Report of the CAA's Post Implementation Review of the implementation of RNAV-1 Standard Instrument Departures at Gatwick Airport

Annex 3: PIR Operational and Technical report

Annex 3 to CAP 1346

Published by the Civil Aviation Authority, 2015

The latest version of this document is available in electronic format at www.caa.co.uk

Contents

Aircraft Navigation Performance

Introduction

1. Performance-based Navigation (PBN) is the International Civil Aviation Organisation (ICAO) concept which integrates the aircraft in a given navigation infrastructure in accordance with a defined performance specification. The specification reflects not only the navigation accuracy required to be flown, but also the integrity and continuity and the minimum functional capability required of the aircraft on-board systems. PBN covers a range of navigation performance specifications to be applied in oceanic/remote airspace continental en-route airspace, arrival and departure procedures and the final and missed approach elements at an airport.

2. PBN specifications can be categorised as either having RNAV or RNP attributes. Essentially the difference is that RNP specifications require additional on-board integrity monitoring of aircraft positioning usually attributed to position updating from Global Navigation Satellite System (GNSS).

3. From an airspace perspective, Terminal Airspace surrounding an airport or group of airports contains Standard Terminal Arrival Routes (STARs), Standard Instrument Departures (SIDs) and Transitions to the Final Approach. RNAV and RNP specifications with different performance requirement may be applied in the various flight phases in order to provide connectivity between the runway and the en-route network which makes up our national airspace system.

4. In this section, we are discussing the operational and technical outcomes from the approval to deploy 19 Standard Instrument Departure procedures at Gatwick Airport in November 2013. The associated navigation performance specification is RNAV-1.

Navigation Performance

5. The navigation performance (with respect to accuracy) can be described by way of three error terms:

   - How accurately the aircraft determines its position;
   - how accurately the path or track over the ground is defined relative to the desired path; and
   - how accurately the path is being followed.

6. These terms are respectively referred to as Navigation System Error (NSE), Path Definition Error (PDE) and Path Steering Error – the latter usually referred to as

Flight Technical Error (FTE). When summed, these terms form Total System Error (TSE) by which all PBN specifications are associated by either accuracy or by specification name.

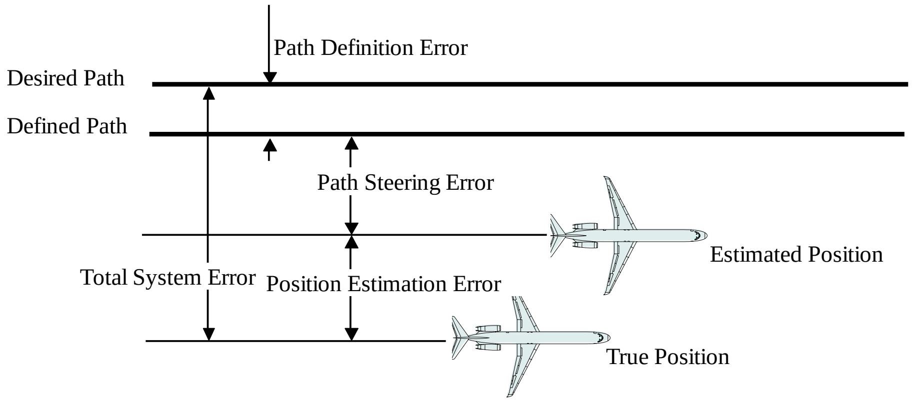


Figure 1 Lateral Components of Navigation Error Terms

7. NSE is a function of the navigational infrastructure and aircraft positioning. In terminal airspace the allowed navigation sensors for departures is through a pair of ground-based Distance Measuring Equipment (DME) ranges providing a DME/DME 'fix' or directly from GNSS – in the UK GNSS services are currently provided by the US Global Positioning System (GPS). DME/DME accuracy is dependent upon the number of ground-based DME facilities, line of sight to the aircraft and the geometry of any two facilities with the aircraft. South East England is considered a 'DME rich' environment although reliable coverage is not generally available until the aircraft are approximately 1600ft AMSL. Navigation accuracies of between 0.3 and 0.5 NM can be achieved in DME environments depending on coverage etc. In general there is no on-board integrity monitoring of DME positioning limiting DME/DME only aircraft to capabilities linked to RNAV specifications.

8. When sufficient satellites are in view (typically four or more), the positioning accuracy associated with GPS is in the order of 0.05 NM. Integrity is provided by an on-board algorithm making any GPS equipped aircraft capable of meeting not only RNAV performance requirements, but also those associated with RNP specifications.

9. Path definition is what the aircraft computes as the path between fixed ground references called waypoints. Usually based on great circle calculations the errors associated with PDE are quite small and usually ignored when considering TSE within a terminal airspace context.

10. The path steering or FTE is the degree of accuracy by which the aircraft flies around the defined path. This is dependent on the means employed by the flight

crew in operating the aircraft. In order of degrees of accuracy, there are three means of providing what is called 'Flight Guidance'. The first is manual guidance with the flight crew 'hand-flying' the aircraft with reference to cross-track errors displayed on a Course Deviation Indicator. The second is with the flight crew again 'hand-flying' but against an engaged Flight Director command in the Primary Flight Display – typically cross-bars. The third and most accurate method is through engagement of the aircraft's autopilot which automatically steers the aircraft such as to null the calculated cross-track error.

11. Figure below shows the relationship at an aircraft functional level between Navigation Positioning, Path Definition and Path Steering. They are then related to other elements of the navigation system including the aircraft displays and alerting system, the navigation data base which hosts the coded procedures and routes and the flight control system providing the guidance of the aircraft.

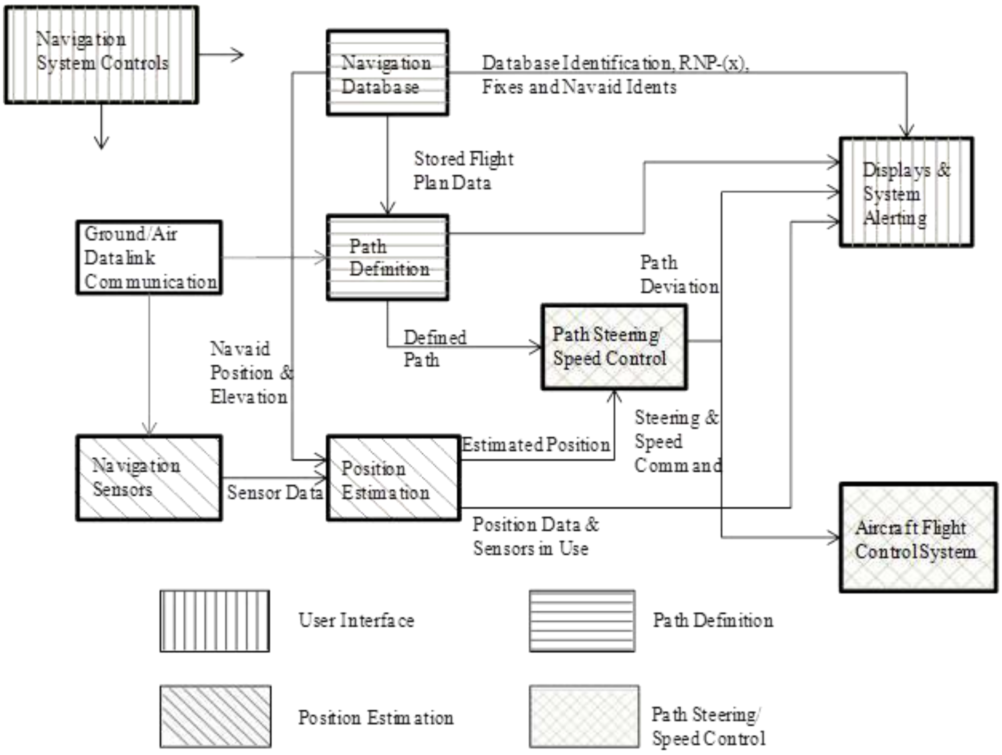


Figure 2 Navigation System Block Diagram

The ICAO RNAV-1 Specification

12. The specification applied at Gatwick Airport for the introduction of new PBN SIDs is the ICAO RNAV-1 specification. As the label indicates, the navigation accuracy is +/- 1 NM for 95% of the flight time. Allowable positioning sensors include DME/DME or GPS. There is no specific requirement for use of either Flight Director or Autopilot, although with the fleet and operator mix at Gatwick Airport one would expect flight crews to be engaging Flight Director with lateral navigation as a minimum and then coupling Autopilot shortly after take-off.

13. The RNAV-1 specification includes a minimum requirement for required navigation performance (accuracy, integrity, continuity and functionality). This is then reflected through aircraft certification material which together with criteria supporting an operational approval sets the process required for any operator wishing to become RNAV-1 qualified. In Europe the relevant approval material may be found in Joint Aviation Authorities (JAA[1]) Temporary Guidance Leaflet No. 10 rev 1. For US certified products and US operators, the relevant aircraft certification and operational approval material is contained in FAA Advisory Circular (AC) 90-100A.

Navigation System Operations

14. With the navigation system at the heart of PBN, it is worth taking a minute to briefly explain how the system processes navigation information to steer the aircraft along an instrument procedure or route.

Flight Plan

15. The flight plan is a string of instrument flight procedures and airway (en-route) segments denoting the route the aircraft plans to fly. Commencing with a SID procedure, the flight plan then links to the airway structure, via an Air Traffic Services (ATS) route. From the airway, the aircraft is directed (again through an ATS route) to a STAR linking either directly to the runway or via a runway transition. Guidance on the final approach to the runway is provided through reference to an instrument landing system such as ILS or via a PBN approach procedure (Required Navigation Performance – Approach (RNP APCH)). The Flight Management System (FMS) executes the various instrument flight procedures in a sequence depending on the aircraft position and flight crew route selection.

Sequencing of legs

16. Individual SIDs, STARs and ATS routes comprise legs denoting point-to-point navigation. At any one time the aircraft is flying an Active Leg to a fix (also referred to as a waypoint). Close to the fix the navigation system looks ahead to the next leg and depending on the nature of leg currently being flown, begins the transition. The navigation system always attempts to follow the leg sequence as denoted by the instrument flight procedure e.g., SID.

---

1 The JAA preceded EASA as the pan-European regulatory body in Europe. However, whilst their certification standards are still applicable in certain circumstances, EASA is now the responsible body to which any related certification and approval matters should be referred.

Path terminators

17. The coding that is used within the FMS to capture the defined path and which is stored in the navigation data base is reflected through an Industry standard called ARINC Specification 424. The current version is ARINC 424-20, although earlier versions are still employed in many navigation databases with varying functional capability. RNAV-1 defines a subset of functional blocks termed as 'Path Terminators' for use in design of instrument flight procedures. In this way, all RNAV-1 qualified aircraft are capable of executing leg transitions and maintain tracks consistent with ARINC 424 path terminators. The required path terminators for RNAV-1 are:

- Initial Fix (IF)
- Track to Fix (TF)
- Course to Fix (CF)
- Course from a Fix to an Altitude (FA)
- Direct to a Fix (DF)

18. Although RNAV-1 defines the above Path Terminators, only a subset has been used in the designs for the Gatwick Airport RNAV-1 SIDs. Those used are described as follows:

Track to Fix (TF)

A TF leg is defined as a geodesic path between two fixes. The first fix is either the previous leg termination or an IF leg. The termination fix is normally provided by the navigation database, but may also be a user-defined fix.

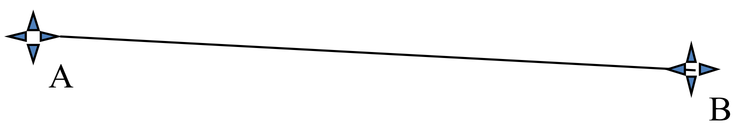


Figure 3 Track to Fix (TF) Leg

Path: Geodesic Path between A and B with Termination at Fix B

Course To Fix (CF)

A CF leg is defined as a geodesic path that terminates at a fix with a specified course at that fix. The inbound course at the termination fix and the fix are provided by the navigation database. If the inbound course is defined as a magnetic course, the source of the magnetic variation is needed in order to convert magnetic courses to true courses.

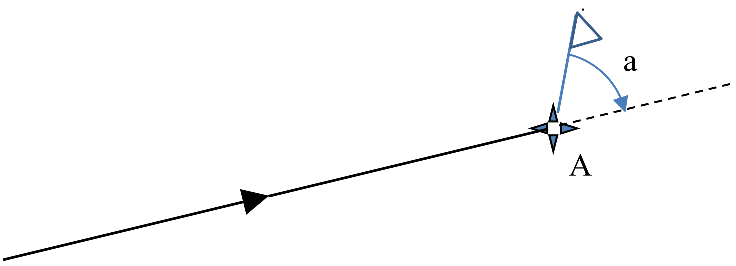


Figure 4 Course to Fix (CF) Leg

Path: Geodesic Path to Fix A with Inbound Track "a" with Termination at Fix A

Waypoint Types and Sequencing

19. The navigation system provides a means to automatically sequence from one leg to another via the Fix – also described as a waypoint. ICAO Doc 8168 PANS-OPS describes a waypoint as a specified geographical location used to define an area navigation route or the flight path of an aircraft employing area navigation. The type of waypoint determines the method by which the sequencing will be executed[2]. Waypoints are identified as either:

- *Fly-by waypoint.* A waypoint which requires turn anticipation to allow tangential interception of the next segment of a route or procedure; or
- *Flyover waypoint.* A waypoint at which a turn is initiated in order to join the next segment of a route or procedure.

20. A minimum stabilisation distance is used to compute the required minimum distance between waypoints. It is the minimum distance to complete a turn manoeuvre and after which a new manoeuvre can be initiated. To prevent waypoints being placed so close that RNAV-1 systems are forced to bypass them, a minimum distance between successive waypoints must be taken into account.

21. When course changes exceed the rules as provided in the design criteria, there may be cases where a route could be created in which the expected waypoint sequencing will not be possible due to factors such as aircraft performance, course change and leg length. In effect, the defined path is not fly-able. Under nominal conditions this situation should not occur in a database-defined procedure. Therefore, in the event that the entry requirements for the succeeding leg cannot be satisfied the navigation system may ‘by-pass’ this leg and instead transition to the next waypoint to be sequenced. In some aircraft types the transition may change from a lateral navigation mode into a basic (heading) mode requiring flight crew intervention. The figure below is taken from

[2] ICAO Doc 9613, PBN Manual and industry standards refer to the sequencing of legs as leg transitions and the term is used interchangeably with waypoint types.

ICAO Doc 8168 PANS-OPS and indicates the types of waypoint and the allowance for minimum stabilisation distance within a procedure design.

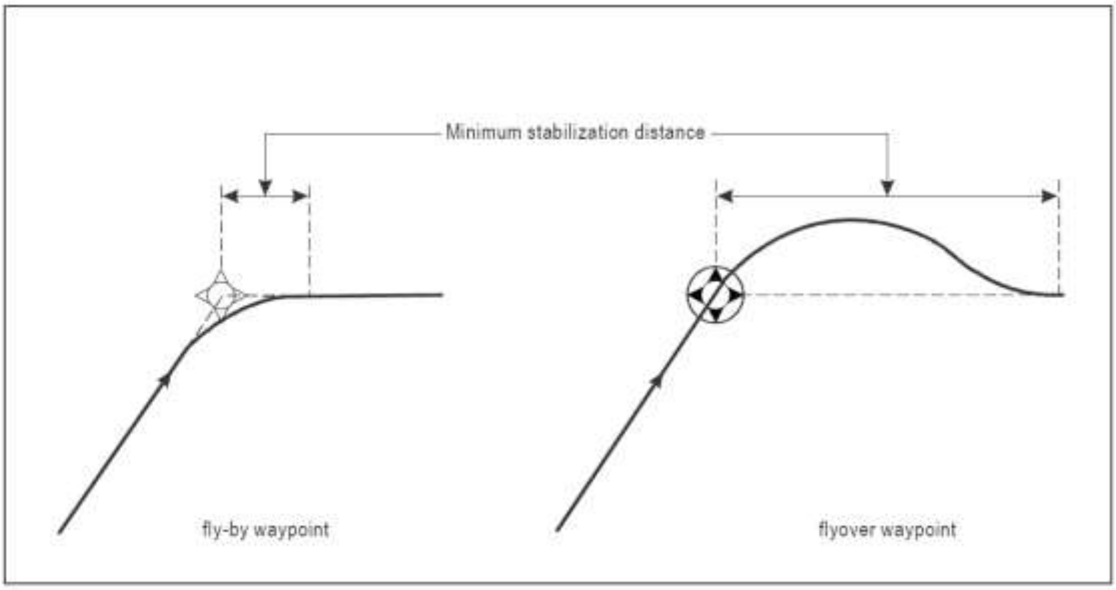


Figure III-2-1-1. Determining the minimum stabilization distance

Figure 5 Extract from ICAO Doc 8168 PANS-OPS

22. For fly-by waypoints, no predictable and repeatable path is specified, because the optimum path varies with airspeed and bank angle. Fly-by waypoints are the default transition in PBN procedures when the transition type is not specified. For fly-by waypoints, a theoretical transition area is defined within which an infinite number of acceptable ground tracks can be defined per individual airborne system design. The fly-by transition areas are significantly larger than that required for acceptable transition performance. This is a result of accommodating near worst-case conditions of ground speed and roll angle. The speed that an aircraft approaches a fly-by turning waypoint will affect where the turn commences. The higher the ground speed of the aircraft, the further from the waypoint the turn will commence and conversely the slower the ground speed the closer to the waypoint the turn will commence. The impact of this can be seen and explained further in the Route 4 technical analysis in the CAA IFP Recommendations report (Annex 6 to CAP 1346).

