Safety & Airspace Regulation

# Description of Today's ATC Route Structure and Operational Techniques

**CAP 1379**

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# Introduction

This CAP has been developed through the work of the Future Airspace Strategy Noise Task force which was convened as a temporary group to investigate the Noise implications of deploying Performance Based Navigation, which is published as a separate CAP document – CAP1378.

This CAP describes some of the Air Traffic Management techniques used to manage air traffic in the UK, the material is intended to support engagement between industry experts and those not engaged in the aviation industry but may be interested or affected by operations.

Chapter 1

# The air traffic management route structure and operation

The Air Traffic Control (ATC) task needs to be supported through a highly structured and systemised operation in order to manage air traffic to deliver the high levels of traffic throughput required whilst maintaining high safety levels.

Part of this system is a network of routes which aircraft fly. The majority of these routes are made up of the following components:

- Standard Instrument Departures (SIDs);
- Airways;
- Standard Arrival Routes (STARs).

Air Traffic Controllers (ATCOs) relay instructions to the pilots of aircraft verbally via radio transmissions. Each ATC instruction is required to be read back by the pilot to ATC so as to ensure it has been understood correctly

## Standard instrument departures (SIDs)

On departure from a runway, aircraft are flying a SID. This includes a vertical profile including an associated minimum rate of climb. The SID ensures obstacle clearance (e.g. tall buildings, radio masts, terrain etc.) and also separation[1] against aircraft following other SIDs from adjacent aerodromes. Some SIDs have associated Noise Preferential Routes (NPRs) and are designed to maintain separation between successive aircraft departing from the same runway. For this reason, SIDs do not always follow the optimum lateral profile (i.e. a direct track) and often have extra track miles built in to ensure separation from other SIDs.

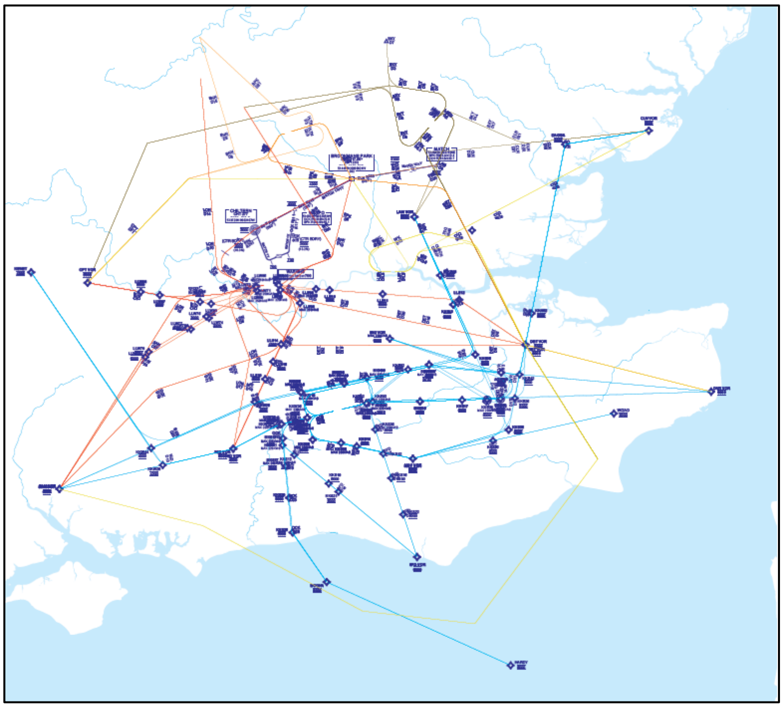
[1] Usually a minimum of 3 or 5nm laterally depending on the surveillance environment or 1,000ft vertically

Currently, most of the UK's SIDs are designed using a Conventional Navigation Specification which requires aircraft to use ground-based navigational aids (NAVaids). This results in aircraft having to route towards and over physical, permanent locations which can add on extra track miles with an associated fuel burn.

The numbers of ground based NAVaids are limited therefore multiple SIDs converge on the same places albeit separated vertically.

Consider these NAVaids to be junctions and like a busy railway station. Multiple routes are all feeding into one place. The rail network manages this by stopping trains and holding them outside of the junction until there is room to fit them in. The only way ATC can stop aircraft is by not letting them depart. Permitting only a few aircraft at a time to depart from a network of adjacent airports would lead to exceptionally high delays. So if ATC let all aircraft stay on their SIDs, navigating by the same point, the network would be highly inefficient.

