Technical Report

From

Think Research Limited

to

Runway Innovations Limited

For

ATC and Airspace Feasibility of Heathrow Hub

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Executive Summary

This report discusses and analyses the ATC and airspace feasibility of a third in-line runway at Heathrow in support of the Heathrow Hub Concept. There are three main threads to the work as listed below:

- Feasibility study;
- Missed approach procedures;
- Modelling of four runways.

The current airspace structure of the London TMA (LTMA) will not support an additional runway, regardless of airfield, runway layout and orientation. However, multiple projects either in R&D or implementation stages are expected to deliver an increase in both capacity and efficiency within the LTMA.

In addition, technological advances are aiming to reduce controller workload to enable more flights to be handled. As a result, findings and conclusions within this report are based on the proposed future infrastructure. It is this combination of future concepts and technological enablers that will help meet the demand of future predicted air traffic growth.

The unique design of the Heathrow Hub Concept provides multiple benefits over alternative Heathrow solutions. These include the ability to perform compass mode departures with the potential for reduced taxi times, minimal disruption to current methods of operation, deep landings (for noise mitigation), the addition of a fourth runway very close to the existing infrastructure to support long-term future growth and an ability to cope with changes in fleet mix in the future.

The suggested method for implementing missed approaches within the Heathrow Hub concept are largely compatible with current ICAO recommendations with the exception of missed approaches on the inline runways. Current guidance does not cover a scenario of two independent inline runways operating arrivals from the first runway and departures from the second runway. A missed approach procedure in this scenario would still need to diverge from the departure track but a safety case will be required to determine how much divergence is required.

Heathrow Airport operating with four runways (as modelled) should be capable of supporting up to 900,000 movements annually on two sets of parallel independent runways. This figure could reduce if runways are dependent with converging approaches.

Overall, the option of a third in-line runway at Heathrow does not present any major obstacles that cannot be resolved. Whilst the workload of Tower, Approach and TMA controllers will increase, sometimes substantially, various projects including PBN, LAMP and Advanced Controller Toolsets will help offset the associated increase in controller workload. The findings of this report conclude that the option of a third in-line runway at Heathrow is feasible from an ATM perspective.

Acronyms

Term	Definition
A-CDM	Airport Collaborative Decision Making
AMAN	Arrival Manager
ANSP	Air Navigation Service Provider
ASMGCS	Airport Surface Movement and Ground Control System
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
BNN	Bovingdon
CAA	Civil Aviation Authority
CATIIIC	Category III C ILS
CPT	Compton
DCB	Demand and Capacity Balancing
DET	Detling
DME	Distance Measuring Equipment
DPI	Departure Planning Information
FIN	Final Director
FUM	Flight Update Messages
ICAO	International Civil Aviation Organisation
iFACTS	Interim Future Area Control Tools Support
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INT	Intermediate Director
LACC	London Area Control Centre
LAM	Lambourne
LAMP	London Airspace Management Project
LTMA	London Terminal Control Area
LVP	Low Visibility Procedures
MID	Midhurst
MLS	Microwave Landing System
MRS	Minimum Radar Separation
OCK	Ockham

PBN	Performance Based Navigation
QDR	Magnetic bearing from a station
RMA	Radar Manoeuvring Area
RNAV	Area Navigation
SESAR	Single European Skies ATM Research
SID	Standard Instrument Departure
SOIR	Simultaneous Operations on Independent Runways
STAR	Standard Arrival Route
SWIM	System Wide Information Management
TBS	Time Based Separation
TEAM	Tactically Enhanced Arrivals Mode
TMA	Terminal Manoeuvring Area
VHF	Very High Frequency
VLA	Very Large Aircraft
XMAN	Cross Centre Arrival Manager

1 Introduction

1.1 Background to this report

In 2012, the Airports Commission was tasked with investigating the future airport capacity needs of the UK. Their findings concluded that there is a case for "*one net additional runway in London and the South East, to come into operation by 2030*". Further to this "*the Commission's forecasts also indicate that there is likely to be a demand case for a second additional runway in operation by 2050 or, in some scenarios, earlier".*

Proposals were submitted and, following assessment, three potential options proposed at two different airport sites were selected for further investigation. This included the Heathrow Hub Concept as addressed within this report.

In preparation for the next stage of the selection process, Runway Innovations Ltd has enlisted Think Research Ltd. (Think) to produce this report highlighting Air Traffic Management (ATM) issues that may influence the successful operation of the Heathrow Hub Concept. Think are well placed to offer expert opinion and advice on future ATM operations. Think have many years of experience advising on Air Traffic Management and airport implementation projects and have staff from a range of relevant backgrounds including engineering, analysis, modelling, Air Traffic Control (ATC) and piloting. As an associate member of the SESAR SJU, Think have provided expert advice and support on future Air Traffic Management projects as part of both the short and long term Single European Skies vision.

This report highlights the technical and operational ATM challenges faced in increasing the number of traffic movements in the South East of England and the ability of the Heathrow Hub runway layout to support this. Heathrow Hub Phase 1 looks at the option of a third runway at Heathrow while Phase 2 looks at the later addition of a fourth runway.

1.2 Report Objectives

The high level objectives of the report are to:

- Assess the impact of increased capacity within the Terminal Manoeuvring Area (TMA) and discuss how future planned projects in the London TMA airspace have the potential to offset various concerns (Phase 1);
- Assess the impact of a third 'in-line' runway at Heathrow on the current design of TMA/EnRoute airspace (Phase 1);
- Assess the impact of a third runway on Air Traffic Control Officer (ATCO) Human Factors and operating procedures (Phase 1);
- Identify the main safety concerns regarding missed approaches for the Heathrow Hub Concept (Phase 1);
- Estimate increases in runway capacity that could be provided by a fourth runway (Phase 2).

While the report predominantly discusses the airspace above Heathrow, prevalent issues/benefits associated with ground operations are also included.

1.3 Structure of the Report

The structure of the document is as follows:

- **Section 1** (this section) contains the introduction to the report and puts the report into context for the benefit of the reader;
- **Section 2** describes the feasibility of the Heathrow Hub solution with specific focus on impacts for London airspace and controller roles and possible mitigating solutions. This section also includes an initial study of Phase 2;
- **Section 3** describes missed approach procedures in a three runway layout and addresses their adherence to current day guidelines;
- **Section 4** consists of a fourth runway model to assess the possible throughput of a fourth runway at Heathrow taking into consideration differing runway layouts and future fleet mixes;
- **Section 5** states all the conclusions obtained from findings within this report;
- **Section 6** states all suggestions for further airspace study
- **Section 7** Appendix

2 ATM Feasibility of Heathrow Hub Phase 1

This section of the report highlights the ATM operational and technical challenges faced when increasing the number of air traffic movements in the South East of England and the ability of the Heathrow Hub Concept to support this.

It covers:

- Current controller responsibilities;
- Current performance of the London TMA airspace and influencing factors;
- Impact of introducing a third runway (and the associated increase of traffic) on the current design of TMA/EnRoute airspace;
- How new technologies/concepts will mitigate many of the challenges faced;
- What potential barriers still exist;
- The net outcome and conclusion for the feasibility of a third runway.

2.1 Current Day Operations

2.1.1 Generic Modes of Operation

The mode of operation at an airfield describes the manner in which a runway(s) can be utilised in order to meet the demands of the current traffic situation. Changing the mode of operation on available runways can help reduce delays whether they exist on the ground or in the air.

An airport's operating mode depends upon a range of factors including fleet mix and traffic pattern mix. The two main operating modes are mixed mode and segregated mode. Mixed mode involves using an individual runway for arrivals and departures while segregated mode involves using one runway for arrivals and another runway for departures. A combination of methods can also occur such as one runway has only arrivals or departures while the other operates in mixed mode. Utilising mixed mode tends to be the most efficient method to maximise capacity when there is an even mix of departures and arrivals.

Focusing on mixed mode, there are two further splits that can be made. The first is compass mode which is shown in Figure 1**Error! Reference source not found.** below. This has the aim to optimise routes in the air. Therefore for an easterly/westerly operation such as Heathrow the northerly departures use the northern runway while the southerly departures use the south runway. All crossovers occur on the ground.

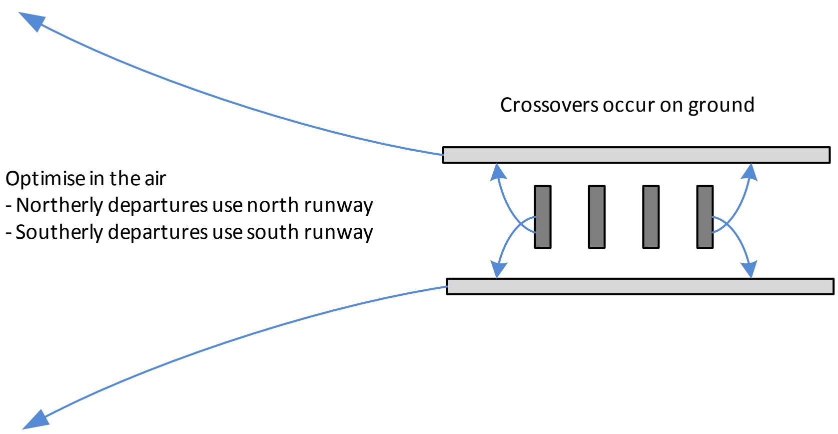


Figure 1 Compass Mode Operation

The opposite of compass mode is terminal mode as shown in Figure 2 overleaf**Error! Reference source not found.**. This intends to optimise the ground operation by taxiing aircraft to the nearest runway regardless of departure direction. All crossovers occur in the air which makes the airspace design more complicated.

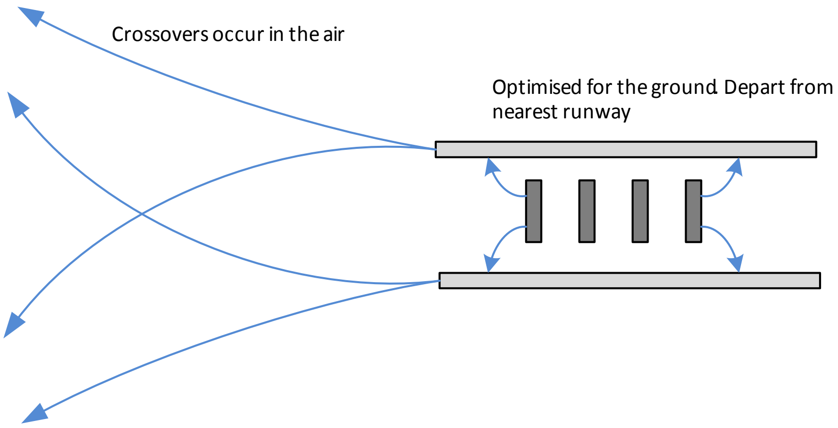


Figure 2 Terminal Mode Operation

To maximise capacity during compass mode there would need to be an approximately even split of northerly and southerly traffic.

2.1.2 Current Day Modes of Operation at Heathrow

Heathrow operates with two parallel runways running from west to east. The majority of winds in the UK are from a South Westerly direction and due to safety reasons airlines prefer to land into a headwind. The majority of operations at Heathrow are Westerly (i.e. approaching from the east). This orientation accounts for approximately 70%[1] of the operations throughout the year. In addition, Heathrow operates a 'preference' for Westerlies meaning that even in light winds from the east (meaning the aircraft will land with a slight tailwind), the airport may still use westerly operations in order to minimise aircraft departures to the east. When wind speeds from the east start to increase, ATC will switch to easterly operations meaning aircraft will approach from the west and depart to the east.

ATC use a variety of methods during the day to maximise capacity on the two parallel runways enabling the system to cope with high demand. Throughout the day, Heathrow will experience peaks in arriving or departing traffic; any excessive demand for either type of traffic can lead to delays in the air or on the ground respectively.

Under normal conditions, one runway is usually dedicated to departures (alternating between northerly and southerly departures) while the other is used only for arrivals (segregated mode). When there is a high proportion of arrivals, it is possible for Heathrow to use both current runways for landings in a mode known as Tactically Enhanced Arrival Mode (TEAM). This is most common during the morning (0600-0700) when there is a high density of traffic arriving from the Americas and the Far East. TEAM may also be employed during the day through periods of high demand or to position aircraft on the most appropriate side of the airfield in relation to their terminal, thereby reducing taxi times on the ground. TEAM may also be used for tactical reasons, for example; if separation between aircraft on final approach could potentially be breached, a request to use the departing runway for the arriving aircraft may be made. The CAA states that during normal operating procedures there is an imposed cap of six TEAM arrivals per hour.

[1] http://www.heathrowairport.com

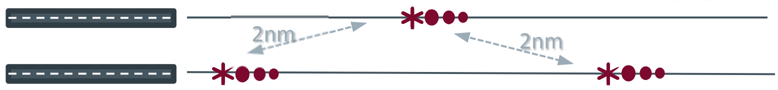


Figure 3 TEAM operations

If TEAM were performed throughout the day, runway alternation procedures would cease to exist and therefore no noise respite for local residents would be offered; for this reason its use is limited.

While permanent mixed mode operations on both runways could be expected to provide extra capacity at the airport in the region of 60,000-80,000 traffic movements a year, the environmental and noise implications make the scenario unlikely to be implemented.

2.1.3 Current TMA Holding

Holding is an ATC procedure where an aircraft is asked to fly a designated 'racecourse' pattern close to its destination airport. Several aircraft may be in the same hold at the same time, at different levels with aircraft descending through the levels whilst in the hold. Aircraft holding most commonly occurs when an aircraft has reached its destination airfield, but is unable to land due to runway availability. Some holding is designed into the system at Heathrow to ensure tight spacing of aircraft and maximum usage of its constrained runways.

Since aircraft are optimized for the cruise phase of flight, holding in tight patterns is inefficient and results in in higher concentrations of emissions (NO_X, CO and SO_2). In a scenario where runways are unconstrained, holding would not be desired for environmental and economic (fuel cost) reasons.

Heathrow airport is fed by four holds, Ockham (OCK) (South West), Bovingdon (BNN) (North West), Lambourne (LAM) (North East) and Biggin (BIG) (South East). During periods of high traffic, these holds can be utilised up to flight-level 150 (FL150) (OCK and BIG) or FL170 (BNN and LAM) with the lowest level usually kept vacant adding resilience in the event aircraft perform a missed approach.

All aircraft entering the London TMA will follow a Standard Arrival Route (STAR) that determines which holding facility they will use. If aircraft are approaching a holding facility which is already at full capacity, controllers may provide them with a 'stack swap' to another hold to help ease congestion. The use of holding facilities in the London TMA greatly contributes to the TMA controller's workload (stack swapping increases this further) and during especially busy periods, a support controller may be required.

During periods of excessive demand of arriving aircraft or during contingency periods such as bad weather or aircraft emergencies, aircraft may be required to hold in EnRoute airspace when capacity in the LTMA is full. However this is rare and as such is considered an unusual circumstance. It can place a high workload on EnRoute controllers due to its infrequency of occurrence and due to the fact that EnRoute airspace is not specifically designed for sustained holding to occur.

2.1.4 Current London Controller Responsibilities

2.1.4.1 EnRoute Controllers

EnRoute controllers provide air traffic services to aircraft within the London Flight Information Region (FIR). London Area Control (LAC) has a variety of sectors, both high level and those that start at the base of controlled airspace. EnRoute controllers are responsible for receiving departing aircraft from TMA controllers and climbing them to their requested cruising flight level and are responsible for descending arriving aircraft from their cruising levels to deliver them to the TMA for their final approach into their destination airfield. During these transitions to and from cruising levels, controllers are responsible for the safe separation between other aircraft in similar phases of flight.

Many of the responsibilities for EnRoute controllers are the same as those for TMA controllers (e.g. monitoring of aircraft profiles, de-conflicting aircraft etc.). However EnRoute controllers do not routinely make use of holding facilities as often as TMA controllers.

2.1.4.2 TMA Controllers

The London Terminal Control Area (LTMA) constitutes the busiest airspace in the UK. Operating in excess of 200 movements in a busy hour, the LTMA is defined as a very high density/very high complexity environment according to SESAR definitions. All five main London airfields (Heathrow, Gatwick, Stansted, Luton and London City) lie within relatively close proximity of each other resulting in highly complex route structures with multiple interactions, requiring constant monitoring by ATCOs.

ATCOs are responsible for the safe, orderly and expeditious flow of aircraft in the LTMA and surrounding airways. This requires them to:

- Coordinate flights into and out of their sectors;
- Ensure aircraft separation, typically 3nm between all aircraft (Inbound, Outbound & Overflights);
- Monitor flight profiles to ensure aircraft are conforming to flight plans and executive instructions;
- Deliver aircraft to holding facilities during periods of airborne delay and coordinate with approach control for release levels.

Due to the complex nature of the airspace, different aircraft characteristics, holding facilities and transiting flights, controllers need to provide multiple tactical instructions (both lateral and vertical) to maintain separation whilst trying to provide the best possible flight profile for the aircraft. This complexity produces a high workload, limiting capacity and resulting in many aircraft receiving sub-optimal flight profiles.

2.1.4.3 Approach Controllers

Heathrow Approach controllers are primarily responsible for vectoring arrivals from the holding facilities to intercept the extended runway centreline before transferring the aircraft to the tower. Approach controllers have a defined volume of airspace in which to operate, known as the Radar Manoeuvring Area (RMA). The dimensions of the RMA vary with the runway in use and provides a safe area in which approach controllers can descend aircraft to defined altitudes.

Due to the high volumes of inbound traffic at Heathrow, the approach function is split into intermediate (INT) and final (FIN) positions. INT controllers vector the aircraft from the holding facility and deliver them to FIN whilst on the downwind leg of their approach. The INT position is further split between two controllers, INT North filters aircraft from the two northern holds and INT South integrates aircraft from the two southern holds.

Figure 4 below shows a schematic of the two northern holds, BNN & LAM and the different phases of approach. The INT N controller is responsible for determining the best time to remove aircraft from the hold in order to start their approach to the airfield. Once the INT controller has successfully integrated the aircraft on the downwind leg they are then transferred to FIN. From here the FIN controller will turn the aircraft onto the base leg and instruct the aircraft to start reducing their speed while at the same time descending the aircraft. As the aircraft closes in perpendicular to the extended centreline of the runway, the FIN controller will provide an intercept heading for the Instrument Landing System (ILS) so the aircraft can begin the final approach to the airfield. As well as vectoring aircraft from the northern holds, the FIN controller will simultaneously be providing the same service to aircraft that have been released from the southern holds. The FIN director is responsible for then integrating all aircraft transferred from Heathrow INT N and S and providing the necessary separation on the ILS.

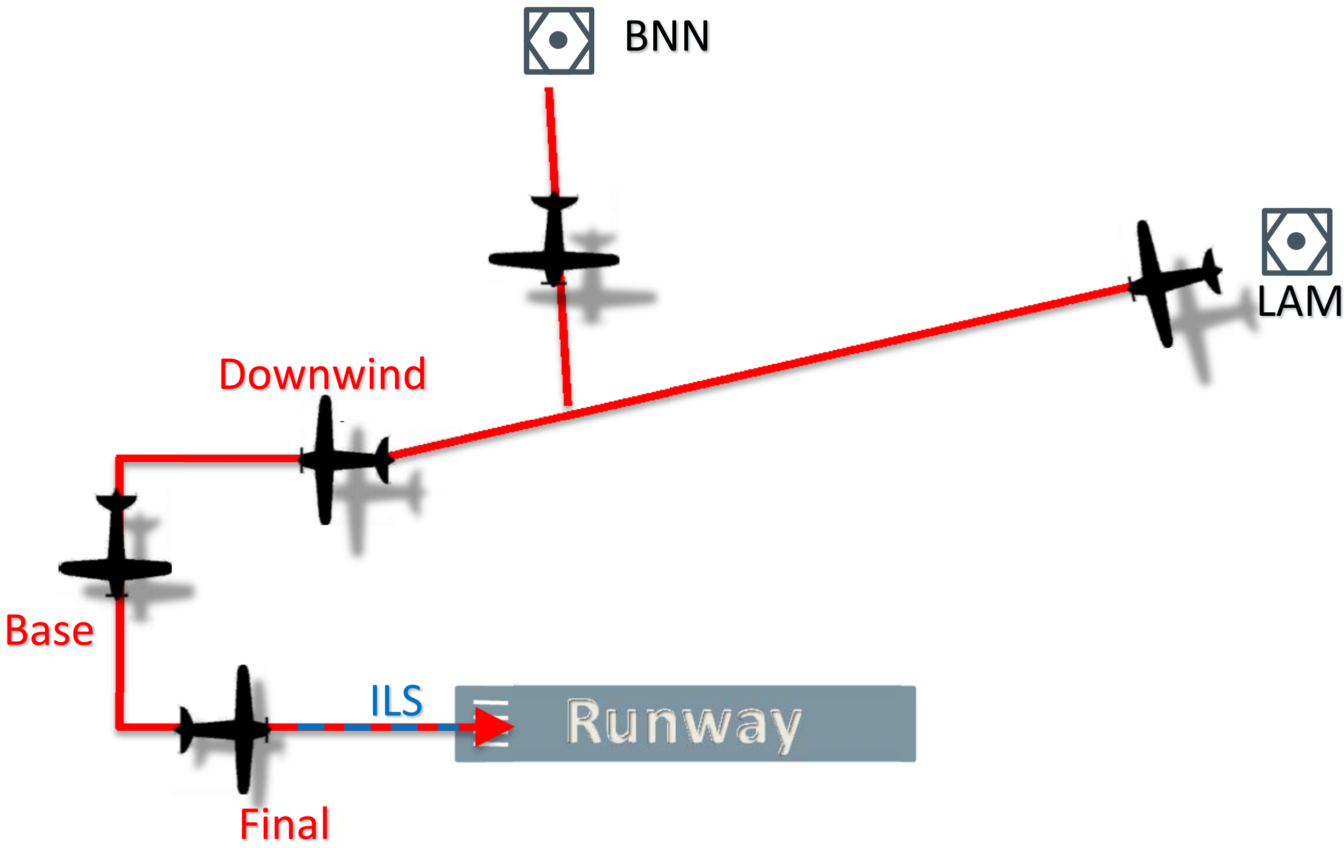


Figure 4 Different phases of approach

2.1.4.4 Tower Controllers

In the current day operations during busy periods, the Heathrow Aerodrome Controller positions are split into the following:

- Air North;
- Air South;
- Ground (x3);
- Delivery;
- Lighting Panel Operator.

