Safety & Airspace Regulation

Performance-based Navigation

Airspace Design Guidance: Noise mitigation considerations when designing PBN departure and arrival procedures

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Contents

Background

1. The UK's airspace infrastructure is currently based on 'conventional' navigation, using ground-based beacons. This system has been in place for many decades and does not exploit the modern navigational capabilities with which most commercial aircraft are already equipped. It is therefore relatively inefficient, both operationally and environmentally.

2. Modernisation will enable UK aviation to reap the benefits of the latest technologies including Performance-based Navigation (PBN). A route system using PBN standards allows more flexible positioning of routes and enables aircraft to fly them more accurately. This helps improve operational performance in terms of safety and capacity, and also offers the flexibility to attempt to design routes to mitigate the environmental impact of aviation. Most aircraft are already navigating using PBN which has led to a gradual greater concentration of aircraft on route centrelines over the years. However, as the routes have not been originally designed to a PBN specification, some operators have interpreted the conventional route centrelines and created 'overlays'. These are their individual interpretations of the conventional route centreline which will vary slightly between airlines and across aircraft fleets. Once a route is formally designed to a PBN specification and published by the Civil Aviation Authority (CAA) for use, it creates an identical standard for all operators to follow, thereby increasing concentration of aircraft on that route centreline.

3. The move to a PBN environment is considered to be inevitable and beyond the scope of this guidance; its focus is instead on providing a range of options for consideration when applying PBN and how best to mitigate noise impacts[1]. The Noise Task Force was established to consider the issues associated with the negative impacts of PBN and create this guidance.

[1] For further details on PBN and why the UK must modernise its airspace see www.caa.co.uk/FAS

Introduction

1. This document provides guidance on a range of design options for PBN (Performance-based Navigation) procedures with the intention of offering options for different kinds of noise mitigation guidance, including varying degrees of relief and dispersal, and incorporates them into this guidance which:

   - outlines the potential benefits and impacts;
   - outlines technical requirements and constraints;
   - provides guidance on where solutions may be considered and where they may be inappropriate.

2. This document explores the impacts and possibilities of using PBN routes to mitigate noise impacts and does not make reference to the stand-alone benefits of performance based versus conventional navigation.

3. The design solutions presented are drawn from existing designs, emerging concepts generated by the aviation industry and solutions proposed by environmental groups.

4. This guidance aims to provide a constant and transparent basis to the design of PBN procedures in UK airspace. It aims to achieve this by listing the key characteristics of all noise related PBN design solutions and provide generic guidance on the circumstances where they should be considered as options.

5. It is likely there will be no optimal solution that addresses all stakeholder needs but a balance will be required in order to find the most acceptable route positioning or operating concept. The optimal solution will be heavily dependent on the local circumstances; establishing ‘what good looks like’ across the local collective of stakeholders will remain the key factor in identifying which solution is most appropriate in any given circumstance. For example, for some stakeholders, concentration on a single route avoiding main population centres may be their preferred option, whereas

others may seek multiple routes to disperse traffic or achieve periods of relative relief from aircraft noise.

6. This guidance is intended to provide options for consideration by airspace designers and sponsors. The guidance is intended to provide a common reference when considering aircraft noise mitigation in the placement of PBN routes.

Airspace design and vectoring

7. The scope of the guidance is on the design of route centrelines. This is a key factor in determining traffic patterns. However, traffic patterns are also dictated by vectoring[2] practices. Vectoring is expected to reduce as the Air Traffic Management (ATM) system becomes more systemised through the introduction of PBN routes and other new technologies. However, maintaining system safety and efficiency will mean that some vectoring is always likely in certain circumstances. This will be in unpredictable circumstances such as bad weather, and also in some more predictable ways, such as where for safety and efficiency reasons the procedures are planned to be available for use on a more or less permanent basis.

8. In a systemised ATM network the routes to/from different airports must be interwoven. Consider a situation where there is a departure route that interacts with an arrival hold. To ensure they are safely separated[3] the departure route may be designed to fly additional miles around the hold and/or be capped at a low level beneath the hold. However if there happens to be no arrivals in the system as the departure gets airborne, ATC will have the opportunity to provide a more direct/efficient routeing climbing directly through the holding area. This type of situation can lead to vectored traffic patterns that deviate from the published route alignment.

[2] Aircraft vectoring is a service provided to aircraft by ATC. The controller decides on a particular direction for the aircraft to fly by issuing tactical instructions or 'vectors'.
[3] In a systemised airspace environment routes must be designed to be separated by a designated amount to ensure that there no risk of the aircraft on each route coming too close to one another. The safe separation depends on the route configuration in question.

9. Where there are defined Noise Preferential Routes (NPRs) for departures, vectoring is only allowed on departure routes once aircraft have climbed through the NPR ceiling (typically 3,000 or 4,000ft).

10. It is important that the impact of vectoring is taken into account when considering the PBN solutions presented here and in particular when setting stakeholder expectations with regard to benefits. For example, a design solution may aim to provide some noise relief from aircraft below 4,000ft by providing two routes, each with an associated NPR swathe; route A and route B, each being activated at different times. When route A is deactivated, all the flights below 4,000ft would be on route B. However, aircraft may be vectored at 4,000ft and in most cases this will be before the end of the NPR. The vectoring may therefore take the aircraft over the geographic area covered by route A's NPR swathe even though it is during the route A relief period. As these aircraft would be above 4,000ft they would, in general, be quieter, however this may not meet stakeholder expectations of an acceptable form of relief from aircraft noise.

11. It must therefore be made clear that in most cases relief will mean relief from aircraft directly overhead *at low altitude*, but not will not mean relief from all overflight/noise. Note also that relief routes may not be spaced sufficiently to remove all noise impact – see Annex A for details.

12. Vectoring is expected to decrease in the future, as ATM systemisation increases, and any PBN relief design that is implemented now would be expected to become increasingly more effective over time. This will be a gradual process and depends on the continued modernisation of the whole route network to the PBN standard and on the development and implementation of supporting tools to manage traffic flows. It is vital that designers and stakeholders alike understand the limitations of the solutions presented in this guidance.

Chapter 1

Guidance to complement consultation

1.1 All significant route changes will be subject to consultation. This guidance is intended to complement the consultation process by providing a common understanding of the options available and their pros and cons across the wide community of stakeholders.

1.2 A common understanding and wide perspective is key to ensuring that consultation is effective and focussed on design solutions that are optimal in the long term. New routes may be in place for many decades and so it is vital that the design and consultation process has a long-term focus.

1.3 The guidance is intended to be a living document which will be updated periodically as new ideas, research and technology emerge.

How to use the guidance

1.4 The guidance is designed to be a practical reference document highlighting the design solutions available and how each can mitigate noise impacts in certain circumstances.

1.5 Design solutions are therefore described in turn and key characteristics identified relating to:

- Noise objective,
- Environmental impacts,
- Operational impacts,
- Aircraft capability issues,
- Applicability.

1.6 Departure route options and arrival route option are considered in turn.

1.7 Whilst this document presents potential solutions for individual routes it must be noted that routes can rarely be designed in isolation from one another as they need to be positioned to ensure that aircraft on each route can be safely separated. For example, departure routes will often need to cross the arrival routes to the same airport, and/or departures/arrivals for neighbouring airports.

1.8 Designing airspace to manage these route interactions will be a factor in what can be achieved; therefore whilst this guidance provides a toolkit of ideas for consideration, it cannot be guaranteed that all solutions can be applied in all circumstances.

Chapter 2

Environmental impacts

2.1 Changing routes to achieve noise mitigation can have knock on consequences. This guidance identifies four generic categories of such impacts and assesses each design solution against these criteria. The categories are described below.

Noise objectives

2.2 In broad terms, the design solutions seek to provide noise mitigations in three broad categories:

Concentration

2.3 Current DfT guidance[4] says "…that, in general, the balance of social and environmental advantage lies in concentrating aircraft taking off from airports along the fewest possible number of specified routes and that these routes should avoid densely populated areas as far as possible. The framework also stresses that any changes to departure routes should avoid significantly increasing the number of people affected by aircraft noise." Air traffic management considerations such as the requirement to maintain safe separation between departures, the need to minimise conflicts with inbound aircraft and the desire to make efficient use of runway capacity gives rise to a concentration of departures along a limited number of fixed routes. Standardising procedures also helps to reduce air traffic controller workload, which contributes to the safe and efficient use of available capacity; combining this with practical issues arising from the position of navigational aids, results in a concentration of departing traffic along a relatively small number of routes.

[4] DfT Guidance to the Civil Aviation Authority on Environmental Objectives Relating to the Exercise of its Air Navigation Functions (Para 7.3) - https://www.gov.uk/government/publications/air-navigation-guidance

2.4 To alleviate the noise impact, currently, many airports adopt NPRs for their departure routes which aim to avoid areas of dense population. Whilst this 'concentration' aims to reduce the total numbers of people affected by aircraft noise, conventional navigation techniques, weather, aircraft performance, pilot or ATC reaction and different RNAV[5] 'overlays' created by operators generates a slight dispersion in tracks. Many of these factors are also variable and unpredictable.

2.5 The implementation of PBN routes to the global specification results, however, in an 'Increased Concentration'.

Increased concentration through the use of PBN

2.6 Increased Concentration through the use of PBN is the consequence of the accuracy and predictability of PBN design criteria. This accuracy and predictability means it is possible to make a more efficient use of airspace by allowing more aircraft through a similar volume by positioning adjacent routes closer to each other, reducing ATC intervention and the numbers of people affected by aircraft noise. Increased concentration through the use of PBN can deliver great benefit to local communities owing to the reduction in numbers of people affected by aircraft noise. However, the increased concentration of aircraft concentrates the aircraft noise over a smaller area which can negatively affect those communities in the close vicinity of the PBN flight path.

Relief provided by dispersion

2.7 Relief provided by Dispersion is where there is planned variation in areas impacted. For example, this may be through different runways being used at different times of day; this gives residents near to the runways predictable relief. Another example could be alternating or changing between different Standard Instrument Departures (SIDs) routes heading to the same UK exit point. Relief can be designed into airspace structures more easily once aircraft tracks are predictably concentrated on to safely separated routings, enabling the use of them to be alternated or varied.

[5] Where each operator designs their 'best fit' PBN route leading to a host of different and non-standard PBN routes.

There is, however, currently no agreed minimum distance between routes that would result in what is considered to be an acceptable level of relief from aircraft noise.

2.8 Moving traffic away from an area will not necessarily provide communities the relief they expect. The extent of the relief offered will depend on how far routes are moved and at what height the aircraft are flying. Annex A discusses the parameters which should be considered in the development of any relief solution. Annex B contains material produced by the CAA's Environmental Research and Consultancy Department (ERCD) which the Noise Task force considered for the definition of aircraft overflight.It does not constitute formal guidance and is published within this document for transparancy purposes only.

2.9 For the purposes of this guidamce, relief is considered to be a category of its own, distinct from dispersal and concentration.

Altitude based priorities

2.10 DfT's 'Guidance to the Civil Aviation Authority on Environmental Objectives Relating to the Exercise of its Air Navigation Functions, January 2014' states that when considering airspace change proposals, the CAA should keep in mind the following altitude-based priorities:

1) in the airspace from the ground to 4,000 feet (above mean sea level (amsl)) the Government's environmental priority is to minimise the noise impact of aircraft and the number of people on the ground significantly affected by it;
2) where options for route design below 4,000 feet (amsl) are similar in terms of impact on densely populated areas the value of maintaining legacy arrangements should be taken into consideration;
3) in the airspace from 4,000 feet (amsl) to 7,000 feet (amsl), the focus should continue to be minimising the impact of aviation noise on densely populated areas, but the CAA may also balance this

requirement by taking into account the need for an efficient and expeditious flow of traffic that minimises emissions;

4) in the airspace above 7,000 feet (amsl), the CAA should promote the most efficient use of airspace with a view to minimising aircraft emissions and mitigating the impact of noise is no longer a priority;

5) where practicable, and without a significant detrimental impact on efficient aircraft operations or noise impact on populated areas, airspace routes below 7,000 feet (amsl) should, where possible, be avoided over Areas of Outstanding Natural Beauty (AONB) and National Parks; and

6) all changes below 7,000 feet (amsl) should take into account local circumstances in the development of airspace structures.

Redistribution

2.11 The design of PBN routes offers more flexibility than the historic conventional alternatives. This allows tracks and the associated noise to be re-distributed away from noise sensitive areas. Of course this assumes that there is an adjacent area that is less sensitive to noise that the flights can be moved over. Noise sensitivity is a subjective concept therefore the relative noise sensitivity of an area must be carefully considered where re-distribution is the aim.

2.12 The intended benefits of a design solution will fall into one or more of the above categories.

Increases in the total number of people affected by noise

2.13 The Government's overall objective on aircraft noise is to limit and where possible reduce the number of people in the UK significantly affected by aircraft noise[6]. Customarily this has meant a priority has been placed on reducing the overall number of people over flown. The accuracy of PBN affords the ability to greatly reduce the total number of people directly over

[6] Aviation Policy Framework, 2013, p. 57,para.3.12 - https://www.gov.uk/government/publications/aviation-policy-framework

flown on a specific route as overflight will be more concentrated. However, any design solution that introduces more routes to provide dispersal or relief is likely to negate that benefit by spreading flights over a greater area and potentially affecting new people.

New populations exposed to noise

2.14 In placing the priority on reducing the overall number of people over flown, the government guidance makes no distinction between populations already exposed to noise and those that are newly exposed to noise. However, in a recent consultation process[7] the CAA required a count of 'newly over flown' population to be included. It is not clear how such information would be taken into account in a decision making process. However, it represents the common sense and anecdotal evidence that suggests previously unaffected communities are likely to be particularly sensitive when it comes to changes in airspace use.

2.15 NPRs and their associated swathes are used by those living in the vicinity of airports as an indicator of the likelihood of disturbance from departing aircraft noise. An airspace change that shifts the centreline[8] of an NPR or puts aircraft outside established NPR swathes is likely to face opposition from the communities affected.

Reductions in fuel / CO_2 efficiency[9]

2.16 The Future Airspace Strategy (FAS) has challenging targets in terms of reducing the impact of harmful CO_2 emissions produced by aircraft fuel burn. The flexibility of PBN can enable the shortening of aircraft routes as the constraint of navigation via ground-based aids is removed. Furthermore, strategic positioning of routes to separate them from one

[7] 2014 Gatwick Airport Limited Consultation on SID and NPR changes.
[8] Note that moving the centerline of a route means the established NPR of the previous centerline has changed.
[9] The scope of the document is contained to noise and does not contain assertions about air quality.

another can enable aircraft to climb or descend continuously, reducing the requirement to fly at low level for long periods of time.

2.17 Design solutions aimed at noise mitigation can increase route length and have detrimental impacts on the CO_2 efficiency. The effect of noise mitigations on CO_2 efficiency therefore needs to be understood to ensure that an appropriate balance is struck between objectives.

2.18 There is no established method for monetising noise benefits. However, an indication of the opportunity cost may be determined by comparing the fuel / CO_2 cost of a noise mitigation design against one that has been optimised for fuel and CO_2. Annex C describes an opportunity cost method. Until there is a methodology for monetising noise benefits directly, the fuel / CO_2 opportunity cost methodology should be employed whenever noise mitigation solutions are being proposed.

Chapter 3

Operational impacts

3.1 Changes to airspace design to mitigate noise will not work in isolation. They will sit within, and have an effect on, the wider ATM framework, the primary objective of which is to enable a safe, efficient, and competitive aviation sector to contribute to the UK economy.

3.2 This guidance identifies the likelihood that each of the listed solutions will have on key operational performance measures.

Runway capacity

3.3 Runway capacity is affected by the departure route configuration. If all departure routes follow the same initial trajectory, a greater distance (i.e. time) is required between successive departures, and this limits runway capacity. Generally, successive departures following the same initial track must be separated by at least 2 minutes. However, if the routes diverge shortly after departure, the time between successive departures can be as low as 1 minute, subject to certain criteria.

3.4 Runway capacity is also affected by the way in which arrival routes are managed; arrivals must be organised into an efficient stream or ‘sequence’ for landing. An efficient sequence is where aircraft are safely spaced, thus ensuring that the runway is fully utilised and flights are not unnecessarily delayed in the air. Ensuring optimal spacing between aircraft reduces holding; in turn this minimises delay, CO_2 emissions and the visual/noise impact of circling aircraft.

3.5 ATC currently arrange aircraft into the required sequence by vectoring the aircraft as they descend from holds (usually, aircraft leave the holds at major UK airports when they are at least 7,000ft) towards the final approach; some aircraft are given longer flight paths, and some shorter, so that the spacing between them when they finally line up to land is just right.

This variance means that today, aircraft flight paths from the holds do not follow a single path and can be dispersed over a wider area.

3.6 ATC can start to organise this sequence some distance from the airport at higher levels – this is generally more efficient and so is the objective of much of the on-going work to modernise the route network at higher levels. However, whilst the initial sequence can be established it cannot be finalised until the lower portions of the route because:

- Aircraft arrive from multiple directions;
- Variation in aircraft performance (different rates of noise/fuel optimal deceleration and turning radius);
- The effects of weather which can affect airspeed.

3.7 Vectoring of arrivals gives controllers the flexibility to ‘offset’ or ‘stagger’ consecutive arrivals and increase or reduce the miles to touchdown according to how each aircraft is behaving and the spacing required between them.

3.8 For this reason, even with published PBN routes for arrivals, it is likely there will still over time be a swathe pattern of air traffic created at some point on the approach path as a consequence of some vectoring. However, that swathe will likely be smaller than today as there is a prescribed route centreline to use until vectoring is required (for example vectoring may be restricted to one route segment), a defined path to aim for when intervention has been necessary and, importantly, a defined path to use during periods of lower arrival demand. The latter is particularly important when considering use of relief routes for arrivals; when the demand is lower, for example at night, the ability to use PBN arrival routes more rigidly is much more likely.

3.9 It should also be noted that over time we expect developments in the wider network (including practices such as point merge, and computer based ATC tools) to start the sequencing process much further out. While this will not negate the need for all vectoring for the reasons specified in Para 35, such enhancements will help ATC manage them and therefore generally lead to less vectoring at lower levels.

ATC system capacity

3.10 Designing terminal airspace where multiple airports are in close proximity to each other is a complex task. All arrival and departure routes to / from all runway ends have to be a safely separated from each other; either laterally or vertically. Where this is not achievable, airports share routes resulting in a ‘one at a time’ procedure with associated inefficiencies resulting in delay, extra fuel burn and CO_2 emissions.

3.11 The flexibility of PBN is an enabler for the aspirations of airports wishing to operate without a dependence on what other airports are doing. Even so, there are significant challenges in trying to separate all new procedures, particularly in the South East where over 1 million flights a year are operating in and out of the London airports. Route positioning is limited in order to provide de-conflicted procedures. Positioning of one airport’s route can be dependent, for example, on the positioning of another airport’s route.

ATC system complexity

3.12 Greater complexity in the airspace system can lead to safety issues. In particular, multiple routes designed to provide relief, can introduce a risk of error by either ATC or pilot in terms of route allocation. Safety is, of course, the number one priority. It is therefore important to understand the impacts particular design solutions might have on the complexity and overall safety of the airspace system.

Aircraft capability issues

3.13 Whilst PBN offers greater flexibility in terms of airspace design, there are some constraints on what can be achieved operationally because of limitations in aircraft capability.

Flyability

3.14 All routes must be designed to meet certain criteria that ensure all aircraft required to use them can do so in all scenarios[10]. It is possible to ‘weave’ routes around some areas of population but operational limits on the turn radius and proximity of successive turns mean that the granularity of the ‘weave’ is limited. For example, if two areas are close to one another, avoiding one may necessitate overflight of the other and vice versa. In general, the further from the runway, the more flexible procedures can be. However, closer to the runway and at lower altitude, aircraft can be less manoeuvrable and routes naturally converge to or diverge from the runway – these factors reduce design flexibility.

Flight Management Computer (FMC) capacity

3.15 Navigation database capacity (memory size) is an important issue for PBN implementation. There is a limit on the number of routes and associated points that FMC databases can hold. This is not an issue for modern aircraft, however, many aircraft in operation are more than a decade old and FMC capacity cannot be upgraded easily. Many airlines must strictly tailor the available sets of procedures in their databases according to geographic areas they are flying to so that they meet the FMC memory capacity constraints. Potential solutions for noise management which require multiples of routes could be hindered over the next few years due to this lack of storage capacity on some aircraft which airspace designers will need to take into account.

[10] An Instrument Flight Procedure (IFP) designer is responsible for the design and maintenance of IFPs and the applicable safety regulatory requirements. This is to ensure that all published IFPs intended for use by aircraft operating under Instrument Flight Rules (IFR) meet ICAO requirements. In the interest of safety, the IFP design provider shall implement the provisions in Doc 8168 PANS-OPS in a consistent manner, using processes that will minimise the possibility of errors.

Applicability

3.16 The aim of the guidance is to provide a consistent and transparent basis to the design of arrival and departure routes for noise mitigation purposes. It therefore provides guidance on the generic circumstances where each noise related design solution should be considered, taking into account the current DfT guidance on environmental objectives.

3.17 This does not preclude any of the solutions from being considered elsewhere if exceptional circumstances are identified. However, even then the guidance is expected to be beneficial as it will enable more focused discussion around what makes the circumstances exceptional, rather than starting from first principles each time.

3.18 A number of concepts are as yet unproven which means that more trials will be needed in order to accurately assess technical feasibility and/or environmental impacts.

3.19 Regarding technical feasibility, recent live PBN departure trials have begun to provide the basis for new design protocols, but more evidence is needed to develop the actual technical feasibility of some of the methods for distributing/reducing noise impacts contained within this report.

3.20 Furthermore, the environmental impacts are not fully understood, in particular, the understanding of how far away a route has to be from an area to provide stakeholders with the relief from the noise that they expect.

3.21 Any concept that has options for the positioning of an airspace structure will, by definition, be less efficient; this is because one would assume the default position is optimal and that any alternative generated for the purposes of avoiding overflight of specific areas would be less efficient (otherwise it would be the default).

Chapter 4

Concepts, options and impacts

4.1 The following is a consolidated list of concepts and potential options which could be deployed in order to manage the impact of aircraft noise on those communities affected as a result of airspace change, specifically by PBN procedures.

4.2 For each concept there are a range of potential options on how they may be applied. Concepts are described generally and then impacts assessed against the specific options.

Height bandings

4.3 The concepts and options refer to the height bands based on the altitude priorities described in DfT guidance[11]. It should be noted that these height bands relate to the height achieved at the minimum climb gradient, or shallowest descent profile.

4.4 With respect to departures this means that the 4,000ft threshold referred to for a departure would be expected to be towards the end of the NPR. However, in reality aircraft have a range of climb profiles; and the majority will climb in excess of the minimum gradient required. However, as long as these aircraft remain on the route (and are not vectored) they would follow the alignment of the routes regardless of being higher or lower than the procedure requires.

4.5 This means that care needs to be exercised when considering actual track data alongside these design solutions. For example, a design solution may refer to a threshold at 7,000ft above which populations aren’t avoided by a departure route design. Real data may show departures passing 7,000ft

[11] https://www.gov.uk/government/publications/air-navigation-guidance

well before this threshold; however, this does not mean that they would follow an alternative route on reaching 7,000ft (unless they are vectored).

4.6 For arrivals, the thresholds refer to shallowest descent profile. In reality there is variation in optimal descent profiles. This is because the most efficient and least noisy descent profiles are achieved with engines idling and with an aerodynamically ‘clean’ configuration (i.e. landing gear & flaps retracted). If their descent is too shallow they will need more power which will increase noise – if they stay high too long and descend too steeply, they may have to use flaps, landing gear, and even air brakes to slow down - all of which create more noise.