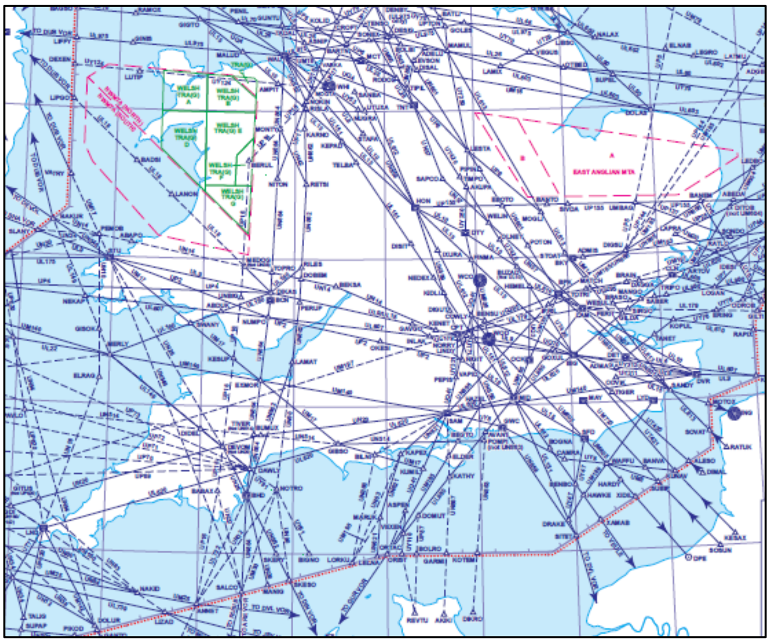
**Figure 1: SIDs from Heathrow, Gatwick, Stansted, Luton and London City**



## Airways

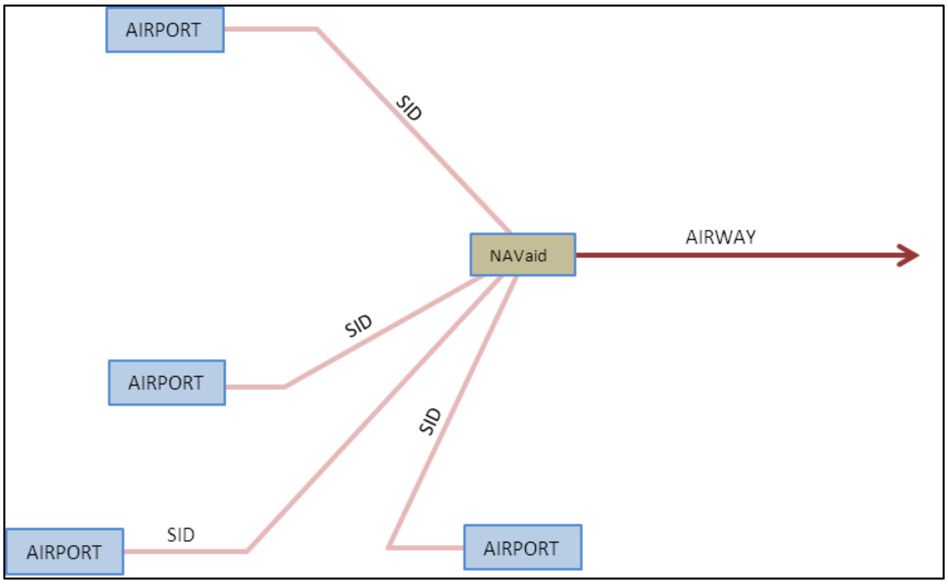
The SID links to an airway and multiple SIDs from multiple aerodromes can link to the same airway. The airways form the en-route network which enables aircraft to safely navigate from A to B. The UK airway network is also currently designed using a Conventional Navigation Specification.

**Figure 2: The southern UK airway network**



Only one aircraft at a time can be at the same point on an airway centreline at the same height. For multiple SIDs all feeding onto the same airway, aircraft would either have to be vertically stacked and climb up underneath each other or metered out of the airports to ensure only one aircraft at a time reaches the airway. If ATC only had this method to rely on, the network would be extremely limited in capacity.

**Figure 3: Example of SIDs converging on a NAVaid and airway**



## Vectoring

In order to ensure the network doesn't grind to a halt, Air Traffic Control Officers (ATCOs) intervene and take aircraft off their flight planned routes. This is done via a process known as 'vectoring' whereby the ATCO instructs the pilot to fly a radar heading or 'vector'. The radar heading is given as a compass bearing e.g. an instruction to fly a heading of 090 degrees will result in the aircraft turning towards the East. Headings are generally given in blocks of 5 degrees therefore there are 72 possible vector instructions at the ATCO's disposal.