The Air North and Air South Controllers are responsible for their respective runways. Depending on the mode of operation they can be controlling departures or arrivals. At times they may be dealing with both arrivals and departures simultaneously on their respective runways (TEAM).

The three Ground positions deal with their designated ground areas and take control of a departing aircraft when the aircraft is ready to 'Push and Start'. For arriving aircraft Ground takes control once it had landed and is in the process of vacating the runway. The ground controllers will ensure that the aircraft can taxi safely around the airfield to and from and their designated stands.

The Delivery controller is responsible for issuing initial clearances to the aircraft. The Delivery controller will issue the aircraft a departure SID and a transponder code (Squawk). This is usually done electronically via Controller Pilot Data-Link Communication (CPDLC). Once the aircraft is ready to 'Push and Start' they will also contact Delivery who will then instruct the aircraft to contract the Ground controller.

The Lighting Panel Operator (LPO) assists the ground controller(s) by ensuring that the correct lighting on the taxiways are illuminated.

2.2 Proposed Methods of Operation for Heathrow Hub

The Heathrow Hub Concept proposes a third runway in-line with the current northern runway. (Figure 5 below shows the proposed layout of the new extended three runway design for Phase 1 and the four runway design being considered in Phase 2.

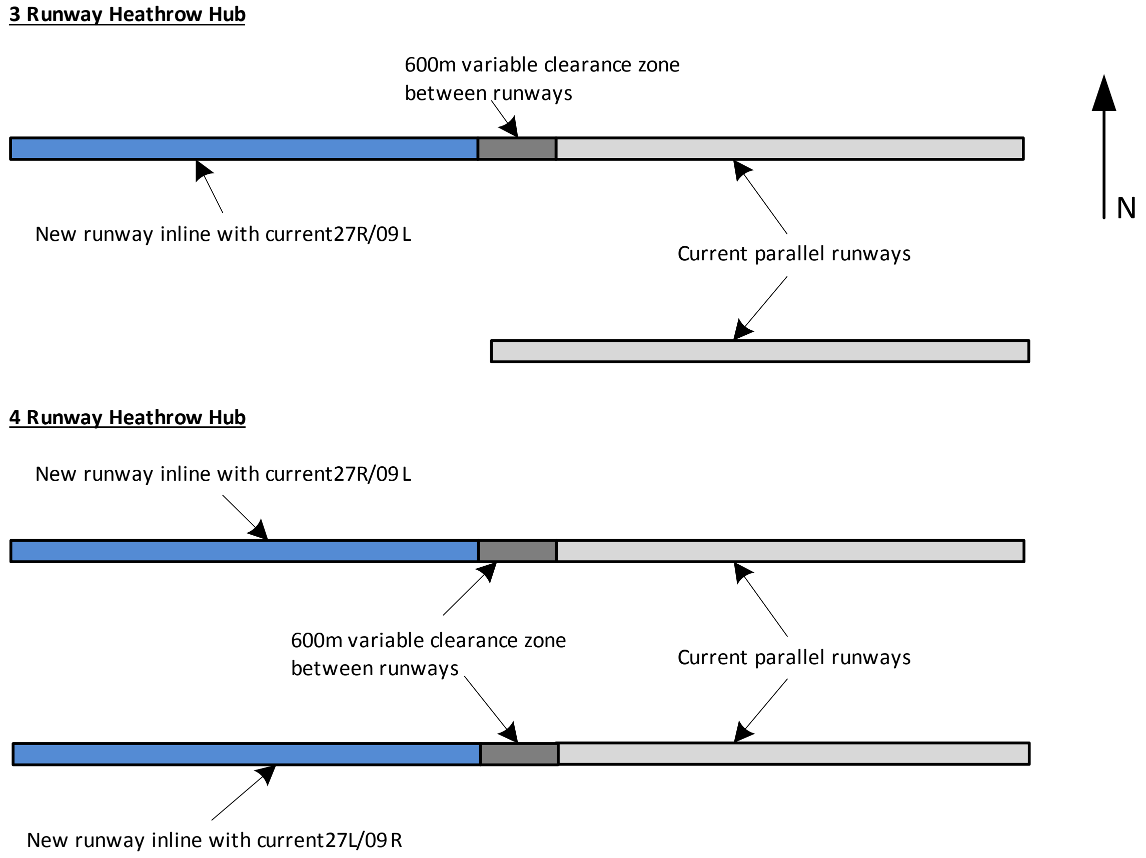


Figure 5 New proposed layouts of the three and four runway option

2.2.1 Proposed Modes of Operation on three runways

Currently Heathrow operates in segregated mode due to current noise abatement procedures. In order for the Heathrow Hub concept to maximise on capacity it would need the ability to operate in a variety of modes including mixed mode. It will also need the ability to switch quickly between modes in case a runway is closed unexpectedly.

To maximise departures there will need to be independence between runways where possible. As stated in PANS-ATM Doc 4444 the following requirements can be used to maximise both parallel runways and a single runway:

- For independence between departures on parallel runways, routes need to diverge by 15 degrees after take-off;
- To maximise departure rate on a single runway, routes need to diverge by 45 degrees to allow 1 min departure spacing (unless wake spacing requirements dictates it should be higher).

Based on these two requirements there are two high level design options available. Firstly as shown in Figure 6**Error! Reference source not found.** the simplest option is to operate in compass mode. The ideal operation when using two departure runways is to depart from the preferred compass mode SIDs shown by the bold blue lines. The northerly SIDs would be independent from the southerly SIDs.

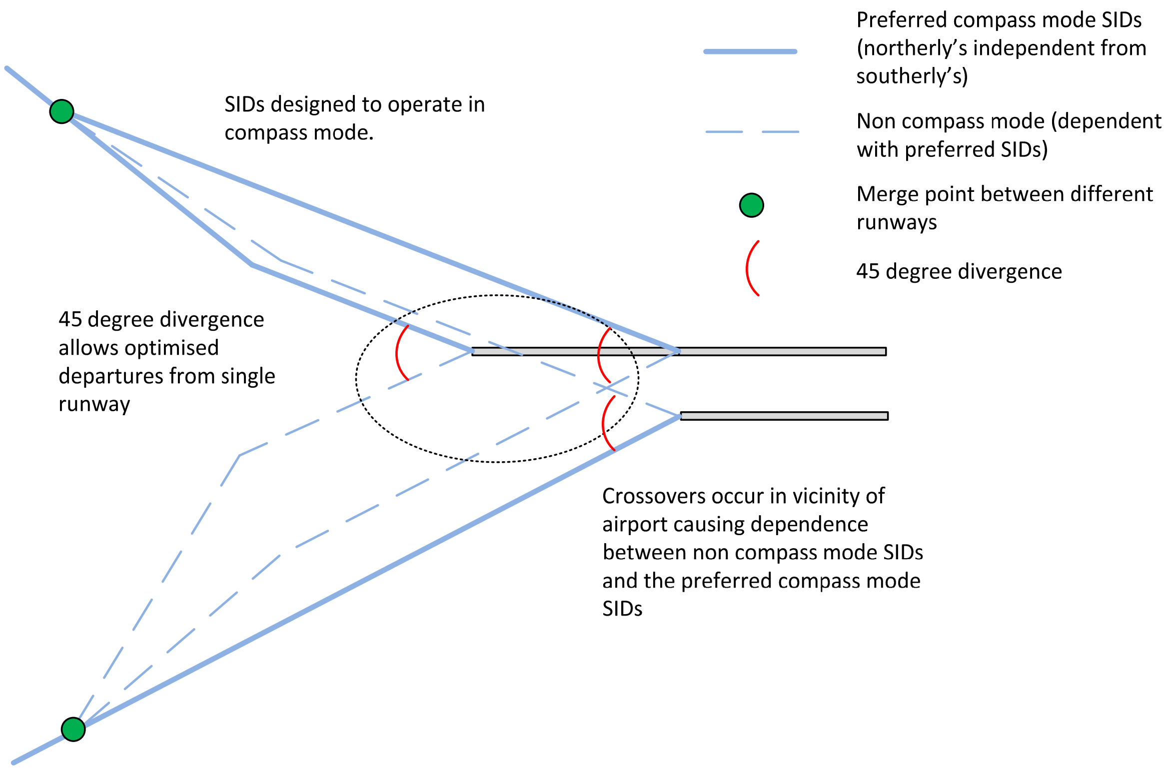


Figure 6 Simple SID Design Based on Heathrow Hub Operating in Compass Mode

During operations requiring a single departure runway the 45 degree divergence between northerly and southerly routes will be used to maximise departure rate.

When two parallel departure runways are in operation departures can use a non-compass mode runway (for example northerly departure from southern runway) but this would impact a parallel runway due to non-compass mode SIDs crossing other SIDs in close vicinity to the airport. Runway capacity modelling taking into account departure direction would be needed to assess if such a design would be feasible at different times of day without having a significant impact on capacity.

As the design naturally relies on compass mode it increases the complexity for ground movements. Due to the potential impact on capacity due to releasing non compass departures means there is less flexibility for the ground movements. In current operations, which is mainly segregated mode the ground flow tends to go in one direction reducing complexity. Ground modelling would be required to assess the feasibility of operating in compass mode. The current central terminal developments (T1, 2 and 3) will improve the ground layout and contribute to greater flexibility. Other ground issues include the fact that T4 and World Cargo are located south of the southern runway meaning a large taxi distance for northerly departures using the new runway.

The second design option shown in Figure 7 **Error! Reference source not found.**shows a concept using primary and secondary SIDs. There is still a preference to operate in compass mode but there is greater flexibility regarding non compass mode departures due to the full independence between departure runways. However it increases the airspace complexity as the non-compass mode SIDs needs to cross each other to reach their relevant exit points. Although airspace complexity increases there is more flexibility for the ground movements as non-compass mode departures could be used without impacting departure capacity.

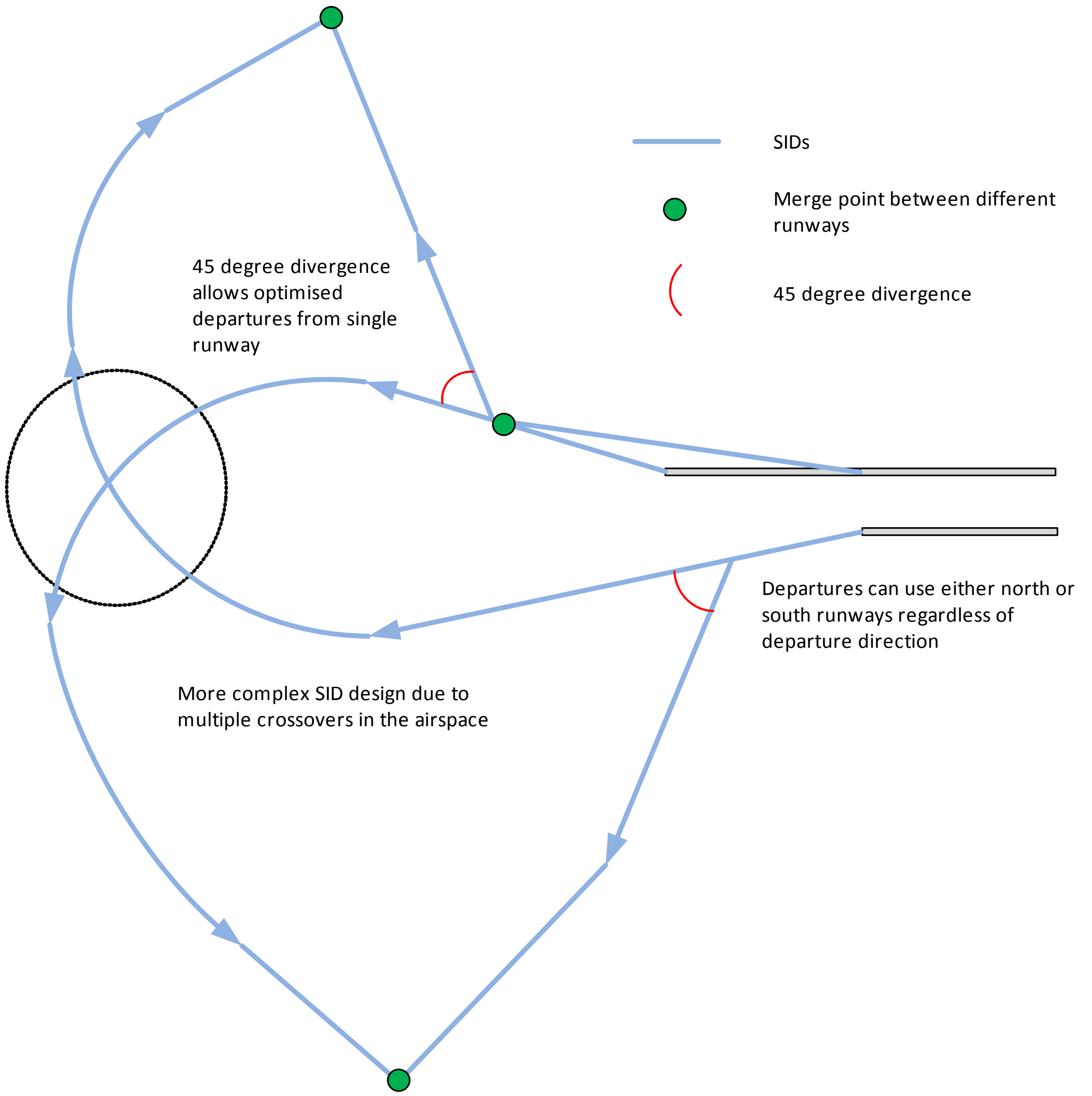


Figure 7 Primary and Secondary SID Design

2.2.2 Summary

The simple SID design is most similar to current operations and ensures SIDs do not have to cross each other. It still allows for independence during compass mode operations. However it relies on the traffic mix being an even split between northerly's and southerly's. The main advantage of a simple design is there are fewer routes required which should allow more efficient routes to be accommodated. The primary and secondary design removes any dependencies between non compass mode departures but has double the amount of routes in the airspace which leads to crossovers and potentially less efficient routes. Both options allow for single departure runway operations. Ideally the Heathrow Hub concept will use compass mode to reduce complexity in the airspace considering London TMA is already a high complexity environment.

In the current operation the primary and secondary SID design would not be feasible due to complexity however the introduction of PBN and the benefits from LAMP should improve the situation. Further capacity modelling considering these design options is recommended to see if the simple SID design is feasible without too much of a negative impact on capacity due to the non-compass mode dependencies.

Ground modelling would also be required to assess the differences in complexity and efficiency between using strictly compass mode operations (simple SID design) compared with a more flexible approach using primary and secondary SIDs.

2.3 Impact of Heathrow Hub on EnRoute

2.3.1 Introduction

Last year EnRoute controllers at Swanwick handled nearly 1.8 million flights with a peak day of 6,697 movements. There is naturally more available airspace EnRoute compared to the TMA but there are various restrictions. Many parts of UK airspace are shared with the military and as such commercial flights are restricted at certain times where they can fly. These areas include danger areas, Military Training Areas (MTA), Temporary Reserved Areas (TRAs) and radar corridors. In addition there can be parachute dropping areas, gliders and large expanses of uncontrolled airspace. As a result, commercial aviation does not have the freedom to transit these areas and are therefore confined to airways or upper air routes.

While the style of EnRoute controlling differs from the TMA, there can be certain sectors that can experience extremely high workloads for sustained periods of time. However, since the introduction of iFACTS (an advanced controller toolset) into the operational room, much needed capacity has been freed up and increased levels of safety have been achieved.

Traditionally, the sector team consists of two controllers – one (the “planner”) responsible primarily for the planning of flights into and out of the sector, and the other (the “tactical”) who communicates with the aircraft and achieves the plan ensuring the aircraft maintain separation.

2.3.2 Impact of a third runway on EnRoute capacity

The introduction of a third runway at Heathrow will inevitably lead to an increase in traffic volumes in EnRoute airspace. However, this will be true of any airport capacity solution and so this report takes the view that the inevitable impact on capacity can be assumed and does not need to be analysed further. Instead, this report will consider the many planned initiatives within EnRoute airspace that will assist in increasing the capacity.

2.3.3 Mitigation

2.3.3.1 Enhanced Conflict Detection and Resolution Support Tools

In 2011 NATS introduced interim Future Area Control Tools (iFACTS), an advanced controller toolset, into the EnRoute operational room at Swanwick (London Area Control Centre). This provided a transition from paper flight strips to an electronic environment. The core of the iFACTS engine provided controllers with trajectory prediction, medium term conflict alert (up to 18 minutes into the future) and flight conformance monitoring. The trajectory prediction along with Medium Term Conflict Alert (MTCD) provides support in the decision-making process for the controllers, and flight conformance monitoring ensures all aircraft are adhering to controller’s expectations.

Through the support iFACTS provides to the controllers, workload decrease and a capacity increase in the order of 15-40%[2] (depending on the sector) has been seen within NATS EnRoute centre. Since the introduction of iFACTS, there is still extra capacity for EnRoute sectors to handle an increase in traffic.

[2] http://nats.aero/blog/2013/07/how-technology-is-transforming-air-traffic-management/

2.3.3.2 4D trajectory Based operations

One of the main aims of the SESAR initiative is to develop and validate initial 4D (i4D) Trajectory Management.

Moving from current airspace operations to 4D Trajectory Management entails the systematic sharing of aircraft trajectories between various participants in the ATM process; this will ensure that all partners have a common view of a flight and have access to the most up-to-date data available to perform their tasks. It enables the dynamic adjustment of airspace characteristics to meet predicted demand with minimum alterations to the aircraft trajectories.

Before an aircraft departs, the 4D trajectory is agreed and becomes a reference that the airspace user agrees to fly and the ANSP agrees to facilitate. Throughout the flight, detailed information about the projected-position of the aircraft is exchanged with all service providers on the route, and times are agreed with departure and arrival airports in advance.

Aircraft trajectories can be more accurately predicted through the use of data sharing between the aircraft and ground. As trajectory prediction increases, the ATM industry will see gains in network predictability, safety, capacity and flight efficiency.

Another aspect of the i4D programme is the concept of Required Time of Arrival (RTA). This is an airborne function of the Flight Management System (FMS) that allows aircraft to self-manage their speed in order to achieve a Controlled Time of Arrival (CTA) over a specified fix. This has the potential to greatly enhance the management of arrival sequences by absorbing TMA delays EnRoute and achieve greater environmentally optimised flight profiles.

2.3.3.3 Flow Management

The aim of Flow Management is to monitor and update the Daily Traffic Flow Plan that is established the day before operations. This is done with the aim of optimising capacity according to real time traffic demand and looking for ways to minimize delays using various techniques, e.g. alternative routings for aircraft or alternative flight profiles.

Extra Heathrow traffic generated as a result of the third runway will have an impact on the Flow Management Unit. Currently, certain sectors within LACC (e.g. Sector 17 in South Airspace) regularly cap the number of Heathrow Inbounds that are allowed in the sector at any one time as it can easily become overloaded. As this happens at the current Heathrow Capacity, the implication is that this happen more regularly with the addition of a third runway.

As mitigation, projects such as Dynamic Capacity Balancing (DCB) aim to identify ‘hotspots’, aim to reduce traffic complexity and better manage air traffic controller workload. DCB ultimately aims to improve capacity and safety.

2.3.4 Summary

The addition of a third runway at Heathrow is not considered to have a large negative impact on EnRoute airspace. The introduction of iFACTS has already seen benefits in safety and increased capacity and there are multiple projects underway which further aim to increase safety, capacity and efficiency.

It is expected that while there will be an increase in density of traffic through the surrounding EnRoute sectors, the impact on controller workload will not be so severe as to warrant an airspace redesign or implementation of new technologies to handle the increase in traffic.

In addition to the provision of advanced concepts and controller tools to support the safe management of the anticipated growth in traffic, the organisation of the controller team(s) to maximize the potential benefits of these concepts and to provide future ATM in the most efficient manner is also of important consideration.

As future air traffic concepts develop towards 4-D trajectory management, these roles will evolve as new separation techniques become available. With that evolution, the way in which controller teams are structured may develop e.g. Single Person Operations (SPO) which is one controller working as both a Tactical and a Planner and also Multi-Sector Planner (MSP) where one planner is responsible for multiple Tactical Controllers.

It is also important to consider the impact on adjacent Air Traffic Services Units[3] (ATSUs). The addition of a third runway at Heathrow will increase the traffic volumes for the adjacent Terminal airspace, the adjacent EnRoute airspace and therefore adjacent ATSUs. Studies and co-operation with these units must be implemented in order to assess the impact of increased traffic flows.

2.4 Impact of Heathrow Hub on the LTMA

2.4.1 Introduction

The LTMA can only accommodate a finite amount of traffic before inefficiencies appear and ultimately safety is compromised. There are many factors which contribute to capacity within the LTMA airspace such as:

- Required separation thresholds between aircraft;
- Route structure;
- Fleet mix;
- Hot Spots;
- Controller workload;
- Airspace complexity;
- Physical dimensions of the airspace;
- Accommodating other airspace users, e.g. military, SVFR;
- Ensuring resilience is built into the system;
- How many times the airspace can be “split” in order for controllers to handle more traffic.

All of these contribute to the available capacity in the LTMA. However the limits that affect capacity will be influenced by the most critical and sensitive elements.