4.7 Aircraft passing a 4,000ft design threshold based on the shallowest approach path may therefore be somewhat higher in reality.

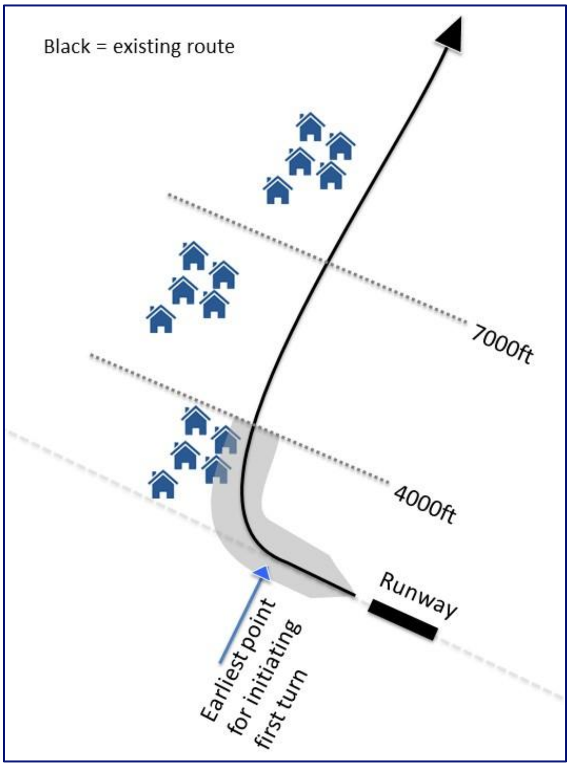
Chapter 5

Departure options

5.1 This chapter lists options for mitigating noise impacts through different departure route design concepts and options. The concepts group together options which apply the concept in different height bands.

Concept 1: Single PBN SIDs to Replace Conventional Routes

Option 1a: PBN SID replication



The black route signifies the historic nominal centreline. The PBN replication of this route would aim to match the nominal centreline as closely as is possible.

Replication does not take into account local geography as the aim is to match the existing procedure rather than redesign it.

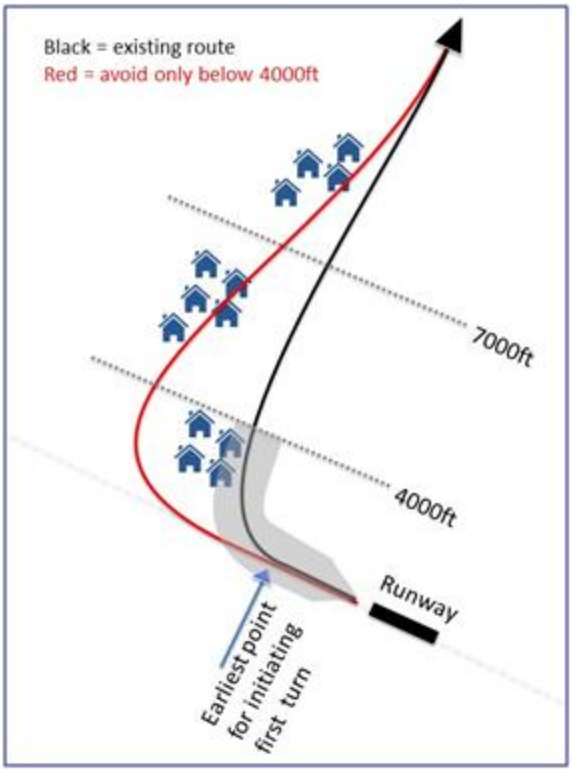
Whilst the replication would aim to match the historic procedure in terms of centrelines, the application of PBN would be expected to lead to an increase in concentration as a consequence of improved track keeping.

Table 1: Noise objective - concentration

Environmental impacts	
Total number of people affected by noise	Fewer people under concentrated route
New populations exposed to noise	None[12]
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise preferential routes	Assuming the NPR can be accurately replicated
Fuel / CO_2 efficiency	No impact
Operational impacts	
Runway capacity	No impact
ATC system capacity	No direct benefit in isolation, although a system of PBN routes will provide additional ATM capacity
ATC system complexity	No impact
Aircraft capability issues	
Flyability	Some conventional procedures cannot be replicated
FMC capacity	No impact
Applicability	
Replication is the default option for modernising conventional routes.	

[12] An exact replication will mean no new populations exposed, but conventional procedures that cannot be replicated precisely could mean new populations are exposed.

Option 1b: PBN SID re-design avoiding populations below 4,000ft



The red route signifies a new PBN route which avoids dense population below 4,000ft. The black route is the original route which is shown for reference – in this solution the black route would be disestablished. After passing 4,000ft, the red route goes back towards the intended direction, ignoring populations which are overflown above 4,000ft.

In order to avoid the dense population below 4,000ft, the departing aircraft needs to fly straight ahead for longer, possibly outside the current NPR swathe (typically 3km wide). This adds on some distance and could affect runway throughput. It will now fly over new areas.

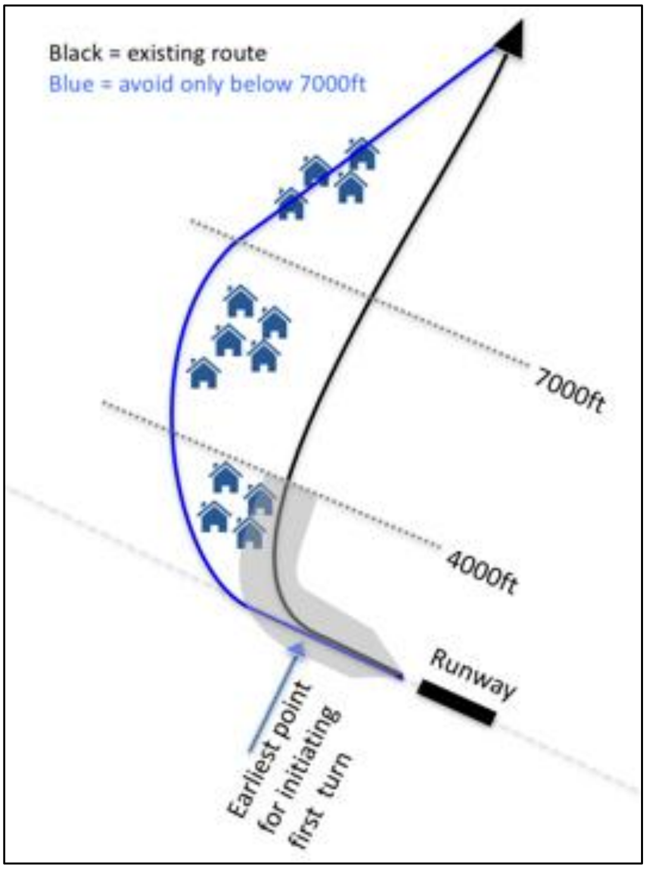
This solution was implemented in 2015 on the Luton RWY26 MATCH and DET SIDs although the PBN SID remained within the existing NPR swathe.

Table 2: Noise objective - concentration

Environmental impacts	
Total number of people affected by noise	Fewer people under concentrated route, fewer people over flown below 4,000ft (but maybe more over flown above this)
New populations exposed to noise	Yes – avoiding populations below 4,000ft will put routes over adjacent less populated rural areas. There could be an increase in the numbers overflown above 4,000ft
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration

Noise Preferential Routes	NPR will need to be redrawn
Fuel / CO_2 efficiency	Longer route will mean more fuel / CO_2. Possibly more delay on ground with engines running (runway capacity)
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity
ATC System capacity	No direct benefit in isolation – although a system of PBN routes will provide additional ATM capacity
ATC system complexity	No impact
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
Noise is the priority below 4,000ft, therefore avoiding populations should be considered as an option for any SID proposal below 4,000ft which goes beyond replication.	

Option 1c: PBN SID re-design avoiding populations below 7,000ft



The blue route signifies a new PBN route which avoids dense population below 7,000ft. The black route is the original route which is shown for reference – in solution the black route would be disestablished. After passing 7,000ft, the blue route goes back towards the intended direction, ignoring populations overflown above 7,000ft.

In order to avoid the dense population below 7,000ft, the departure needs to fly straight ahead for longer, possibly outside the current NPR. This adds on more distance and will fly over more new areas than the red route.

Environmental impacts	
Total number of people affected by noise	Fewer people under concentrated route, fewer people over flown below 7,000ft
New populations exposed to noise	Yes – avoiding populations below 7,000ft will put routes over adjacent less populated rural areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	NPR will need to be redrawn
Fuel / CO_2 efficiency	Longer route will mean more fuel / CO_2. Possibly more delay on ground with engines running (runway capacity)

Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity
ATC System capacity	No direct benefit in isolation – although a system of PBN routes will provide additional ATM capacity
ATC system complexity	No impact
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
Noise and CO_2 must be balanced between 4,000 and 7,000ft, therefore avoiding populations should be considered as an option for any SID proposal change which goes beyond replication. The CO_2 opportunity cost of the option should also be assessed (see Annex C) so that the environmental benefits can be balanced.	

Option 1d: PBN SID re-design avoiding populations above 7,000ft

The green route signifies a new PBN route which avoids overflight of dense population both below and above 7,000ft. The black route is the original route which is shown for reference – in this solution the black route would be disestablished.

In order to avoid the dense population even above 7,000ft, the green departure route needs to fly straight ahead for longer, possibly outside the current NPR. This increases the distance flown and more new areas are overflown than the red route.

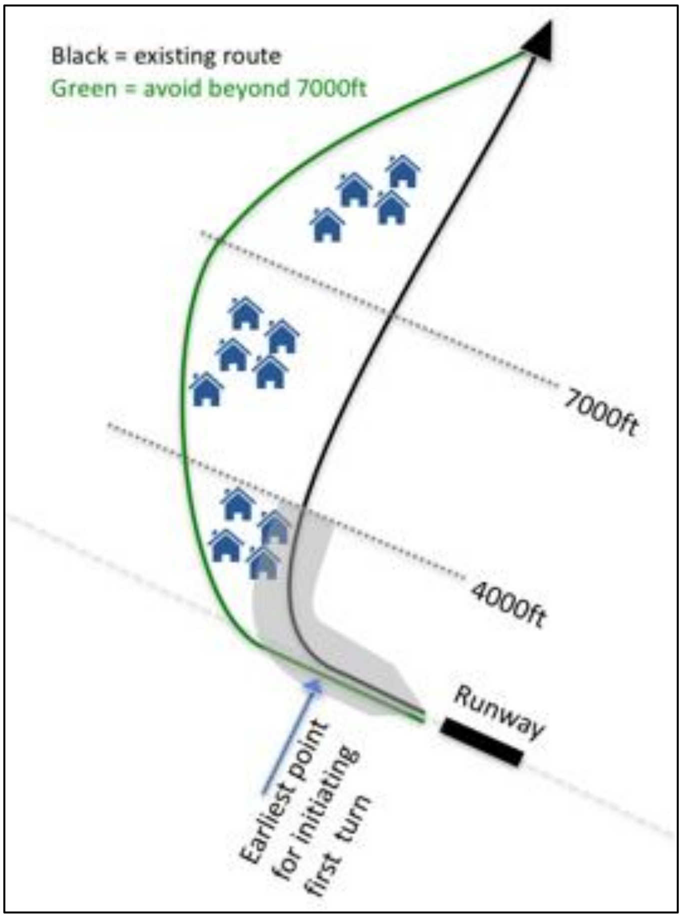


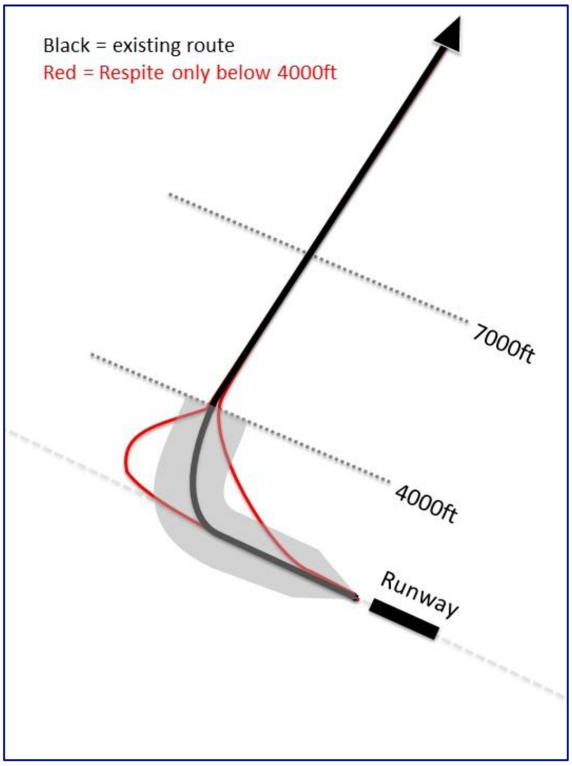
Table 3: Noise objective - concentration

Environmental impacts	
Total number of people affected by noise	Fewer people under concentrated route, fewer people over flown
New populations exposed to noise	Yes – avoiding populations below 7,000ft will put routes over adjacent less populated rural areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	NPR will need to be redrawn

Fuel / CO_2 efficiency	Longer route will mean more fuel / CO_2. Possibly more delay on ground with engines running (runway capacity)
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity
ATC System capacity	No direct benefit in isolation – although a system of PBN routes will provide additional ATM capacity
ATC system complexity	No impact
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
CO_2 is the priority above 7,000ft therefore avoiding populations above this height at the expense of fuel / CO_2 would not be expected in normal circumstances; therefore this solution would not be expected to be used unless there are exceptional local circumstances that override the network need for efficiency.	

Departures concept 2 – Relief options for PBN SIDs not constrained by NPRs

Option 2a: Relief options for PBN SIDs not constrained by NPRs below 4,000ft



This option provides either 1 or 2 additional SIDs to offer relief for those under the primary route but only below 4,000ft. New communities are affected by noise at the expense of those under the primary SID.

For the SID that turns earlier than the primary SID, this may be beneficial for runway throughput and CO_2 whereas the SID which goes straight ahead for longer is detrimental to both. The earlier turn also angles the starboard engine(s) towards the ground whilst the aircraft is still very low and very early turns may be technically challenging to be designed and flown; almost certainly requiring lower airspeed which, in turn, creates more noise. The longer relief route may be limited for use during times of lower runway demand.

These red routes stray outside of the existing NPR.

Multiple routes for one direction starts to add to the complexity of the ATC system increasing the chance of error (selection of the wrong procedure) and in complex airspace may start to affect adjacent routes from other airfields. The number of procedures required in the aircraft and ATC database is now increasing.

At the point where the relief routes converge, it is possible that the precise community beneath that point will experience more noise from aircraft on the relief routes than those on the primary route itself owing to the turning airframe and angle of the engines towards the ground.

The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

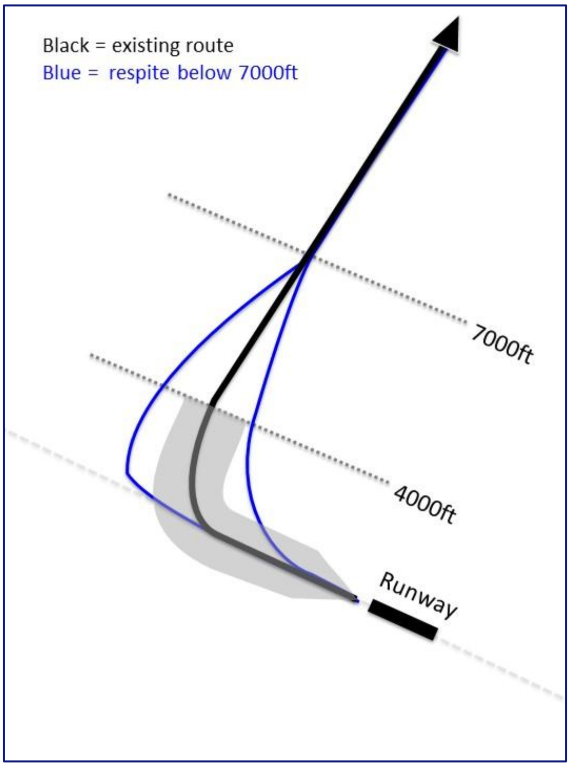
During periods of use, **all** flights would be concentrated on the relief route in question.

Table 4: Noise objective - relief

Environmental impacts	
Total number of people affected by noise	More people over flown below 4,000ft albeit less regularly
New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Flights outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2, shorter route less
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity
ATC System capacity	No impact
ATC system complexity	Additional routes would add complexity
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues

Applicability
Noise is the priority below 4,000ft, therefore relief options below 4,000ft should be considered in redesign projects where avoiding populations is not possible with a single route. However, agreement on relief from the wide community of stakeholders should be forthcoming to justify the potential negative impacts. Relief options that turn inside existing routes could also bring positive impacts to fuel / CO_2 and runway capacity and are therefore particularly desirable.

Option 2b: Relief options for PBN SIDs not constrained by NPRs below 4,000ft



The blue route(s) provides relief to those communities under the primary route below 7,000ft. New communities are affected by noise at the expense of those under the primary SID.

The route re-joins the primary route at 7,000ft so the noise impact referred to in the previous example at this exact point is less severe. There are now more new communities affected as the proposed routes provide relief for those under the primary route for longer.

There are the same issues regarding runway throughput, complexity, and fuel burn as in the previous example.

Avoiding the primary route for a longer period of time increases the likelihood of issues with spacing from adjacent routes from other airfields.

The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

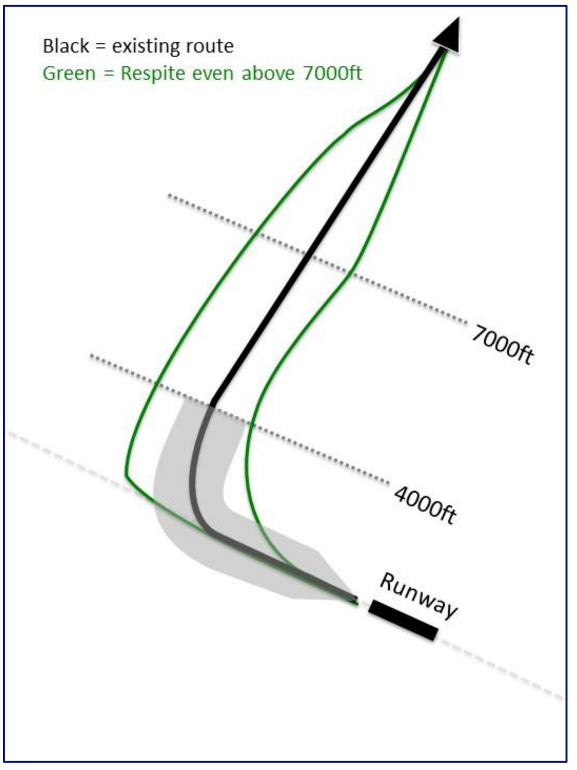
During periods of use, **all** flights would be concentrated on the relief route in question.

Table 5: Noise objective - relief

Environmental impacts	
Total number of people affected by noise	More people over flown below 7,000ft albeit less regularly

New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Flights outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2, shorter route less
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity
ATC System capacity	SIDs are likely to interact with neighbouring routes once above 4,000ft – multiple options will have knock on impacts to system route design / efficiency
ATC system complexity	Additional routes would add complexity
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Noise impact is not the sole priority between 4,000 and 7,000ft, therefore given the negative impacts relief options in this altitude range should only be considered in exceptional circumstances and where there is clear support for the relief solution from the wide community of stakeholders. Relief options that turn inside existing routes could also bring positive impacts to fuel / CO_2 and runway capacity.	

Option 2c: Relief options for PBN SIDs not constrained by NPRs above 7,000ft



The green route(s) provide relief for those communities under the primary route even above 7,000ft. This will impact more new communities although those above 7,000ft are unlikely to be significantly affected by noise.

The impact on the complexity of the network is increasing; the further from the airfield the more likely it is that routes will be interacting. Relief routes from one airport have to be separated from relief routes from another airport. It is very unlikely that airports will co-ordinate their relief routes with other airports which will lead to increased distances between all routes.

The ATC benefits of PBN are eroding.

The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

During periods of use, **all** flights would be concentrated on the relief route in question.

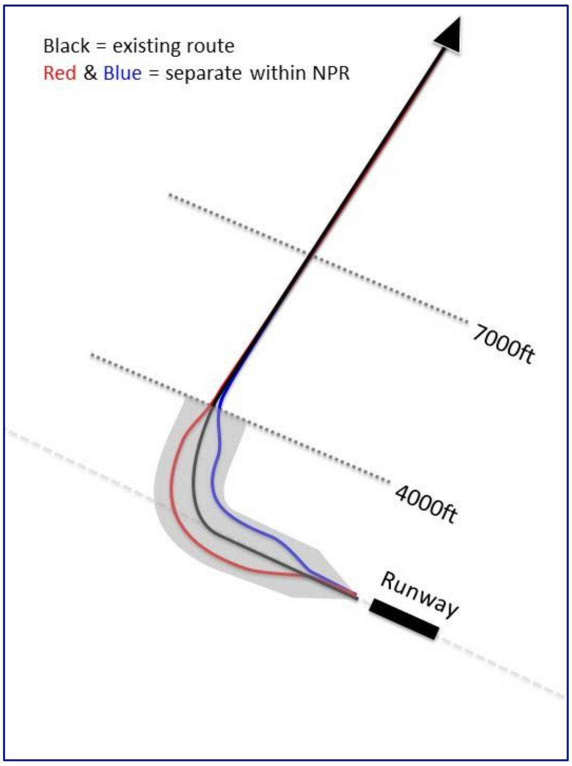
Table 6: Noise objective - respite

Environmental impacts	
Total number of people affected by noise	More people over flown below 7,000ft albeit less regularly

New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Flights outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2, shorter route less
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity
ATC System capacity	SIDs will interact with neighbouring routes once above 7,000ft – multiple options will have knock on impacts to system route design / efficiency
ATC system complexity	Additional routes would add complexity
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Noise impact is not a priority above 7,000ft, therefore relief options should not normally be considered above this altitude.	

Departures concept 3 – Relief options for PBN SIDs which are constrained by NPRs

If relief is being provided below 4,000ft but those routes all have to be contained within the NPR swathe, it could be a significant challenge.



The NPR swathe is typically 3km wide so the ability to distance the blue and/or red route(s) far enough from the primary route to actually provide effective relief is limited. The communities under the point where the routes all converge is also likely to experience more noise than if there was only the one primary route i.e. no relief.

There is likely to be technical challenges reducing the ability to achieve this, all whilst the aircraft are at slow speed and less manoeuvrable.

The red route turns to the left, away from the primary route which could have an even more detrimental impact on runway throughout than by going straight ahead for longer.

Additional route options are more complicated to manage, require more database memory and therefore increased risk of error however as these additional interactions are below 4,000ft, the impact on the airspace Network is minimal. The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

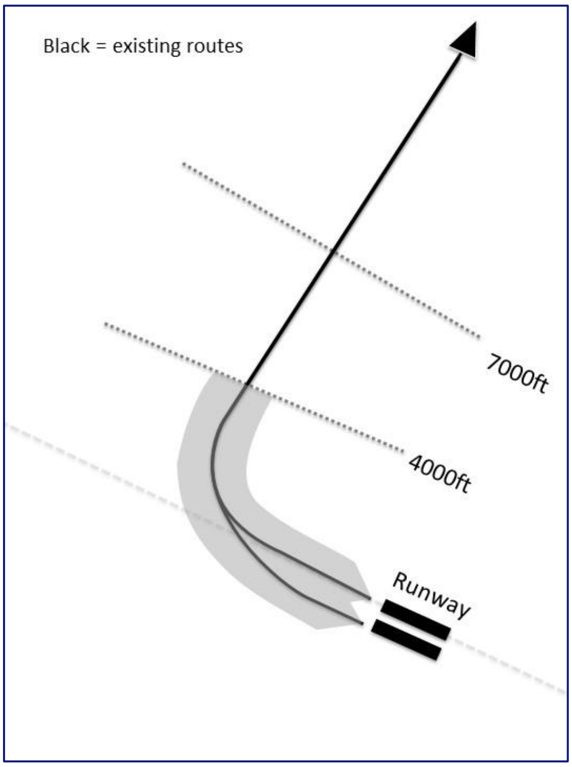
During periods of use, **all** flights would be concentrated on the relief route in question.