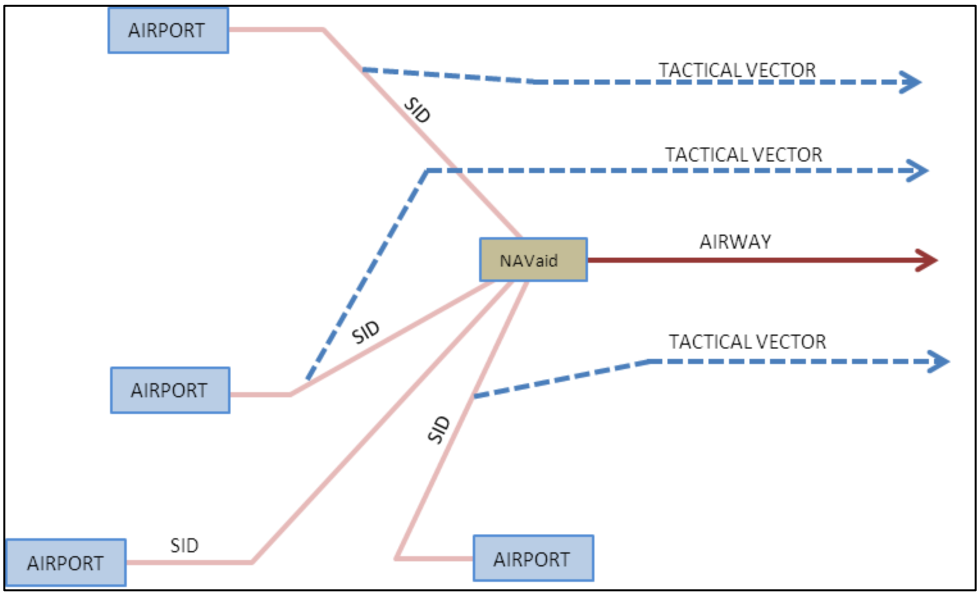
When aircraft are on their own navigation, the avionics take into account the effect of wind ensuring the aircraft stay on the exact route centreline. However, when under vectors, aircraft are susceptible to the wind and therefore suffer from 'drift'. Therefore the exact vector given to an aircraft on one day can have a different track over the ground than the exact same vector given to the same aircraft another day where the wind speed and direction is different.

Through vectoring, ATCOs are in effect, making up their own endless and variable supply of tracks to allow multiple aircraft to share the same filed routes and continuously climb / descend, independent of each other.

## Vectoring of departures

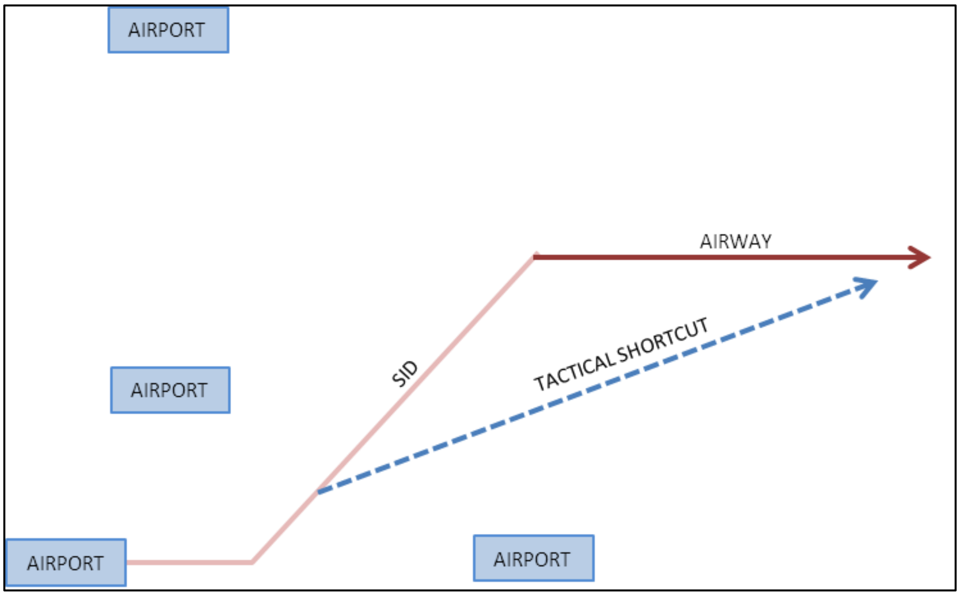
The ATCO vectoring allows simultaneous departures from multiple airfields to be integrated into the ATC network. Through vectoring, ATC can climb multiple aircraft independently until they reach their cruise level where they can be put back on their own navigation to follow the Airway network. However, where multiple aircraft require the same cruising level, they too can still be vectored at high level although often one of the aircraft is assigned an alternative cruising level. This level can be slightly inefficient for the aircraft in question.