2.4.2 Current Capacity of the TMA

The current methods of controlling within the London TMA and Approach sectors provide a very robust flow of aircraft to major airfields. This is achieved at the expense of controller workload due to constant Radio Telephony (R/T) loading. Multiple climb/descent and vectoring instructions are issued to ensure separation between departure and arrival flows which culminates in extremely high R/T loading. These metrics indicate that LTMA is reaching its absolute capacity and this method of operation is unlikely to be sustainable for the future considering the predicted increases in air traffic growth. Without any further changes to the airspace or implementation of new technology and concepts this is unlikely to change.

Predicted future demand is likely to exceed what the current TMA design is capable of handling safely and expeditiously. By 2019, traffic is expected to reach 11.2 million IFR movements (±1 million) in Europe - 17% more than in 2012. For Europe as a whole, the most-likely scenario of regulated growth has 14.4 million flights in 2035 - 50% more than 2012. This represents an average annual growth of 1.8%.[4]

[3] Air Traffic Services Units (ATSUs): A generic term meaning variously, air traffic control unit, flight information centre or air traffic services reporting office. [EUROCONTROL ATM Lexicon]

[4] Eurocontrol Task 4: European Air Traffic in 2035

Figure 8 overleaf shows the annual movements of the London Area Airports. In 2007 total movements exceeded 1.2 million, the highest ever recorded. Expert opinion of the capacity of the TMA is that the number of movements handled in 2007 was very close to the limits of what the current system could handle. The 2008 Global downturn reduced demand and provided some temporary relief in the TMA but traffic numbers are again rising as the global economy recovers, and are predicted to approach the 2007 peak again.

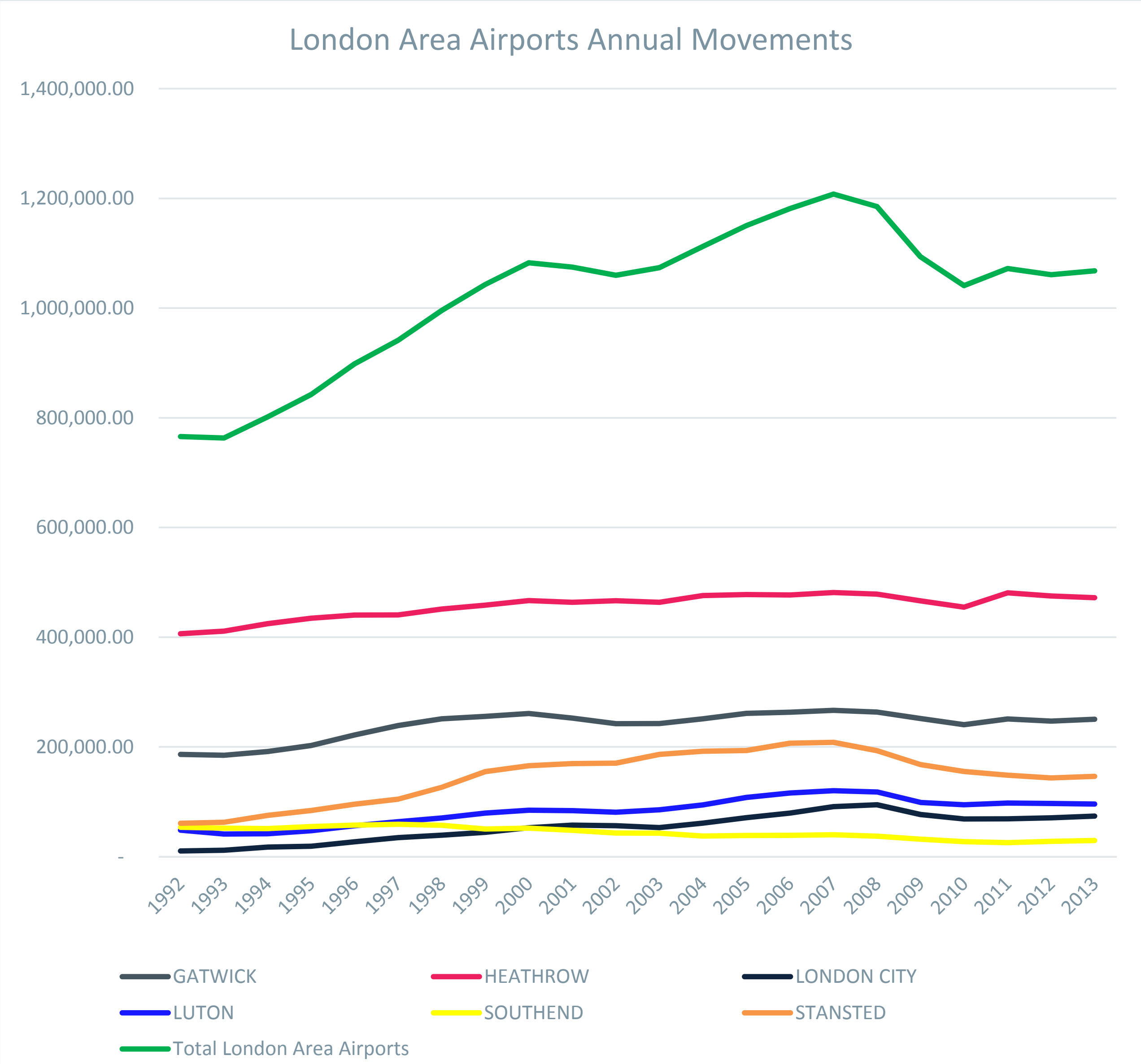


Figure 8 London air traffic movements 1992-2013

2.4.3 Impact of third runway at Heathrow on surrounding airspace and other London Airfields

The Heathrow Hub Concept aims to increase Heathrow's capacity from 480,000 (capped) to between 670,000 and 700,000 depending on the accepted mode of operation. The associated 200,000 extra movements a year that a third runway at Heathrow aims to deliver signifies a 40-45% growth in movements, increasing the demand on the surrounding TMA airspace infrastructure (approximately a 15% increase for the year in the whole of the TMA).

The track density plot in Figure 9 overleaf shows an example of today's traffic in the TMA. Figure 10 overleaf shows a sample in which Heathrow's traffic has been artificially grown by 40% to indicate the impact of Heathrow's third Runway (the natural increase in demand at other major London airfields is not taken into account here). The transition of colours through grey, green, yellow to red indicates an increase in flight track densities.

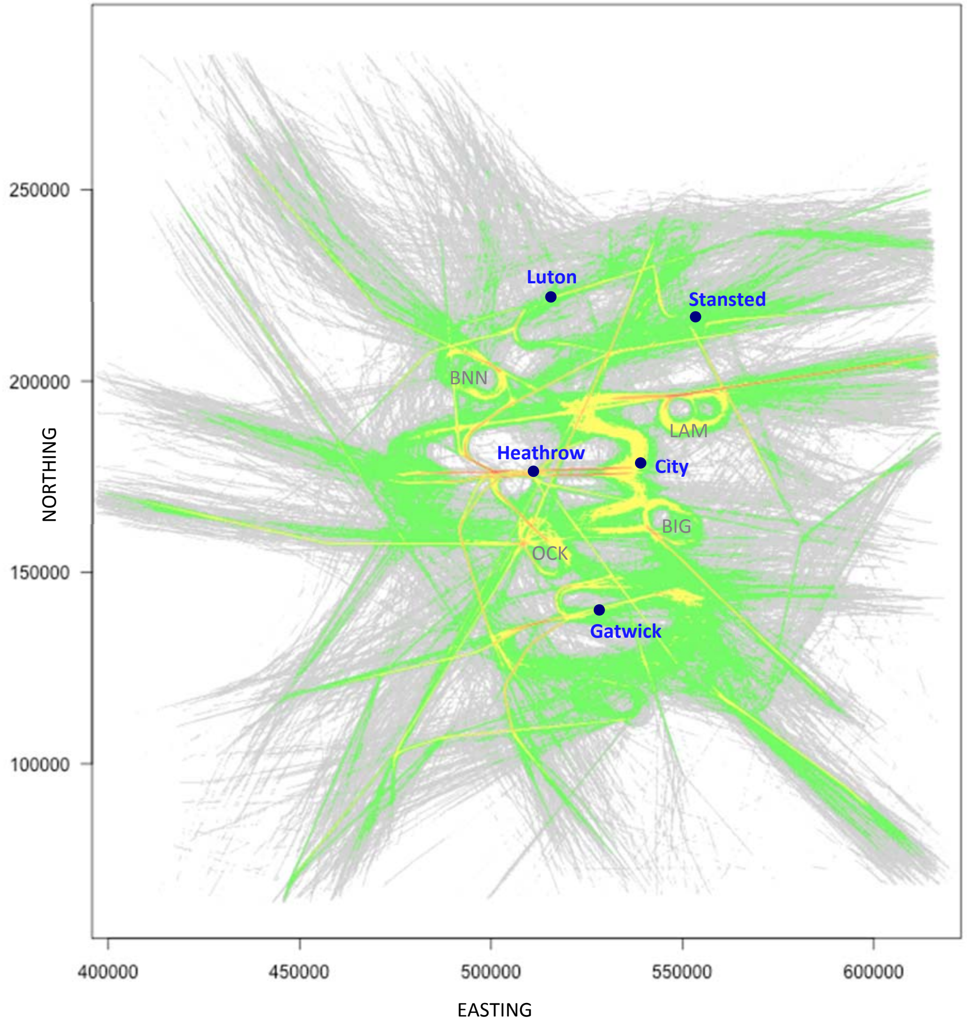


Figure 9 London TMA Track Density Plot Baseline

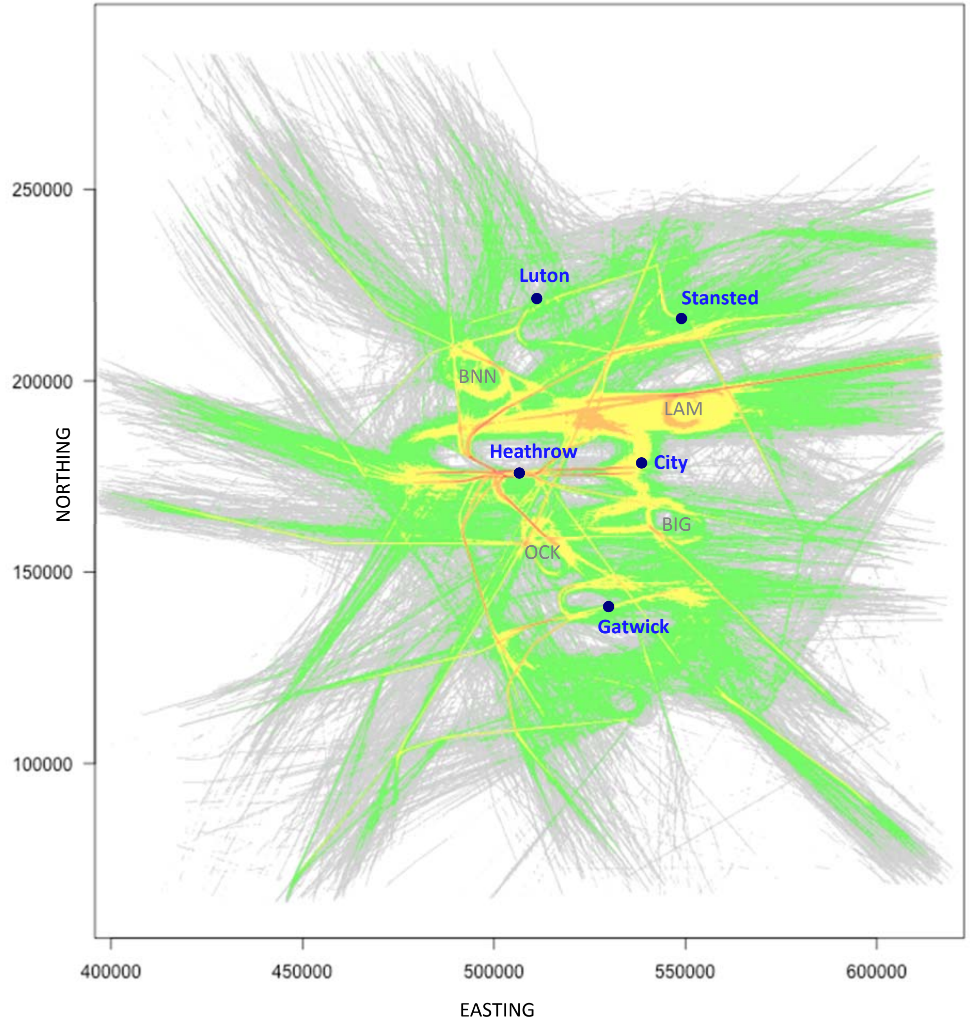


Figure 10 London TMA Track Density Plot with 40% Growth in Heathrow Movements

Keeping in mind the highly complex nature of the TMA, the extra 200,000 movements attributed from a 40% increase in Heathrow traffic may place too much stress in certain parts of the LTMA. The traffic growth is particularly apparent to the north of Heathrow (shown in yellow/orange in Figure 10) meaning there is potential for a third runway at Heathrow to affect the number of movements at London City, Luton and Stansted. The increased interactions between inbound and outbound traffic from these airfields would further add to the complexity of this airspace. Whilst the airspace is expected to have the physical capacity to accommodate this increase, it is likely the controller's workload will exceed levels that are considered safe.

2.4.4 Mitigation

Concerns over the ability of the controller in the LTMA to safely control the additional traffic that will accompany a third runway at Heathrow would be well founded if no changes were to be made to relieve the pressure on ATC. Aware that the LTMA cannot contend with traffic numbers greatly in excess of those numbers experienced in 2007, NATS are already taking action to deliver extra capacity through various implementation projects.

2.4.4.1 LAMP

One of the biggest projects currently being undertaken is the London Airspace Management Project (LAMP) project. Through an airspace redesign and introduction of critical technical enablers its intention is to help alleviate route structure problems and relieve various bottlenecks within the system. LAMP in itself will not completely remove delay, however If successful it will result in more efficient routeings for aircraft and see controller workload more evenly balanced across the sectors. Utilisation of advanced navigational capabilities it is expected to smooth traffic flows, reduce the amount of time aircraft remain in the holds at low levels and reduce total fuel burn. These benefits are expected to reduce controller workload and in combination with Performance Based Navigation (PBN) there is expected to be an overall increase in airspace capacity.

2.4.4.2 PBN

The concept of PBN makes use of more accurate navigational performance specifications. It utilises area navigation and global navigation satellite systems to enable more precise and repeatable three dimensional paths to be flown through the airspace. It is one of the biggest enablers for the TMA airspace redesign and has the potential to deliver benefits to capacity, efficiency and the environment. Due to the extensive benefits of PBN, it is covered in further detail In Section 2.10.

2.4.4.3 Advanced Controller toolset

LTMA controllers currently use paper flight strips when controlling aircraft. Since the introduction of iFACTS (see section Enhanced Conflict Detection and Resolution Support Tools2.3.3.1) into London Area Control there have been significant gains in capacity and safety in EnRoute airspace. Projects are underway within NATS with the aim of implementing an advanced controller tool set into the TMA, targeting further capacity and safety gains.

2.4.5 Summary

Current traffic levels are again approaching levels seen in 2007 which were considered by TMA controllers as very high with little spare capacity available in workload terms. Without any improvements in airspace design or technological improvements it is highly unlikely controllers would be able to handle the extra movements introduced by an additional runway at Heathrow, coupled with the growth in TMA traffic from other airports.

However, by 2023 it is expected several implementation projects will be introduced enabling additional capacity and efficiency to be achieved. This will in turn reduce controller workload to enable them to safely handle the extra proposed movements. Projects such as LAMP, PBN and Advanced Controller tool support are all considered important enablers to achieving the predicted growth in air traffic within the London TMA.

2.5 Impact of Heathrow Hub on Approach Control

2.5.1 Introduction

Heathrow Approach controllers are responsible for vectoring arrivals from the holding facilities to intercept the extended runway centreline before transferring the aircraft to the tower. Approach controllers have a defined volume of airspace in which to operate, known as the Radar Manoeuvring Area (RMA). The dimensions of the RMA vary with the runway in use. It provides a safe area in which approach controllers can descend aircraft to defined levels.

2.5.2 Current Heathrow Approach

Due to the high volumes of inbound traffic at Heathrow, the approach function is split into intermediate (INT) and final (FIN) positions. When traffic density is very high a support (SPT) controller may be required to help the INT controller. The main responsibilities include accepting inbound releases, coordinating, and descending aircraft within the holds as levels become vacant and general awareness of the radar picture.

Intermediate controllers vector the aircraft from the holding facility and deliver them to final approach, on the downwind leg of their approach. The INT position is further split between two controllers, INT North filters aircraft from the two northern holds and INT South integrates aircraft from the two southern holds.

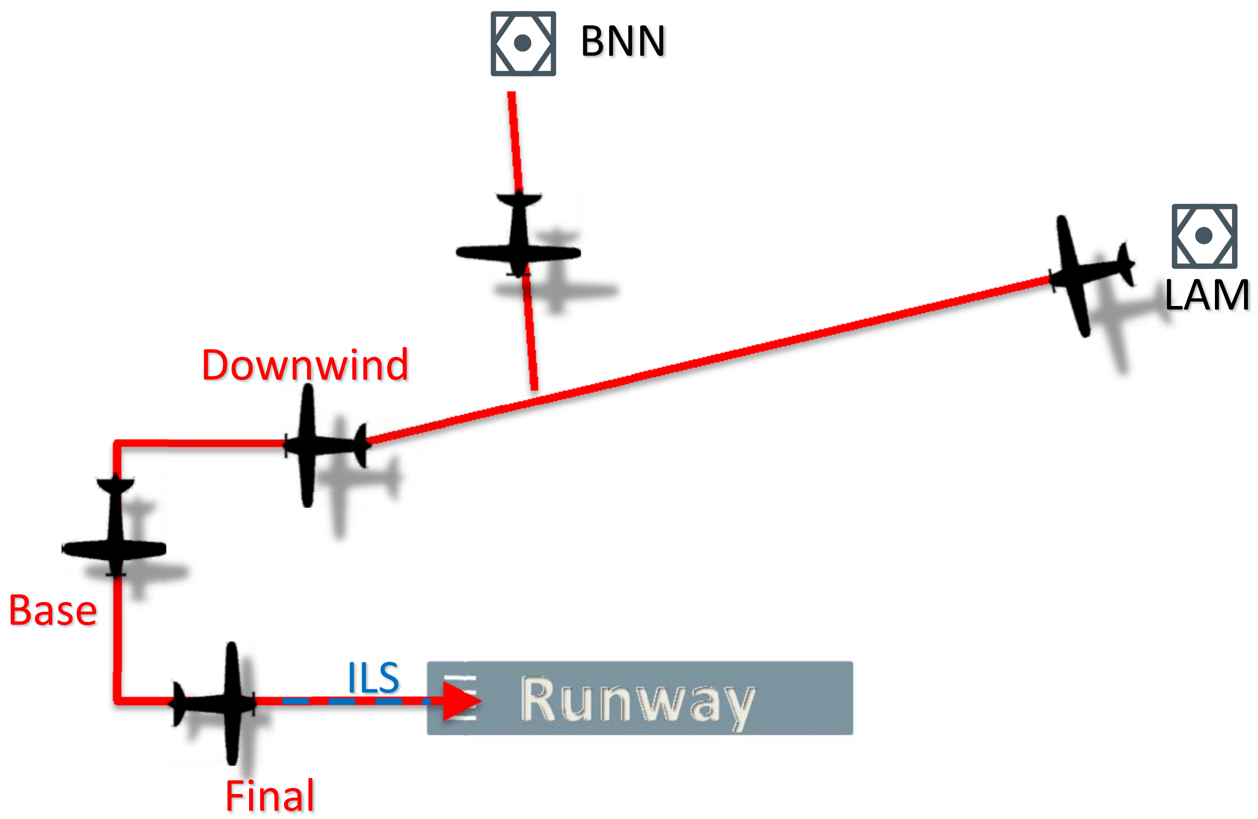


Figure 11 Different phases of approach

Figure 11 above shows a schematic of the two northern holds, BNN & LAM and the different phases of approach. The INT N controller is responsible for determining the best time to remove aircraft from the hold in order to start their approach to the airfield. Once the INT controller has successfully integrated the aircraft on the downwind leg they are then transferred to FIN. From here the FIN controller will turn the aircraft onto the base leg and instruct the aircraft to start reducing their speed. As the aircraft closes in perpendicular to the extended centreline of the runway, the FIN controller will provide an intercept heading for the Instrument Landing System (ILS) so the aircraft can begin the final approach to the airfield. As well as vectoring aircraft from the northern holds, the FIN controller will simultaneously be providing the same service to aircraft that have been released from the southern holds. The FIN director is responsible for then integrating all aircraft transferred from Heathrow INT N and S and providing the necessary separation on the ILS.

The current setup in Approach enables controllers to deliver a very high and predictable throughput onto the runway at Heathrow. During TEAM operations the FIN controller is responsible for alternating aircraft between the northerly and southerly on the final approach track. For a third in-line runway, this task would conceivably remain very similar as today. During westerly operations, the extended runway could be used for departures and the two original runways used as arrivals.

2.5.3 Impact of Heathrow Hub on Approach control

Owing to the unique nature of the Heathrow Hub Concept and due to the fact that the extended runway remains in-line with the existing runway it is envisaged that there will be minimal changes in the way approach controllers operate in their day to day tasks. Ultimately this means the INT and FIN controllers will still need to control the aircraft in a very similar manner as they do today. Furthermore, if the extended runway was used for ‘deep landings’ on westerlies to mitigate noise over the London area, aircraft would intercept their final approach track in a very similar position as they do today.