Table 7: Noise objective - respite, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below 4,000ft compared to just having one route
New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Within existing NPR swathe but new routes will still alter definition of existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel/CO_2, shorter route less
Operational impacts	
Runway Capacity	Red option likely to reduce runway throughput if ‘left turn’ required
ATC System capacity	No impact
ATC system complexity	Additional routes would add complexity
Aircraft capability issues	
Flyability	A succession of tight turns at low level could rule out this option and/or limit what can be achieved within an NPR swathe
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Noise is the priority below 4,000ft, therefore relief options below 4,000ft should be considered in redesign projects where avoiding populations is not possible with a single route. However, agreement on relief from the wide community of stakeholders should be forthcoming to justify the potential negative impacts.	

Departures concept 4 – Relief options for dual runway operations

Option 4a: Relief option for dual runways – routes converge as early as possible (as per current routes)



At Manchester and Heathrow, their SIDs from each runway converge into one track shortly after departure (simultaneous departures not allowed).

Heathrow and Manchester's runways are operated very differently. Manchester's southerly runway is only used during times of peak demand and is also staggered by 1,850m so regular relief for local communities is more achievable, although use of the southerly runway is permissible from 0600-2200 if required[13].

Demand at Heathrow dictates dual runway operations all day. Heathrow offers some relief out to over 10nm from the runway for arrivals as the runways alternate throughout each day to a published timetable[14]. However, except for communities under the SID flight path very close to the airport, there is very little alternating relief from departures[15].

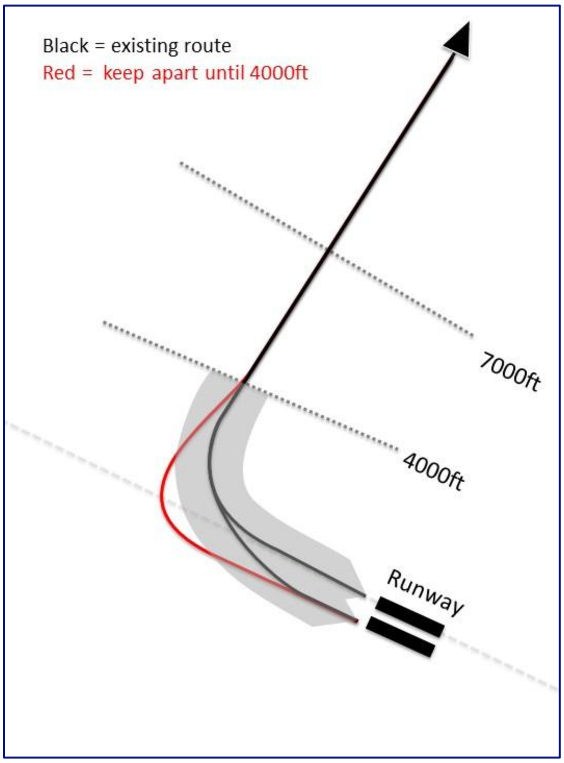
For those communities under the SID flight paths from the point at which they converge, runway alternation makes no difference.

[13] For more detail on Manchester's mode of operation, go to the Runway Data Sheet at http://www.manchesterairport.co.uk/community/living-near-the-airport/

[14] For more information on Heathrow's alternating relief go to http://www.heathrowairport.com/noise/heathrow-operations/runway-alternation

[15] Owing the 'The Cranford Agreement', there is no relief for departures on easterly operations as Heathrow are limited to departing from 09R

Option 4b: Relief option for dual runways – routes converge at 4,000ft



This option is to keep the SIDs from each runway laterally apart at low level so they don’t converge until 4,000ft.

This exposes new communities to noise but has little impact on the network and adds no issues for aircraft data base memory. The extra track mileage is likely to be insignificant.

However all this depends on how far apart the routes are to be kept. Heathrow’s runways are less than a mile apart so unless they actively diverge before converging, the distance achievable in relatively small. This goes back to the question: what is effective relief?

If they were to actively diverge, this would start to negatively impact the factors we have assessed.

This option is likely to mean leaving the current NPRs and the communities living under the point at which the routes converge may experience slightly more noise than if both routes followed the black line due to the turning aircraft.

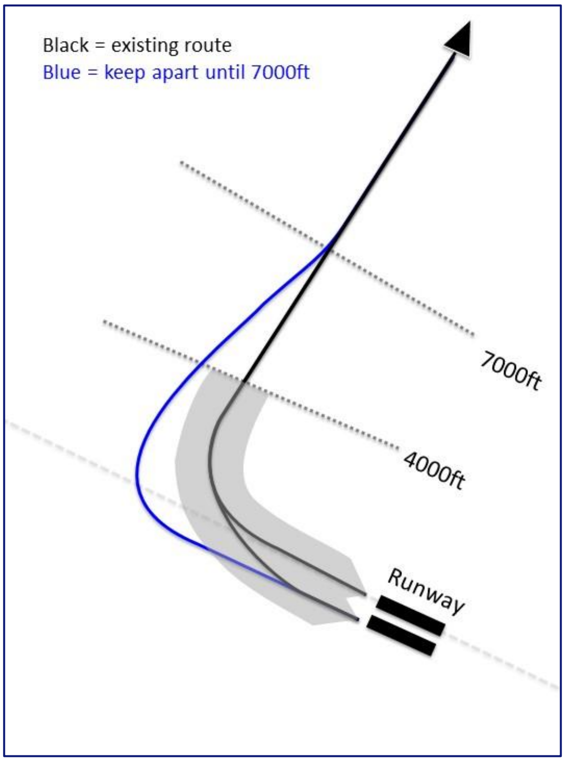
The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2k m away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

Table 8: Noise objective - relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below 4,000ft however some relief achieved through runway alternation
New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Flights likely to be outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2
Operational impacts	
Runway Capacity	Straight ahead for longer reduces departure separations (runway capacity)
ATC System capacity	No impact
ATC system complexity	No impact
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
Noise is the priority below 4,000ft, therefore relief options below 4,000ft should be considered in redesign projects where avoiding populations is not possible with a single route. However, agreement on relief from the wide community of stakeholders should be forthcoming to justify the potential negative impacts.	

Option 4c: Relief option for dual runways – routes converge at 7,000ft

The SID from the left runway (blue) follows a different path to that from the right runway (black) until converging at 7,000ft.



The mileage of this route has increased with new and more populations exposed to noise.

Still no issue for aircraft capabilities or data base memory but, if in congested airspace, the impact on the network is starting to be felt due to adjacent routes from other airfields.

The issue in the previous example of the routes converging at 4,000ft and the slight increase in noise at that exact point has probably now been improved with the higher convergence altitude of 7,000ft. NPRs will be affected.

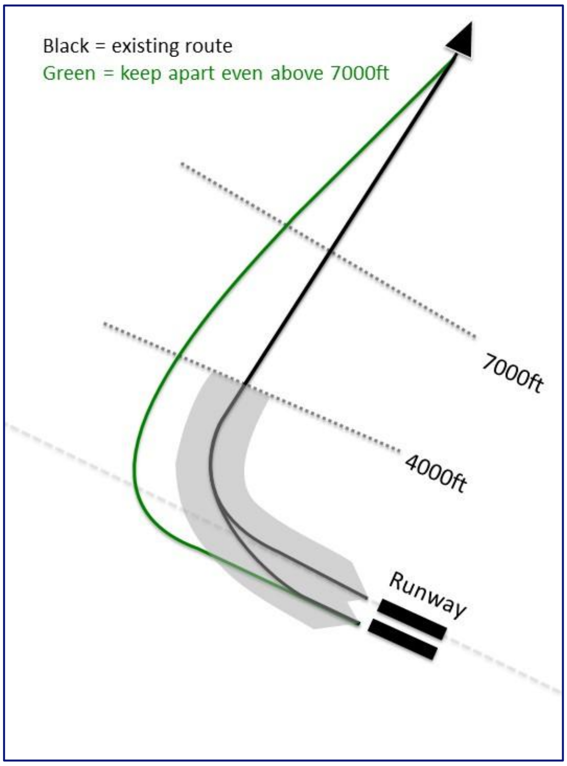
The amount of relief offered would depend on the route separation, at 5000ft relief routes would need to be at least c. 1.8km away to be perceptibly quieter, c. 3km away to be half as loud and over 5km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document).

During periods of use, **all** flights would be concentrated on the relief route in question.

Table 9: Noise objective - relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown up to 7,000ft however more relief achieved through runway alternation
New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2
Operational impacts	
Runway Capacity	Straight ahead for longer reduces departure separations
ATC System capacity	SIDs are likely to interact with neighbouring routes once above 4,000ft – multiple options will have knock on impacts to system route design / efficiency
ATC system complexity	As above
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
Noise impact is not the sole priority between 4,000 and 7,000ft, however, there is operational impact to take into consideration. This option should be considered where there is clear support for the relief solution from the wide community of stakeholders.	

Option 4d: Relief option for dual runways – routes converge above 7,000ft



The SID from the left runway (green) follows a different path to that from the right runway (black) until converging some point after 7,000ft.

Mileage increases as does the impact on the network however there is no impact to aircraft capabilities or data base memory.

NPRs affected and now even more new population and more people exposed although above 7,000ft the impact is likely to be negligible.

The amount of relief offered would depend on the route separation, at 7000ft+ relief routes would need to be at least c.2.5km away to be perceptibly quieter, c. 4km away to be half as loud and well over 5km away to be considered 'much quieter' (see relief definition in the noise objectives section of this document).

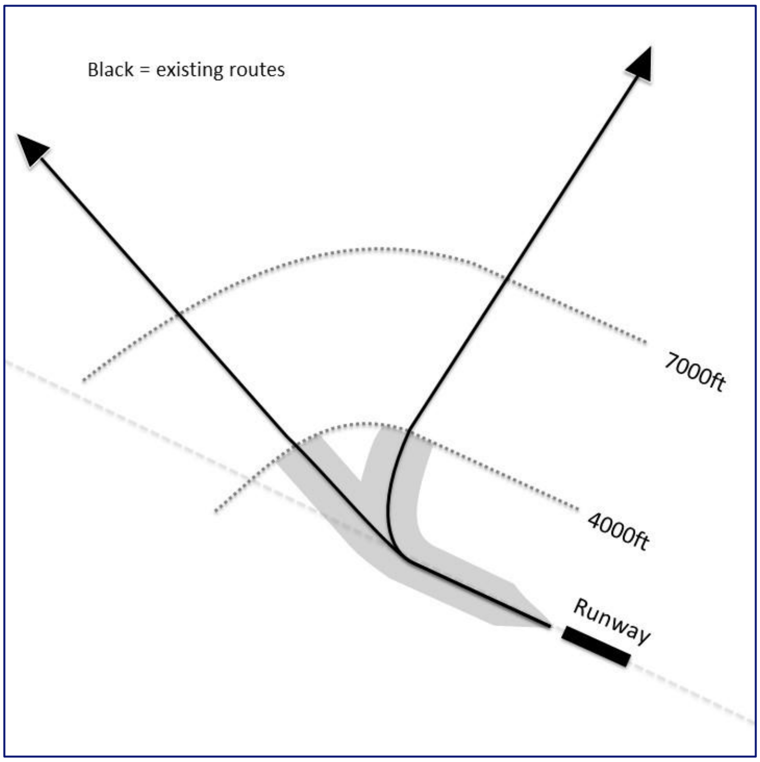
During periods of use, **all** flights would be concentrated on the relief route in question

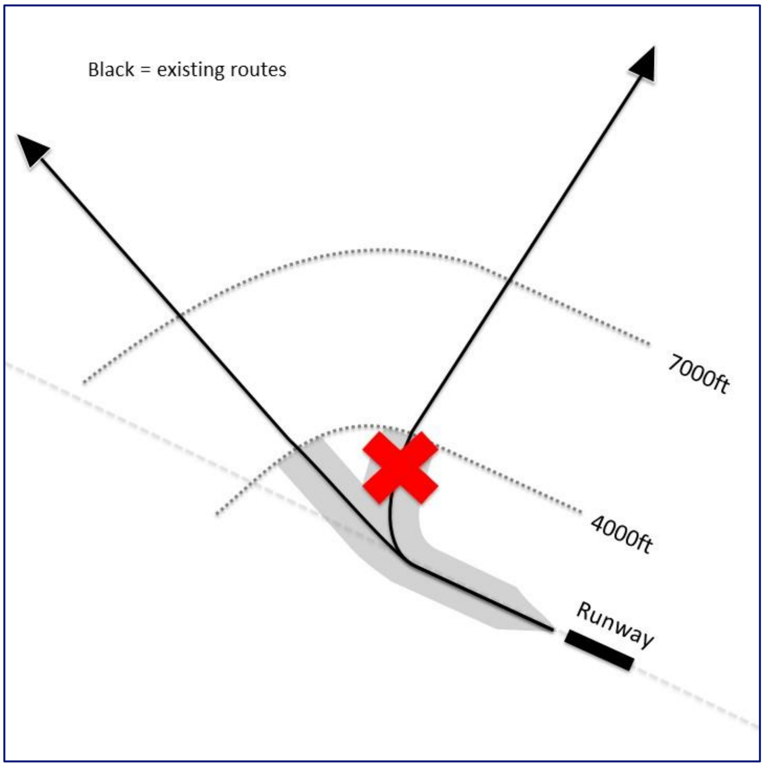
Table 10: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown up to 7,000ft however those under the route above 7,000ft are unlikely to be adversely impacted by noise
New populations exposed to noise	New alignments will put routes over adjacent areas
Intensity / frequency of aircraft experienced by those affected	PBN more accurate therefore greater concentration
Noise Preferential Routes	Outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2
Operational impacts	
Runway Capacity	Straight ahead for longer reduces departure separations
ATC System capacity	Route interactions above 7,000ft mean that additional route alignments will impact capacity.
ATC system complexity	As above
Aircraft capability issues	
Flyability	No impact
FMC capacity	No impact
Applicability	
Noise impact is not a priority above 7,000ft, therefore relief options would not normally be considered above this altitude.	

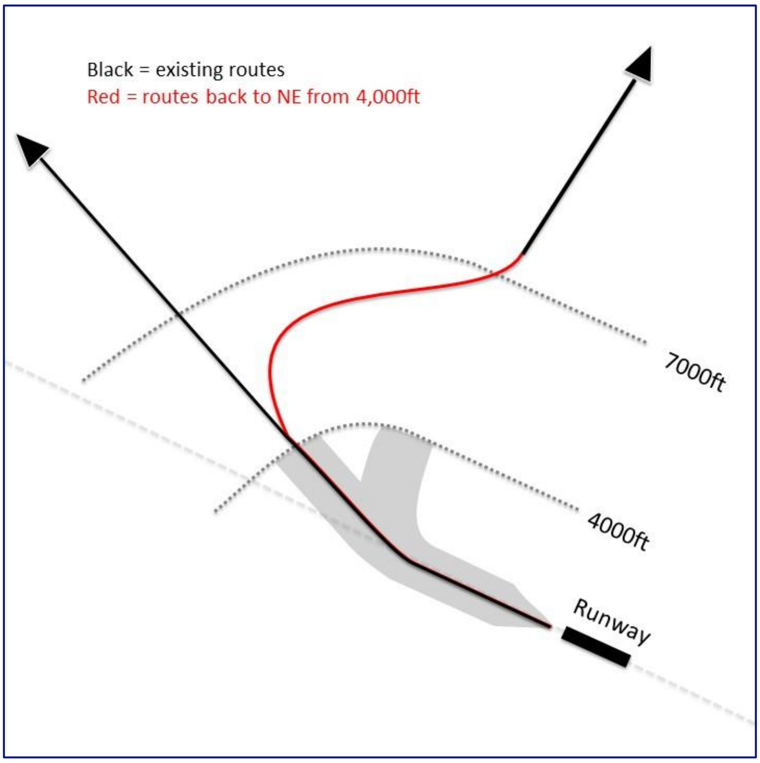
Departures concept 5 – Alternating SID usage with offloads

This is the principle of 'turning off' a departure route at a certain time of the day or night. In order to do this, departures will all follow an alternative existing route but then route back to the original track when above a certain height.





Option 5a: Alternating SID usage with offload 4,000 - 7,000ft



In this example the departures to the North East depart on the SID to the North West until passing 4,000ft and then route back, along the red path, to re-join the original track.

NPRs are not affected and no new populations are exposed to noise below 4,000ft.

Above 4,000ft, there are new populations exposed to noise although it will depend on a case by case basis whether or not more people are exposed to noise.

When the SID is deactivated use of the alternative SID will be doubled increasing the impact/concentration, however, this would be offset by the relief offered when the SID deactivation is alternated (i.e. it is assumed that reciprocal offload routes would be put in place so that the alternate SID could be deactivated).

The impact on the network is likely to be detrimental and it will also reduce runway capacity so for those reasons this sort of relief, although effective, is likely to be deployed at quieter times of traffic demand.

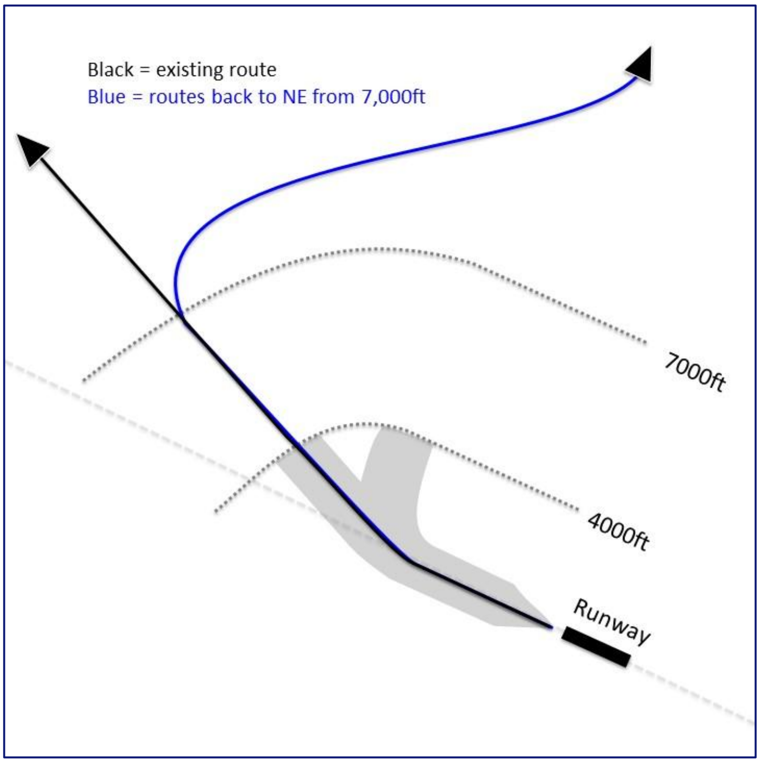
Track miles have increased but there are now additional procedures for aircraft databases.

Table 11: Noise objectives - relief, concentration

Environmental impacts	
Total number of people affected by noise	More people over flown below 7,000ft albeit less regularly

New populations exposed to noise	Populations under new flight paths although above 4,000ft
Intensity / frequency of aircraft experienced by those affected	Those under offload route experience higher numbers of flights. PBN increases concentration
Noise Preferential Routes	Use of existing NPRs although would increase the frequency of use of one which requires an ACP
Fuel / CO_2 efficiency	Longer routes would mean more fuel / CO_2
Operational impacts	
Runway Capacity	Consecutive departures on the same SID will impact runway capacity (although use of offloads at other times may improve runway capacity)
ATC System capacity	SIDs are likely to interact with neighbouring routes once above 4,000ft – offload options will have knock on impacts to system route design/efficiency
ATC system complexity	Additional offload routes would add complexity
Aircraft capability issues	
Flyability	No impact
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
This would provide effective relief below 7,000ft. However as it would significantly impact runway capacity it should primarily be considered an option for night time operations.	

Option 5b: Alternating SID usage with offload above 7,000ft



This sees the aircraft not leaving the route to the North West until 7,000ft in order to return to its intended direction.

The track miles are now significantly more but any new populations are over flown above 7,000ft and therefore the impact of new noise is minimal.

The same issues apply regarding runway capacity but the impact on the network is even more negative, possibly affecting the airspace sectorisation of the ATC system.

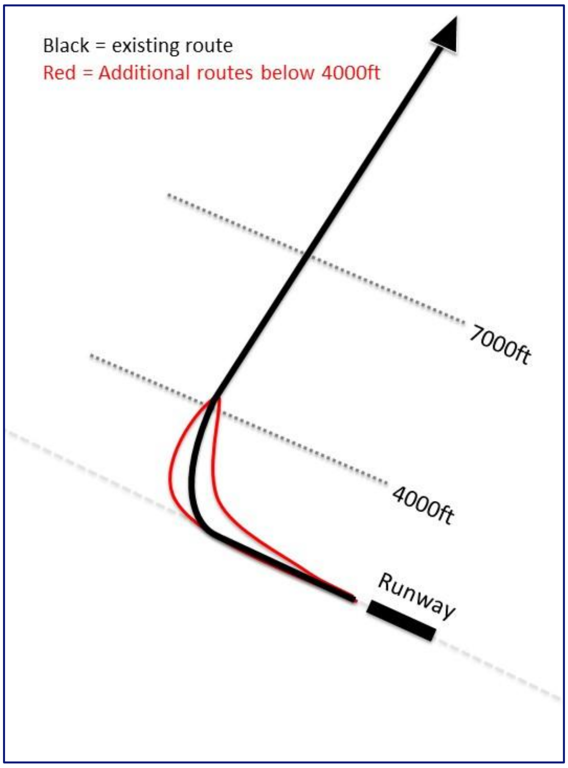
Table 12: Noise objectives - respite, concentration

Environmental impacts	
Total number of people affected by noise	No change to numbers affected below 7,000ft, but impact changed. Intensity increased when SID is active offset by relief when it is deactivated
New populations exposed to noise	No new routes below 7,000ft
Intensity / frequency of aircraft experienced by those affected	Those under offload route experience higher numbers of flights. PBN increases concentration
Noise Preferential Routes	Use of existing NPRs although would increase the frequency of use of one

Fuel / CO_2 efficiency	Longer routes would mean more fuel / CO_2
Operational impacts	
Runway Capacity	Consecutive departures on the same SID will impact runway capacity (although use of offloads at other times may improve runway capacity)
ATC System capacity	SIDs will interact with neighbouring routes once above 7,000ft – offload options will have knock on impacts to system route design / efficiency
ATC system complexity	Additional offload routes would add complexity
Aircraft capability issues	
Flyability	No impact
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
This would provide effective relief below 7,000ft. However as it would significantly impact runway capacity it should primarily be considered an option for night time operations. The impact on overall system efficiency must also be considered – there may not be sufficient airspace for all the offload options.	

Departures concept 6 – Multiple PBN routes to replicate conventional dispersal

Option 6a: Traffic dispersal below 4,000ft



This is an option where multiple PBN routes are used via random allocation throughout the day to create a swathe of departures, attempting to replicate the dispersal observed on conventional routes.

Achieving this at low level with enough distance between the routes to provide any perceptible difference in noise impact will affect runway capacity. This is because the track mileage for each of the PBN tracks will differ, which in turn means that by the time the routes converge, an aircraft on a shorter route (inside turn) will catch up one on a longer route (outside turn). The time separation between the successive departures may have to be increased to manage this risk.