**Figure 4: Example of Vectoring away from route centreline**




Vectors are not just used for capacity purposes. When able, if there are no conflicting departures from other airports, ATC will give an aircraft a shortcut. Note that shortcuts are also given during periods of high workload in order to keep an aircraft ahead of another aircraft so as to effectively 'stream' the aircraft onto the airway network.

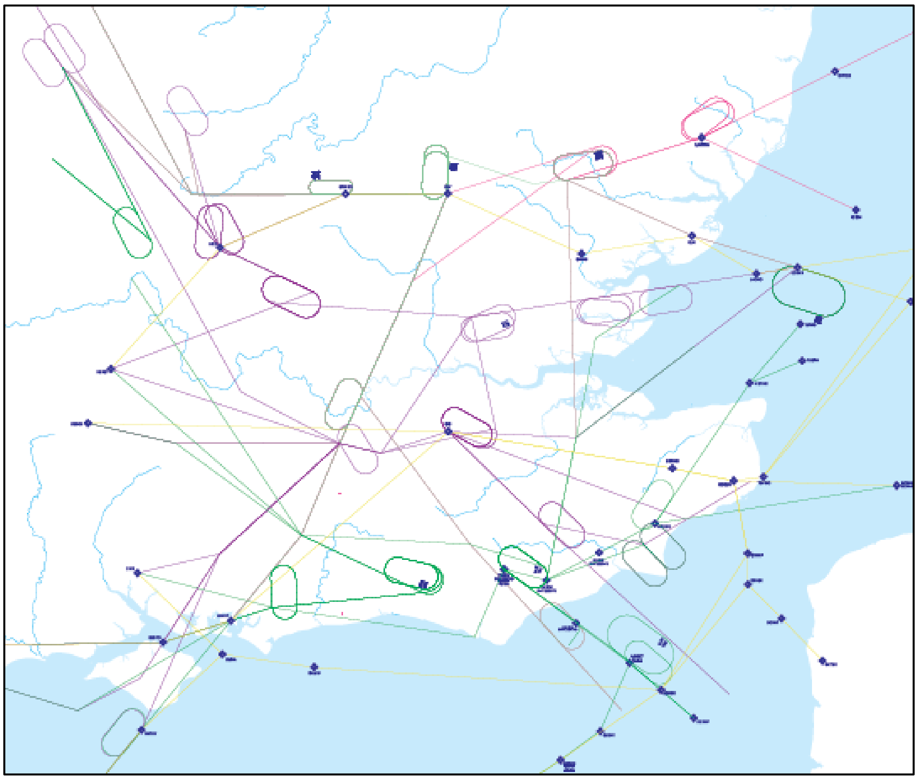
**Figure 5: Example of tactical shortcut to reduce fuel burn**



# Standard arrival routes (STARs)

As arriving aircraft begin their descent, they have to leave the Airway structure. At this point they join one of a series of STARs to their destination airport. Each airport has multiple STARs feeding their arrivals.

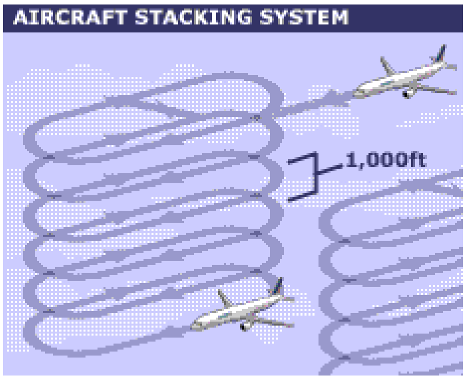
**Figure 6: STARs into Heathrow, Gatwick, Stansted, Luton and London City**



In the same way that departures converge on the NAVaids, multiple arrivals are required to use the same portion of the STAR at the same time. In order to allow multiple aircraft to continuously descend, independent of each other, ATC will vector aircraft in order to separate them laterally.

However, these aircraft are approaching their destination where the runway is the end of the line. The runway is limited in capacity whereby only one aircraft can use it at the same time therefore, multiple arrivals need to be ‘held’ until their runway landing slot is available. Imagine a three-lane motorway, narrowing to one lane. Queues are inevitable however where road vehicles can stop, aircraft cannot. At this point, the aircraft are put into orbital holding patterns. The first aircraft goes in at the lowest level with subsequent arrivals ‘stacked’ 1,000ft on top. This allows ATC to cater for the runway bottlenecks.

**Figure 7: Example of 'Stack' holding**




Courtesy of news.bbc.co.uk

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

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

Aircraft are cleared from each hold according to the landing sequence. This may be on a first come, first served basis, the airport may dictate a particular sequence for operational purposes or ATC may elect a sequence which is optimised for runway throughput / demand[2].