Despite the addition of a third runway, no more than two runways will be able to be used at any one time for arrivals. Current day operations see the same complement of ATCOs (two INT and one FIN) integrating aircraft for final approach even in the case of TEAM when both runways are used for arrivals. However, with the associated increase in traffic movements, the frequency of INT and FIN controllers working to capacity is expected to increase. It is possible that if Heathrow were allowed to perform independent arrivals there may be the need for two FIN positions (North and South) to offset the additional workload.

2.5.4 Mitigation

Due to the layout of the Heathrow Hub design it is anticipated that any changes to the way Approach control operate will be minimised. As a result it is not felt necessary to apply any mitigating factors against the new concept. However, it must be taken into account that roles and operating procedures will change naturally as a result of implementation projects such as LAMP Phase 1 and 2 and also Time Based Separation (TBS – see Section 2.7.1.4 for more details). There will be a large impact for the project design teams for these projects once a third runway is operational.

2.5.5 Summary

One of the main advantages of the Heathrow Hub Concept over other concepts is the geographical location of the third runway. As a result of remaining in-line with today’s northern runway, the point at which approach controllers vector aircraft downwind, base leg and intercept will remain almost identical as it is today. It has been considered that LAMP will change the approach controller’s roles slightly but it is the design of these projects that will have the biggest impact on the controllers, not the Heathrow Hub concept. The workload of the INT and FIN controllers is expected to increase overall where a constant flow of arrivals maintain a high workload. While this may not be ideal it is not expected to impact negatively on the Heathrow Hub concept since controllers today are very capable of dealing with high arrival flows and ensuring a high throughput is delivered to Heathrow’s runways.

2.6 Impact of Heathrow Hub on Tower

2.6.1 Considerations for Tower Control Staffing

The addition of a third runway at Heathrow Airport is likely to have an impact on the number of staff needed during peak times. The following considerations will need to be addressed:

- The Air North position will be affected if the Northern runway is extended. However, if as stated earlier, the controller on some occasions deals with both arriving and departing aircraft on the same runway, then the implication may be that there is no extra position required for the extra runway. However with the increased volume of traffic it may not be viable for one person to be expected to pay full attention to both arriving and departing streams at the same time. When working departing aircraft, the controller is focusing intently on the timing between each departure as it is imperative to ensure as tight a spacing as possible, and when working arriving aircraft they are watching closely for the aircraft to vacate the runway, in order that they can instruct the next aircraft to land. It will be necessary to conduct Workload assessments to see if the workload of this position is kept at acceptable levels;
- With the anticipated increase in traffic numbers due to the addition of the third runway an extra delivery position may be required;
- The Ground Movement controller position when busy can be split into a maximum of 3 positions. The addition of a third runway will inevitably add complexity to the ground movements, so therefore analysis will need to be conducted to establish if a further ground position will be required.

Implications:

- Increased number of controller positions and therefore an increased number of controllers;
- Current controllers will need additional training on third runway procedures and MOPs;
- Heathrow is already a highly complex difficult environment for a controller to validate (qualify) in – the addition of a third runway will only increase this.

2.6.2 Mitigation

Various projects are underway at R&D or implementation stages that aim to increase the efficiency of operations at airfields. The most relevant projects pertinent to the Heathrow Hub concept are listed below.

- Remote tower – To provide mitigation, technological enhancements currently being developed for use in Remote Tower operations, could be applied and integrated into the current ATC tower. Technologies such as cameras with various advanced visual features could be applied to cover areas where extra visual support is required such as blind spots. This would aim to enhance controller's situational awareness and provide safety benefits. The Remote Tower Concept could be used at an extended Heathrow for contingency or low visibility conditions thereby adding resilience;
- The current tower at Heathrow may not be in a suitable location to support landings in low visibility conditions on 27Rext/09Lext. The addition of a remote camera closer to this threshold is a possible mitigation factor;
- Alerts for conflicting ATC clearances will be generated based on the ATC clearances input by the controller in the Electronic Flight Strips (e.g. one aircraft cleared to land while another aircraft is cleared to cross the same runway). This is achieved by combining Electronic Flight Strip (EFS) data with Advanced-Surface Movement Guidance and Control Systems (A-SMGCS) surveillance data. A-SMGCS is a tool that enables controllers to track ground vehicles during low visibility procedures thereby enhancing safety during Low Visibility Procedures (LVP);

- Conformance monitoring alerts can be generated and transmitted to the controllers and/or the flight crews in case of non-conformance to ATC instructions, or non-conformance to ATC procedures and aircraft state. Two types of alerts are envisaged: on the ground for controllers and on-board for flight crews:
  - For the on-ground segment the 'conformance monitoring' safety support tool is developed by using new technical enablers that will be developed in the SESAR programme such as 'system knowledge of the mobile cleared route', 'system knowledge of the controller instructions given to mobile', as well as existing operational rules associated to a given airport e.g. taxiway layout and rules;
  - For the on-board segment, the 'conformance monitoring' safety support tool monitors:
    - Compatibility between taxiways and aircraft;
    - Taxiway/Runway Status;
    - Deviation from the Taxi Route;
    - Conformance for aircraft for operations on runway.

All of the above initiatives aim to reduce the amount of workload for an aerodrome controller and reduce the risk of safety related incidents, therefore enabling the controller to potentially handle greater volumes of traffic.

2.6.3 Summary

Tower controllers will see the biggest change to operating procedures and this will involve a transition and training stage to enable controllers to feel comfortable with the new layout.

2.7 Impact of Heathrow Hub on Holding

The option of a third runway at Heathrow and subsequently the permanent use of two landing runways during busy arrival flows has the potential to reduce the amount of time an aircraft is placed into a hold before commencing its approach. Currently, Controllers normally only have the use of one runway for landing while the other runway is used solely for departures. Two runways dedicated to arrivals during arrival peaks could effectively double the landing rate (provided independent approaches were approved) and therefore reduce the holding time for aircraft in the holds surrounding Heathrow.

However, if demand were to further increase in line with the added capacity, the holding times could increase to levels seen in current day operations. If the capacity and subsequently the demand at London Heathrow is substantially raised, the likelihood of Heathrow holding facilities becoming full are increased and EnRoute holding may become a more common occurrence. This places strain and high workload on the EnRoute operations.

The previous benefits regarding holding times are dependent on Heathrow being allowed to operate independent arrivals. Currently Heathrow operates a runway alternation system where the landing and arrival runways are switched to provide noise respite for the residents below the flight paths. The option of permanently using two runways for landings does not enable runway alternation to take place. At present there is strong opposition on environmental grounds for ensuring TEAM operations are not continued all day in order to provide relief from aircraft noise.

With the possibility that this mode of operation may not be approved on environmental grounds, alternative solutions will need to be found to ease congestion. Some respite may be made available to communities below the northern runway (westerly) arrival path as deep landings (arrivals on 27Rext West) would favourably displace the noise footprint away from London's centre.

2.7.1 Mitigation

NATS are implementing various projects to reduce the strain placed on holding facilities within the London TMA; these are described below:

2.7.1.1 Hold Relocation

A major project is in progress at NATS that proposes to move the four Heathrow holds further away from the airfield and raise the lowest available holding level from 7000ft to at least 10,000ft. This will enable departing traffic to climb to a more fuel efficient altitude sooner than current day operations allow. This has the potential to provide reductions in fuel consumption.

2.7.1.2 Arrival Managers TMA

The principle aim of the queue management project is to stream traffic inbound to the London TMA using the Arrival Manager (AMAN) tool and provide the most efficient order for landing. Gains are achieved through more efficient traffic sequencing whereby 'in-trail' wake vortex separation is optimised between aircraft. In this regard, the runway can maintain a high throughput of aircraft.

2.7.1.3 Arrival Managers EnRoute

AMAN proposes to provide instructions regarding Controlled Time of Arrivals (CTA) into the London TMA. Flight crew can subsequently make speed adjustments when in the EnRoute phase of flight to help reduce holding closer to the airport. It is more fuel efficient for the aircraft to absorb the delay in the cruise as opposed to lower levels whilst orbiting a holding facility.

Cross-centre Arrival Manager (XMAN) is the next evolutionary stage of this process where AMAN is expanded across Functional Airspace Blocks (FAB) in order to extend the capability of absorbing delays EnRoute into London from all directions. This involves cross border cooperation with other Air Traffic Service Units (ATSUs) including Reims (France), Maastricht (Netherlands), Shannon (Ireland) and Prestwick (Scotland). The ability to make small adjustments in aircraft speeds up to 350 miles away from their destination airfield provides the opportunity to better manage the traffic flow. Initial studies indicate up to three minutes of holding could be absorbed EnRoute, saving on both fuel consumption and CO_2 emissions.

2.7.1.4 Time Based Separation (TBS)

In addition to AMAN, TBS is expected to deliver large benefits for Heathrow, particularly in strong winds. The TBS concept is intended to provide greater resilience at capacity constrained airports where a large amount of delay is attributed to head winds. Heathrow is a prime example of such an airport, hence the ongoing programme aiming to implement TBS in 2015. Current estimates suggest that TBS will reduce delays by half due to headwinds (which at Heathrow is the largest cause of delay).

The TBS concept intends to keep the time spacing between aircraft the same. In the second row of diagrams the same aircraft pair has separations applied using TBS. The 90 second time spacing is kept the same resulting in a reduced distance separation during a strong headwind.

Note that the landing rate will still reduce to a certain extent while using TBS in strong headwinds due to limitations such as MRS which still needs to be applied. Hence delay due to headwind is not eliminated but should be substantially reduced.

2.7.1.5 Trombone Approaches

Trombone approaches offer the opportunity to absorb some delay through lateral holding that would previously have been done in the holds. Current methods of radar vectoring aircraft from the holds towards final approach involve extremely high workload for approach controllers and result in a large trajectory dispersal at lower altitudes. A trombone approach (Figure 12 below) consists of a Precision Navigation (P-RNAV) route that involves publishing the downwind leg of the approach and extending the STAR. The final approach leg is also extended and contains numerous waypoints along the route. Additional legs can be added parallel to the downwind leg, however, at any time the controller can issue direct clearances to an aircraft to shorten the approach profile. The trombone legs are only used when the path needs to be 'stretched' and hence absorb the delay through lateral holding. The London TMA is expected to incorporate trombone approaches at Heathrow under redevelopment plans currently at the pre-operational research phase.

While this procedure has the potential to increase aircraft track mileage, it does have the benefit of increasing the overall traffic awareness for the approach controller and therefore culminating in additional capacity in the TMA. Additional benefits of a trombone approach include simplification of controller tasks, more orderly flows of traffic with improved containment of trajectories (thereby reducing noise impact and increasing flight efficiency) and standardisation of operations.

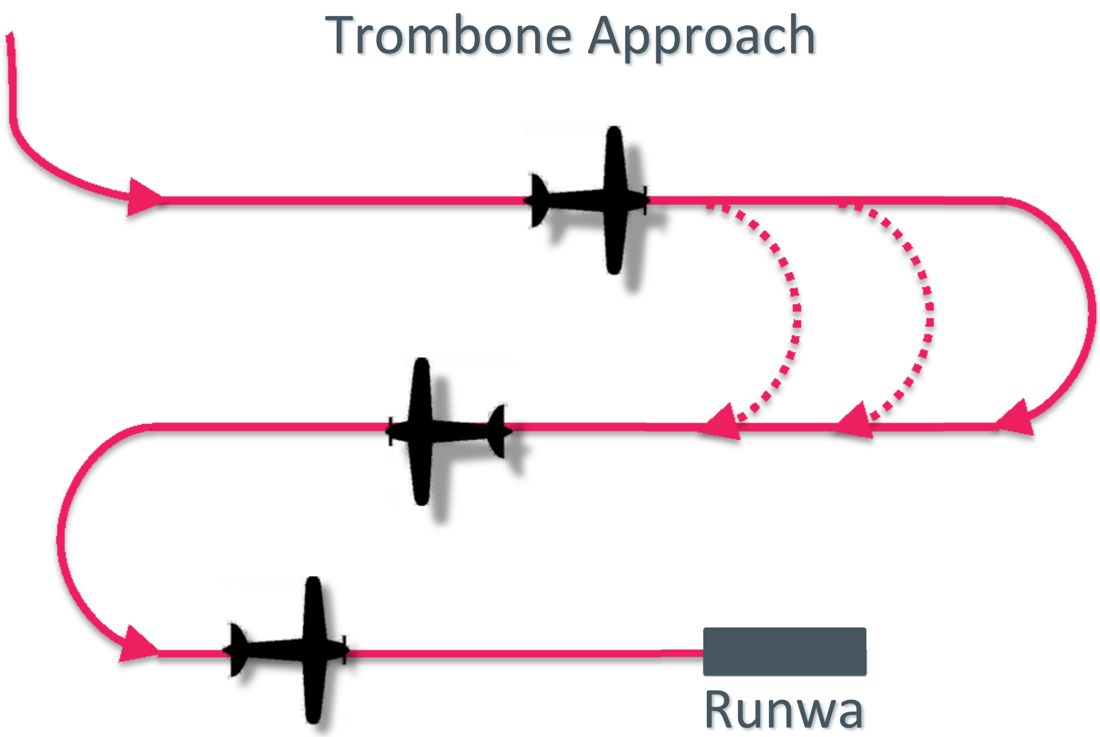


Figure 12 Trombone Approach

2.7.2 Summary

In today's environment, it is unlikely the holding facilities would be able to handle the extra traffic movements, considering the expected year on year increase in traffic combined with the additional capacity afforded by a third runway option at Heathrow regardless of runway design. If no extra measures were taken, holding facilities would become full forcing excess traffic movements to hold EnRoute culminating in excess fuel costs and high controller workload.

Holding will almost certainly exist at capacity constrained airports like Heathrow, not necessarily due to inefficiency but due to the need to maintain a high throughput. As a result there will always be a need for some delay to exist in the LTMA. It is pivotal to keep this delay as low as possible while still maintaining a high throughput. Projects such as XMAN will help deliver these expectations while trombone approaches will help absorb the orbital holding around the London holding facilities. Finally, PBN will help maintain a high throughput and add resilience during periods of strong headwinds.

The conclusions drawn here will be relevant for all runway designs as holding will continue to exist regardless of where additional runways are placed in the LTMA. The previously described projects of AMAN, XMAN, and TBS all aim to provide a level of planning and efficiency not currently seen within

London airspace; these projects will be critical enablers to support the extra movements envisioned. Providing the airspace is not operated at full capacity and some resilience is built in, it is feasible that controllers will be able to handle the increased traffic through the holding facilities.

2.8 Impact of Fleet Mix on operations at Heathrow Hub

The maximum arrival rate and hence the declared capacity of an airport is dependent on the types of aircraft that make up that airport's traffic; this is the fleet mix. Aircraft create wake vortices that disrupt the air in their trail. In general a larger aircraft will create a larger wake vortex and will be more stable flying through a wake vortex. A small aircraft flying in the wake of a larger one can result in losses of control. As such aircraft are separated according to the size of wake of the aircraft they are following compared to their own wake category. In the UK the wake categories are:

- J-Jumbo (Super Heavy/Very Large Aircraft, A380)
- H-Heavy (e.g. B747)
- UM-Upper Medium (e.g. B757)
- LM-Lower Medium (e.g. B737)
- S-Small (e.g. Gulfstream 4)
- L-Light (e.g. C525)

An LM aircraft following another LM aircraft requires less spacing for example than an LM following a J. Aircraft are sequenced to minimise the required spacing by grouping aircraft of a particular type and avoiding placing smaller aircraft in the trail of much larger ones.

Due to the large wake vortex created by an A380, a new separate wake vortex category has had to be created: Super Heavy. The A380 requires trailing aircraft to maintain increased separation compared to conventional heavy aircraft due to the increased wake vortex and this can reduce throughput. The reduction in number of movements through the increase in the proportion of the fleet mix made up of heavy and super heavy aircraft does not however imply a reduction in passenger numbers. The effect of fleet mix on landing rate can be seen in the results of Section 4.

The Heathrow Hub Concept has the potential to provide flexibility in day to day operations regardless of the fleet mix. The flexibility of the Heathrow Hub Concept is mainly attributable to the unique layout of the design.

The extended runway enables terminal buildings to remain between the northerly and southerly runways. In this setup, one arrival runway could be used solely for heavy/super heavy jets and the other runway for all other wake categories. This is particularly prevalent in Low Visibility Procedures (LVP) where A380s require 10nm in trail separation. Using a dedicated runway for aircraft in the 'J' and 'H' wake turbulence categories provides the ability to avoid large wake separations such as a medium aircraft following a Super Heavy. Regardless of the runway used for arriving, a centralised terminal setup ensures aircraft do not have to cross active runways to reach their terminal. The only exception will be arrivals for Terminal 4 and cargo which may have to cross the southern runway if they did not land on that runway.

Centralised terminal access between the northerly and southerly runways removes any additional workload on controllers to ensure aircraft are aligned on the most efficient runway. While it may be difficult to optimise the landing runway for both S and J use and ground operations at the same time, Heathrow Hub does provide full flexibility to adapt quickly to changing traffic situations.

2.9 Instrument Landing System Considerations

The Instrument Landing System (ILS) configuration has been considered at a high level to assess if there are any areas of concern regarding their application as part of the unique runway configuration brought about by the Heathrow Hub concept.

2.9.1 Introduction

An ILS is a ground-based instrument approach system that transmits radio beams in both a vertical and lateral plane. This provides precision guidance to approaching aircraft to enable them to remain on the extended centreline of a runway and provides a glideslope from which the flight crew can ascertain their height in relation to a nominal 3 degree path. This approach aid is particularly useful in Instrument Meteorological Conditions (IMC) where low visibility can obscure the runway from the field of vision until relatively late into the final approach.

Different categories of ILS support different types of approaches. Heathrow is equipped with CATIIIC ILS enabling appropriately equipped aircraft to land with zero visibility.

2.9.2 Current day ILS operations

Figure 13 provides an illustration of the approximate placement of the main ground equipment for a single runway ILS. The far right shows the localiser antenna which is located at the far end of the landing runway. This provides a beam up the approach giving lateral guidance enabling aircraft to maintain their profile on the centre line. Although there is not a specific recommended distance relative to the end of the runway to place the localiser it is ideal to minimise the effect of the ILS critical area on the runway operations. Further detail will follow regarding the ILS critical area.

Adjacent to the touchdown point is the glideslope antenna which provides a beam along the approach path giving aircraft the ability to follow the glideslope. Finally there are three marker beacons along the approach which project a beam vertically upwards showing pilots when they reach key points on the approach. The inner marker needs to be located between 75-450m from the landing threshold and within 30m of the runway centre line. It indicates the point of lowest decision height during poor visibility conditions. The middle marker is located about 1050m +/- 150m from the landing threshold and has to be within 75m of the runway centreline. During Visual Meteorological Conditions (VMC) this marker shows the pilots where the approach transitions from instrument to visual. Finally the outer marker is typically located 3.9Nm from the landing threshold and has to be within 75m of the runway centreline. But it can be within the range of 3.5Nm to 6Nm if terrain does not permit the ideal location. However markers are not needed if there is a suitable substitute such as DME equipment.

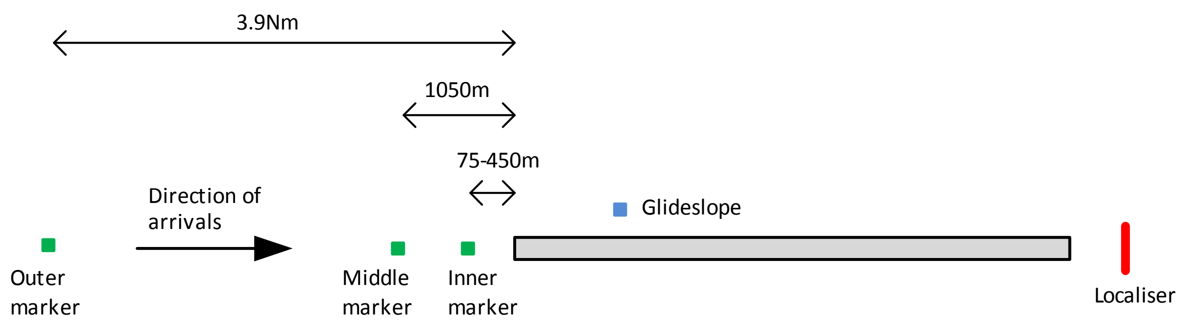


Figure 13 Approximate Placement of ILS Equipment on Single Runway

2.9.3 Impact of ILS/Localiser placement for the Heathrow Hub Concept

These basic location requirements will be assessed against the Heathrow Hub configuration focusing on the northerly inline runways as this is where differences would occur. Both northerly runways need the ability to operate as landing runways from both directions (although not simultaneously). Looking from one direction there would need to be two ILS setups. As shown in Figure 14 the ILS could share the localiser antenna assuming it can be configured to cover 4.5Nm of runway as well as the full approach path for both runways. It is beyond the scope of this assessment to say if this is feasible or not. The runways would require two glideslope antennas which would be located at the touchdown zones for each runway. The second runway may require an inner marker between 75m and 450m from the second threshold. Also with the restriction of it being located within 30m of the centreline means it would have to be placed in the space between the two runways. However this may not be needed as it could be substituted by DME equipment eliminating the need to place equipment directly in between the runways. The middle marker for the second runway would need to be approximately 1050m from the second threshold but is allowed up to 75m from the centreline. This would mean it could be positioned next to the first runway. The outer marker for the second runway would be beyond the airfield boundary hence would not be impacted by the runway configuration.