However, having multiple very slightly different SID tracks may be possible in order to create a wider swathe than would occur with just one SID centreline although the difference in track miles would have to be considered negligible i.e. a hundreds of metres, not kilometres and this may only be achievable with high-end PBN specifications.

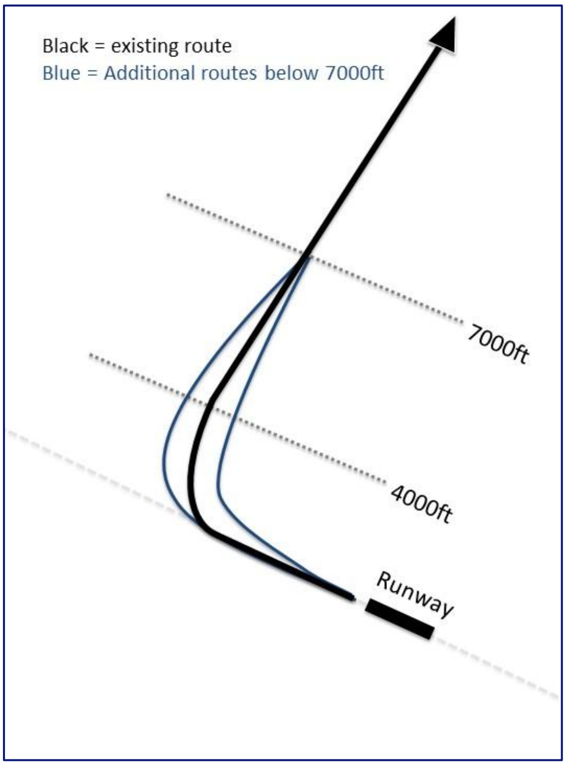
A random allocation of such routes will be extremely challenging for current airport and ATC systems to cater for, adding complexity and flight planning issues for airlines. The number of procedures required in the aircraft and ATC database is now increasing.

At the point where the relief routes converge, it is possible that the precise community beneath that point will experience more noise from aircraft on the relief routes than those on the primary route itself owing to the turning airframe and angle of the engines towards the ground.

Table 13: Noise objective - dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below 4,000ft than just one routes albeit less regularly. Noise reduction likely to be minimal
New populations exposed to noise	No impact
Intensity / frequency of aircraft experienced by those affected	Slightly less concentration of traffic
Noise Preferential Routes	Will affect the NPR swathe
Fuel / CO_2 efficiency	Assume the difference in track miles is negligible
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity
ATC System capacity	No impact
ATC system complexity	Additional routes would add complexity. A total random allocation of such routes may be unachievable
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues. Also issues with flight planning
Applicability	
Where there is a requirement to create a ‘thicker’ swathe than just a single PBN route at low level.	

Option 6b: Traffic dispersal below 7,000ft



The same as Option 6a however the multiple routes stay apart until 7,000ft.

The route re-joins the primary route at 7,000ft so the noise impact referred to in the previous example at this exact point is less severe. There are now more communities affected as the dispersal routes provide a slightly larger swathe of aircraft.

There are the same issues with regards to complexity of the ATC system.

Further away from the airport, the distance between the routes may be able to increase along straight, parallel segments as track distance remains similar although this will start to affect spacing from adjacent routes to/from other airports and the requirement may be less owing to the higher altitude of the aircraft.

Table 14: Noise objectives – relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below 4,000ft than just one routes albeit less regularly. Noise reduction likely to be minimal
New populations exposed to noise	No impact
Intensity / frequency of aircraft experienced by those affected	Slightly less concentration of traffic
Noise Preferential Routes	Will affect the NPR swathe
Fuel / CO_2 efficiency	Assume the difference in track miles is negligible

Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity
ATC System capacity	Will effect route spacing against other routes
ATC system complexity	Additional routes would add complexity. A total random allocation of such routes may be unachievable
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues. Also issues with flight planning
Applicability	
Where there is a requirement to create a 'thicker' swathe than just a single PBN route at low level.	

Option 6c: Traffic dispersal below 10,000ft

The same as option 6a and 6b however the routes stay apart until 10,000ft.

The routes re-join the primary route at 10,000ft so the dispersal is achieved even at a higher altitude. It is likely that the effect on the network would be too complex owing to interaction with routes to/from other airports.

There are the same issues with regards to complexity of the ATC system.

It is unlikely that active traffic dispersal above 7,000ft would be achievable when designing an efficient ATC network.

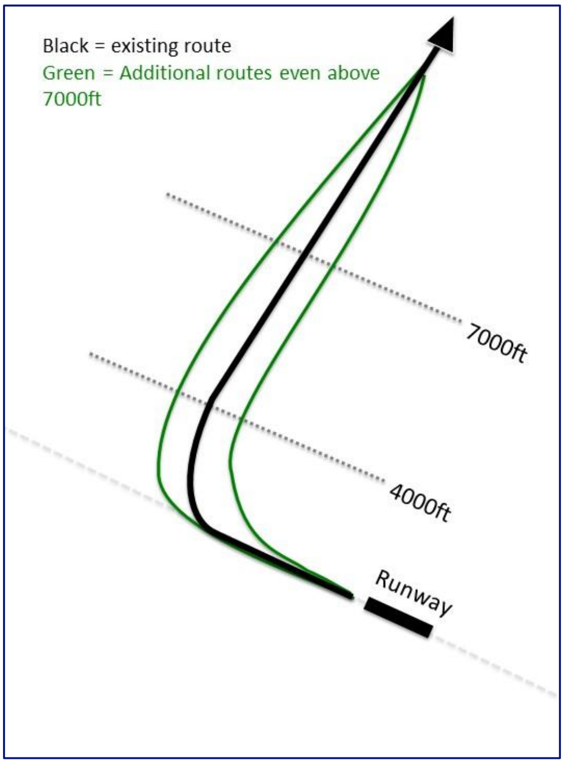
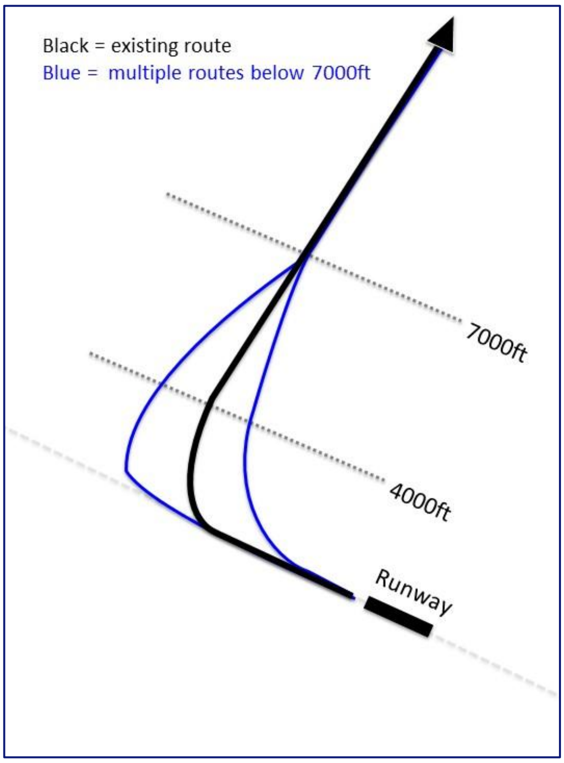


Table 15: Noise objectives – relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below than just one route albeit less regularly. Noise reduction likely to be minimal
New populations exposed to noise	No impact
Intensity / frequency of aircraft experienced by those affected	Slightly less concentration of traffic
Noise Preferential Routes	Will affect the NPR swathe
Fuel / CO_2 efficiency	Assume the difference in track miles is negligible
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity, earlier turn may improve runway capacity

ATC System capacity	No impact
ATC system complexity	Additional routes would add complexity, especially above 7,000ft and further away from the airport. A total random allocation of such routes may be unachievable
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues. Also issues with flight planning
Applicability	
Where there is a requirement to create a ‘thicker’ swathe than just a single PBN route at low level. Noise impact is not a priority above 7,000ft, therefore dispersal options should not normally be considered above this altitude.	

Departures concept 7 – Traffic dispersal into new / wide areas



This is a combination of relief and dispersal. At smaller airports which aren't capacity constrained and with fewer departure routes, it may be possible to create multiple departure routes with sufficient distance between them to offer greater dispersal and thus provides an element of relief from noise between successive departures.

The impact on the complexity of the network would be significant although it is likely that this would only be achievable in quieter parts of the network. The further from the airfield the more likely it is that routes will be interacting. In this circumstance it is likely that populations who currently experience few aircraft from the airport would now start to see more aircraft as multiple routes are implemented.

A totally random allocation of departures along multiple routes will be extremely challenging to achieve as it will create problems for ATC systems, airline flight planning and potential increases in safety risk.

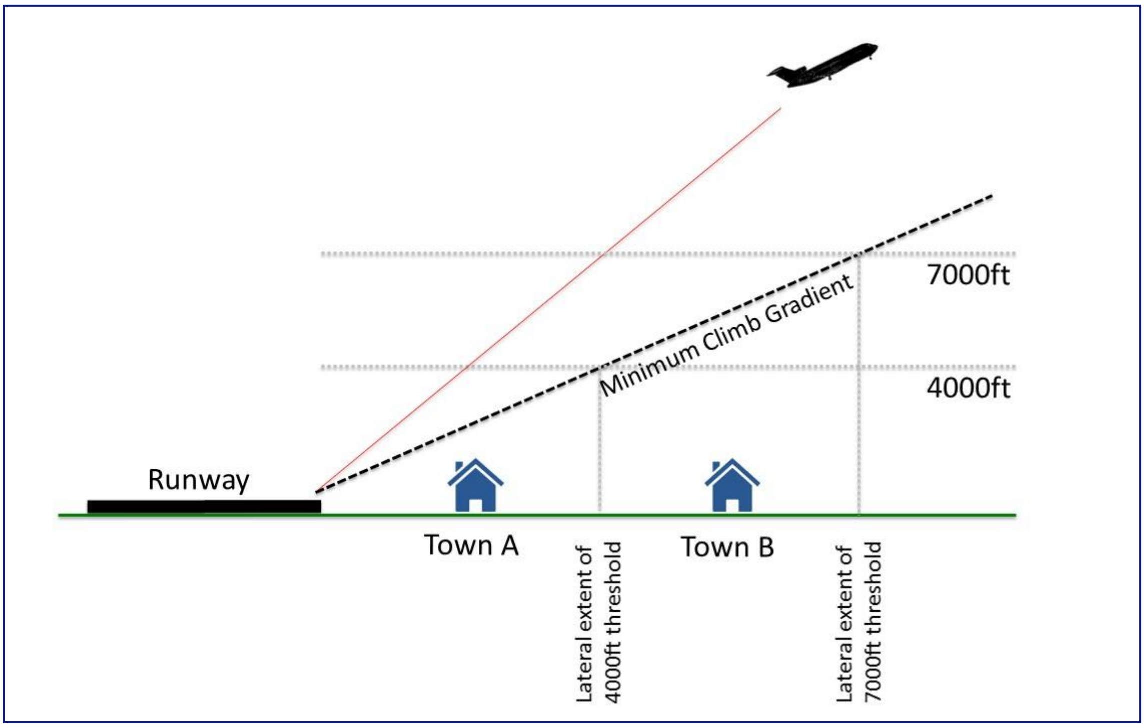
The additional routes may be able to merge anywhere between 4,000 and 10,000ft in a low complexity environment.

Table 16: Noise objectives – relief, dispersal

Environmental impacts	
Total number of people affected by noise	More people over flown below 7,000ft and potentially new populations
New populations exposed to noise	New alignments will put routes over adjacent areas

Intensity / frequency of aircraft experienced by those affected	Less frequent than a single PBN route
Noise Preferential Routes	Flights outside existing NPR swathe
Fuel / CO_2 efficiency	Longer route would mean more fuel / CO_2, shorter route less
Operational impacts	
Runway Capacity	Straight ahead for longer would impact runway capacity; earlier turn may improve runway capacity. Although unlikely to be an issue at airports where this may be possible
ATC System capacity	SIDs will interact with neighbouring routes once above 7,000ft – multiple options will have knock on impacts to system route design / efficiency
ATC system complexity	Additional routes would add complexity although likely to be in quieter parts of the network
Aircraft capability issues	
Flyability	Although early turns may be technically challenging to be designed and flown
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Not for capacity constrained airports but could be suitable for smaller airports with only one or two departure routes and adequate time between successive departures.	

Departures concept 8 – Increased climb gradients



The introduction of PBN SIDs may afford an opportunity to increase minimum climb gradients, although it should be noted that this could also be undertaken on conventional SIDs.

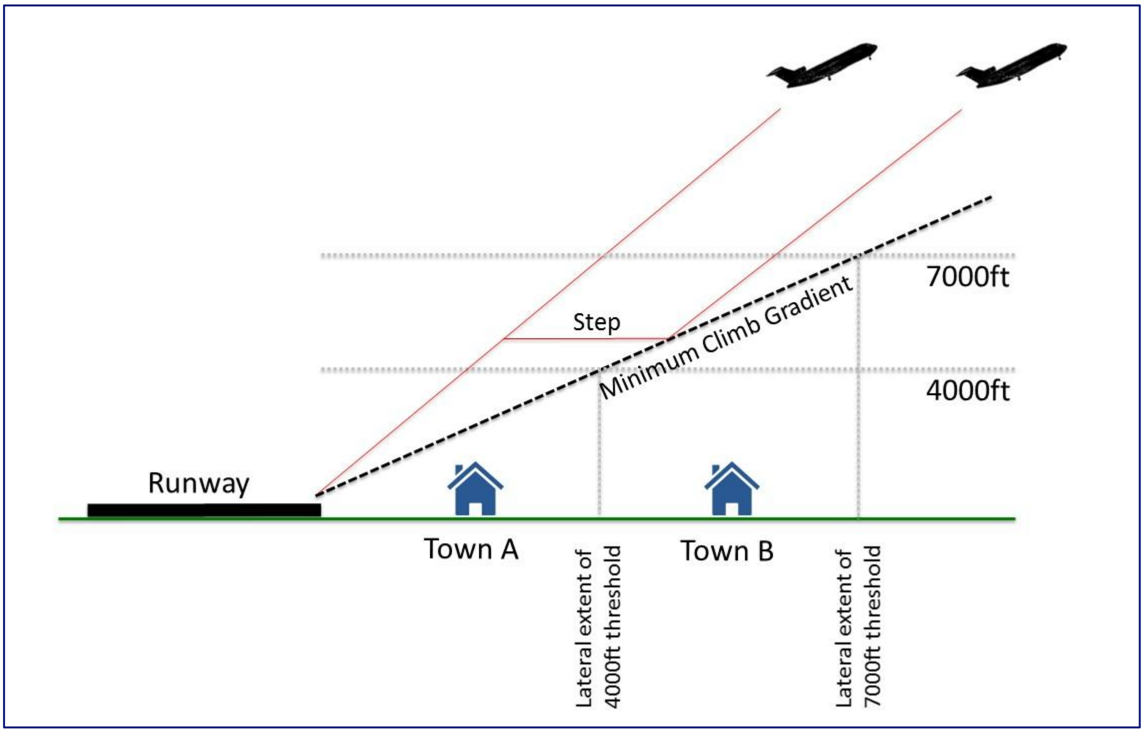
An increased minimum climb gradient will, in general, result in some of the slowest climbing aircraft reaching a higher altitude sooner in their profile.

This has potential operational benefits and also some noise benefits as, in general, noise experienced on the ground reduces with height. However, heavier aircraft may have to increase their engine thrust in order to achieve the steeper gradient which may alter the noise profile experienced and also reduce engine service life.

Table 17: Noise objectives – relief, dispersal

Environmental impacts	
Total number of people affected by noise	Reduced as aircraft reach threshold sooner
New populations exposed to noise	No new routes below 7,000ft
Intensity / frequency of aircraft experienced by those affected	Those under initial climb phase may experience more noise
Noise Preferential Routes	No change to NPRs although aircraft may pass NPR ceiling earlier meaning change to vectoring patterns above 4,000ft
Fuel / CO_2 efficiency	Potential negative effect if thrust increased
Operational impacts	
Runway Capacity	No impact
ATC System capacity	Getting aircraft higher earlier is beneficial to system capacity
ATC system complexity	No additional complexity
Aircraft capability issues	
Flyability	May require deferent engine settings increasing engine wear
FMC capacity	No impact
Applicability	
This is always considered beneficial if minimum gradients can be increased without change to thrust settings. However if an increase is required there would need to be an understanding of the balance between increased effects near to the airport against decreased effects further away.	

Departures concept 9 – Remove step climbs



The introduction of PBN SIDs may afford an opportunity to remove step climbs, although it should be noted that this could also be undertaken on conventional SIDs

Removing a step climb will, in general, result in aircraft climbing more continuously and reaching a higher altitude sooner in their profile. This has potential operational benefits and also some noise benefits as, in general, noise experienced on the ground reduces with height. Noise also increases as aircraft change attitude, in particular when resuming climb after a level segment.

Table 18: Noise objectives – relief, dispersal

Environmental impacts	
Total number of people affected by noise	Reduced as aircraft reach threshold sooner
New populations exposed to noise	No new routes below 7,000ft
Intensity / frequency of aircraft experienced by those affected	Those under initial part of step may experience more noise
Noise Preferential Routes	No change to NPRs although aircraft may pass NPR ceiling earlier meaning change to vectoring patterns above 4,000ft
Fuel / CO_2 efficiency	Improved as level step is inefficient
Operational impacts	
Runway Capacity	No impact
ATC System capacity	Getting aircraft higher earlier is beneficial to system capacity
ATC system complexity	Reduces complexity
Aircraft capability issues	
Flyability	Easier
FMC capacity	No impact
Applicability	
This is always considered beneficial unless there are exceptional circumstances that mean there are particular noise sensitivities around the areas where the aircraft currently level off.	

Chapter 6

Arrival options

6.1 This section lists options for mitigating noise impacts through different arrival route design concepts and options. The concepts group together options which apply the concept in different height bands.

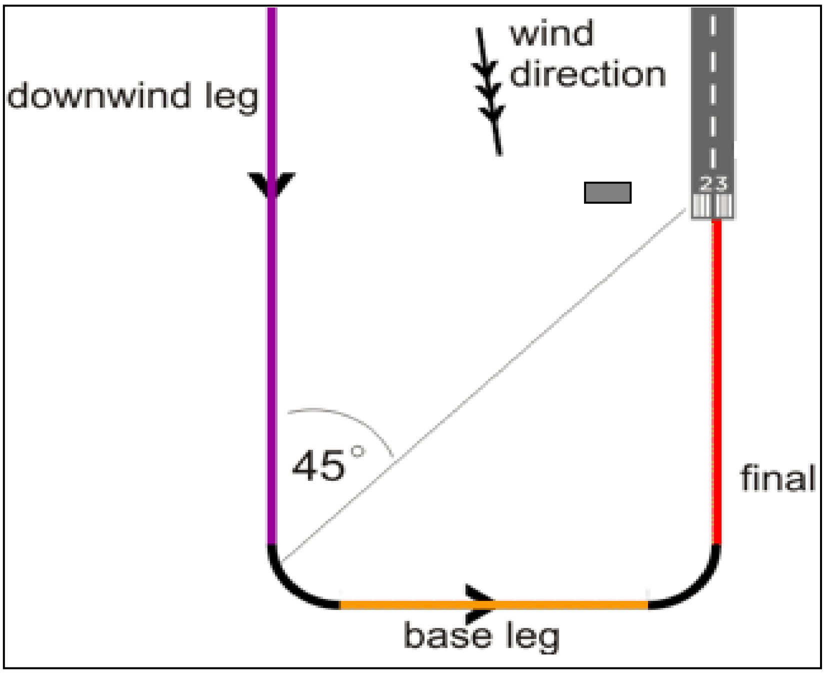
Arrivals definitions

6.2 Aircraft have to land facing into the wind. The approach path to a runway is generally split into three segments as shown below. The downwind leg runs parallel to the runway and the base leg turns aircraft to intercept the final approach which, in today’s systems, head straight on towards the runway.

6.3 In today’s ‘conventional’ air traffic environment there are very few defined routes for everyday use for downwind and base leg, but the final approach path is usually defined by the Instrument Landing System (ILS) which aircraft follow for their approach to the airport.

6.4 This means that traffic is currently vectored on downwind and base leg. The vectoring can vary on a flight by flight basis as aircraft are positioned to achieve a safe and efficient landing sequence.

6.5 Utilisation of PBN standards allows modernising the route structure will allow PBN routes to be defined down to the final approach which will improve predictability although in busy times some vectoring will still be required to maintain the landing sequence (see runway capacity).



Continuous descent approach (CDA)

6.6 In the UK, in order to keep fuel burn, CO_2 and aircraft noise to a minimum, approach controllers and pilots are trained to try and achieve a Continuous Descent Approach[16]. When a CDA procedure is flown the aircraft stays higher for longer, descending continuously from the bottom level of the stack (or higher if 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. It may sometimes not be possible to fly a CDA due to airspace constraints or overriding safety requirements.

Curved approaches

6.7 Curved Approaches are those where aircraft are following a strictly defined PBN approach path from downwind of the airfield and round onto final approach. At some point the aircraft may even be required to switch ‘mode’ depending on the landing system in operation at the airfield in question.

[16] CAP1165: Managing Aviation noise – www.caa.co.uk/CAP1165

6.8 Curved approaches vary in their technical demands on the navigational capability of the aircraft, the airfield and ATC equipment. Curved approaches provide the ability to allow a much shorter minimum final approach, from, typically, 7 or 8nm down to 4 or even 3nm. However, the technical demand on the aircraft's navigational performance, the relevant immaturity of curved approaches and the resultant reduction in runway throughput during peak hours (if they were to be used by **all** arrivals) means that curved approaches cannot currently be used widely enough as a method of providing noise relief in order to support all high intensity runway operations.

Network enablers for low altitude PBN noise solutions

6.9 The options presented in this section relates to PBN routes that deliver aircraft through low level airspace onto the runway. As described earlier, there will be always circumstances where aircraft need to be vectored off these PBN routes to maintain safety and capacity; however the degree to which this is required will depend on the way in which aircraft are delivered onto these routes from the network airspace that sits above. In turn, this will depend on how the network airspace is configured and managed.

6.10 Managing the way in which multiple aircraft arrive simultaneously is key to the performance of PBN routes. If the network is configured and managed so that the aircraft 'bunches' are sorted into an orderly stream before they join the low level PBN routes then it is more likely that aircraft can be left to follow the low level routes autonomously. Conversely if 'bunching' is not addressed in the network airspace then air traffic control will be required to tactically manage the aircraft in the lower airspace – providing more instructions that lengthen or shorten flight paths which means less route adherence and a greater variation in track distribution.