In the UK, STARs only provide a published route for aircraft to follow as far as the holding stack. So, in respect of normal operations, there are no notified / published routes between the STARs / holds and the final approach (i.e. the point at which the aircraft is aligned with the runway centre line for its landing). At the UK's major airports, the only defined notified routes between the holding stack and the final approach are those to be used in unusual or emergency situations, for example loss of radar or radio communications. So use of these defined routes is extremely rare as the flexibility that vectoring offers provides the ability to achieve much higher landing rates, reduced holding and more optimal approach paths.

[2] Further information - Runway and / or arrival demand and spacing, Page17

Holding stacks used within the LTMA for arriving aircraft typically have a minimum useable level of 7,000ft above mean sea level. So there are very few published useable routes linking the end of the STAR to final approach into the UK airports[3] between 7,000ft and 3,000ft.

Instead of fixed routes and in order to cater for the variable demand of arriving traffic, operational procedures are drawn up by the Air Navigation Service Provider (ANSP) and Air Traffic Control Officers (ATCOs) are trained to optimise delivery of aircraft onto the runway. In order to achieve this, ‘Approach Controllers’ make a series of tactical decisions and vector aircraft onto the final approach.

## Vectoring of arrivals: Radar manoeuvring areas (RMAs) and radar vectoring patterns

To achieve an optimised delivery of aircraft onto the runway, approach controllers are given an area of airspace, known as an RMA. The RMA provides approach controllers with the minimum airspace necessary to perform their primary function of sequencing the aircraft into the required landing order, ensuring the distance between each aircraft is the minimum required by the airport at any particular time. That distance varies according to the runway demand.

The RMA is an ATC operational area articulated as a volume of airspace by the ANSP. It is, generally, close in to the airfield and is usually established solely for the purposes of segregating and protecting aircraft arriving and departing the same airfield. It facilitates the close-in radar vectoring by ATCOs that is required to get the aircraft from a holding stack and established onto final approach. RMAs are not notified / published; they are an area within extant notified Controlled Airspace (CAS) reserved by the ANSP for particular ATC operations and they vary in size and shape according to the operating environment.

A number of holding stacks can service one airport, so ATC has to sequence multiple arrivals onto one landing runway. As soon as possible, aircraft are instructed to leave the holding stack and at this point aircraft are always under radar vectors. ATC creates a ‘radar vectoring pattern’ within the RMA. That is where they turn a

3 Exception Bristol – STARs down to 4,000ft and then RNAV arrival routes down to the runway

flow of aircraft from multiple holding stacks into one stream (sequence) of aircraft for positioning onto final approach. The RMA gives controllers freedom to vector aircraft within that area in order to create a landing sequence. RMAs are close to the airport and have vertical and lateral limits so as to allow other controllers to operate in areas of airspace adjacent to them.

Although the radar vectoring patterns are repetitive in nature and, over time, create recognisable swathes of traffic, the effect of wind, the different aircraft characteristics (rate of deceleration, radius of turn etc.) and variable runway demand continually change the dimensions of the pattern. However, the RMA boundaries remain constant although an ANSP is allowed to change the size and shape of an RMA without requiring permission from the Regulator.

The radar vectoring patterns created by approach controllers are therefore structured but also randomised according to their decisions, the time taken to make those decisions, their workload, reaction time by aircrew, the effect of wind, aircraft type and also the arrival demand and final approach spacing requirements. Alternatively, during periods of low demand a radar vectoring pattern is not required and aircraft may fly direct to final approach from the earliest opportunity.

Owing to airspace constraints and proximity to other airports, some RMAs are limited to just one side of the airport whereas others allow sequencing of aircraft to take place on either side. For example, at Manchester and Heathrow, aircraft are positioned onto final approach from both sides of the final approach whereas from Gatwick and Luton, they generally only approach from one side. The ability to sequence from only one side can sometimes have a direct impact on the achievable landing rate.

ATC vector arrivals into a radar vectoring pattern and into a landing sequence and then onto final approach where they resume their own navigation for the last phase of flight.

In the UK, in order to keep fuel burn, CO2 and aircraft noise to a minimum, approach controllers and pilots are trained to try and achieve a Continuous Descent Approach[4]