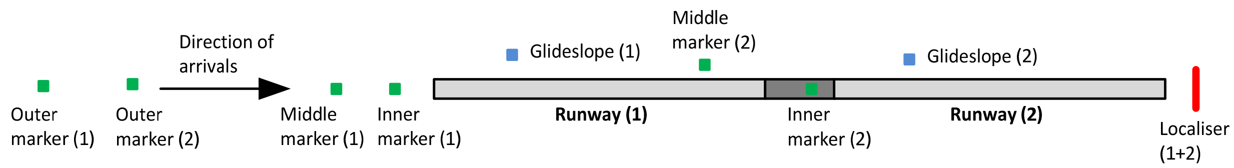


Figure 14 ILS Applied to Heathrow Hub Inline Runway Configuration Using Single Localiser

This configuration for the ILS could be feasible for normal operations but could be a problem during Low Visibility Procedures (LVPs). During poor visibility there are restrictions in place to ensure there is no interference of the ILS signal at a time while pilots are relying solely on instruments potentially close to the ground. The areas of ILS interference are called the critical area and the sensitivity area. The critical area must be kept clear during all ILS operations. This area is near the localiser and glideslope beacons. Its size and shape depend on many factors regarding the environment and the size of objects (i.e. aircraft) that could obstruct the beam. The sensitivity area is a larger area that needs to be protected during LVP operations. This could cover the runway and potentially some taxiways.

During LVPs the sensitivity area must be clear when an arrival is within a specified distance of the threshold which is typically 1 or 2Nm. This means any previous arrival needs to have cleared the runway and cleared the sensitivity area while any preceding departure needs to have passed overhead the localiser beacon. It is the second point regarding departures where the above ILS configuration will introduce a dependency between the inline runways during LVPs. This occurs because a departure on the second runway must have passed overhead the localiser before an arrival on the first runway is within for example 2Nm from touchdown. This could further impact capacity at a time when capacity would already be lowered due to larger separations required during LVPs. This impact could be calculated using runway capacity modelling and applying this runway dependency.

It should be understood that this is a unique runway configuration hence there may be technical mitigations that can limit the impact of the ILS sensitivity area which are not currently applied in typical runway configurations. Through more detailed analysis of the sensitivity area there may be options to allow departures to line up on the second runway while an arrival is landing on the first runway (if proven safe). There is therefore potential to limit the impact of dependencies on LVP capacity hence needs further investigation.

Another possible mitigation to this could be to have a localiser beacon for each runway as shown in Figure 15 below. This places an additional localiser beacon in between the two inline runways.

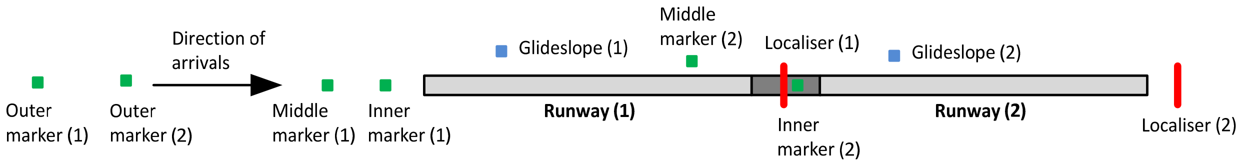


Figure 15 ILS Applied to Heathrow Hub Inline Runway Configuration Using Two Localisers

Placing a second localiser in between the runways would mean the sensitivity area only covered the first runway as shown in Figure 16 below. Therefore aircraft landing on the first runway are not affected by departures on the second runway. However this would mean that the localiser would not be available to departures requiring assistance on maintaining the centreline during particularly bad visibility which would be a limitation.

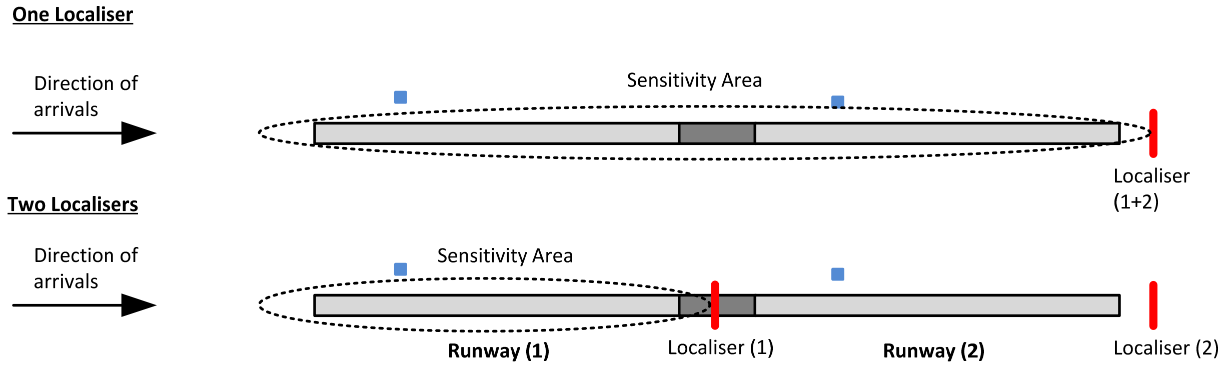


Figure 16 Illustration of Differences in Sensitivity Areas Comparing One Localiser and Two Localisers

There may be technical solutions allowing a localiser in between the runways to both cover the approach but also reach backwards to give guidance to departures without the departures impacting the arrivals. However proposing such a technical solution is beyond the scope of this document.

The sizes of the sensitivity area would need to be considered in case there is a difference between the widths of the sensitivity areas shown in Figure 16 above. These could impact taxiway operations and lead to restrictions for large aircraft such as A380s. Such a question could only be answered after a detailed assessment of these ILS configurations.

Another consideration to placing a localiser in between the runways is how close the antennas are to the thresholds. As stated earlier there is a critical area near the antenna that no aircraft or vehicle can obstruct during all ILS operations. A localiser antenna is typically positioned several hundred metres from the threshold to reduce the amount of runway that is effected by the critical area. For example Table 1 below shows the current distances between the localisers and thresholds at Heathrow today based on the UK AIP.

Runway	Distance Between Localiser and Threshold (m)
27L	397
27R	429
09L	597
09R	607

Table 1 Distances between Localiser and Threshold at Heathrow Today

In the Heathrow Hub concept there is a 600m area between the two inline runways. Placing localiser beacons in between the two runways would mean they will be 300m from the thresholds. There will need to be consideration of how far the critical areas impinge on the runway in order to assess operational impact if any. During normal operations arrivals would likely vacate the runway considerably before the end of the runway and therefore the critical area may not be affected. Finally there will have to be consideration as to how the central localisers would be implemented. There would need to be two central localisers; one for each direction. If individual antennas are required then there may need to be a certain gap in between so the structure of one antenna doesn't impact the operation of the other. Any required gap would further increase the area of runway that the critical area covers. A solution to this may be to have the two central localisers combined in one antenna although it is beyond the scope of this document to state if this is possible.

2.9.4 Mitigation

With a single localiser for each direction at the end of the combined in-line runway there is a limitation during LVPs due to a dependency, as the ILS sensitivity area must be kept clear. Possible technical mitigations that could be applied to an ILS for the inline runway configuration need to be investigated to assess if the effect of the ILS sensitivity area could be reduced. It could also be mitigated by using a localiser in between the runways however reduces the flexibility of the concept. Note that there is the possibility of other dependencies between the inline runways caused by missed approaches during LVPs (see Section 3.4) hence mitigating against the ILS concern may not completely remove the dependency.

Normally an inner marker is required between 75m and 450m from the landing threshold which in the case of the second inline runway would mean it would be placed in between the two runways. However this marker may not be needed as it could be substituted by DME meaning this marker does not need to be in the gap between the runways and allows more flexibility for using the tarmac.

Another key mitigation will be to switch from ILS to MLS as a greater proportion of aircraft become suitably equipped. MLS has a smaller sensitivity area and will reduce the impact of LVPs on capacity. Also an alternative in the long term will be to use GBAS which does not rely on ground equipment.

2.9.5 Summary

In conclusion an ILS system can be operated on the two inline runways. This could be done with a single localiser for each direction meaning it will not require one in between the two runways. Also there is normally an inner marker required before a landing threshold which would have to be placed in between the two runways. However if the purpose of the inner marker can be provided by DME there is the possibility of not requiring any equipment in between the inline runways. This provides extra flexibility for using the tarmac.

Nevertheless, a single localiser potentially hinders capacity during LVPs due to the dependency caused by the ILS sensitivity area. However further investigation will be needed to assess if any technical mitigation exists which could be applied to Heathrow Hub to limit this. Capacity loss caused by the ILS sensitivity area could be mitigated through using a localiser between the runways but that reduces the flexibility of changing runway lengths. However, even with a single localiser the touchdown points will be fixed by the locations of the glideslope antennas.

Finally there is a limitation in switching between the two inline runways for arrivals such as switching from early morning operations and also during an unexpected runway closure. For safety only one ILS could be turned on at once. This means switching between the runways for arrivals would require an approximately 15Nm gap in arrivals.

2.10 Use of PBN in SIDs

2.10.1 Introduction

SIDS are well defined at all major London airfields. SIDs and STARs (see Section 2.7.1.5 for more information on current day STARs and future changes) aim to optimise air traffic flows while also providing safe terrain clearances and Noise Preferential Routeings (NPRs). While the SIDs and STARs over London help de-conflict inbound and outbound aircraft, the congested airspace results in these procedures severely limiting the opportunity for airlines to get the profiles they wish to fly.

2.10.2 Current SIDs

Current day SIDs are not defined by precision navigation (e.g. RNP-1). Instead pilots navigate along a SID using VHF Omni-Directional Range (VOR) and radial Distance Measuring Equipment (DME). A Dover (DVR) departure out of Heathrow will pick up the Detling (DET) Magnetic bearing from a station (QDR) which is a Non-Directional Beacon (NDB). This can result in aircraft not flying predictable routes along the initial segments of the SIDs. While the margins of error are not large enough to cause concern, SIDs are designed through PBN standards offer many benefits over current operating methods.

Many current SIDs in the London TMA cross in close proximity (or directly underneath) holding facilities (as previously shown in Figure 18). Controllers have to wait until the outbound aircraft is clear of the hold until further climb clearances can be tactically given. Currently the alternative solution is vectoring the departing aircraft away from the hold in order to provide lateral separation against aircraft in the hold; this option increases the workload of the controllers in an already busy environment. Workload for the controller is elevated as the aircraft would have to be closely monitored when on a radar heading.

2.10.3 Split SIDs

Figure 17 below shows a potential use for PBN in the redesign of a Compton (CPT) departure from Heathrow. Currently two successive CPT departures require a minimum of two minutes separation. However, PBN affords the opportunity to reduce this to potentially one minute through the means of designing a northerly and southerly Standard Instrument Departure (SID). Such a design will see two successive departures that are coordinated to traverse the same down route London sectors self – separated via their individual SIDs.

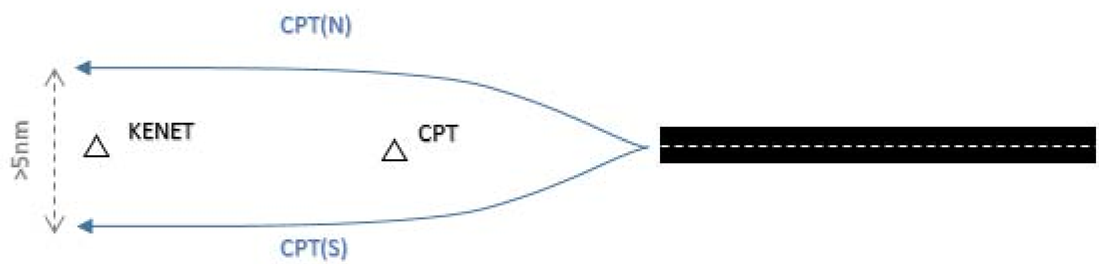


Figure 17 PBN SID design

2.10.4 Impact of Heathrow Hub on SID design

The addition of a third runway at any of the proposed Heathrow solutions will naturally involve redesign of the SIDs out of Heathrow. There are many considerations when designing SIDs out of a busy airfield such as Heathrow, however the Heathrow Hub Concept potentially offers the easiest redesign solution. Due to the nature of the runway layout (i.e. the new runway is not offset from the existing northern runway) it is envisaged the SID design will be less complex than a north/south westerly option. During westerly operations the extended runway will predominantly be used for departing aircraft. In this sense it is an extended version of the current SIDs from the northern runway and therefore it is envisaged the inline option will place less stress on any redesigns.

2.10.5 Mitigation

The LAMP project proposes to redesign SIDs to PBN standards so that aircraft left on their SID can be climbed initially to a higher altitude than they are today. In addition, SIDs and STARs can be designed to precision navigation standards enabling noise distribution to be concentrated to non-sensitive areas.

LAMP offers an opportunity to redesign current SIDs and STARs so that they do not conflict with each other. Conflicting SIDS and STARS often result in aircraft climbing/descending to suboptimal levels/altitudes in order to maintain separation. In addition to providing environmental benefits, de-conflicting the SIDS and STARS is expected to provide another means of reducing controller workload.

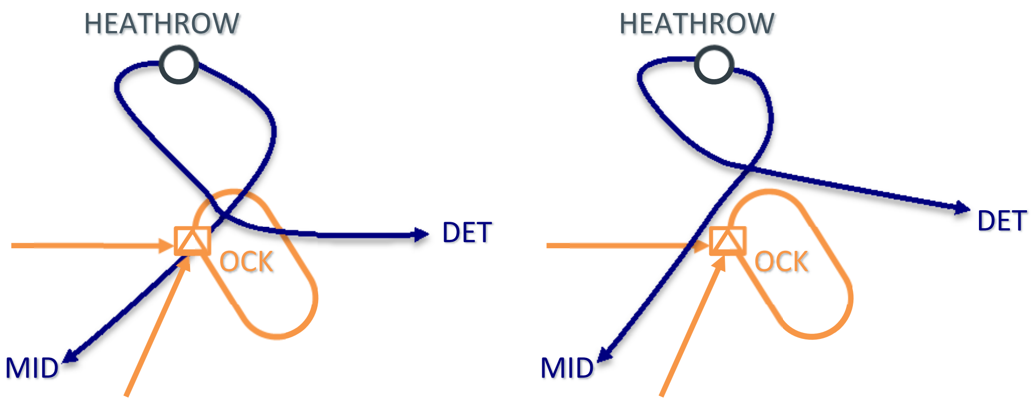


Figure 18 SID Redesign

Figure 18 above represents an example in the London TMA where Heathrow SIDs interact with the surrounding holds. The figure on the left shows the westerly DET SID and Easterly MID SID both of which transit underneath the OCK hold. In this circumstance outbound aircraft are restricted to 6000ft on their SID until clear of the hold. To keep the aircraft climbing, controllers have to vector the aircraft away from the hold thereby increasing their workload. It has been proposed that the PBN SIDs are designed to eliminate interactions with the hold allowing controllers to climb aircraft without having to apply multiple vectors to avoid the hold. This will greatly reduce controller workload and hence allow for an increase in capacity of the TMA.

PBN offers the potential for closer spaced routes where the advanced navigational capabilities provide additional means of assuring separation is maintained. Where routes can be placed closer together it provides the opportunity to control more aircraft in the same airspace and therefore has the potential to increase capacity. Additionally, if aircraft maintain these predefined routes there is a potential for a decrease in tactical intervention thereby decreasing controller workload. The additional accuracy of the flight paths afforded by PBN enable routes to be designed to avoid noise sensitive areas where possible.

The TMA-Manager (SESAR) project aims to provide TMA controllers with warnings of potential upcoming conflicts where aircraft on SIDs from separate airfields converge on a single waypoint. The project aims to provide controllers with information with sufficient time to take the necessary action to avoid losses of separation; this should reduce workload.

2.10.6 Summary

The proposed changes to SID/STAR redesign, if successful, will greatly reduce controller workload within the TMA. In addition to increasing R/T workload, the workload for the controller is elevated as the aircraft would have to be closely monitored when on a radar heading. Designing SIDs and STARs that naturally de-conflict and where SIDs can be moved away from holding facilities has the potential to greatly increase capacity within the TMA.

2.11 Looking at further growth 2050+

2.11.1 Introduction

This section will look at the challenges in predicting the impact of a fourth runway at Heathrow. The Heathrow Hub Concept brings the opportunity for further capacity growth through the construction of a fourth runway (Phase 2), located to the south of the proposed third runway. A fourth runway is outside of the scope of the immediate plans for capacity expansion in the South East. However the Airports Commission Report (Airports Commision, 2013) indicates that there is likely to be demand for a second additional runway to be operational by 2050 or earlier.

2.11.2 Challenges of a fourth runway

Having two additional runways has the potential to more than double Heathrow's capacity. Four runways could each be dedicated to arrivals or departures.

The challenges faced by expansion to four runways are much the same as those for three runways. All of the challenges to Phase 1 Heathrow Hub remain and may be exacerbated by the further increase in expected movements in Phase 2. Some additional challenges and benefits unique to a Phase 2 four runway layout are listed below:

2.11.2.1 Runway Layout

A Site of Special Scientific Interest (SSSI) which contains Wraysbury Reservoir, supplying water to London is located to the west of Heathrow Airport. This area has been highlighted by the commission as an area of concern if the south western area of the Heathrow site was developed (Airports Commision, 2013). To minimise impact in this area, three options have been proposed for the location and direction of a fourth runway (with varying impact on the SSSI).

One of those options is to angle the southern runway to minimise incursion into the SSSI; the available modes of operation on an angled runway are potentially limited. This option would require easterly approaches to converge on the two newest runways. Safety may only be assured on converging approach paths if additional spacing is imposed between aircraft on the two approach paths; this type of operation (dependent approaches) cannot support as many movements as independent arrivals (that would be available on parallel runways). The other layout options have parallel runways and should support independent operations.

2.11.2.2 Additional growth/development at London airfields

Within the timescale envisioned for the Phase-1 development, it is highly unlikely that another of the five London Airfields will undergo major restructuring in order to greatly increase their movements. Before 2050 however it is conceivable that other London airfields will have constructed and be operating additional runways of their own. As such it is difficult to speculate on the ability of the 2050 LTMA to manage the additional movements from a fourth Heathrow runway and those from other airfields.

2.11.3 Mitigation

It is likely that the mitigating technologies and airspace restructuring mentioned in earlier sections, and additional enablers not yet envisioned, will be implemented and working harmoniously by a 2050 launch date.

2.11.4 Summary

The inability to accurately predict so far into the future limits the realistic scope of the feasibility assessment of a Phase-2 Heathrow Hub from an airspace perspective. Whilst four runway capacity has been modelled at a high level, the airspace capacity is unpredictable. There are currently too many unknowns, the state of technology, the airspace design, movements at other London airfields etc. to be able to confidently reflect on Phase-2 feasibility at this stage.

3 Missed Approaches

3.1 Introduction

Missed approaches are an area that was identified as a potential concern regarding implementation within the Heathrow Hub Concept. The unique runway configuration means there are no current examples to compare with hence the need to investigate at a high level how missed approaches could work for Heathrow Hub.

The basic requirements for missed approaches on parallel runways in terms of divergence from other traffic flows is firstly understood, and then followed by investigation of how these requirements may be accommodated within the concept. Areas where these requirements are not met by the concept in its current form will highlight areas where further development and investigation is required.

Further to the investigation of the application of missed approaches, suggestions are given as to how to proceed and improve the maturity of the concept regarding missed approaches.

A missed approach is effectively an aborted approach to an airport which is considered a normal operating procedure and not an emergency. They are conducted for a variety of reasons when an aircraft is on final approach and can be initiated by either the controller or the pilot. Airports typically have instrument missed approach procedures that a pilot can fly without being instructed what to do at least until the procedure is completed.

Controllers can allow aircraft to fly a standard missed approach knowing which traffic flows are separated from the procedure and which are not. They could also provide a non-standard missed approach using a heading and altitude instruction but then separation becomes the responsibility of the controller. After a missed approach has been initiated and when the controller is ready, the aircraft will be vectored back to be incorporated into the arrival flow.

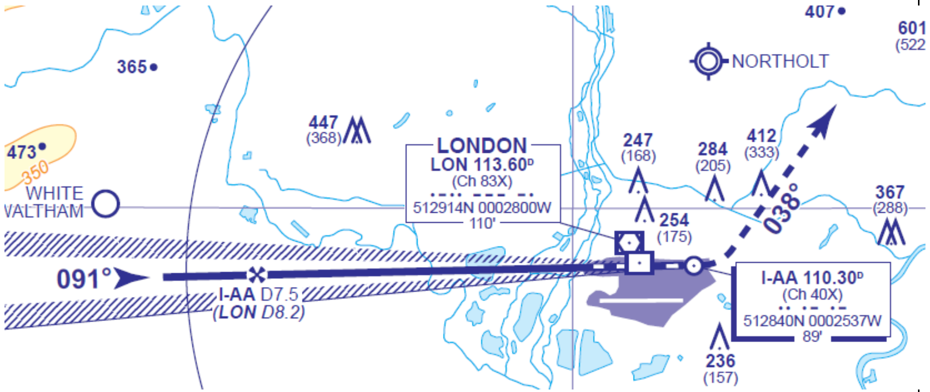
3.2 Current day Missed Approach Procedures

The following describes the current missed approach procedures at Heathrow. Diagrams are provided in Figure 19 which are taken from the UK AIP. These represent the ILS/DME approach / missed approach procedures:

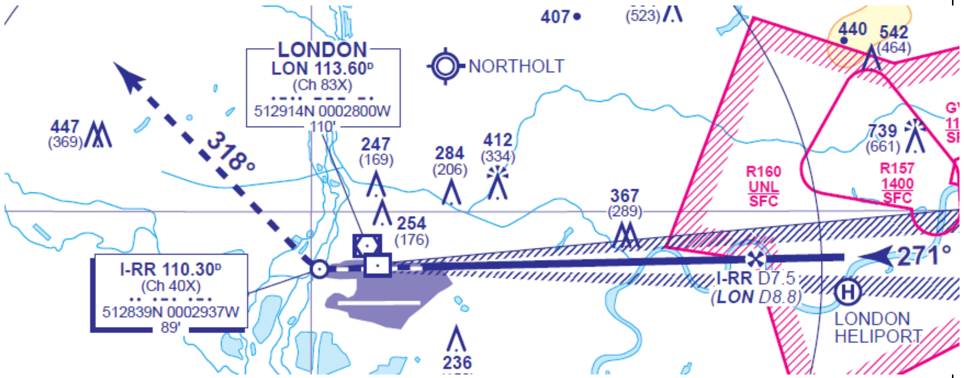
- R09L – Climb to 3000ft on runway heading until passing 1580ft or threshold of R09L, whichever is later, then turn left onto track 038 degrees;
- R09R - Climb to 3000ft on runway heading;
- R27L – Climb to 2000ft on runway heading until passing 1080ft or threshold of 27L, whichever is later, then turn left onto track 149 degrees;
- R27R – Climb to 3000ft on runway heading until passing 1580ft or threshold of 27R, whichever is later, then turn right onto track 318 degrees.