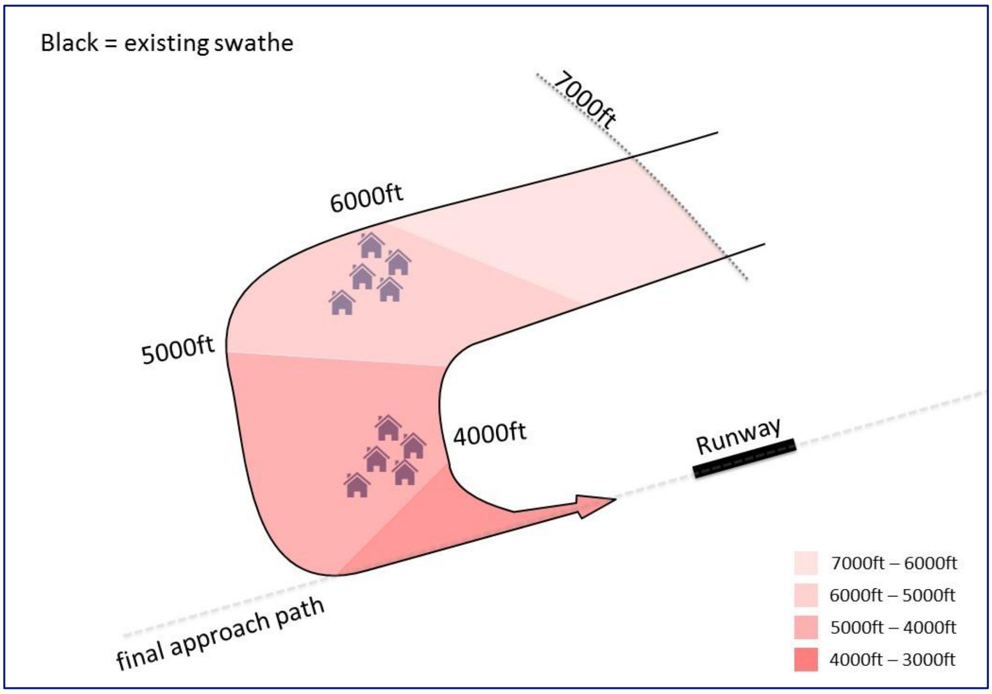
6.11 Multiple aircraft arriving within a short time frame are currently managed through holds in the network airspace (for major airports these are generally at 7,000ft or above). These are effective at absorbing inbound delay but are not a particularly efficient means for generating a single, orderly stream of arrivals – hence at busy airports there is a tendency for dispersed arrival traffic patterns at low levels.

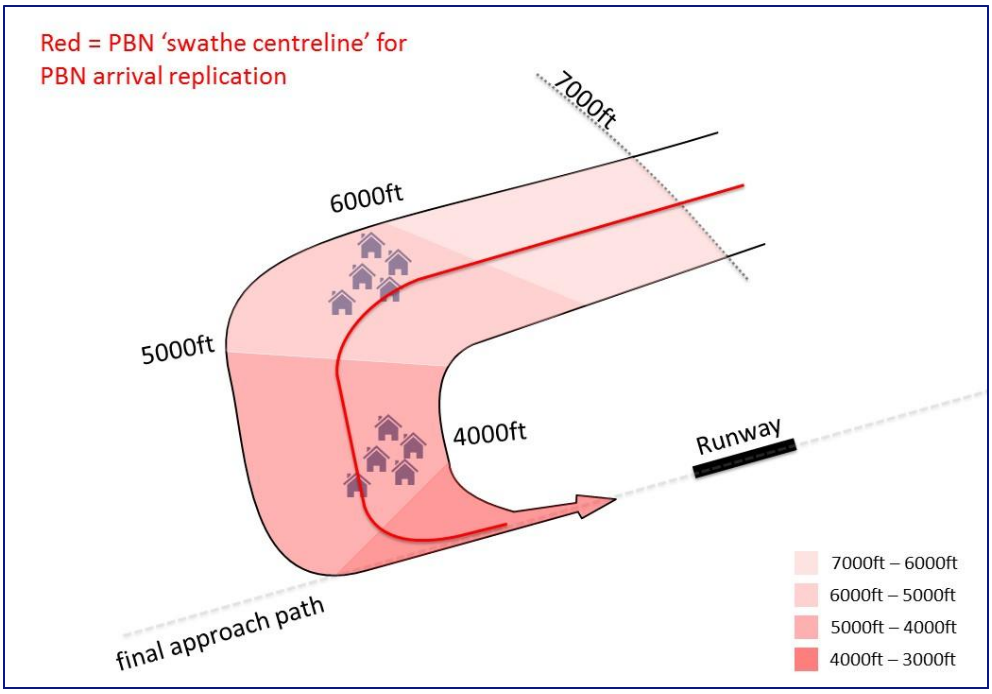
6.12 In a future PBN environment there are other techniques, with associated route structures, that can work alongside or instead of holds to generate a more orderly stream. The two principle techniques are referred to as ‘Point Merge’ or ‘Tromboning’. These concepts are for managing airborne delay, generally[17] in higher level airspace above 7,000ft, rather than being techniques to mitigate noise. As such, the techniques themselves are described in Annex E rather than being listed in this section as separate noise mitigation techniques. However, it is worth noting that the efficiency of any low level PBN route structure will be limited unless there is an appropriate network design that delivers an orderly sequence of arrivals.

[17] These techniques are not necessarily limited to higher level airspace

Arrival concept 1 – Single PBN routes for arrivals

Option 1a: PBN arrival 'replication'





The current arrival swathe is depicted by the extremities of the black arrows. The swathe covers 2 areas of dense population. Replicating this arrival flow by means of a single PBN route requires that route to be in the middle part of that swathe (the most frequently used path) and provides a single consistent point of interception of the final approach.

Replication here means that potential PBN capabilities are not utilised to provide relief in specific areas.

In this circumstance, traffic is concentrated on the red centreline subject to the issues described in the runway capacity section of this document.

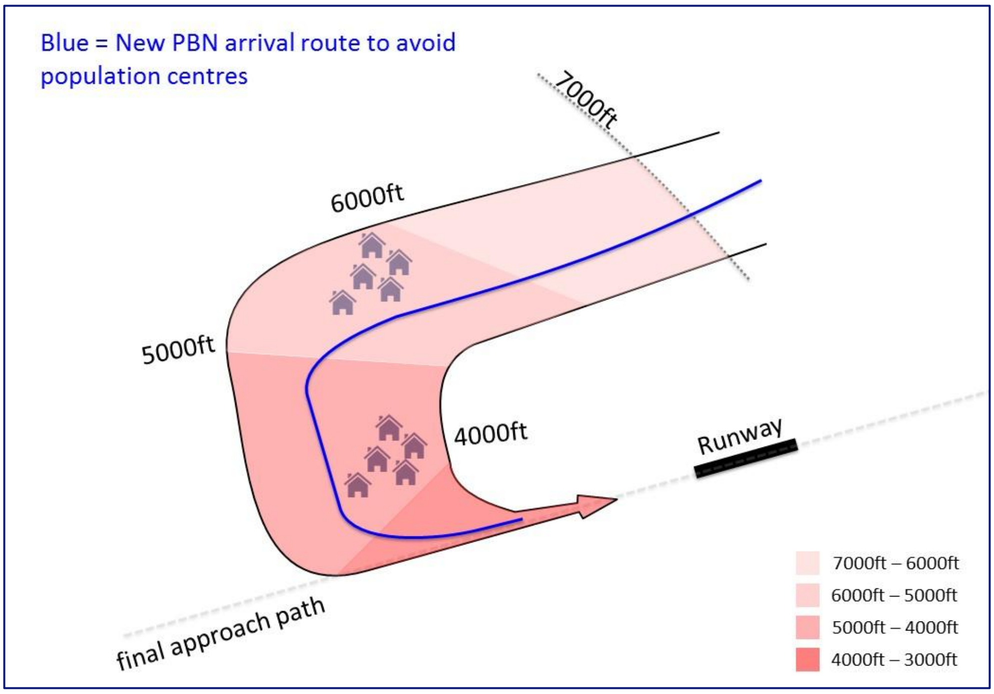
This was implemented at Bristol airport in 2014.

Table 19: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Reduced
New populations exposed to noise	No
Intensity / frequency of aircraft experienced by those affected	Increased for those under the route
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Positive impact. Optimised final approach and the route allows the FMS to fly an optimised CDA
Operational impacts	
Runway Capacity	Reduced runway throughput unless vectoring still allowed
ATC System capacity	Reduced ATC workload means they can optimise the final approach spacing
ATC system complexity	The existence of a route reduces ATC workload even if vectoring still sometimes required
Aircraft capability issues	
Flyability	No issues – positive impact for operators

FMC capacity	No Issues
Applicability	
Replication, that matches the centre of today's distribution of traffic is the default option for modernising approach tracks.	

Option 1b:A single PBN arrival route avoiding population centres



PBN is used to avoid overflight of specific areas, in this case, areas of dense population.

The blue route avoids those areas and concentrates arrivals onto a single track, subject to the issues described in the runway capacity section of this document.

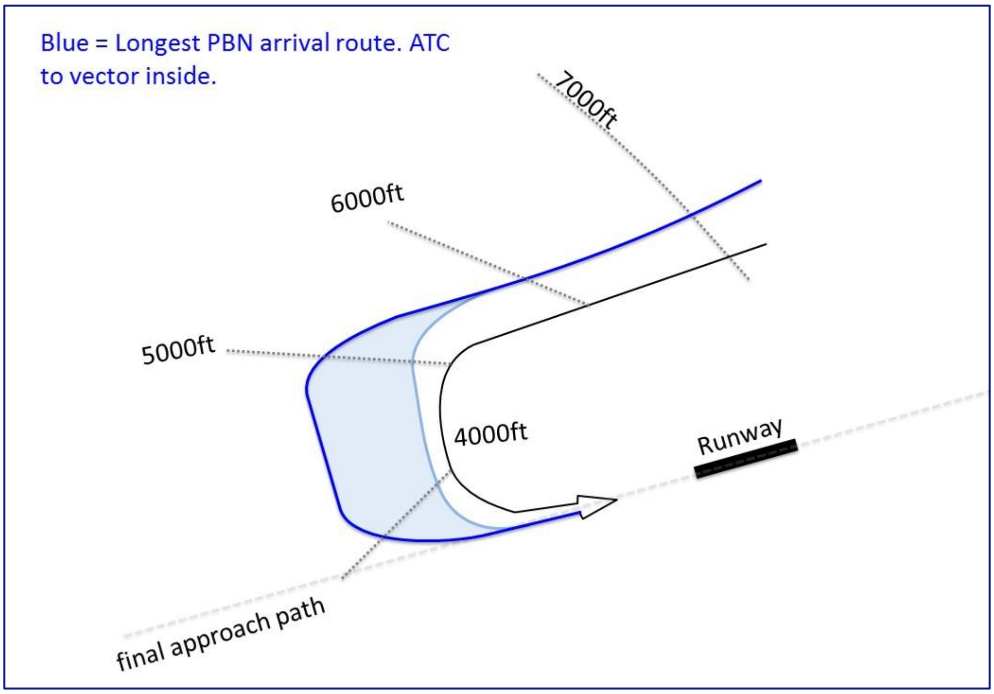
This has been successfully applied at Bristol airport for their easterly approaches in 2014, as the replicated route was adapted to minimise flight over land.

Table 20: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Reduced
New populations exposed to noise	No new populations although a PBN route means concentration of aircraft along that route
Intensity / frequency of aircraft experienced by those affected	Increased for those under the route
Noise Preferential Routes	N/A

Fuel / CO_2 efficiency	A single, optimised route enables FMS to fly the aircraft, enhancing CDA performance however the route length may have increased to avoid population
Operational impacts	
Runway Capacity	Reduced runway throughput unless vectoring still allowed
ATC System capacity	Reduced ATC workload means they can optimise the final approach spacing
ATC system complexity	The existence of a route reduces ATC workload even if vectoring still sometimes required
Aircraft capability issues	
Flyability	Positive impact as FMS can fly the aircraft
FMC capacity	No impact
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Option 1c: Single route with tromboning for dispersal (and capacity)



This solution involves a single PBN route (blue line) that reflects the widest turn onto final approach, with ATC routinely tactically vectoring aircraft inside the turn to achieve the optimal runway spacing, and, as a by-product generating dispersal.

This will produce concentration downwind with dispersal on the base leg.

Note that the alternative approach of defining the shortest route as the default PBN route, and tactically elongating it to achieve the sequence, **presents significant safety issues.** This is because aircraft left on the PBN route would turn onto the short base unless instructed otherwise – introducing a risk of catch up with aircraft tactically following a wider turn. It is therefore not considered further in this paper.

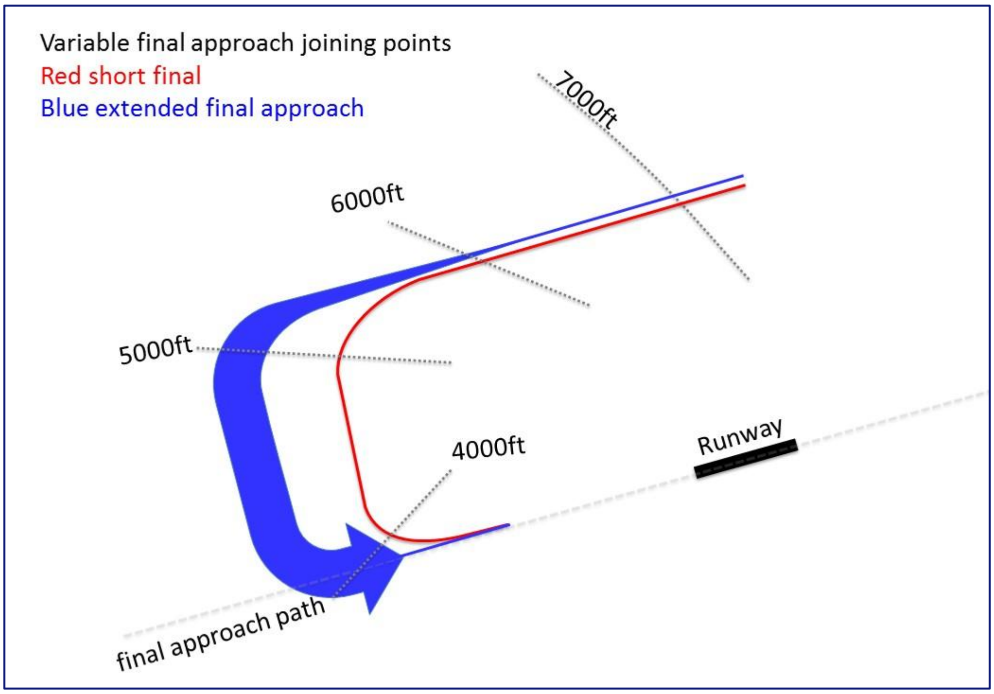
Table 21: Noise objectives - relief, dispersal

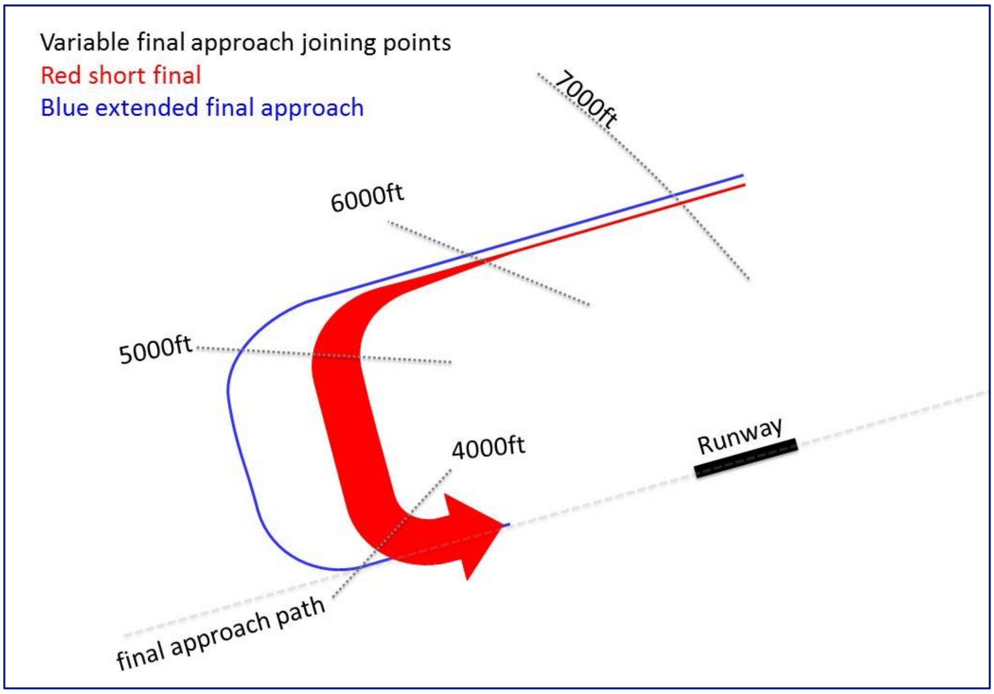
Environmental impacts	
Total number of people affected by noise	The downwind can be optimised to avoid population
New populations exposed to noise	No

Intensity / frequency of aircraft experienced by those affected	Concentrated downwind but the same on base leg
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Not ideal for fuel/ CO_2. Aircraft fuel for the longest published route although would very rarely fly it. Therefore carrying more fuel than required
Operational impacts	
Runway Capacity	Positive impact as ATC only have to rely on vectors for the base leg turn as opposed to downwind as well. Reduced ATC workload means they can optimise the final approach spacing
ATC System capacity	Positive impact as ATC only have to rely on vectors for the base leg turn as opposed to downwind as well
ATC system complexity	Positive impact as ATC only have to rely on vectors for the base leg turn as opposed to downwind as well
Aircraft capability issues	
Flyability	Operators would prefer a single route for the FMS to fly all the way to the ground
FMC capacity	No Issues
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Arrival concept 2: Multiple routes for arrivals relief

Option 2a: Quiet hours relief route





Instead of a single PBN route this has two routes to offer a degree of relief.

The blue route is used for periods of high demand (the longer final approach is necessary for ATC to provide optimal spacing between arriving aircraft). It is likely vectoring will still be required either side of the PBN route.

The red route delivers a shorter final approach which may be unsuitable during periods of high arrival demand but may be used during quieter periods e.g. at night. Depending on the length of final approach required, a very short route may need to utilise certain technologies which not all aircraft and/or operators have. It is likely that during these quieter periods, most arrivals will be left to follow the red route without the need for vectors.

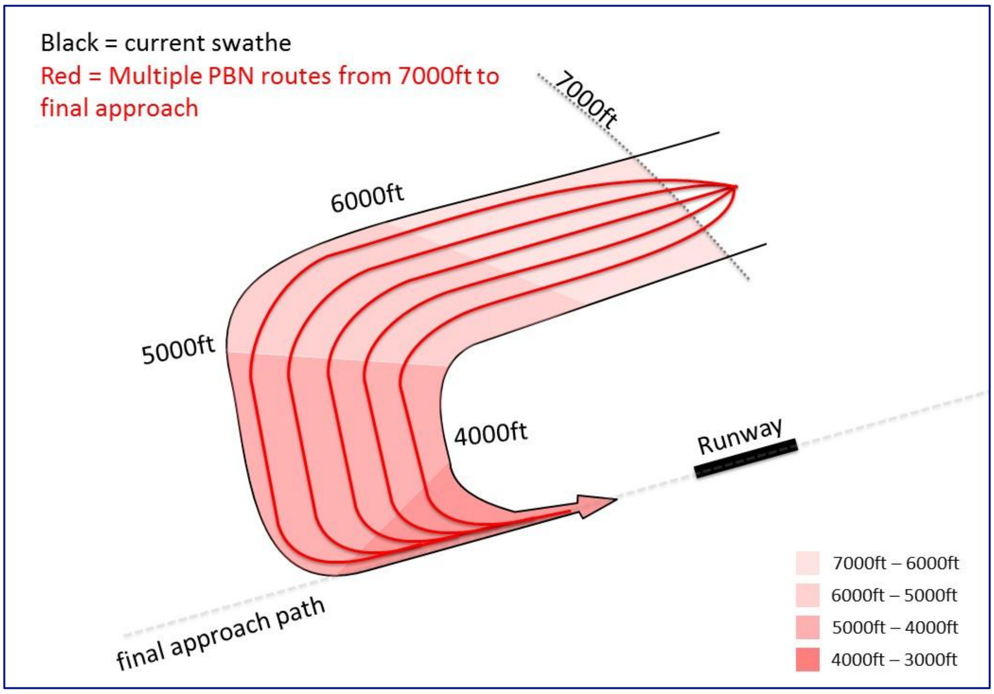
Note that the blue route could either be replication (1a) or a population avoiding alignment (1b).

Table 22: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	More than with just one route
New populations exposed to noise	Yes – this is likely depending on how ‘short’ the relief option is
Intensity / frequency of aircraft experienced by those affected	Increased for those under the primary route and relief route
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Positive impact. The shorter route reduces CO_2 emissions
Operational impacts	
Runway Capacity	No impact – some vectoring will ensure accurate spacing between pairs of arriving aircraft
ATC System capacity	Positive impact as ATC only have to rely on vectors for the base leg turn as opposed to downwind as well

ATC system complexity	The additional route increases complexity slightly although would only be used during quieter periods. Increased chance of error in crews selecting ‘wrong’ procedure
Aircraft capability issues	
Flyability	The shorter route may require the latest technology which very few operators currently have
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Option 2b: Multiple PBN arrival relief routes



This option consists of multiple arrival routes to offer a degree of relief to communities under the arrival paths.

These would not be used to disperse traffic as ATC would operate one route at a time but those routes could vary throughout the day or week.

As described in the runway capacity section of this document, although a single route may be in use at any time, the effects of vectoring and existence of an arrival swathe would still exist, albeit a smaller swathe than compared to sole reliance on vectoring. These routes may exist from 7,000ft down to final approach, typically 3-4,000ft.

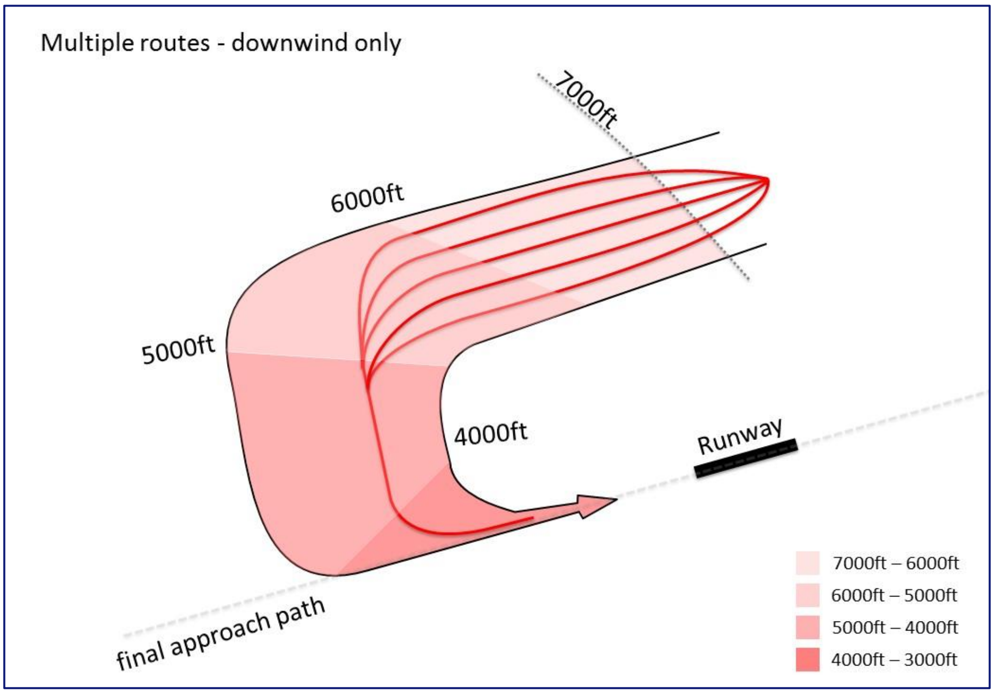
The amount of relief offered would depend on the route separation, at 3000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document). These distances would need to increase for options aimed at relief from higher altitude routes.

During periods of use, all flights would be concentrated on the chosen relief route.