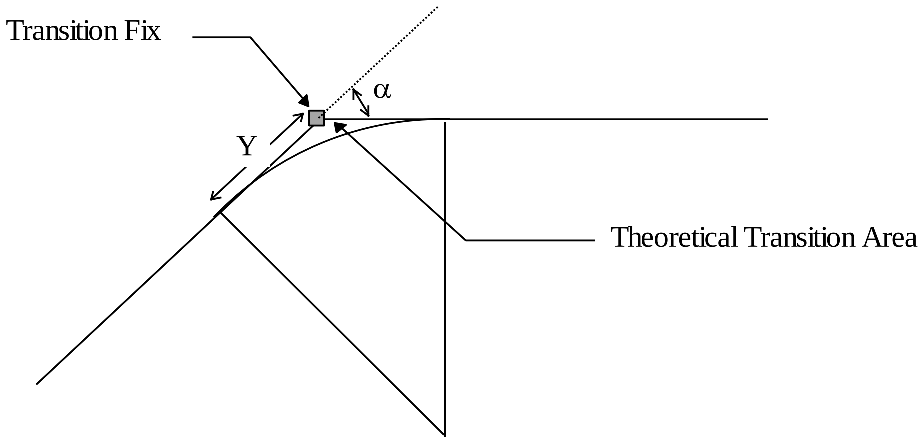


Figure 6 Fly-by Theoretical Transition Area

23. For fly-over waypoints the navigation system will not begin sequencing the next leg until having passed over the fix. Therefore fly-over transitions result in an overshoot of the fix and a required turn back to the outbound leg segment. There is no turn anticipation.

Turn Anticipation at Fly-by Waypoints

24. The navigation system provides a means for look-ahead manoeuvre anticipation and guidance such that the aircraft lateral path will follow a known trajectory. The main factors affecting the commencement of turn anticipation are:

- Turn transition angle (change in course from inbound to outbound leg)
- Ground speed of aircraft (indicated airspeed taking account of encountered wind speed and direction).
- Bank angle authority available (a value commanded by the navigation system, but limited by the flight guidance system depending on the altitude of the aircraft and speed).
- Aircraft loading (available ‘g’ manoeuvre).

25. The non-deterministic nature of the fly-by turn and therefore the track over the ground is a consequence of when the turn anticipation commences together with the available bank angle authority. If the commanded bank angle required to complete the leg transition exceeds that available, the aircraft will drift according to the wind until such time as the commanded angle can be achieved or until there is a change in the active leg or navigation system mode.

26. The effect on the aircraft of wind (speed and direction) in influencing ground speed cannot be overstated. An aircraft encountering a cross-wind component when turning downwind through 90° will now pick up tailwind component which

sums with the indicated airspeed. Hence an indicated speed of 220 knots encountering a 40 knot cross-wind (to the runway direction) at altitude becomes 260 knots after the turn with no change of aircraft thrust setting. The navigation system sees this ground speed and will use that value for computation of turn anticipation. It is this ground speed that the aircraft has to accommodate in setting bank angle authority in order to manage the turn performance of the aircraft.

Radius to Fix (RF) Turns

27. The other form of transition between two leg segments is the fitting of a fixed radius turn tangential to the inbound and outbound legs. A Radius to Fix (RF) leg is defined as a constant radius circular path about a defined turn centre that terminates at a waypoint. The termination waypoint, the turn direction of the leg and the turn centre are provided by the navigation database. The radius is computed as the distance from the turn centre to the termination waypoint by the navigation computer. The beginning of the leg is defined by the termination waypoint of the previous leg, which also lies on the arc. RF legs use fly-by waypoints with a zero degree leg change.

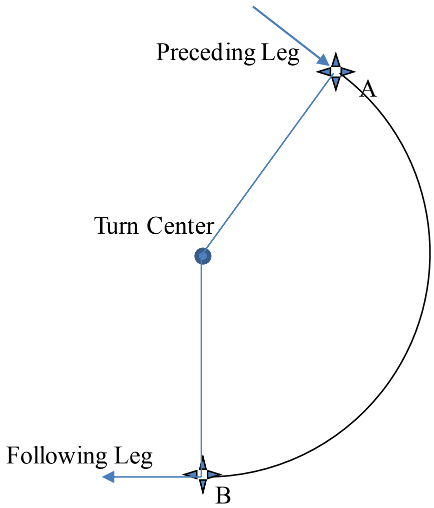


Figure 7 Radius to Fix Leg

Path: Constant Radius Arc to Fix B with Termination at Fix B

Note: Radius to Fix (RF) is associated with Terminal Airspace procedures requiring an RNP specification and therefore is not available for RNAV-1 procedure designs.

Altitude and Speed Constraints

28. The navigation system is not operating in just the horizontal plane. On the modern air transport aircraft it also provides vertical navigation and can issue speed commands in accordance with constraints associated with the instrument

flight procedure design. The navigation system is therefore managing the complete aircraft trajectory including interactions between both vertical and lateral elements of the procedure design. Indeed, behaviour of the aircraft following a vertical or speed command may have a consequence on the lateral performance, especially in the fly-by turn where the speed of the aircraft has a direct bearing on turn anticipation and therefore track over the ground. The ranges of available constraints that can be associated with a waypoint or 'fix' are as follows:

Altitude Constraints

- An "AT" or "ABOVE" altitude constraint (e.g., 2400A may be appropriate for situations where bounding the vertical path is not required);
- An "AT" or "BELOW" altitude constraint (e.g., 4800B may be appropriate for situations where bounding the vertical path is not required);
- An "AT" altitude constraint (e.g., 5200); or
- A "WINDOW" constraint (e.g., 2400A, 3400B).

Note: In the instrument flight procedure design the terms ABOVE and BELOW may be represented in the published coding tables by "+" and "-" respectively.

Speed Constraints

29. Where the navigation system supports airspeed restrictions at altitudes and/or fixes. These restrictions may be a required for tactical airspace operations or as part of a procedure. When speed restrictions are assigned at a waypoint or 'fix', the system should support "AT", "AT or ABOVE" and "AT or BELOW" types when the waypoint is sequenced.

Note: In many aircraft the Flight Management System executes the charted maximum speed constraints as "AT" speeds. For this reason flight crews will on occasions be required to intervene in order to adjust the indicated airspeed to prevent acceleration to the maximum speed constraint and thus ensuring that the navigation system is capable of executing the instrument flight procedure as intended e.g., when encountering a strong tailwind component whereby ground speed increases in the turn.

Note: Flight phase (Climb or Descent) affects the way the speed restriction is applied before and after the waypoint. The navigation system may support speed restrictions through system automation or by suitable information and cues to the flight crew.

Sequencing of Legs and Constraints

30. The fly-by turn look-ahead feature, highlighted previously, begins computation of the next leg at the bi-sector of the turn. Therefore the active leg changes at the bi-sector and the FMS computes path steering according to the new path

terminator. It also means that any altitude or speed constraint previously associated with the sequenced waypoint are dropped and the constraints of the new leg, assumed. As an example, in the Route 4 SIDs where waypoint (KKN06) has a maximum speed constraint of 220 knots associated with it and the subsequent waypoint (KKE14) a maximum speed constraint of 250 knots, the maximum 220 knots constraint will be dropped at the bi-sector of KKN06 and the aircraft will be commanded to accelerate to the new maximum speed constraint of 250 knots.

Flight Guidance System Operations

31. The flight guidance system on modern large air transport aircraft typically comprises the Flight Director command bars presented to the flight crew in the primary flight display, the autopilot and autothrottle. All of these require steering commands but operate within their own limits tied to the flight control envelope of the aircraft. As an example, the navigation system might provide a lateral steering command with a bank angle limited to say 25° whereas the engaged autopilot system could accept commands up to 30° i.e., it’s bank angle authority has a wider envelope. In a lateral navigation context, the aircraft will only ever be commanded to the value provided by the navigation system, but depending on the lateral mode and the nature of the leg type this may not fully use all of the flight guidance authority.

The Instrument Flight Procedure (IFP) Design

The CAA Role

32. The Airspace Regulation Section, within the CAA is responsible for the formulation of policy relating to the design and approval of Instrument Flight Procedures (IFPs), as documented in CAA Publication CAP 785. This responsibility includes regulatory oversight of external organisations engaged in the design of IFPs for subsequent use in the UK Flight Information Regions (FIRs) and at UK civil airports. Regulation is achieved, as appropriate, through the application of requirements as laid out in the relevant articles to the Air Navigation Order (ANO) by the CAA. The aim of CAA regulation is to ensure that IFPs:

- Are designed to the required standard as stipulated in Section 3, Chapter 1, paragraph 2 of CAP 785;
- are safe and fly-able;
- meet Air Traffic Management requirements; and
- are environmentally acceptable.

33. The criterion for IFP design in UK airspace is based on ICAO Doc 8168-OPS/611, Procedures for Air Navigation Services – Aircraft Operations Volume II, Construction of Visual and Instrument Flight Procedures (PANS-OPS Volume II). In accordance with the latest ICAO policy, UK national differences to Doc 8168 are notified in the UK Aeronautical Information Publication (AIP).

34. PANS-OPS Volume II, is intended for the guidance of procedure design specialists and describes the essential areas and obstacle clearance requirements and design assumptions for the achievement of safe, regular instrument flight operations. It provides the basic guidelines to States, and those operators and organisations producing instrument flight charts that will result in uniform practices at all aerodromes where instrument flight procedures are carried out. As an example, it includes guidance for turn protection with allowance of up to 30 knots of wind.

35. The design of procedures in accordance with PANS-OPS criteria assumes normal operations. It is the responsibility of the operator to provide contingency procedures for abnormal and emergency operations.

Secretary of State Guidance to the CAA on Environmental Objectives Relating to the Exercise of its Air Navigation Functions

36. Published in January 2014, Section 7 of the document includes general and specific guidance on concentration versus dispersal of aircraft tracks and respite. Paragraph 7.5 states:

> The Government supports the adoption of PBN as endorsed by FAS (see Chapter 4.13). PBN will mean that aircraft following a particular route will adhere to that route more consistently than they do the historic conventional routes. This will increase the concentration of traffic and impact over the areas directly beneath the published NPR, but will reduce the overall extent of the areas overflown, thereby offering the potential to reduce the number of people exposed to noise from aircraft flying below 7000ft AMSL.

CAA Guidance on PBN SID Replication for Conventional SID Replacement Policy Statement

37. The purpose of this Policy Statement is to outline guidance for specific consultation, environmental assessment and airspace change proposal requirements when change sponsors intend to replicate conventional SIDs with SID designs using PBN. http://www.caa.co.uk/docs/33/20130819PBNSIDReplacementReviewProcessFinal.pdf.

38. The CAA recommends that for future PBN SID replication projects the conventional SID should be reviewed prior to the RNAV replication design being commenced so as to ensure that the published conventional instrument flight procedure is correctly aligned with the Noise Preferential Route (NPR), which should be checked for its correctness.

Note: It is recognised that conventional SIDs are stored in the FMS navigation data base and flown by operators using a “coded overlay” derived by the contracted navigation data base provider based on their ‘best-fit’ of the conventional design using ARINC 424 path terminators. The designer of the PBN procedure is advised to first assess the coded overlay prior to commencing the PBN replication design. This will provide an appreciation of how operators are executing the conventional SID and the track being flown over the ground.

Fly-ability

39. The navigation system is clearly not the only on-board equipment affecting aircraft lateral navigation performance. How the FMS interfaces with the

automation guiding the aircraft and the presentation of both navigational and situational awareness information to the flight crew, has a bearing on how the aircraft will behave on a given flight planned route or instrument flight procedure. This coupled with the flight crew operating procedures i.e., how the flight crew manage the task of flying and operating the aircraft together with external environmental conditions e.g., temperature, density altitude and wind (strength, direction and gradient) are all factors on where the aircraft will fly over the ground at a given moment in time.

Validation of IFP – CAA Policy Statement

40. The Validation of Instrument Flight Procedures (IFPs) policy statement sets out the UK CAA policy on the validation of Conventional and RNAV IFPs designed by third-party IFP Approved Procedure Designers (APDs) http://www.caa.co.uk/docs/33/DAP_IFPValidationPolicy.pdf.

41. ICAO PANS-OPS Doc 8168 Volume II, Part I, Section 2, Chapter 4; ICAO Doc 8071 Volume 1 Chapter 8 and Volume II Chapter 5; and ICAO Doc 9906 Volume 1 form the requirement and basis for validation of instrument flight procedures together with any additional requirements as stated in the policy statement.

42. The Department for Transport has delegated to the CAA the responsibility for ensuring the safe design of instrument flight procedures within the UK and the CAA is therefore required to establish an IFP regulatory framework to ensure compliance with its responsibility.

43. The process for producing instrument flight procedures encompasses the acquisition of data, and the design and promulgation of procedures. It starts with the compilation and verification of the many inputs and ends with ground and/or flight validation of the finished product and documentation for publication. The CAA is responsible for the formulation of policy in this area and the regulatory oversight of procedure designs submitted to it for approval.

44. Consequently, ground and/or flight validation and, in the case of RNAV instrument flight procedures, an additional navigation database validation become part of the package of instrument flight procedure design activities that the CAA require industry to complete.

45. In the case of the Gatwick Airport RNAV-1 departure procedures, the primary evidence for the fly-ability of the RNAV-1 SIDs was the PRNAV trial data. Flight simulator assessment was carried out for the assessment of ‘Category D’ (Large Air Transport) aircraft which had not participated in sufficient numbers in the trial.

46. In hindsight, due to the limited participation of operator and different aircraft types a more robust assessment of the fly-ability of each of the SIDs under adverse weather conditions could have been undertaken prior to approval and

introduction. However, it must be stressed that the trial data did not suggest any untoward behaviour at the time and upon which the validation evidence was accepted by the CAA.

CAA investigations with Gatwick Airport operators and the Met Office

General

47. Although Gatwick gathered feedback from the Gatwick Airport-based operators as part of their submission for this Post Implementation Review, the CAA felt that further investigation was required, especially with respect to the responses received from Operator "A" and Operator "B", both of whom experienced issues with the Route 4 behaviour.

48. Furthermore, given that wind conditions plays an important part in the fly-ability of the departure procedures, it was felt that researching historical wind conditions would be beneficial in understanding the percentage of days where winds encountered in a south to west quadrant were greater than 30 knots. This information was prepared by the Met Office.

Questions to major Gatwick Airport operators

49. Additional questions were put to the major Gatwick Airport operators and were followed-up with meetings in order to better appreciate the flight crew operating procedures and actions undertaken within the respective companies in addressing any issues with the RNAV-1 SIDs. The questions posed were as follows:

a) Could you please provide the CAA with a copy of the navigation database coding for the RNAV SIDs - RWY 08 (SAM3Z) and RWY 26 (CLN3X or LAM1X).

The request was intended to confirm that the RNAV-1 coding that is published in the UK AIP is the one captured in the aircraft FMS navigation database. In all instances, the coding was correctly re-produced.

b) We would also be interested to see if you still carry the existing conventional departures in you navigation data base and again, having a copy of the overlay coding for the RWY 08 (SAM3P/3W) and RWY 26 (LAM4M).

This request was in order to make a comparison between the different operator, aircraft fleet, FMS and navigation database provider combinations of coding for both the easterly and westerly wrap-around departure procedures. The principal concern of the CAA with an overlay of a conventional procedure is the potential interpretation of the conventional *design by the navigation data provider. The provider has discretion to apply ARINC 424 path terminators as they see best, fitting the intended path and accounting for FMS capability i.e., version of ARINC 424 supported. This process is neither controlled nor overseen by the CAA.*

In fact, the conventional procedure navigation database coding was very similar. Taking the RWY 26L wrap-around as an example; Lufthansa Systems code as a CF on runway magnetic course of 259° to IWW23 and then treating this as a Fly-over waypoint execute a CF to the downwind course of 081°. The Jeppesen coding is identical. The Navtech coding is slightly different. They code as a CF to IWW23 on course 259° and from the Fly-over waypoint execute a VI (Vector to Intercept) leg on a course of 350° before a CF onto 081°. In all instances the IWW23 waypoint has an AT OR ABOVE 700 feet altitude constraint.

Only the Operator "A" database coding contained a speed constraint (of 190 knots) in the wrap-around turn.