As can be seen from the above missed approach procedures they all, with the exception of R09R, make a turn away from the airport. The earliest the turn can be initiated is the runway threshold and the latest is a defined altitude. This turn away from the airport and away from departure routes will also be needed for Heathrow Hub. The R09R missed approach is the only one which continues on runway heading climbing to 3000ft. Historically all the missed approaches from Heathrow continued on the runway heading but to better protect them against departures these were later changed. It was felt this was not needed for 09R as 09L is not typically used for departures and therefore the safety implications are not as extreme.

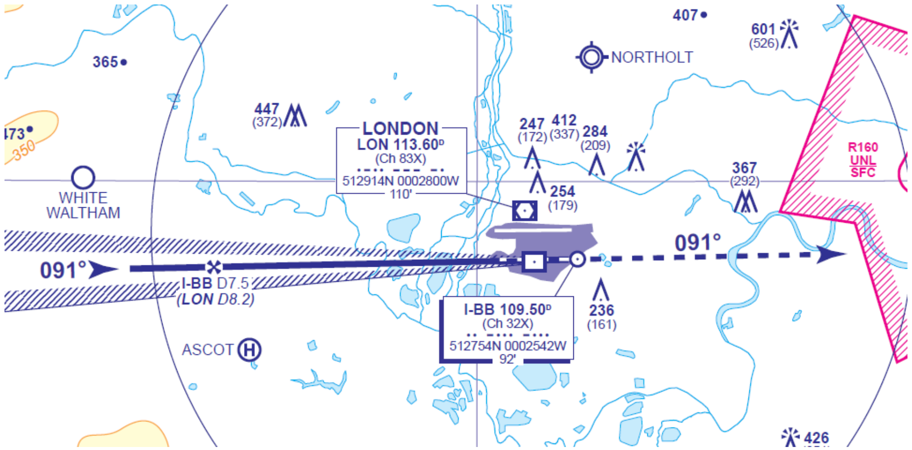
Runway 09L



Runway 27R



Runway 09R



Runway 27L

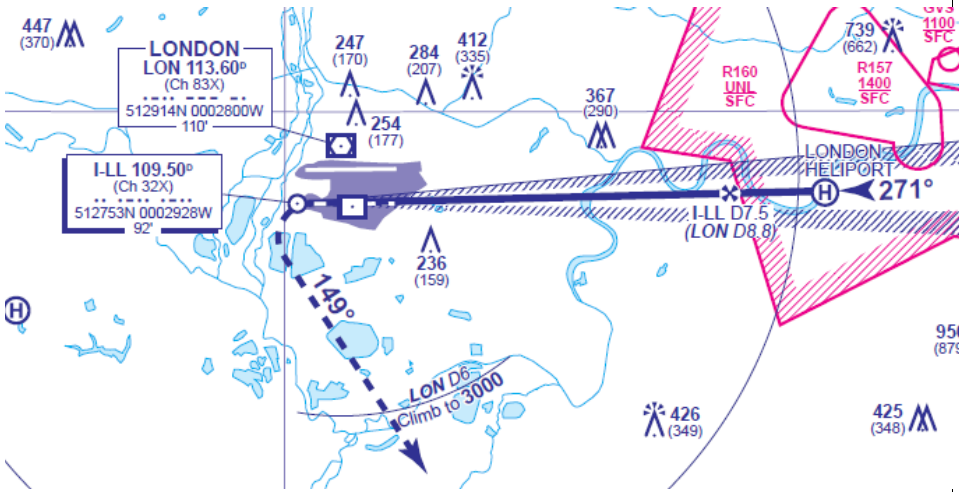


Figure 19 ILS/DME Missed Approach Procedures for Heathrow (Current Day Operations)

3.3 Missed Approaches Requirements Relating to SOIR

Simultaneous Operations on Instrument Runways (SOIR) requirements as stated in PANS-ATM Doc 4444 provide guidelines for developing procedures for simultaneous operations from parallel runways. There are 4 basic modes of operation that are covered in these guidelines including the following:

- Mode 1 – Independent parallel approaches: simultaneous approaches to parallel or near parallel instrument runways where radar separation minima between aircraft on adjacent extended runway centre lines are not prescribed;
- Mode 2 – Dependant parallel approaches: simultaneous approaches to parallel or near parallel instrument runways where radar separation minima between aircraft on adjacent extended runway centre lines are prescribed;
- Mode 3 – Independent parallel departures: simultaneous departures from parallel or near parallel instrument runways;
- Mode 4 – Segregated parallel operations: simultaneous operations on parallel or near parallel instrument runways in which one runway is used exclusively for approaches and the other runway is used exclusively for departures.

In the case of Heathrow Hub where there will be the aim for independent runway operations then all 4 modes of operations would be considered. However regarding missed approaches only modes 3 and 4 need discussing as it is only the design of the departure route that will affect the missed approach procedure.

Modes 3 and 4 can be explained using a generic two parallel runway airport which operates in mixed mode. Firstly considering Mode 3 as shown in Figure 20, to allow simultaneous departures from parallel runways the departure tracks need to diverge by a minimum of 15 degrees after take-off.

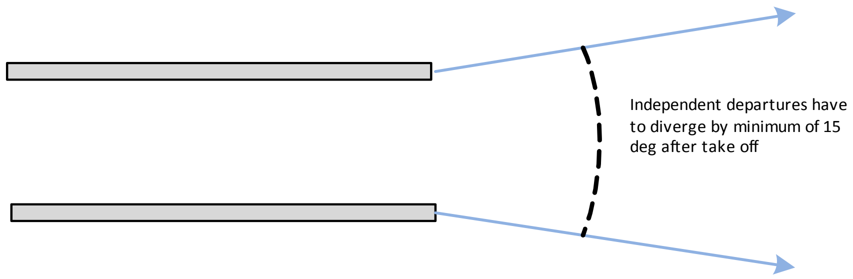


Figure 20 Mode 3 – Independent Departures

Figure 21 overleaf represents Mode 4. For segregated operations on parallel runways to be considered independent the missed approach track on one runway has to diverge by a minimum of 30 degrees from the departure tracks on the adjacent runway.

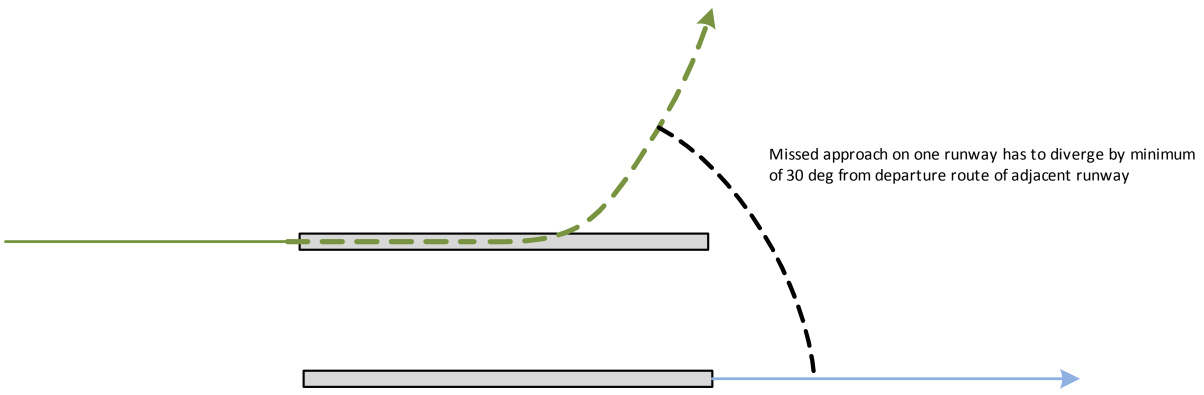


Figure 21 Mode 4 - Segregated Parallel Operations

Next these modes of operation can be combined as shown in Figure 22 to give a mixed mode operation from parallel runways. This enables the departures to be fully independent as the tracks diverge by a minimum of 15 degrees after take-off. Also the arrivals are independent of departures on the adjacent runway as the missed approaches diverge from the departure track on the adjacent runway by a minimum of 30 degrees. Note in this example the arrivals could be independent (Mode 1) or dependant (Mode 2). However this would not impact the missed approaches at least at this level of analysis.

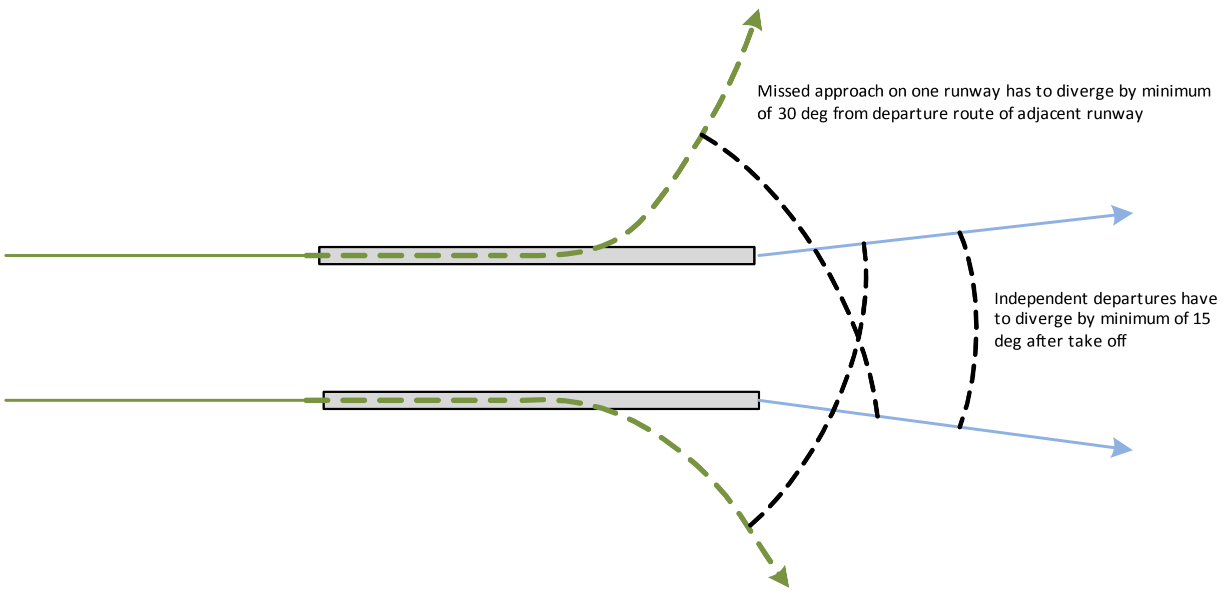


Figure 22 Mixed Mode Operations from Parallel Runways

3.4 Third runway Heathrow Hub – Normal Operations

In the three runway Heathrow Hub scenario during normal operations (mixed mode with all runways operating) the southern runway is intended to be operated as mixed mode, the north eastern runway would operate arrivals (during R27 operations) and the north western runway would operate departures (during R27). During R09 operations the roles of the northern runways would swap. There would also be contingency modes of operations when one or more runways are closed but for now all runways are considered operational. The missed approaches discussed below will initially climb on runway heading until passing a minimum of 500ft before turning onto a diverging heading. The details of the diverging heading in each example are discussed below.

Initially considering departures the SOIR guidelines could be applied resulting in a minimum of 15 degrees divergence between departure tracks. The divergence of departures will likely be higher to enable efficient single runway departure operations as discussed in Section **Error! Reference source not found.** however the logic is still relevant and this section refers to the ICAO minimum divergence of 15 degrees. Next considering arrivals, the missed approach track on the south runway has to diverge by a minimum of 30 degrees from the departure track on the north western runway. Also note the SOIR guidelines state that when the runways are staggered (with arrival runway staggered in the direction of the approaching aircraft) as is the case with the southern and north western runways then wake turbulence from heavy aircraft doing missed approaches needs to be considered as it could drift into the path of departures during a cross wind coupled with the missed approaches being higher than the departures due to the stagger. However this guidance is stated for the minimum runway spacing for segregated parallel operations of 760m. The Heathrow runways have a spacing of 1414m hence this may not be a concern but needs to be considered.

The final scenario which is the missed approach track on the north eastern runway is harder to define as it ideally would be designed to allow independent departures from both the north western and the southern runway. To be independent from the southern runway it just needs to diverge by a minimum of 30 degrees from the southern runway departure track. However to be independent from the north western runway it also needs to diverge sufficiently from the departure track of the north western runway. This scenario is not covered in SOIR guidelines hence a safety case would need to be proven to allow independent operations between the two inline runways. A missed approach procedure from this runway would have to diverge towards the north in order to route away from the departure tracks. This is similar to a missed approach track diverging from the departure track on a single runway. On a mixed mode single runway there is the possibility of a "piggy back" scenario where a missed approach occurs behind a departure. However the key difference is a single runway is naturally dependent between arrivals and departures whereas the Heathrow Hub concept is ideally independent between the inline runways.

An area of concern for a missed approach safety case will be during LVPs. It is possible an operational dependency is required during low visibility as the missed approach aircraft will not have visual confirmation of the departure's position, leading to an impact on capacity during LVPs.

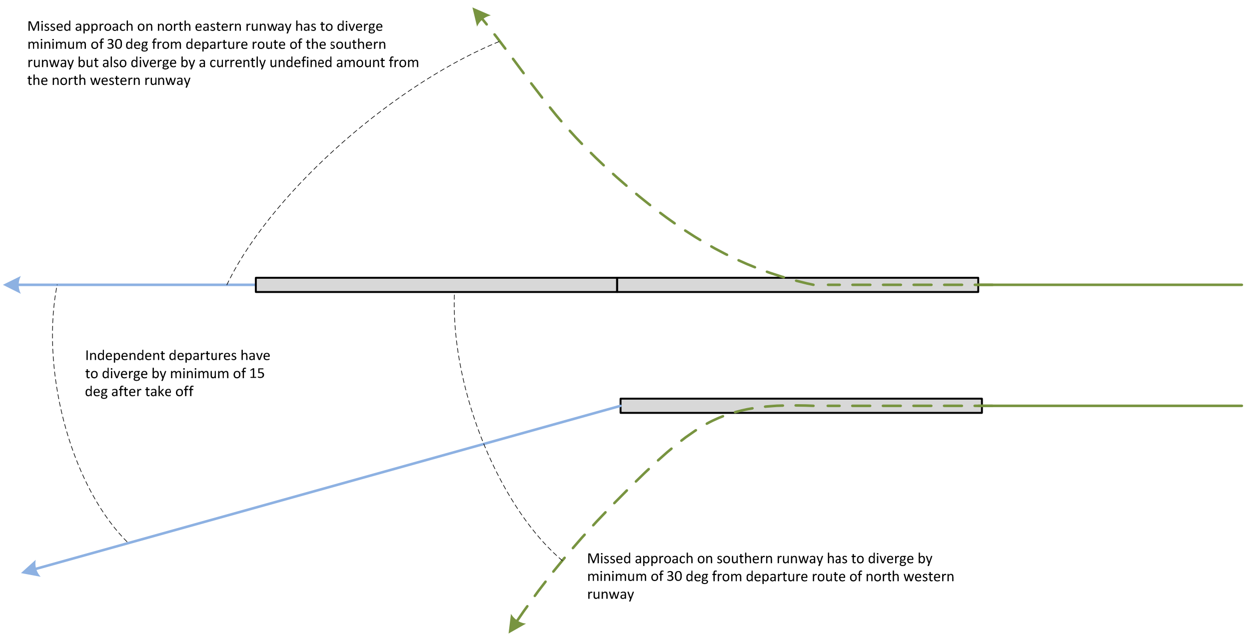


Figure 23 Heathrow Hub (three runways) Operating on R27

Regarding R09 operations there is a similar set up for missed approaches. The departures from the southern and north eastern runway are able to operate independently by achieving the minimum of 15 degrees divergence after take-off. Also the arrivals on the southern runway can be independent from the departures on the north eastern runway by ensuring the southern runway missed approach diverges by a minimum of 30 degrees from the departures on the north eastern runway.

However as with R27 operations there is an unknown divergence required for missed approaches on the north western runway and the departure track from the north eastern runway to enable independence between these runways. Again a safety case would be required to show that this independence can be achieved.

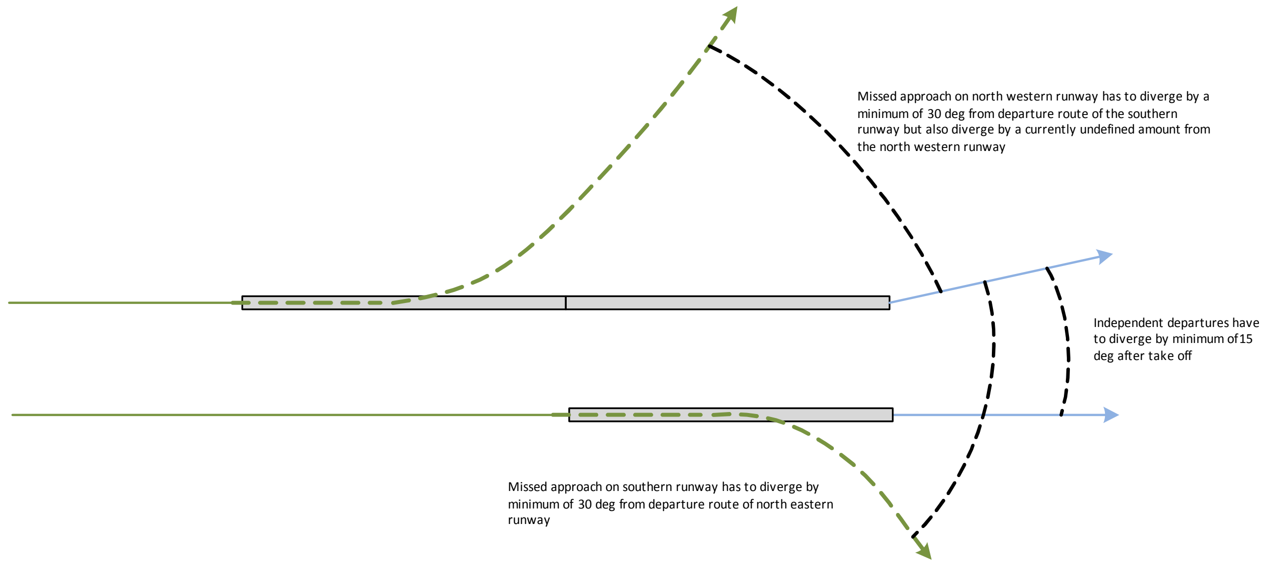


Figure 24 Heathrow Hub (3 Runways) Operating on R09

3.5 Heathrow Hub – Contingency Operations

The following describes how the missed approach procedures could work during contingency scenarios when one runway is closed. As this discussion focuses on simultaneous operations then a double runway closure is not considered as it would result in a single runway mixed mode operation.

The first example shows how it could operate with the north eastern runway closed. In this case there are two staggered parallel runways. Both runways could operate in mixed mode if traffic required it. This is very similar to the generic two runway example provided above but with a staggered runway. The departure routes have to diverge by 15 degrees after take-off while the missed approaches have to diverge by 30 degrees from the departure routes of the adjacent runway. The staggered runway will mean wake turbulence from heavy aircraft conducting missed approaches from the southern runway could affect departures from the north western runway during R27 operations and vice versa during R09 operations. This means this scenario would need further investigation however runway spacing of 1414m is likely sufficient to deem this not a problem.