Table 23: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	More than just one route but a similar number to today
New populations exposed to noise	No as all routes are under the current arrival swathe
Intensity / frequency of aircraft experienced by those affected	Yes, when one of the route is in use, all aircraft will use that route for the duration of the specified time period
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Crews would probably always fuel for the longest route, increasing CO_2 emissions
Operational impacts	
Runway Capacity	No impact so long as vectoring still allowed
ATC System capacity	Positive impact as ATC only have to rely on vectors to ‘fine tune’ arrival spacing
ATC system complexity	Multiple routes much harder to manage, increased chances of error and flight planning issues. Ability to use downwind routes depends on the delivery of aircraft from the network
Aircraft capability issues	
Flyability	No flyability issues but there are flight planning issues and increased chances of error
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Option 2c: Multiple PBN arrival relief routes (downwind only)



Similar to Option 2b but multiple routes are only utilised on the ‘downwind’ leg and then they concentrate onto a single ‘base-leg’ route.

This may be advantageous where there is an obvious area to position a single route on base leg in accordance with local requirements.

The amount of relief offered would depend on the route separation, at 3000ft, relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document). These distances would need to increase for options aimed a relief from higher altitude routes.

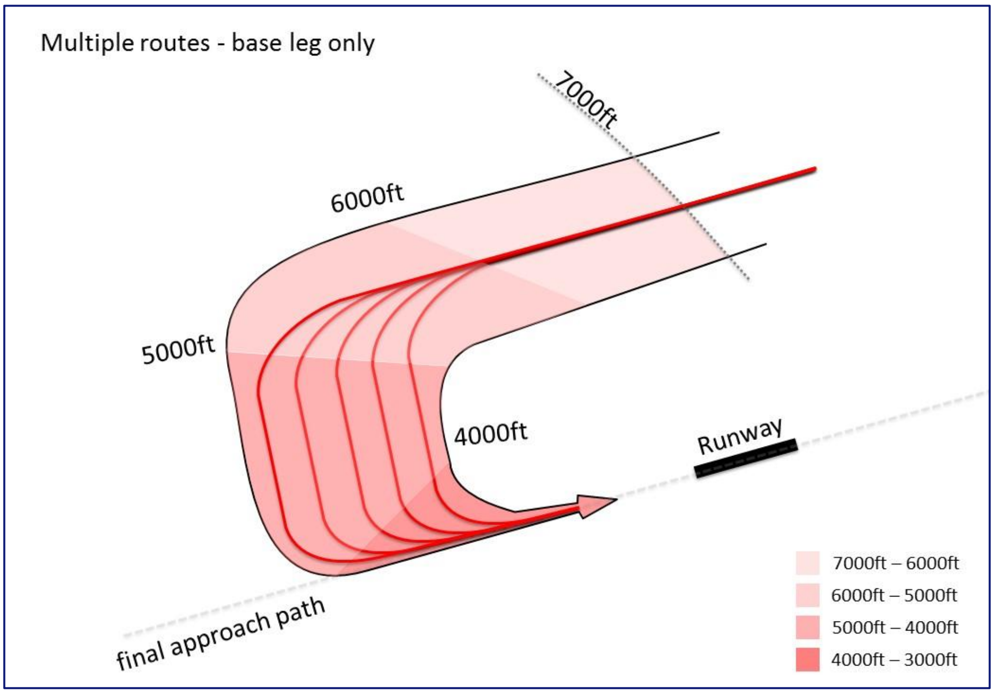
During periods of use, **all** flights would be concentrated on the chosen relief route.

Table 24: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Fewer on base leg
New populations exposed to noise	No

Intensity / frequency of aircraft experienced by those affected	Increased for those under the base leg route
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	No impact
Operational impacts	
Runway Capacity	No impact so long as vectoring always allowed
ATC System capacity	Positive impact as ATC only have to rely on vectors to ‘fine tune’ arrival spacing
ATC system complexity	Ability to use downwind routes depends on the delivery of aircraft from the network. Multiple routes much harder to manage, increased chances of error and flight planning issues
Aircraft capability issues	
Flyability	No flyability issues but there are flight planning issues and increased chances of error
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Option 2d: Multiple PBN arrival relief routes (base-leg only)



Opposite to Option 2c, there may be an obvious area to position the downwind route (c. 7,000-4,500ft) however communities situated under ‘base-leg’ desire relief. Consequently, a series of multiple PBN base-leg routes are designed and their use rotated to afford a degree of relief.

The amount of relief offered would depend on the route separation, at 3,000ft relief routes would need to be at least c.1km away to be perceptibly quieter, c.2km away to be half as loud and c.4km away to be considered ‘much quieter’ (see relief definition in the noise objectives section of this document). These distances would need to increase for options aimed a relief from higher altitude routes.

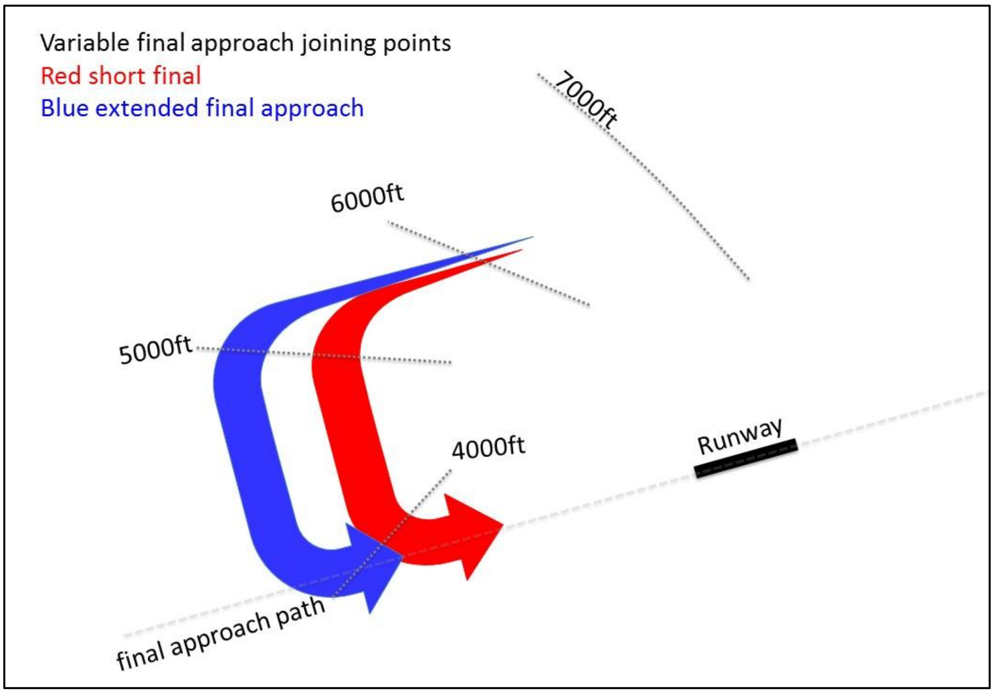
During periods of use, **all** flights would be concentrated on the chosen relief route.

Table 25: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Reduced downwind, more on base-leg than just a single route
New populations exposed to noise	No

Intensity / frequency of aircraft experienced by those affected	Increased for those under the route in use at the specified time
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Crews likely to always fuel for the longest route increasing CO_2 emissions
Operational impacts	
Runway Capacity	No impact if vectoring still allowed
ATC System capacity	Positive impact as ATC only have to rely on vectors to 'fine tune' arrival spacing
ATC system complexity	Multiple routes much harder to manage, increased chances of error and flight planning issues
Aircraft capability issues	
Flyability	No flyability issues but there are flight planning issues and increased chances of error
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
Applicability depends on the height of the proposed change: Applicability depends on the height of the proposed change, a description of the altitude based priorities is presented earlier in this document, local requirements for noise relief should be agreed as part of the design options.	

Option 2e: Variable joining point for quiet hours relief route (vectoring)



This solution uses vectors to provide variable final approach joining points to generate periods of relief for each affected community.

These points would be target areas for ATC to refer to while tactically managing flows, rather than being formal PBN routes.

The blue route is used for periods of high demand, subject to longer final approach which is necessary for ATC to provide optimal spacing between arriving aircraft.

The red route delivers a shorter final approach which may be unsuitable for use during periods of high arrival demand but may be used during quieter periods e.g. at night.

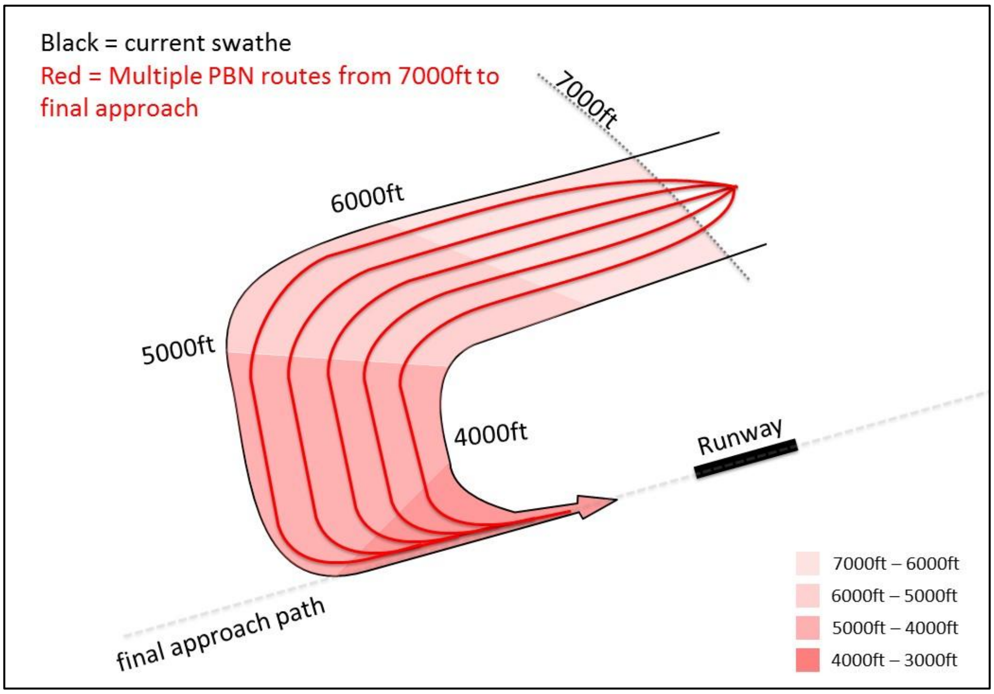
It should be noted that this is not strictly a PBN solution; it relies on local procedures to influence tactical interventions and so may be applied in today's airspace environment.

Table 26: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Increased compared to just the one swathe
New populations exposed to noise	No, assuming the shorter route is already sometimes used. Yes, if the shorter route is not currently overflown
Intensity / frequency of aircraft experienced by those affected	Same as today assuming the shorter route is already, at least sometimes, used. Frequency is increased if the shorter route is not currently overflown
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Potential improvement if the shorter route is not currently used.
Operational impacts	
Runway Capacity	No impact
ATC System capacity	No impact
ATC system complexity	Slight increase but likely to be manageable
Aircraft capability issues	
Flyability	No issues assuming the shorter route is already sometimes used
FMC capacity	No issues
Applicability	
This could be applied in either conventional or PBN route environments.	

Arrival concept 3: Multiple PBN arrival routes for dispersal

Option 3a: Multiple PBN arrival routes for dispersal



Multiple arrival routes are deployed here to offer a degree of dispersal through random or sequential allocation.

In principle this option could be designed to mirror option 2a, 2b or 2 c with the multiple route option following the whole procedure, just base leg or just downwind leg.

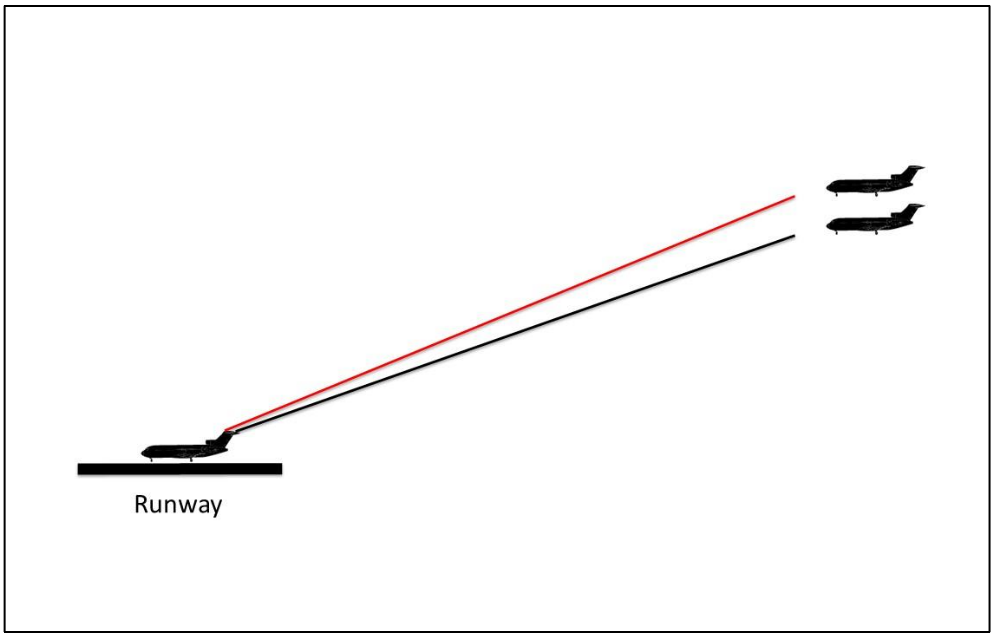
Table 27: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	No more than currently but more than just one route
New populations exposed to noise	No
Intensity / frequency of aircraft experienced by those affected	Similar to today
Noise Preferential Routes	N/A

Fuel / CO_2 efficiency	Operators would probably always fuel for the longest route
Operational impacts	
Runway Capacity	Negative impact – would be extremely difficult to judge accurate spacing
ATC System capacity	Negative impact. Significant chance of error. ATC likely to leave much bigger gaps between arriving pairs
ATC system complexity	Introduces significant complexity and safety issues as a result of catch up, flight planning and fuelling scenarios. A random allocation is not possible
Aircraft capability issues	
Flyability	Significant issues with flight planning and fuelling. Which route would they file on their flight plan? Chances for controller and pilot error
FMC capacity	Additional routes would add pressure to FMC capacity issues
Applicability	
This would present runway spacing and safety issues as routes with tighter turn would catch up those with wider turns and vice versa. This could not be implemented safely with current technology.	

Arrival concept 4: Options for final approach

Option 4a: Slightly steeper final approach



Approach angles are normally 3° (meaning a reduction in height of 318ft for every nautical mile travelled) and international guidelines deter airports from implementing approach angles in excess of this unless they are for the avoidance of obstacles (i.e. buildings or terrain).

Angles above 3.25° (Steeper approach) can become problematic during periods of poor visibility and angles in excess of 4.5° trigger special rules and regulations which would be prohibitive for many airports. However, airports are now beginning to trial, implement and challenge the international guidelines in order to prove that a slightly steeper 3.2° approach angle is acceptable without impacting on the ATC, airport and airline operation and affording a degree of noise benefit to those communities underneath and around final approach.

It should be noted that this option does not rely on PBN as the ILS could be re-configured to a steeper approach, although. However PBN approaches can stipulate approach angles as well.

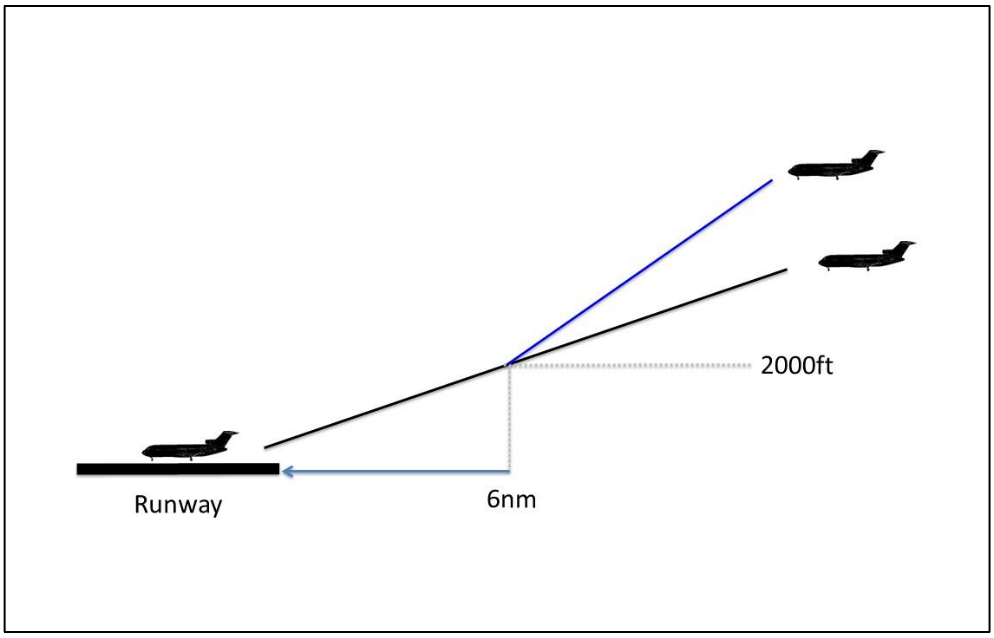
In order to overcome the technical difficulties mentioned above, Option 4b has potential to offer improved noise mitigation.

Please note that steeper approaches could work in combination with other arrival options depending on the specific circumstances.

Table 28: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Fewer as noise contour likely to be reduced
New populations exposed to noise	No although noise may be 'moved around' so some communities may have increased noise whereas others may hear less
Intensity / frequency of aircraft experienced by those affected	No effect
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	No impact
Operational impacts	
Runway Capacity	No impact
ATC System capacity	No impact if all arrivals are using the same approach path up to 3.2°
ATC system complexity	No impact if all arrivals are using the same approach path 3.2°. Effects of an approach steeper than 3.25° are unknown
Aircraft capability issues	
Flyability	3.2° under investigation at Heathrow and implemented at Frankfurt. Approaches steeper than 3.25° create difficulties
FMC capacity	No issues
Applicability	
Subject to current studies and a challenge to ICAO, approaches up to 3.2° could be applied widely.	

Option 4b: 2-segment approaches (to overcome issue with approaches greater than 3.25°)



The technical issues described in Option 4a are most prevalent in the final stage of the approach, typically within 5-6nm from touchdown.

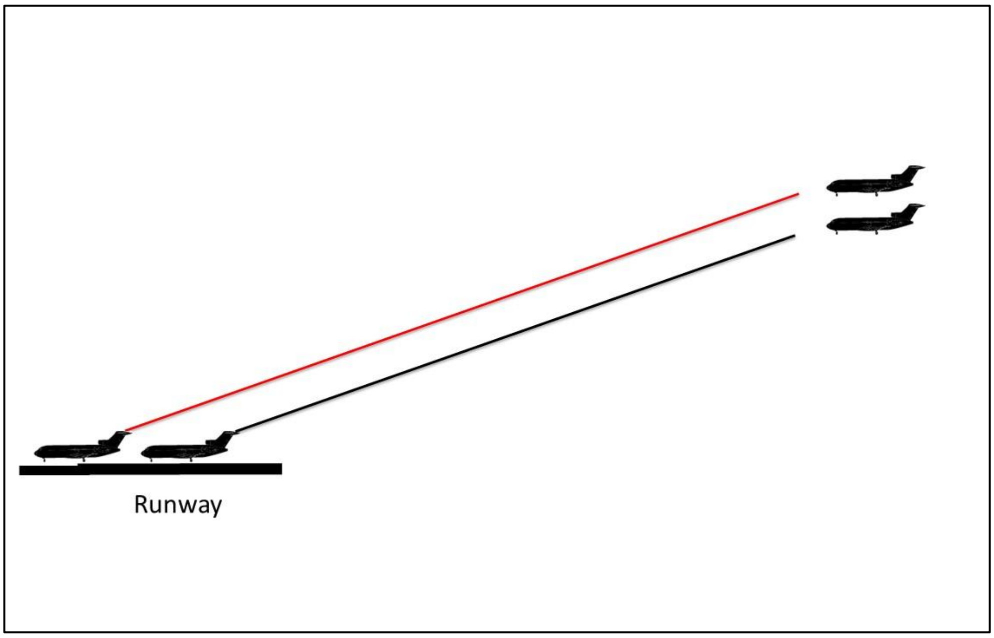
Simulator trials have taken place (outside of the UK) in order to understand the art of the possible with regards to steeper approaches (up to 5°) until the aircraft reaches 5-6nm from the runway whereby it reverts to a standard 3° (or 3.2°) approach. The trials have identified numerous issues, however work is still ongoing to further develop the concept and identify solutions to these problems.

Heathrow carried out some 'proof of concept' live trial flights between December 2014 and June 2015 whereby 6 British Airways arrivals flew a 4.5° approach, reduces to a shallower standard 3° approach at 4nm from touchdown. The resulted in aircraft 1000ft higher at 12nm from touchdown than if they were on a 3° approach. The trials were carried out in a controlled environment with a much greater distance between arrivals than would ordinarily be operationally acceptable. Therefore, further research, potentially supported by further trials, will be required in order to be able to safely increase the numbers of arrivals performing such approaches.

Table 29: Noise objectives - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Likely to be reduced
New populations exposed to noise	No although Noise likely to be ‘moved around’
Intensity / frequency of aircraft experienced by those affected	Possibly increased noise at the point at which the approach angle reduces
Noise Preferential Routes	N/A
Fuel / CO_2 efficiency	Unknown
Operational impacts	
Runway Capacity	Unknown
ATC System capacity	Unknown
ATC system complexity	Unknown
Aircraft capability issues	
Flyability	Unknown
FMC capacity	Unknown
Applicability	
Unknown	

Option 4c: Displaced threshold



This does not change the angle of approach but moves the earliest point at which the aircraft can touchdown further along the runway. The effect is the same as ‘moving the runway’ slightly further away therefore the approaching aircraft are higher over existing communities.

Such a concept may only be possible at airports with long runways where its full length is not required by landing aircraft but it is required for departing aircraft as some aircraft need more runway to take-off than they do to land.

Table 30: Noise objective - relief, dispersal

Environmental impacts	
Total number of people affected by noise	Likely to be reduced as Noise Contour may be smaller
New populations exposed to noise	Unlikely
Intensity / frequency of aircraft experienced by those affected	The same
Noise Preferential Routes	N/A

Fuel / CO_2 efficiency	No impact, although there is a potential for slightly different ground taxi routes and times
Operational impacts	
Runway Capacity	No impact assuming an airport would not displace the threshold so much so as to reduce throughput i.e. make rapid exit taxiways unavailable
ATC System capacity	As above
ATC system complexity	As above
Aircraft capability issues	
Flyability	No issues assuming adequate stopping distance still available
FMC capacity	No issues
Applicability	
Airports which have a runway longer than operationally required to accommodate even their heaviest/fastest aircraft.	

Option 4d: Variable network airspace structures above 7,000ft for relief

Network airspace structures include holds, point merge or network tromboning routes structures (see Appendix E) in addition to routes.

The DfT environmental guidance[18] to the CAA highlights that noise is not normally a priority for airspace structures above 7,000ft, the focus being on route efficiency. This is also in line with the operational requirement for the airspace which focus on operational efficiency which generally involves processing aircraft through the system as quickly as possible with minimal interval intervention – conditions which contribute to fuel/ CO_2 efficiency.

Any concept that has options for the positioning of an airspace structure will, by definition, be less efficient; this is because one would assume the default position is optimal and that any alternative generated for the purposes of avoiding overflight of specific areas would be less efficient (otherwise it would be the default).

Furthermore network route structures, in particular those designed to absorb airborne delay (holds, point merge and trombones), take up large volumes of airspace which in turn means other routes have to have suboptimal positioning to get around them. Having alternative positions would increase the volume of airspace required to an impractical level – significantly degrading the overall performance of the neighbouring routes and significantly increasing the complexity and associated risk of the airspace structure.

For these reasons no further consideration is given to noise solutions for airspace structures in the network above 7,000ft.

