Monitoring and Management System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
Baro-VNAV	Barometric Vertical Navigation
CAA	Civil Aviation Authority
CAVOK	Cloud and Visibility OK
CDA	Continuous Decent Arrival
dB	Decibel
dBA	A-weighted decibel units
DfT	Department for Transport
EFPS	Electronic Flight Progress Strip
ERCD	Environmental Research and Consultancy Department
FAS	Future Airspace Strategy
HAL	Heathrow Airport Limited
HCNF	Heathrow Community Noise Forum
ICAO	International Civil Aviation Organization
IF	Initial Fix
ILS	Instrument Landing System
ISA	International Standard Atmosphere
Kts	Knots
LEQ	Equivalent Sound Level
LHR	London Heathrow
LTC	London Terminal Control
NM	Nautical Mile
PAPI	Precision Approach Path Indicator
PBN	Performance-based Navigation
R&D	Research and Development
RMT	Remote Monitoring Terminal
RNAV	Area Navigation
RoT	Runway Occupancy Time
RVR	Runway Visual Range
SEL	Sound Exposure Level
SESAR	Single European Sky ATM Research
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
TBS	Time Based Spacing