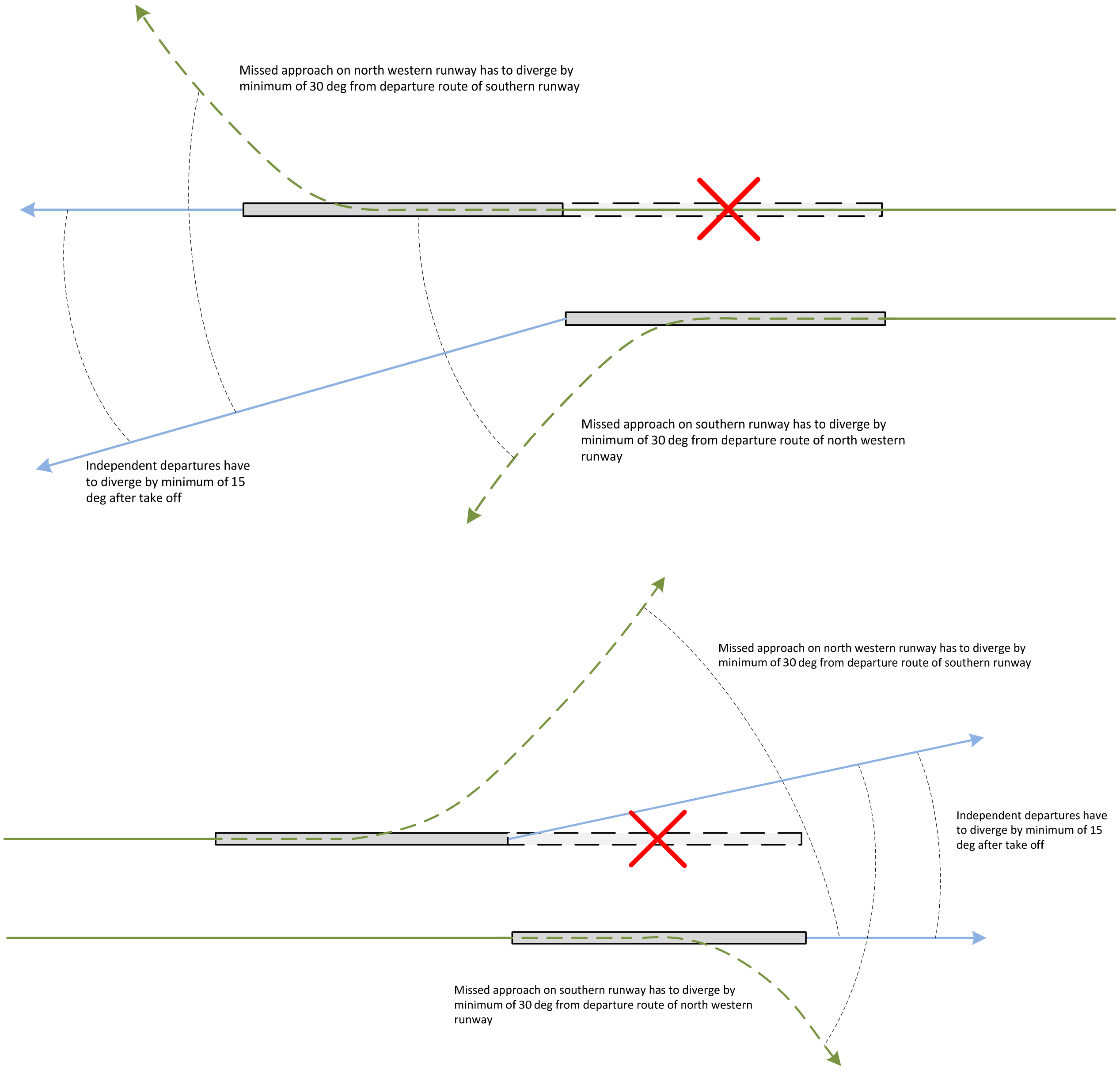


Figure 25 Heathrow Hub (3 Runways) R27 and R09 Operations with North Eastern Runway Closed

The next contingency scenario considers what happens when the southern runway is closed. In this case the arrivals will use the north eastern runway while the departures use the north western runway during R27 operations and vice versa during R09 operations. There will only be one departure stream hence no need to consider independent departures. However as explained in Section 3.4 there will need to be a safety case to show that the northern runways can operate independently.

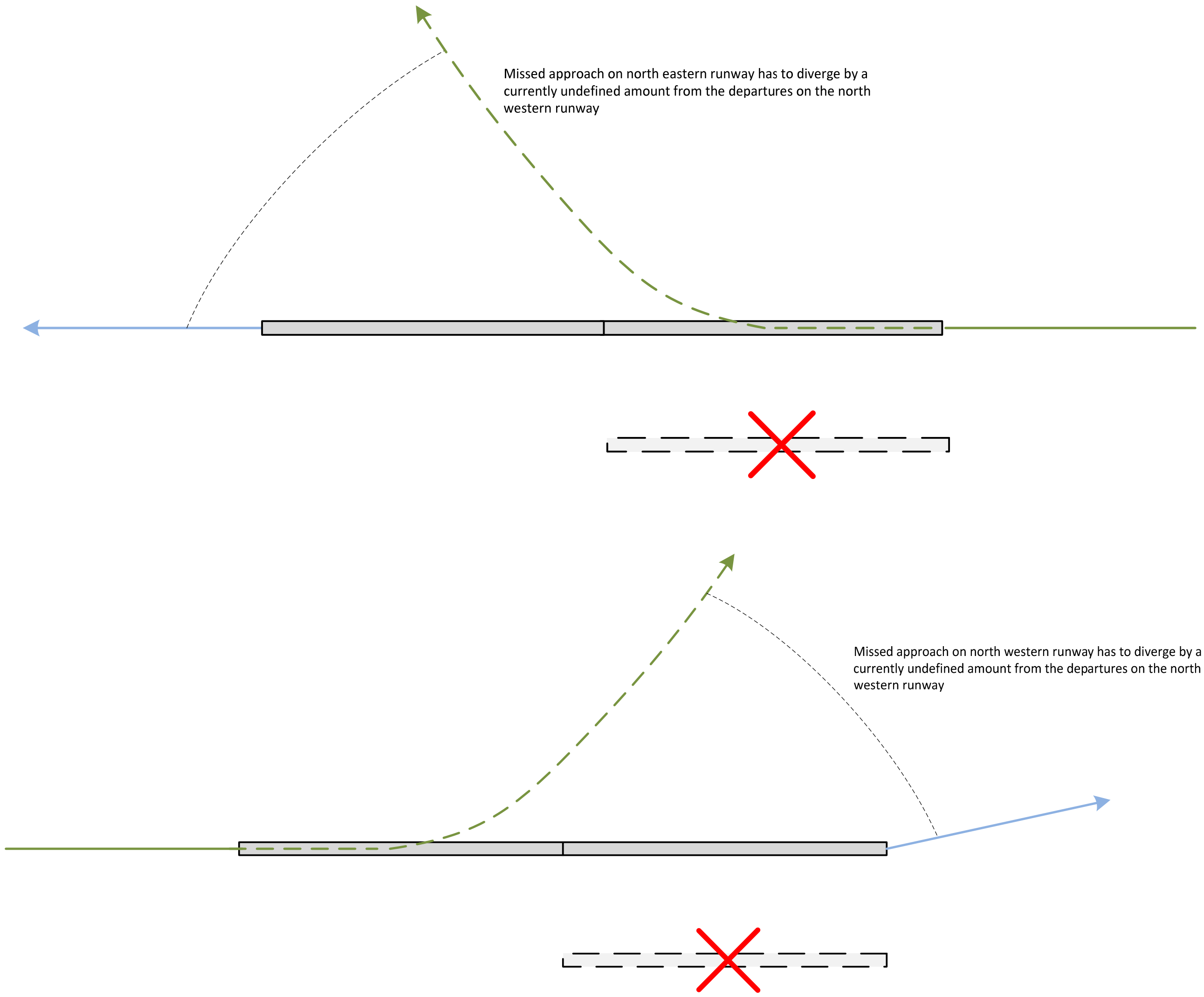


Figure 26 Heathrow Hub (3 Runways) R27 Operations with Southern Runway Closed

The final contingency scenario occurs with the north western runway being closed. This means there are 2 parallel runways with no stagger which is the same as current day operations. The departures routes need to diverge by a minimum of 15 degrees after take-off while the missed approach tracks need to diverge by a minimum of 30 degrees from the departure tracks of the adjacent runway.

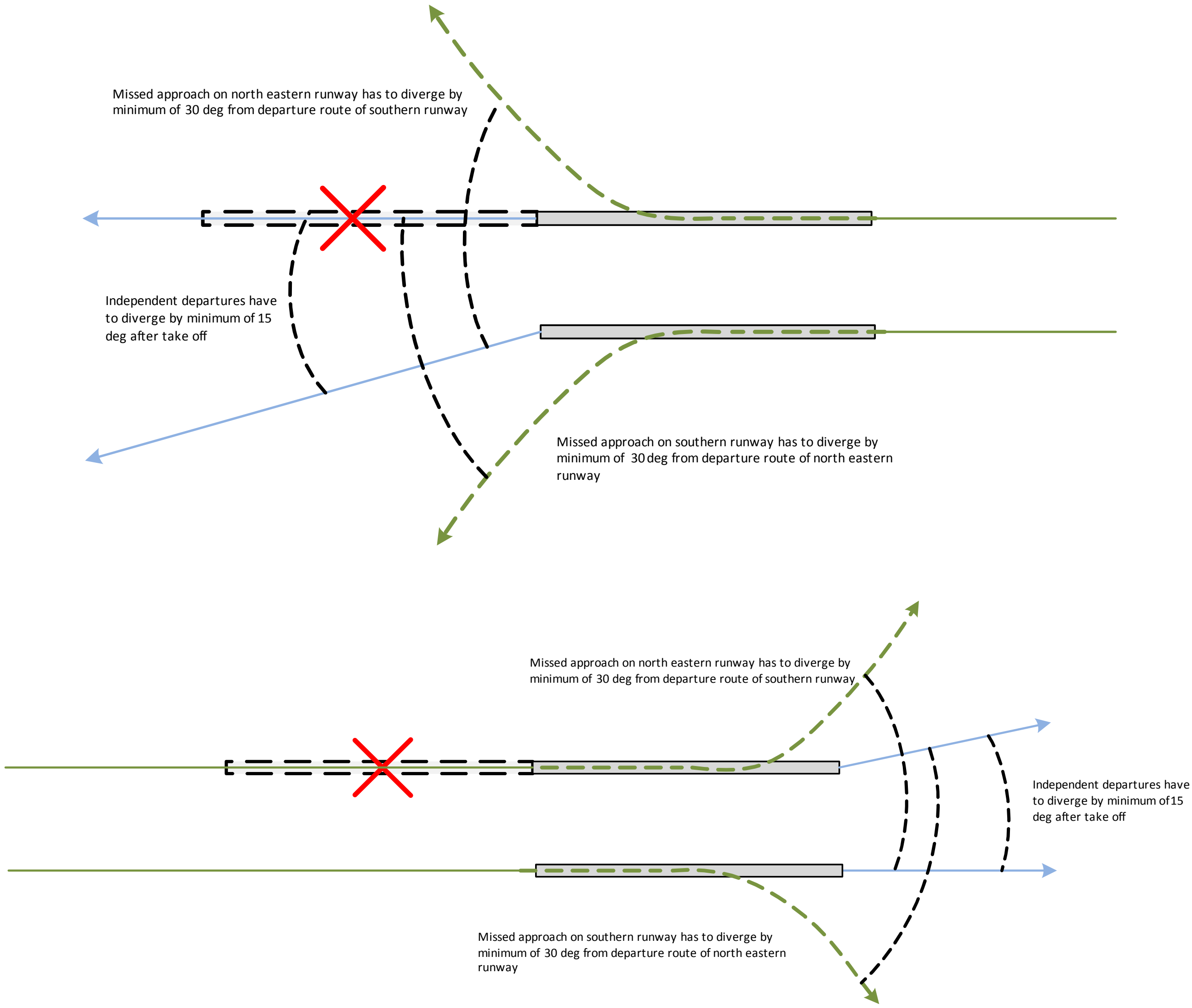


Figure 27 Heathrow Hub (3 Runways) R27 Operations with North Western Runway Close

3.6 Summary

The suggested method for implementing missed approaches within the Heathrow Hub concept are largely compatible with current ICAO recommendations with the exception of missed approaches on the inline runways. Current guidance does not cover a scenario of two independent inline runways operating arrivals from the first runway and departures from the second runway. A missed approach procedure in this scenario would still need to diverge from the departure track but a safety case will be required to determine how much divergence is required. An operational dependency may be required during LVPs which could limit capacity during LVPs.

To continue improving the maturity of this concept it is recommended that some initial computer modelling is carried out to assess different divergence angles and to determine key metrics such as how close missed approaches come to departures and how rapidly they potentially converge (or not) over a range of scenarios. This can then be expanded to a more detailed Monte Carlo simulation which will consider probability of certain scenarios occurring in order to develop a collision risk model. At this stage there will be an improved idea if the inline runways can be operated independently or if missed approaches are a safety issue.

4 Modelling Capacity of Four Runways in 2050: Phase 2

4.1 Introduction

The Heathrow Hub Concept offers the option for further capacity growth through the construction of a fourth runway, located to the south of the proposed third runway. A fourth runway is currently outside of the scope of the immediate plans for capacity expansion in the South East; however the Airports Commission Report indicates that there is likely to be a demand case for a second additional runway to be operational by 2050 or possibly earlier. With this longer term vision in mind Think have conducted mathematical and statistical modelling to estimate the potential capacity of four runways in a Heathrow Hub configuration operating in 2050. This section of the report considers only the final approach into the airport and does not consider constraints imposed by the airspace.

A Site of Special Scientific Interest (SSSI) which contains Wraysbury Reservoir, supplying water to London is located to the west of Heathrow Airport. This area has been highlighted by the commission as an area of concern if the south western area of the Heathrow site was (Airports Commision, 2013). To minimise impact in this area, three options have been proposed for the location and direction of a fourth runway (with varying impact on the SSSI).

Three potential layouts exist for a four runway layout (see Table 2 Phase 2 Layouts):

- Layout A
    - parallel to existing runways;
    - thresholds adjacent to the third runway;
    - Maximum impact on Wraysbury Reservoir.
- Layout B
    - parallel to existing runways;
    - Both southern runways moved eastward;
    - Minimal impact on Wraysbury Reservoir.
- Layout C
    - Runway angled (designations 08R/26L);
    - 26L threshold adjacent to new 27R runway;
    - Minimal impact on Wraysbury Reservoir.

Layouts A and B are predicted to support both independent arrivals and departures by 2050 in both directions. In layout C the fourth runway is angled by 10 degrees away from the 09/27 runways (making it 08R/26L). The converging approaches to the relatively closely spaced runways 09L-ext and 08R could dictate that arrivals to these runways must be separated laterally (dependent arrivals) for safety reasons. To account for this possibility, arrivals streams have been modelled with both options, complete independence (independent) and with the need for lateral separation (dependent).

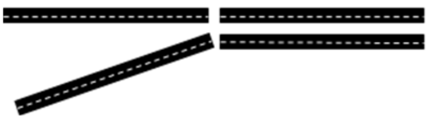
Departures (all directions)	Westerly Arrivals	Easterly Arrivals	Layout	Diagram (not to scale)
Independent	Independent	Independent	A	
Independent	Independent	Independent	B	
Independent	Independent	Potentially Dependent	C	

Table 2 Phase 2 Layouts

4.2 Model

In modelling airport capacity 35 years into the future there are many assumptions and predictions that have to be made. The most meaningful results are obtained by fixing some variables whilst altering those most likely to change.

The following sub sections describe the variables and assumptions used in the model.

4.2.1 Runway layout

Three potential layouts exist for a four runway layout (see above)

For modelling purposes, the expected method of operations (and not the exact layout of the airport) is important. The layouts can be reduced to:

1. A&B
   - independent arrivals and departures in all directions;
2. C
   - Independent departures in all directions

or

   - Independent westerly arrivals
   - Dependent easterly arrivals

Speculation will exist as to what operations may be allowable in 2050, with the potential improvement in technology and performance; as such both "All Independent", and "Easterly Arrival Dependent" results will be reported.

4.2.2 Weather

The meteorological conditions for the purposes of this modelling activity have been assumed to be equivalent to today, with the ratio of westerly to easterly operations remaining at 7:3. The reported results cover a year's operations and take into account the variance in wind conditions through all seasons. Time Based Separation (TBS) is expected to be introduced long before 2050; it promises to add resilience, making arrivals less susceptible to strong headwinds. TBS is used as the separation method in this modelling activity.

4.2.3 Airspace

This is a runway capacity model and assumes that the Airspace is unconstrained.

4.2.4 Ground Movements

The runway is not constrained by access to runways/terminals, delays in taxiing or runway occupancy times.

4.2.5 Sequencing

Sequencing is expected to be controlled through AMAN and XMAN tools in the future; these contain complicated algorithms that aim to sequence the traffic in such a way as to avoid large wake separations. For the purposes of this modelling activity, some sequence optimisation has been achieved through random sampling algorithms.

4.2.6 Fleet mix

The future fleet mix of London Heathrow airport is dependent on a multitude of factors including, global economy, emerging economies, fuel costs, restrictions (emissions/noise), etc.

New routes will exist; the makeup of routes will change, along with the aircraft types required to fly these routes. New Aircraft whose wake categories may be smaller (through improved design) than aircraft that fly similar routes today are also expected to be operational.

The commission took four key forecast scenarios. The impact on future fleets/technology taken in each forecast scenario was very similar with a focus on fuel efficient aircraft with extended ranges. The commission concluded that the future technology is likely to include new longer range fuel efficient aircraft such as A350s and Boeing 787 Dreamliner’s. Existing short-medium haul fleets will be replaced by new A320neos and B737MAXs improving on both range and efficiency. With fleet life ranging between 20-25 years it is feasible that by 2050 a new generation of aircraft will also exist.

The Airports Commission forecast that aircraft size will grow at an average equivalent to 0.35% per annum to 2035; however the impact of any increase in aircraft size is likely to be offset by technological improvements.

EUROCONTROL’s forecast for average annual growth to 2035 predicts growth on both long and short haul routes primarily to ASIA Pacific, Eastern Europe, Africa and the Middle East. These forecasts predict that passengers will travel more long-haul in 2035 with the average distance per journey increasing by around 8% for European departures.

Taking all of these aspects into consideration, a decision was taken to report results by traffic makeup, using the most prevalent predictions of future traffic mix at international hub airports. Reducing the variables to:

- A stable distribution of route and aircraft types;
- An increase in long range aircraft;
- An increase in short/medium range aircraft.

The traffic distributions have been further manipulated in order to approximate two distinct scenarios. These include a scenario where an increase in very large aircraft (VLA) is modelled, thus reflecting an increase hub and spoke model within the aviation market. Conversely a reduced reliance on VLA has also been modelled, reflecting an increase in point-to-point routes.

4.2.7 Current and future Fleet Mix (2014-2023)

Current fleet mix at Heathrow is predominantly made up of medium wake aircraft (approximately 70% in a peak hour) with the remainder either being heavy or super heavy aircraft. Forecasts suggest that an airport such as Heathrow may experience an increase in Heavy and Super Heavy in the next few decades. A shift from Medium to Heavy/Super Heavy aircraft has the potential to reduce arrival runway capacity.

4.2.8 Traffic samples

As the current traffic is made up of 6 wake category groups, there exist 6 independent variables within traffic mix alone. To reduce the variables, a number of assumptions have been made:

- The Boeing 707 (manufactured 1958-1979) and Boeing 757 (1981-2004) will no longer be in service, thus removing the Upper Medium Wake category completely. It is assumed that no new types will be produced that fit this category;
- The number of Light and Small aircraft will be negligible;

The number of controlled variables is thus reduced to three: Super Jumbo, Heavy and Medium (Lower). Table 3 below illustrates the fleet mixes modelled:

Wake Category	Example Types	No Change	Increase in Long-Haul		Increase in Medium/Short-Haul	
		Mix 1 Peak hours Baseline Traffic Mix	Mix 2 Moderate VLA	Mix 3 High number of VLA	Mix 4 Moderate VLA	Mix 5 High number of VLA
Jumbo/ Super	*A380 (VLA)*	2%	5%	**10%**	2.5%	**5%**
Heavy	*Airbus A300, A310, A330, Boeing 747, 777, 787*	27%	35%	30%	17.5%	15%
Upper Medium	*Boeing 707, 757*	≈0%	0%	0%	0%	0%
Lower Medium	*Airbus A320 Boeing 737*	71%	60%	60%	80%	80%
Small	*CRJ 100, 200 & 700 Embraer 135, 145, 170*	0%	0%	0%	0%	0%
Light	*Lear jet 25, 35, 45, 55, 60 Cessna Citation 500, 525*	0%	0%	0%	0%	0%

Table 3 Model Fleet Mixes

4.2.9 Annual Capacity

Currently declared capacity varies throughout the day at Heathrow. Daily declared arrival capacity currently sits at approximately 88% of the maximum hourly arrival throughput scaled throughout the day (Winter 2013/Summer 2014 schedule), and departure capacity 90% of the maximum hourly departure throughput (Winter 2013/Summer 2014 schedule). Theoretical maximum capacity will not feasibly be reached due to issues with resilience and over separation. To adapt the modelling results (which predict maximum realistically achievable hourly throughput) to reflect a daily declared capacity, 90% of peak movements has been assumed.

4.3 Results

The capacity that has been output by the model is a theoretical maximum capacity. However it has not been fully optimised to achieve maximum capacity in all aspects. The model considers a daily traffic schedule based on current operations and has therefore not been optimised for absolute capacity purposes.

This theoretical maximum capacity should be considered to be practically unachievable. Operation at 100% of the maximum capacity for any sustained period reduces the resilience of operations and leads to an unacceptable level of service in terms of delay per flight. The practical capacity is thought to be more sustainable at 90% of maximum capacity ((Airports Commision, 2013). This practical capacity (90% of maximum capacity) would be the declared capacity of Heathrow.

4.3.1 Arrivals

Figure 28 Peak Hour Arrivals shows box and whisker plots of the expected peak hour arrival rate using two dedicated Arrivals runways. Box and whisker plots show more information than a bar chart and have been chosen to illustrate variance within the results. For a description of the elements of a box and whisker plots and how they should be read, please see section **Error! Reference source not found.**.

In all cases an increase in proportion of Large and Very Large Aircraft will reduce the overall capacity, and an increase in Medium Aircraft will increase capacity, due to wake vortex categories. However as the passenger carrying capacity of a larger aircraft is naturally greater, this will not necessarily result in a reduction in passenger numbers at the airport.