[18] https://www.gov.uk/government/publications/air-navigation-guidance

Annex A

Changes in on-track noise level due to lateral displacement

A.1 When designing noise mitigation routes it is important to understand the objective in terms of stakeholder expectations. This is because the degree of noise mitigation provided by routes that are offset from one another will depend on the spacing between the routes and the height of the aircraft.

A.2 CAA’s ERCD produced a discussion paper on behalf of the Noise Task Force which presents a scientific analysis of the relationship between spacing, height and the noise mitigation offered. Figure A1 is reproduced from that discussion paper and describes the relationship between lateral spacing and noise considering four broad thresholds – from ‘just perceptible’ to ‘much quieter’. Stakeholder engagement will be critical in determining which threshold a relief solution aims for.

A.3 Once the appropriate threshold has been determined, Figure A1 may then be used to determine the spacing required to provide the required noise mitigation.

A.4 Consider ‘Scenario A’ where noise mitigation through the need for relief routes is required for routes up to 4,000ft. If the stakeholder expectation is that relief will mean that the perceived noise impact is halved (i.e. a 10dBA reduction) when the relief route is active, then Figure A1 shows that the spacing between two routes would need to be at least 2500m (where the purple bar which represents impacts from aircraft at 4,000ft reaches the line for ‘half as loud’).

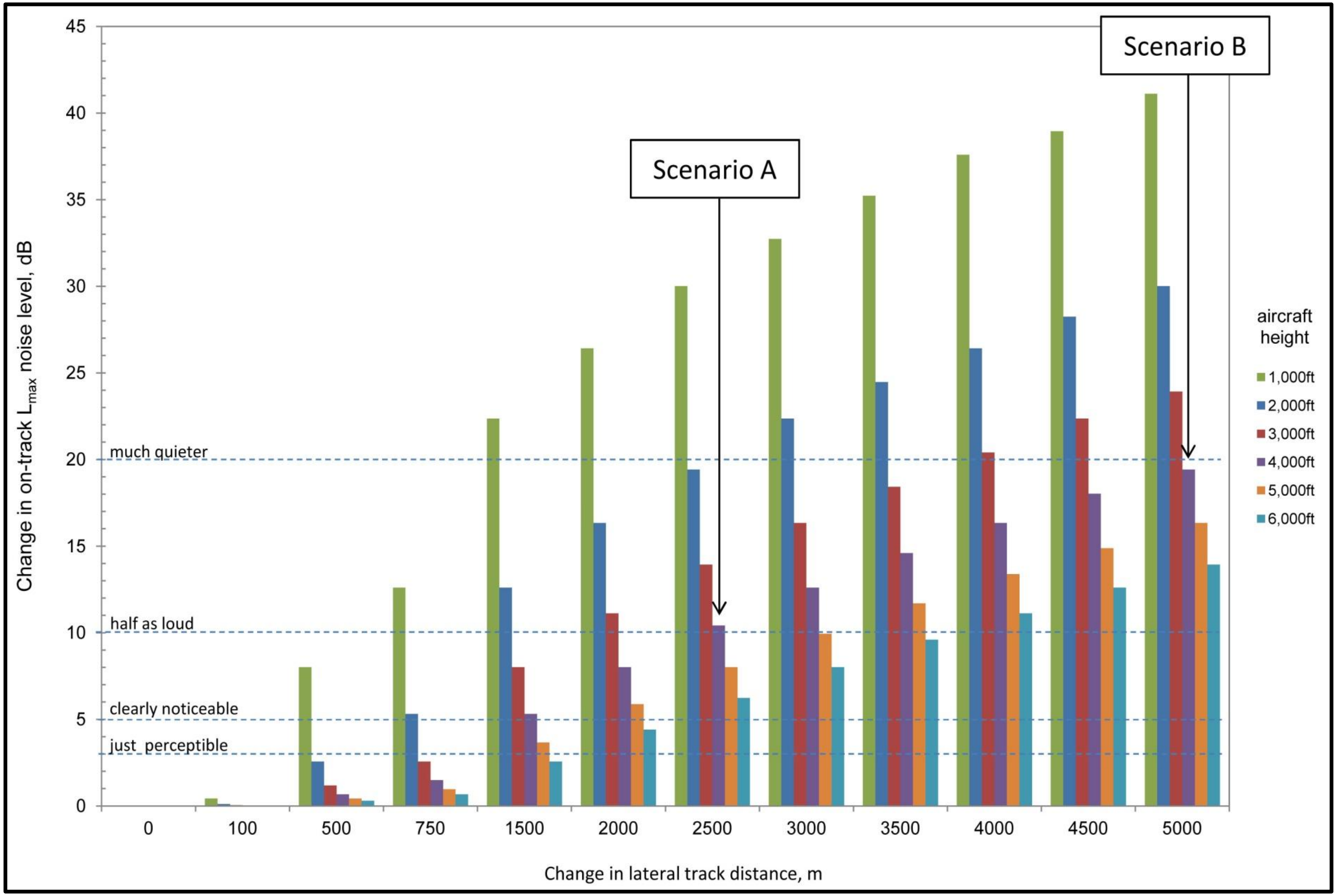
A.5 If, however, the stakeholder expectation is that relief will mean periods that are ‘much quieter’ (i.e. a 20dBA reduction), then the spacing required would need to be at least 5,000m, as per ‘Scenario B’.

A.6 Managing stakeholder expectations will be key to the successful application of relief routes. Halving the perceived noise will not be seen as a success if stakeholders had expected aircraft noise to be much quieter.

A.7 Furthermore, track keeping of aircraft must be taken into account. Interpreting Figure A1 as the required separation between routes takes no account of potential variation in track keeping of aircraft on the route.

A.8 Finally it should be noted that no relief solution is likely to reduce noise to an absolute zero due to the potential propagation of noise over large distances and the volume of air traffic in UK airspace.

Figure A1: Changes in on-track noise level due to lateral displacement as a function of aircraft altitude. This table applies equally to arrivals and departures.



Annex B

FAS Noise Task Force discussion paper: Definition of aircraft overflight for the purposes of noise[19]

Introduction

B.1 In Guidance published in January 2014 to the Civil Aviation Authority on the environmental factors it should take into account when exercising its air navigation functions, the Government stated:

"Flights over National Parks and AONB are not prohibited by legislation as a general prohibition against overflights would be impractical. Government policy will continue to focus on minimising the overflight of more densely populated areas below 7,000 feet (amsl)."

B.2 Feedback from residents affected by recent SID trials at the London airports has highlighted the difficulties in determining whether an aircraft is considered to be overhead or to the side of its expected flight path. Separately, the CAA has also recognised that there is no internationally agreed definition of an aircraft 'over-flight'.

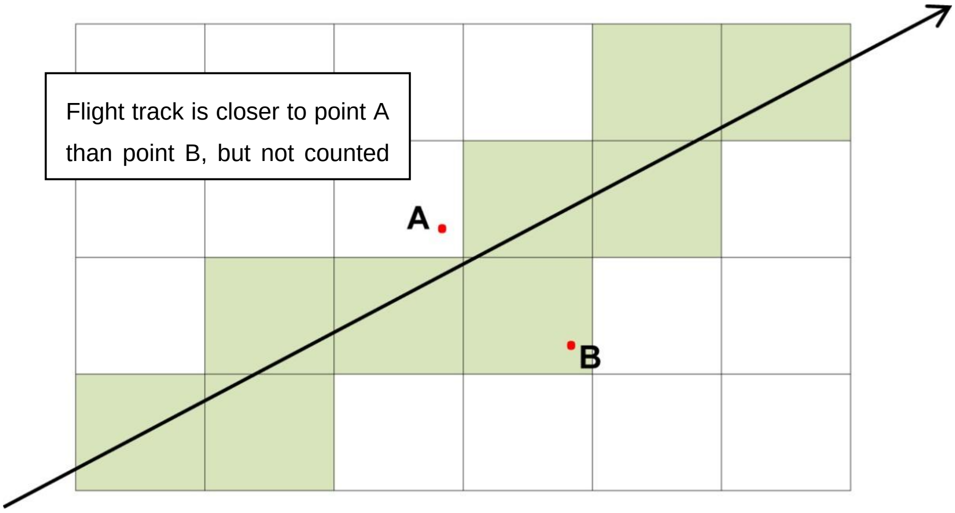
B.3 One workstream area the CAA is planning to do, as part of its duty to publish information on aviation and the environment, is to develop consensus on supplemental information, such as the number of overflights. This paper provides information on a proposed definition of overhead based on the direction of the sound propagating from an aircraft in relation to the receiver (e.g. a person on the ground or a noise monitor). The proposal is based on methods of modelling sound propagation from aircraft which have been agreed internationally by the aviation industry and the aircraft noise modelling community.

[19] This paper was produced by the CAA's Environmental Research and Consultancy Department (ERCD) which the Noise Task Force considered for the definition of aircraft overflight. It does not constitute formal guidance and is published within this document for transparency purposes only.

Track density diagrams

B.4 Track density diagrams have been used previously for ad-hoc studies to indicate the intensity of flights over a particular region. These diagrams effectively count the number of flights that pass through grid squares positioned over a region of interest. However, depending on the geometry of the flight path and the size of the grid squares, a ground track could be located relatively close to a point on the ground but still not be counted as overhead, whereas other points further away would be counted as being overflown, see Figure B1. Larger grid squares can be used to overcome this issue but the diagrams then become less effective at indicating the overall pattern of flight paths.

Figure B1: Illustrative flight track passing through grid squares



Lateral attenuation of aircraft noise

B.5 Above ground elevation angles of 60° (where 90° would be directly overhead), aircraft sound is influenced by the distance between the aircraft and a location on the ground, the amount of sound emission and for integrated noise metrics, the duration of the sound.

B.6 Below ground elevation angles of 60° the sound propagation begins to be influenced by atmospheric scattering effects, engine shielding (which is also influenced by engine type/location) and at low angles, ground absorption. To avoid the added complications of these effects a current working assumption that has been used previously[20] is that an aircraft is overhead if it passes above 60° to the horizontal (i.e. within 30° either side of vertical).

B.7 For aircraft (with wing mounted engines) to the side of a noise monitor, studies have shown no evidence of lateral directionality at ground elevation angles greater than 60°, see Figure B2. At lower elevation angles 'lateral attenuation' starts to become important – i.e. the propagation of sound down to the ground is no longer directionally uniform.

B.8 It is straightforward to calculate the lateral distance of an aircraft flying through the boundary of the 60° region for any given height above the ground. At this boundary an aircraft would give a noise level approximately 1.5 dB lower than if it had directly overflown the centre at the same height, irrespective of the aircraft height. The same is not true of aircraft at a fixed distance to the side, where the noise difference relative to overhead will diminish with increasing altitude.

B.9 The effect of the 60° concept is illustrated in Figure B3. Also shown for information is the boundary of a 48.5 degree region (relative to horizontal). At this boundary, an aircraft would give a noise level approximately 3 dB lower than if it had directly overflown the centre at the same height.

B.10 Under the 60° concept, an aircraft at a height of 2,000ft and located, for example, 400 metres to the side of a point on the ground would not be considered overhead. However, at the same lateral distance an aircraft flying at 3,000ft would be considered overhead. Whilst an aircraft at a ground elevation angle of less than 60° may still be perceived (visually) as overhead, its noise level will be attenuated to a greater, potentially noticeable extent compared with directly overhead and thus the 60° concept provides consistency across different altitudes.

[20] ERCD Report 0207, *"Departure Noise Limits and Monitoring Arrangements at Heathrow, Gatwick and Stansted Airports"*, March 2003

60° track density diagrams

B.11 As noted above, although track density diagrams can be useful for indicating the intensity of flights over a particular region, they may not always provide a useful indication of whether an aircraft is likely to be considered ‘overhead’ or not, since an aircraft is only counted if the ground track passes through particular grid squares - see Figure B4 which shows an example for a single 27R BPK departure at Heathrow.

B.12 However as illustrated previously in Figure B3, the height of an aircraft can also affect whether an aircraft is considered to be overhead or not (i.e. whether it falls inside or outside a 60° region). To overcome this problem it is possible to generate a track density plot which also counts an aircraft if its ground track passes within 60° to the horizontal of any grid square.

B.13 Figure B5 illustrates, for the same 27R BPK departure, how the coverage area gets progressively wider as the aircraft continues to climb. Thus in Figure B5, the outer edge of the green shaded area defines a constant 1.5 dB reduction in noise relative to the maximum noise level directly beneath the aircraft flight track (in this example, up to 17,000ft).

B.14 Building on Figure B4, a traditional 500 metre grid square track density plot is shown in Figure B6 for Heathrow summer 2012 departures. A corresponding track density plot using the 60° concept is shown in Figure B7. Closer to the airport, there is little difference between the two figures.

B.15 The CAA intends to update this paper to illustrate overflight diagrams for the 3 dB / 48.5°concept (amending Figures B4 to B7 in this paper).

Figure B2: Attenuation of noise to the side of an aircraft (wing mounted engines, SAE AIR-5662)

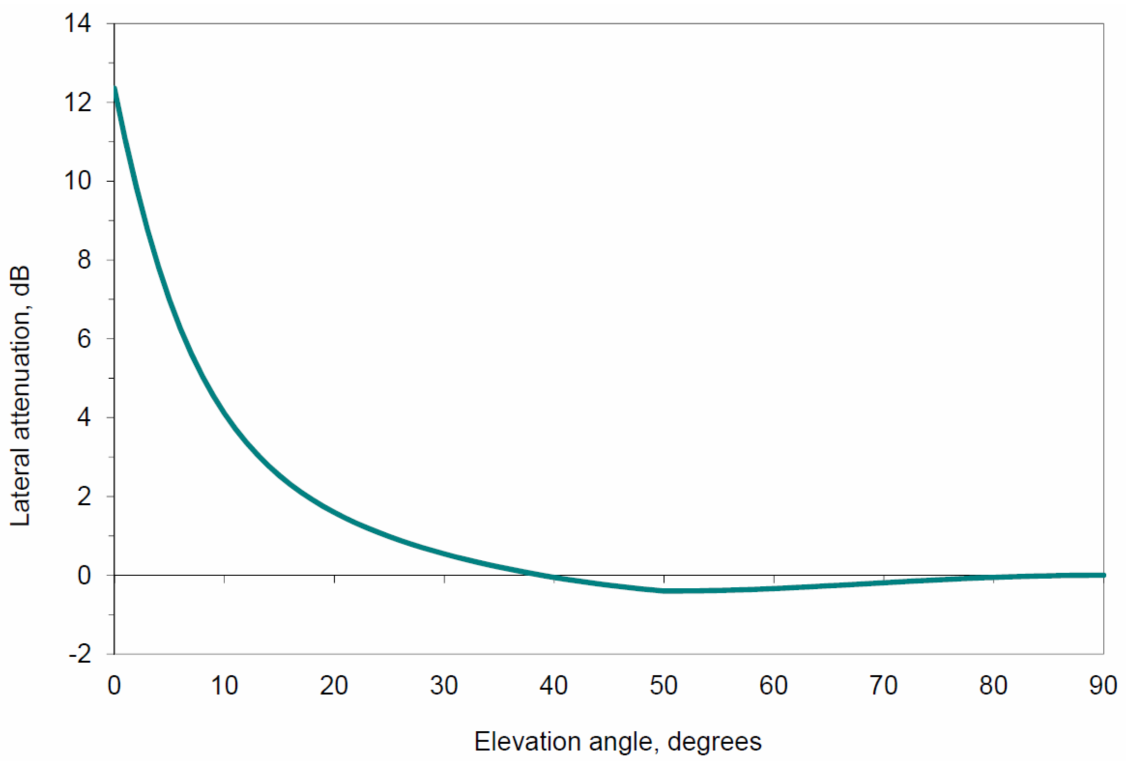


Figure B3: Lateral distance of aircraft from overhead at the boundary of a 60° region (48.5° region also shown for information)

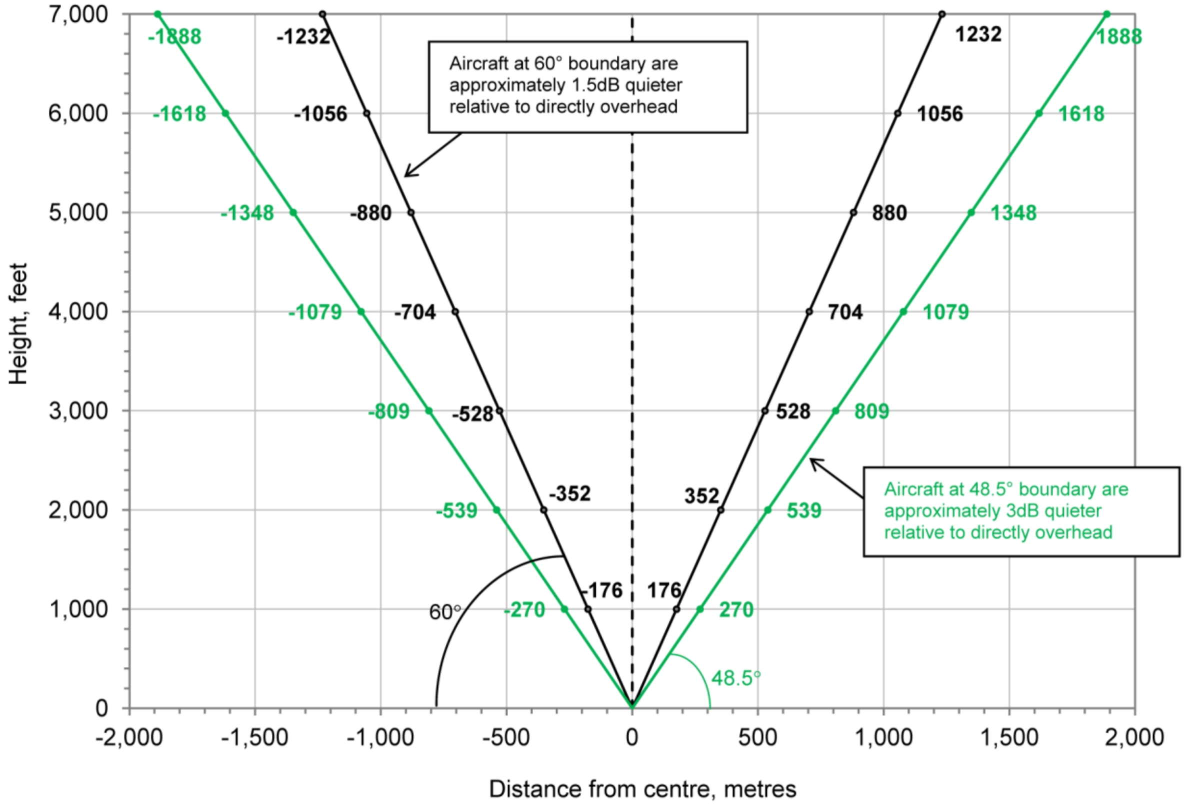


Figure B4: Heathrow 27R BPK departure track passing through grid squares

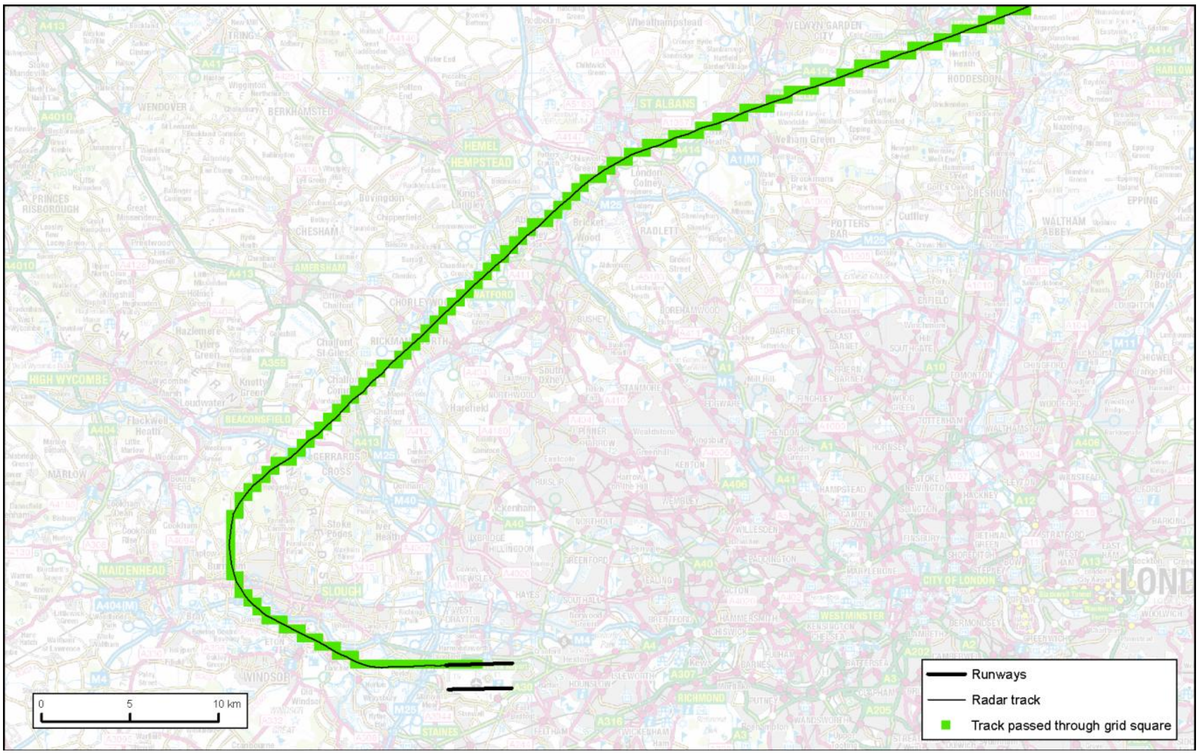


Figure B5: Heathrow 27R BPK departure track passing within 60° to the horizontal of grid squares (i.e. within ±30° of vertical)