In the absence of a speed constraints in the other data bases examined, the conventional overlay coding is susceptible to effects from a strong southerly or south westerly wind and will drift north of the 081° course, before recovering it. The CF-CF or CF-VI-CF designs are not vulnerable to the waypoint "BYPASS" phenomena and the location of the IWW23 (Fly-over) waypoint ensures that the turn is less likely to balloon out to the west.

c) Please provide an indication of the FMS manufacturer and software release on your aircraft.

The range of FMS varied, both between aircraft models and between FMS manufacturers within a given aircraft model. FMS from GE Aviation were found on B737-800, and FMS from Honeywell and Thales on the Airbus A320 family. Airbus A330, A380 and B747-400 are all Honeywell FMS products. The predominance of jet traffic at Gatwick meant that we were not able to survey turboprop FMS.

d) The name of your navigation data base and flight planning and charting provider.

Jeppesen, Lufthansa Systems and Navtech navigation database coding have all been exposed to the RNAV-1 SIDs.

e) An indication of bank angle authority available and/or prescribed to flight crews on wraparound procedures.

The majority of FMS command up to 25 degrees bank angle on Fly-by procedures, subject to altitude.

f) Whether that bank angle authority changes depending on the type of turn transition being flown e.g., flying a fly-by turn, flying a course change through a Course to Fix (CF) ARINC 424 path terminator or when flying on a Radius to Fix (RF) path such as is available in Zurich, Schiphol or London Stansted.

This question established that on both Airbus and Boeing designs the FMS computes the Fly-by path with an assumed bank angle authority of 25 degrees. Where the path is defined by the procedure – as in a Radius to Fix leg, the FMS defers to the outer-loop Flight Guidance System bank angle authority – typically 30 degrees.

g) Whether *operator X* is currently flying any procedures containing Radius to Fix (RF) path transitions.

Operator "C" has flown RF leg as part of the A380 low-noise SIDs trial at LHR. Operator "B" has participated to the Stansted RNP 1 and RF trial and Operator "A" fly recurrent training exercises in the training simulator with RNP AR procedures using RF.

Note: Stansted Airport has run a trial with Standard Instrument Departures (SIDs) utilising RNP 1 and RF since May 2013. Their trial report (dated May 2015) can be found at:

http://mag-umbraco-media-live.s3.amazonaws.com/1001/rnp1-trial.pdf

Note: A CAA PBN survey of summer 2010 flight plan data indicated the following fleet capability at London Gatwick based on aircraft movements:

- *RNAV 1 96%*
- *RNP 1 95% (based largely on RNAV 1 aircraft also being GNSS equipped)*
- *Radius to Fix 88%*

Note: Under the deployment of SESAR through the Commission Implementing Regulation (EU) No. 716/2014 – 'Pilot Common Project', the airports of London Heathrow, London Gatwick, London Stansted and Manchester are required to deploy ATM Functionality AF#1 requiring terminal airspace procedures based on RNP 1 and Radius to Fix (RF) by January 2024.

h) An indication of whether your Standard Operating Procedures (SOPs) contain instructions to your crews to apply a speed constraint on conventional wrap-around procedures where none is charted. If so, what speed is typically applied?

A varied response. Some operators provide procedures to their flight crews as part of the airfield briefing (Operator "E"); others have procedures in place for conventional wrap-around departures where no speed constraint is specified (Operator "B"). Other operators are reliant on the coded speed constraints - where defined (Operator "C"). Operator "A" has gone to lengths with the London Gatwick wrap-around SIDs to stress the need to their flight crews for speed management in strong southerly wind conditions.

Operator "A"

50. Two meetings were held with the company on 26 February and 23 April 2015. Their primary concern was speed management on the wrap-around turn on strong southerly or south westerly days. On the more benign wind days, they are very satisfied with the performance of the RNAV-1 SIDs and the B737-800 handles the procedures well.

51. Despite the speed constraint being MAX 220 knots, they had noticed that the constraint was being treated as a target speed i.e., the aircraft accelerated to the 220 knots. On the strong wind days this had led to waypoint "BYPASS" and flight crews had noticed that bank angle was reduced. We believe this may due to the KKN06 waypoint being dropped and the next sequenced waypoint being KKE14 with the FMS computing required bank angle authority to achieve this waypoint and track. The Operator "A" response was to advise flight crews on these strong wind days to reduce speed in the wrap-around turn and to this effect a number of Base Information bulletins have been issued to flight crew:

"LGW July Base Info

RNAV1 SIDs

Firstly you are very unlikely to be cleared for a conventional SID now as RNAV1 is the standard clearance. The instructions for conventional SIDs do not follow for RNAV1 SIDs although you may find it beneficial to follow these guidelines if strong SW wind is prevailing. Bear in mind that the FMC will draw a magenta line at 220 Knots as coded so if you stay in LNAV the reduction of speed in any mode will only cause the angle of bank to decrease because it will still fly the wider 220 Knots computed track therefore you need to ask PM to update the speed at KKN06 (CLN3X) in flight or check it before departure. Having said all that, it does not stipulate anywhere that you must not overfly any particular radial so you are within your rights to fly at 220Kts past the first two fly-by waypoints. I am waiting for absolute clarity on this from LGW ATC.

CONVENTIONAL NAVIGATION DEPARTURES WITH A 180 DEG TURN.

RWY 26 with BIG7M/V CLN8M/V DVR8M/V LAM4M/V

RWY 08 with KEN3P/W   SAM3P/W

We had observed repetitive violations of Noise Abatement (track routing) i.e. overshooting DET R-261 in the turn. It is therefore strongly recommended to observe distance 2.3 IWW (first turning point) and add R261/D-31 DET (first intercept fix) on the fix page before departure and if required fly in HDG mode.

An initial speed limit of 190 Knots is programmed into the FMC data base and must be maintained until completing the initial 180 degree turn. It is highly recommended to adhere to Noise Abatement Departure Procedure 1 i.e. maintain take-off thrust to 800 feet AGL and continue climb at V2 +10 to 20 knots to 3000 feet AGL before accelerating and cleaning up. This is not for noise purposes but for expeditious climb to 3000' at which point ATC can take over from the SID and give vectors therefore taking over track keeping responsibility.

London Gatwick Base Info August 2014

- **RNAV 1 Departures**

This is hopefully the final piece on this. We are expected to fly the RNAV 1 departure meaning we must be within 1 mile of the assigned track so to re-iterate last month's message; if you notice the ballooning of the first turn on a SID with 180' turn after departure due updating with calculated wind you must do something about it. The best thing is to reduce the speed in the turn through FMC input by PM. Vref flap40 + 70 equals clean speed, this would be a good min speed to use. Speed intervention will do nothing to help as it will still follow the computed track at Max220Kts it must be input to the FMC. Our track adherence is very good so it is not proving a problem but to be perfectly compliant this is the action we should make.

When departing on any RNAV SID there is an altitude restriction of 2500' at first waypoint, this must be adhered to and when 68 tons or more can become difficult to achieve if CLB2 and no IMP CLB selected. I suggest that if more than 68 tons as well as using IMP CLB also use CLB thrust at thrust reduction altitude. If heavier and FMC selects CLB as default then consider doing NADP 1 (OM B 4.8.2)."

November 2014

BASE UPDATE

The London Base

Northerly RNAV SIDs from RWY 26L

A couple of weeks ago I had a complaint from GAL that we were not performing well on these SIDs due to occasional "bubbling out" of the 180' turn. Thankyou very much to all of you who I contacted asking for some experimentation and feedback of these departures. I am afraid it hasn't uncovered very much as we are still unsure as to why the turn has been occasionally drawn at a greater radius than required. Since we have been focussing on this our performance has gone up and nearly all of our departures have been very accurate. I am afraid it still cannot be explained. In consolation I have been informed that other B737-800 operators have been having similar problems at LGW, it appears to be a common issue.

The undesirable tracks we've flown.

Better performance

If a strong Southerly or Westerly wind is suspected please put a max 190 Kts speed restriction at the second waypoint KKN06, although the wind does not appear to account entirely for the problem this will certainly help in keeping the turn tighter. If you notice the ballooning of the magenta calculated track, as in the first slide then use another mode ie HDG SEL and posn trend vector (turn prediction arc) to avoid following the wider arc magenta track and then re-instate LNAV when the track is correct. If you can follow these guidelines until the NAV managers have got to the bottom of this it would be much appreciated.

52. One comment from Operator “A” concerned the use of speed constraints in the SID designs. They requested that speed constraints only be applied where necessary and in particular, not be extended to the end of the procedure. The RNAV-1 SIDs are designed to terminate at 6000ft AMSL (radio-fail case). However, under normal operations ATC will vector and climb aircraft from 4000ft AMSL and it will only ever be the failure case where an aircraft remains at 6000ft AMSL with the MAX 250 Knots speed constraint. The constraint is

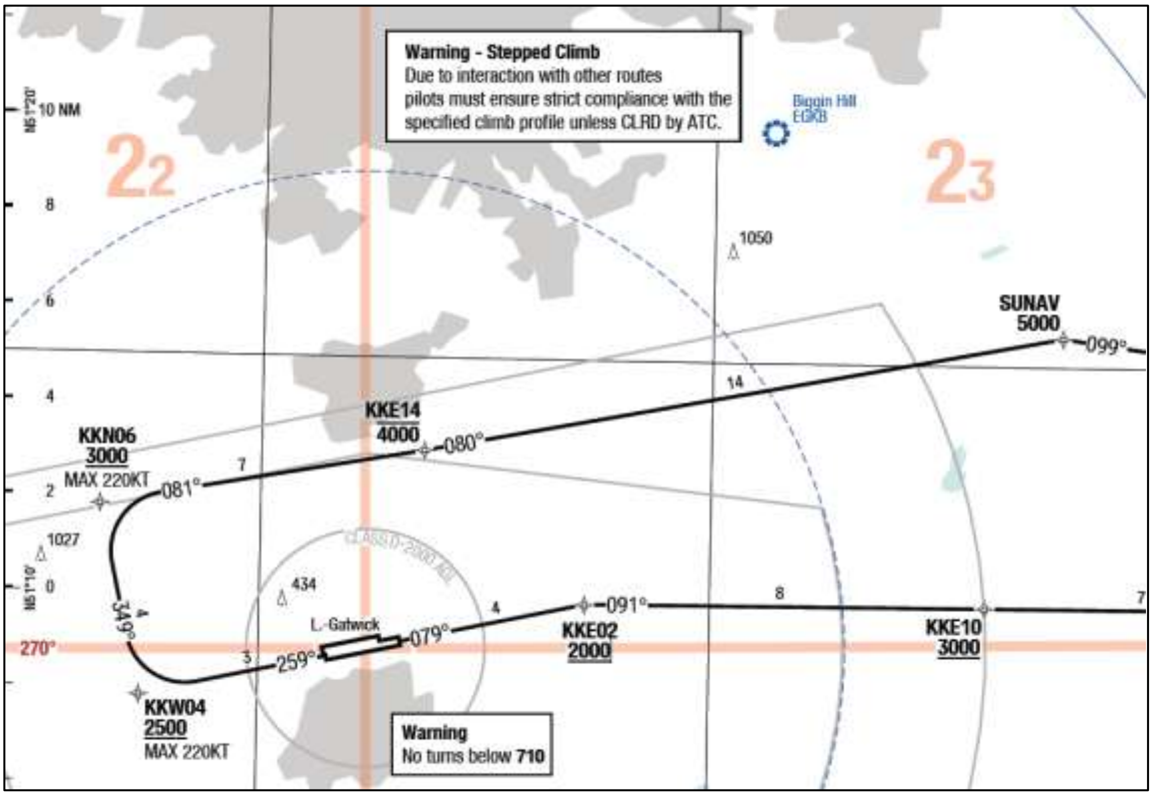
derived from the convention of a maximum of 250 Knots below FL100. Consequently, flight crews have to remove the speed constraints, which create additional workload.

53. Operator "A" would welcome a Radius to Fix (RF) turn in the wrap-around design, bringing as it does greater predictability in path performance. They currently use procedures containing RF in their re-current training.

Operator "B"

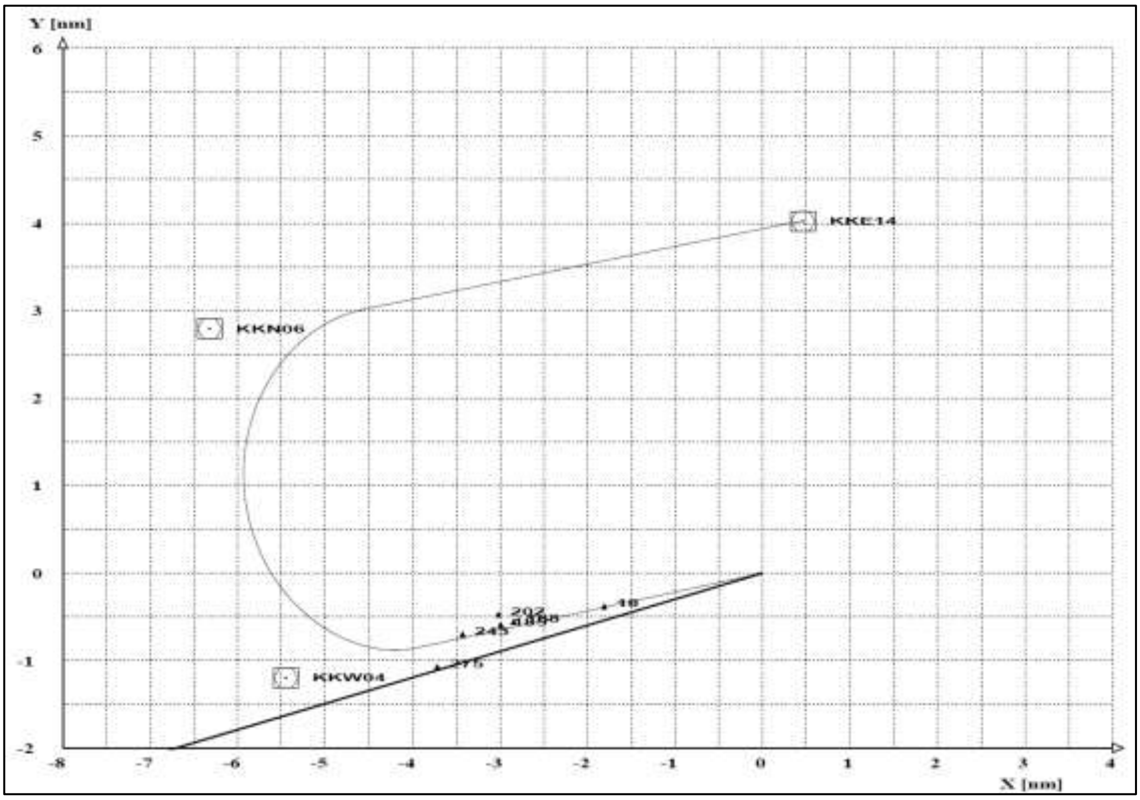
54. One meeting was held with Operator "B" on 11 March 2015. Operator "B" is the operator with most issues on the Route 4 RNAV-1 SIDs. After a number of incidents, the airline conducted their own investigation with reconstruction of flights using their Flight Replay and Airbus Performance tools. The following extract is taken from an Operator "B" Flight Operations Technical Navigation Report investigating the Gatwick Airport RNAV-1 SID Track deviations.

> "General Comment
>
> While the AIP and published charts reflect a very well defined crosswind leg, in reality the time where an aircraft can fly wings level between waypoints [KKW04] and [KKN06] is minimal.
>
> The environmental design criteria for these procedures was reported to be 30kts yet when ground speeds are close to 250 kts the procedures are quite challenging due to the resulting turn radius.