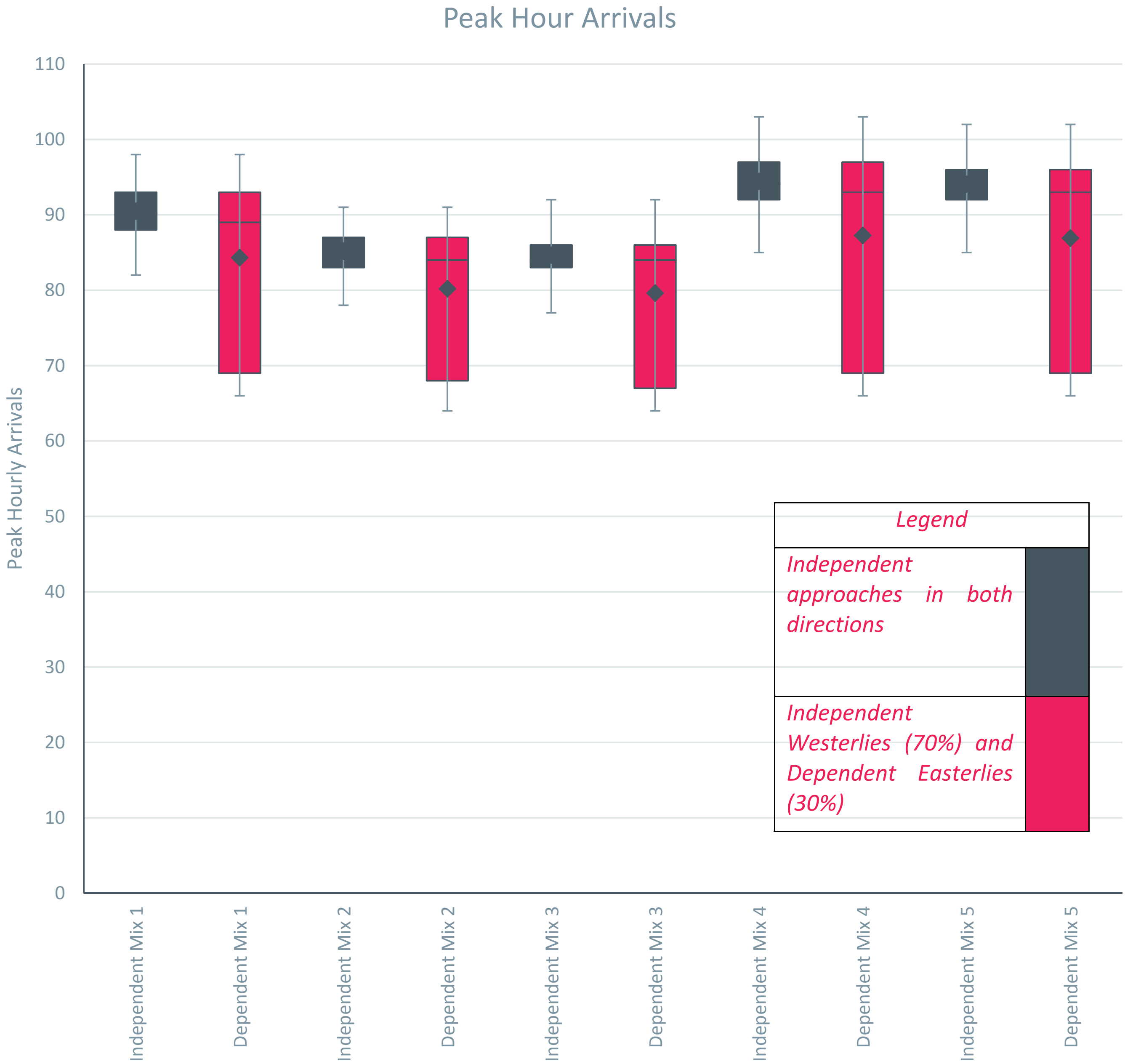


Figure 28 Peak Hour Arrivals

	Median		Mean	
	independent	dependent	independent	dependent
Mix 1	90	89	90.5	84.3
Mix 2	85	84	85.2	80.2
Mix 3	84	84	84.7	79.6
Mix 4	94	93	94.4	87.3
Mix 5	94	93	94.1	86.9

Table 4 Peak Hour Arrivals

Operations in both easterly and westerly runway directions were modelled. When arrival dependence between runways 09L-ext and 08R is assumed, due to the convergence of the approach paths, there is a relatively large capacity reduction (Table 4) when operating easterly dependent arrivals compared to all-independent arrival operations. This is shown by the larger distributions on the dependent operations (Figure 28). The average peak hour dependent arrival capacity (mean) is lower by 5-7 movements compared to independent arrivals. The relatively minimal impact on the median number of movements is due of the biased towards westerly operations (7:3). However when considered individually it is clear that easterly dependent operations result in a reduced peak hour arrival capacity (shown in Figure 29 Dependent vs. Independent Easterly Arrivals), with a reduction in mean arrival rate due to dependent arrivals in the order of 17-24 movements.

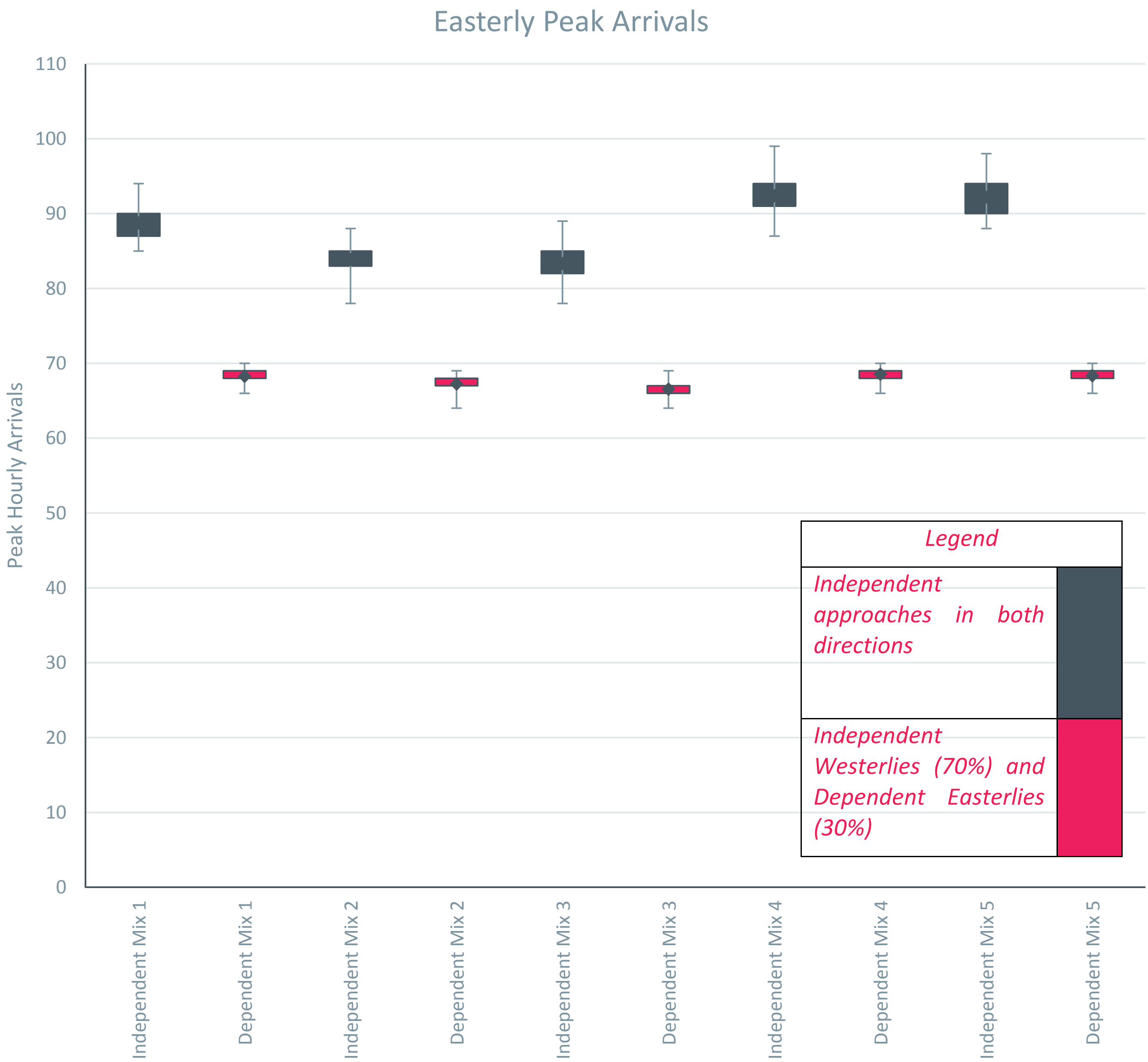


Figure 29 Dependent vs. Independent Easterly Arrivals

	Median		Mean	
	independent	dependent	independent	dependent
Mix 1	89	68	88.8	68.3
Mix 2	84	67	83.9	67.2
Mix 3	83	67	83.3	66.5
Mix 4	92	69	92.4	68.5
Mix 5	92	68	92.2	68.3

Table 5 Dependent vs. Independent Easterly Arrivals

4.3.2 Treatment of declared arrival capacity

In this scenario two capacities may be declared, one for each runway direction. For the purposes of scheduling it would be more appropriate to take a conservative approach and declare only the lower capacity. This would underestimate the maximum capacity of westerly operations by up to 24 movements per hour. Despite this obvious drawback, using the lower capacity would ensure that resilience was inbuilt into schedules in the event that easterly operations dominated for a sustained period, thus generating a more robust capacity assumption. This would minimise potential disruption to schedules and reduce EnRoute delay and/or terminal holding.

A further approach would be to produce forecasts of the utilisation of easterly operations, based upon past use. The model considers that easterly operations are used 30% of the time. This percentage could hence be used to weight the declared capacity in favour of westerly operations. An indication of this figure can be gained however the proportion of westerly and easterly operations may shift from 7:3 in the long term to 2050.

4.3.3 Departures

Departures are considered to be independent in both directions. Peak departures are shown in Figure 30. Departures assume independence and the existence of split SIDS that would allow for 60 second separations for aircraft travelling to the same initial fix. There is little difference between peak hourly departures with traffic mix. Departures, under the assumptions stated would not limit capacity; arrival capacity would likely be the limiting factor.

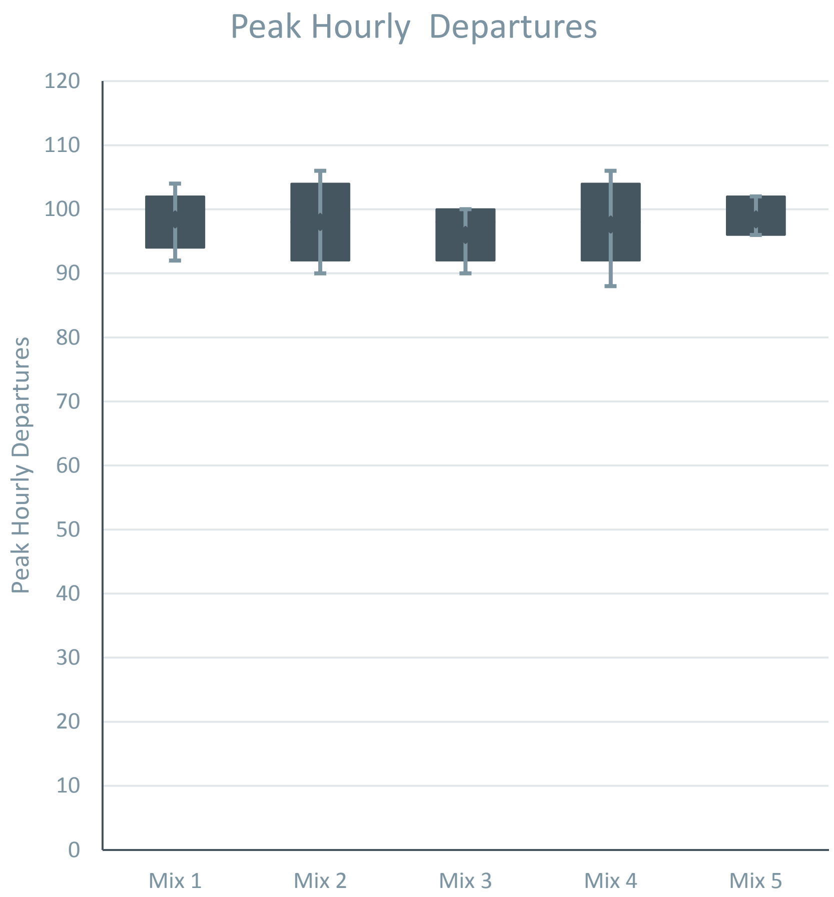


Figure 30 Peak Hourly Departures

Traffic	Median	Mean
Mix 1	100	98.4
Mix 2	98	98
Mix 3	98	96
Mix 4	98	97.6
Mix 5	96	98.4

Table 6 Peak Hourly Departures

4.3.4 Annual Declared Capacity

Figure 31 and Table 7, describe the potential annual capacity of Heathrow Operating with 4 runways in 2050. Results (mean) range between approximately 950,000 and 1.05 million movements for independent operations; this would drop to approximately 890,000-975,000 if Easterly arrivals were dependent. The declared capacity for dependent operations in a single direction as mentioned above is a complex issue that would need further analysis if traffic movements in excess of 750,000-800,000 were envisioned.

Figure 31 Annual traffic movements

Traffic	Median		Mean	
	independent	dependent	independent	dependent
Mix 1	1,005,200	994,000	1,010,500	941,700
Mix 2	949,400	938,200	951,400	895,700
Mix 3	938,200	938,200	945,600	889,300
Mix 4	1,049,900	1,038,700	1,054,700	974,700
Mix 5	1,049,900	1,038,700	1,050,700	970,700

Table 7 Annual traffic movements

4.4 Summary

Heathrow Airport operating with 4 runways as modelled and according to the assumptions stated above should be capable of supporting 950,000-1.05 million movements annually on runway layouts A & B. It is considered likely that layout C would require some dependency between easterly approaches, as such annual movements would drop to 890,000-975,000; further analysis would be required if movements in excess of 750,000-800,000 were envisioned to ensure resilience exists within the system.

5 Conclusions

5.1 Conclusions on Heathrow Hub Concept ATM Feasibility

Due to current restrictions and inefficiencies in the LTMA design, expert opinion has deemed it unlikely that an extra 200,000 movements per year is feasible using today's systems and procedures. Controller workload is very high and rapidly approaching levels where any extra demand in the TMA cannot be met. However multiple projects are underway which ultimately aim to increase capacity and reduce controller workload. LAMP and PBN are the biggest enablers for increasing capacity within the TMA whilst maintaining/improving safety standards. A third runway solution, regardless of layout is critically dependent on long term projects delivering the expected increase in capacity.

The addition of a third runway at Heathrow is not considered to have a large negative impact on EnRoute airspace. The introduction of iFACTS has already seen benefits in safety and increased capacity; there are multiple projects underway which further aim to increase safety, capacity and efficiency.

Tower controllers will see the biggest change to operating procedures. The current day operations of segregated mode will need to evolve into a mixed mode operation using a new runway layout. This will involve a transition and training stage to enable controllers to feel comfortable with the new layout and operating procedures.

TMA controllers will likely see the biggest impact on their workload. This will possibly require a greater use of support controllers to help distribute workload. There are multiple projects, such as LAMP, which aim to increase capacity and efficiency while at the same time reducing or maintaining controller workload as per current day levels.

Overall, the option of a third in-line runway at Heathrow does not present any major obstacles that cannot be overcome. Although the workload of Tower, Approach and TMA controllers will increase, sometimes substantially, various projects including PBN, LAMP and Advanced Controller Toolsets will help offset the associated increase in controller workload. The findings of this report conclude that the option of a third in-line runway at Heathrow is feasible from an ATM perspective.

5.2 ATC Benefits of Heathrow Hub

The following benefits of the Heathrow Hub Concept over other potential solutions have been identified:

- The intended third runway design will use the same centreline as today's northern runway. This should enable some of the ATC infrastructure to remain the same. The visual presentation of traffic to the TMA controller will remain similar to today's presentation, enabling an easier transition into the operational environment;
- There is potential that the necessary SID/STAR redesign will have less of an impact on the rest of the TMA and other airfields than other third runway options. Due to the absence of any major London Airfields to the west of Heathrow, a westward shift in the SIDS has the potential to have less of an impact on the LTMA than other third runway options. However consideration will need to be given to the Farnborough group of airfields;
- Deep landings on 27Rext will be possible without the added complexity of displaced thresholds. Additionally, controllers will have minimal change to operating methods as the extended runway has the same centre line as the current day northerly runway. Therefore the area in which controllers' vector aircraft to intercept the ILS will be similar compared to today's operations and therefore have minimal impact on surrounding airspace;
- An adjacent and in-line fourth runway can be added to further increase capacity if required and would maintain a compact hub;

- As a result of remaining in-line with today's northern runway, the point at which approach controllers vector aircraft downwind, base leg and intercept will remain almost identical as it is today;
- Heathrow Hub Concept is uniquely placed to handle changes in fleet mix over other current proposals. By introducing a concept of a dedicated runway for heavies and super heavies when these aircraft types are in excess, delays in the air can be minimised;
- The layout of a centralised terminal between the southerly and northerly runways has the potential to reduce taxi times on the ground and eliminates the need for aircraft to cross active runways thereby reducing controller workload.

5.3 Outstanding ATC issues with Heathrow Hub

There remain some outstanding issues that require further research that was unachievable in the time scales available for producing this report:

- An ILS system can be operated on the two inline runways. This could be done with a single localiser for each direction meaning it won't require one in between the two runways however this could impact capacity due to the ILS sensitivity area (see Section 2.9.3). But further investigation will be required to assess any possible technical mitigations including ILS technological developments that could be applied to the inline runway configuration to reduce this impact. Also there is normally an inner marker required before a landing threshold which would have to be placed in between the two runways. However if a technical mitigation through the use of DME equipment can be found then there is the possibility of not requiring any equipment in between the inline runways. This provides extra flexibility for using the tarmac;
- The suggested method for implementing missed approaches within the Heathrow Hub concept are largely compatible with current ICAO recommendations with the exception of missed approaches on the inline runways. Current guidance does not cover a scenario of two independent inline runways operating arrivals from the first runway and departures from the second runway. A safety case will be required to determine how much divergence is required and also to determine if independent operations between the inline runways can occur during LVPs;
- The inability to accurately predict too far into the future limits the realistic scope of the feasibility assessment of a Phase-2 Heathrow Hub from an airspace perspective. Whilst four runway capacity has been modelled at a high level, the airspace capacity is unpredictable. There are currently too many unknowns, the state of technology, the airspace design, movements at other London airfields etc. to be able to confidently reflect on Phase-2 feasibility at this stage. Ultimately the extra demand a fourth runway would bring in would have further detrimental impacts on the efficiency of the TMA unless concepts are continually developed and new technologies created to act as enablers. There is a finite capacity of the LTMA regardless of air traffic concepts and technologies available and there will always exist an important trade-off between capacity and resilience.

6 Suggestions for Further ATC Study

There are outstanding issues uncovered in the production of this report that were not possible to answer in the timescales available. The authors of this report therefore make the following recommendations of areas of interest that require further investigation.

- **Fast-time modelling of the TMA and Approach:**
  - Fast time modelling of the TMA and Approach (including the interaction of Heathrow traffic from non-Heathrow traffic) should be conducted to garner accurate quantitative insight into capacity figures, delay predictions, resilience and interactions;
- **Controller Workshops:**
  - To get further qualitative input on the feasibility of added movements in the TMA and the Heathrow hub layout, it is suggested that controller workshops (focus groups) be conducted. Workshops should include representatives of all key roles from Area Control, Terminal Control and Aerodrome Control;
- **Missed Approach Safety Assessment Modelling:**
  - Safety assessment modelling should be undertaken to assess the collision risk during missed approaches on this unique combination of runway layout and mode of operation. A Monte-Carlo simulation should provide a quantitative level of safety that can be used in determining if the concept is statistically safe;
- **Ground Movement Modelling:**
  - To fully understand the ability of the ground layout to support the envisioned movements and operating modes, fast time ground modelling should be carried out. Ground modelling will uncover bottlenecks in the terminal and taxiway design that may limit capacity;
- **LVP Capacity Modelling and ILS Sensitivity Mitigation:**
  - To investigate possible technical mitigations that could be applied to an ILS for the inline runways to reduce the effect of the sensitivity area on the operation. The impact of the solutions could then be quantified through runway capacity modelling considering any relevant dependencies that may exist.

Appendix A - Explanation of Graphical Depictions

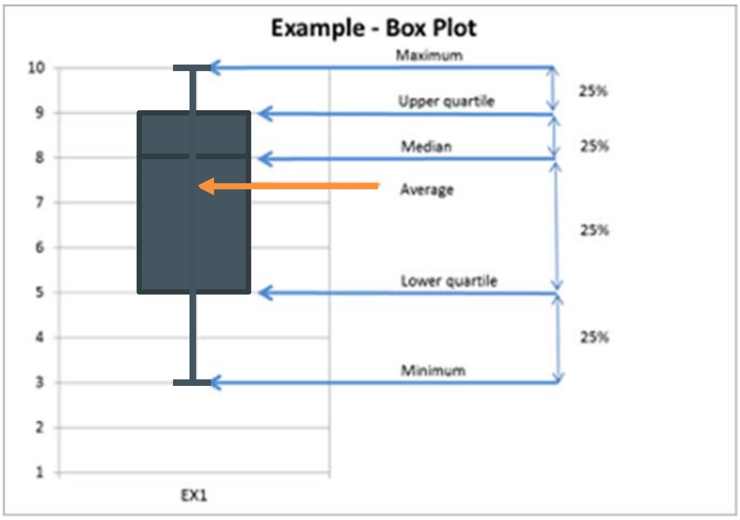


Figure 32 Box Plot Example

The box plot (e.g. box and whisker diagram) as illustrated in Figure 32 is a standard way of displaying the distribution of data based on key components which can be used to graphically represent data. It indicates the mean (average) value and also the spread of the data by indicating the most extreme values, the median and the upper/lower quartiles. The span of the central rectangle (the first quartile to the third quartile) shows the interquartile range of the data. A segment/line inside the rectangle shows the median number and "whiskers" above and below the box show the locations of the minimum and maximum data points. It should be noted that due to the discrete nature of the data that there are several cases where much of the data falls on one value hence the median and quartiles bunch up together.