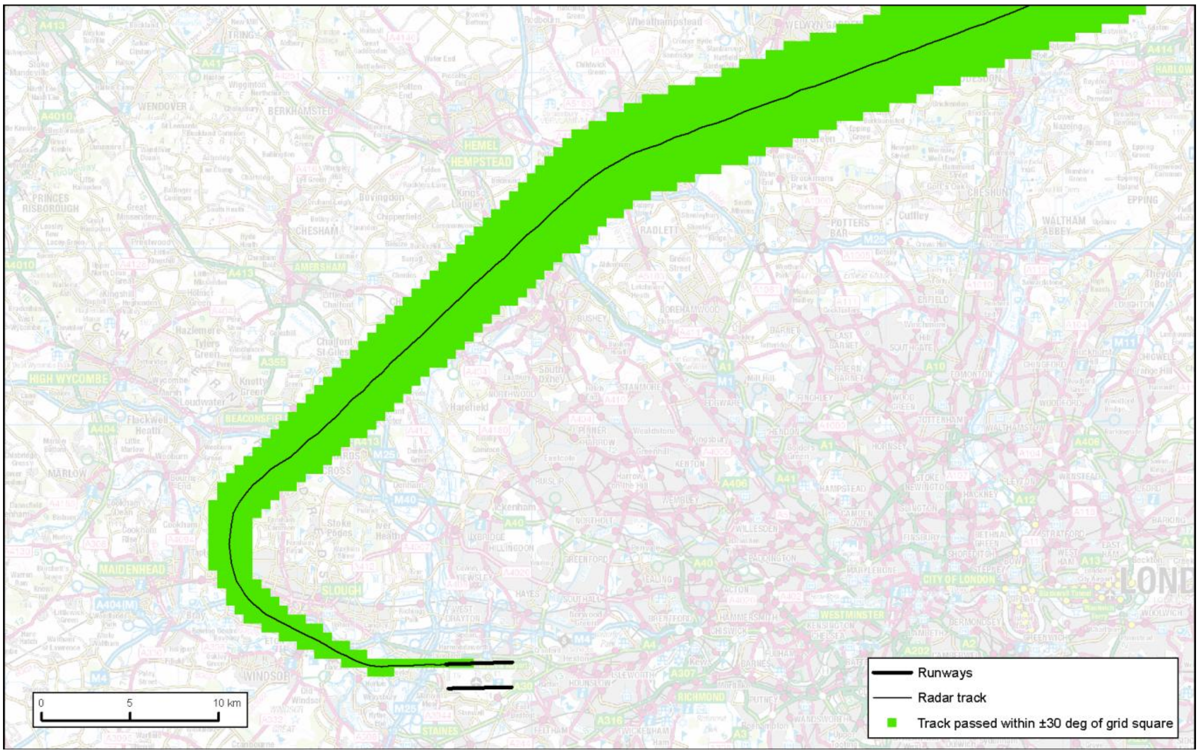


Figure B6: Track density plot for Heathrow summer 2012 departures

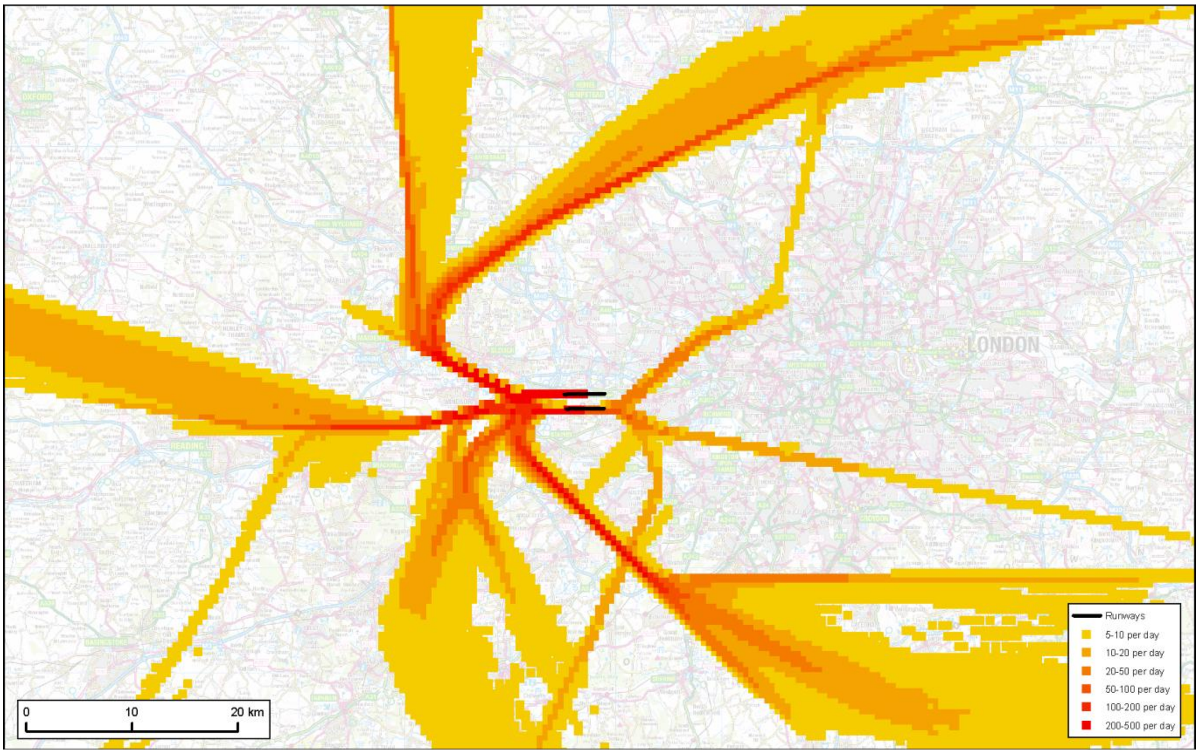
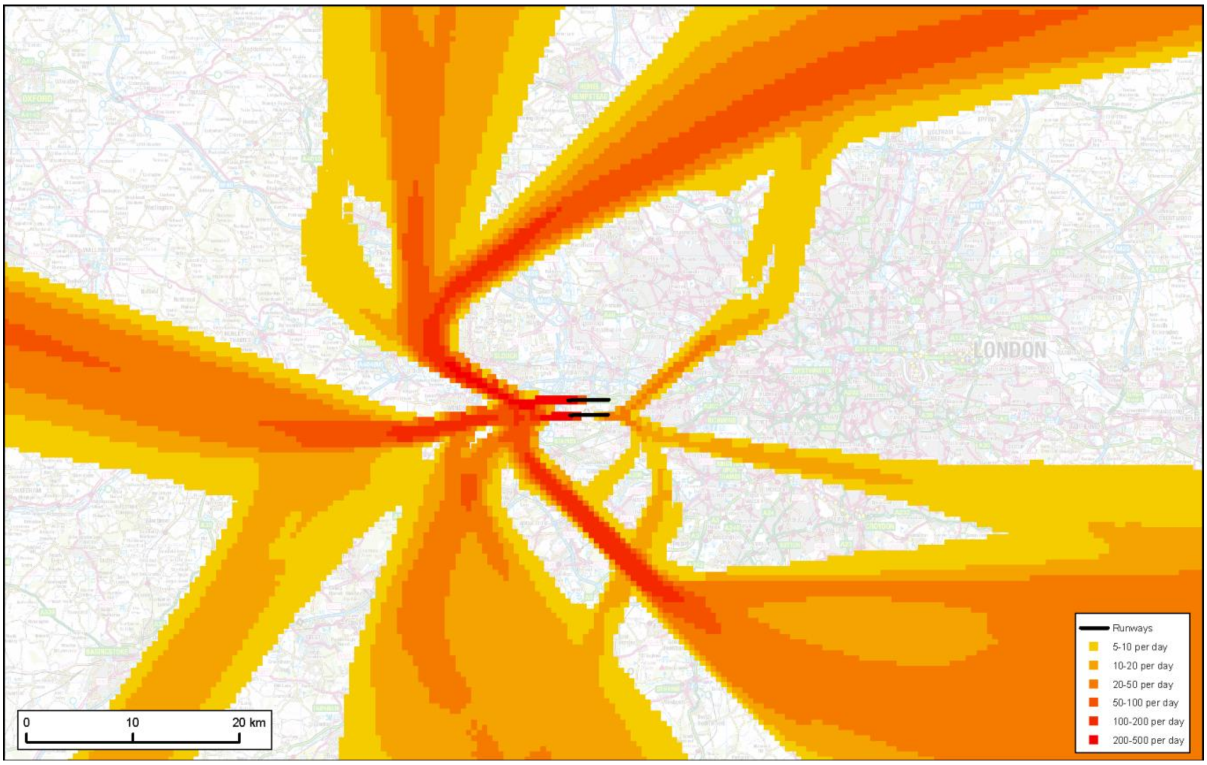


Figure B7: 60 track density plot for Heathrow summer 2012 departures



ERCD August 2015

Annex C

Fuel / CO_2 opportunity costs calculation for noise mitigation solutions

C.1 A method for comparing the relative benefits of airspace designs that seek to address different objectives is key to establishing a justification for a chosen design that meets CAP725 requirements and is robust to challenge.

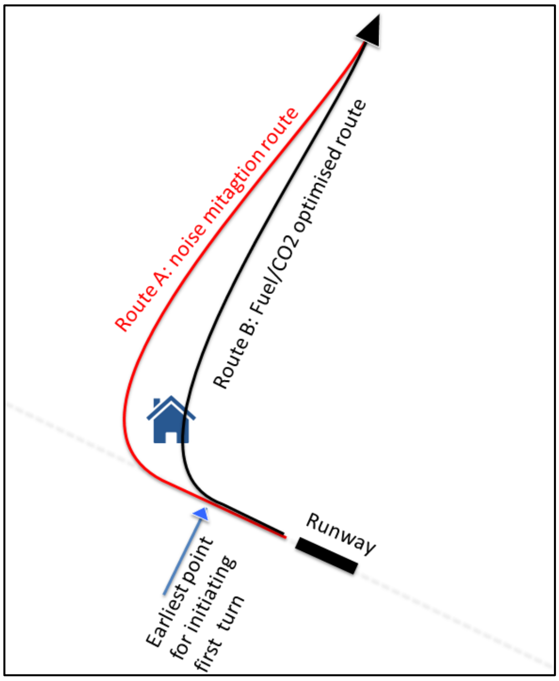
C.2 This is particularly relevant to the 4,000 to 7,000ft altitude band where noise and fuel / CO_2 benefits are to be balanced but can also help evaluate the opportunity costs noise mitigations below 4,000ft.

C.3 Balancing the noise benefits against CO_2 impacts objectively, requires the effects of both to be expressed in a similar metric. There is no established method for monetising noise benefits; however, CO_2 benefits can be readily calculated using established flight path and fuel burn modelling.

C.4 It is therefore possible to calculate an opportunity cost of the noise mitigation design in terms of the fuel / CO_2 benefit that could be accrued if the design was instead focused on fuel / CO_2 rather than noise.

C.5 For example, Route A in Figure C1 is optimised for noise by extending the route to avoid the populated area. Route B is the fuel / CO_2 optimised alternative. If the difference between these routes is 10kg fuel per flight (31.5kg CO_2) and there are 10,000 flights per year, the opportunity cost of the noise mitigation is 100 tonnes of fuel and 315 tonnes of CO_2 per year. Assuming a £500 per tonne cost of fuel and a £10 per tonne CO_2 (these figures are illustrative only – current prices should be used), then the overall opportunity cost is £50,000 of fuel and £3,150 of CO_2 per year.

Figure C1



C.6 Should Route A be chosen for noise mitigation reasons, it would implicitly mean that the value of the noise mitigation is more than the opportunity cost, therefore more than £53,150 per year.

C.7 Whilst the CO_2 opportunity cost does not describe the full value of a design aimed at noise mitigation, if the noise mitigation design solution is subjectively prioritised over one which minimises the CO_2 impact then the noise mitigation can be inferred to be worth at least the value of the fuel / CO_2 generated as a consequence. Until there is a methodology for monetising noise benefits directly, the fuel / CO_2 opportunity cost methodology should be employed whenever noise mitigation solutions are being proposed.

Annex D

Noise abatement departure procedures (NADP)

D.1 Noise Abatement Departure Procedures (NADP) are described in ICAO guidance[21] and provides two examples of noise abatement departure procedures:

- NADP 1 which mitigates noise close to the aerodrome,
- NADP 2 which mitigates noise more distant from the aerodrome.

D.2 The procedure selected can affect how efficiently an aircraft climbs to cruise altitude, and thus affect the overall fuel used for a flight. Although a wide range of procedures may be developed within the NADP1 and NADP2 definitions, typical airline practice is to adopt an NADP2 procedure with reduced levels of both take-off thrust and climb thrust.

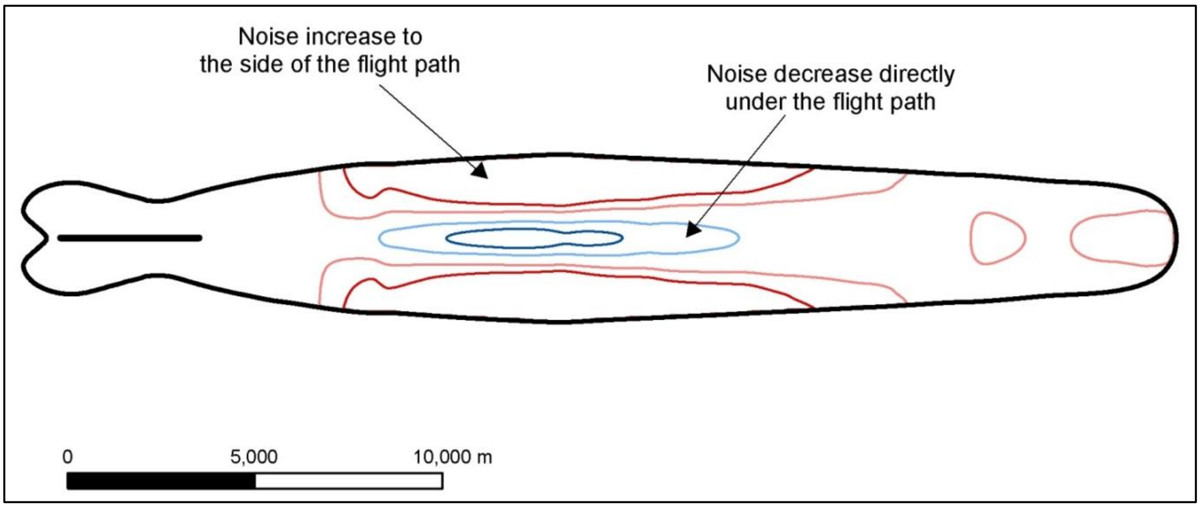
D.3 Airline operating procedures and practices dictate the choice of departure configuration and are not defined by procedures design or airport operators.

D.4 Procedure design around airfield departures that look to reduce the impact of noise may look to implement steeper departure climb gradients. This may encourage a change in operator departure procedures which may indeed reduce noise impact directly under the aircraft but, may have the unintended consequence of redistributing noise impacts on the ground, around the aircraft track. Designers should be aware of this consequence when considering increasing departure climb gradients.

D.5 The figure below shows the redistribution of noise associated with a change from an example noise abatement departure procedure to another: NADP2 to NADP1.

[21] ICAO Doc 8168

Figure D1


Noise increase to
the side of the flight path
Noise decrease directly
under the flight path
0
5,000
10,000 m

Annex E

Network solutions for streaming arrivals

E.1 This section describes PBN arrival route structures that may be required in the network airspace, generally above 7,000ft[22] to support the low level route options discussed earlier in this document.

Holds or 'stacks'

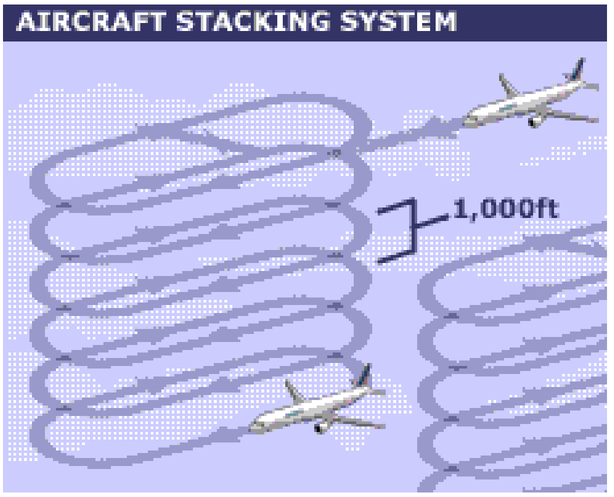
E.2 There are periods where arrival demand, i.e. the number of aircraft to land on a given runway, can exceed the runway capacity. This results in delay to the arriving stream of aircraft which is absorbed through the use of holding facilities such as racetrack or orbital holds, point merge arcs or the use of vectored tromboning or 'S'S patterns.

E.3 Aircraft racetrack holds are the most common in use today.

E.4 As aircraft are approaching their destination, the runway is the end of the line and is limited in capacity whereby only one aircraft can use it at aa time therefore multiple arrivals need to be 'held' until their runway landing slot is available. Imagine a three-lane motorway, narrowing to one lane. Queues are inevitable however where road vehicles can stop, aircraft cannot. At this point, the aircraft are put into orbital holding patterns. The first aircraft goes in at the lowest level with subsequent arrivals 'stacked' 1000ft on top. This allows ATC to manage the runway capacity constraint.

[22] These techniques are not necessarily limited to higher level airspace.

Figure E1: Example of stack holding



Courtesy: news.bbc.co.uk

E.5 There is often more than one holding stack catering for an airport. The stacks are used by ATC to delay excessive aircraft numbers and help maintain high landing rates by providing a constant reservoir of arriving aircraft to sequence onto a landing runway.

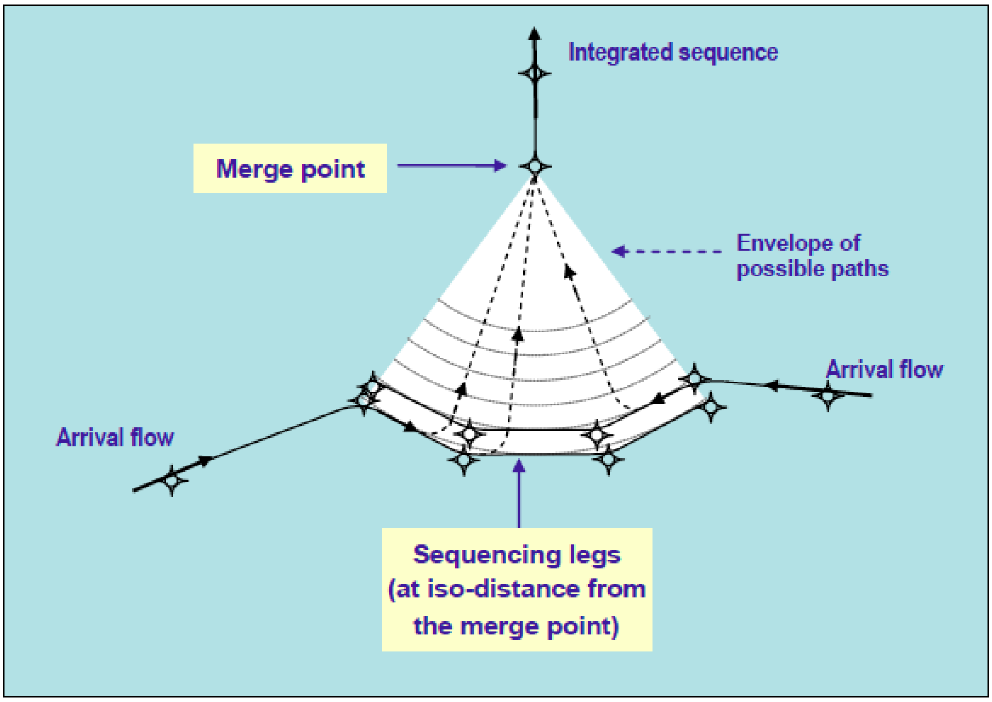
E.6 As ATC clear aircraft out of the hold, subsequent arrivals are ‘laddered’ down on top, ensuring at least 1,000ft vertical separation is maintained between each aircraft in the same hold.

Point merge

E.7 Point Merge is a method of delaying aircraft to reduce the use of orbital holding patterns whilst allowing controllers to sequence aircraft without, or with reduced, vectoring.

E.8 Aircraft fly along the sequencing legs in level flight and are instructed to turn to the ‘Merge Point’ at suitable intervals to create the distance between successive pairs of arrivals.

Figure E2

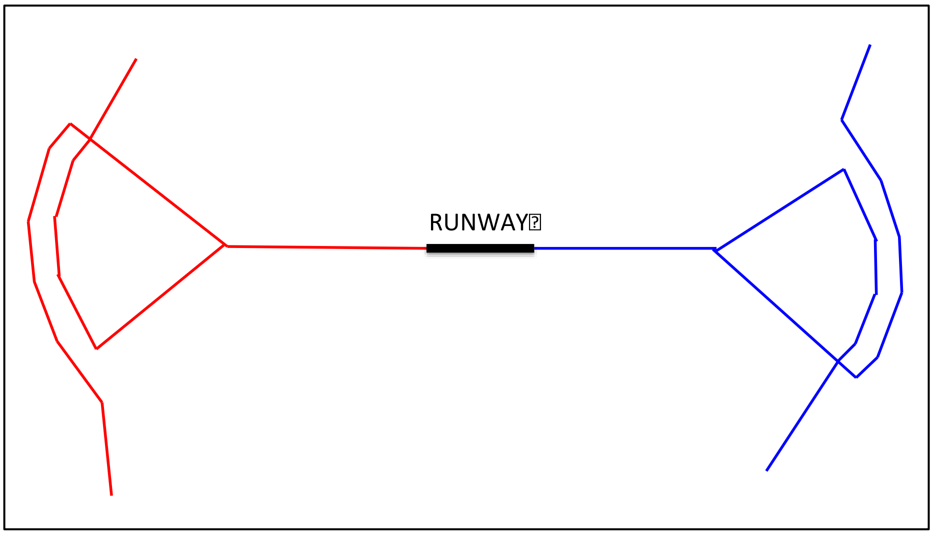


E.9 This creates a swathe of aircraft which concentrates towards the Merge Point into a single PBN path. Obviously the communities underneath the Merge Point and subsequent single PBN path will experience more overflight than compared to a vectored swathe. However, controller and pilot workload is reduced and the aircraft can perform more efficiently owing to being on a PBN course which enables them to be accurately aware of distance to touchdown and thus enhances CDA performance.

E.10 Point Merge is now operational in Oslo and three Norwegian regional airports, Dublin, Seoul Paris, Kuala Lumpur, Lagos, Canary Islands, Hannover and, from February 2016, London City.

Point merge (different sequencing legs for the runway in use)

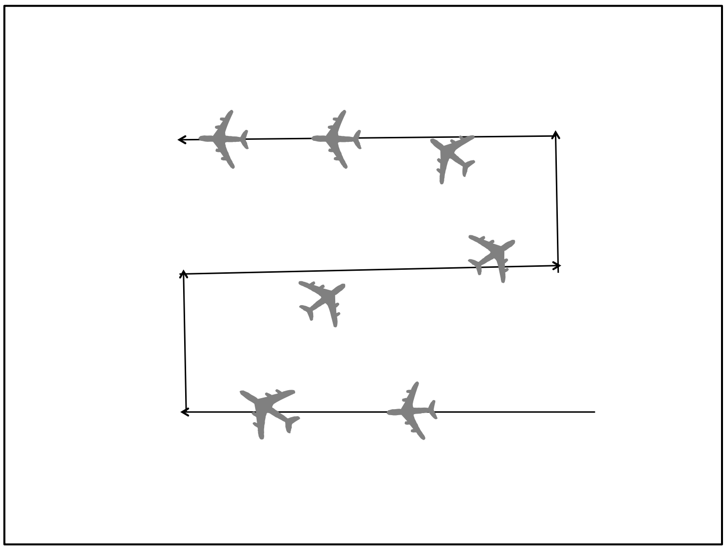
Figure E3



E.11 Where possible, different Point Merge Systems can be used according to the runway in use. This provides the most optimum arrival routes for the operators whilst creating totally independent arrival swathes according to the runway in use at the time. Point Merge Systems can take up a lot of airspace therefore this option is generally only available in areas of lower airspace congestion.

Network trombones

Figure E4



E.12 Trombones are PBN arrival routes which aircraft follow until ATC intervene. They are typically long but pre-defined tracks which aircraft can follow and plan for instead of vectors alone. At the appropriate point, ATC will give the aircraft a short cut to reduce the distance between aircraft, providing an efficient flow to the runway.

E.13 Trombones inevitably concentrate traffic along the straight segments, but the shortcutting of aircraft creates a swathe. Trombones may be applied in low level or network airspace.

E.14 Trombones are a common feature of PBN around the world e.g.: Munich, Frankfurt and Dubai.

Annex F

List of acronyms

AMSL	Above mean sea level
AONB	Are of outstanding natural beauty
APC	Approach
ATC	Air traffic control
ATM	Air traffic management
CAA	Civil Aviation Authority
CA Leg	Course to an altitude leg
CF Leg	Course to a fix leg
CO_2	Carbon dioxide
dBA	Decibels
DfT	Department for Transport
ERCD	Environmental Research and Consultancy Department
FAS	Future airspace strategy
FMC	Flight management computer
ft	Feet
ICAO	International Civil Aviation Organisation
IFP	Instrument flight procedure
NPR	Noise preferential route
PBN	Performance-based navigation
RF Turn	Radius to fix a turn
RNAV	Area navigation
RNP	Required navigation performance
SIDs	Standard instrument departures