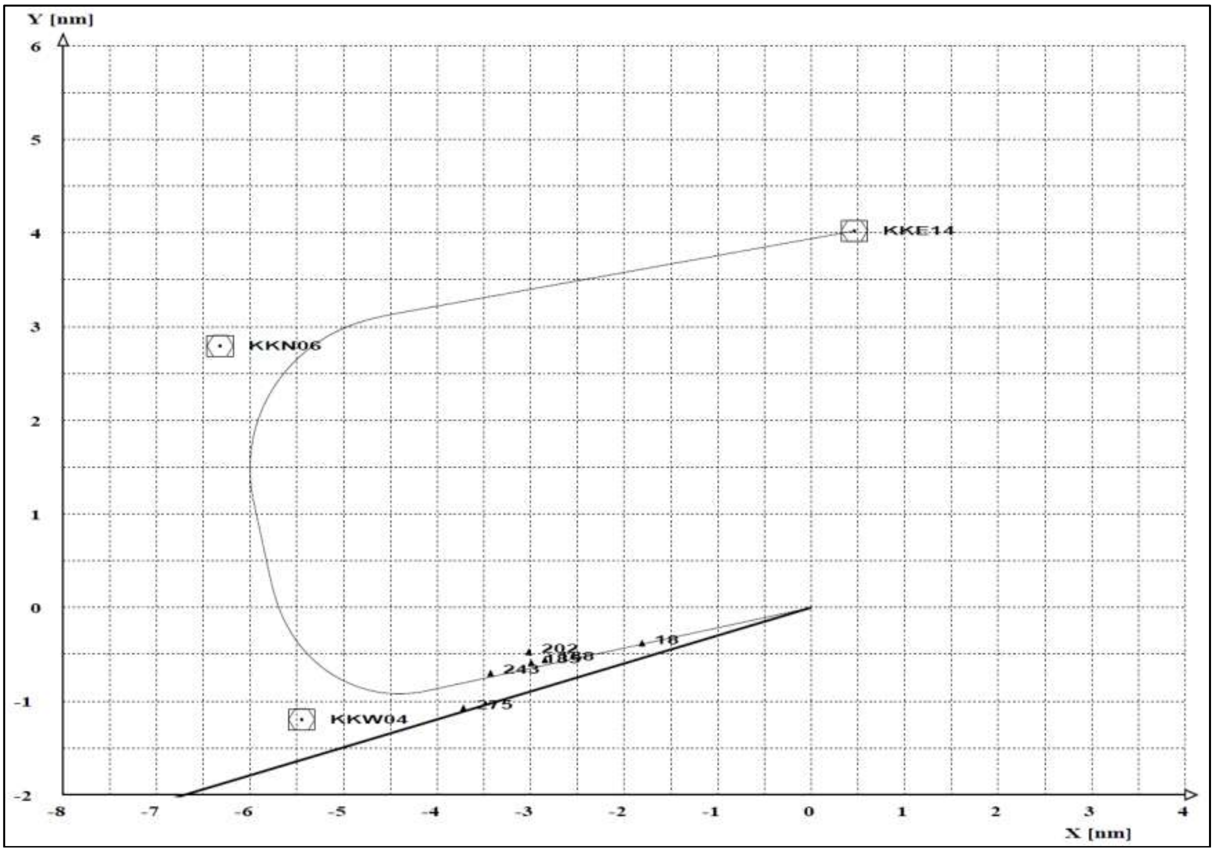
With a 30 knot tailwind experienced between [KKW04] and [KKN06] the aircraft must apply 30 degrees bank angle and maintain this through a continuous turn to achieve the required eastbound track towards waypoint [KKE14]. If the autopilot commands anything less than 30 degrees then deviation north of the required track is almost guaranteed. The depiction below actually appears more in alignment with the conventional procedures (DVR8M). In still air the procedures work well.

EGKK (DVR1X) - A319-111 (NADP2) 220kts CONF 0
KKW04 > KKN06 TRK WIND = STILL AIR



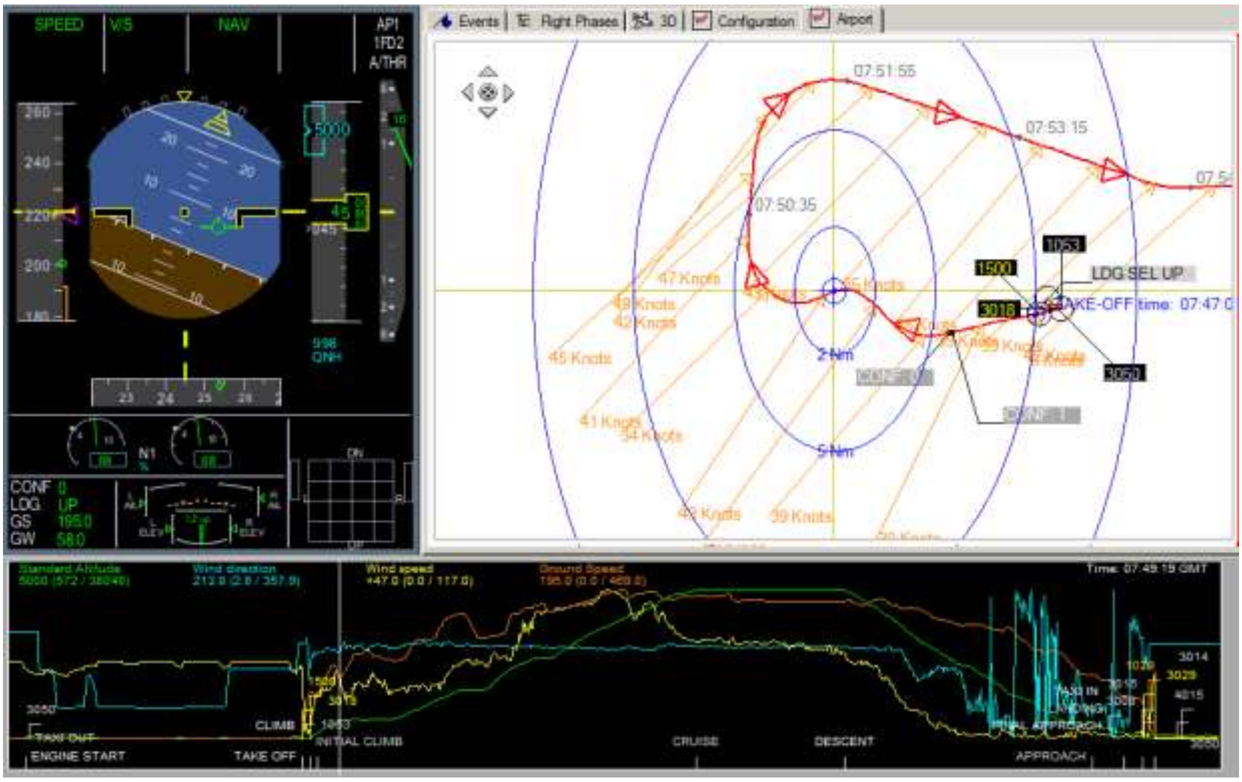
However the air is rarely still and autopilot behaviour and aircraft weight / energy is inconsistent from one flight to the next. In reality the wings level element in still air is less than 20 seconds. Turn anticipation at 220 knots is approximately 1.5nm so with a distance of only 4.1nm between the two waypoints, in operation the procedure looks entirely different. The Airbus PEP tool used to generate these graphics assumes a Flex Take-off (CONF 1+F) with standard (NADP2) clean up and acceleration to 220 knots. Bank angle is applied and maintained perfectly with no “wash out”, or hesitation to establish in the turn.

EGKK (DVR1X) - A319-111 (NADP2) 220kts CONF 0 - Bank Angle 30°
KKW04 > KKN06 WIND = 169/30kts



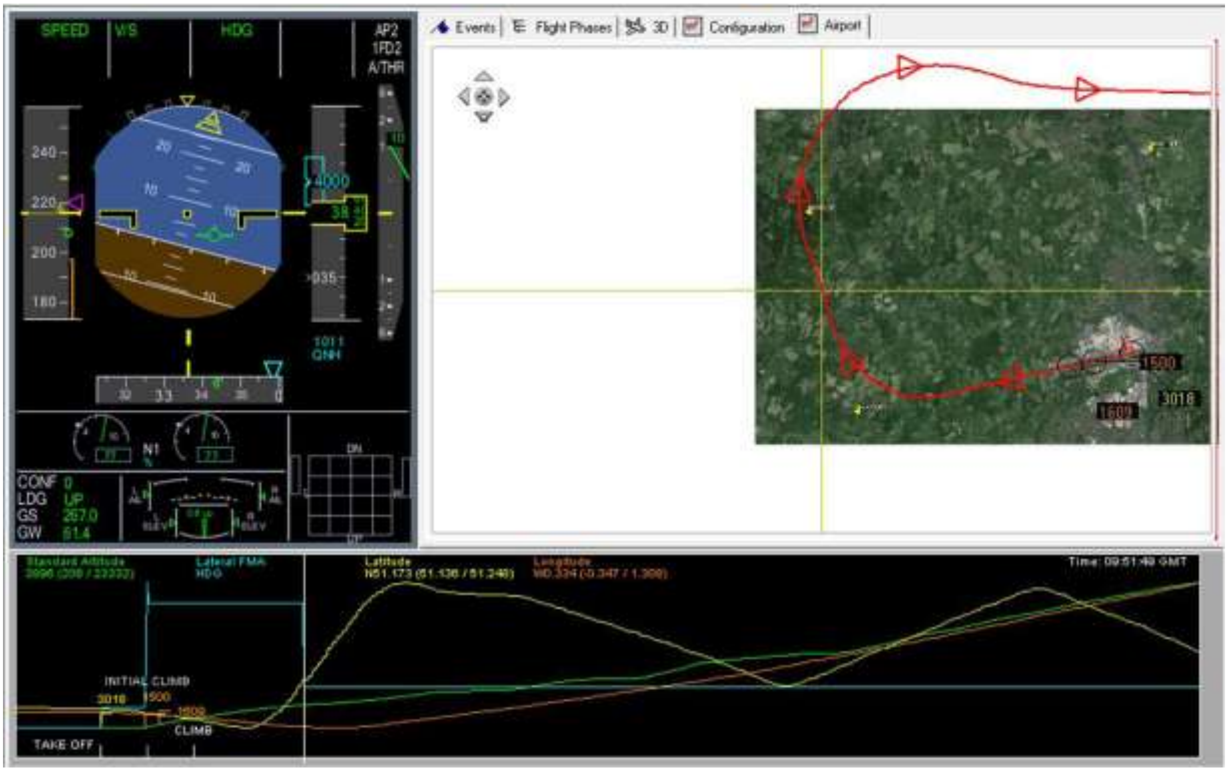
Example 1 Crew Report

On departure from LGW on LAM1X aircraft flew normally, beginning right turn until passing approximately 4000' when it turned left onto heading of approximately 240 degrees. Heading selected and right turn initiated. Wind from approximately 210 degrees at 20 knots increasing rapidly to 55 knots. GPS accuracy high throughout. Flight continued normally.



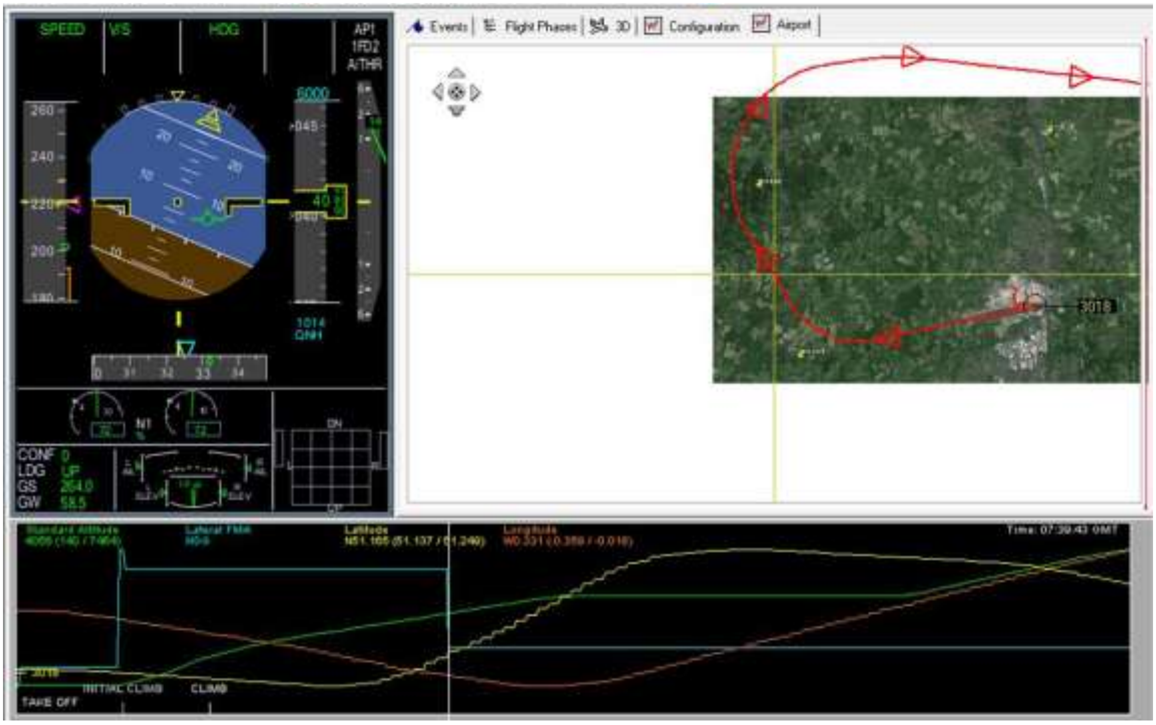
Example 2 Crew Report

After passing WPT KKW04 while getting KKN06 as TO WPT FMGC started to recalculate the following turn towards KKE14 several times. The radius first appeared too large but corrected itself to normal. Pilot flying (PF) initially left the automatic, but then FMGC recalculated again and started a left turn to regain the wider radius. At that moment PF changed to selected mode and Pilot Monitoring (PM) told ATC about the deviation. Shortly after we got issued HDGs. Wind was moderate from SW.

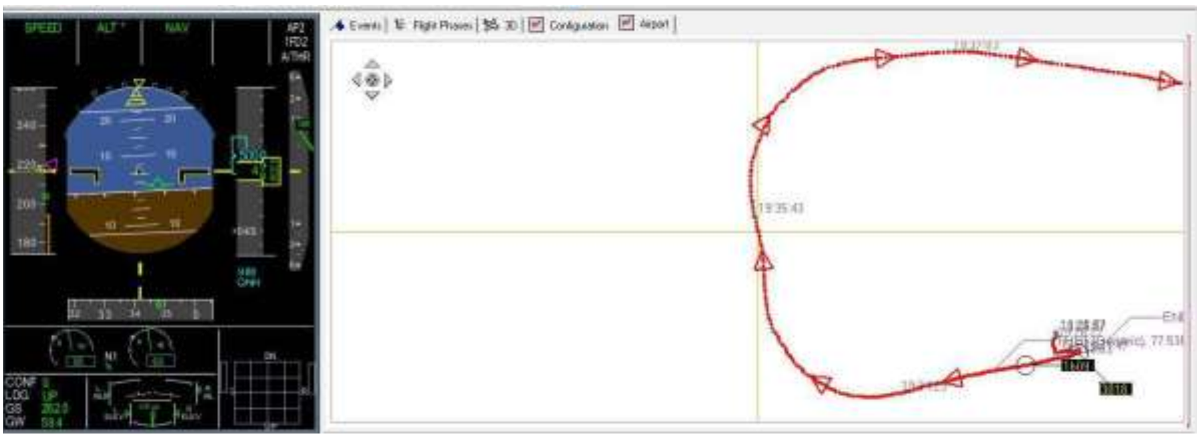


Example 3 Crew Report

Departure from LGW RWY26L on LAM1X SID, flown in managed speed with 220 knot constraint as published on the chart. After initial turn from KKW04 aircraft rolled wings level well inside track displayed on ND, then began left turn towards KKN06 rather than continuing right turn to KKE14. PF selected heading and continued right turn manually whilst Pilot Not Flying (PNF) advised ATC unable RNAV due equipment. Given radar heading 090; once established on this we were 2.5 miles left of original SID track."



Example 4



55. One can see from the Flight Replays that the aircraft track performance under certain environmental conditions can be problematic.

56. For Example 1, the initial turn north and then turn west around KKW04 is believed to be attributable to a strong wind gradient effect encountered. With an FMS computation based on a 20 knot wind a path is computed for the Fly-by turn with bank angle accordingly applied. As the aircraft climbs and encounters a stronger wind it re-calculates the turn anticipation and this instance computed a turn west before manual intervention.

57. Example 2, 3 and 4 are all cases where the second Fly-by turn at KKN06 has been "BYPASSED" before the aircraft has recovered the nominal track downstream on the SID at KKE14.

58. Operator "B" is already participating to the RNP 1 and Radius to Fix (RF) trial at London Stansted and would welcome a wrap-around design containing RF at London Gatwick, again for reasons of meteorological resilience and predictable lateral track performance.

Operator "C"

59. One meeting was held with Operator "C" on 6 March 2015. The operator has had no reported incidents with any of the SIDs. A degree of overshoot can be observed on the B777 tracking of the Fly-by turn at KKE03 on the RWY 08R SFD4Z. The speed constraint of MAX 220 Knots, whilst assigned to this waypoint will be dropped at the bi-sector of the turn as the FMS sequences the next leg which has a MAX 250 Knots speed constraint. Were the speed constraint at KKS08 also restricted to 220 Knots, the track adherence would likely be improved.

60. Of note is the fact that some of the newer Operator "C" A319/A320 aircraft operating from Gatwick Airport are Thales FMS equipped. Although the same (latest) Airbus software revision as the Honeywell FMS equipped aircraft i.e., FMS 2 Release 1A, the Thales FMS seems to better cope with the strong wind conditions suggesting the computation of a higher update rate of path steering commands around the turn. The following are responses to the CAA questionnaire from the Fleet Base Captains and Technical Pilots:

> "Here are the missing details for the Operator "C" A320 family:
>
> c) We have both Honeywell and Thales FMS2 with Release 1a installed. The guidance software is at differing standards however we are about to begin an upgrade to S7AI12 on both the Honeywell and Thales FMS's.
>
> e) Generally the SON is limited to 25 degrees in both automatic and manual flight.

f) In certain circumstances the auto flight guidance system can increase the AOB to 30 degrees in order to maintain the required Navigation path.