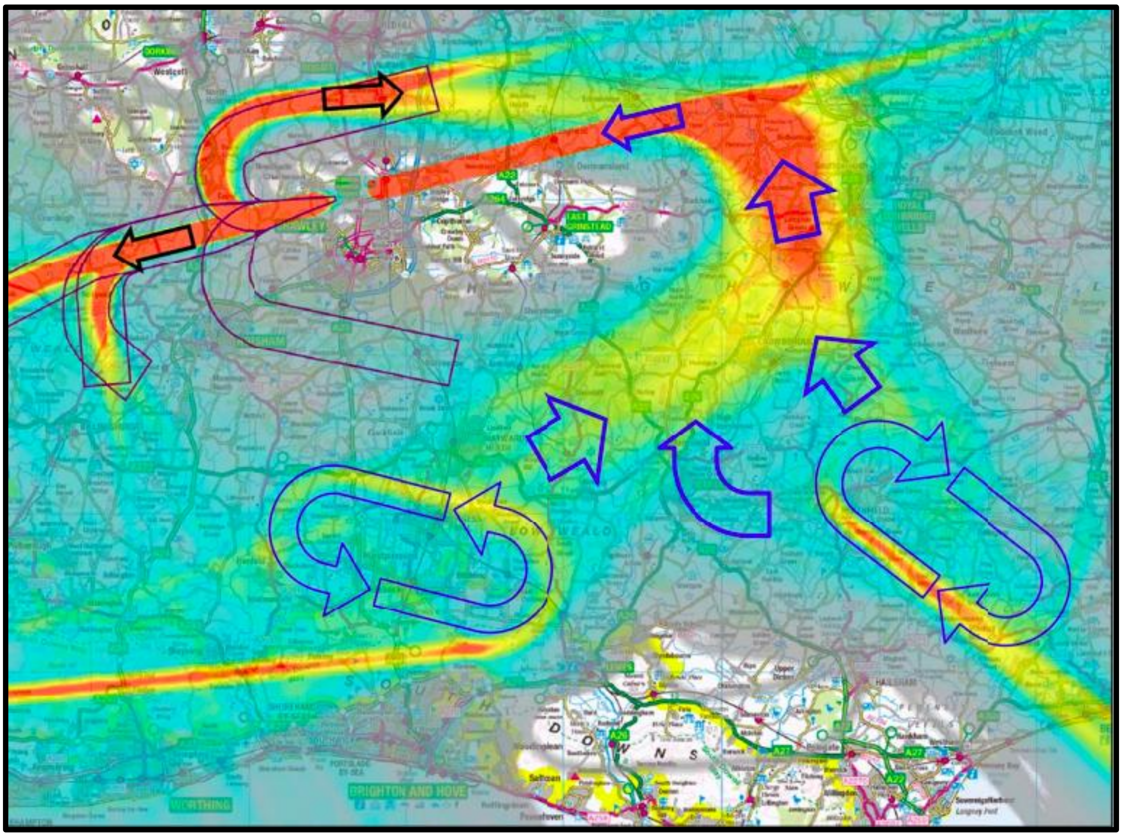
[4] Further Information - http://www.caa.co.uk/Environment/Environmental-information/Information-by-environmental-impact/Climate-change/Aviation-and-climate-change/

(CDA). When a CDA procedure is flown the aircraft stays higher for longer, descending continuously from the bottom level of the stack (or higher if possible) and avoiding any level segments of flight prior to intercepting the final approach. A continuous descent requires significantly less engine thrust than prolonged level flight. It may sometimes not be possible to fly a CDA due to airspace constraints or overriding safety requirements.

In this phase of flight prior to final approach, aircraft are typically between 3,000ft and 7,000ft and at speeds of 210 / 220Kts and in a clean configuration, that is no flaps extended therefore creating less drag and noise than when on final approach. Generally, aircraft are only instructed to reduce to 180Kts prior to being issued with a last vector to join final approach. In order to fly at this speed many aircraft, especially large passenger aircraft, will require deployment of flaps, which in turn creates drag and associated noise.

Departing aircraft often fly through RMAs and ATCOs ensure separation between these and arriving aircraft. Sometimes the same controller is responsible for this task or sometimes there are two different controllers who are mutually responsible. The departure tracks can constrain where the arriving aircraft can be positioned but, alternatively, if there are no departures, the arrivals can be vectored or descended into the airspace usually reserved by departing aircraft, thus adding to the structured but random dispersal of aircraft within an RMA.

**Figure 8: Radar vectoring pattern for Gatwick Runway 26 . Blue Arrows indicate holding stacks and arrival swathes. Black arrows indicate departure swathes. Note the wider swathe for arrivals than departures.**



## Final approach

Final approach is where the aircraft are, usually, lined up with the runway, and aircraft descend in accordance with a published procedure. The point at which ATC vector onto final approach varies; at the UK's major airports this is typically within a range of 7 – 18nm from the runway depending on airspace availability.

The final approach joining point varies according to several factors:

- **The numbers of aircraft ATC have taken off the holding stacks**

  Sometimes, to avoid an aircraft entering the hold and flying approximately 18nm in the holding pattern, ATC will issue a vector and extend its final approach joining point by just the 3-5nm actually required.