The wrap-around SIDs work well generally.

On a normal 2 engine climb out, we start to accelerate at 1000 AAL, which leads to a full clean-up and 220 knots being achieved prior to KKW04. 2500 feet I've not known to be an issue either. The only time we'd hold the speed back below 220 knots during the turn, would be if our minimum clean speed was above 220 knots. This would only be the case on a pretty heavy 320 or 321. Operator “C” does not have any 321s at LGW but others do. Typically, if minimum clean was say 225, we'd hold the speed back at 210 with Flap 1 plus F, as to fly at 220 would put us very close to the flap limit speed of 230 knots, if we experience an increasing headwind or gust/turbulence. Once past KKN06, we'd then complete the acceleration and clean up, on the way to 250 knots.

As for southerly winds, again, at 220 knots I've not noticed a "blow through the turn" effect. The Airbus cranks on 30 degrees of bank which is normally enough for us to stay within the turn radius. That said, we are talking to London ATC by then and they often ask us to roll out on a heading of around 090-110 depending on wind, so they can give us a continuous climb above 4000 feet. If in a light 319, heading to Scotland, we normally add on first contact with London, that we have a good rate of climb available, which often leads to an early turn onto North and climb to a FL, knocking 5 minutes off the flight time and saving fuel.

Regarding the 777 …

The FMC is made by Honeywell. I’m not aware of FMC software version but the aircraft have different Block Point versions if that helps.

As for angle of bank, the FD will command up to 30 degrees angle of bank and moderate as required. In LNAV the AFDS (autopilot flight director system) will command whatever it requires to achieve the procedure. In the case of an RF leg it’ll vary the angle of bank to achieve the prescribed path. In other instances it’ll apply 25 or 30 degrees aob (can’t remember which one) and when close to the next waypoint it’ll adjust it to capture the waypoint.”

Operator “D”

61. Based on email correspondence dating back to May 2014 when Operator “D” flight crews reported issues on Smiths/GE equipped aircraft when using the DVR1X RNAV 1 SID (Route 4) at Gatwick Airport. The following analysis was made by GE Aviation:

> "We have performed some analysis using our simulation tools and find that when the FMC tries to compute a lateral path that honours the waypoints in the procedure, with light winds, it can just barely meet its criteria for creating a legal path. When there is a wind that increases ground speed in the turn, the FMC can no longer meet its criteria for creating a legal path, and inserts what we call a "BYPASS". This "BYPASS" is what you are seeing in situations where you have sufficient wind to trigger this behaviour.
>
> We did find that the behaviour is improved if speed is kept in check. We note that the charts and the data include a 'AT or BELOW 220 knots' speed restriction. Don't know if your incident aircraft was doing this or not. You will still see a "BYPASS" in these cases, but the deviation from desired path is not as large.
>
> We would suggest that Operator "D" notify your procedure design authority that aircraft have difficulty negotiating the turn with strong southerly winds."

Operator "E"

62. The following is based on a telephone conversation with Operator "E" Flight Technical Support in May 2015. Note: the operator has not received reports from their flight crews, although the fleet of B747-400 and A330 rarely fly the Route 4 RNAV-1 SID. However, they do have a standing crew briefing for Gatwick Airport with an extract as follows:

> "If flying a reversal turn as the initial part of the SID, the turn must be flown at 210-220kt to stay on the Noise Preferential Route; speed intervention/selection is recommended. After any speed restrictions on the SID, ATC expect aircraft to accelerate to minimum clean speed below FL100".

Boeing input regarding speed constraints and bank angle limits

63. A telephone conference call was held with Boeing on 10 March 2015. A specific question was posed concerning speed constraints and in particular, how Boeing FMS handle a MAX 220 Knots constraint given that the ARINC 424 navigation data base coding (-220) suggests a "less than" constraint. Boeing responded that their B737NG systems treat the constraint as a target speed, as per the description in paragraph 29. This is consistent with the behaviour seen by Operator "A".

64. The second question concerned bank angle authority in different types of turn. For a Fly-by turn there is no defined path for the aircraft to steer against and

therefore the FMS computes its own path in order to fly-by the waypoint. This computation is based on aircraft ground speed, turn angle and bank angle authority. The FMS assumes a maximum bank angle (outside of the initial climb) of 25 degrees and therefore the aircraft will not apply bank angles any greater than this. On a Radius to Fix (RF) turn, the aircraft is provided with a defined path from the navigation data base. The Flight Guidance System therefore applies the bank angle required up to a limit of authority for the aircraft, which is typically 30 degrees. For the major large aircraft types, a design with RF therefore has greater bank angle authority than one defined using Fly-by turns.

Noise Abatement Departure Procedures (NADP 1 and NADP 2)

65. In their response to the CAA, the operators have mentioned Noise Abatement Departure Procedures (NADP). The two ICAO conventions – NADP 1 and NADP 2 are described below in an extract taken from ICAO Doc 8168 Volume I.

Appendix to Chapter 3

NOISE ABATEMENT DEPARTURE CLIMB GUIDANCE

1. General

1.1 Aeroplane operating procedures for the departure climb shall ensure that the necessary safety of flight operations is maintained while minimizing exposure to noise on the ground. These procedures are provided as examples because the noise reductions obtained depend greatly on the type of aeroplane, engine type, thrust required, and the height at which thrust is reduced. For this reason, procedures that provide the best possible noise benefit may differ significantly from one aeroplane type to another, and between aeroplanes of the same type with different engines. States should avoid the practice of requiring all operators to use one of the example procedures for departures from specific runways, and should instead allow aircraft operators to develop operational procedures that maximize the noise benefits obtainable from their aeroplanes. This is not intended to prevent States from suggesting the use of a procedure based on one of the examples, as an alternative to operator-specific procedures. The following two examples of operating procedures for the climb have been developed as guidance and are considered safe when the criteria in 3.2 are satisfied. The first example (NADP 1) is intended to describe one method, but not the only method, of providing noise reduction for noise-sensitive areas in close proximity to the departure end of the runway (see Figure I-7-3-App-1). The second example (NADP 2) similarly describes one method, but not the only method, of providing noise reduction to areas more distant from the runway end (see Figure I-7-3-App-2). Aircraft operators may find that to suit their particular route system (i.e. at aerodromes where they operate), two different procedures, one designed for close and the other designed for distant noise reduction, may be appropriate.

1.2 The two example procedures differ in that the acceleration segment for flap/slat retraction is either initiated prior to reaching the maximum prescribed height or at the maximum prescribed height. To ensure optimum acceleration performance, power or thrust reduction may be initiated at an intermediate flap setting.

Note 1.— For any procedure, intermediate flap transitions required for specific performance-related issues may be initiated prior to the prescribed minimum height; however, no power reduction can be initiated prior to attaining the prescribed minimum altitude.

2. Noise abatement departure climb — Example of a procedure alleviating noise close to the aerodrome (NADP 1)

2.1 This procedure involves a power or thrust reduction at or above the prescribed minimum altitude (240 m (800 ft) above aerodrome elevation) and the delay of flap/slat retraction until the prescribed maximum altitude is attained. At the prescribed maximum altitude (900 m (3 000 ft) above aerodrome elevation), the aircraft is accelerated and the flaps/slats are retracted on schedule while maintaining a positive rate of climb, to complete the transition to normal en-route climb speed. The initial climbing speed to the noise abatement initiation point is not less than V_2 plus 20 km/h (V_2 plus 10 kt).

2.2 In the example shown below, on reaching an altitude of 240 m (800 ft) above aerodrome elevation, engine power or thrust is adjusted in accordance with the noise abatement power/thrust schedule provided in the aircraft operating manual. A climb speed of V_2 plus 20 to 40 km/h (V_2 plus 10 to 20 kt) is maintained with flaps and slats in the take-off configuration. On reaching an altitude of 900 m (3 000 ft) above aerodrome elevation, the aircraft is accelerated and the flaps/slats are retracted on schedule while maintaining a positive rate of climb to complete the transition to normal en-route climb speed.

3. Noise abatement departure climb — Example of a procedure alleviating noise distant from the aerodrome (NADP 2)

3.1 This procedure involves initiation of flap/slat retraction at or above the prescribed minimum altitude (240 m (800 ft) above aerodrome elevation) but before reaching the prescribed maximum altitude (900 m (3 000 ft) above aerodrome elevation). The flaps/slats are to be retracted on schedule while maintaining a positive rate of climb. Intermediate flap retraction, if required for performance, may be accomplished below the prescribed minimum altitude. The power or thrust reduction is initiated at a point along the acceleration segment that ensures satisfactory acceleration performance. At the prescribed maximum altitude, a transition is made to normal en-route climb procedures. The initial climbing speed to the noise abatement initiation point is not less than V_2 plus 20 km/h (V_2 plus 10 kt).

3.2 In the example shown below, on reaching 240 m (800 ft) above aerodrome elevation, the aircraft body angle/angle of pitch is decreased, the aeroplane is accelerated towards V_{zf}, and the flaps/slats are retracted on schedule. Power or thrust reduction is initiated at a point along the acceleration segment that ensures satisfactory acceleration performance. A positive rate of climb is maintained to 900 m (3 000 ft) above aerodrome elevation. On reaching this altitude, a transition is made to normal en-route climb speed.

3.3 An aeroplane should not be diverted from its assigned route unless:

a) in the case of a departing aeroplane it has attained the altitude or height which represents the upper limit for noise abatement procedures; or

b) it is necessary for the safety of the aeroplane (e.g. for avoidance of severe weather or to resolve a traffic conflict).

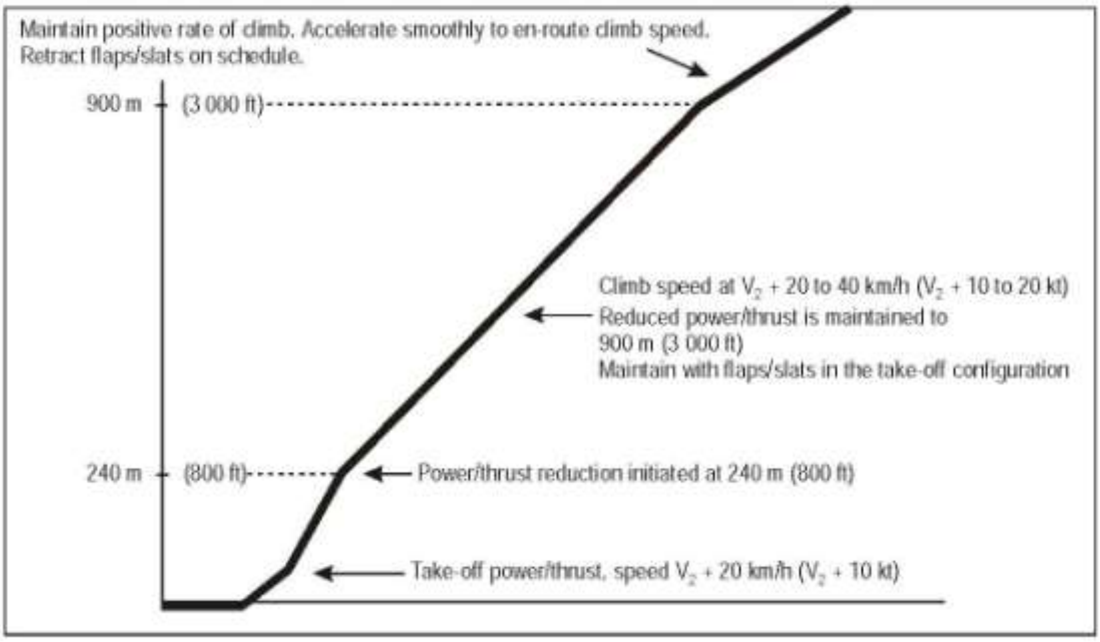


Figure I-7-3-App-1. Noise abatement take-off climb — Example of a procedure alleviating noise close to the aerodrome (NADP 1)

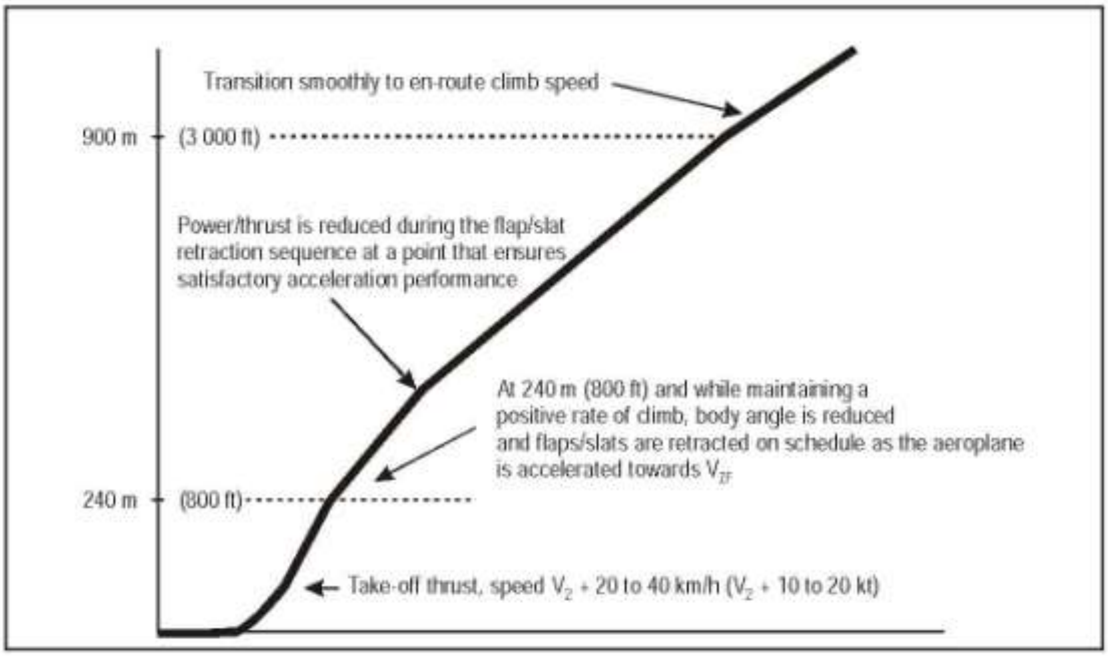


Figure I-7-3-App-2. Noise abatement take-off climb — Example of a procedure alleviating noise distant from the aerodrome (NADP 2)

66. Most operators apply standard operating procedures consistent with NADP 2. NADP 1 is applied by some operators and is required at certain airports. An NADP convention is neither required nor necessarily recommended and the above explanation is provided for information and completeness.

Meteorological Resilience/Impact

67. A survey of the wind speed and direction at Gatwick Airport based on a 950 hPa altitude (2400ft AMSL) has been made based on historical information covering the periods from January 2000 to July 2009 (Table 1) and from January 2010 to December 2014 (Table 2).

68. What is of most interest is the percentage associated with winds greater than 30 knots i.e., the design wind speed used in the Instrument Flight Procedure design in the quadrant from due South to due West. It is in this quadrant that the most adverse (in terms of fly-ability) wind conditions have been observed.

69. The results indicate that from the period from January 2000 to July 2009, 12.75% of the 2400ft AMSL winds exceeded 30 knots in the quadrant of interest. In the more recent period from January 2010 to December 2014, this value drops to 9.51%. Nevertheless, this still reveals that around 10% of the winds exceed the design assumptions taking the design outside of its design assumptions and vulnerable to adverse fly-ability issues without flight crew intervention i.e., speed management.