- **The spacing required between successive arrivals on final approach**

  The tower controller may request an additional gap (increased distance between a pair of landing aircraft) to facilitate time on the runway for a departure. Aircraft off the holding stack are already committed to the runway therefore the approach controller will extend the final approach joining point as required to create a greater distance between the arriving pair.

- **Reaction time of pilots, ATCOs and performance of the aircraft**

  The manual variability of the radar vectoring pattern and final approach joining point therefore creates swathes of arrival flight paths to the same airport as seen in Figure 8.

There are different types of published Instrument Flight Procedures (IFPs) available in the UK for use on final approach and which one is used depends on the equipment available at the airfield, the technical capability of the landing aircraft and the weather conditions at the time. With all approaches, aircraft are aiming to perform a 3° descent gradient i.e. for every nautical mile along final approach, an aircraft will descend by approximately 320ft whilst also using as little engine thrust as possible, in accordance with achieving a CDA.

An aircraft usually establishes on final approach at 180Kts and then has to reduce and maintain the speed dictated by ATC. Adherence to accurate speed instructions in this phase of flight is essential as ATC are aiming to deliver the exact spacing required between each successive pair. At many airports, aircraft are required to maintain 160Kts until 5 or 4nm from touchdown and then they can reduce speed as necessary to execute a safe landing.

In order to adhere to the slower speed instructions, further flap extensions are usually required, again generating more drag and noise. In addition aircraft are required to lower their landing gear (wheels) which in turn creates drag and requires more thrust to maintain airspeed, thus producing engine noise. The timing of all these scenarios vary according to the aircraft type and ATC operating environment e.g. landing gear deployment will vary between 5nm and 10nm from touchdown.

## Runway and / or arrival demand and spacing

The distance approach controllers are required to achieve between successive pairs of arriving aircraft in final approach is extremely variable.

At an airport with a single runway used for both take-off and landing, the spacing is dictated by the traffic demand on that runway. In a scenario where both inbound and outbound demand is equal, then the approach controller is likely to be aiming to achieve the minimum distance between arrivals so that the preceding aircraft can land and vacate the runway, the departure can enter the runway and depart and then landing clearance can be given to the next arrival in adequate time. The spacing required to achieve this is in the region of 6nm although that is dependent on wind speed and direction and the types of aircraft involved.

Of course there are times when the outbound demand exceeds the inbound demand (larger gaps between successive arrivals) or when inbound demand exceeds outbound demand (smaller gaps).

Another important factor is the airport infrastructure on the ground; the position of the runway entry / exit points, the taxiways, the position of the holding points, the number and location of the passenger terminals and, importantly, the visibility on the ground. During periods of poor visibility, the pilots and controllers have little visual reference to the ground and are therefore purely reliant on instruments and procedures. During this time, the distance between aircraft in the air and on the ground is increased which has a direct impact on the number of landings and departures that can be achieved. Hence, poor visibility can quickly lead to delays.

Alternatively where a runway is dedicated purely to landing, approach controllers are aiming to achieve the minimum safe distance required between successive arrivals. That distance depends on the infrastructure described above but, where infrastructure is not a constraint, there are minimum prescribed safe distances between arriving aircraft to ensure adequate spacing due to the ‘Vortex Wake Turbulence’ created by an aircraft. This is the, often invisible, turbulence that forms behind an aircraft as it passes through the air, and can be extremely hazardous to the following aircraft. Therefore, an adequate minimum distance must be provided to ensure this turbulence has dissipated before the following aircraft reaches that position. The minimum distance varies from 3-8nm depending on the types of aircraft in each pair. ATC will, wherever possible, sequence arrivals into the most optimum landing order so as to ensure the most efficient runway throughput.

**Figure 9: Wake vortices behind a landing aircraft**

Chapter 2

# The Future

ATC and controller skills have evolved over time in order to safely and efficiently cater for the increased demand on the ATC network. However the higher the number of instructions that ATC need to give, the more congested the radio frequency becomes. During peak periods in busy airspace, the radio frequencies can reach their limit where physically, no more instructions can be given by ATC and read back by the pilot. At this point, combined with individual human performance, the airspace is deemed to be at capacity. At other times, the physical size of the available airspace can be the constraint.

The amount of aircraft Air Traffic Controllers can safely handle through tactical control is therefore finite and we are reaching that limit. At certain times of day in certain parts of the network we have already reached that limit. However the numbers of flights the UK network is required to handle is forecast to rise so we need to find other efficient ways for ATC to cater for this demand.