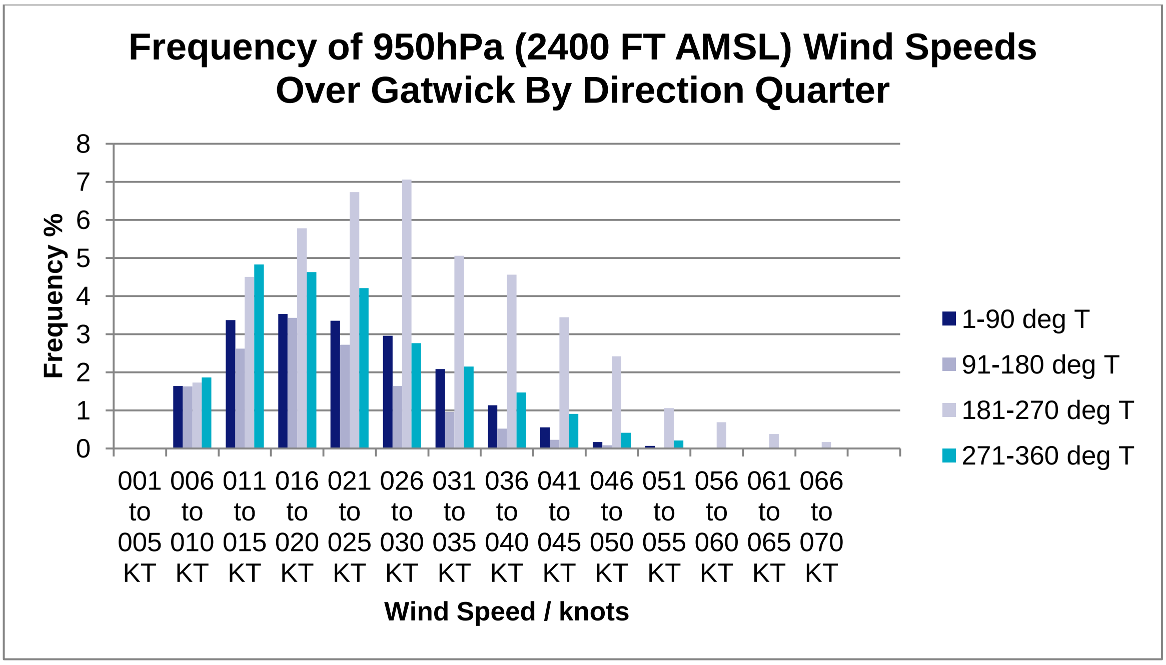


Table 1 Wind Data from period January 2000 to July 2009

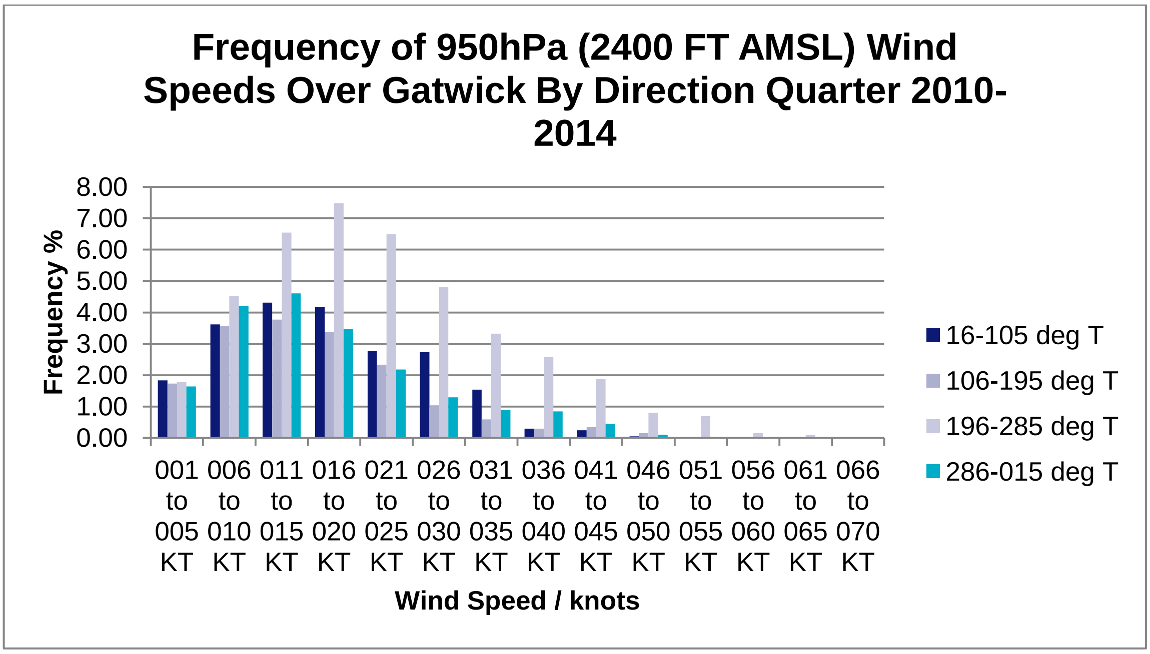


Table 2 Wind data from period January 2010 to December 2014

Period	Quadrant	Percentage > 30 knots
January 2000 to July 2009	181-270 degrees True	12.75
January 2010 to December 2014	196-285 degrees True	9.51

Acronyms

A330	Airbus 330 Aircraft
A380	Airbus 380 Aircraft
AIP	Aeronautical Information Publication
AMSL	Above Mean Sea Level
ANO	Air Navigation Order
APD	Approved Procedure Designer
ARINC 424	Airlines Electronic Engineering Committee - Navigation System Data Base
ATC	Air Traffic Control
ATS	Air Traffic Service
B747-400	Boeing 747-400 Aircraft
B777	Boeing 777 Aircraft
CAA	Civil Aviation Authority
CF leg	Course To Fix leg
DME	Distance Measuring Equipment
ERCD	Environmental Research & Consultancy Department
FAS	Future Airspace Strategy
FB WP	Fly-by waypoint
FDR	Flight Data Recorder
FIR	Flight Information Regions
FL	Flight Level
FMC	Flight Management Computer
FMGC	Flight Management Guidance Computer
FMS	Flight Management System
FO WP	Fly-over waypoint

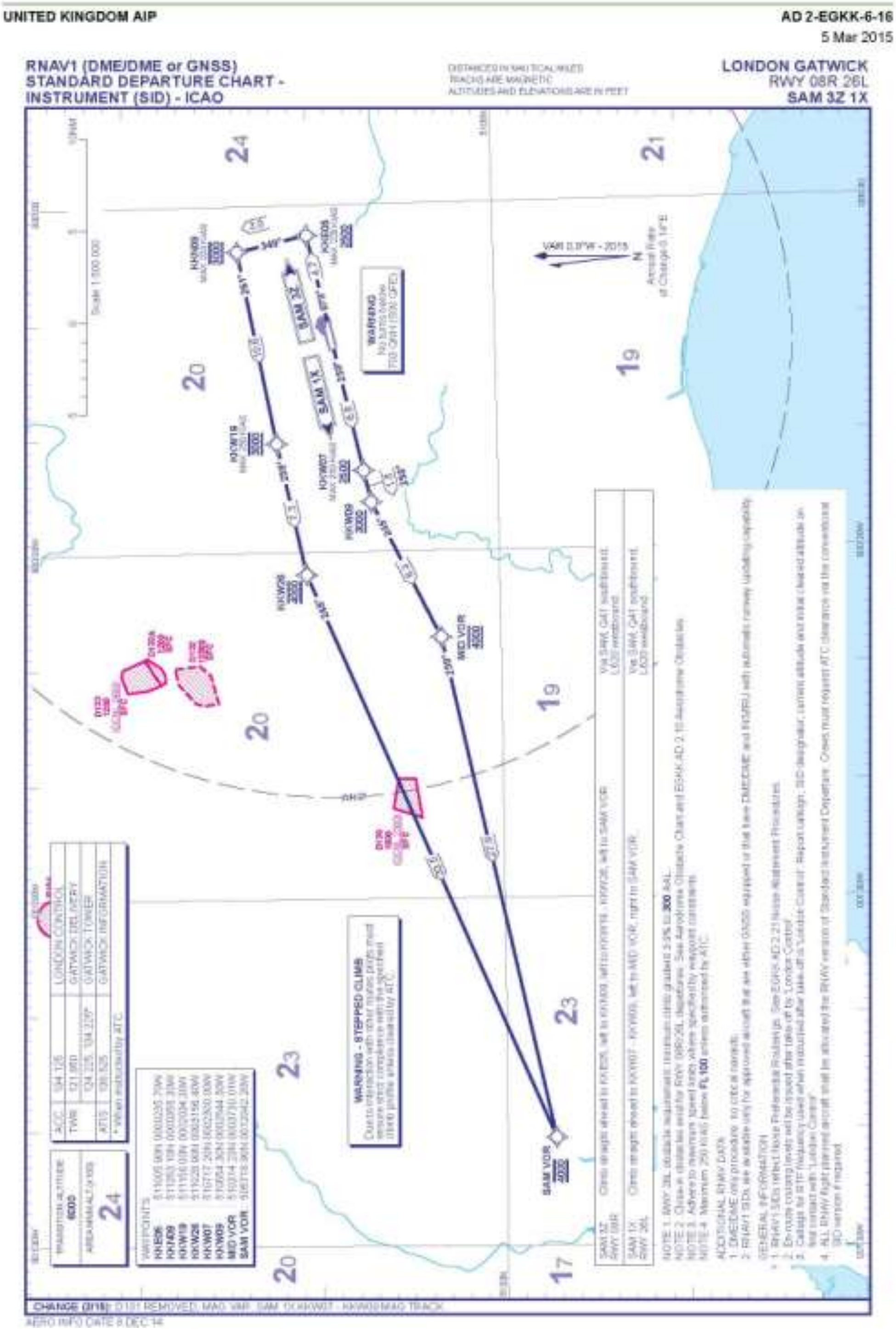
FTE	Flight Technical Error
Gatwick	Gatwick Airport Limited
GE	General Electric
GNSS	Global Navigation Satellite System
GPS	US DoD Global Positioning System
HDGs	Headings
hPa	Hectopascal – 1 hectopascal is equivalent to 1 millibar
ICAO	International Civil Aviation Organisation
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
IRS	Inertial Reference System
JAA	Joint Aviation Authorities
KIAS	Indicated Airspeed in Knots
Kts	Knots
LHR	London Heathrow
MSD	Minimum Stabilisation Distance
NADP	Noise Abatement Departure Procedures
ND	Navigation Display
NPR	Noise Preferential Route
NPR Swathe	Noise Preferential Route Swathe
NSE	Navigation System Error
PANS OPS	Procedures for Air Navigation Services Operations
PBN	Performance-based Navigation
PDE	Path Definition Error
PF	Pilot Flying
PM	Pilot Monitoring
PNF	Pilot Not Flying

PT	Path Terminator
RF Turns	Radius to Fix Turns
RNAV-1	Area Navigation
RNP	Required Navigation Performance
RNP APCH	PBN approach procedure
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
SW	South West
TF leg	Track to Fix leg
TSE	Total System Error
VI leg	Vector to Intercept leg
VOR	Very High Frequency Omnidirectional Radio Range

APPENDIX A

UK AIP Charts and Coding Tables for the Gatwick Airport RNAV-1 SIDs

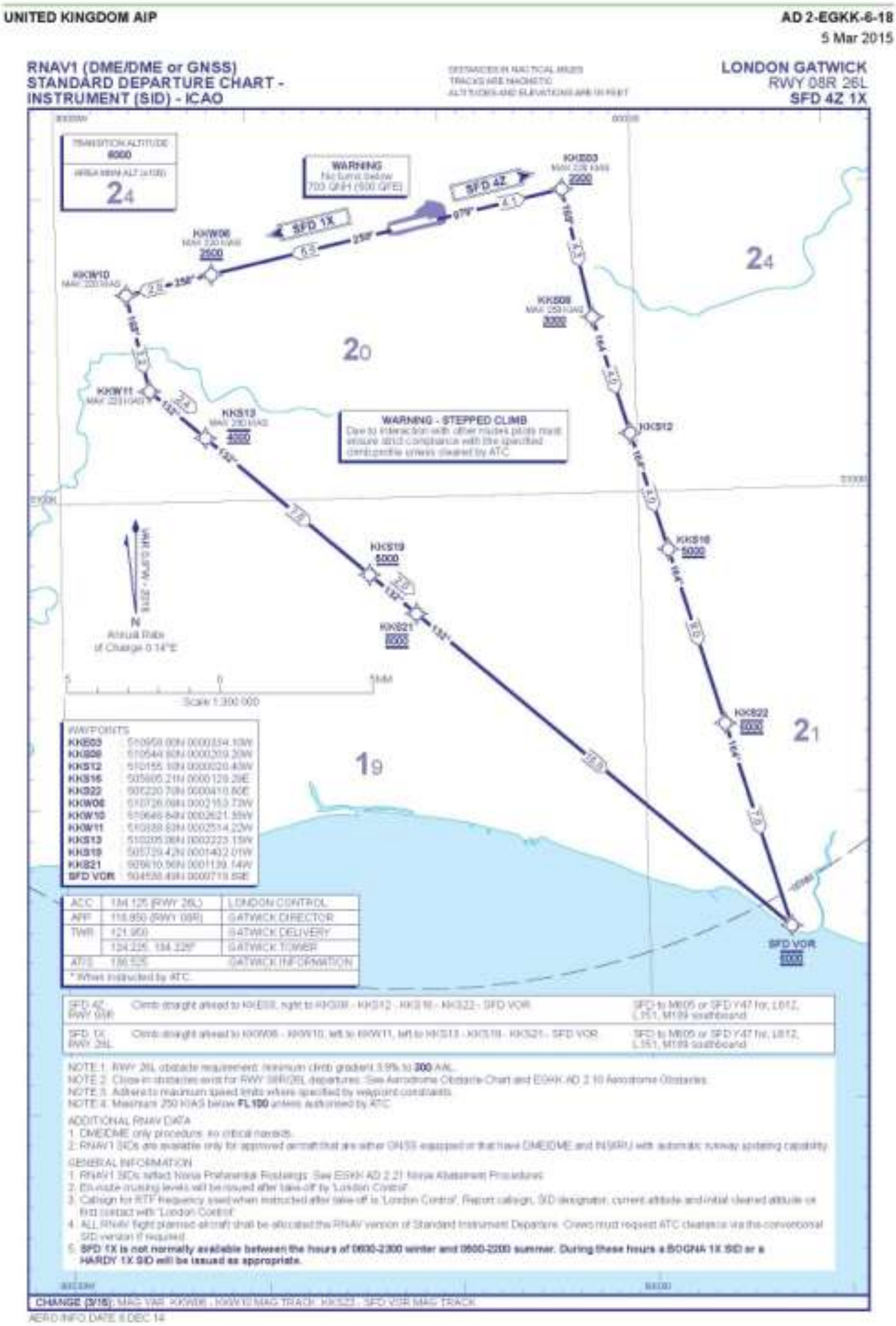
Route 1 RWY 26L SAM 1X



London Gatwick Runway 26L SAM 1X

Designator	Sequence Number	Path Terminator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
SAM 1X	001	CF	KKW07	510717.20N 0002300.00W	N	259° (257.7°)	-0.9	6.6	-	+2500	-250	RNAV1
SAM 1X	002	TF	KKW09	510654.30N 0002544.30W	N	258° (257.5°)	-0.9	1.8	LEFT	+3000	-250	RNAV1
SAM 1X	003	TF	MID	510314.23N 0003730.01W	N	245° (243.7°)	-0.9	8.3	RIGHT	4000	-250	RNAV1
SAM 1X	004	TF	SAM	505718.90N 0012042.20W	N	259° (258.0°)	-0.9	27.9	-	4000	-250	RNAV1

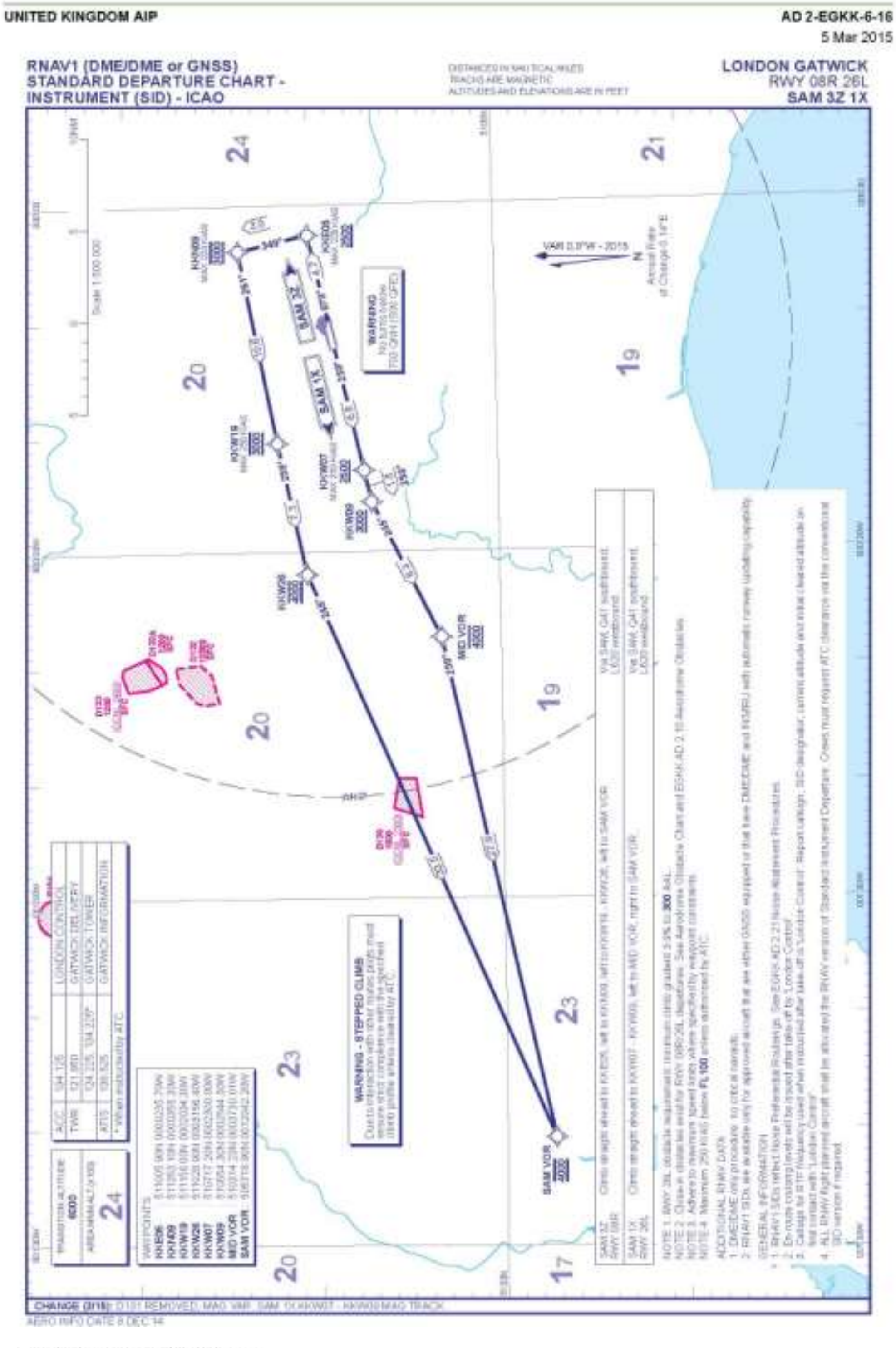
Route 2 RWY 08R SFD 4Z



London Gatwick Runway 08R SFD 4Z

Designator	Sequence Number	Path Term-inator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
SFD 4Z	001	CF	KKE03	510958.00N 0000334.10W	N	079° (077.6°)	-0.9	4.1	RIGHT	+2000	-220	RNAV1
SFD 4Z	002	TF	KKS08	510544.80N 0000209.20W	N	169° (168.1°)	-0.9	4.3	LEFT	+3000	-250	RNAV1
SFD 4Z	003	TF	KKS12	510155.10N 0000020.40W	N	164° (163.4°)	-0.9	4.0	-	-	-250	RNAV1
SFD 4Z	004	TF	KKS16	505805.21N 0000128.29E	N	164° (163.4°)	-0.9	4.0	-	+5000	-250	RNAV1
SFD 4Z	005	TF	KKS22	505220.70N 0000410.60E	N	164° (163.4°)	-0.9	6.0	-	6000	-250	RNAV1
SFD 4Z	006	TF	SFD	504538.49N 0000718.89E	N	164° (163.5°)	-0.9	7.0	-	6000	-250	RNAV1