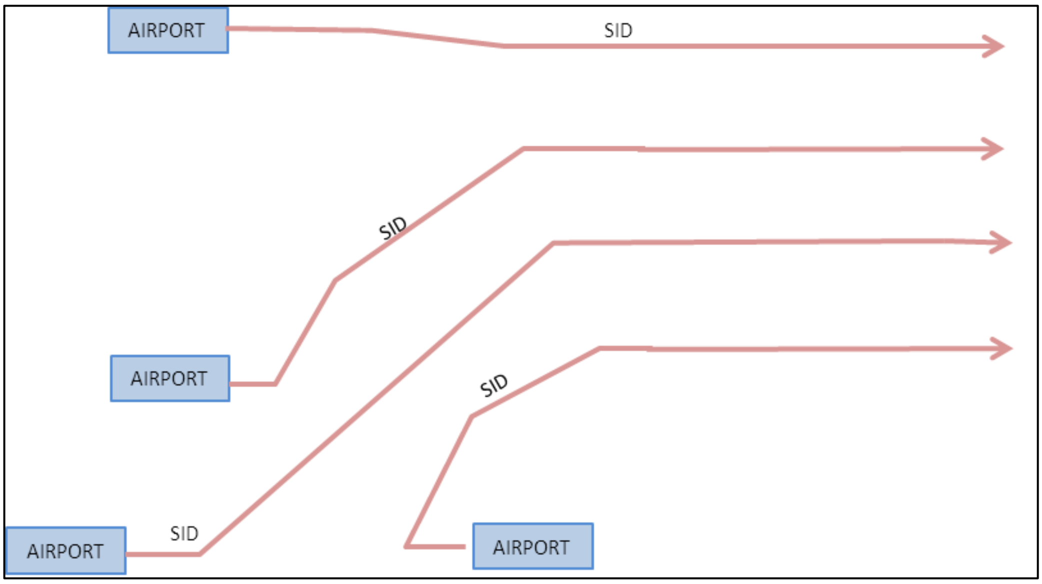
There are a host of ATC enhancements under development and implementation but one of the most relevant to this topic is Performance Based Navigation.

## Performance Based Navigation (PBN)

This allows aircraft to no longer navigate by means of ground based NAVaids but uses satellite technology instead. Aircraft already use this functionality as it allows them to navigate much more accurately but the UK ATC infrastructure requires updating so as to fully realise the benefits of the technology.

In essence, PBN affords ATC much greater flexibility of route positioning as well as catering for placing routes closer together than today. The result is a reduction in the amount of vectoring required by ATC thereby lowering controller workload.

**Figure 10: Example of PBN routes to reduce vectoring**




The reduction in ATC vectoring combined with the accuracy of aircraft navigation performance results in a concentration of aircraft on the route centrelines. An added benefit of PBN is the ability to position routes not only independently from each other but also the flexibility to position routes away from physical locations on the ground e.g. areas of dense population.

The flexibility of PBN enables the introduction of routes for arriving aircraft at low level which will reduce the dependency on vectoring of arrivals which currently takes places within RMAs.

## The Future Airspace Strategy (FAS)

The UK Future Airspace Strategy (FAS) is a programme of investment designed to modernise the UK's airspace and air transport route network. It is an important part of the Government's transport policy and involves the airlines, airports, air traffic control and many other aviation stakeholders.

The programme also forms part of the Single European Sky (SES) initiative, which sets out implementing rules, backed by legislation, to drive the reform of airspace and air traffic management across all European States. Similar modernisation initiatives are taking place across the globe, coordinated by the International Civil Aviation Organization (ICAO).

Much of the air navigation technology that supports air transport needs upgrading. The introduction of new technology, like Performance Based Navigation (PBN), will strengthen the resilience of our major airports to react effectively to disruption, improve the environmental performance of aircraft arrival and departure routes and further enhance air safety.

The measures included in FAS are a pre-requisite for accommodating future growth in demand for aviation, regardless of whether there is a decision to build new runway capacity. This is important for the whole country because the aviation sector is a key driver for the economy, international trade and employment.

The Government and aviation industry are committed to ensuring that local communities have a say in how the modernisation programme is delivered. Effective engagement with those that may be impacted by the changes is critical to the development of a modern, sustainable air transport route network.

More information on the Future Airspace Strategy is available at www.caa.co.uk/fas.

For information on future ATC concepts, including potential methods to mitigate the effect of aircraft noise, see PBN Airspace design Guidance (CAP 1378).

Appendix A

# Abbreviations

| Abbreviations | |
|---|---|
| ATC | Air Traffic Control |
| ATCO | Air Traffic Control Officer |
| ATM | Air Traffic Management |
| FAS | Future Airspace Strategy |
| ICAO | International Civil Aviation Organisation |
| NAVaids | Navigation aids (generally ground based) |
| PBN | Performance Based Navigation |
| RMA | Radar Manoeuvring Area |
| SES | Single European Sky |
| SID | Standard Instrument Departure |
| STAR | Standard Arrival Route |