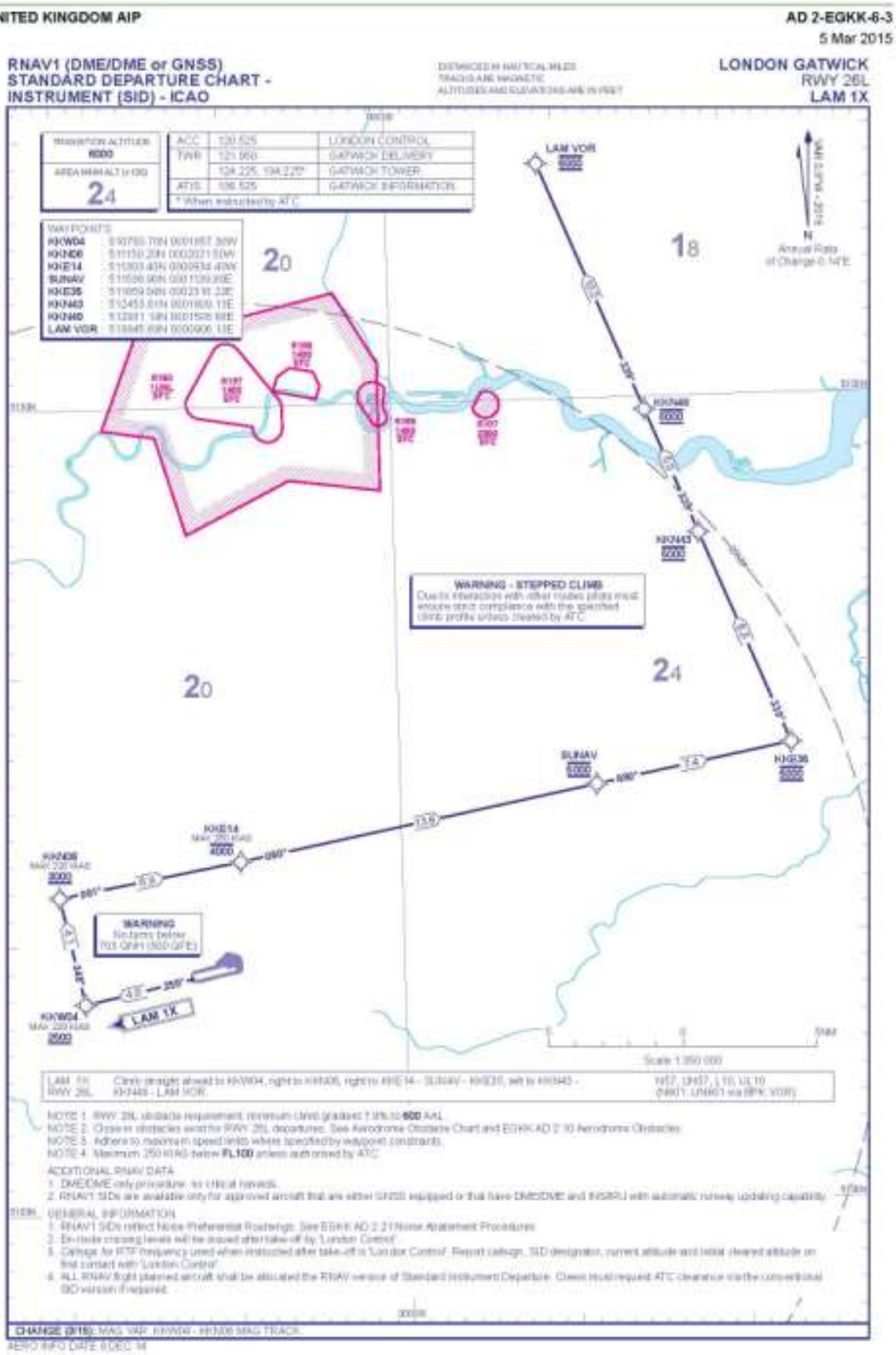
Route 3 RWY 08R SAM 3Z



London Gatwick Runway 08R SAM 3Z

Designator	Sequence Number	Path Term-inator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
SAM 3Z	001	CF	KKE05	511005.90N 0000235.70W	N	079° (077.7°)	-0.9	4.7	LEFT	+2500	-220	RNAV1
SAM 3Z	002	TF	KKN09	511353.10N 0000355.30W	N	349° (347.6°)	-0.9	3.9	LEFT	3000	-220	RNAV1
SAM 3Z	003	TF	KKW19	511158.00N 0002034.30W	N	261° (259.7°)	-0.9	10.6	-	3000	-250	RNAV1
SAM 3Z	004	TF	KKW26	511028.90N 0003156.40W	N	259° (258.3°)	-0.9	7.3	LEFT	4000	-250	RNAV1
SAM 3Z	005	TF	SAM	505718.90N 0012042.20W	N	248° (247.1°)	-0.9	33.5	-	4000	-250	RNAV1

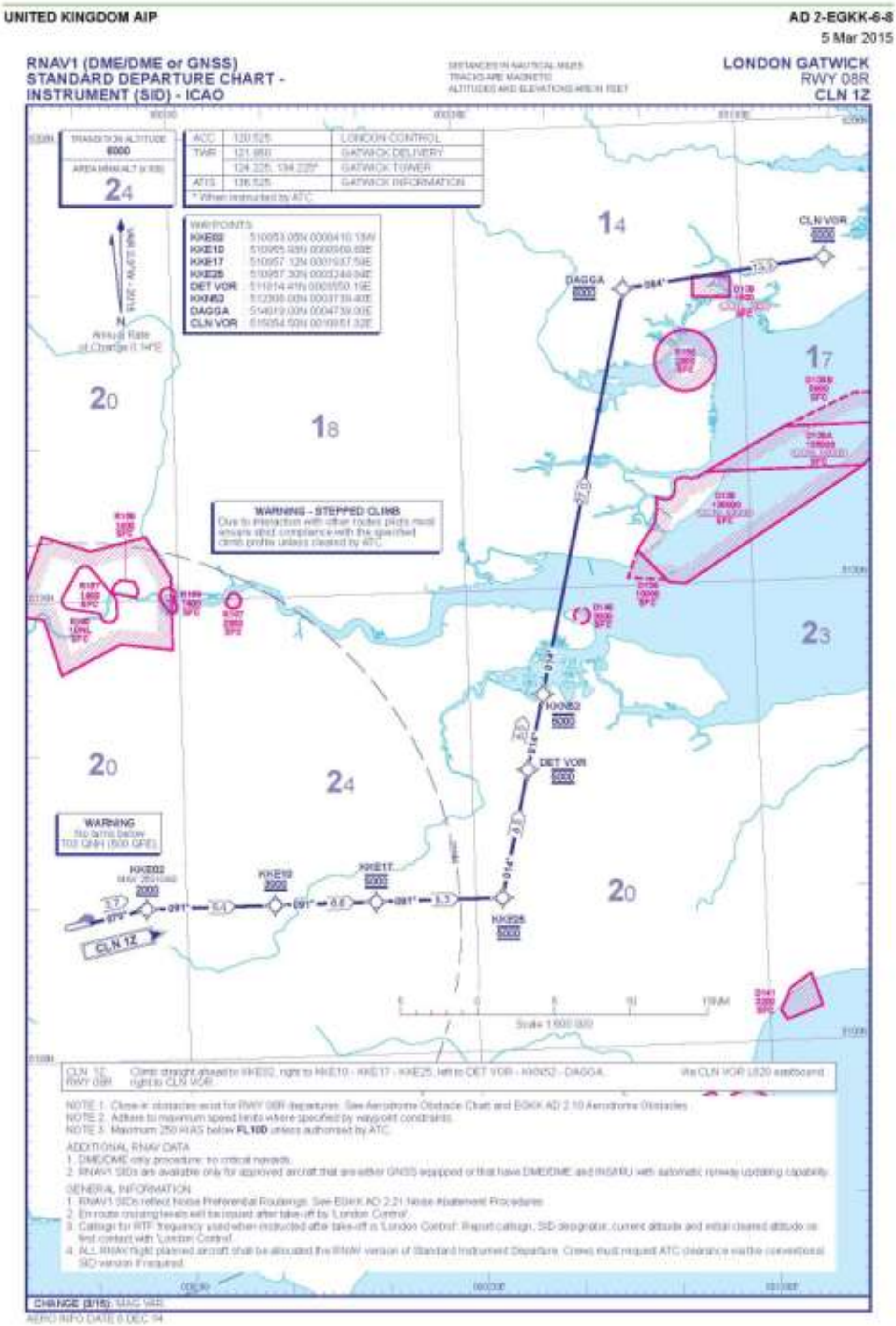
Route 4 RWY 26L LAM 1X



London Gatwick Runway 26L LAM 1X

Designator	Sequence Number	Path Terminator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
LAM 1X	001	CF	KKW04	510750.70N 0001857.30W	N	259° (257.6°)	-0.9	4.0	RIGHT	+2500	-220	RNAV1
LAM 1X	002	TF	KKN06	511150.20N 0002021.50W	N	348° (347.5°)	-0.9	4.1	RIGHT	+3000	-220	RNAV1
LAM 1X	003	TF	KKE14	511303.40N 0000934.40W	N	081° (079.7°)	-0.9	6.9	-	-4000	-250	RNAV1
LAM 1X	004	TF	SUNAV	511536.90N 0001139.80E	N	080° (079.0°)	-0.9	13.6	-	5000	-250	RNAV1
LAM 1X	005	TF	KKE35	511859.04N 0002316.22E	N	080° (079.3°)	-0.9	7.4	LEFT	5000	-250	RNAV1
LAM 1X	006	TF	KKN43	512453.61N 0001809.13E	N	339° (338.0°)	-0.9	8.5	-	5000	-250	RNAV1
LAM 1X	007	TF	KKN48	512931.14N 0001508.88E	N	339° (337.9°)	-0.9	5.0	-	6000	-250	RNAV1
LAM 1X	008	TF	LAM	513845.69N 0000906.13E	N	339° (337.9°)	-0.9	10.0	-	6000	-250	RNAV1

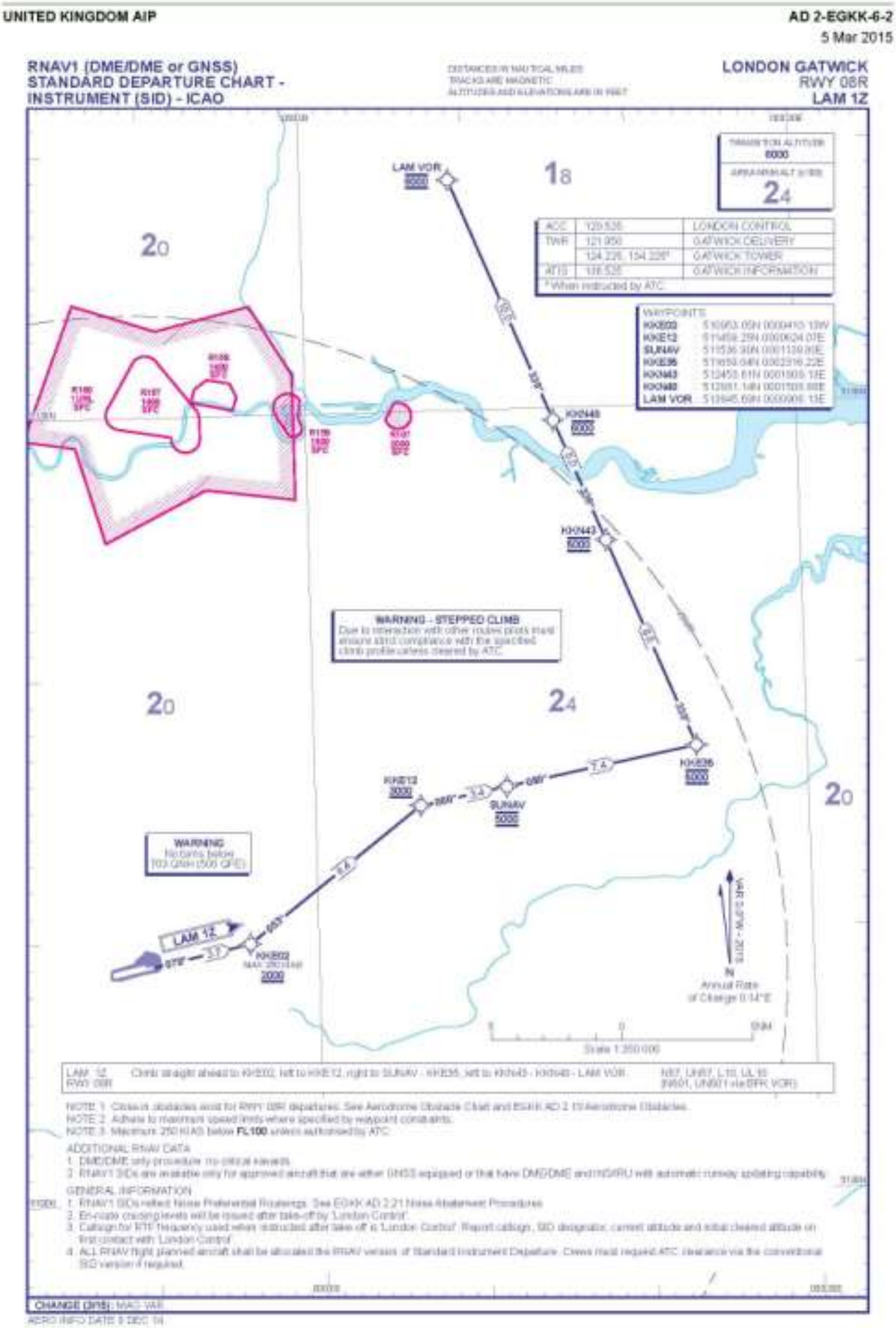
Route 5 RWY 08R CLN 1Z



London Gatwick Runway 08R CLN 1Z

Designator	Sequence Number	Path Terminator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
CLN 1Z	001	CF	KKE02	510953.05N 0000410.13W	N	079° (077.7°)	-0.9	3.7	RIGHT	+2000	-250	RNAV1
CLN 1Z	002	TF	KKE10	510955.93N 0000909.88E	N	091° (089.6°)	-0.9	8.4	-	+3000	-250	RNAV1
CLN 1Z	003	TF	KKE17	510957.12N 0001937.59E	N	091° (089.8°)	-0.9	6.6	-	5000	-250	RNAV1
CLN 1Z	004	TF	KKE25	510957.30N 0003244.84E	N	091° (089.9°)	-0.9	8.3	LEFT	5000	-250	RNAV1
CLN 1Z	005	TF	DET	511814.41N 0003550.19E	N	014° (013.2°)	-0.9	8.5	-	5000	-250	RNAV1
CLN 1Z	006	TF	KKN52	512306.00N 0003739.40E	N	014° (013.2°)	-0.9	5.0	-	6000	-250	RNAV1
CLN 1Z	007	TF	DAGGA	514918.00N 0004739.00E	N	014° (013.3°)	-0.9	27.0	RIGHT	6000	-250	RNAV1
CLN 1Z	008	TF	CLN	515054.50N 0010851.32E	N	084° (083.1°)	-0.9	13.3	-	6000	-250	RNAV1

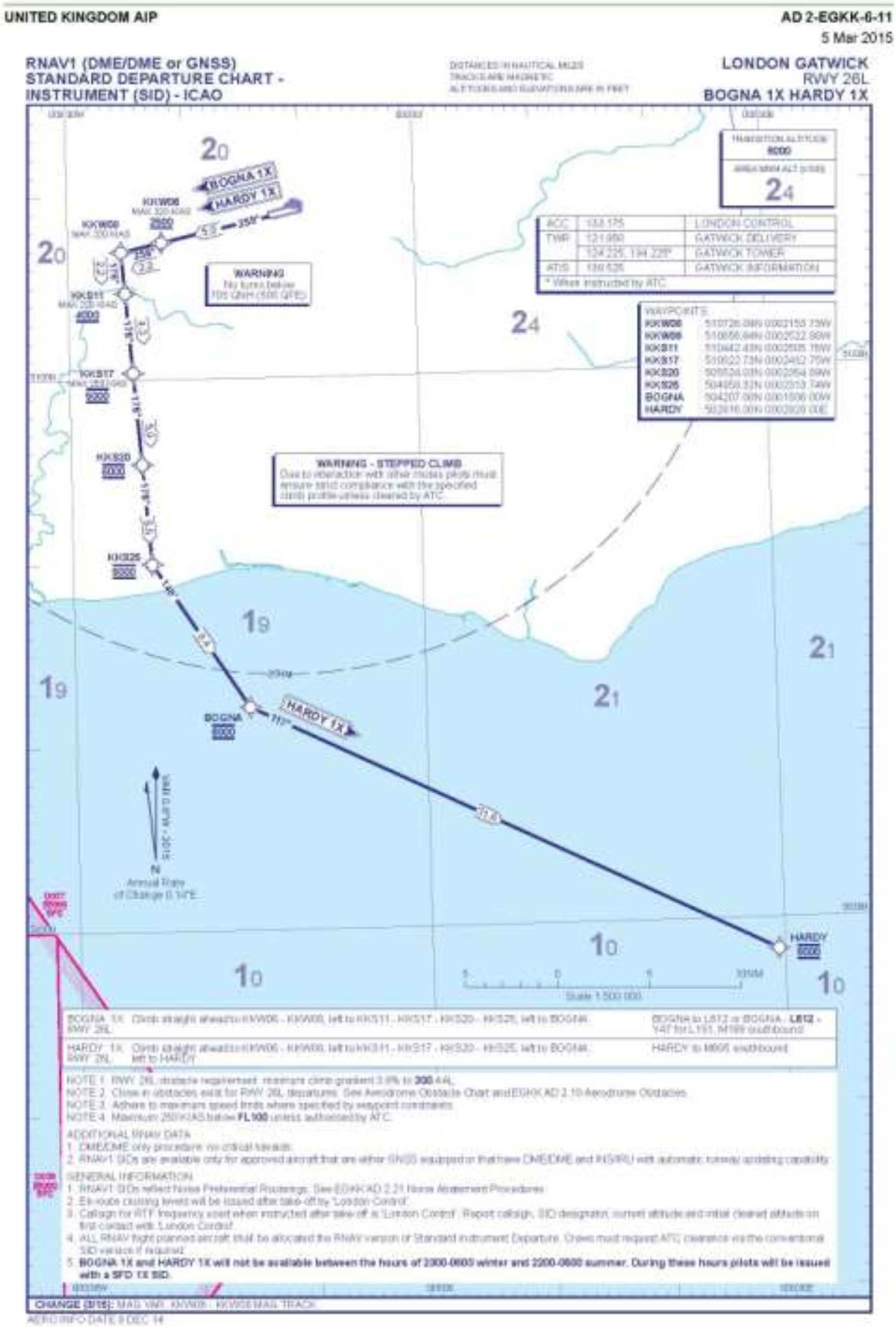
Route 6 RWY 08R LAM 1Z



London Gatwick Runway 08R LAM 1Z

Designator	Sequence Number	Path Terminator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
LAM 1Z	001	CF	KKE02	510953.05N 0000410.13W	N	079° (077.7°)	-0.9	3.7	LEFT	+2000	-250	RNAV1
LAM 1Z	002	TF	KKE12	511459.25N 0000624.07E	N	053° (052.4°)	-0.9	8.4	RIGHT	+3000	-250	RNAV1
LAM 1Z	003	TF	SUNAV	511538.90N 0001139.80E	N	080° (079.2°)	-0.9	3.4	-	5000	-250	RNAV1
LAM 1Z	004	TF	KKE35	511659.04N 0002316.22E	N	080° (079.3°)	-0.9	7.4	LEFT	5000	-250	RNAV1
LAM 1Z	005	TF	KKN43	512453.61N 0001809.13E	N	339° (338.0°)	-0.9	8.5	-	5000	-250	RNAV1
LAM 1Z	006	TF	KKN48	512931.14N 0001508.68E	N	339° (337.9°)	-0.9	5.0	-	6000	-250	RNAV1
LAM 1Z	007	TF	LAM	513845.69N 0000906.13E	N	339° (337.9°)	-0.9	10.0	-	6000	-250	RNAV1

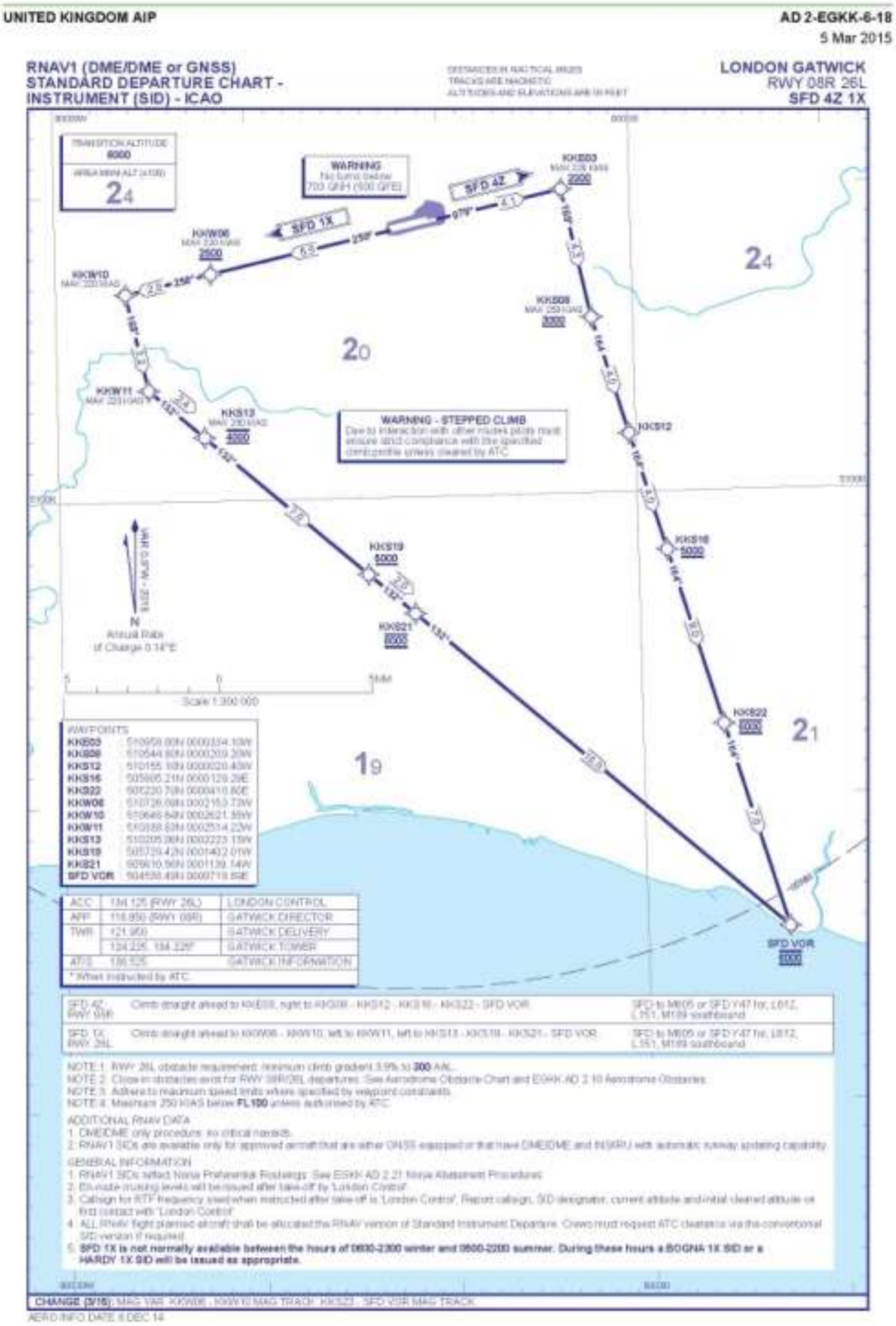
Route 7 RWY 26L BOGNA 1X HARDY 1X



London Gatwick Runway 26L BOGNA 1X

Designator	Sequence Number	Path Terminator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
BOGNA 1X	001	CF	KKW06	510726.09N 0002153.73W	N	259° (257.6°)	-0.9	5.9	-	+2500	-220	RNAV1
BOGNA 1X	002	TF	KKW08	510656.84N 0002522.88W	N	258° (257.5°)	-0.9	2.2	LEFT	-	-220	RNAV1
BOGNA 1X	003	TF	KKS11	510442.43N 0002505.78W	N	176° (175.4°)	-0.9	2.2	-	+4000	-220	RNAV1
BOGNA 1X	004	TF	KKS17	510022.73N 0002432.75W	N	176° (175.4°)	-0.9	4.3	-	5000	-250	RNAV1
BOGNA 1X	005	TF	KKS20	505524.03N 0002394.89W	N	176° (175.4°)	-0.9	5.0	-	6000	-250	RNAV1
BOGNA 1X	006	TF	KKS25	504958.32N 0002313.74W	N	176° (175.4°)	-0.9	5.5	LEFT	6000	-250	RNAV1
BOGNA 1X	007	TF	BOGNA	504207.00N 0001506.00W	N	148° (148.7°)	-0.9	9.4	-	6000	-250	RNAV1

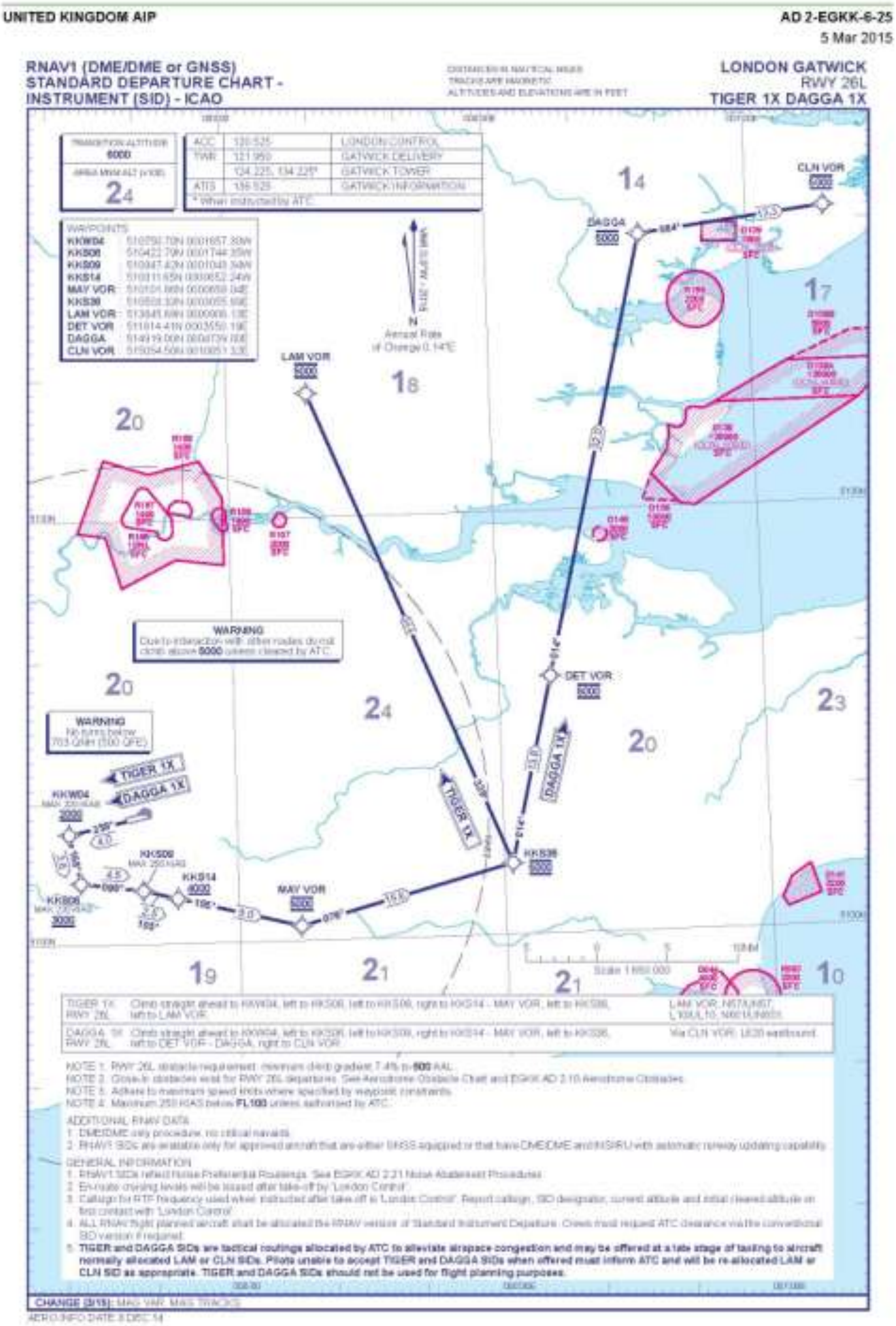
Route 8 RWY 26L SFD 1X



London Gatwick Runway 26L SFD 1X

Designator	Sequence Number	Path Term-inator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
SFD 1X	001	CF	KKW06	510726.09N 0002153.73W	N	259° (257.6°)	-0.9	5.9	-	+2500	-220	RNAV1
SFD 1X	002	TF	KKW10	510648.64N 0002621.35W	N	258° (257.5°)	-0.9	2.9	LEFT	-	-220	RNAV1
SFD 1X	003	TF	KKW11	510338.83N 0002514.22W	N	168° (167.4°)	-0.9	3.2	LEFT	-	-220	RNAV1
SFD 1X	004	TF	KKS13	510205.06N 0002223.13W	N	132° (131.0°)	-0.9	2.4	-	4000	-250	RNAV1
SFD 1X	005	TF	KKS19	505729.42N 0001402.01W	N	132° (131.0°)	-0.9	7.0	-	+5000	-250	RNAV1
SFD 1X	006	TF	KKS21	505610.56N 0001139.14W	N	132° (131.1°)	-0.9	2.0	-	6000	-250	RNAV1
SFD 1X	007	TF	SFD	504538.49N 0000718.89E	N	132° (131.1°)	-0.9	16.0	-	6000	-250	RNAV1

Route 9 RWY 26L TIGER 1X DAGGA 1X



London Gatwick Runway 26L TIGER 1X

Designator	Sequence Number	Path Term-inator	Waypoint Name	Waypoint Co-ordinates	Fly-over	Course/ Track °M (°T)	Magnetic Variation	Distance (NM)	Turn Direction	Level Constraint	Speed Constraint	Navigation Performance
TIGER 1X	001	CF	KKW04	510750.70N 0001857.30W	N	259° (257.6°)	-0.9	4.0	LEFT	+2000	-220	RNAV1
TIGER 1X	002	TF	KKS08	510422.79N 0001744.35W	N	168° (167.5°)	-0.9	3.6	LEFT	+3000	-220	RNAV1
TIGER 1X	003	TF	KKS09	510347.42N 0001043.34W	N	098° (097.5°)	-0.9	4.5	RIGHT	-	-250	RNAV1
TIGER 1X	004	TF	KKS14	510311.65N 0000652.24W	N	105° (103.8°)	-0.9	2.5	-	+4000	-250	RNAV1
TIGER 1X	005	TF	MAY	510101.86N 0000658.04E	N	105° (103.8°)	-0.9	9.0	LEFT	5000	-250	RNAV1
TIGER 1X	006	TF	KKS36	510503.33N 0003055.89E	N	076° (074.9°)	-0.9	15.6	LEFT	5000	-250	RNAV1
TIGER 1X	007	TF	LAM	513845.69N 0000906.13E	N	339° (338.1°)	-0.9	36.4	-	5000	-250	RNAV1